B.C. Works' Sulphur Dioxide Environmental Effects Monitoring Program

Phase III Plan for 2019 to 2025
Final (V.3)

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V.1	December 17, 2020	Draft for review by the B.C. Ministry of Environment and Climate Change Strategy (B.C. ENV)
V.2	July 18, 2021	Draft with revisions per B.C. ENV comments, for Rio Tinto review
V.3	July 13, 2022	Draft for Consultation
V.4	September 28, 2022	Revised draft addressing comments
Final	February 28, 2023	Finalization based on "Tracking Table SO_2 EEM Phase III responses (FINAL to B.C. ENV) Feb 7 2023.xlsx"
Final (V.2)	March 28, 2023	Corrections to table 4 and page 52.
Final (V.3)	June 13, 2023	Section 3.0 added: "The Director issued a decision on October 25, 2022, designating the Service Centre Station to be an attainment station for the human health KPI, effective on January 1st, 2023. Reporting on the attainment of the KPI will commence in the 2023 Annual Human Health KPI Technical Memo."

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Executive Summary

This document describes the modeling and monitoring that is planned for the Phase III Plan of the SO_2 EEM Program (2019 to 2025) under the sulphur dioxide (SO_2) Environmental Effects Monitoring (EEM) Program for B.C. Works, and thresholds for increased monitoring or mitigation if warranted based on the monitoring results. Rio Tinto will implement SO_2 mitigation strategies if the outcomes of monitoring and/or modeling described in this plan show adverse impacts causally related to SO_2 cumulative emissions that are considered to be unacceptable.

The SO_2 EEM Program is specific to SO_2 emissions from B.C. Works and the added SO_2 emissions from new LNG projects in Kitimat. Effects from non-SO_2 emissions from B.C. Works and other sources, and research and development of new indicators or monitoring methods are all outside of the scope of the EEM Program.

Rio Tinto is volunteering to add a section on tracking climate change to the annual SO_2 EEM Program reporting as the SO_2 EEM plan collects valuable data that can inform on the effects of climate change in the Kitimat Valley. Climate change indicators are identified and will be further developed through a review of historical meteorological datasets. Some monitoring scopes will be enhanced for collecting data that are useful for tracking climate changes occurring in the valley.

The plan distinguishes two types of indicators: key performance indicators (KPIs) which have quantitative thresholds for increased monitoring or for mitigation, and informative indicators which provide evidence in support of key performance indicators. Exceedances of KPI thresholds for mitigation will lead to the development and implementation of mitigation action plans. The following table presents a summary of the indicators described in this Phase III Plan.

Pathways / Receptors	Key Performance Indicators	Informative Indicators
Atmospheric Pathways	None	Atmospheric SO_2 concentrations Atmospheric S (wet and dry) deposition Precipitation chemistry
Human Health	1-hour Provincial Ambient Air Quality Standard for SO_2	None
Terrestrial Ecosystems	Critical load (CL) exceedance from modelled atmospheric S deposition (estimated only if S deposition changes) Long-term soil acidification (decrease in base saturation) attributable to S deposition	Exchangeable acidity and base cations (Ca, Mg, K, Na) Modelled S deposition[1] Net base cation uptake (Ca, Mg, K) in trees Vegetation health (including potential SO_2 injury) Plant biodiversity Cyanolichen biodiversity

[1] There are no plans to revise modelled S deposition in Phase III.

Pathways / Receptors	Key Performance Indicators	Informative Indicators
Aquatic Ecosystems	Water chemistry – acidification (CBANC)	Water chemistry – acidification (pH) Water chemistry – acidification (Gran ANC, BCS) (i.e., alternate ANC metrics) Changes in SO_4 Observed changes in SO_4, ANC and pH vs. predicted changes from STAR and 2019 Comprehensive Review Predicted steady state ANC and pH versus current ANC and pH Aquatic biota: fish presence/absence per species on sensitive lakes Episodic pH change

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Glossary

acceptable impact	Not exceeding impact threshold criteria for mitigation (interchangeable with 'attainment')
acid deposition	Transfer of acids and acidifying compounds from the atmosphere to terrestrial and aquatic environments via rain, snow, sleet, hail, cloud droplets, particles, and gas exchange
acidification	The decrease of acid neutralizing capacity in water, or base saturation in soil, by natural or anthropogenic processes
acid neutralizing capacity	The equivalent capacity of a solution to neutralize strong acids; acid neutralizing capacity (ANC) and alkalinity are often used interchangeably; ANC includes alkalinity plus additional buffering from dissociated organic acids and other compounds
adaptive management	A systematic process for improving management policies and practices by learning from the outcomes of operational programs
anion	An ion with more electrons than protons, giving it a negative charge, e.g., sulphate ion (SO_4^{2-})
assess attainment	Calculate the KPI
attainment	Not exceeding impact threshold criteria for mitigation (interchangeable with 'acceptable impact')
attainment ambient air station	Any one of the three residential ambient air stations (Riverlodge, Whitesail, Kitamaat Village or Service Centre) that are used to assess attainment of the health KPI as set out in the 2019 B.C. Environmental Appeals Board Consent Order settling Appeals No. 2014-EMA-003, 2014-EMA-004, 2014-EMA-005
base cations	An alkali or alkaline earth metal (Ca^{2+}, Mg^{2+}, K^+, Na^+)
biodiversity	A measure of community complexity, described by the variety of all living things, the ecosystems in which they live and the ways they interact with each other
causality	Exceedance of a KPI that is caused by SO_2 emissions from B.C. Works and other SO_2 emission sources from Kitimat
critical load	A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur, according to present knowledge[2]
dry deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via gravitational settling of large particles and turbulent transfer of trace gases and small particles

[2] From Nilsson, J. and P. Grennfelt. 1988. Critical loads for sulphur and nitrogen. Nordic Council of Ministers. Copenhagen, Denmark. Report No. 1988:15.

environmental effects	Impacts on receptors from sulphur dioxide (SO_2) emissions from the modernized smelter
exceedance(s)	An exceedance or non-attainment of a KPI
facility-based mitigation	SO_2 emission reduction at B.C. Works
impact threshold criteria	Quantitative thresholds for a KPI that trigger additional monitoring or modelling, receptor-based mitigation, and/or facility-based mitigation
informative indicator	Indicators that will provide supporting information for key performance indicators, and may have quantitative thresholds triggering additional monitoring or modelling, but on their own will not trigger mitigation
key performance indicator	An indicator that has quantitative thresholds triggering additional monitoring or modelling, receptor-based mitigation, and/or facility-based mitigation
lichen	An organism comprising an algae or cyanobacteria and a fungus growing in symbiotic association
liming	The addition of any base materials to neutralize surface water or sediment or to increase acid neutralizing capacity
non-attainment	Exceeding impact threshold criteria for mitigation (interchangeable with 'unacceptable impact')
pathways	Routes of exposure or effects from atmospheric dispersion and deposition
percentile	A statistical measure for the value below which a given percentage of observations fall within a data set
pH	A measure of how acidic or basic a solution is, on a scale of 0-14; the lower the pH value, the more acidic the solution; pH 7 is neutral; a difference of 1 pH unit indicates a tenfold change in hydrogen ion activity
post-KMP	The period from 2016 forward
pre-KMP	The period of the VSS smelter operations
proportional reduction	The amount of SO_2 emissions reductions required for an exceedance of a facility based SO_2 emissions reduction threshold that is proportional to the smelter's contribution to the KPI exceedance
receptor-based mitigation	Receptor-specific actions to reduce exposure or effects, such as liming of selected lakes
receptors	Lines of evidence assessed for potential impacts from SO_2 emissions from the modernized smelter: Human Health; Terrestrial Ecosystems; and Aquatic Ecosystems
relative abundance	Abundance of a plant species relative to other species in the community, typically measured by percent cover

richness	Number and type of species represented in a plant community
structure	Composition of the plant community (including species richness and relative abundance)
study area	The area depicted by the black hatched line in Figure 1. For the soils, the study area is the area within the modelled 7.5 kg SO_4^{2-}/ha/year deposition isopleth under the 42 tpd scenario
Semi-natural uplands forest soils	Free draining mineral soils in forested (planted / second growth and natural) ecosystems
threshold	The measurement level of a KPI that triggers action to either increase monitoring or implement mitigation (receptor of facility based)
unacceptable impact	Exceeding impact threshold criteria for mitigation (interchangeable with 'non-attainment')
wet deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via precipitation (e.g., rain, snow, sleet, hail, and cloud droplets)

Abbreviations and Symbols

Δ	delta, meaning quantitative change (e.g., ΔANC or ΔSO_2)
<	is less than what follows
>	is greater than what follows
Al	Aluminum
ANC	Acid neutralizing capacity
ANC_{OAA}	Organic acid-adjusted ANC
ARC	Annual review cycle
Bc	Base cations (Ca^{2+} + Mg^{2+} + K^+)
BC	Base cations that include Ca^{2+}, K^+, Mg^{2+} and Na^+
B.C.	British Columbia
BCS	Base cation surplus
Bcu	Base cation uptake
Ca^{2+}	Calcium ion
CAAQS	Canadian Ambient Air Quality Standards
CBANC	charge balance ANC
Cl^-	Chloride ion
CL	Critical load
DFO	Fisheries and Oceans Canada (formerly Canadian Department of Fisheries and Oceans)
EEM	SO_2 environmental effects monitoring
B.C. ENV	British Columbia Ministry of Environment and Climate Change Strategy

Gran ANC	The capacity of a solution to neutralize strong acids, determined by titration to the inflection point of the pH-alkalinity titration curve
GTC	Gas Treatment Centre
H^+	Hydrogen ion
K^+	Potassium ion
KAG	Kitimat Airshed Group Society
KMP	Kitimat Modernization Project
KPAC	Kitimat Public Advisory Committee
KPI	Key performance indicator
Mg^{2+}	Magnesium ion
Na^+	Sodium ion
NA	Not applicable
NADP	National Atmospheric Deposition Program
NO_2	Nitrogen dioxide
QA/QC	Quality assurance / quality control
S	Sulphur (as in sulphur deposition)
SO_2	Sulphur dioxide
SO_4^{2-}	Sulphate ion
SO_2 EEM	Rio Tinto B.C. Works' SO_2 Environmental Effects Monitoring Program
STAR	2013 SO_2 Technical Assessment Report (for KMP)
TBD	To be determined

Measurement Units

g/m^3	grams per cubic metre
ha	hectares
m	metres
Mg/d	mega grammes per day, equivalent to metric tonnes per day
ppb	parts per billion
tpd	tonnes per day
µeq/L	microequivalents per litre

1 Introduction

1.1 Purpose and Scope of the SO_2 EEM Program and this Phase III Plan

In 2013 an SO_2 technical assessment report - STAR (ESSA et al. 2013) was completed for the Kitimat Modernization Project (KMP), to determine the potential impacts of sulphur dioxide (SO_2) emissions on Human Health, Vegetation, Terrestrial Ecosystems (soils), and Aquatic Ecosystems (lakes and streams, and aquatic biota). An EEM Plan was developed to guide the first six years of the SO_2 EEM Program, from 2013 to 2018 (ESSA et al. 2014). In 2019 we undertook a Comprehensive Review of the first six years of the SO_2 EEM Program (ESSA et al. 2020, ESSA et al. 2022, and Appendix E). Recommendations from the 2019 Comprehensive Review informed this Phase III Plan of the SO_2 EEM Program. The SO_2 EEM plan is a continuing process that does not start and stop based on the phases of the plan. The new phases of the plan update and improve the plan based on the learnings gained.

The purpose of the SO_2 Environmental Effects Monitoring (EEM) Program is to monitor effects of SO_2 along the lines of evidence examined in the STAR. Results from the SO_2 EEM Program will inform decisions regarding the need for changes to the scale or intensity of monitoring, as well as decisions regarding the need for mitigation. The SO_2 EEM plan also includes impact threshold criteria either for emission reduction or other mitigations that, when exceeded, would trigger emission reduction and/or other mitigation. The SO_2 EEM Program is a requirement of section 4.2.5 of the P2-00001 Multimedia Waste Discharge permit (P2 Permit). The SO_2 EEM Program is part of the P2 Permit and is also governed by the P2 Permit.[3]

The scope of the SO_2 EEM Program encompasses B.C. Works SO_2 emissions at full production capacity, and this Phase III Plan focuses on the SO_2 EEM Program from 2019 to 2025. What is learned during this period will be reviewed in 2026 and applied to improve the Program going forward.

There will be incrementally increased SO_2 emissions from the LNG projects being developed in the Kitimat Valley. The cumulative effects of SO_2 emissions from both B.C. Works and the new LNG projects are a shared responsibility. This shared responsibility has been added to the SO_2 EEM Phase III plan by adjusting the causality framework to include the cumulative SO_2 emissions effects and a proportional emission reduction framework should emissions reductions be required. Other smelter emissions and non-SO_2 emissions are outside of the scope of the SO_2 EEM Program.

As the SO_2 EEM Program collects data that can be used to track climate change effects in the Kitimat Valley, Rio Tinto has volunteered to add a section to the annual SO_2 EEM reports for tracking climate change. Where feasible, some additional monitoring will be added to enhance the collection of data for interpreting climate change effects in the Kitimat Valley.

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[3] The P2-00001 Multimedia Waste Discharge Permit was amended on April 27, 2021 with the 2019 BC Environmental Appeals Board Consent Order where all parties of appeal numbers 2014-EMA-003, 2014-EMA-004, and EMA-005 agreed that SO_2 EEM Program forms part of the P2 permit and where there are inconsistencies between P2 Permit and the SO_2 EEM, the P2 Permit will prevail.

The study area for the Phase III Plan is shown in Figure 1.

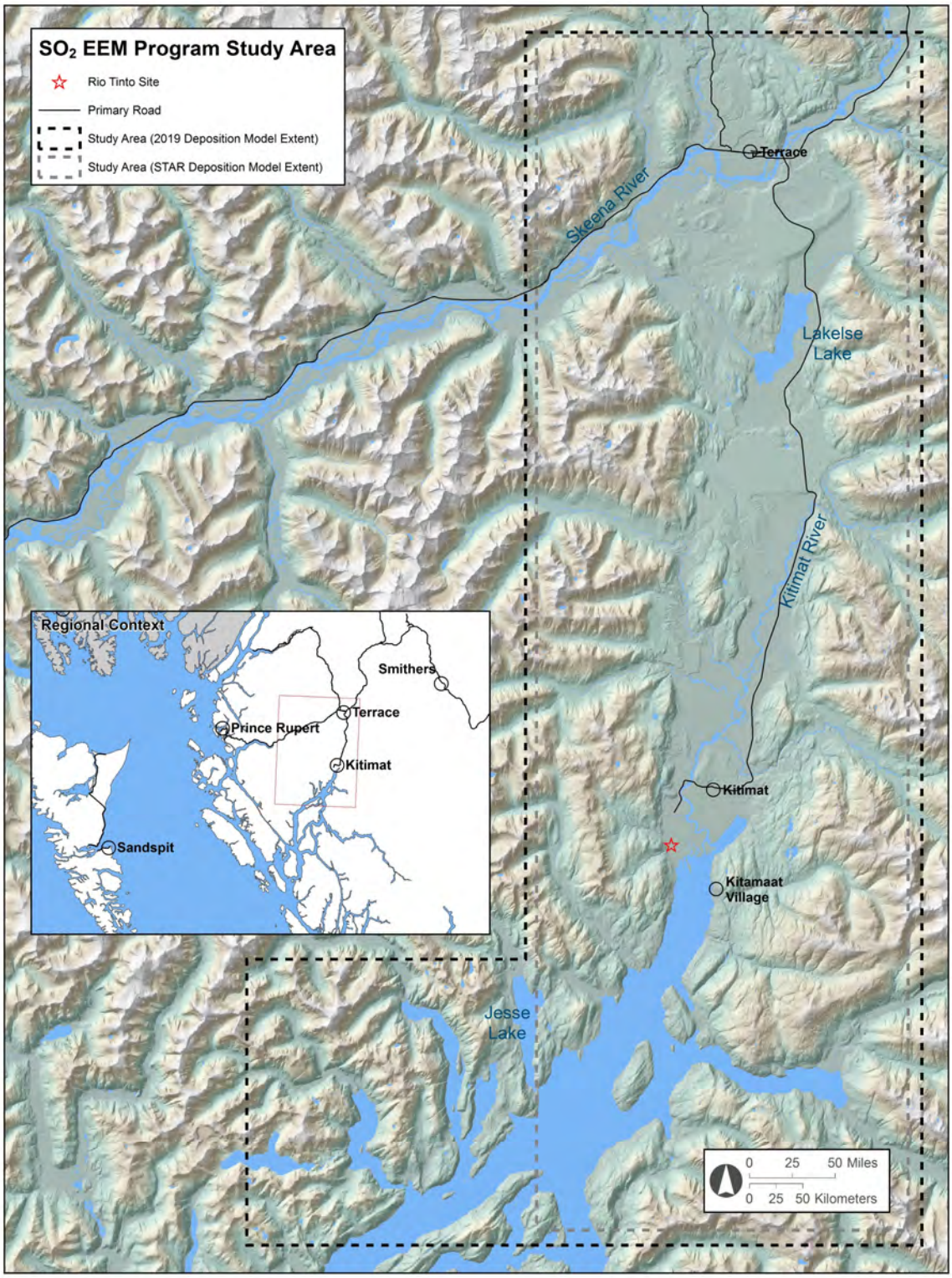


Figure 1. Map of the study area for Phase III.

This document describes the modeling and monitoring that is planned to 2025, and decision rules based on quantitative indicator thresholds for increased monitoring or mitigation if warranted based on the results. Two broad categories for mitigations are identified:

Receptor-based – mitigations that would be receptor-specific in design and application, for example adding lime to selected lakes

Facility-based – sulphur dioxide (SO_2) emission reduction at B.C. Works

The SO_2 EEM Program focuses on indicators which can be causally related to SO_2 emissions. Two types of indicator are recognized:

Key performance indicator (KPI) – which will have decisions rules (quantitative thresholds) for increased monitoring and for mitigation

Informative indicator – which may have decision rules for increased monitoring, but will have no decision rules for mitigation on their own; instead they will provide evidence in support of key performance indicators

Chapters 2 through 6 present indicators and methods for the pathway and receptor lines of evidence depicted in Figure 2. In this Phase III Plan the Vegetation and Terrestrial Ecosystems (Soils) receptors have been combined into one new Terrestrial Ecosystems receptor. Chapter 7 is new to the SO_2 EEM Program and adds the tracking of climate change KPIs. Chapter 8 describes how a causal relationship to B.C. Works will be determined. Chapter 9 summarizes the actions that Rio Tinto will take if unacceptable impacts occur. Chapter 10 describes the schedule and content for SO_2 EEM reporting.

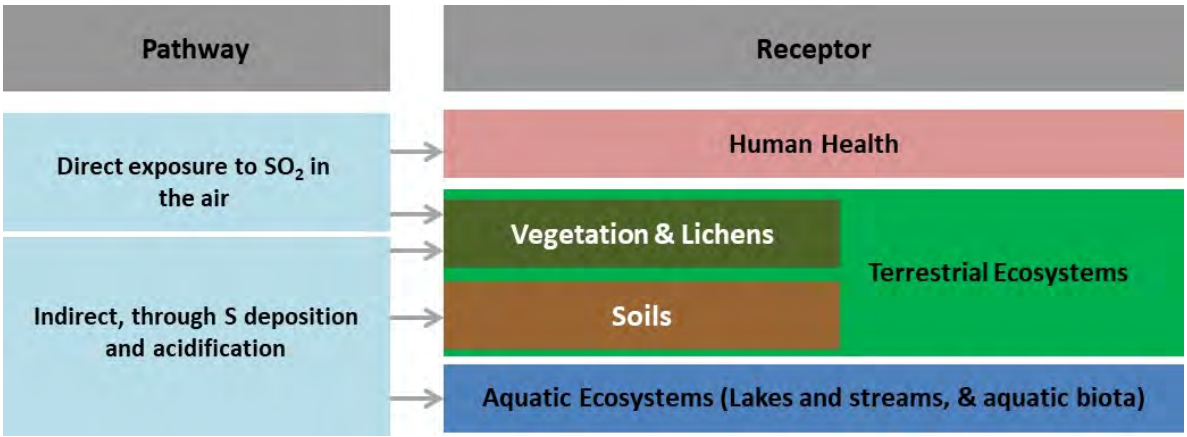


Figure 2. Organization of the three lines of evidence in this Phase III Plan.

The development of this Phase III Plan has been guided by a suite of principles that are closely aligned with the principles used to guide the original development of the SO_2 EEM Program in 2013:

- Safety is paramount,
- Monitor in a manner that does not harm the environment,
- Make wise use of financial and human resources,
- Ensure all information gathered is helpful for assessing risk, refining monitoring design or making decisions on mitigation,
- Measures must have sufficiently low spatial and temporal variability to provide useful information,
- Review and adjust processes based on results, and
- Regular evaluation and reporting of results.

1.2 SO_2 EEM Framework

Figure 3 illustrates the decision framework for the SO_2 EEM Program. It is divided into three overall phases: pre-KMP, ramp-up and initial operation under the new smelter (2013-2018), and 2019 onward.

The first phase began before the modernization of the smelter with the SO_2 technical assessment to determine the potential impacts of SO_2 emissions from KMP. Four potential impact categories were identified, and remain relevant for interpreting monitoring results from the SO_2 EEM Program (Table 1):

Table 1. Impact categories used in the SO_2 Technical Assessment Report (STAR).

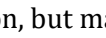
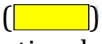
Impact Category	Interpretation
Low	No impact or acceptable impact
Moderate	Acceptable impact but in need of closer scrutiny
High	Unacceptable impact; mitigation action needed
Critical	Extremely unacceptable impact; mitigation action needed

The SO_2 technical assessment predicted that impacts on vegetation would fall into the green (low) impact category, and that impacts on human health, soil, and water and aquatic biota would fall into the yellow (moderate) impact category. The SO_2 EEM Program will determine whether these predictions were correct, and if EEM results indicate that actual outcomes post-KMP for any of the receptors will fall into higher impact categories than predicted, describe the decisions rules for action.

In addition, the SO_2 EEM Program was set up to answer questions that arose during the technical assessment. The answers would result in one of three possible outcomes for the receptors:

- The pre-KMP assessment *over*estimated or accurately estimated the impact category. In other words, the impact category predicted in the assessment was either too high, or correct. In the framework, this situation is represented by a "thumbs up". 
- The pre-KMP assessment *under*estimated the impact category. In other words, the assessment was overly optimistic – represented in the framework as one or two "thumbs down", depending on the implications of the underestimation of impacts. 
- It is unclear whether the assessment underestimated or overestimated the impact risk – represented in the framework as "thumbs down" with a question mark. 

The second phase occurred in 2013 to 2018, from KMP ramp-up through to the first years of full operation of the modernized smelter. It focused on learning, through regular evaluation of results designed to provide:

- Evidence that the technical assessment *under*estimated the impact category () **and/or** that the impacts are (or are expected to be) high () or critical ().
  This will require mitigation and an escalation in either the frequency or extent of monitoring, or both.
- Evidence that the assessment correctly or *over*estimated the impact category (), or *under*estimated the impact category () **but** the impacts are (or are still expected to be) low () or moderate ().
  This will require no mitigation, but may require modifications to monitoring.
- Unclear evidence either way due to lack of time for effects to be manifested (e.g., to observe that a lake is acidifying) (), and the impact category is still estimated to be no higher than moderate ().
  This will require no mitigation, but may require modifications to monitoring, either to increase the frequency or number of monitoring locations, or both.

Annual SO_2 EEM Program reports were produced during the first 6 years to convey results as well as any mitigation that has been undertaken during the preceding year. Annual monitoring plans for the subsequent years were developed based on these results.

The third phase began in 2019, when a Comprehensive Review was conducted and a Comprehensive Review report was prepared (ESSA et al. 2020) that synthesized what has been learned during the first 6 years and assessed which questions have been sufficiently answered and which remain. Based on this report decisions were made about what monitoring should continue, and the frequency of reporting. Those decisions are reflected in this Phase III Plan.

The SO_2 EEM Program is expected to evolve over time according to what is learned.

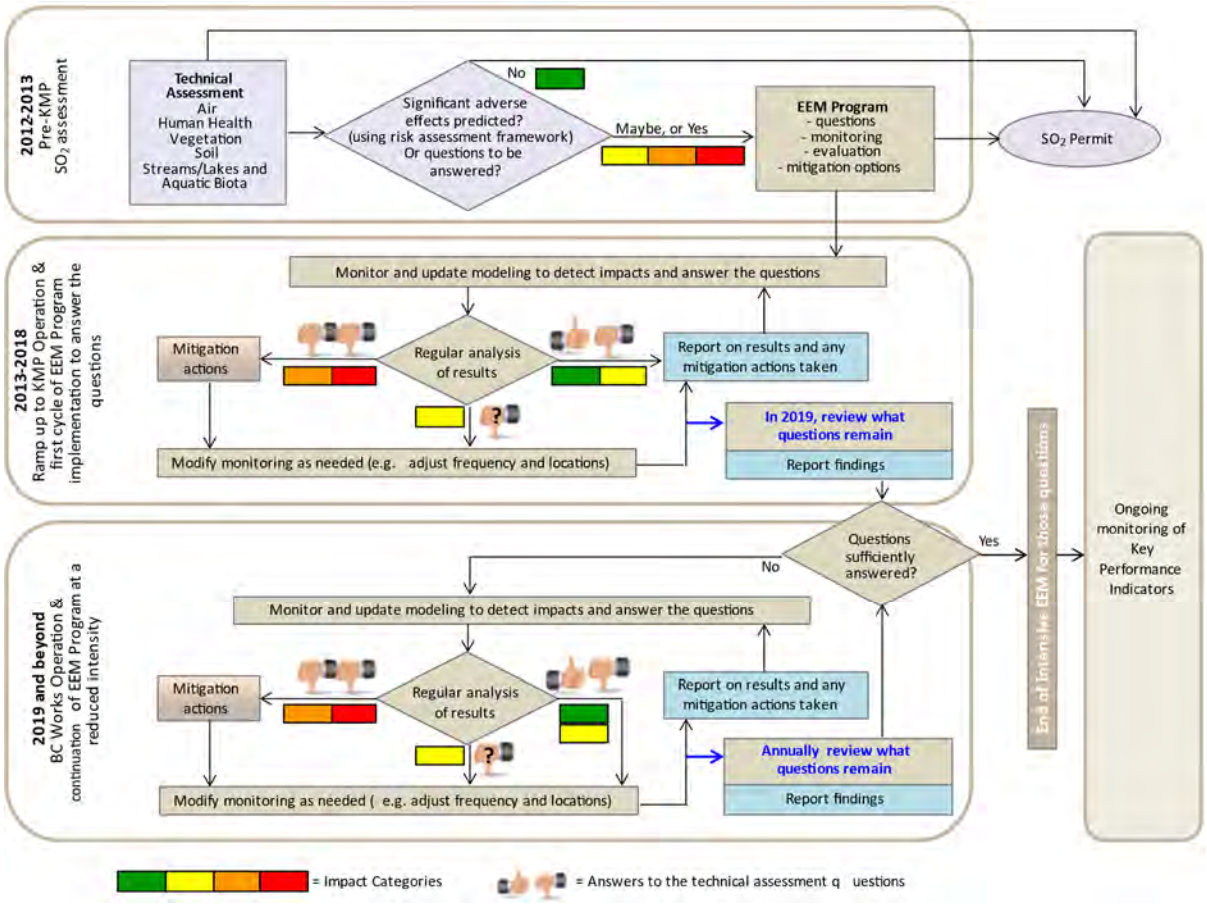


Figure 3. SO_2 EEM framework for B.C. Works.

The SO_2 EEM Program is structured around the conceptual model shown in Figure 4. In the first phase of the SO_2 EEM Program (2013-2018), vegetation and soils were separate receptors. In this Phase III Plan, these have been combined into one Terrestrial Ecosystems receptor, with indicators for both vegetation and soils components.

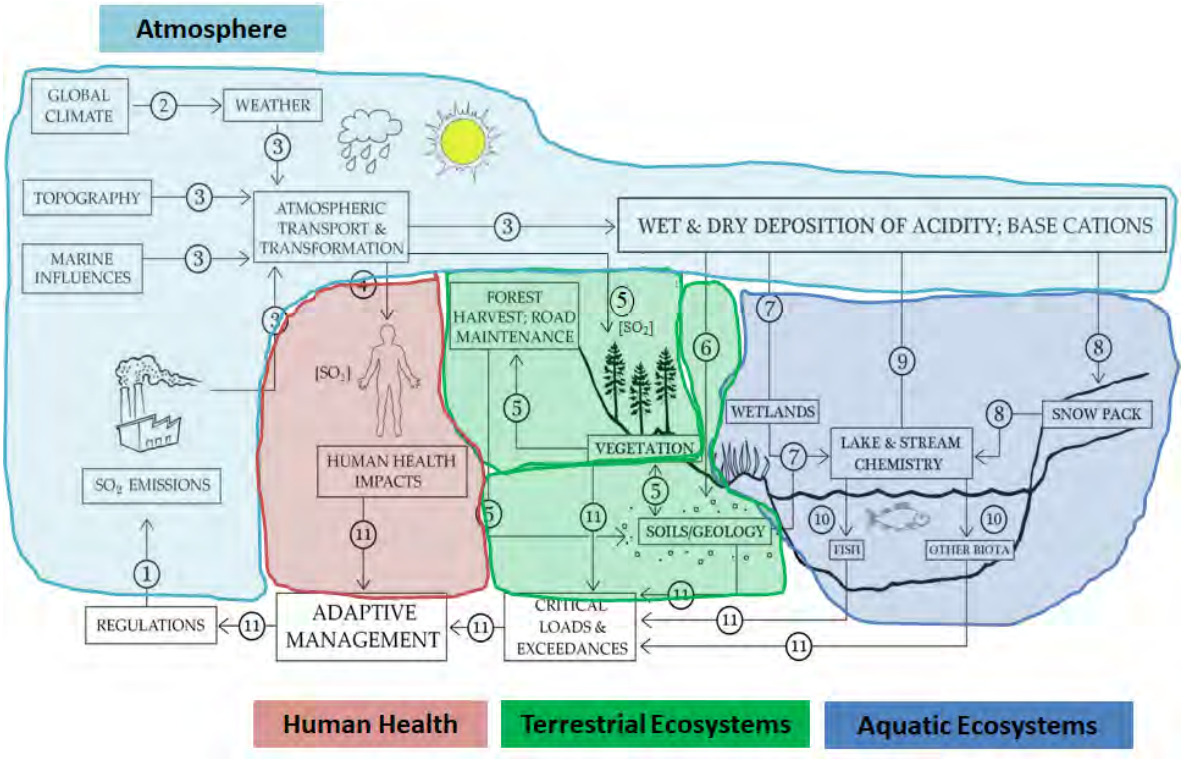


Figure 4. Conceptual (source-pathway-receptor) model of SO_2 emissions in the environment, showing linkages between sources and receptors. Source: Figure 1-1 from ESSA et al. 2020.

1.3 Decision Rules

The cycles within the second phase (2013-2018) and the third phase of the framework in Figure 3 involve a set of quantitative, threshold-based "decision rules" as illustrated in Figure 5. Thresholds for increased monitoring are lower than thresholds for mitigation, and thresholds for receptor-based mitigation are lower than thresholds for facility-based mitigation. If receptor-based mitigations are not feasible, or are implemented but found to be ineffective, facility-based mitigations will be implemented.

As shown in Figure 5, for each line of evidence in the SO_2 EEM, attainment of KPIs will be determined through assessing the individual KPI results and associated informative indicators for change and comparison to their respective thresholds for increased monitoring or mitigation. The result or change in a KPI will first be assessed through an evidentiary framework to determine if the KPI change is causally related to SO_2 emissions (strong statistical confidence or belief that the result is not a false positive). If a KPI is shown to have exceeded a threshold for increased monitoring or mitigation and is causally related to SO_2 emissions, then a pathway to mitigation would be implemented through consultation with B.C. ENV. Actions for

mitigation would be developed into an action plan and implemented according to the respective KPI table and / or mitigation outlined in Chapter 9.

KPI attainment assessment activities and results will be reported in each annual SO_2 EEM Program report. Annual SO_2 EEM Program reports will specify which KPIs do not have attainment results to report in a given year (such as for soils), and will explain why. Annual SO_2 EEM Program reports will also convey when the next attainment assessment is expected for each KPI.

Results of the next comprehensive end of cycle review in 2026 will inform decisions about:

- which KPIs and informative indicators should be monitored in 2026 and beyond and at what level of intensity,
- modifications to monitoring methods,
- refinement to KPI thresholds (decision rules), and
- the timeline for the next comprehensive end of cycle review.

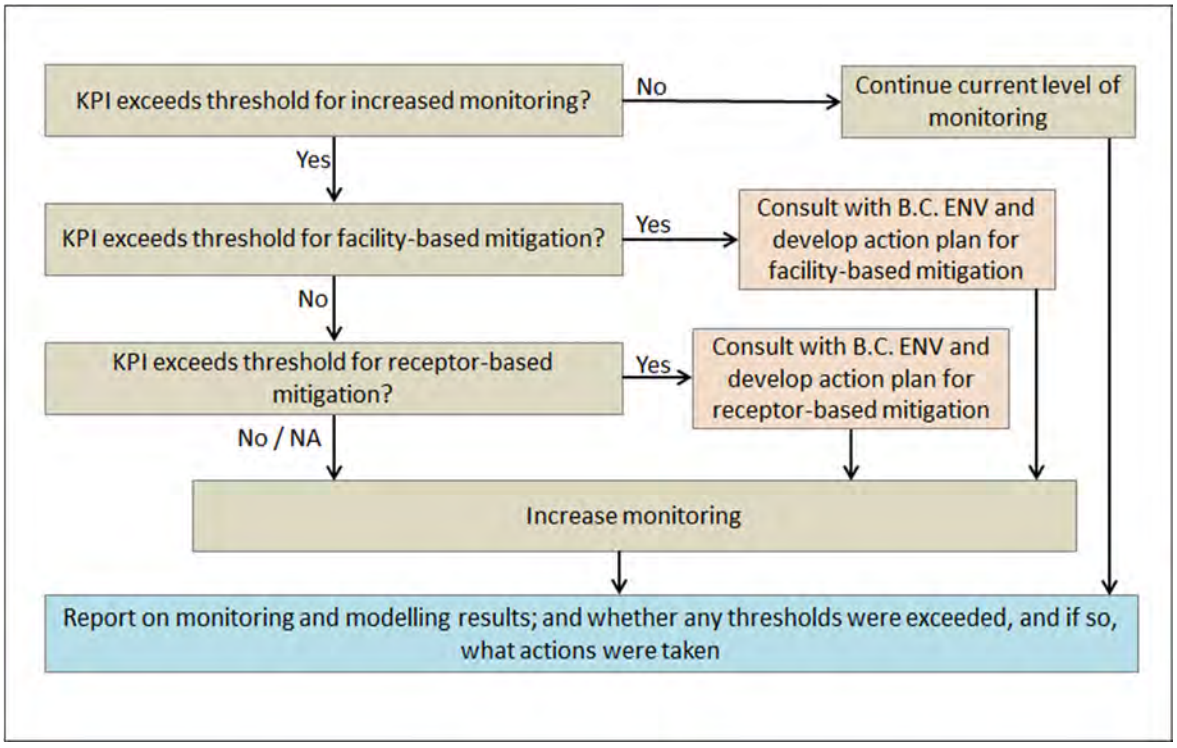


Figure 5. Decision tree for quantitative thresholds of key performance indicators and pathways to mitigation.

2 Atmospheric Pathways

2.1 Introduction

The measured SO_2 concentrations and wet S deposition provide important information. The continuous SO_2 analysers provide real-time, accurate, and reliable direct measurements, which can be directly tied to the smelter's current SO_2 emissions. The continuous SO_2 analysers also provide hourly and sub-hourly data that can be used to understand how concentrations change over time and how 1-hour concentrations relate to long-term average concentrations. The continuous SO_2 analyser data combined with the 30-day passive sampling data also provide valuable information to understand the spatial distribution of the plume, and to determine dry deposition. Precipitation chemistry (wet deposition of sulphur (S), chloride (Cl), and base cations) are collected on a weekly basis. Total (wet plus dry) atmospheric S deposition is important to the assessment of risk of impacts on vegetation, terrestrial, and aquatic ecosystems.

The SO_2 concentration measurements also provide key information about the accuracy of dispersion models used for SO_2 effects assessments and to make decisions when updating the SO_2 EEM Program. Learning whether the models over-predicted or under-predicted concentrations at various locations provides important information about whether the STAR and 2019 Comprehensive Review SO_2 effects assessments over-predicted or under-predicted risk of impacts on receptors. Understanding the model accuracy at various locations (i.e., whether the model accurately predicted the extent and position of the plume) also provides valuable information about the design of the EEM Program related to the locations selected for monitoring.

2.2 Indicators

We use SO_2 atmospheric concentrations to assess the risk of direct impacts on human health and vegetation (including cyanolichens). Measured SO_2 atmospheric concentrations are used to assess health impact; modelled and measured SO_2 concentrations are used to evaluate the risk of direct injury to vegetation. We use predictions of atmospheric deposition under different emission scenarios to assess the risk of impacts on vegetation, terrestrial, and aquatic ecosystems. Since the effects of SO_2 concentrations and total S deposition on receptors are assessed in receptor-specific evaluations, there are no KPIs for atmospheric concentrations or atmospheric deposition. There are also no thresholds for increased mitigation or monitoring for this reason.

The atmospheric pathway has one atmospheric concentration informative indicator: atmospheric SO_2 concentrations, which is measured through two types of equipment: continuous SO_2 analysers and passive SO_2 monitors. There are also two atmospheric deposition informative indicators: atmospheric S deposition and precipitation chemistry. These informative indicators are listed in Table 2 and an overview of methods for calculating them is provide in Table 3.

Table 2. Informative indicators for Atmospheric Pathways.

Informative indicators	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Atmospheric SO_2 concentration	Not applicable; will support KPIs and informative indicators for the receptors	• Exceedance of SO_2 CAAQS • Vegetation and cyanolichen health (including potential SO_2 injury)
Atmospheric S (wet and dry) deposition	Not applicable; will support KPIs and informative indicators for the receptors	• Atmospheric S deposition and critical load (CL) exceedance risk • Long-term soil acidification (decrease in base saturation) attributable to S deposition • Water chemistry – acidification • Plant biodiversity – community structure (including species occurrence and abundance) of select vascular plants • Cyanolichen biodiversity (occurrence and relative abundance)
Precipitation chemistry	Not applicable; will support KPIs and informative indicators for the receptors	• Critical load (CL)

2.3 Methods

Table 3. Overview of methods for calculating informative indicators for Atmospheric Pathways.

Informative indicators	Method overview
Atmospheric SO_2 concentration	Continuous analyser measurements of SO_2 air concentrations from continuous SO_2 monitoring network. Passive SO_2 sampler measurements from network of passive samplers in the Kitimat Valley with co-deployments at continuous analyser stations.
Atmospheric S (wet and dry) deposition	NADP wet deposition monitoring stations at Lakelse Lake and Haul Road[4] Estimation of dry deposition of S (using SO_2 from continuous analyser at Lakelse Lake and big-leaf dry deposition model; requires ancillary meteorological monitoring)
Precipitation chemistry	Wet precipitation chemistry for major ions at Lakelse Lake

[4] As the Haul Road station's precipitation chemistry data provide little value towards understanding risk. of ecological impacts and does not provide value for evaluating CALPUFF deposition modeling, a decision for discontinuing or relocating the Haul Road precipitation chemistry will be reviewed with B.C. ENV.

2.3.1 Atmospheric SO_2 concentration

A review of the ambient air quality monitoring network for SO_2 in Kitimat was completed in two phases based on the dispersion modelling from the STAR (phase 1) and the updated dispersion modelling from the 2019 Comprehensive Review (phase 2). The phase 2 network optimization evaluation (draft report) for SO_2 was re-submitted to B.C. ENV in 2022 following reanalysis to correct a meteorological data error. The report provided recommendations on the number and location of continuous SO_2 analysers.[5] Similarly, a passive monitoring program plan for the plume path network (valley network) was completed May 7, 2021 for deploying approximately mid-May or mid-June (depending on sites access) and continuing through approximately mid-October, and again from approximately mid-May or mid-June. The passive plan includes objectives of the program and decision criteria for continuing sampling beyond 2025.

Sampling locations:

- Continuous SO_2 analysers currently operated at Haul Road, Riverlodge, Kitamaat Village, Service Centre, and Whitesail, with additional SO_2 from Lakelse Lake (operated by Rio Tinto for dry S deposition) and Terrace-Skeena middle school (operated by B.C. ENV).
- Passive sampling locations will be consistent with the 2020-2021 passive sampling plan in general, with possible minor variation based on annual data evaluations and any siting issues identified during deployment. The 2020-2021 passive sampling plan included fifteen sites along the Kitimat Valley from V15 at Emsley Creek south of the smelter north to A04 at Lakelse Lake (co-located with the continuous SO_2 station).

Sampling timing, frequency and duration:

- Continuous SO_2 analysers operate continuously and the network as determined from Phase 2 monitoring network evaluation will operate through the duration of Phase III (through 2025).
- Passive samplers will be deployed from approximately mid-May or mid-June to mid-October with 30-day sampling periods.

Monitoring protocols and sampling methods:

- Continue to follow the monitoring protocol for continuous analysers including maintenance, calibration, and data collection and quality review.
- Continue to follow the monitoring protocol for passive samplers including deployment site evaluation, calibration based on continuous monitors, and quality review.

How and when monitoring data will be evaluated:

- Continuous and passive sampling SO_2 monitoring data will be evaluated for quality and reported annually. Evaluation of continuing the SO_2 passive monitoring network will be made in the 2026 Comprehensive Review of the SO_2 EEM Program.

[5] Errors in the alignment of wind direction sensors at the Whitesail and Yacht Club stations were found that impacted the dispersion modelling used in the 2019 SO_2 EEM Comprehensive Review.

- Annually, compare CALPUFF predictions of SO_2 (2016-2018 results from the 2019 Comprehensive Review) to continuous SO_2 monitoring data and general spatial coherence with passive SO_2 sampling data.

2.3.2 Atmospheric S (wet and dry) deposition

Sampling locations:

- Continue wet deposition at Lakelse Lake; review the value of the Haul Road wet deposition monitoring with B.C. ENV to determine if the monitoring should be discontinued or relocated.
- Include continuous SO_2 at Lakelse Lake in order to estimate dry S deposition.
- Continue to collect meteorological data at existing stations to estimate dry S deposition.

Sampling timing, frequency and duration:

- Continue monitoring at one NADP station providing data to evaluate sulphur, base cation, and chloride deposition in 2025.
- Precipitation chemistry samples will continue to be collected on a weekly duration from the National Atmospheric Deposition Program protocol.

Monitoring protocols and sampling methods:

- Precipitation chemistry monitoring will be carried out by the NADP following standard NADP network protocols for sample collection, handling and analysis (http://nadp.sws.uiuc.edu). The analysis of precipitation samples will include sulphur (S), nitrate (NO_3^-), ammonium (NH_4^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+); as well as chloride (Cl^-). Rainfall volume is measured daily by automated (digital) rain gauge collector.

How and when monitoring data will be evaluated:

- Wet and dry deposition will be reported annually.
- Precipitation chemistry data will be regularly evaluated by the NADP for quality, and reported annually.
- CALPUFF wet deposition predictions will be compared with NADP measurements at Lakelse Lake annually.

2.3.3 Additional studies

2.3.3.1 Ambient Air Network Rationalization

- The Phase 2 SO_2 monitoring network optimization effort (including addressing comments from B.C. ENV) is expected to conclude in 2023.

2.3.3.2 Special monitoring of deposition

- Include ion-exchange resins monitoring of deposition at sites of interest for plant biodiversity program or permanent soil plots if necessary.

2.4 Summary of Atmospheric Pathways Activities Planned for 2019-2025

The schedule for planned activities is provided in Table 4, and may be subject to change.

Table 4. Schedule of work on the Atmospheric Pathways line of evidence planned under Phase III.

Topic	2019	2020	2021	2022	2023	2024	2025
Atmospheric SO_2 Concentrations – Continuous Analysers	Maintain existing 5 continuous SO_2 analysers	Maintain existing 6 continuous SO_2 analysers	Maintain existing 6 continuous SO_2 analysers	Maintain existing 6 continuous SO_2 analysers	Update (as applicable) continuous SO_2 analysers as determined from phase 2 network optimization	Update (as applicable) continuous SO_2 analysers as determined from phase 2 network optimization	Maintain continuous SO_2 analysers as determined from phase 2 network optimization
Atmospheric SO_2 Concentrations –Passive Diffusive SO_2 Monitoring	Continue spring-autumn passive monitoring program in plume path network (aka Valley network)	Continue spring-autumn passive monitoring program in plume path network (aka Valley network)	Continue spring-autumn passive monitoring program in plume path network (aka Valley network)	Continue spring-autumn passive monitoring program in plume path network (aka Valley network)	Continue spring-autumn passive monitoring program in plume path network (aka Valley network) Conduct reconnaissance for three additional sites south of the smelter	Continue spring-autumn passive monitoring program in plume path network (aka Valley network)	Continue spring-autumn passive monitoring program in plume path network (aka Valley network)
Wet S Deposition, Precipitation Chemistry (Base Cations, Chloride)	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake)	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake)	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake)	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake) Review value of continuing wet deposition monitoring at the Haul Road	Pending a decision on the Haul Road station, maintain 2 rain chemistry stations (Haul Road and Lakelse Lake)	Pending a decision on the Haul Road station, maintain 2 rain chemistry stations (Haul Road and Lakelse Lake)
Dry S Deposition	Continue to estimate dry deposition at both Haul Road and Lakelse Lake stations	Continue to estimate dry deposition at both Haul Road and Lakelse Lake stations	Continue to estimate dry deposition at both Haul Road and Lakelse Lake stations	Continue to estimate dry deposition at Lakelse Lake station	Continue to estimate dry deposition at Lakelse Lake station	Continue to estimate dry deposition at Lakelse Lake station	Continue to estimate dry deposition at Lakelse Lake station
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

3 Human Health

Sections 3.1 to 3.3 of the SO_2 EEM Program were amended by the 2019 B.C. Environmental Appeals Board Consent Order. All parties of appeal numbers 2014-EMA-003, 2014-EMA-004, and 2014-EMA-005 agreed to amending the human health section of the SO_2 EEM Program through a mediated settlement of the appeals. The Director issued a decision on October 25, 2022, designating the Service Centre Station to be an attainment station for the human health KPI, effective on January 1st, 2023. Reporting on the attainment of the KPI will commence in the 2023 Annual Human Health KPI Technical Memo.

3.1 Indicators and Thresholds

The "impact threshold criteria" under clause 4.2.5 of the P2-00001 Multimedia Permit for Human Health shall be the Human Health Key Performance Indicator ("KPI") as defined by the following air quality standards:

> Until January 1, 2020, the Human Health KPI is the 1-hour Interim Provincial Ambient Air Quality Objective for SO_2. From January 1, 2020 onwards, the Human Health KPI is the 1-hour Provincial Ambient Air Quality Standard for SO_2.

3.2 Methods

The following ambient air quality monitoring stations will be used to assess attainment of the Human Health KPI: Riverlodge, Whitesail, Kitamaat Village and Service Centre. [6]

3.2.1 Further monitoring stations at Service Centre

An ambient air quality monitoring station will be established by October 1, 2019 at or in close proximity to the Service Centre, subject to Ministry siting requirements and property access, and will collect SO_2 and meteorological data (the "Service Centre Station").[7]

The data collected by the Service Centre Station will be made available to the public and will be considered by the Director as part of a decision under Section 3.2.1.1.

The data collected by the Service Centre Station will not be used for determining attainment of the Human Health KPI under this permit before such a decision is made under Section 3.2.1.1.

3.2.1.1 Decision on designating the Service Centre Station to be an attainment station

Once sufficient data and information has been collected by the Service Centre Station, the Director will make a decision (as defined in section 16 of the *Environmental Management Act*) and provide reasons to the public and any potentially affected party, on whether to amend

[6] Attainment of the SO_2 Human Health KPI is assessed for each of the Riverlodge, Whitesail and Kitamaat Village stations.
[7] Service Centre's data reporting started on May 12th, 2020.

In making this decision, the Director must consider: the *Environmental Management Act* and associated regulations; relevant Ministry policies; the applicable air quality standards, including the Provincial Ambient Air Quality guidelines; and relevant data and information. The Director may receive information from a variety of interested parties.

The Director shall make this decision no later than 24 months from the day that the Service Centre Station is established.

If the Director decides that Section 3.2 shall be amended to include the Service Centre Station, the Director may consider data that the Service Centre Station has gathered prior to the date of that decision in making any subsequent decision on whether there has been non-attainment.

3.3 Steps in the Event of Non-attainment of the Human Health KPI

Section 3.3 overrides Chapters 8 and 9 of the EEM Plan with respect to non-attainment of the Human Health KPI.

- If potential non-attainment of the Human Health KPI is identified, the Director will review available information and data with respect to the non-attainment as well as consider exceptional events, in order to confirm the non-attainment. Meteorological conditions are not an acceptable justification for non-attainment.
- If the Director determines that there is non-attainment of the Human Health KPI, the Permittee shall take action to bring the Human Health KPI into attainment by implementing mitigation measures to reduce SO_2 emissions.
- Within 3 months of notification by the Director for the non-attainment of the Human Health KPI, the Permittee shall submit a report to the Director outlining a mitigation action plan to reduce SO_2 emissions that will bring the Human Health KPI into attainment. This report shall include an implementation timeline not to exceed one year.
- If the Human Health KPI is not brought into attainment by the following year, the maximum allowable SO_2 emissions set out in clause 4.2.2 of the P2-00001 Multimedia Permit will be reduced by an amount the Director deems needed to bring the Human Health KPI into attainment. If there are other permitted emitters of SO_2 emissions authorized under the Environmental Management Act and located within the Kitimat airshed, the amount of SO_2 emissions reduction required under this clause shall be proportional to the percentage of the Permittee's permitted SO_2 emission limit as compared to the total SO_2 emission limit of all such permitted emitters of SO_2.
- The Director will consider the Permittee's proposed mitigation action plan schedule to determine when the reduced SO_2 emission limit will come into force and effect.
- The total SO_2 permit reduction for the Permittee under this clause will not exceed 15 Mg/day.

The mitigation action plan will include public education and recommendations for limiting health risks. Health communications and recommendations will be developed in consultation with the B.C. Northern Health Authority.

3.3.1 Exceptional events

The Director may consider "exceptional events" in determining whether there is non-attainment of the Human Health KPI, to account for events that are outside the control of Rio Tinto and are time bound. Examples of exceptional events include, but are not limited to:

- Fire within the community that may emit SO_2;
- emergency conditions at the facilities within the Kitimat airshed (e.g., Rio Tinto Smelter upset conditions or LNG Canada emergency flare);
- vandalism or corruption of data from other point sources such as vehicle emissions in close proximity to the ambient air monitoring station; and
- temporary global events that impact SO_2 levels such as a volcano eruption.

Examples that would NOT be considered an exceptional event include, but are not limited to:

- inputs to smelting activities such as high sulphur coke;
- ongoing global SO_2 influences that are not temporary, such as industrial emissions;
- scheduled bypass of works for maintenance at facilities in the Kitimat airshed; and
- meteorological conditions.

3.4 British Columbia SO_2 Air Quality Guideline

British Columbia has adopted the Canadian Ambient Air Quality Standards (referred to by the acronym CAAQS) as the provincial air quality standard for SO_2. The CAAQS constitute a set of pollutant-specific standards that place limits on and establish goals for the levels of pollutants in the air. The CAAQS values for SO_2 were announced in October 2016 . They establish a specific SO_2 concentration limit (70 ppb) starting in 2020, and a lower limit starting in 2025 (65 ppb). A specific statistic of the observed air pollutant levels is employed to compare to the limit values ("The three-year average of the annual 99th percentile of the SO_2 daily-maximum of 1-hour-averaged concentrations."). In 2017 B.C. ENV inserted the provincial air quality objective into the SO_2 EEM Program as the health KPI (Table 5). This included the interim SO_2 air quality guideline that was effective from 2017 to 2019 and the SO_2 CAAQS which are effective in 2020.

Table 5. KPI for Human Health.

Exposure Year	KPI Threshold	KPI Percentile	KPI Averaging Time	KPI
2019	75 ppb	98th	3 years	The average of the 1-hour daily maximum on the 8th worst day in each of 2017, 2018, 2019
CAAQS 2020-2024	70 ppb	99th	3 years	The average of the 1-hour daily maximum on the 4th worst day in each of three consecutive years
CAAQS 2025+	65 ppb	99th	3 years	The average of the 1-hour daily maximum on the 4th worst day in each of three consecutive years

The Health KPI is calculated annually using validated SO_2 hourly data. The validation is done by B.C. ENV and validated data is typically available before March 31st of the following year.

Sampling locations:

- Riverlodge, Whitesail, Kitamaat Village and Service Centre continuous [SO_2] monitoring stations.

Sampling timing, frequency and duration:

- Data from the sampling locations are collected continuously and hourly-averaged concentrations are available in near-real time via the website https://www.env.gov.bc.ca/epd/bcairquality/readings/find-stations-map-SO2.html.
- Historic data are available from the BC Air Data Archive at https://envistaweb.env.gov.bc.ca.

Monitoring protocols and sampling methods:

- Continuous SO_2 ambient air quality monitoring will be done according to The British Columbia Field Sampling Manual, Part B Air and Air Emission Testing, 2020.
- Calculations of the 1-hour Provincial Ambient Air Quality Standard for SO_2 will be done consistent with the CCME, 2020 Guidance Document on Achievement Determination For Canadian Ambient Air Quality Standards for Sulphur Dioxide, once exceptional events as defined in Section 3.3.1 are accounted for.
- Some adjustments may be made to the calculation (i.e., what day constitutes the 99th percentile) if data are missing for certain parts of the year beyond tolerable limits.

How and when monitoring data will be evaluated:

- Data for a given year are validated by June 1st of the following year.
- Calculation of the KPI will be done annually after Rio Tinto has been notified by B.C. ENV that the SO_2 hourly data have been validated B.C. ENV.

3.5 Additional Activities

To increase knowledge of air quality objectives and how air quality objectives are set for health protection, either an air quality health expert will be retained to present to the KPAC or an external organization will be co-sponsored to provide a session on air quality and health. This activity will be done in either 2023 or 2024.

3.6 Summary of Human Health Activities Planned for 2019-2025

The schedule for planned activities is provided in Table 6, and may be subject to change.

Table 6. Schedule of work on the Human Health line of evidence planned under Phase III.

Topic	2019	2020	2021	2022	2023	2024	2025
Reporting	Annual reporting of KPI for the 2018 year, after data validation (normally by March 31)	Annual reporting of KPI for the 2019 year, after data validation (normally by March 31)	Annual reporting of KPI for the 2020 year, after data validation (normally by March 31)	Annual reporting of KPI for the 2021 year, after data validation (normally by March 31)	Annual reporting of KPI for the 2022 year, after data validation (normally by March 31)	Annual reporting of KPI for the 2023 year, after data validation (normally by March 31)	Annual reporting of KPI for the 2024 year, after data validation (normally by March 31) Note that the 2025 KPI annual reporting will be done in 2026
Additional activities					Air quality objectives and health protection presentation	Air quality objectives and health protection presentation, if not done in 2023	

4 Vegetation

The Vegetation line of evidence has been combined with the Terrestrial Ecosystems line of evidence. Please refer to Chapter 5, Terrestrial Ecosystems, for Vegetation indicators and methods.

5 Terrestrial Ecosystems

5.1 Introduction

We continue to monitor components of Terrestrial Ecosystems as they are known to respond to S deposition. The Terrestrial Ecosystems line of evidence integrates the former Terrestrial Ecosystems (Soils) and Vegetation receptors (Figure 6). Based on the results of the 2019 Comprehensive Review, we are shifting our emphasis to detecting mid-to-long term changes in vascular plant biodiversity as an indicator of changes in soil chemistry as affected by SO_2 emissions from the smelter and subsequent deposition. We will also evaluate changes in the biodiversity of 19cyanolichen species as an indicator of effects of SO_2 emissions and potential acidification of c19yanolichen substrate. The addition of these plant and 19cyanolichen biodiversity metrics (including species richness and abundance) provides informative indicators of potential SO_2 effects by allowing the detection of shifts in community structure and composition based on species-specific responses to S deposition. We retain the periodic visual inspection in order to detect short-term changes in plant health or symptoms due to direct exposure to SO_2. The Terrestrial Ecosystems (Soils) KPIs are retained. We present an evidentiary framework based on pathways of exposure and potential resulting effects.

Figure 6 illustrates the Terrestrial Ecosystems line of evidence showing the pathways for direct effects on soils, vegetation, and cyanolichens as well as soil mediated effects on plant and 19cyanolichen biodiversity and health.

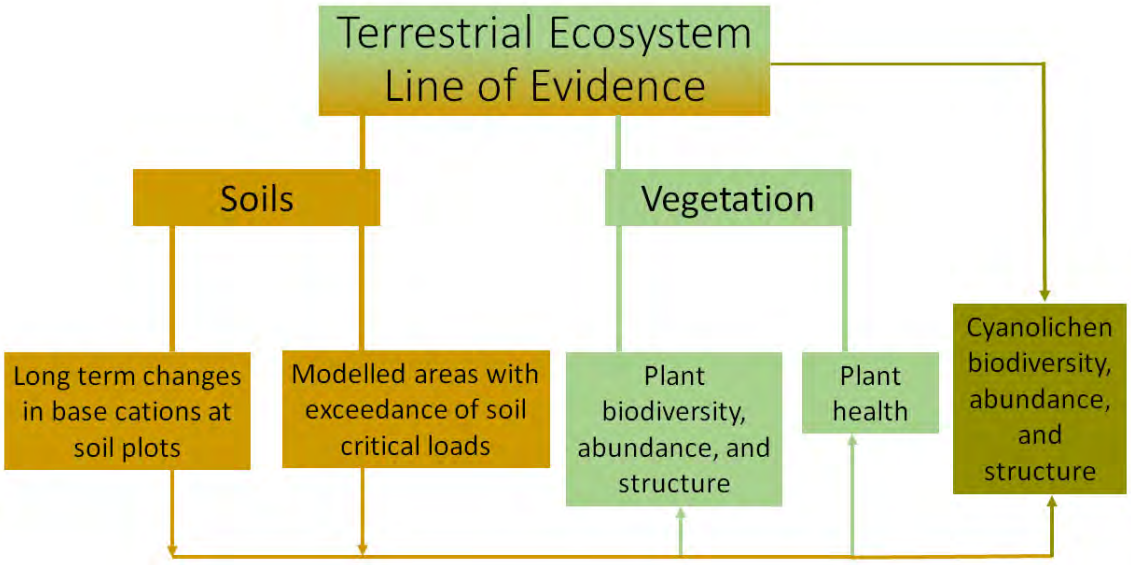


Figure 6. Effects pathways for soils and vegetation within the new Terrestrial Ecosystems line of evidence.

5.2 Indicators and Thresholds

The two soils KPI have been retained: exceedance of critical loads of acidity for forest soils from modelled S deposition, and observed change in soil base cations over time. The KPIs, their thresholds, informative indicators and other indicators to be jointly considered are presented in Table 7 and Table 8. Methods for calculating these indicators are provided in Section 5.3. The Phase III Comprehensive Review will assess if a KPI can be established for the plant biodiversity component of the terrestrial ecosystems line of evidence.

Table 7. KPIs for Terrestrial Ecosystems.

Key performance indicators	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Critical load (CL)[8] exceedance from modelled atmospheric S deposition (estimated only if S deposition changes) **This KPI will not be assessed for attainment during Phase III**	Modelled CL exceedance is > 5% of semi-natural upland forest soils in the study area[9] Action: an extended soil survey will be carried out to provide data for a dynamic modelling assessment of the timeline of the areal exceedance (i.e., the time for soils to reach the critical threshold)	Dynamic model assessment[10]: Modelled CL exceedance is >5% of semi-natural upland forest soils in the study area and dynamic modelling estimates the time for soils to reach the critical thresholds is less than 200 years (based on projected change in base cations) Action: Pilot application of lime/wood ash, to reduce soil acidity and increase base cation pools to pre-KMP levels, subject to B.C. ENV approval[11]	Dynamic model assessment: Modelled CL exceedance is >5% of semi-natural upland forest soils in the study area and dynamic modelling estimates the time for soils to reach the critical thresholds is less than 100 years (based on projected change in base cations) Action: reduction in SO_2 emissions	• Magnitude of exchangeable cation (Ca, Mg, K, Na) • Atmospheric S deposition

[8] Critical load exceedance mapping will be re-run in the Comprehensive Review of the Phase III Plan. However, if significant changes are observed in cyanolichen and vascular plant biodiversity that are causally related to SO_4^{2-} deposition, then the critical load exceedance mapping would also be re-run.
[9] Exceedance > 5% of forested soils (broadleaf, coniferous, mixed wood and shrub cover types in Figure 6-3 of the Comprehensive Review report) in the effects domain (the area delineated by modelled 7.5 kg SO_4/ha/year deposition isopleth).
[10] Dynamic modelling, if needed for either receptor-based or facility-based mitigation, would begin in 2026 (i.e., after Phase III).
[11] Section 5.3.7.3 describes the development of the pilot project scope.

Key performance indicators	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Long-term soil acidification (decrease[12] in base saturation) attributable to S deposition	For one or both plots: a 40% decrease in base saturation since plot establishment, causally related to SO_2 emissions Action[13]: re-sampling of control plot and sampling of tree base cation content to confirm decrease is causally related to SO_2 emissions; if causally related then extended soil survey will be carried out to provide data for a dynamic modelling assessment of the spatial significance of base cation loss	Dynamic model assessment[14]: A predicted 40% decrease in soil base saturation in > 1% (~20 km^2) of the area of semi-natural upland forest soils, based on dynamic modelling. Action: pilot application of lime/wood ash to reduce soil acidity and increase base cation pools to pre-KMP levels, subject to B.C. ENV approval	Dynamic model assessment: A predicted decrease in base saturation of ≥ 40% in > 5% (~100 km^2) of the area of semi-natural upland forest soils, based on dynamic modelling Action: reduction in SO_2 emissions	• Atmospheric S deposition • Magnitude of exchangeable soil cations (Ca, Mg, K, Na) • Magnitude of net increase in base cations (Ca, Mg, K) in trees

Table 8. Informative indicators for Terrestrial Ecosystems.

Informative indicators	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Exchangeable acidity and base cations (Ca, Mg, K, Na)	Not applicable; supports calculation of long-term acidification	• Atmospheric S deposition and critical load (CL) exceedance • Long-term soil acidification (decrease in base saturation) • Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)
Modelled S deposition[15]	Not applicable; supports calculation of CL exceedance	• Areal exceedance of critical load (CL)

[12] The baseline for comparison is base saturation in plots sampled and measured in 2015. The intent is to resample every 5 years, with the next sampling occurring in 2025.
[13] This would be done after Phase III, as plot sampling will occur in 2025, the last year of Phase III.
[14] Dynamic modelling, if needed for either receptor-based or facility-based mitigation, would begin in 2026 (i.e., after Phase III).
[15] There are no plans to revise modelled S deposition in Phase III.

Informative indicators	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Net base cation uptake (Ca, Mg, K) in trees	Not applicable, supports dynamic modelling if KPI thresholds are exceeded	• Magnitude of change in exchangeable soil cation (Ca, Mg, K, Na)
Vegetation Health (including potential SO_2 Injury)	More than occasional symptoms[16] of SO_2 injury outside of Rio Tinto Kitimat properties, causally related to SO_2 emissions Appearance of symptoms on vegetation of soil acidification/aluminum toxicity in areas of predicted soil CL exceedance Action: assess ambient air data, meteorological data and B.C. Works SO_2 production data to find the potential causes; and increase visual inspection frequency to annual	• Atmospheric SO_2 concentration • Atmospheric S deposition (specifically, wet deposition)
Plant Biodiversity	If there is a biologically significant differential change, causally related to SO_2 emissions, relative to reference sites in vascular plant biodiversity in the low shrub and/or herb layer outside the Comprehensive Review -modelled 7.5 kg SO_4^{2-}/ha/year the following actions will be taken: visual assessment of plant health will be expanded to include all plant biodiversity monitoring plot sites; soils will be re-sampled at the sites where the biological change is significant to determine if soils at these sites are acidic enough to potentially be causing damage; plant root simulator probes (PRS Probes) will be deployed in conjunction with soil sampling to provide an indication of changes in soil water ion concentrations [e.g. SO_4^{2-}, Ca^{2+}, Al^{3+}] and; ion exchange resin columns will be installed at the plots to determine if S deposition is greater than expected.	• Atmospheric S deposition and critical load (CL) exceedance risk • Atmospheric SO_2 concentration • Atmospheric S deposition (specifically, wet deposition)

[16] Injury, causally related to SO_2 emissions, on two or more species at two or more plant biodiversity monitoring plot sites.

Informative indicators	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Cyanolichen Biodiversity	If there is a biologically significant differential change, causally related to SO_2 emissions, in c24yanolichen biodiversity outside the Comprehensive Review -modelled 7.5 kg SO_4^{2-}/ha/year the following actions will be taken: visual assessment of 24cyanolichen health will be expanded to include all plant biodiversity monitoring plot sites; soils will be re-sampled at the sites where the decrease is significant to determine if levels of acidity or acidity-related ions (i.e. Al^{+3}) have changed; plant root simulator probes (PRS Probes) will be deployed in conjunction with soil sampling to provide an indication of changes in soil water ion concentrations [e.g. SO_4^{2-}, Ca^{2+}, Al^{3+}] and; ion exchange resin columns will be installed at the plots to determine if S deposition is greater than expected.	• Atmospheric S deposition and critical load (CL) exceedance risk • Atmospheric SO_2 concentration • Atmospheric S deposition (specifically, wet deposition)

5.3 Methods

Table 9 and Table 10 provide an overview of the methods for calculating the KPIs and informative indicators, respectively. More information on the methods is provided in the subsections below these two tables.

Table 9. Overview of methods for calculating the KPIs for Terrestrial Ecosystems.

Key performance indicators	Method overview and frequency of attainment assessment
Critical load (CL) exceedance risk from modelled atmospheric S deposition	Critical loads and exceedance were completed during the 2019 Comprehensive Review. CL exceedance risk will only be recalculated if modelled S deposition changes.[17] For more information, please refer to Section 5.3.1.
Long-term soil acidification (decrease in base saturation)	Soil sampling at long-term soil plots to assess the rate of change in base saturation following identical protocols as outlined in the 2019 Comprehensive Review. Soils will be sampled every 5 years along with tree diameter at breast height (DBH); the next sampling will be in 2025. Attainment will be assessed at each sampling period. If soil acidification [40% decrease in base saturation]

[17] S deposition will not be modelled during Phase III; therefore, CL exceedance will not be determined (revised) during Phase III.

Key performance indicators	Method overview and frequency of attainment assessment
attributable to S deposition	occurs, dynamic modelling will be undertaken in the next phase of the SO_2 EEM Program to assess regional base cation losses. For more information, please refer to Section 5.3.2.

Table 10. Overview of methods for calculating the informative indicators for Terrestrial Ecosystems.

Informative indicators	Method overview
Exchangeable acidity and base cations (Ca, Mg, K, Na)	Measured from soil samples in long-term soil plots (and for regional soils if >5% exceedance in study area) following identical protocols to those described in the 2019 Comprehensive Review. For more information, please refer to Section 5.3.3.
Net base cation uptake (Ca, Mg, K) by trees	Measured from trees in long-term soil plots following well established field and laboratory techniques.
Vegetation Health (including potential SO_2 Injury)	Inspection at the 33 cyanolichen and vascular plant biodiversity plots. For more information, please refer to Section 5.3.4.
Plant biodiversity	A total of 33 sites will be monitored on a three-year rotating panel. These sites will be the same locations as the c25yanolichen biodiversity and vegetation health plots. For more information, please refer to Section 5.3.5.
Cyanolichen biodiversity	A total of 33 sites that meet the criteria used by B.C. ENV – many of which are previously established by B.C. ENV for c25yanolichen monitoring – will be monitored. For more information, please refer to Section 5.3.6.

5.3.1 Critical load (CL) exceedance risk from modelled atmospheric S deposition – KPI

Critical load and area of exceedance was assessed during the 2019 Comprehensive Review. The assessment included revised soil mapping, updated determination of weather rates, revised model parameterisation and total S deposition. The threshold for critical loads KPI was not reached, i.e., the area of critical load exceedance was < 1%. The KPI will not be re-evaluated during Phase III.

5.3.2 Long-term soil acidification (decrease in base saturation) attributable to S deposition – KPI

Sampling locations:

- Near-field and far-field plots were established at Coho Flats and Lakelse Lake, respectively, during October–December 2015, and the control plot was established at

Kemano during 2016. At each location, primary and secondary (backup) plots were established within forest stands dominated by western hemlock.

Sampling timing, frequency and duration:

- Soils and tree diameter at breast height (DBH) at the primary plots at Coho Flats and Lakelse Lake will be resampled during 2025 to assess changes in soil chemistry (e.g., base saturation) and tree volume since the initial sampling during 2015. The control plot is only resampled and analysed if changes in soil chemistry exceeding the KPI threshold for increased monitoring is detected at the Coho Flats or Lakelse Lake plots.

Monitoring protocols and sampling methods:

- Each long-term soil plot is 32 m by 30 m in size and composed of twenty 8 m by 6 m sub-plots lettered A to T. Each sub-plot is further divided into twelve 2 m by 2 m sampling grids (numbered 1 to 12); one numbered grid will be randomly sampled (without replacement) from each lettered sub-plot.
- Soil will be sampled at three depths in the mineral soil: 0–5 cm, 5–15 cm, and 15–30 cm depths (yielding a total of 60 soil samples for each plot, i.e., three soil samples by depth within each of the 20 lettered sub-plots).
- Soils (fine fraction) will be analysed for organic matter content by loss on ignition (LOI), and exchangeable base cations and exchangeable acidity. Exchangeable base cations were measured using an ammonium acetate extraction and exchangeable acidity was measured using a potassium chloride extraction. Further details are provided in the 2019 Comprehensive Review.
- The diameter at breast height (DBH) of all trees >10 cm will be measured.

How and when monitoring data will be evaluated:

- The change (decrease) in base saturation (%) will be assessed between two sampling periods (accommodating the variability in soil chemistry during both sampling events). The analysis will use soil concentrations in the top 0–30 cm.
- The minimum detectable difference will be used to evaluate the potential of an early warning change in soil base saturation using a lower level of significance and / or lower power.
- The analysis will be carried out and reported under the next comprehensive end-of-cycle review.
- Forest biomass will be estimated using baseline tree data and data collected in 2025. Combined with tree nutrient concentrations, uptake of base cations by trees can be calculated.

5.3.3 Exchangeable acidity and base cations – Informative indicator

Next steps: if there are changes at either Coho Flats or Lakelse Lake, we will carry out additional sampling in 2026 (after Phase III):

- We will sample soils at the control plots to determine if the change is causally related to B.C. Works.
- If needed based on the results, we will estimate tree biomass to evaluate the role of nutrient uptake (which may affect the control plots also).
- If there is a causal relationship, we will proceed with dynamic modelling.

5.3.4 Vegetation health (including potential SO_2 injury) – Informative indicator

Inspection locations:

- Inspection sites will be the 27cyanolichen and vascular plant biodiversity measurement plots. Vegetation in the areas of predicted soil CL exceedance will be inspected if safely accessible.

Sampling timing, frequency and duration:

- The inspection will be conducted in a 3-year rotating panel with one-third of the sites inspected each year.

Monitoring protocols and sampling methods:

- During the site visit, a qualified professional in the plant sciences will assess vegetation for the presence of insects and plant pathogens, any symptoms of abiotic stress such as drought, flooding, physical disturbance (natural or human), or nutrient deficiencies, or injury due to SO_2 exposure. Cyanolichen thalli will be inspected and their health will be assessed. The site measurement/inspection schedule will be such that sites located around the valley are visited each year. That will assure that we will detect changes affecting the ecosystem if and where they occur.

How and when monitoring data will be evaluated:

- Each year visual inspection and assessment results will be reported along with the activities related to measuring biodiversity. Every third year there will be an end-of-cycle report that will summarize the state of the health of vegetation in the Kitimat Valley.

5.3.5 Plant biodiversity – informative indicator

Sampling locations:

- We intend to use the B.C. ENV-established c27yanolichen monitoring sites if safely accessible. If not, or if the exact site cannot be located, we will establish sites nearby within stands that meet the criteria used by B.C. ENV (stands with no history of commercial logging and at least 100 years old). Locations will be characterised by stand age, modelled critical load of acidity, and CALPUFF-modelled SO_4^{2-} deposition from the 2019 Comprehensive Review.

Sampling timing, frequency and duration:

- Plots will be visited between June 1st and August 31st. We will implement a 3-year rotating panel design with one-third of the sites visited in any given year. A full measurement cycle will be completed after year 3, 6, 9, and so on.

Monitoring protocols and sampling methods:

- When crews arrive, the boundary of a 20m x 20m permanent plot will be marked using a stringline and flagging tape, which will be removed at completion of measurements. During the initial assessment, the crew will complete the following minimum Site

Information (per FS1333 form, British Columbia Ministry of Forests and Range and British Columbia Ministry of Environment 2010):

- project name and plot #
- date
- surveyors
- plot location (i.e., description of how to get there)
- UTM and elevation
- BGC zone/subzone/variant
- site series
- soil moisture and nutrient regime
- slope and aspect
- surface shape and mesoslope position
- exposure type and/or site disturbance (if applicable)
- total % cover of each vascular plant species in the low shrub and herb layers at initial measurement and each subsequent remeasurement
- total % cover for the tree, shrub, herb and moss layers (but not individual species in the tree, tall shrub, or moss layers) at initial measurement and each subsequent remeasurement

- Photographic documentation will include, at minimum, views from plot centre to the north, east, south, west, up (canopy) and down (forest floor).
- Linear transects will then be conducted along the boundary stringlines on the west and north perimeters of the plot. For each species in the low shrub and herb layers, the drip-line length will be measured along the string line, and the start and end of each occurrence along the line will be documented. For shrubs, a plumb bob will be used to accurately record species coverage. Percent cover, by species, will be estimated from these measurements.
- Additional information for plants in the low shrub and herb layers will be collected as follows:
  - plant species present in the plot, and
  - distribution, vigor, and phenology codes.
- The presence and abundance of invasive plant species will be recorded, irrespective of their vegetation layer.
- The presence of plant species of "special interest" (as identified in Table 1 of Laurence et al. 2020, and provided in Appendix D) will be recorded.
- The presence of species or ecosystems of concern (per B.C. Conservation Data Centre) will be recorded, irrespective of their vegetation layer.
- General comments will be recorded, if/as applicable, regarding the vegetation and ecosystem as a whole both in and near the plot, including any disturbances or potential sources of change or impact that may be noted.
- At the time of first measurement, soil samples will be taken to determine soil pH, exchangeable cations, and exchangeable acidity. Samples will be taken in the upper 10 cm of mineral soil.
- During subsequent assessments, Site Information will be confirmed or modified, as required. During each remeasurement, we will record the following minimum information:
  - current presence and % cover of all vascular plants in the low shrub and herb layers in the 20m x 20m permanent plot;
  - current total % cover for the tree, shrub, herb and moss layers;
  - photographic documentation;

  - remeasurement of the west and north boundary linear transects for low shrub and herb layer % cover;
  - "additional information" for plants in the low shrub and herb layers (described above);
  - occurrence of plant species of special interest (e.g. cultural use; see Table 1 in Laurence et al. 2020);
  - presence and abundance of invasive plant species;
  - presence of species or ecosystems of concern within the plot (per current status provided by the B.C. Conservation Data Centre); and
- any applicable comments about the plot or activities/changes (etc.) in the immediate vicinity which may affect the plot.
- Additional details are provided in "A Plan to Monitor Components of Cyanolichen and Vascular Plant Communities in the Vicinity of Rio Tinto B.C. Works as a Component of the SO_2 Environmental Effects Monitoring Program" (Laurence et al., 2020), which is presented as Appendix D.

How and when monitoring data will be evaluated:

- Starting at the end of the first remeasurement (year 4 from program initiation), slopes of trend lines can be calculated and compared between low (reference sites), moderate, and high deposition sites. As additional remeasurement cycles are completed, our estimation of the slope and the power to detect change improves. At the end of each 3-year measurement cycle, an analysis comparing trends at moderate and high deposition sites to those at low (reference) deposition sites.
- Field monitoring methods will be reviewed after completion of a monitoring cycle. Recommendations (if any) for improving the methodology will be brought forward for updating the field method manual and work plan for the next monitoring cycle.
- For the soils samples taken at the time of first biodiversity plot measurement, laboratory methods and variables measured will be the same as those described in ESSA Technologies et al. (2020). If necessary to establish causality, soils will be re-sampled and analysed and PRS Probes will be deployed to indicate changes in soil water ion concentrations (Watmough et al. 2013). If necessary, to establish causality, plant tissues will be analysed to measure S, base cations, and aluminum.
- The effectiveness of the plant biodiversity monitoring program will be assessed in the end of cycle 2026 Comprehensive Review and completion of the 2nd monitoring cycle (year 6). Statistical analysis of the monitoring data will be conducted to assess the effectiveness of the program and to identify adjustments to the monitoring program design.

5.3.6 Cyanolichen biodiversity – informative indicator

Sampling locations:

- We intend to use the B.C. ENV-established 29cyanolichen monitoring sites if safely accessible. If not, or if the exact site cannot be located, we will establish sites nearby within stands that meet the criteria used by B.C. ENV (stands with no history of commercial logging and at least 100 years old). Locations will be characterised by stand age, modelled critical load of acidity, and CALPUFF-modelled SO_4^{2-} deposition from the 2019 Comprehensive Review.

Sampling timing, frequency and duration:

- Plots will be visited between June 1st and August 31st. We will implement a 3-year rotating panel design with one-third of the sites visited in any given year. A full measurement cycle will be completed after year 3, 6, 9, and so on.

Monitoring protocols and sampling methods:

- We will conduct a 1-hour timed search for c30yanolichen species and record their relative abundance (0-None; 1-Rare: 1-2 colonies per plot; 2-Occasional: 3-5 colonies per plot; 3-Common: 6 colonies to 20% cover of host trees within plot; 4-Very Common: 21-51% cover of host trees within plot; 5-Abundant: 51+% cover of host trees within plot) these lichen abundance categories were adapted in consultation with Patrick Williston (B.C. ENV) from the B.C. standards for rating arboreal lichen loading (British Columbia Ministry of Forests and Range and British Columbia Ministry of Environment 2010). The timed search will be conducted within the established 20m x 20m plot; however, if limited c30yanolichen substrate is available within the established plot and the search area is exhausted prior to the one-hour time limit, the search will continue immediately outside the plot boundaries until the time limit is achieved (surveyors will record the fact that the search extended beyond plot boundaries, and results will reflect whether inside or outside the plot).
- Ion exchange resin columns (above ground) may be used at selected locations to quantify actual S deposition depending on the risk of soil acidification.
- If necessary, to establish causality, soils will be re-sampled and analysed and PRS Probes will be deployed to indicate changes in soil water ion concentrations (Watmough et al. 2013).
- If necessary, to establish causality, c30yanolichen tissues will be analysed to measure SO_4^{2-}, base cations, and aluminum.

How and when monitoring data will be evaluated:

- Starting at the end of the first remeasurement (year 4 after program initiation), slopes of trend lines can be calculated and compared between low (reference sites), moderate, and high deposition sites. As additional remeasurement cycles are completed, our estimation of the slope and the power to detect change improves. At the end of each 3-year measurement cycle, an analysis comparing trends at moderate and high deposition sites to those at low (reference) deposition sites.
- Field monitoring methods will be reviewed after completion of a monitoring cycle. Recommendations (if any) for improving the methodology will be brought forward for updating the field method manual and work plan for the next monitoring cycle.
- The effectiveness of the 30cyanolichen biodiversity monitoring program will be assessed in the end of cycle 2026 Comprehensive Review and completion of the 2nd monitoring cycle (year 6). Statistical analysis of the monitoring data will be conducted to assess the effectiveness of the program and to identify adjustments to the monitoring program design.

5.3.7 Additional studies

5.3.7.1 Survey of wetland geochemistry

- A survey of wetlands will be carried out to determine their acid-base status, i.e., are they acid sensitive? To do this we will measure base cations, pH, and organic matter in wetlands that vary in distance from the smelter. These data will be used to verify a number of assumptions regarding wetlands included in the 2019 Comprehensive Review. The steps in this study are:
    - Review of GIS and Google earth data to locate wetland coverage
    - Select accessible sites along a gradient with distance from the smelter
    - Collect surface water (if water present at site) / wetland soil from each site during 2023 / 2024
    - Analyse samples for water chemistry and soil chemistry
    - Also potentially analyse for sulphate adsorption changes with climatic conditions

5.3.7.2 Assessment of aluminum solubility

- Acidification impacts are primarily caused by elevated concentrations of aluminium. Under the 2019 Comprehensive Review, aluminium solubility was modelled using a static relationship but the relationship can change depending on soil type. The objective of this study is to conduct experiments on Kitimat soils to better understand Al solubility and hence risk of toxic concentrations (this parameter is used within the determination of CL). The steps in this study are:
    - Review potential soil types using data from existing surveys (STAR) and surface geology maps
    - Select sites to cover a range of soil types
    - Where possible use existing archived soils from STAR and long-term plots
    - Where needed, supplement soils with new sites sampled during 2023 / 2024
    - Run laboratory experiments to extract base cations, aluminium, free aluminium, and evaluate relation between organic matter, aluminium and pH in soils

5.3.7.3 Pilot project scope for receptor-based mitigation

The scope of a pilot project to demonstrate the feasibility of receptor-based mitigation will be developed during SO_2 EEM Phase III. The purpose of the pilot project is to ensure that there is a receptor-based mitigation solution that can be feasibly implemented should the soils KPI exceed the threshold for receptor-based mitigation. The scope of the pilot project will include providing a review on the state of knowledge on soil liming and or other soil amendments to buffer soil acidification, different methods and technologies that have been successfully applied to treat acidified soils. Methods and technologies that are identified as potentially feasible for a pilot project will be developed into a scope of work for a pilot project that will ensure there is a mitigation method that can be successfully applied. If a solution is found that is sufficiently proven for mitigating soil acidification, that method/technology will written up as the scope of the pilot project.

5.4 Summary of Terrestrial Ecosystems Activities Planned for 2019-2025

The schedule for planned activities is provided in Table 11, and may be subject to change. The critical loads KPI will not be assessed for attainment in Phase III.

Table 11. Schedule of work on the Terrestrial Ecosystems line of evidence planned under Phase III.

Topic	2019	2020	2021	2022	2023	2024	2025
Long-term soil acidification					Sampling of primary plot at Coho Flats and Lakelse Lake[18]	Sampling of primary plot at Coho Flats and Lakelse Lake, if not completed in 2023	
Wetland geochemistry					Establish project objectives Field survey of wetland geochemistry	Field survey of wetland geochemistry (continuation)	Study results reporting
Aluminium solubility					Establish project objectives Laboratory analysis of archived soil samples	Laboratory analysis of archived soil samples	Study results reporting
Visual inspection and assessment of plant health		Program Design	Implement first 1/3 of the plots	Implement second 1/3 of the plots	Implement third 1/3 of the plots	Re-inspect first 1/3 of the plots	Re-inspect second 1/3 of the plots
Vascular plant biodiversity		Program Design	Implement first 1/3 of the plots	Implement second 1/3 of the plots	Implement third 1/3 of the plots	Re-measure first 1/3 of the plots First calculation of slopes for the first 1/3 of the plots First comparisons of slopes for the first 1/3 of the plots First End-of-3-Year-Rotation Report	Re-measure second 1/3 of the plots First calculation of slopes for the second 1/3 of the plots First comparisons of slopes for the second 1/3 of the plots
Cyanolichen biodiversity		Program Design	Implement first 1/3 of the plots	Implement second 1/3 of the plots	Implement third 1/3 of the plots	Re-measure first 1/3 of the plots First calculation of slopes for the first 1/3 of the plots First comparisons of slopes for the first 1/3 of the plots First End-of-3-Year-Rotation Report	Re-measure second 1/3 of the plots First calculation of slopes for the second 1/3 of the plots First comparisons of slopes for the second 1/3 of the plots
S content in hemlock needles and vegetation health monitoring	Sampling from mid-August to mid-September	Sampling from mid-August to mid-September					
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting and first End-of-3-Year-Rotation Report	Annual reporting

[18] If long-term plot sampling in 2025 triggers dynamic modelling, that task will occur in 2026.

6 Aquatic Ecosystems

6.1 Introduction

Biologically relevant water chemistry provides the best early warnings of changes in lake chemistry that could be damaging to aquatic biota *in advance* of potential damage to aquatic biota and is therefore a *proactive* indicator. The Bayesian statistical methods and simple evidentiary framework described in the 2019 Comprehensive Review report provides an approach to detect if any lakes are experiencing an increase in sulphate concentrations due to the smelter, and determining if any changes in CBANC or pH are likely to exceed thresholds for biological effects.

6.1.1 EEM Lakes

The aquatic ecosystems component of the SO_2 EEM Program includes 11 lakes – 7 sensitive lakes and 1 less sensitive lake, as identified in the STAR, plus 3 control lakes added in 2015 (with 2013 baseline data from the KAA) (Table 12). The SO_2 EEM Program Plan for 2013-2018 included a structured, multi-factor approach for assigning relative ratings to each of the sensitive lakes, which informs how the lakes are used for evaluation of the different tiers of thresholds within the KPI. The 7 sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044) are used in the assessment of KPI attainment.

Table 12. Lakes in the SO_2 EEM Program.

Lake ID	Name	Acid-sensitive	EEM group	Lake Rating*	**Attainment Lakes** (i.e., used in KPI assessment)	
					Used in assessment of KPI thresholds for **increased monitoring** and **receptor-based mitigation**	Used in assessment of KPI threshold for **facility-based mitigation**
LAK006	End Lake	Yes	Sensitive	High	Yes	Yes
LAK012	Little End Lake	Yes	Sensitive	High	Yes	Yes
LAK016		Moderately	Less Sensitive	n/a	No	No
LAK022		Yes	Sensitive	Medium	Yes	Yes
LAK023	West Lake	Yes	Sensitive	Medium	Yes	Yes
LAK028		Yes	Sensitive	Low	Yes	No
LAK042		Yes	Sensitive	Low	Yes	No
LAK044		Yes	Sensitive	Low	Yes	No
DCAS14A	Alistair Lake	Yes	Control	n/a	No	No
NC184		Yes	Control	n/a	No	No
NC194		Yes	Control	n/a	No	No

* Lake ratings were developed in the SO_2 EEM Program Plan for 2013-2018. Vulnerable lakes (i.e., the sensitive lakes) were assigned a relative ranking on each of seven criteria and an aggregate rating (see ESSA et al. 2014, Appendix D for full details on the methods and results). The criteria included: 1) accessibility and non-recreational use; 2) recreational values; 3) lake surface area; 4) sustainable fish species present; 5) importance for anadromous salmon habitat; 6) influence of DOC and organic acids; and 7) lake volume and residence time.

6.2 Indicators and Thresholds

6.2.1 ANC KPI and pH informative indicator

The water chemistry KPI is based on ANC. The pH KPI applied during the first phase of the SO_2 EEM Program is an informative indicator. This was the most significant modification to the Aquatic Ecosystems line of evidence from the 2013-2018 SO_2 EEM Program. The 2019 Comprehensive Review recommended moving to an ANC KPI because ANC better fulfills the criteria for a KPI and therefore this change strengthens the SO_2 EEM Program. Specifically, the new ANC KPI utilizes charge balance ANC (CBANC) as the indicator metric. In summary, the rationale for the shift to CBANC are: CBANC is the most common metric applied in acidification studies, it is easily measured and calculated; the SO_2 EEM Program has a continuous record of CBANC; it is not affected by changes in DOC; and we have lake-specific thresholds for changes in CBANC. See Appendix A for further details on the rationale).

6.2.2 Two-threshold structure for acidification indicators

Both of the acidification indicators (ANC and pH) use a two-threshold structure (Table 13). This structure includes two components: a *level of protection* to prevent acidification of lakes that are currently not at risk of aquatic impacts (i.e., an absolute threshold); and a *change limit* which prevents further acidification (for lakes already below the level of protection due to natural organic acids or past acidic deposition) (i.e., a relative threshold).

Table 13. Structure of thresholds for acidification indicators. See Table 17 for more information.

	ANC (KPI)[19]	pH (informative indicator)
Level of Protection (i.e., absolute threshold)	Decrease† below 20 µeq/L	Decrease† below pH=6.0
Change Limit (i.e., relative threshold)	Decrease† of greater than lake-specific thresholds (from titration analyses; see Table 14)	Decrease† of ≥ 0.30 pH units
Exceedance	**BOTH** thresholds exceeded	**BOTH** thresholds exceeded

† Change must be causally related to SO_2 emissions

6.2.3 Lake-specific thresholds for the ANC change limit

The lake-specific thresholds for the ANC change limit are the same as those applied during the 2019 Comprehensive Review. These thresholds are shown in Table 14. We developed these thresholds during the previous phase of the SO_2 EEM Program, using the titration data from Trent University from the derivation of Gran ANC values, which provide measurements of the incremental change in pH in response to sample titration with sulphuric acid. For each lake, the thresholds represent the median estimate (over many samples across years) of the change in ANC that is equivalent to a decline in pH of 0.3 pH units from the 2012 baseline pH.

[19] Acid neutralizing capacity (ANC) will be used as the key performance indicator to determine if a lake has acidified. pH will be used as supporting information for understanding changes in the ANC KPI.

Table 14. Lake-specific ANC thresholds for change limits. Values were calculated from analyses of the titration data, showing the change in CBANC or Gran ANC associated with a pH decline of 0.3 pH units from the 2012 (or 2013 for control lakes) pH value for each lake. A lake-specific threshold cannot be estimated for control lake NC194 given limited data.

	EEM Group	Median [mean, SE] of the lake-specific ANC threshold (µeq/L, applies to both CBANC and Gran ANC)	# titrations used to estimate medians, means, and SE
LAK006	Sensitive Lake	-10.8 [-10.8, 0.3]	19
LAK012	Sensitive Lake	-16.3 [-18.2, 1.5]	23
LAK022	Sensitive Lake	-11.5 [-11.4, 0.2]	4
LAK023	Sensitive Lake	-10.5 [-10.2, 0.3]	22
LAK028	Sensitive Lake	-13.4 [-13.9, 0.7]	13
LAK042	Sensitive Lake	-24.4 [-25.4, 1.1]	10
LAK044	Sensitive Lake	-6.2 [-6.3, 0.2]	11
LAK016	Less Sensitive Lake	-25.6 [-26.2, 1.7]	4
DCAS14A	Control Lake	-21.7 [-21.7, 3.6]	2
NC184	Control Lake	-10.8 [-10.8, n.a.]	1
NC194	Control Lake	n.a.	0

6.2.4 Key Performance Indicator

The evaluation of the KPI is based on number and rating of lakes that show an ANC exceedance under the two-threshold structure. The KPI thresholds and response actions are defined in Table 15. The lake ratings, as developed in the 2013-2018 SO_2 EEM Program Plan (ESSA et al. 2014), are shown in Table 12. Section 6.3.1 provides details on the methods by which attainment of the KPI will be assessed each year.

Table 15. KPI for Aquatic Ecosystems.

Key performance indicator	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Water chemistry – acidification (CBANC)	Observed decrease in CBANC in one of the acid sensitive lakes (relative to the pre-KMP baseline) that exceeds the CBANC thresholds and is causally related to SO_2 emissions. Action: increase the frequency of fall sampling in subsequent year, to more accurately estimate mean and variability of CBANC and other informative indicators during the fall index period.	More intensive sampling confirms a decrease in CBANC (relative to the pre-KMP baseline) that exceeds the CBANC thresholds in one or more lakes and is causally related to SO_2 emissions. Action: liming to bring the lake back up to pre-KMP CBANC and pH, subject to approval by B.C. ENV/DFO prior to implementation (see 2014 EEM Plan, Appendix G).	3 or more lakes rated Medium or High (based on relative lake rating) show decreases in CBANC (relative to the pre-KMP baseline) that exceed the CBANC thresholds and are causally related to SO_2 emissions. Action: reduction in SO_2 emissions.	• Changes in CBANC in control lakes • Changes in alternate ANC metrics • Change in mean lake pH relative to pre-KMP baseline, and control lakes • Changes in SO_4, to evaluate whether ΔANC and ΔpH are causally related to B.C. Works and other SO_2 emissions

6.2.5 Informative indicators

The informative indicators for the Aquatic Ecosystems line of evidence are defined in Table 16. The informative indicators support and complement the KPI.

Table 16. Informative indicators for Aquatic Ecosystems.

Informative indicators	Threshold for increased monitoring[20]	Indicators to be jointly considered
Water chemistry – acidification (pH)	A decrease in pH relative to the pre-KMP baseline that exceeds the pH thresholds (Table 13) and is causally related to SO_2 emissions. Action: additional monitoring during the fall sampling season to determine variation in	• All ANC metrics • SO_4 • The changes in all metrics (i.e., CBANC, Gran ANC, BCS, pH, SO_4) should be jointly considered prior to deciding to increase the

[20] Thresholds for mitigation are not applicable. These indicators will provide weight of evidence for assessing the magnitude, extent and causes of lake acidification.

Informative indicators	Threshold for increased monitoring[20]	Indicators to be jointly considered
	pH, ANC and SO_4^{2-} and obtain a more precise estimate of their mean values.	intensity of monitoring, and what form of increased monitoring would provide the most useful incremental information.
Water chemistry – acidification (Gran ANC, BCS) (alternate ANC metrics)	A decrease in Gran ANC or BCS relative to the pre-KMP baseline that exceeds the indicator thresholds (see Section 6.2.6) and is causally related to SO_2 emissions. Action: additional monitoring during the fall sampling season to determine variation in ANC , pH and SO_4^{2-} and obtain a more precise estimate of their mean values.	• pH • SO_4 • The changes in all metrics (i.e., CBANC, Gran ANC, BCS, pH, SO_4) should be jointly considered prior to deciding to increase the intensity of monitoring, and what form of increased monitoring would provide the most useful incremental information.
Changes in SO_4	Strong evidence for an increase in SO_4 relative to the pre-KMP baseline, consistent with evidence of increased SO_2 emissions (from the smelter) and SO_4 deposition, indicates that the smelter is having an influence on the water chemistry of the lake.	• This indicator is used as input to the evidentiary framework, to inform the assessment of causality.
Level of SO_4	[SO_4] exceeds the B.C. guideline for very soft waters ([SO_4] > 128 mg/L or 2,665 µeq/L) [21]. Action: consultation with B.C. ENV on subsequent actions (e.g., more intensive investigation to assess watershed sulphate sources, increased monitoring frequency).	• Anion-cation chemistry of the sample, to determine if watershed sulphate sources are likely responsible for the high sulphate concentrations
Observed changes in SO_4, ANC and pH vs. predicted changes from the STAR and the 2019 Comprehensive Review	N/A	• Changes in mean lake pH, ANC and SO_4 relative to pre-KMP baseline (i.e., retrospective change)
Predicted steady state ANC and pH	N/A	• N/A

[21] Over the period from 2012 to 2021, the highest recorded average [SO_4] in any EEM lake was 7.3 mg/L (in LAK028), which is only 5.7% of the 128 mg/L BC guideline for sulphate in soft waters (hardness ≤ 30 mg/L). The BC sulphate guideline is described here: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-wqgs/sulphate/bc_moe_wqg_sulphate.pdf

Informative indicators	Threshold for increased monitoring[20]	Indicators to be jointly considered
versus current ANC and pH		
Aquatic biota: fish presence / absence per species on sensitive lakes	Decrease in CBANC beyond lake-specific threshold. Action: assess fish presence, potentially using eDNA so as to minimize impact of gillnet sampling on lake fish populations.	• Decrease in pH ≥0.30 units from pre-KMP baseline
Episodic pH change	N/A	• None

6.2.6 Summary of thresholds for ANC and pH aquatic acidification indicators

The two thresholds (level of protection and change limit) for each of the ANC and pH aquatic acidification indicators are shown in Table 17. The suite of indicators provide complementary information. The level of protection thresholds for pH and Gran ANC are points below which acidification impacts on aquatic biota begin to occur. The level of protection threshold for BCS is the level below which concentrations of inorganic monomeric aluminum increase and there are chronic toxic effects on aquatic biota. The change limit of 0.3 pH units was derived from studies of acidification impacts on biota in Sweden (Fölster et al. 2007), which concluded that lakes should be maintained within 0.4 pH units of their original, pre-industrial pH_o; the change limit of 0.3 pH units in the SO_2 EEM Program is more precautionary. The lake-specific change limits for CBANC in Table 14 are consistent with a pH decline of 0.3 pH units.

Table 17. Thresholds for level of protection and change limits for aquatic acidification KPI and informative indicators.

Indicators	**Type**	**Level of Protection** (i.e., absolute threshold)	**Change Limit** (i.e., relative threshold)
CBANC	KPI	Decrease below 20 µeq/L	Decrease greater than lake-specific thresholds (Table 14)
pH	Informative	Decrease below 6.0 pH units	Decrease ≥0.3 pH units
Gran ANC	Informative	Decrease below 30.7 µeq/L	Decrease greater than lake-specific thresholds (Table 14)
BCS	Informative	Decrease below 0 µeq/L	Decrease greater than 13 µeq/L

6.3 Methods

The methods associated with the KPI and informative indicators for the Aquatic Ecosystems line of evidence are summarized in Table 18 and Table 19 and described in further detail in their own subsections below the two summary tables.

Table 18. Overview of methods for calculating the KPI for Aquatic Ecosystems.

Key performance indicator	Method overview and frequency of attainment assessment
Water chemistry–acidification (CBANC)	1. Analysis of level of change in CBANC **in each lake:** o Apply Bayesian analysis to determine the strength of evidence that ΔCBANC exceeds the thresholds for CBANC o Determine whether there has been an exceedance for CBANC 2. Causal linkage to smelter emissions **for each lake:** o Apply the evidentiary framework (integrating changes in SO_4, pH and ANC) o Inputs to evidentiary framework are from annual application of Bayesian analysis to determine strength of evidence that $\Delta SO_4 > 0$, ΔCBANC > KPI thresholds causing biological effects, and ΔpH > 0.3 units 3. KPI is exceeded if there is an **exceedance of both thresholds for CBANC** and those changes are **causally linked to smelter** for **one or more lakes.** Mitigation **response depends on number and rating of lakes with CBANC exceedances (see** **4.** **5. Table 15)** The assessment of KPI attainment is conducted annually. For more information, please refer to Section 6.3.1.

Table 19. Overview of methods for calculating the informative indicators for Aquatic Ecosystems.

Informative indicators	Method overview
Water chemistry–acidification (pH)	Apply Bayesian analysis to determine the strength of evidence that ΔpH is greater than thresholds. Apply the simple evidentiary framework to assess the causal linkage to smelter emissions. Evaluate the differential trends between sensitive lakes and control lakes using the BACI methods from the 2019 Comprehensive Review. For more information, please refer to Section 6.3.1.
Water chemistry – acidification (Gran ANC, BCS) (alternate ANC metrics)	Apply Bayesian analysis to determine the strength of evidence for ΔGran ANC or ΔBCS greater than thresholds. Apply the simple evidentiary framework to assess the causal linkage to smelter emissions. Evaluate the differential trends between sensitive lakes and control lakes using the BACI methods from the 2019 Comprehensive Review[22]. For more information, please refer to Section 6.3.1.
Changes in SO_4	Apply Bayesian analysis to determine the strength of evidence for an increase in SO_4. For more information, please refer to Section 6.3.1.
Observed changes in SO_4, ANC and pH vs. predicted changes from STAR and 2019 Comprehensive Review	Re-apply methods from the 2019 Comprehensive Review at time of 2026 Comprehensive Review. For more information, please refer to Section 6.3.2.
Predicted steady state ANC and pH versus current ANC and pH	Re-apply methods from STAR and 2019 Comprehensive Review at time of 2026 Comprehensive Review. For more information, please refer to Section 6.3.3.
Aquatic biota: fish presence / absence per species on sensitive lakes	If CBANC KPI triggers are exceeded in any lake which contained fish during baseline sampling in Phase I of the SO_2 EEM Program, then resample this lake for fish presence. If resampling is required, explore using eDNA methods. For more information, please refer to Section 6.3.4.
Episodic pH change	To be studied in LAK006 (End Lake) and LAK028. For more information, please refer to Section 6.3.5.

[22] These analyses will also be conducted on the primary ANC metric (used for the KPI), but only as an informative indicator. The KPI is not based on this methodology.

6.3.1 KPI and informative indicators for changes in primary water chemistry metrics

The indicators associated with the primary water chemistry metrics (i.e., SO_4, pH and ANC) all use data that come from the same water chemistry sampling program. Therefore, the methods for the following indicators are described together in this subsection:

1. Water chemistry–acidification (CBANC) **[KPI]**
2. Water chemistry–acidification (pH) **[informative indicator]**
3. Water chemistry – acidification (Gran ANC, BCS) (alternate ANC metrics) **[informative indicator]**
4. Changes in SO_4 **[informative indicator]**

Sampling locations:

- Water chemistry samples will be taken at 7 sensitive lakes, 3 control lakes, and 1 less sensitive lake, shown in Figure 7.
- For broader context, Figure 8 (from the 2019 Comprehensive Review) shows the locations of all of the additional lake and stream sites that were sampled and analysed as part of the STAR, the KAA, or during the SO_2 EEM Program and have thus contributed to the assessment of the Aquatic Ecosystems receptor within the Program.
    - The lakes sampled during the STAR represent a census of all lakes greater than 1 ha within the target sampling areas (based on deposition exposure, geography, and bedrock sensitivity) that fulfill the selection criteria from the U.S. Environmental Protection Agency protocols for aquatic acidification studies (Eilers et al. 1987; Landers et al. 1987).
    - The SO_2 EEM Program included **all** the lakes within the defined sampling regions of the STAR for which the STAR predicted a future pH decline of >0.1 pH units under the maximum emissions. The resulting set of "EEM sensitive lakes" represents the entire population of lakes within the sampling regions that could potentially change.
    - Figure 8 identifies the full set of sensitive, less sensitive and control lakes included in the 2013-2018 phase of the SO_2 EEM Program. The only change to this set in Phase III is the discontinuation of three of the less sensitive lakes, as recommended in the 2019 Comprehensive Review, because true control lakes were added to the program and it has been shown that these lakes are not sensitive.

Sampling timing, frequency and duration:

- Six sensitive lakes (LAK006, LAK012, LAK023, LAK028, LAK042, LAK044) will be sampled 4 times / year in October
- One inaccessible sensitive lake (LAK022), one less sensitive lake (LAK016) and three control lakes (NC184, NC194, DCAS14A) will be sampled once annually by helicopter at the start of October
- Resampling of LAK030 (Bowbyes Lake) in 2022
- Resampling of Lakelse Lake in 2025 and including these results in the 2026 Comprehensive Review
- No additional lakes or stream sites need to be sampled

Monitoring protocols and sampling methods:

- Monitoring protocols and sampling methods will follow those of Phase I of the EEM Program, as described in Limnotek annual reports and the 2019 Comprehensive Review.
- During the helicopter lake sampling, standardized photos will be taken for each lake to document changes for both the lakes and their respective watersheds.

How and when monitoring data will be evaluated:

- Water chemistry data will be analysed annually for the annual SO_2 EEM Program report.
- QA/QC will be performed on all data as described in Phase I of the SO_2 EEM Program
- ANC metrics will be calculated.
- Apply Bayesian statistical analysis for changes in SO_4, pH and ANC (Bayesian Method 1 in Aquatic Appendix F of the 2019 Comprehensive Review (ESSA et al. 2020)) compared to absolute and relative thresholds specified in Section 6.2.
- Apply the simple evidentiary framework to assess causal linkage to smelter emissions, as described in section 7.3.4.5 of the 2019 Comprehensive Review.
- Changes in lake chemistry will be assessed against two baselines:
    - The pre-KMP baseline (2012), as was applied throughout Phase I of the SO_2 EEM Program. This will be the baseline utilized for the KPI evaluation.
    - The extended baseline (2012-14), as was applied in the sensitivity analyses included in Aquatic Appendix I of the 2019 Comprehensive Review; those sensitivity analyses will be repeated every year.
- The analyses described above provide the foundation by which to assess the attainment of the KPI on an annual basis.

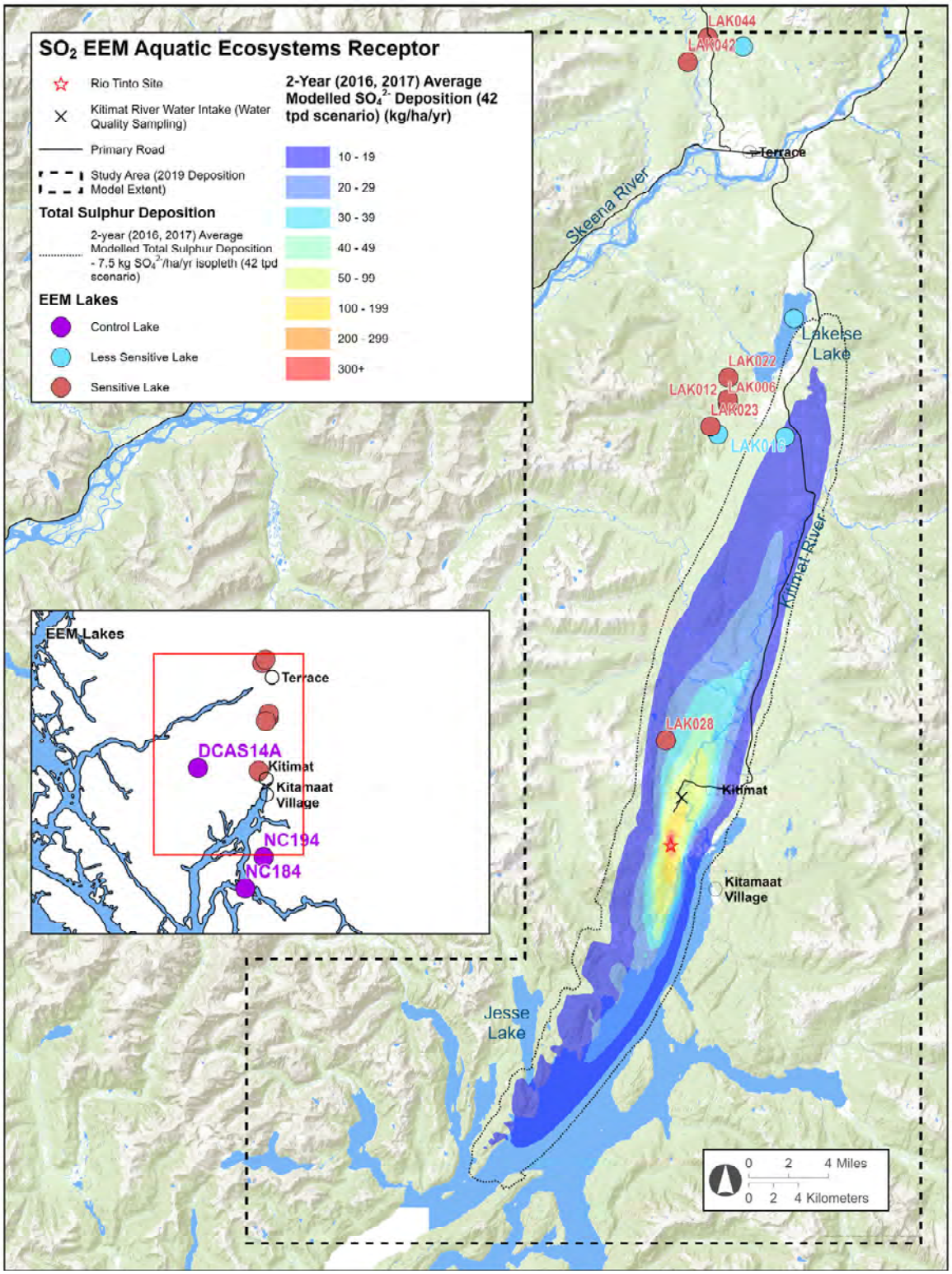


Figure 7. Lakes from which water chemistry samples will be taken.

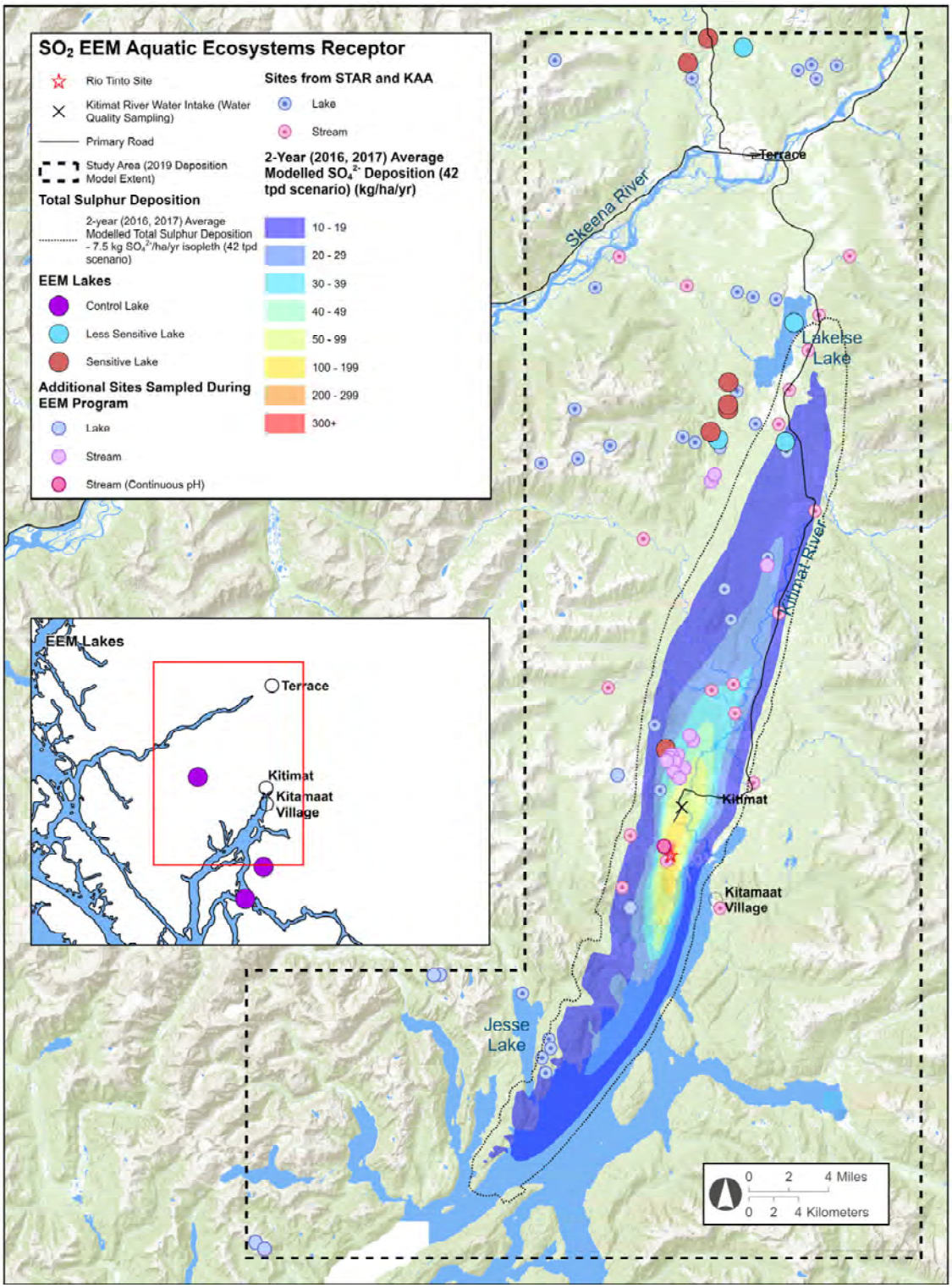


Figure 8. Locations of all lake and stream sampling locations utilized within the course of the SO_2 EEM Program. (Source: Figure 7.2 in Aquatic Appendix A of the 2019 Comprehensive Review.)

6.3.2 Observed changes in SO_4, ANC and pH vs. predicted changes from STAR and 2019 Comprehensive Review – informative indicator

This indicator uses the same water chemistry data as described in Section 6.3.1 and will use the same methods to acquire these data. Therefore, the following information is identical to above: sampling locations; sampling timing, frequency and duration; and monitoring protocols and sampling methods.

How and when monitoring data will be evaluated:

- Use ESSA-DFO model results, adjusted to reflect actual emissions, similar to the methods described in the 2019 Comprehensive Review (Aquatic Appendix 7, Section 7.1.3.2.4).
- These analyses will be conducted at the time of the 2026 Comprehensive Review.

6.3.3 Predicted versus observed chemistry – informative indicator

This indicator uses the same water chemistry data as described in Sections 6.3.1 and 6.3.2, and will use the same methods to acquire these data.

How and when monitoring data will be evaluated:

- Apply ESSA-DFO model to estimate predicted steady-state ANC and pH under 42 tpd emissions, as described in the STAR and the 2019 Comprehensive Review.
- These analyses will be conducted at the time of the 2026 Comprehensive Review.

6.3.4 Aquatic biota: fish presence/absence per species on sensitive lakes – informative indicator

This indicator is conditional on the results of the KPI (i.e., Water chemistry–acidification (CBANC).

Trigger for additional sampling:

- Resampling of individual lakes for fish presence will only be required if the triggers for CBANC are exceeded in a particular lake that contained fish during baseline sampling in Phase I of the SO_2 EEM Program.

Sampling locations:

- Lakes in which the conditions for resampling are met (as described above)

Sampling timing, frequency and duration:

- Completed at time of annual water sampling

Monitoring protocols and sampling methods:

- If resampling is required, the potential use of eDNA methods rather than capture-based methods for assessing fish presence will be explored.

- The rationale for exploring eDNA methods is to avoid sampling methods that involve the capture of fish because the study lakes are small enough that the act of sampling using gill nets could in itself have a negative impact on the small fish populations.
- eDNA methods would be based on methods developed by the Rocky Mountain Research Station of the US Forest Service, Bureau Veritas Labs (Guelph, Ontario) and the University of Victoria.
- If eDNA methods are not possible, then the pros and cons of resampling with original gillnet/angling methods will be assessed and discussed with B.C. ENV.
- If resampling is required, the choice of method, rationale and implementation details will be documented in the annual SO_2 EEM Program report.

How and when monitoring data will be evaluated:

- Presence/absence results will be compared to baseline measurements to determine if there have been any changes in species presence.
- Monitoring data will be evaluated during the preparation of the annual SO_2 EEM Program report for the year in which the sampling occurred.

6.3.5 Episodic pH change – informative indicator

Sampling locations:

- LAK006 (End Lake) and LAK028

Sampling timing, frequency and duration:

- Intensive sampling with installation of continuous pH monitor
- Record pH every half hour during the ice-free period of each year

Monitoring protocols and sampling methods:

- Onset pH monitor which accurately measures pH every half hour
- Recalibrate Onset every two weeks
- The protocols and methods are described in more detail in Limnotek (2021)

How and when monitoring data will be evaluated:

- Examine continuous data in LAK006 for sudden drops in pH
- Analyze lake level data to assess if a storm event was associated with the acidic episode
- If acidic episodes were coincident with a storm event, analyze calibration samples taken before and after the episode for full chemistry, as well as precipitation and deposition data from Lakelse Lake to assess if the acidic episode was likely driven by sulphate inputs (smelter related) as opposed to base cation dilution, or organic acid inputs (not smelter related)
- Since acidic episodes can be of very short duration, calibration samples taken every two weeks, and weekly deposition samples, may not detect episodic changes in sulphate or organic anions

6.3.6 Additional studies

6.3.6.1 Re-evaluate EEM Lakes

The EEM lakes will be re-evaluated in the 2026 Comprehensive Review, with respect to their inclusion in the SO_2 EEM Program going forward. By 2026 there will be 10 years of post-KMP data (i.e., 2016-2025). Some of the EEM lakes (which were all identified in the STAR as being potentially sensitive to increased acidic deposition) are now not predicted to acidify under emissions of 42 tpd, based on updated modelling and additional years of data. There are multiple lakes that are not predicted to exceed their critical loads, not predicted to decrease in pH below their 2012 baseline values, and do not show any evidence in their empirical observations of lake chemistry of patterns that are consistent with smelter-driven acidification. The power analyses conducted in 2014-2015 recommended that the SO_2 EEM Program should not make any strong conclusions about the changes in lake chemistry that have occurred until there have been at least five years of post-KMP data collected. To be precautionary, the SO_2 EEM Program will collect ten years of post-KMP data prior to making any decisions about which lakes to include or exclude in post-2025 monitoring.

6.3.6.2 Pilot project scope for receptor-based mitigation

The scope of a pilot project to demonstrate the feasibility of receptor-based mitigation will be developed during Phase III of the SO_2 EEM Program. The purpose of the pilot project is to ensure that there is a receptor-based mitigation solution that can be feasibly implemented should the aquatics KPI exceed the threshold for receptor-based mitigation. The scope of the pilot project will include providing an update (from the 2014 SO_2 EEM Plan) on the state of knowledge on lake liming and different methods and technologies that have been successfully applied to treat acidified bodies of water. The review of technologies will include applications for both natural lakes and mining pit bodies of water. The feasibility of the technologies will be assessed through the lens of the acid sensitive lakes monitored in the SO_2 EEM Program and current provincial and federal regulations. Methods and technologies that are identified as potentially feasible for a pilot project will be developed into a scope of work for a pilot project that will ensure there is a mitigation method that can be successfully applied. If a solution is found that is sufficiently proven for mitigating lake acidification, that method/technology will be written up as the scope of the pilot project.

6.4 Summary of Aquatic Ecosystems Activities Planned for 2019-2025

The schedule for planned activities is provided in Table 20, and may be subject to change.

Table 20. Schedule of work on the Aquatic Ecosystems line of evidence planned under Phase III.

Topic	2019	2020	2021	2022	2023	2024	2025
Water chemistry sampling	Annual water sampling and laboratory analysis (subject to re-evaluation in 2022)	Annual water sampling and laboratory analysis (subject to re-evaluation in 2022)	Annual water sampling and laboratory analysis (subject to re-evaluation in 2022)	Annual water sampling and laboratory analysis (subject to re-evaluation in 2022)	Annual water sampling and laboratory analysis (subject to re-evaluation in 2022)	Annual water sampling and laboratory analysis (subject to re-evaluation in 2022)	Annual water sampling and laboratory analysis (subject to re-evaluation in 2022)
Developing ANC KPI			Exploratory analyses on different ANC metrics; select metric; finalize and apply new KPI				
Fish presence / absence sampling	Resample if lake pH change reaches threshold	Resample if lake pH change reaches threshold	Resample if lake ANC change reaches threshold	Resample if lake ANC change reaches threshold	Resample if lake ANC change reaches threshold	Resample if lake ANC change reaches threshold	Resample if lake ANC change reaches threshold
Receptor-based Mitigation							Pilot project scope for lake liming
KPI attainment assessment	Annual assessment	Annual assessment	Annual assessment	Annual assessment	Annual assessment	Annual assessment	Annual assessment
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

7 Climate Change

7.1 Introduction

The SO_2 EEM Program collects data that are of value for understanding and tracking the effects of climate change in the Kitimat Valley. Rio Tinto has volunteered to add the tracking of climate change indicators using some of the data currently collected by the SO_2 EEM Program and some additional new monitoring data.

The purpose of this chapter is to synthesize the SO_2 EEM collected monitoring data through the lens of climate change into indicators for tracking the changes in climate and the physical effects of the climatic change over time. The intent of adding climate change to the SO_2 EEM Program is to be able to provide an understanding of how the climate and environment are changing in the Kitimat Valley using the SO_2 EEM Program's monitoring data. This chapter is not intended to look beyond the beneficial data collected by the pathways and receptor based monitoring conducted under the SO_2 EEM Program, but reasonably accessible data of interest may be added by Rio Tinto.

7.2 Climate Change Indicators

Indicators for climate change (Table 21) are divided into two categories. First category of indicators are the Meteorological Indicators that are derived from data collected in the atmospheric pathways monitoring programs. These indicators will provide direct meteorological measurements that can be interpreted to understand how the climate in the Kitimat Valley has changed over time. The second category of indicators are the Effects Monitoring Indicators; these indicators will measure the physical response of the environment in the Kitimat Valley to the changing climate.

Table 21. Climate Change Indicators.

Meteorological Indicators	Measurement Locations	Reporting Frequency
Precipitation annual average against historical normal	Haul Road and Lakelse Lake	Annual
Precipitation patterns (cumulative and storm depths)	Haul Road and Lakelse Lake	Annual
Precipitation pH (weekly and annual average)	Haul Road and Lakelse Lake	Annual
Air temperature against historical normals (seasonal, extremes and annual averages)	Yacht Club	Annual
Still air days (days with low windspeed)	Yacht Club	Annual
Solar irradiance (to be added at Lakelse Lake or possibly another location)	Lakelse Lake	Annual

Effects monitoring Indicators	Measurement Locations	Reporting Frequency
SO_4 deposition rates and ratios of wet vs. dry deposition (seasonal and annual averages)	Haul Road and Lakelse Lake	Annual
Soil moisture (to be added at Lakelse Lake soil plots)	Lakelse Lake	Annual
Vascular plant biodiversity (specifics of the indicator are to be developed)	Kitimat and Kemano Valleys	Every 3rd year
Lake chemistry	Control Lakes DCAS14A, NC194 and NC184	Annual
Water temperature and water levels	Lak006 and Lak028	Annual

7.3 Methods

A review of available data will be conducted in 2022 and the first quarter of 2023 for both the Meteorological and Effects Monitoring indicators. The review will determine the best quality data set to use for establishing the historical normal (baseline) of the meteorological indicators. Data sets from Rio Tinto, Environment and Climate Change Canada, and B.C. ENV will be included in the review. Specific statistics to set the baseline and evaluate change will be identified for each of the indicators data sets in addition, the graphical plots of the data showing trends will also be determined. Future changes to both the statistical analysis and displays of the analysed data may made based on learnings.

Annual averages, seasonal averages and other statistics for the indicators will be calculated from data collected by the SO_2 EEM Program from 2012 to 2021. On an ongoing, annual basis, subsequent years of data will be added to the analysis and trend plots.

7.4 Reporting of Climate Change Trends

Trend plots of the climate change indicators will be provided in the annual SO_2 EEM Program report in a separate chapter on climate change. That chapter will present indicators but will not provide an interpretation or analysis of the indicators. The interpretation of the climate change indicators will be done in the 2026 Comprehensive Review (for the Phase III plan). The climate change trends chapter in annual SO_2 EEM Program reports will not interpret the effects of annual weather variation on the monitoring data as the influence of weather variation on the KPIs and associated indicators is assessed in the relevant chapters for the pathways and receptors.

7.5 Additional Studies

A project will be sponsored under SO_2 EEM Phase III that will review and summarize the available predictions and literature for climate change in the Kitimat Valley and develop predictions for environmental responses. The intent of this project is to develop an understanding of the predicted climate changes that may occur in the Kitimat Valley and to develop an understanding of the potential effects of the changes. This project will be completed between 2023 to 2025.

8 Determination of Causal Relationship to B.C. Works

The KPI thresholds presented in Chapters 2 through 6 include the condition that threshold exceedances are causally related to cumulative SO_2 emissions from B.C. Works and LNG projects in the Kitimat Valley. The process for determining causality is summarized below, by line of evidence. These steps would be undertaken for a given KPI if the thresholds for increased monitoring or mitigation are reached.

Human Health

- Investigate each 1-hour exceedance of the numerical component of the 1-hour health KPI (e.g.: 70 ppb) by assessing meteorological conditions, and estimates of B.C. Works' SO_2 emissions.
- Update the CALPUFF SO_2 dispersion model from the 2019 Comprehensive Review with meteorology and SO_2 source emission data from all industrial sources.

Terrestrial Ecosystems

- Soils, vegetation and lichens will be evaluated along a S deposition gradient. Estimates of total S deposition will be obtained from CALPUFF using emissions from B.C. Works and LNG source emissions.
- For long-term soil plot monitoring results, causal relationship to B.C. Works and LNG SO_2 emission sources will be determined by comparison with changes (or lack thereof) at the background (control) plot.
- Vascular plant and cyanolichen biodiversity: If there are differential changes in trends in plant or cyanolichen biodiversity (high or moderate deposition sites compared to low deposition sites) chemical analysis of foliage, fine roots, and/or thalli will be done to determine if indicators of acidification are present (e.g., elevated levels of S concentration in tissues; changes in the concentration and availability of base cations in soil; an increase in the concentration of Al+3 on soil; increased concentrations of Al in plant tissues or lichen thalli; morphologic or cellular aberrations in plant tissues or lichen thalli). If so, a determination will be made whether the affected area has expanded beyond that historically affected (pre-KMP)[23] as determined by initial measurements. The evidentiary framework is presented in Figure 9.

Aquatic Ecosystems

- Apply the simple evidentiary framework each year shown in Figure 10 (from Figure 7-3 in the 2019 Comprehensive Review).
- Apply the more detailed evidentiary framework in 2026 (Table 7-12 in the 2019 Comprehensive Review).

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[23] For sulphur, pre-KMP S levels in vegetation were within background levels reported in literature. Historical impact area of the old smelter was determined using the fluoride measurements in western hemlock. From 2010 on, there were no sulphur concentrations that exceeded the background levels identified in literature. Sites are within and outside the area historically affected by fluoride.
Current scientific literature shows that at levels less than 7.5 kg SO_4^{2-}/ha/year effects on plants and lichens are not observed.

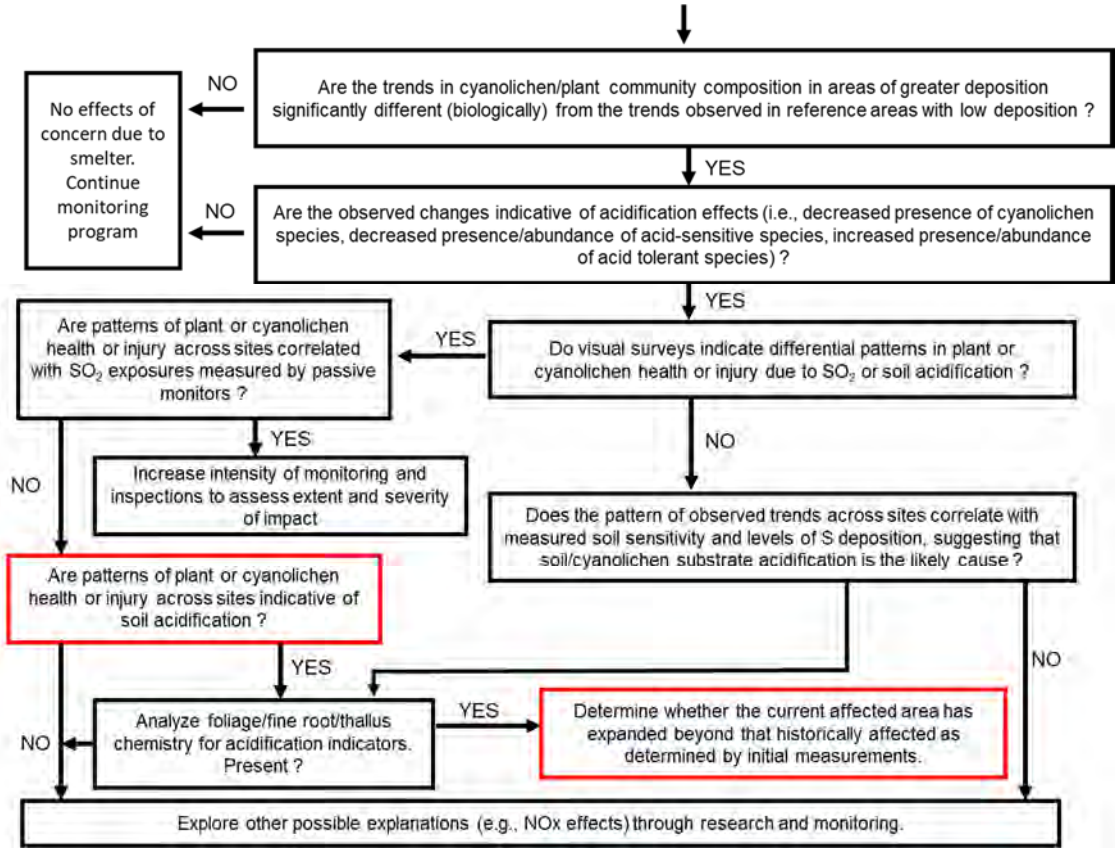


Figure 9. Evidentiary framework for determining a causal relationship between changes in trends in plant biodiversity and SO_2 emissions from B.C. Works and other sources. Red boxes show where causality to the smelter's SO_2 emissions is established.

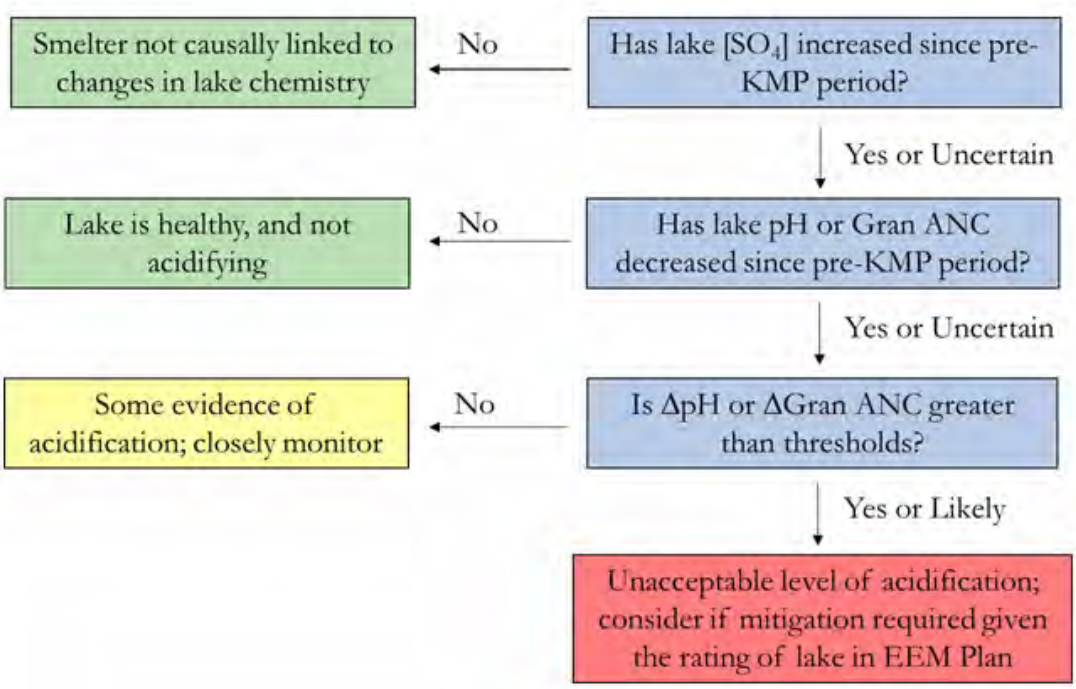


Figure 10. Simplified evidentiary framework for determining whether lakes have experienced acidification that is causally related to SO_2 emissions.

9 Pathways to Mitigation

Rio Tinto will implement SO_2 mitigation strategies if the outcomes of monitoring and modeling under the SO_2 EEM Program show adverse impacts related to Rio Tinto emissions of SO_2 that have contributed to an exceedance of a KPI threshold for mitigation. The SO_2 EEM Program distinguishes two types of mitigations: receptor-based mitigations and facility-based mitigations. Mitigation for episodic events in either the Terrestrial or Aquatic Ecosystems will be restricted to specific well-defined situations where it is very clear that the likelihood of reoccurrence is very low and temporary mitigations might be appropriate because the impact is short-term and reversable.

Pathway to mitigation:

- If potential non-attainment of the either the Terrestrial or Aquatic Ecosystems KPIs are identified, the Director will review available information and data with respect to the non-attainment as well as consider exceptional events, in order to confirm the non-attainment. Meteorological conditions are not an acceptable justification for non-attainment.
- If the Director determines that there is non-attainment of either the Terrestrial or Aquatic Ecosystems KPIs the Director will provide notification to Rio Tinto of the determination of non-attainment of a KPI threshold for mitigation.
- Within 6 months of notification by the Director for the non-attainment of either the Terrestrial or Aquatic Ecosystems KPIs, Rio Tinto will submit a report to the Director outlining an action plan to determine the amount of SO_2 emissions required to bring the KPI back into attainment and the proportionality of Rio Tinto's SO_2 emission reduction. The action plan will detail the proposed mitigation option and both the short and long term actions to implement the mitigation. The action plan will also contain steps for monitoring the success of the implemented mitigation. The development of the action plan will be done in consultation with B.C. ENV.

The following paragraphs describe examples of each type of mitigation.

9.1 Receptor-based Mitigation

If a Terrestrial Ecosystems KPI threshold for receptor-based mitigation (detailed in Sections 5.2 and 5.3) is exceeded, the application of lime and wood ash are options for reducing soil acidity in very localized applications, increasing calcium concentrations in trees, and potentially improving tree growth. Given the wide range of effectiveness of these treatments (summarized in Appendix F in the SO_2 EEM Plan for 2013-2018 (ESSA et al. 2014)), small scale pilot applications would be required as a proof of concept prior to large scale application. The 200 year horizon allows ample time for a liming/wood ash pilot, and consideration of a shift to facility-based mitigation if the pilot is unsuccessful. Most studies show a response in the soil within 5-10 years.

If CBANC in any EEM lake declines by more than its lake-specific threshold, and the most likely explanation of this CBANC decline is increased SO_2 emissions from B.C. Works, then if liming is both logistically feasible and recommended by B.C. ENV, Rio Tinto would develop and

implement receptor-based mitigation to restore the lake's CBANC and pH back to 2012 levels. This would reverse the acidification caused by B.C. Works SO_2 emissions. The options for treating a lake will be developed in the pilot project scope of work (Section 6.3.6.2). One of the options used to mitigate acidic conditions in surface water is the addition of alkaline materials like limestone (calcium carbonate). Depending on lake access, safety and other environmental considerations, liming could be done on the whole lake, its running water or on its watershed using a boat, truck or helicopter (Olem 1990). A summary of the state of knowledge regarding liming of lakes is provided in Appendix G of the 2014 SO_2 EEM Plan. If three or more lakes rated Medium or High[24] show decreases in CBANC that exceed their lake-specific thresholds (relative to the pre-KMP baseline, prior to receptor-based mitigation and causally related to SO_2 emissions from B.C. Works), Rio Tinto would implement facility-based mitigation[25] (see Table 15).

If cumulative SO_2 emissions have caused the exceedance of a receptor-based mitigation threshold, Rio Tinto will work with B.C. ENV on a proportional model for implementing the mitigation.

[24] Refer to Appendix D the EEM Plan for 2013-2018 (ESSA et al. 2014) for information on the method and results for rating the vulnerable lakes.
[25] Refer to Section 6.2 for the thresholds for receptor-based mitigation.

9.2 Facility-based Mitigation

9.2.1 SO_2 Emission reductions and options

Sections 3.1, 5.2 and 6.2 describe (respectively) the human health, terrestrial ecosystems and aquatic ecosystems thresholds for facility-based mitigation. Facility-based mitigation will be a response to demonstrated exceedances of KPI threshold for SO_2 emission reductions. Facility-based mitigation will proportionally reduce SO_2 emissions from the smelting operation, and may be episodic or permanent depending on the persistence of the threshold exceedance. The implemented reduction options will be sufficient to meet the proportional emissions reduction level identified.[26] The methodology for reducing SO_2 emissions will be a Rio Tinto business-based decision that will factor in consideration of the nature of the impacts, feasibility and sustainability of alternative mitigation methods, and marketplace conditions.

Rio Tinto will consult with B.C. ENV on the specifics the selected mitigation options. This consultation may include a review of the specific option selected by Rio Tinto in the context of B.C. ENV's policy on best available technology (BAT), if a major operational control option is selected by Rio Tinto.[27] However, the specifics of the mitigation option will be based on the total SO_2 emission load reduction that is required to mitigate the exceedance of the facility based mitigation threshold.

Some examples of options that Rio Tinto will consider for reducing SO_2 emissions are briefly described below, followed by Table 22 which presents the range of SO_2 reduction in t/day that could be achieved, and the implementation timeline.

a) Procuring lower sulphur content coke

The coke blend used for anode manufacturing can be adjusted to lower the overall sulphur content in the anode. The magnitude of the sulphur content reductions will be determined based on marketplace conditions and accessibility to anode grade cokes with lower sulphur content.

b) Reducing the amount of calcined coke produced on site

Increased quantities of calcined coke can be procured to reduce or stop coke calcining onsite. The feasibility of this option will be based on marketplace conditions for anode grade calcined coke.

c) Importing anodes

Baked anodes can be imported to Kitimat to either reduce or stop coke calcining or anode baking operations. This option would be reviewed for feasibility based on marketplace access to baked anodes and transportation costs.

d) Scrubber on Coke Calciner

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[26] Reducing SO_2 emissions beyond the identified proportional emissions reduction requirement will be a Rio Tinto business decision.

[27] A best available technologies (BAT) review on SO_2 scrubbing options for the modernized smelter was completed as part of the 2013 SO_2 Technical Assessment Report for the 2013 amendment of the P2-00001 Multimedia Waste Discharge Permit.

Implementing a scrubber on the coke calciner is possible. A decision to implement scrubbing on the coke calciner will be based on a business review of the carbon products and scrubbing options. The assessment will also consider the environmental impacts and lifecycle assessment of the mitigation measure selected, including waste generation, energy consumption, GHG emissions, the operating risks of the scrubber and the acceptability to stakeholders of the selected type of feasible scrubbing.

e) Scrubbing on one or both gas treatment centres

The option of implementing scrubbing on one or both gas treatment centres will be based on a business case review of the options to reduce SO_2 emissions from the Kitimat smelter. The review will consider the construction and operating costs of the scrubber in comparison to the feasibility assessment of the other options to reduce SO_2 loadings from smelting operations. The assessment will also consider the environmental impacts and lifecycle assessment of the mitigation measure selected, including waste generation, water release, energy consumption, GHG emissions, the operating risks of the scrubber and the acceptability to stakeholders of the selected type of feasible scrubbing.

f) New Technologies

New technologies (that are in development or may be developed in the future) that reduce or eliminate SO_2 emission sources may be considered by Rio Tinto. The selection of new technologies will depend on degree of readiness and cost efficiency of the technology.

Table 22. Examples of SO_2 reduction options and potential implementation timelines[28].

Reduction option	Potential range of reduction		Implementation timeline
	Lower t/day	Upper t/day	
Procuring lower sulphur content coke	1	15	> 12 months
Reducing the amount of calcined coke produced on site	1	8	Short-term curtailment: 2 weeks Long-term curtailment: > 16 months
Importing anodes with lower sulfur content	1	20	6 to 18 months
Scrubber on Coke Calciner	7	NA	5 - 6 years : a) Feasibility study: 1 year b) Permitting: 1 years c) Engineering, Procurement, Construction: 2 - 3 Years d) Commissioning: 1 years

[28] One or more of these reduction options would only be implemented if:
- there is a confirmed environmental impact causally related to SO_2 emissions, and
- an SO_2 EEM KPI facility-based mitigation threshold has been exceeded.

These options are not binding, as the efficacy and availability of some options may vary with time and other options may become available in the future. The specific proportional reduction levels required will determine the level of either the efficiency or reduction level required.

Reduction option	Potential range of reduction		Implementation timeline
	Lower t/day	Upper t/day	
Scrubber on 1 GTC	14	NA	7-8 years : a) Feasibility study: 1 years b) Permitting: 2-3 years c) Engineering, Procurement, Construction: 3 years d) Commissioning: 1 years
Scrubbers on 2 GTC	29	NA	
New technologies	TBD	TBD	TBD

9.2.2 Proportional Emissions Reductions for Terrestrial and Aquatic Ecosystems

The SO_2 effects pathway for both the terrestrial and aquatic ecosystems are through acidic, sulphate (SO_4) deposition.

If SO_2 effects from SO_2 emissions (from Rio Tinto or cumulative from LNG facilities in the Kitimat Valley) are measured through an exceedance of a KPI's threshold for facility-based mitigation and that it is demonstrated through applying the relevant evidentiary framework in the SO_2 EEM Phase III Plan (with strong statistical confidence or belief to be actual (not a false positive)) then Rio Tinto will proportionally reduce SO_2 emissions.

The total amount of SO_2 emissions reduction required to bring the KPI back into attainment will be determined through estimating the SO_4 deposition level that caused the exceedance. The specific contribution of each SO_2 emitter to the SO_4 deposition level that caused the exceedance will be estimated through modeling and/or measurements as identified below. The percentage of Rio Tinto's contribution to the total SO_4 deposition that caused the exceedance will be the proportion of Rio Tinto's SO_2 emissions reduction.

Tools used to determine the proportion of SO_2 emissions reduction will be:

- 2019 SO_2 EEM Comprehensive Review's CALPUFF SO_2 dispersion model (updated with new meteorology and the SO_2 emission inventory from all SO_2 emitters),
- SO_2 EEM's deposition model (to both validate the SO_4 deposition levels that caused the KPI exceedance and refine the CALPUFF deposition model results to improve the agreement with observations), and
- Updated relevant Aquatic and Terrestrial Ecosystems models from the 2019 SO_2 EEM Comprehensive Review.

Further emissions reductions to address a future KPI exceedance will only be made after all other SO_2 emitters have proportionally reduced their SO_2 emissions to in response to the first KPI exceedance.

The combined total amount of facility-based SO_2 emissions for Rio Tinto will not exceed 15 Mg/d and the 2013 unamended P2-00001 Multimedia Permit limit of 27 Mg/d.

10 Reporting, Consultations and Comprehensive Review

10.1 Reporting and Consultation Schedule

SO_2 EEM Program reporting and consultation will occur on an annual basis in accordance with Table 23. Additional requirements (terms of reference) related to the deliverables in Table 23 are outlined in Appendix B, and work plans are provided in Appendix C.

Table 23. Reporting and consultation requirements under the SO_2 EEM plan.

Deliverable	Due Date (current year) [1]
Annual Review Cycle[2]	
Review of interim draft results and QP recommended adjustments to work plans	March 15th to April 20th [3]
Draft work plans[4]	April 30th
Final annual work plans (for current year)	May 31st
Draft documents[5] (Annual SO_2 EEM Program Report for previous year)	May 31st
Implementation of work plans	In accordance with finalized work plans[6]
Consultation process (on draft documents) [7]	To be completed by June 30th
Consultation report (for draft documents)	September 15th
Final Annual SO_2 EEM Program Report with finalized technical memoranda (for previous year)	October 31st
Comprehensive Review (2026)	
Terms of reference and schedule for completing the Comprehensive Review	December 31st, 2025

[1] Rio Tinto may submit requests to B.C. ENV to extend due dates.
[2] The annual review cycle for the Phase III Program will commence in 2022, following B.C. ENV approval of the program.
[3] A meeting(s) will be held with Rio Tinto, select QPs and B.C. ENV to review interim draft results and recommended adjustments to the work plans.
[4] Draft work plans will be issued concurrently to B.C. ENV, KPAC, and KAG (atmospheric pathways and human health at a minimum). The Stakeholders will have a 14 day commenting period on the changes made to the work plans. The commenting period will start on the day after the work plans are issued.
[5] Draft documents (Annual SO_2 EEM Program Report with technical reports/memoranda that are relevant to the reporting year) are intended to be complete drafts according to the respective terms of reference and using data that are available up to April 30th of the year that the draft report is written.
[6] If the B.C. ENV has not commented or acknowledged the finalized annual work plans within 10 days of the submissions the field monitoring work will commence according to the most recent submitted versions of the annual work plans.
[7] A 30-day consultation period on the draft annual SO_2 EEM Program report with technical memoranda will be conducted according to Section 10.4.

10.2 Annual Work Plans

Five-year work plans have been prepared for atmospheric pathways and each line of evidence. These work plans are presented in Appendix C. On an annual basis, the five-year work plans

will be updated based on (if any) learnings from the previous year. The work plans will be updated and issued in draft to B.C. ENV for review and approval based on the schedule outlined in Table 23. Monitoring work for the SO_2 EEM Program will be conducted according to the approved work plans.[29]

10.3 Annual Reporting

The annual SO_2 EEM Program report will be prepared according to both the schedule in Table 23 and the terms of reference presented in Appendix B. The purpose of the annual SO_2 EEM Program report is to provide a summary of the knowledge gained, an evaluation of the KPIs and recommendations for adjusting the work plans for the following year. Technical reports and/or memoranda that are completed as sub-components for the atmospheric pathways and the lines of evidence will be completed according to the terms of reference in Appendix B. The technical reports and/or memoranda will be appended to the annual SO_2 EEM Program report.

10.4 Annual SO_2 EEM Consultations

10.4.1 Consulted Parties

Consulted parties will include the following:

- Haisla Nation and other First Nations as identified by the Director,
- B.C. Works' Kitimat Public Advisory Committee (KPAC),
- Kitimat Airshed Group (KAG) for the atmospheric pathways and human health at a minimum, and
- Other groups as specified by the Director.

10.4.2 Consultation Process

At a minimum, the consultation process will consist of:

- Referral of the draft annual SO_2 EEM Program report (with technical memoranda) to the consulted parties on or before May 31st of the current year. Documents will either be sent to the consulted parties as attachments by email or an email will be issued to the consulted parties inviting them to download the files from a public-facing website. The draft annual SO_2 EEM Program report will be made available at least one week in advance of meeting.
- Hosting of a consultation event made available to all consulted parties according to Section 10.4.1. Notice of the event will be issued a minimum of 2 months prior to the consultation event.
- One consultation event will be hosted for the KPAC , First Nations and other groups as specified by the Director. Presentations of the draft annual SO_2 EEM Program report will be given at the session, with content tailored for a non-technical audience. One

[29] If the work plans have not been acknowledged by the director according to Chapter 10, the most recent version of the work plan submitted to B.C. ENV will be applied for initiating the monitoring work.

consultation session will be offered to the Kitimat Airshed Group on the atmospheric pathways and human health chapters of the annual SO_2 EEM Program report.

- Consulted parties will be given 30 days to provide written comments on the draft annual SO_2 EEM Program report. Received written comments and verbal comments received during the consultation session will be consolidated into a tracking table.
- Responses to comments received will be provided in the consultation tracking table. This tracking table will be posted to a public-facing website and the consulted parties will be issued an email inviting them to download the tracking table and provide follow-up comments within 10 days. Received comments that are within scope of the draft annual SO_2 EEM Program report will be taken into consideration. Revisions to the draft annual SO_2 EEM Program report will be considered for material comments that are in scope of the consultation documents.

10.4.3 Consultation Report

A concisely written consultation report will be prepared that summarizes the consultation process, comments received and responses. The consultation report will be a short and concisely written document (according to the terms of reference provided in Appendix B) that includes the summary of the consultation process, meeting minutes, presentations and completed tracking table.

10.5 Comprehensive Review in 2026

A compressive review of the monitoring conducted during the Phase III SO_2 EEM Program will be undertaken in 2026. A draft report synthesizing the results of this review will be prepared by December 31, 2026, which will:

- Build on the knowledge gained in the 2019 SO_2 EEM Comprehensive Review,
- Summarize what has been learned, and what question have been answered,
- Describe which if any of the KPI thresholds have been exceeded, and if so, what actions were taken,
- Describe any modifications to KPIs, methods or thresholds that have been made based on annual results to date, and why,
- Summarize the effects of climate change based on an assessment of the climate change indicators,
- Look across the data for of the three lines of evidence to develop a holistic understanding of B.C. Works aluminium smelter's SO_2 effects on the environment and human health, and
- Recommend changes if/as needed to: the suite of KPIs to be continued post-2025, their measurement methods, and/or their thresholds – along with the rationale for these recommended changes.

Terms of reference for the 2026 Comprehensive Review (including an approved dispersion model protocol) will be prepared by December 31st, 2025. The terms of reference will be developed according to Table 24. The schedule will target completion of the terms of reference by October 31st, 2025 but will allow 2 months of contingency time. The finalized terms of reference will be the scope of work for the 2026 Comprehensive Review.

Table 24. 2026 Comprehensive Review Terms of Reference development.

Deliverable	Due Date
Terms of Reference	
Scoping Workshop (one to two days)[1]	January - February 2025
Tracking table[2]	Two weeks following the scoping workshop
B.C. ENV Scoping comments stemming from Scoping workshop via tracking table[3]	30 days following the receipt of the tracking table from Rio Tinto
Rio Tinto response to B.C. ENV Scoping Comments via tracking table[4]	45 days following the receipt of scoping comments from B.C. ENV
Draft terms of reference[5]	June 15th, 2025
B.C. ENV review of draft terms of reference via tracking table	July 30th, 2025
Rio Tinto response to B.C. ENV comments on draft terms of reference via tracking table	September 30th, 2025
Final terms of reference[6]	December 31st, 2025
Dispersion Model Protocol	
Draft Dispersion Model Protocol[7]	May 30th, 2025
B.C. ENV review (and comments) of draft dispersion model protocol	June 30th, 2025
Rio Tinto Response to B.C. ENV comments on draft dispersion model protocol via tracking table	July 31st, 2025
Final Dispersion Model Protocol	July 31st, 2025
B.C. ENV approval of dispersion model protocol	August 31st, 2025

[1] Rio Tinto will host a scoping workshop with QPs (who are available to attend) and B.C. ENV. The scoping workshop will be held over 1 to 2 days and may be either an in-person or virtual (remote) attended workshop.

[2] Rio Tinto will prepare a tracking table based on the scope of the 2026 Comprehensive Review developed in the workshop. The tracking table will be provided in a spreadsheet format that is editable.

[3] B.C. ENV will be invited to provide follow-up comments to the scope agreed to at the scoping workshop. Comments will be entered in the tracking table provided by Rio Tinto.

[4] Rio Tinto with the input from the QPs will provide responses to the received comments from B.C. ENV. The responses will be used to prepare the draft terms of reference.

[5] The draft terms of reference will contain at a minimum: table of contents, section and sub-section headings, and summary bullets of the scope for each section and sub-section.

[6] Rio Tinto will submit the finalized draft terms of reference to B.C. ENV for review and approval. Two months of contingency time (Nov and Dec) is provided to allow for further iterations of the terms of reference (if required).

[7] Dispersion modelling is a long lead process that is relied on for the analysis the lines of evidence in the Comprehensive Review. The dispersion model protocol will be developed from B.C. ENV's template for dispersion model protocols. Approval of the dispersion model protocol will be required before September 1st in order for the development of the dispersion model to begin in 2025 and completion of the model runs to be done in the first quarter of 2026.

10.6 Mid-stream Adjustments

Mid-stream adjustments to the KPIs may be made if there is demonstrable evidence to support adjustments to the KPIs and associated thresholds for the Terrestrial Ecosystems and Aquatic Ecosystems lines of evidence. If Rio Tinto seeks mid-stream adjustments, a request for mid-stream adjustments to the KPIs will need to be made to B.C. ENV.

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Appendix A: Changes in the SO_2 EEM Program and the Rationale

This appendix summarizes the changes to the SO_2 EEM Program in this Phase III Plan, and provides the rationale for the changes.

Atmospheric Pathways

- Establishment of a continuous SO_2 monitoring station within the Service Centre commercial area to provide information on model performance in this area (2019 Comprehensive Review, Atmospheric Pathways recommendation 2). (pg 11)
- Monitoring data evaluation will not include a monitoring data study or a CALPUFF model refinement because this was conducted in the first phase of the SO_2 EEM Program and reported in the 2019 Comprehensive Review.
- Review of passive sampling network sites (2020 and 2021 Kitimat Passive Monitoring Plan for Sulphur Dioxide, prepared by Trinity Consultants, September 2020). The details of the passive sampling program were formalized in the passive sampling plan currently under review. (pg. 11)
- Review the recommendation to discontinue the Haul Road wet deposition monitor, as the monitoring of wet deposition at Haul Road provides no ecological value (i.e., for the assessment of impacts) owing to its fence line location, and it provides limited value for model (CALPUFF) evaluation (2019 Comprehensive Review, Atmospheric Pathways recommendation 5). (pg. 12)
- Change of the third informative indicator from base cation deposition to precipitation chemistry, from the Lakelse Lake NADP station. This reflects the importance of chloride (CL-) as a tracer for sea-salts, in addition to the use of base cations for CL exceedance should CLs need to be recalculated. (pg. 10)

Human Health

- Shifting of the KPI for the SO_2 EEM Program toward alignment with the CAAQS for SO_2 (2019 Comprehensive Review recommendation for human health). (pg. 16)
- 2019 settlement of the SO_2 EEM appeal. (pg. 14)
- Mitigation action plan to include public health messages and recommendations. (pg. 15)

Terrestrial Ecosystems

- Combining of the Vegetation and Terrestrial Ecosystems (Soils) lines of evidence into a new Terrestrial Ecosystems line of evidence (2019 Comprehensive Review, Vegetation recommendation 1). (pg. 19)
- Discontinuation of sampling and chemical analysis of western hemlock foliage in favour of maintaining a valley passive sampler network (2019 Comprehensive Review, Vegetation recommendation 3).
- Change of the visible injury KPI to an informative indicator to support the Terrestrial Ecosystems line of evidence (2019 Comprehensive Review, Vegetation recommendation 1).

- Change of the focus of vegetation monitoring to detect mid to long-term effects on Terrestrial Ecosystems (2019 Comprehensive Review, Vegetation recommendation 3) by:
    - Implementing a 3-year rotating panel of 33 plots for monitoring the biodiversity (species richness and abundance) of cyanolichens and of vascular plants in the low shrub and herb layers, and
    - Assessing the health of the vegetation at the biodiversity plots during the annual measurement cycle. (pg. 27-29)

- Revision of the assessment of changes in exchangeable base cation at the long-term soil plots (2019 Comprehensive Review, Soils recommendation 3) to:
    - Use soil concentrations in the top 0–30 cm (rather than 0–5cm or 0–15 cm) of mineral soil rather than pools to assess changes in soil chemistry, (pg. 26)
    - Use a change (decrease) in base saturation (%) to calculate KPI (rather than a change in exchangeable base cation pools), (pg. 26)
    - Further analyse the minimum detectable difference to evaluate the potential of an early warning change in soil base saturation using a lower level of significance and / or lower power, (pg. 26) and
    - Carry out the next sampling of long-term plots during 2025 (to return to a five-year period) and measure trees (DBH) at time of soil sampling. If the KPI is triggered, measure tree chemistry to estimate Bcu [base cation uptake] by trees and its contribution to soil chemistry changes. (pg. 26)

Aquatic Ecosystems

- Change of the KPI calculation from pH to ANC (rationale provided in 2019 Comprehensive Review, Aquatic Ecosystems recommendations 10, 11, 12, 13 and 14). (pg. 36-37)

- Rationale for using CBANC as the indicator metric:
    - CBANC is the most common ANC metric applied in acidification studies
    - It is easily measured/calculated (doesn't require special lab equipment like Gran ANC)
    - The SO_2 EEM Program has a continuous record of the constituent data needed to calculate CBANC with single analytical laboratory (whereas there was an unavoidable change in analytical laboratories for pH and Gran ANC, with overlap in 2019)
    - CBANC does not change in response to changes in DOC and organic acids and therefore can be interpreted as a more direct indicator of anthropogenic acidification (though acidification can sometimes cause a decline in DOC so it is still useful to also have Gran ANC and BCS)
    - We have lake-specific thresholds for change limits directly obtainable from the record of Gran ANC titrations

- Rationale for the CBANC level of protection threshold (i.e., 20 µeq/L) (pg. 39)

- Based on ANC Literature Review (Aquatic Appendix B of the 2019 EEM Comprehensive Review report) shift of the role of pH from KPI to informative indicator (rationale provided in 2019 Comprehensive Review, Aquatic Ecosystems recommendation 10). (pg. 41)

- Change of the number of lakes being sampled annually, from 14 to 11 (rationale provided in 2019 Comprehensive Review, Aquatic Ecosystems recommendations 1, 2, 3, 5 and 9). (pg. 42)
- Change of the number of lakes being monitored intensively from 3 to 1 (rationale provided in 2019 Comprehensive Review, Aquatic Ecosystems recommendations 6 and 7).
- No further CL modeling or predictions of steady state pH unless emissions change substantially from 42 tpd scenario (rationale provided in 2019 Comprehensive Review, Aquatic Ecosystems recommendations 15, 16 and 17).

Climate Change (pg. 50-51)

- Addition of new chapter on climate change that will develop climate change indicators (meteorological and effects monitoring).
- Indicators will be reported in the annual SO_2 EEM Program report.
- Support of a study to review and summarize available climate change predictions for the Kitimat Valley.

Determination of Causal Relationships to B.C. Works

- Addition of vegetation and lichens to Terrestrial Ecosystems (pg. 52)

Pathways to Mitigation

- Chapter name changed from "Rio Tinto Alcan Mitigation Response for Unacceptable Impacts" to "Pathways to Mitigation". (pg. 55)
- Description of process with B.C. ENV for determining a KPI non-attainment and development of a mitigation action plan. (pg. 55-56)
- Addition of cumulative SO_2 effects from BC Works' smelter and two LNG projects in Kitimat. (pg. 56)
- Addition of proportional SO_2 emissions reductions on facility-based emissions reduction thresholds. Exceedances. (pg. 56-57)
- Addition of "New technologies" to the examples of facility-based mitigation options. (pg. 57-58)

Reporting, Consultations and Comprehensive Review

- Chapter name changed from "Annual Reporting, Consultations and Comprehensive Review in 2019" to "Reporting, Consultations and Comprehensive Review" (pg. 60)
- Addition of a work cycle that identifies the key tasks and dates for conducting work and consultations (pg. 60)
- Addition of annual work plans that are based on five year work plans that are updated annually. (pg. 60-61)
- Addition of annual SO_2 EEM Program report and technical memoranda terms of references. (pg. 61)
- Addition of an expanded consultation process. (pg. 61-62)
- Description of the 2026 Comprehensive Review process. (pg. 62-63)

Appendix B: Terms of Reference for Reporting and Consultation Deliverables Required under the SO_2 EEM Plan

This appendix is packaged as a separate document: **SO_2 Environmental Effects Monitoring Program Phase III Plan for 2019-2025. Appendix B, Terms of Reference for Reporting and Consultation Deliverables Required under the SO_2 EEM Plan**.

It contains Terms of Reference for the following technical reports that are expected to be prepared on a routine basis:

- Annual SO_2 EEM Program Report
- SO_2 Passive Sampling Program Technical Memo
- Human Health KPI Technical Memo
- Vascular Plant and Cyanolichen Biodiversity Monitoring Program Annual Report
- Vascular Plant and Cyanolichen Biodiversity Monitoring Program End-of-Cycle Report of Activities
- SO_2 Aquatic Sampling Annual Technical Report
- SO_2 EEM Program Technical Memo - Aquatic Ecosystems Actions and Analyses
- SO_2 EEM Annual Consultation Report

It is provided on the following pages in PDF format.

B.C. Works' Sulphur Dioxide Environmental Effects Monitoring Program

Phase III Plan for 2019 to 2025

Appendix B: Terms of Reference for Reporting and Consultation Deliverables
Final

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Version Tracking Table

No.	Date	Summary of content /changes
V.1	July 2, 2021	Draft for review by the B.C. Ministry of Environment and Climate Change Strategy (B.C. ENV)
V.2	July 18, 2021	Draft with revisions per B.C. ENV comments, for Rio Tinto review
V.3	July 13, 2022	Draft for Consultation
V.4	September 28, 2022	Revised draft addressing comments
Final	February 28, 2023	Finalization based on "Tracking Table SO_2 EEM Phase III responses (FINAL to B.C. ENV) Feb 7 2023.xlsx" February 28, 2023 email from Adriana Almeida-Rodriguez, "2023-02-28 ENV Comments on 2022 Plant biodiversity annual report"

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Annual SO_2 EEM Program Report

Executive Summary

- Summarize key results by line of evidence
- Tabulate the attainment results for each KPI
- Summarize key activities implemented

Introduction

- Summarize the purpose and scope of the EEM Program
- Convey the purpose and scope of the annual report
- Specify the reporting year

Figures:

- Source-pathway-receptor model, updated for Phase III
- Pathway and receptor framework for reporting on EEM activities, updated for Phase III

Facility Emissions

- Note whether the average of the SO_2 emissions for the reporting year is higher or lower than the average in the previous year
- Note whether the SO_2 emissions remained below the 42 tpd permitted limit

Figure:

- Annual SO_2 emissions from the smelter, from 2013 to the reporting year, showing the average each year and the maximum permitted level

EEM Activities

Atmospheric Pathways

SO_2 Concentrations – Continuous Monitoring

- List the continuous monitoring station sites used for the reporting year
- Note any changes from the sites used in the previous year
- Note any changes from the workplan for the reporting year, and the reason
- Specify which passed ENV's audits, and convey the % data capture for the reporting year
- Convey monthly average SO_2 concentrations at the continuous monitoring stations, starting from 2013, compared with monthly SO_2 emissions over the same period; convey any notable patterns or changes
- Convey the relative frequency of hourly averaged concentrations of SO_2 the analyzers
- Compare the monitoring data from the continuous monitoring stations to the modelling results prepared for the EEM 2019 Comprehensive Review

Figures:

- Map of continuous monitoring station locations
- Graph of monthly SO_2 emissions, and monthly average ambient SO_2 concentrations at the continuous monitoring stations; zoom in on low concentrations
- Graph of relative frequency of hourly averaged concentrations at SO_2 the continuous monitoring stations
- Graphs of the comparison between monitored concentrations in the reporting year and the predicted SO_2 concentrations from the 2019 Comprehensive Review

Table:

- Table comparing monitored annual average SO_2 concentrations to modelled concentrations at each monitoring station site

SO_2 Concentrations – Passive Sampling

- Describe the passive sampler network deployment for the year – number of samplers, and their locations, including co-location with continuous monitoring stations
- Note any changes from the sites used in the previous year
- Note any changes from the workplan for the reporting year, and the reason
- Specify the deployment dates in the reporting year
- Specify the total number of sample exposures across the network in the reporting year
- Direct the reader to the Passive Sampling Technical Memo for results from co-located continuous and passive samplers, and for the updated calibration equation

Figure:

- Map of passive sampler locations and average SO_2 concentrations at each station for the reporting year

Tables:

- Table of monthly SO_2 concentrations at each station from the plume path network

Precipitation Chemistry

- Identify the precipitation chemistry monitoring station locations for the reporting year
- Note any changes from the sites used in the previous year
- Note any changes from the workplan for the reporting year, and the reason
- Convey the annual and weekly precipitation volume at each location for the reporting year, and characterize how the volume and chemistry data at these sites compare to each other in the reporting year, and to prior years

Figure:

- Graph of annual precipitation volume starting in 2019 at the precipitation chemistry monitoring station(s)
- Graphs of weekly rainfall volume, rainfall sulphate, and pH at the precipitation chemistry monitoring station(s)

Sulphur: Dry and Wet Deposition

- Identify the model used by the EEM Program to estimate dry deposition
- Summarize how dry deposition was estimated for the reporting year
- Convey estimated dry deposition and wet deposition for the reporting year
- Note patterns and/or any changes in dry deposition from prior years

Figure:

- Graph of dry and wet deposition of sulphur

Human Health

- Explain the KPI calculation method (CAAQS, D1HM percentile, ppb threshold for the 3-year average) for the reporting year
- Convey the KPI calculation and results, and specify whether the locations were in attainment or not in attainment for the reporting year
- Refer the reader to the Health KPI Technical Memo for more details

Table:

- Calculation method and results for the reporting year, including when the data were validated by ENV and when the data were extracted from the Envista database

Terrestrial Ecosystems

Soils

- In 2022, summarize work on the wetland geochemistry project and the aluminum solubility project; refer the reader to the Technical Memo for the reporting year
- In 2025, summarize the work done under the long-term acidification soils monitoring program (analyses and results and results will be reported in 2026)
- Note any changes from the workplan for these projects for the reporting year, and the reason

Plant Biodiversity and Plant Health

- Summarize the status of the Vascular Plant and Cyanolichen Biodiversity Monitoring Program
- Summarize activities conducted during the reporting year
- Note any changes from the workplan for the reporting year, and the reason
- Summarize the results
- Refer the reader to the Technical Report for the reporting year for more details
- Note when the next 3-year biodiversity rotation end of rotation report will be prepared

Aquatic Ecosystems

Major Actions in the reporting year

- Identify which lakes were sampled in the reporting year
- Note any changes in sampling from the previous year
- Note any changes from the workplan for the reporting year, and the reason
- Refer the reader to the Technical Report on lake sampling for the reporting year
- Summarize how changes in water chemistry were examined and analyzed; refer the reader to the Aquatic Ecosystems Technical Memo for the reporting year

Knowledge Gained from Actions in the reporting year

- Summarize the empirical changes in water chemistry
- Summarize the results of the statistical analyses of changes in water chemistry
- Refer the reader to the Aquatic Ecosystems Technical Memo for the reporting year
- Specify whether any KPI thresholds have been reached, and state whether the KPI is in attainment or not in attainment for the reporting year
- Summarize the application of the simplified evidentiary framework and whether any lakes have moved their location in the framework since the 2019 Comprehensive Review

Figure:

- Map of lake locations and spatial distribution of % belief in the chemical change in the reporting year
- Classification of EEM lakes according to the simplified evidentiary framework

Tables:

- Empirical changes (increases and decreases) in lake chemistry, by lake
- Summary of findings of the statistical analysis of changes in lake chemistry across all lakes in the EEM Program

Climate Change

- Summary of any reviews of datasets to identify historical normal or adjust the baseline
- Summary of any changes or additions to the climate change indicators
- Graphs of the meteorological indicators
- Graphs of the effects monitoring indicators

List of Cited Reports

- References for reports cited in the sections above

List of Cited EEM Technical Memos

- References for Technical Memos cited in the sections above

SO_2 Passive Sampling Program Technical Memo

Introduction

- Scope and purpose of the SO_2 passive sampling program

Overview

- Note the sampling period for the reporting year (day, month started; day, month ended; total duration)
- Note the number of samplers deployed
- Summarize any changes in sampler deployment from that planned, e.g.:
  - if any samplers were discontinued during the sampling period, and the shorter number of sampling days at those locations
  - if any sampling periods were substantially different than 30 days and why
- Summarize the overall performance of passive samplers for the reporting year

Study Design

- Note if monitoring employed the same procedures as the previous year and summarize changes if applicable
- Identify any new sites added to or decommissioned from the network; direct the reader to the appropriate figures/tables
- Identify anything else that changed from the previous year's deployment
- Note the number of monitoring sites with valid sample exposures across the network, and the % of time duplicate samplers were deployed

Results

- Note when [month or months] and where the observed data showed elevated/high atmospheric sulphur dioxide (SO_2) along the plume path; cite the appropriate figures/tables
- Note whether average SO_2 concentrations during the reporting year increased or decreased from the previous year, and by how much (%) – cite the previous year's Passive Sampling Program Technical Memo and/or SO_2 EEM report
- Note where monthly exposures were consistently low or high; cite appropriate figure(s)
- Note the % variation between the duplicate passive sampler exposures; cite appropriate Appendix table; explain what these results indicate
- Compare results to those of the co-located continuous SO_2 monitors (degree of correspondence; difference), cite appropriate figure; explain what these results indicate; update calibration equation(s) as appropriate

Figures:

- Figure 1, map(s) of passive sampler locations in the reporting year, colour-coded to convey average atmospheric sulphur dioxide (SO_2) concentration during the sampling period
- Figure 2, scatter plot comparing passive sampler results to continuous SO_2 measurements where the passive samplers are co-located with the continuous monitors

Conclusion

- Explain how the results for the reporting year compared with those in the previous year based on raw data; note any changes from the same monitoring period in the previous year
- Convey whether the results from the network in the reporting year continue to support the use of passive samplers to provide empirical observations of atmospheric SO_2 concentrations to (a) assess spatial and temporal changes, (b) evaluate modelled concentration fields, and (c) estimate dry deposition of SO_2
- Recommendations for adjustments in the passive monitoring program, should changes be warranted
- In 2023, recommend whether to continue or cease deployment in 2024 and 2025

Literature Cited

- Previous year's Technical Memo
- Previous year's SO2 EEM report
- Comprehensive Review Report
- Any other cited references

Appendix A

Tables:

- Table A1, Location of passive sampler monitoring network sites established and deployed during the reporting year
- Table A2, SO_2 concentrations (ppb) at passive sampler monitoring network sites established and deployed during the reporting year
- Table A3, Analysis of replicate passive sampler deployments

Figures:

- Figure A1, Map of average atmospheric SO_2 concentration (ppb) at each sampling site during the reporting year in the passive sampling network [only needed if the map will not duplicate the map(s) in Section 3]
- Figure A2, Site locations and IDs for the Kitimat urban and ambient passive diffusive sampler network

Annual Human Health KPI Technical Memo

Introduction

- Summarize the purpose of the Technical Memo
- Specify the reporting year

Health KPI

- Explain the purpose of the Health KPI in the EEM Program measured at the Riverlodge, Whitesail, Kitamaat Village and Service Centre ambient air quality monitoring stations
- Describe what the KPI is for the reporting year, and when the KPI shifts from 70 ppb to 65 ppb

Exceptional Events

- Identify exceptional event conditions that have occurred during the year from[1]:
    - Fire within the community that may emit SO_2;
    - Emergency conditions at the facilities within the Kitimat airshed (e.g., Rio Tinto Smelter upset conditions or LNG Canada emergency flare);
    - Vandalism or corruption of data from other point sources such as vehicle emissions in close proximity to the ambient air monitoring station; and
    - Temporary global events that impact SO_2 levels such as a volcano eruption
- Describe how the exceptional event has affect the ambient SO_2 concentrations measured at the stations
- Describe the materiality of the exceptional event in relation to the determination of the health KPI

Calculation Method

- List the monitoring stations (Riverlodge, Whitesail, Kitamaat Village and Service Centre) which have sufficient data collected for the reporting year
- Convey when the data were validated for the reporting year and in the two prior years for data also used in the calculation
- Specify when hourly measurements for the reporting year and the two prior years were downloaded from the Envista database

[1] 2019 B.C. Environmental Appeals Board Consent Order between Elisabeth Stannus, Emily Toews, UNIFOR Local 2301 and Delegate of the Director, Environmental Management Act, and Rio Tinto Alcan Inc.

- Identify data that has been affected by exceptional events and remove the impacted data from the health KPI calculation
- List the steps used to process the data, and cite the Guidance[2] followed in doing so, and convey completeness results (Table 1, Attachment 1)
- List the steps used to calculate the KPI, and state whether each monitor station is considered in attainment or non-attainment status for this human health KPI (Table 2)

Tables:

- Table 1: quarterly and annual data completeness results by monitoring station
- Table 2: convey the KPI results and health KPI attainment status, by monitoring station

AQHI plus SO_2 Data Review

- List the dates, times and monitoring station locations at which hourly $S0_2$ measurements triggered additional guidance beyond the standard AQHI messages (at 36 ppb and 185 ppb)

Attachment A

Tables:

- Table A1: Provide the daily 1-hour maximum concentrations and completeness summary
- Table A2: Exceptional events details and summary of daily 1-hour maximum concentrations affected by the exceptional events

[2] CCME, 2020. Guidance document on achievement determination for Canadian ambient air quality standards for sulphur dioxide

Vascular Plant and Cyanolichen Biodiversity Monitoring Program Annual Report

Introduction

- Background
- Current status of the Vascular Plant and Cyanolichen Biodiversity Monitoring Program (PCMP)

Activities Conducted During the Reporting Period

- Schedule of measurements
  - Vascular plant biodiversity
  - Cyanolichen biodiversity
  - Plant health assessment
  - Soil sampling (including soil and atmospheric ion exchange resin columns [IER] if used)
- Variance from planned activities (any new changes for the reported year)
  - Plots lost / inaccessible / added
  - Variables added and measured
  - Variables not measured
  - Any other change of note
- Adjustments to the PCMP (compilation of deviations from PCMP carried over from year to year since the implementation of the Phase III PCMP)
  - Plots lost / added
  - Variables added and measured
  - Variables not measured or dropped
  - Any other changes of note

Results

- Vascular plant biodiversity measurements
  - Species richness
  - Percent cover
  - Calculation of slope (beginning with the first plot re-measurement)
  - Trends acid sensitive and culturally important species

- Cyanolichen biodiversity measurements
  - Species richness
  - Relative abundance
  - Calculation of slope (beginning with the first plot re-measurement)
- Plant health assessment

    - Biotic factors
    - Abiotic factors including natural or human disturbance
    - Patterns observed
        - Related to emissions
        - Unrelated to emissions
- Soil and IER (if used) analysis
- RT BC Works Data
    - SO_2 emissions
    - Metal production
    - Annual average ambient SO_2 concentration (continuous monitoring sites)
    - Annual wet and dry deposition (NADP sites)

Discussion and Interpretation

- Logistics (sites lost, changes to the program, etc.)
- Vascular plant biodiversity
    - High deposition sites
    - Moderate deposition sites
    - Low deposition sites
    - Comparison of variability and trends (beginning with the first plot re-measurement and continuing after that)
- Cyanolichen biodiversity
    - High deposition sites
    - Moderate deposition sites
    - Low deposition sites
    - Comparison of variability and trends (beginning with the first plot re-measurement and continuing after that)
- Plant health assessment
    - High deposition sites
    - Moderate deposition sites
    - Low deposition sites
    - Comparison of variability and trends (beginning with the first plot re-measurement and continuing after that)
        - Related to emissions
        - Unrelated to emissions
- Soil analysis and risk of acidification

Conclusions and Recommendations

Appendix

- Data spreadsheets
- Photo archive

Vascular Plant and Cyanolichen Biodiversity Monitoring Program End of Cycle Report of Activities

Introduction

- Background
- 3-year status of the Vascular Plant and Cyanolichen Biodiversity Monitoring Program (PCMP)

Activities Conducted During the 3-year Cycle

- Schedule of measurements
  - Vascular plant biodiversity
  - Cyanolichen biodiversity
  - Plant health assessment
  - Soil sampling (including soil and atmospheric ion exchange resin columns [IER] if used)
- Variance from planned activities
  - Plots lost / inaccessible / added
  - Variables added and measured
  - Variables not measured
  - Any other change of note
- Adjustments to the PCMP (compilation of deviations from PCMP carried over from year to year since the implementation of the Phase III PCMP)
  - Plots lost / added
  - Variables added and measured
  - Variables not measured or dropped
  - Any other changes of note

Results

- Vascular plant biodiversity measurements
  - Species richness
  - Percent cover
  - Calculation of slopes and comparison of trends between high, moderate, and low deposition sites
- Cyanolichen biodiversity measurements
  - Species richness
  - Relative abundance

    - Calculation of slopes and comparison of trends between high, moderate, and low deposition sites
- Plant health assessment
    - Biotic factors
    - Abiotic factors including natural or human disturbance
    - Patterns observed
        - Related to emissions
        - Unrelated to emissions
- Soil and IER (if used) analysis
- RT BC Works Data
    - SO_2 emissions
    - Metal production
    - 3-year Annual average ambient SO_2 concentration (continuous monitoring)
    - 3-year Annual average wet and dry deposition (NADP sites)

Discussion and Interpretation

- Logistics (sites lost, changes to the program, etc.)
- Trends in vascular plant biodiversity
    - Related to emissions
    - Unrelated to emissions
- Trends in cyanolichen biodiversity
    - Related to emissions
    - Unrelated to emissions
- Plant health assessment
    - Related to emissions
    - Unrelated to emissions
- Soil analysis and risk of acidification
- Analysis of results vis a vis the Evidentiary Framework

Conclusions and Recommendations

Appendix

- Data spreadsheets
- Photo archive

SO_2 Aquatic Sampling Annual Technical Report

Executive Summary

Introduction

- Brief introduction
- Summary of main tasks

Methods

- Sampling sites
  - Names and locations of sampling sites
  - Basic identification/location characteristics presented in table
- Annual lake water sampling
  - Description of methods and procedures
  - Sample collection description, step by step
- Frequent lake water sampling
  - Overview
  - LAK028
  - LAK006 (End Lake), LAK012 (Little End Lake), and LAK023 (West Lake)
  - LAK042 and LAK044
- Quality of chemical data
  - Blanks and duplicates
  - Precision
  - Accuracy
- Instrument effects on pH measurement
  - Onset pH sensor drift
  - Time to stable pH reading
  - EEM lakes sampled
  - Time course pH in End Lake, Little End Lake, West Lake, and LAK028
- Water surface elevation in End Lake, Little End Lake, West Lake, and LAK028

Results

- Overview
- Quality of chemical data
- Instrument effects on pH measurement
- Water surface elevation in End Lake, Little End Lake, West Lake, and LAK028
- LAK028

Discussion and Recommendations

- Data compilation
- Quality of chemical data
- Instrument effects on pH measurement
- LAK028

List of References

Appendix A: Standard Field Sheet for Rio Tinto Water Sampling

Appendix B: Gran-ANC Lab Methods

Appendix C: pH Over Time in Lakes with Continuous Monitoring

SO_2 EEM Program Technical Memo - Aquatic Ecosystems Actions and Analyses

Grey shaded text is boilerplate and expected to be the same each year, with the exception of small portions **bolded and underlined** which will be updated for the reporting year.

Introduction

This Technical Memo provides additional information on the data and analyses in support of the 202**x** requirements for the Aquatic Ecosystems component of the B.C. Works SO_2 Environmental Effects Monitoring (EEM) program (**citation**). These data and analyses thus provide the foundation for Section **x.x** in the 202**x** Annual SO_2 EEM Program Report (**citation**).

This technical memo applies methods and approaches that have already been described in detail in other relevant documents. Most of the methods follow those employed in the SO_2 Technical Assessment Report (STAR) (ESSA et al. 2013), the Kitimat Airshed Assessment (KAA) (ESSA et al. 2014a) and the 2019 EEM Comprehensive Review Report (ESSA et al. 2020). Full details on the collection, processing and analysis of the water chemistry samples are reported in technical reports prepared by [**water sampling technical consultant**] for each year's sampling (Perrin et al. 2013; Perrin and Bennett 2015; Limnotek 2016; Bennett and Perrin 2017; Bennett and Perrin 2018, Limnotek 2019, Limnotek 2020, [**additional citations**]). Wherever possible, the description of methods in this technical report refers to these reports instead of repeating information that is already well-documented elsewhere.

The following four documents (as described above) are listed here because they are referenced extensively throughout this technical memo, often without their full citation:

- The STAR (ESSA et al. 2013)
- The KAA (ESSA et al. 2014a)
- The EEM Plan (ESSA et al. 2014b)
- 2019 EEM Comprehensive Review Report (ESSA et al. 2020)
- The EEM Phase III Plan (**citation**)

Methods

Water Chemistry Sampling

EEM Lakes

In 202**x**, [**water sampling technical consultant**] sampled **xx** lakes as part of the EEM long-term sampling plan. These lakes included the seven sensitive lakes and **xx** less sensitive lakes identified in the EEM Plan, and three additional control lakes added to the EEM in 2015. The three control lakes (NC184, NC194 and DCAS14A) are all located outside of the B.C. Works-influenced airshed and have baseline data for 2013 from sampling as part of the KAA (ESSA et al. 2014a). The sampling methodology is described in detail in [**water sampling technical consultant**]'s technical report on the water quality monitoring (**citation**). Table summarizes all of the EEM sites sampled during 2012-202**x**. Figure shows a map of the lakes sampled in 202**x**.

Tables and figures:

- Table (optional) – Summary of sites sampled within the EEM Program (site name, rationale, years sampled)
- Table (optional) – Summary of lake sampling in current year (site name, location, and sampling dates).
- Figure – Location of the lakes that were sampled.

Sampling frequency

- Note any *differences* in sampling frequency from the Plan

Continuous monitoring

xx lakes (**list**) had continuous monitoring of surface water pH, temperature and lake levels. LAK028 also had a similar instrument installed at depth. This work was planned, implemented and documented by [**water sampling technical consultant**]. The methods and results for 202**x** are reported in [**citation**].

Water chemistry data

- Note any *differences* in sampling compared to the Plan and/or previous years

Empirical Changes in Water Chemistry

The methods applied for examining empirical changes are the same as described in the last several years.

- Note any *differences* in sampling compared to the Plan and/or previous years

Statistical Analyses of Changes in Water Chemistry

The 2019 comprehensive review performed an extensive series of statistical analyses of changes in water chemistry and concluded that the results from the Bayesian statistical analyses provided the greatest ability to assess the level of support for different hypotheses of chemical change. The 2019 comprehensive review further recommended that these analyses be re-run on an annual basis to assess status and detect any anomalous patterns. This annual report represents the **xx** iteration of re-running those analyses, with **xx** additional years of monitoring data. These methods are described in detail in the Appendix F of the 2019 Comprehensive Review Report (see Bayesian Method 1 especially).

Environmental Data

- Identify and describe supplementary environmental observations/data utilized in the interpretation of the water chemistry results (as discussed in Section 4.3)
- For example, data could include:
    - Monthly precipitation over multiple years (as indicator of wetter/drier years or periods within the sampling year)
    - Lake level data (as local-scale indicator of seasonal precipitation patterns and timing of major precipitation events)
    - Anomalous atmospheric events such as forest fires or persistent inversions

Results

Water Chemistry Sampling Results

Appendix 1 reports the results of the water chemistry sampling for the EEM lakes and control lakes from the sampling conducted in 202**x** (with the data from 2012-20**xx** included for reference), for major water chemistry metrics (pH, DOC, Gran ANC, base cations, and major anions).

Empirical Changes in Water Chemistry

- Tabular and graphical results of the empirical changes in ANC, pH, SO_4^{2-}, DOC, sum of base cations, chloride, and calcium
  - Changes are reported in terms of the difference between the post-KMP average (2016-202**x**) and the pre-KMP baseline (2012 for the sensitive and less sensitive lakes; 2013 for the control lakes).
  - The sensitive EEM lakes and less sensitive EEM lakes are presented separately within each of the tables.
  - The inter-annual changes presented in this report use the mean annual values whenever multiple within-season samples were taken for a given lake in a given year.
- The annual changes between individual years ***will not*** be reported and analyzed.
  - As already stated in previous years (e.g., ESSA 2018), year-to-year changes should be interpreted cautiously: "… annual changes should be interpreted with substantial caution due to the combination of large natural variation (both within and between years) and limitations on measurement precision… multiple years of observations are required to reliably detect changes in mean pH, Gran ANC and SO4; it is risky to draw conclusions based only on annual changes".
  - Furthermore, in the December 2018 workshop on the terms of reference for the EEM comprehensive review, the ENV external acidification expert recommended that we stop reporting annual changes because inter-annual variability in lake chemistry is too variable to make any meaningful interpretation of the changes between two years.

Tables and figures:

- Table – Empirical changes in pH, ANC, SO_4^{2-}, DOC, base cations, chloride, and calcium for EEM lakes, 2012-2019.
- Figure – Changes in water chemistry metrics and pH across sensitive EEM lakes, across period of record.
- Figure – Changes in water chemistry metrics and pH across less sensitive EEM lakes, across period of record.
- Figure – Map of observed changes in SO_4^{2-}, ANC and pH, across all lakes, across period of record.

Appendix 2 provides a detailed set of figures showing the inter-annual changes in major water chemistry metrics (Gran ANC, base cations, calcium, SO_4^{2-}, chloride, pH and DOC) for each of the EEM lakes across the **xx** years of annual monitoring (2012-202**x**). Similar figures are also

included for the three control lakes based on their **xx** years of annual monitoring (2013 and 2015-202**x**).

Statistical Analysis of Changes in Water Chemistry

- Statistical analyses in support of the simple evidentiary framework will apply Bayesian Method 1, described in Appendix F of the 2019 Comprehensive Review Report.
- Sensitivity analyses using the extended, transition period baseline (2012-2014)

Tables and figures:

- Table – Summary of results of statistical across all lakes.
- Figure – Map of results of statistical analyses across all lakes.

Discussion

Empirical Changes in Lake Chemistry with respect to the Aquatic Key Performance Indicator

- Discussion or statements with respect to:
  - Whether there have been any exceedances of the KPIs
  - Observed decreases in the metrics associated with the KPI and informative indicators
  - Whether the empirical data indicate that any of the lakes have exceeded:
    - the ANC thresholds associated with the KPI
    - the pH thresholds associated with the informative indicator

The following section applies statistical analyses to the same data to assess the percent belief that KPI thresholds could have been exceeded.

Statistical Analysis of Changes in Lake Chemistry

- Discussion or statements with respect to:
  - Comparison of the results with the 2019 comprehensive review, highlighting differences and magnitude of changes (for all three primary metrics)
  - How many lakes show a moderate percent belief (>20%) or high percent belief (>80%) in a change in any of the primary metrics

Tables and figures:

- Table – Comparison of the results of the statistical analyses to the results presented in the 2019 Comprehensive Review (CR).
  - Changes in SO_4 – % belief in SO4 increase
  - Changes in ANC – % belief that ANC threshold exceeded
  - Changes in pH – % belief that pH threshold exceeded
  - Following the 2019 Comprehensive Review, values of % belief < 20% are coloured green, 20-80% yellow, and >80% red.

Separating Natural and Anthropogenic Factors: the Environmental Context

- Description of significant patterns, trends or anomalies in environmental conditions that could potentially influence the observed patterns in lake chemistry

- Discussion of the impact of relevant environmental conditions on the interpretation of lake chemistry results
- Discussion, if applicable, of whether any potential influence of environmental conditions on lake chemistry warrants considering changes to the field program (e.g., adaptations to lake sampling approach and/or other supplementary environmental monitoring)

Additional Context:

The STAR and EEM program were designed to track potential pathways of effects, as illustrated in the Source-Pathway-Receptor (SPR) conceptual model (Figure 1-1 in the 2019 Comprehensive Review Report). Link 3 of the SPR conceptual model illustrates how weather patterns (e.g., sunlight, winds, precipitation) can affect the transport and transformation of emissions, and subsequent links in the conceptual model (i.e., concentrations of SO_2, the relative amounts of dry and wet deposition, the accumulated snowpack, annual changes in lake chemistry). The objective of the aquatic component of the EEM is to determine if smelter emissions are having medium to long term effects on lake chemistry and aquatic ecosystems. The primary approach to fulfilling this objective is via application of the simple evidentiary framework (Figures 7-3 and 7-10 in the 2019 Comprehensive Review Report), which focuses on statistical analyses of multi-year changes in lake [SO_4], ANC and pH.

As illustrated in the SPR conceptual model, natural and anthropogenic forces combine to determine changes in lake chemistry. Understanding medium to long term changes in lake chemistry therefore may require examination of the causes or effects of natural forces, in addition to the effects of the smelter. For example, major changes in the magnitude of precipitation in the two months prior to fall sampling can affect the concentrations of base cations or organic anions, with resultant effects on acid-base chemistry. These effects may vary across the EEM lakes due to regional differences in precipitation patterns, the topographic characteristics of watersheds, or the water residence time of lakes. Where required to logically explain observed patterns of change in lake chemistry over multiple years and multiple lakes, the annual report may examine changes in regional patterns of wet deposition, dry deposition, and precipitation, and may explore the potential effects of variation in watershed and lake attributes.

The EEM is not designed to explain the causes of changes in lake chemistry that are unrelated to the smelter (section 7.1.4 of the 2019 Comprehensive Review Report). However, if a lake shows significant changes in pH or ANC unrelated to the smelter (i.e., with no concurrent changes in lake [SO_4]), it is prudent to explore what environmental factors and lake attributes might be responsible, as these factors may have also contributed to observed changes in other lakes which have shown changes in lake [SO_4].

Application of the Simplified Evidentiary Framework

We have applied the simplified evidentiary framework, as described in the 2019 Comprehensive Review Report, using the updated results of the statistical analyses. The results are shown in Figure. The underlying results are compiled in Table. The updated application of the simplified evidentiary framework show that:

a) **xx** sensitive lakes, **xx** less sensitive lakes, and all 3 control lakes[3] land within the first box, "smelter not causally linked to changes in lake chemistry";
b) **xx** sensitive lakes and **xx** less sensitive lakes all land within the second box, "lake is healthy, and not acidifying";
c) **xx** [**sensitive/less sensitive**] lakes (**list lakes**) land within "some evidence of acidification"; and
d) **xx** [**sensitive/less sensitive**] lakes (**list lakes**) land within "unacceptable level of acidification".

[3] All of the control lakes are classified in the first box regardless of increases in sulphate because any such increases cannot be causally linked to the smelter due to their location well outside the smelter plume.

- Describe the underlying percent belief values for any lakes falling in the yellow box ("some evidence of acidification") or red box ("unacceptable level of acidification")
- Describe whether these results have changed from previous years:
    - How have any changes in the underlying percent believe values changed (or not changed) the results within the framework

Tables and figures:

- Figure – Classification of EEM lakes according to the simplified evidentiary framework.
- Table – Results used in the application of the simplified evidentiary framework (as described above).
    - Changes in SO_4 – % belief in SO_4 increase
    - Changes in ANC – % belief that ANC threshold exceeded
    - Changes in pH – % belief that pH threshold exceeded
    - Changes in ANC (no threshold) – % belief that ANC decreased
    - Changes in pH (no threshold) – % belief that pH decreased

Recommendations

- Recommendations based on results from this year:
    - Recommendations for adjustments to next year's program (as appropriate)
    - Recommendations for broader program (as appropriate)

References Cited

- Referenced cited in document

Appendix 1: Water Chemistry Data from Annual Sampling, 2012-202x

The two tables below shows the sample results for each of the EEM lakes and control lakes from annual monitoring conducted from 2012 to 202**x**, including pH, dissolved organic carbon (DOC), Gran ANC, and the concentration of major anions and cations, as well as the sum of all base cations (BC). In 2013-202**x**, the pH of the water samples was measured by two different laboratories (Trent University and ALS).

The first table provides the mean annual value and standard error for each metric for lakes with multiple within-season samples, as calculated from all the within-season samples. Lakes with only a single annual sample will show the same value in both tables and no measure of variability. The second table presents the sampling data in its "raw" units, as measured, without converting concentration values to charge equivalents. Although acidification studies require converting measured concentrations to charge equivalents, these unconverted values may be more familiar and therefore easier to interpret for some audiences.

Mean Annual Values

The mean annual values and standard error have been calculated for all lakes with multiple within-season samples. Sample values with no standard error indicate that only a single annual sample was taken for that particular lake in that particular year.

Lake	Year	pH TU	*SE*[1]	pH ALS	*SE*	DOC mg/L	*SE*	ANC µeq/L	*SE*	SO4* µeq/L	*SE*	Cl µeq/L	*SE*	F µeq/L	*SE*	Ca* µeq/L	*SE*	Mg* µeq/L	*SE*	K* µeq/L	*SE*	Na* µeq/L	*SE*	∑ BC* µeq/L
LAK006																								
LAK007																								
LAK012																								
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

[1] SE = standard deviation

Sampling Data in "Raw" Units

The annual or mean annual values (depending on whether the lake had multiple within-season samples) are presented in their "raw" units, as measured, without converting concentration values to charge equivalents.

Lake	Year	pH (TU)	pH (ALS)	DOC (mg/L)	Gran Alkalinity (mg/L)	Conduct-ivity (µS/s)	SO4 (mg/L)	Cl (mg/L)	F (mg/L)	NO3 (µg/L)	NH4 (µg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)
Lak006																		
Lak007																		
LAK012																		
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Appendix 2: Changes in Ion Concentrations from 2012 to 202x

For each of the EEM lakes, the figures in this appendix show the inter-annual changes in six major water chemistry metrics from 2012 to 202**x**: ANC, base cations and calcium (left panel), sulfate and chloride (centre panel), and pH and dissolved organic carbon (right panel). The selection of each pair of metrics is solely based on optimizing graphical representation across all metrics and lakes (i.e., metrics with somewhat similar numeric ranges are shown together). The right panel has two Y-axes. The axis for pH does not start at zero – be aware that this can make relatively minor changes appear to be much more substantial than they are. Due to large variation among the lakes for some of the metrics, the Y-axis is not consistent across the lakes, therefore extra caution is required for making comparisons among lakes with respect to the magnitude of changes. However, these graphs are especially useful for looking at the patterns of changes for individual lakes across the sampling record and determining whether similar patterns are observed across lakes and/or metrics.

These figures show the results for all of the sampling events for each lake in each year, whether that included multiple within-season samples or only a single annual sample. The points represent the values for individual sampling events. The solid lines represent the annual trend, based on either the single annual sample or the average of all the within-season samples, as appropriate for the lake and year. For the sensitive lakes (the only lakes where intensive, within-season sampling was conducted), the point markers have been made hollow so that it is possible to see if there were multiple within-season samples with similar values.

Sensitive Lakes

- 3-panel figures for each lake (as described in text)

Less Sensitive Lakes

- 3-panel figures for each lake (as described in text)

Control Lakes

- 3-panel figures for each lake (as described in text)

SO_2 EEM Annual Consultation Report

Introduction

- Introduces consultation report
- Purpose of consultation report
- Summary of consultation requirements from chapter 10 of the SO_2 EEM Phase III plan

Consulted Parties

- Table of the consulted parties and scope of consultations according to chapter 10 of the SO_2 EEM Phase III plan.
- Summary of consulted parties added by the Director and the agreed consultation scope.

Consultation documents

- Table listing the consultation documents, date issued and transmittal method.

Consultation Results

KPAC and First Nations Consultation Session

Annual SO_2 EEM Program Report

- Summary of consultation results for the annual SO_2 EEM report.

Work plans

- Summary of consultation results for the work plans for atmospheric pathways, Human Health, Terrestrial Ecosystems and Aquatic Ecosystems

KAG Consultation Session

Annual SO_2 EEM Program Report

- Summary of consultation results for the atmospheric pathways and human health line of evidence sections of the Annual SO_2 EEM Program Report.

Work plans

- Summary of consultation results for the atmospheric pathways work plan and human health work plan.

Other Parties Added by the Director

If not included in the KPAC & First Nations Consultation session, summarize the consultation results according to the scope agreed to with the Director.

Consultation beyond requirements of the SO2 EEM Phase III Plan

- Summary of consultation activities that are beyond the requirements specified in the SO_2 EEM Phase III plan (if any were done for a given reporting year).
- Summary of consultation results from activities that are beyond the requirements specified in the SO_2 EEM Phase III plan (if any were done for a given reporting year).

Finalization of the Annual SO_2 EEM Program Report and Work Plans

Annual SO_2 EEM Program Report Finalization

- Summary of in-scope material comments received related to the Annual SO_2 EEM Program Report during the consultation process and revisions made to the SO_2 EEM annual report to resolve the comments.

Work Plan Finalization

- Summary of in-scope material comments received related to the work plans for the reporting year during the consultation process and revisions made to the work plans to resolve the comments.

Appendix A – Document transmittals and invitations to consultation sessions

- Contains:
  - emails advising consulted parties to download the consultation documents from a publicly facing website.
  - emails with attached consultation documents (if any documents were issued to consulted parties by email.
  - Invitations to the consulted parties to attend the consultation sessions

Appendix B – Presentation materials used for the Consultation sessions

- Contains the presentations used at the consultation sessions.

Appendix C – Consultation Tracking table

- Contains the tracking table that documents the comments received from the consulted parties and responses to comments received.
- Tracking table will contain at a minimum:
  - Consulted party name and organization.
  - Date of comment received from the consulted party.
  - Response to comment received from the consulted party.
  - Follow-up comment from the consulted party (if any received).

Appendix D – Comment Correspondence

- Contains the written correspondence with comments on the consultation documents received from stakeholders and responses to the written comments provided on the tracking table.

B.C. Works' Sulphur Dioxide Environmental Effects Monitoring Program

Phase III Plan for 2019 to 2025

Appendix C: Annual Workplans
Final

Prepared for:

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February 28, 2023

Version Tracking Table

No.	Date	Summary of content /changes
V.1	December 17, 2020	Draft for review by the B.C. Ministry of Environment and Climate Change Strategy (B.C. ENV)
V.2	July 18, 2021	Draft with revisions per B.C. ENV comments, for Rio Tinto review
V.3	July 13, 2022	Draft for Consultation
V.4	September 28, 2022	Revised draft addressing comments
Final	February 28, 2023	Finalization based on "Tracking Table SO_2 EEM Phase III responses (FINAL to B.C. ENV) Feb 7 2023.xlsx"

Please cite this report as follows:

> **ESSA Technologies, J. Laurence, Balanced Ecological Management, Risk Sciences International, Trent University, Trinity Consultants, and Rio Tinto.** 2023. B.C. Works' Sulphur Dioxide Environmental Effects Monitoring Program – Phase III Plan for 2019 to 2025. Appendix C: Annual Workplans, Final. Prepared for Rio Tinto, B.C. Works, 22 pp.

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1 Atmospheric Pathways

Section 2.4 in the SO_2 EEM Phase III Plan provides an overview of work activities for the Atmospheric Pathways line of evidence over the period from 2019 to 2025. The targeted timing of EEM work plan activities to be completed in each year of the period from 2021 to 2025 are shown in Table 1 and Table 2. The specifics of each activity are described in Table 3. Timing of activities may be adjusted depending on circumstances. For detailed methods, see the B.C. Field Sampling Manual, Part B, Air and Air Emission Testing[1] and the National Atmospheric Deposition Program (NADP) site operations field manual[2].

[1] BC Field Sampling Manual, Part B, Air and Air Emission Testing, 2020. https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/bc_field_sampling_manual_part_b.pdf
[2] http://nadp.slh.wisc.edu/lib/manuals/NTN_Operations_Manual_v_2-3.pdf

Table 1. Timing of work plan activities to be completed in 2021 for the Atmospheric Pathways line of evidence.

Topic	#	Activity	Half-month periods in 2021																									
			1-Jan	15-Jan	1-Feb	14-Feb	1-Mar	15-Mar	1-Apr	15-Apr	1-May	15-May	1-Jun	15-Jun	1-Jul	15-Jul	1-Aug	15-Aug	1-Sep	15-Sep	1-Oct	15-Oct	1-Nov	15-Nov	1-Dec	15-Dec
Planning	1.1	Preparation & coordination; update workplan if needed (passive sampling)								R	R	R/A														
Planning	1.2	Field operation planning (passive sampling only)																								
Field Work	2.1a	Continuous SO_2 monitoring and weekly precip. chemistry sampling																								
Field Work	2.1b	Check / install field equipment - Passive samping																								
Field Work	2.2a	Collect field samples and field data																								
Field Work	2.2b	Collect field samples and field data - Passive sampling												Annual to 2023, possibly stopping after 2023												
Lab Work	3.1	Analyze field samples in lab																								
Lab Work	3.2	Archive samples and lab data																								
Data Analysis	4.1	Data QA																								
Data Analysis	4.1	Data compilation *	For prior year's data																				For current year's passive data			
Reporting	4.2	Data analysis and modelling			For prior year's data																					
Reporting	5.1	Prepare draft and final technical report on field program	NA; no separate reports on atmospheric monitoring field programs																							
Reporting	5.2	Prepare draft and final technical memos on atmospheric results																								
Reporting	5.3	Prepare draft and final annual report for previous year				Annual EEM Report																				
Reporting	5.4	KPAC consultation on current year's field program								C																
Reporting	5.5	Reviews of draft report for previous year by Rio Tinto																		R		R				
Reporting	5.6	Reviews of draft report for previous year by ENV																			R		D			
Reporting	5.7	Presentation of previous year's results to KPAC								C											C	C				

Table 2. Timing of work plan activities to be completed in 2022-2025 for the Atmospheric Pathways line of evidence.

Topic	#	Activity	Half-month periods in 2022-2025																							
			1-Jan	15-Jan	1-Feb	14-Feb	1-Mar	15-Mar	1-Apr	15-Apr	1-May	15-May	1-Jun	15-Jun	1-Jul	15-Jul	1-Aug	15-Aug	1-Sep	15-Sep	1-Oct	15-Oct	1-Nov	15-Nov	1-Dec	15-Dec
Planning	1.1	Preparation & coordination; update workplan if needed (passive sampling)								D/R	R	R/A														
Planning	1.2	Field operation planning (passive sampling only)																								
Field Work	2.1a	Continuous SO_2 monitoring and weekly precip. chemistry sampling																								
Field Work	2.1b	Check / install field equipment - Passive samping																								
Field Work	2.2a	Collect field samples and field data																								
Field Work	2.2b	Collect field samples and field data - Passive sampling												Annual to 2023, possibly stopping after 2023												
Lab Work	3.1	Analyze field samples in lab																								
Lab Work	3.2	Archive samples and lab data																								
Data Analysis	4.1	Data QA																								
Data Analysis	4.1	Data compilation *	For prior year's data																				For current year's passive data			
Reporting	4.2	Data analysis and modelling			For prior year's data																					
Reporting	5.1	Prepare draft and final technical report on field program	NA; no separate reports on atmospheric monitoring field programs																							
Reporting	5.2	Prepare draft and final technical memos on atmospheric results																								
Reporting	5.3	Prepare draft and final annual report for previous year				Annual EEM Report																				
Reporting	5.4	KPAC consultation on current year's field program								C																
Reporting	5.5	Reviews of draft report for previous year by Rio Tinto								R																
Reporting	5.6	Reviews of draft report for previous year by ENV								R	R	R	R	R												
Reporting	5.7	Presentation of previous year's results to KPAC								C	C	C									D					

Legend: C = Consultation with KPAC R = Review by Rio Tinto R = Review by ENV D = Delivery of final to ENV A = Acceptance by ENV

* NADP data compilation will be up to the data released by the NADP on March 1st of each year. Data that are released past March 1st but up to May 30th will be considered in the finalization of the annual report and technical memos. Data received past May 30th will be included in the following year's SO_2 EEM reporting cycle.

Table 3. Annual work plan activities for the Atmospheric Pathways line of evidence.

Topic	#	Activity	Activity Description
Planning	1.1	Preparation and coordination	Continuous SO_2 monitoring: In 2022, identify what changes are necessary (if any) from the results of the phase 2 network optimization. (Changes identified in 2022 would take place in 2023-2025). Passive SO_2 sampling: In 2021-2023, prepare for any changes needed to the SO_2 Passive Sampling Program for the year (e.g., minor variations to the passive sampling if needed based on the previous year's deployment and data analysis), and prepare to establish any new passive sampling sites to be added to the Program. If new passive sampling sites are needed, determine where the new sites should be located using the site selection procedure for and finalize the list of sites. In 2023, conduct reconnaissance south of the smelter to identify three sites (Kemano, South of Kitamaat Village and Hartley Bay) for passive monitoring to evaluate the plume path for the sampling season. • Locations will be in areas that can help define the plume path. These sites are referred to as the "plume path network." In general, sites are accessible from May or June through October depending on weather. Starting in 2021 the passive monitoring season will run mid-May/mid-June through mid-October, weather and access allowing. • Duplicate samplers will be co-located with continuous active samplers (Haul Road, Riverlodge, Service Centre, and Lakelse Lake) to understanding the accuracy and precision of the SO_2 data collected. In addition, at least 20% of sites will have duplicate samplers. The one to three other duplicate samplers will rotate among several sites. Update the work plan for the year if changes are required based on the past year's results. ENV to review and approve the updated work plan.
	1.2	Field operations planning	Continuous SO_2 monitoring: In 2021-2022, if siting changes are needed, determine where new sites should be located, and where existing sites should be discontinued if applicable. Passive sampling: Evaluate locations at a finer scale to identify/avoid site selection issues during site installation; re-establish (or re-install) samplers at prior sites and any new sites if needed.
Field Work	2.1	Check / install field equipment	Continuous SO_2 monitoring: Contractor performs routine zero span and multi-point checks of continuous SO_2 analyzers at Haul Road, Riverlodge, Kitamaat Village, Service Centre, Whitesail, Lakelse Lake, and ENV checks the analyzer Terrace-Skeena middle school (operated by ENV). In 2023-2025, add, remove, or move analyzers as needed from the phase 2 network optimization. Passive sampling: Local contractor (and potentially QP) sets up the SO_2 passive sampler shelters in May - June and deploys the first set of samplers for the season (and replaces monthly). Precipitation chemistry sampling: Local contractor checks that the samplers are operating properly.
	2.2	Collect field samples and field data	Continuous SO_2 monitoring: Monitoring occurs year-round. Passive sampling: Deploy passive samplers from approximately mid-May or mid-June to mid-October, with approximately 30 days per exposure to allow for a lower detection limit concentration of 0.1 $\mu g/m^3$ (0.04 ppb). Local contactor collects samples every 30 days, and sends them to the laboratory, for analysis. Precipitation chemistry sampling: In 2021-2025, local contractor collects field samples weekly from the operating rain chemistry stations.
Lab Work	3.1	Analyze field samples in the laboratory	Continuous SO_2 monitoring: Field analyzer data are checked and calibrated by contractor. Passive sampling: Field samples are processed by the laboratory. Precipitation chemistry sampling: Field samples are processed by NADP.
	3.2	Archive laboratory data	Continuous SO_2 monitoring: ENV and contractor archive the data. Passive sampling: Rio Tinto and QPs archive the data. Precipitation chemistry sampling: NADP archives the data.
Data Analysis	4.1	Compile data and do QA	Continuous SO_2 monitoring: Contractor conducts routine QA checks. ENV performs audits and annual data validation. Passive sampling: QA and data validation are done by the laboratory. Precipitation chemistry: QA and data validation are done by NADP.
	4.2	Data analysis and modelling	Continuous SO_2 monitoring: QPs analyze the monitoring data for the year after ENV performs annual data validation. QPs compare CALPUFF predictions of SO_2 (2016-2018 results from the 2019 Comprehensive Review) to continuous SO_2 monitoring data. Passive sampling: QPs analyze the monitoring data for the year and compare general spatial pattern to previous years' pattern. QPs evaluate the need for changes to the network of passive samplers; review field notes and exclude invalidated data; and compare replicates. QPs compare results from co-located continuous and passive samplers, and update calibration equation. S deposition: QPs analyze the wet S deposition and precipitation chemistry data (data from NADP that is available at the time of analysis) and estimate dry deposition (using continuous SO_2 monitoring data) at sampling locations for the year.
Reporting	5.1	Prepare report on field program	No specific field reporting; see activities 5.2 and 5.3.
	5.2	Prepare technical reports and memos on atmospheric program	Continuous SO_2 monitoring: QPs prepare SO_2 optimization report in March 2021. In 2022-2023 if siting changes are needed, report on where new sites should be located, and where existing sites should be discontinued if applicable. Passive sampling: QPs prepare a SO_2 Passive Sampling Program technical memo summarizing passive sampling actions, analyses and results, and specify any changes proposed for the sampling program, following the format of EEM Technical Memo P05 (Trent University 2018). See the Terms of Reference for the SO_2 Passive Sampling Program Technical Memo in Appendix B.
	5.3	Prepare Atmospheric Pathways chapter of annual report	QPs prepare the Atmospheric Pathways chapter of the annual SO_2 EEM Program report, according to the Terms of Reference for the Annual SO_2 EEM Program Report in Appendix B.
	5.4	KPAC meeting	Rio Tinto and QPs consult with the KPAC on the intended plan for the monitoring program in the current year, and revise if required.
	5.5	RT review	Rio Tinto reviews the technical memos and annual SO_2 EEM Program report; Atmospheric Pathways QPs make revisions as required.
	5.6	ENV review	ENV reviews the technical memos and annual SO_2 EEM Program report; Atmospheric Pathways QPs make revisions as required.
	5.7	Present results to KPAC	Results from the previous year's annual SO_2 EEM Program report are presented to the KPAC.

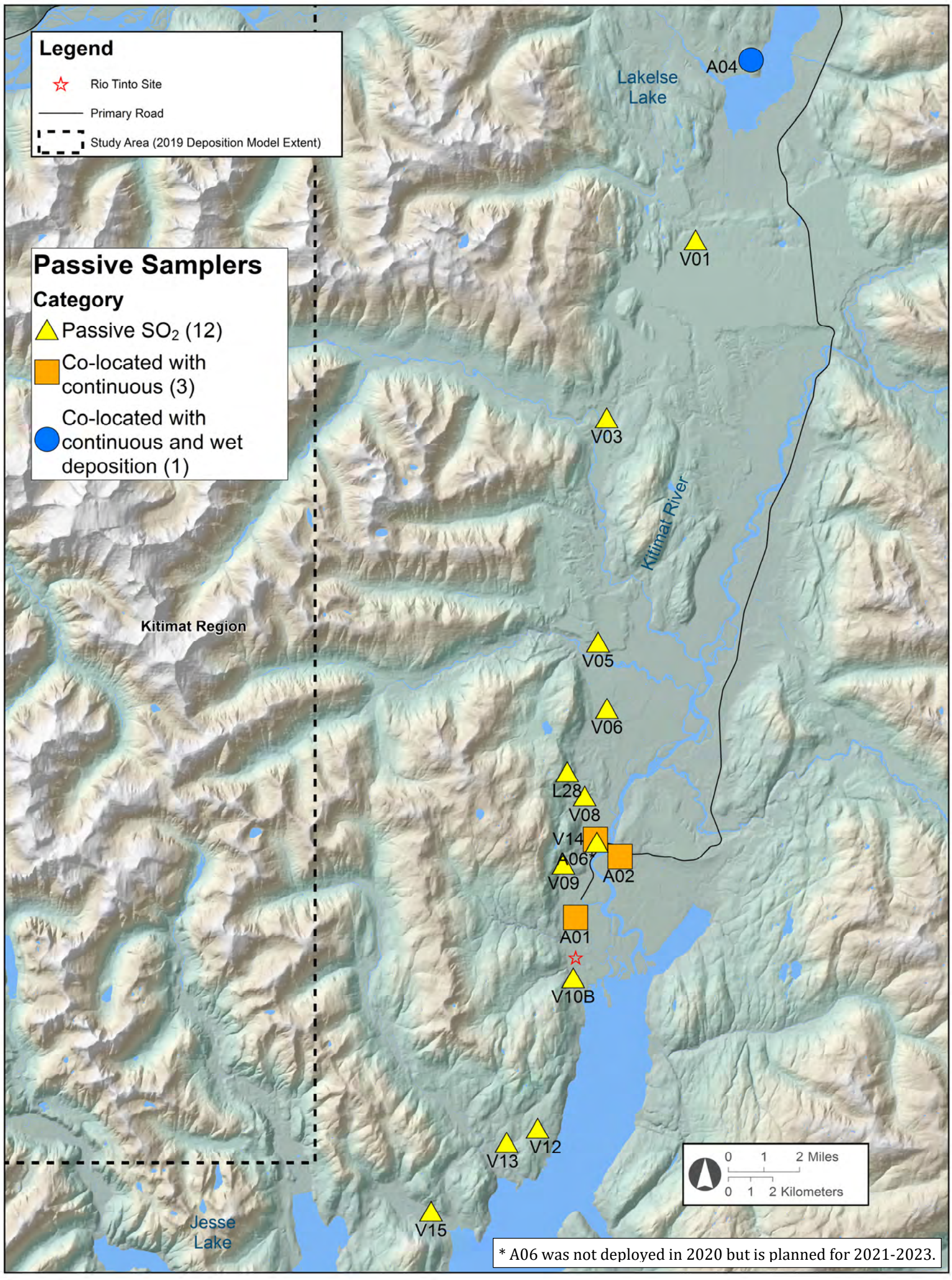


Figure 1. Map showing SO_2 passive sampling locations. Passive monitoring stations may be adjusted each year depending on safe access, learnings from the previous year and questions raised for investigating the plume path.

Table 4. SO_2 passive sampling locations.[a]

ID	Site Name	Reason for Selection [b]	Location Description
A01	Haul Road Station	Continuous site = good siting; co-location with SO2 monitor.	Ambient monitoring station; sampler on roof.
A02	Riverlodge Station	Continuous site = good siting; co-location with SO2 monitor.	Ambient monitoring station; sampler on roof.
A04	Lakelse Lake NADP Station	Continuous site = good siting; farther valley location with year-round access; wet deposition and veg [c] site co-location.	Sampler on roof of NADP wet deposition monitoring station.
A06	Industrial Ave Station	Continuous site = good siting; location of interest.	Future.[d] On roof of continuous monitoring station
V01	Onion Lake Ski Trail North	Far distance but good exposure and good history.	North on Wedeene Road after Onion Lake Ski Trail. Samplers on lone tree in open area.
V03	Mound TKTP92	Good for SO2 plume path; will be moved slightly to improve siting.	Sampler on tree on the right side of road going south. Mound has location marker on top TKTP#92, before km 17 and bridge.
V05	LNG Muster Station	Moderate SO2 levels; OK siting criteria but will be moved to stake to improve siting.	Road opens to LNG muster location, as you enter muster area take road on left opposite gravel / sand hill with ATV tracks and follow to forest edge.
V06	Sand Pit	Good for SO2 plume path; will be moved slightly to improve siting.	Sampler on tree on right side of road going south, before the sand pit with ATV tracks on the right side of road.
V08	Claque Mountain Trail at Powerline	Measured higher SO2, good plume exposure; good candidate for future co-located veg site.[c]	Sampler on powerline post on left side of road going uphill on the Claque mountain trail.
V09	Sand Hill at Powerline	Measured higher SO2; OK siting criteria; may be moved slightly to stake to improve siting.	Sampler on wooden stake on the left side of the road going uphill (at top) across the road from the powerline.
V10B	Rifle Range	Co-located with veg site; [b] OK siting criteria; may be moved slightly to stake to improve siting.	Sampler on wooden stake on gravel mound beside gun club (left of salt / road grit storage units).
V12	Bish Road Pullout 4	Good for SO2 plume path; backup candidate for veg site.[c]	Sampler on tree on the right side of the road going south, across from Pullout 4.
V13	Bish Road at Chevron LNG	Best exposure south of smelter; good candidate for future co-located veg site.[b]	Sampler on wooden stake (on bolder outcrop) on left side of road going south just before Chevron LNG.
V14 /U12	Industrial area Kitimat Hotel	Good for SO_2 plume path and siting	Located on a telegraph pole in the industrial (service) centre across from Kitimat Hotel.
V15	Emsley Creek	Additional southern site in more open location accessible by road	Second clearing after road U turns from heading southeast to heading northwest.
L28 [e]	Lake 28	Higher measured SO_2, good siting, will support defining bounds of plume.	Floating raft in lake.

[a] Passive monitoring stations may be adjusted on an annual basis depending on safe access, learnings from the previous monitoring year and questions being investigated in the current year.

[b] All sites will be evaluated for siting criteria conditions at the time of deployment and will only be included in the program if they meet all siting criteria. This table shows sites as-deployed for 2020. The 2021 plan will use 2020 sites as a starting basis and evaluate siting criteria and need for new sites or changes; 2022 will use 2021 sites as a starting basis; etc.

[c] Passive sampling data at historic vegetation sites initially thought to add value to vegetation program, but data are not actively used for vegetation program. Therefore, V08, V10B, and V13 will continue based on value for defining plume path.

[d] The 2020-2021 passive sampling plan included A06 for a passive sampler co-located at the Industrial Avenue SO2 monitoring station. The location was not established in 2020, but it is planned for 2021-2023.

[e] Lake 28 was deployed in 2020 even though not in the submitted 2020-2021 passive sampling plan. Continued monitoring at the site will consider value in understanding Lake 28 specifically as well as value for defining the plume path.

2 Human Health

Section 3.5 in the Phase III Plan provides an overview of work activities for the Human Health line of evidence over the period from 2019 to 2025. The timing of EEM work plan activities for Human Health to be completed in 2021-2025 are illustrated in Table 5. Activities to be completed each year are shown in Table 6.

Table 5. Timing of annual work plan activities to be completed in 2021-2025 for the Human Health line of evidence.

Topic	#	Activity	Half-month periods in 2021 - 2025																									
			1-Jan	15-Jan	1-Feb	14-Feb	1-Mar	15-Mar	1-Apr	15-Apr	1-May	15-May	1-Jun	15-Jun	1-Jul	15-Jul	1-Aug	15-Aug	1-Sep	15-Sep	1-Oct	15-Oct	1-Nov	15-Nov	1-Dec	15-Dec
Data Analysis	4.2	Calculate the KPI																								
Reporting	5.1	Prepare Health KPI Technical Memo																								
Reporting	5.3	Reviews of draft tech. memo for previous year by Rio Tinto					R							R												
Reporting	5.4	Reviews of draft tech. memo for previous year by ENV						D/R	R	R	R	R	R	R												
Reporting	5.5	Presentation of previous year's Technical Memo to KPAC								C	C	C														

Legend: C = Consultation with KPAC R = Review by Rio Tinto R = Review by ENV D = Delivery of final to ENV A = Acceptance by ENV

Table 6. Annual work plan activities for the Human Health line of evidence.

Topic	#	Activity	Activity Description
Planning	1.1	Preparation and coordination	Please refer to the continuous SO_2 sampling activities for Atmospheric Pathways.
Field Work	2.1	Collect field samples and field data	Please refer to the continuous SO_2 sampling activities for Atmospheric Pathways. Continuous SO_2 sampling locations: Riverlodge, Whitesail, Kitamaat Village and Service Centre (Figure 2).
Lab Work	3.1	NA	NA
Data Analysis	4.1	Compile data and do QA	Please refer to the continuous SO_2 sampling activities for the Atmospheric Pathways line of evidence. Document exceptional events.
	4.2	Analyze the data	Calculate the KPI as described in Section 3.4 of the Phase III Plan. The schedule for calculating the health KPI is dependent on the date when ENV completes the validation of Kitimat's SO_2 air quality data.
Reporting	5.1	Prepare the health KPI technical memo and human health chapter of the annual report	Prepare the Human Health chapter of the annual SO_2 EEM Program report, according to the Terms of Reference for the Annual SO_2 EEM Program Report in Appendix B of the Phase III Plan. Prepare the Annual Human Health KPI Technical Memo according to the Terms of Reference in Appendix B of the Phase III Plan. Completion of the SO_2 Human Health KPI technical memo will be done according to the schedule if the Kitimat SO_2 air quality data are validated by March 31st. Otherwise, the technical memo will be completed using the unvalidated data and a disclaimer will be included in the report identifying the data as being unvalidated.
	5.2	NA	NA
	5.3	Rio Tinto review	Rio Tinto reviews the annual report
	5.4	ENV review	ENV reviews the annual report; Rio Tinto makes revisions as required.
	5.5	Present results to KPAC	Present the results from the previous year's annual SO_2 EEM Program report.

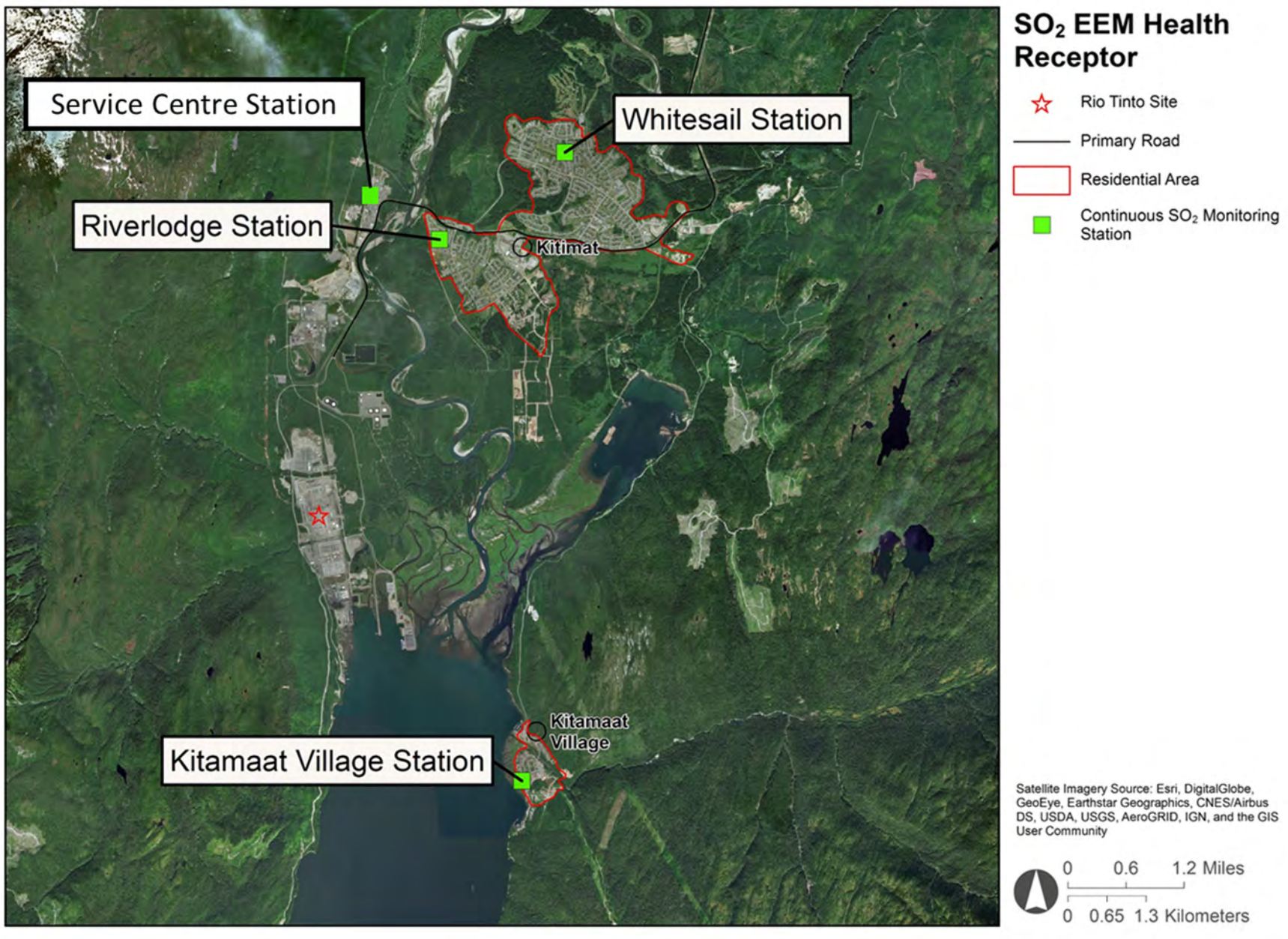


Figure 2. Map showing SO_2 sampling locations used to calculate the Human Health KPI.

3 Terrestrial Ecosystems

Section 5.4 of the Phase III Plan provides an overview of work activities for the Terrestrial Ecosystems line of evidence over the period from 2019 to 2025.

The timing of EEM work plan activities for the Plant Biodiversity Monitoring component to be completed in 2021-2025 are illustrated in Table 7. Activities to be completed each year are shown in Table 8. Table 9 presents the monitoring cycle of cyanolichen and vascular plant monitoring plots.

The target timing of EEM work plan activities for the Soil and Critical Loads Monitoring components to be completed in 2021-2025 are illustrated in Table 10 and Table 11. Activities to be completed each year are shown in Table 12. Timing of activities may be adjusted depending on circumstances.

3.1 Cyanolichen and Vascular Plant Monitoring (Plant Biodiversity Monitoring)

Table 7. Schedule of work plan activities to be completed in 2022-2025 for the plant biodiversity monitoring component of the Terrestrial Ecosystems line of evidence.

			Half-month periods in 2022-2025																							
Topic	**#**	**Activity**	1-Jan	15-Jan	1-Feb	14-Feb	1-Mar	15-Mar	1-Apr	15-Apr	1-May	15-May	1-Jun	15-Jun	1-Jul	15-Jul	1-Aug	15-Aug	1-Sep	15-Sep	1-Oct	15-Oct	1-Nov	15-Nov	1-Dec	15-Dec
Planning	1.1	Initial preparation & coordination; update workplan if needed								R	R	R / A														
Planning	1.2	Field operations							Planning				Coordinating													
Planning	1.3	Coordinate any adjustments to the work plan																								
Planning	1.4	Field crew training																								
Planning	1.5	Pre-field review																								
Field Work	2.1	Check / install field supplies, materials and/or equipment																								
Field Work	2.2	Collect field samples and field data																								
Lab Work	3.1	Analyze field samples																								
Lab Work	3.2	Archival of field samples and lab data																								
Data Analysis	4.1	Data compilation and QA																								
Data Analysis	4.2	Data analysis and modelling	Every 3rd year ---------->																Annual analyses and summaries ---------->						Every 3rd year	
Reporting	5.1	Prepare draft and final technical report on field program	NA; no separate reports on biodiversity monitoring field programs																							
Reporting	5.2	Prepare draft and final technical memo on terrestrial results	End-of-Cycle Report ---------->																				Annual Report ---------->			
Reporting	5.3	Prepare draft and final annual report for previous year				Annual EEM Report																				
Reporting	5.4	KPAC consultation on current year's field program								C																
Reporting	5.5	Reviews of draft report for previous year by Rio Tinto								R																
Reporting	5.6	Reviews of draft report for previous year by ENV								R	R	R	R	R												
Reporting	5.7	Presentation of previous year's results to KPAC								C	C	C								D						

Legend: C = Consultation with KPAC R = Review by Rio Tinto R = Review by ENV D = Delivery of final to ENV A = Acceptance by ENV

Table 8. Annual work plan activities for the plant biodiversity monitoring component of the Terrestrial Ecosystems line of evidence.

Topic	#	Component	Activity Description
Planning	1.1	Initial preparation and coordination	Prepare and coordinate logistics for the annual field monitoring program based on this work plan. Update the work plan if there are any changes required based on the past year's results. Identify risks to the annual project plan and develop strategies to address potential risks. ENV to review and approve the updated work plan.
	1.2	Field operations	**Biodiversity Monitoring** Select and/or confirm field crew. Liaise with Rio Tinto, QPs and field crew throughout the field season, confirming that the work plan is being followed and making any required adjustments due to unexpected events. Identify sites for the current year – 11 total sites to be assessed, plus 3 alternates identified (1 in each deposition type) for a total of 9 alternate sites across all three cycle years. Scope out alternate plot locations during/following the field season to ensure replacement sites are available as needed. Details on plot selection are provided in the Monitoring Plan.
	1.3	Coordinate any work plan adjustments	**Biodiversity Monitoring** Coordinate among field technicians and the QPs regarding any required adjustments to the field programs, and the implications of these adjustments.
	1.4	Training and preparation of field crew	**Biodiversity Monitoring** Train (or retrain) field crews each year, as appropriate, on plant and lichen monitoring methods and soil sampling (soil sampling only occurs during initial plot assessment). Field crews review protocols and procedures in the Field Manual. Conduct planning meeting field crew and Rio Tinto to review: a) site selection, health, safety & environment protocols, and b) decision/communication protocol for field crew selection of alternate site(s). Some (re-)training of field crew will also occur in the field (e.g., lichen identification).
	1.5	Pre-field review	**Biodiversity Monitoring** Update lists of Plants & Ecosystems at Risk (B.C. Conservation Data Centre) and high priority Invasive Plant Species (Invasive Species Council of BC).
Field Work	2.1	Check/install field supplies, materials and/or equipment	**Biodiversity Monitoring** Vegetation: Confirm that all required supplies and materials are available and ready for field visits (as specified in the Field Manual). Confirm GPS, emergency communications and safety equipment is in proper working order. The soil sampling requires bulk density sampling kits or fixed volume sampling kits. There is no additional specialized field equipment for the vegetation sampling. Monument plots on the first sampling visit for long-term monitoring, with permanent stakes placed at plot centre and at each of the four corners. Check/re-establish plot staking in future years.
	2.2	Collect field samples and field data	**Biodiversity Monitoring** Vegetation: Conduct vegetation assessments at 11 plots each year according to the schedule in Table 9. Plot locations are shown in Figure 3. Further details on plot measurements and methods are provided in the Monitoring Plan and Field Manual. Plots will be visited and sampled between June 1 and August 31. Sites are accessed via road (backroad or highway) followed by a walk in. Conduct reconnaissance for plots that need to be established for monitoring in the proceeding years of the 3 year monitoring cycle. *Visual assessment* - When plots are measured to determine biodiversity, a visual inspection and assessment will be conducted to record the condition of vascular plants (including plants in the tree and tall shrub layer), the presence of insects or diseases, or symptoms due to environmental factors (e.g., nutrient deficiencies, SO_2 injury, physical disturbance, drought, flooding, and other abiotic factors). The inspection and assessment will be conducted by a qualified professional (QP) in the plant sciences, as detailed in the Field Manual. Conduct initial internal QA/QC of site data. Physical samples will rarely be taken (e.g., if it is necessary to clarify species identification). Soil chemistry: At the time of first plot measurements, soil samples will be taken to determine soil pH, exchangeable cations, and exchangeable acidity. At each plot, soil samples will be collected outside the plot corners. Samples will be taken at a depth of 0-10 cm. Forest floor material will not be included in the sample. Samples from the four positions will be composited for analysis. Once all samples are collected, ship to laboratory for analysis.
Laboratory Work	3.1	Analyze field samples in laboratory	**Biodiversity Monitoring** Soil chemistry: Following collection, the samples will be analyzed using methods common to the SO_2 EEM (Trent University, 2018) to determine pH, exchangeable cations, and exchangeable acidity. Methods are specified in Field Manual.
	3.2	Archive laboratory and/or field data	**Biodiversity Monitoring** Vegetation: Final field data (and photos) will be archived with Rio Tinto subsequent to the annual processes of compiling, summarizing, and analyzing the data and preparing final reports. Conduct third and final data QA/QC as part of the process of archiving the data. Soil chemistry: The analytical laboratory will record all measurements, note any equipment problems associated with particular analyses, and archive data reports. Once all laboratory and data analyses are complete and finalized, the soil samples are shipped to Rio Tinto for storage in the existing archive of soil samples.
Data Analysis	4.1	Compile data and do QA	**Biodiversity Monitoring** Vegetation: All field observations and field measurements from annual monitoring efforts are entered into a VPro database and Excel spreadsheet. Prepare data summaries and tables. Conduct further QA/QC during process of compiling and summarizing. Soil chemistry: The analytical laboratory will follow standard QA/QC methods and compile the data for analyses.

Topic	#	Component	Activity Description
	4.2	Data analysis and modelling	**Biodiversity Monitoring** Annual Reports. Simple summary statistics (e.g., means and standard deviations of the cover values by deposition class) and simple summary graphics will be developed to present the data for the annual reports. Anomalous data will be identified and, if in error, will be corrected as soon as possible. Beginning in year 4 with the first remeasurements of one-third of the plots, slopes of the trend lines will be calculated. End-of-Cycle Reports. In the first end-of-cycle report (3 years), all of the sites will have a single measurement. Simple analyses of the variability in the observation data across all of the sites and spatial distribution of values relative to levels of deposition will be conducted. At the end of year 6, all plots will have been re-measured, and trends at high and moderate deposition sites will be compared to those at reference sites. The analyses of comparative trends will be repeated every 3 years. We will apply a number of different analytical methods to these data. Apply general linear models in a Before-After-Control-Impact type design to test if S deposition and soil chemistry are significant explanatory variables in explaining differential temporal trends at higher deposition sites (i.e., different from the trends at reference sites), after accounting for common year effects affecting all sites (e.g., due to year to year variation in climate) and other site factors that might influence plant response (e.g., aspect, elevation, available light). Further details on the statistical analyses are provided in the Field Manual.
Reporting	5.1	Prepare report on field program	**Biodiversity Monitoring** Included in 5.2
	5.2	Prepare technical memo on terrestrial program	Prepare a technical memo summarizing terrestrial ecosystem actions, analyses, and results as per the Terms of Reference in Appendix B. **Biodiversity Monitoring** An annual report of activities (5.1) will be submitted by December 31st of the current year except at the end of a 3-year measurement cycle when the annual report will be merged with the End-of-Cycle report. An End-of-Cycle report will be prepared at the end of each 3-year cycle and will be submitted by March 31st of the following year to allow sufficient time to conduct the data analysis and interpret the results. The annual report will describe the methods and results of the field program, as per the terms of reference in Appendix B. The annual summaries of the field program will include implementation (including issues and adjustments, if applicable), data collected, and recommendations for following year's field program. The field program summaries will be integrated into the annual technical reports, as appropriate. The annual reports will also present a summary of each year's field results and recommendations. The first End-of-Cycle report (Year 3) will describe patterns in the observation data across all sites based on the first measurements. From year 4 and onwards, the annual reports will also include the calculated slopes of trend lines for each plot that has had repeat sampling. The results and discussion of the statistical analyses of comparative trends will be included in End-of-Cycle reports starting in year 6. The terms of reference for the annual report are detailed in Appendix B. **Soils Monitoring and Critical Loads Monitoring** *[addressed separately in Table 12]*
	5.3	Prepare chapter for annual report	Prepare the terrestrial chapter of the annual SO_2 EEM Program report, according to the Terms of Reference for the Annual SO_2 EEM Program Report in Appendix B.
	5.4	KPAC meeting	Consult with the KPAC on the intended plan for the field program(s) in the current year, and revise if required.
	5.5	RT review	Rio Tinto reviews the tech memos and annual report; QPs makes revisions as required.
	5.6	ENV review	ENV reviews the tech memos and annual report; QPs makes revisions as required.
	5.7	Present results to KPAC	Present the results from the previous year's annual SO_2 EEM Program report. In 2021, task 5.7 is delayed due to work on finalizing the Phase III Plan.

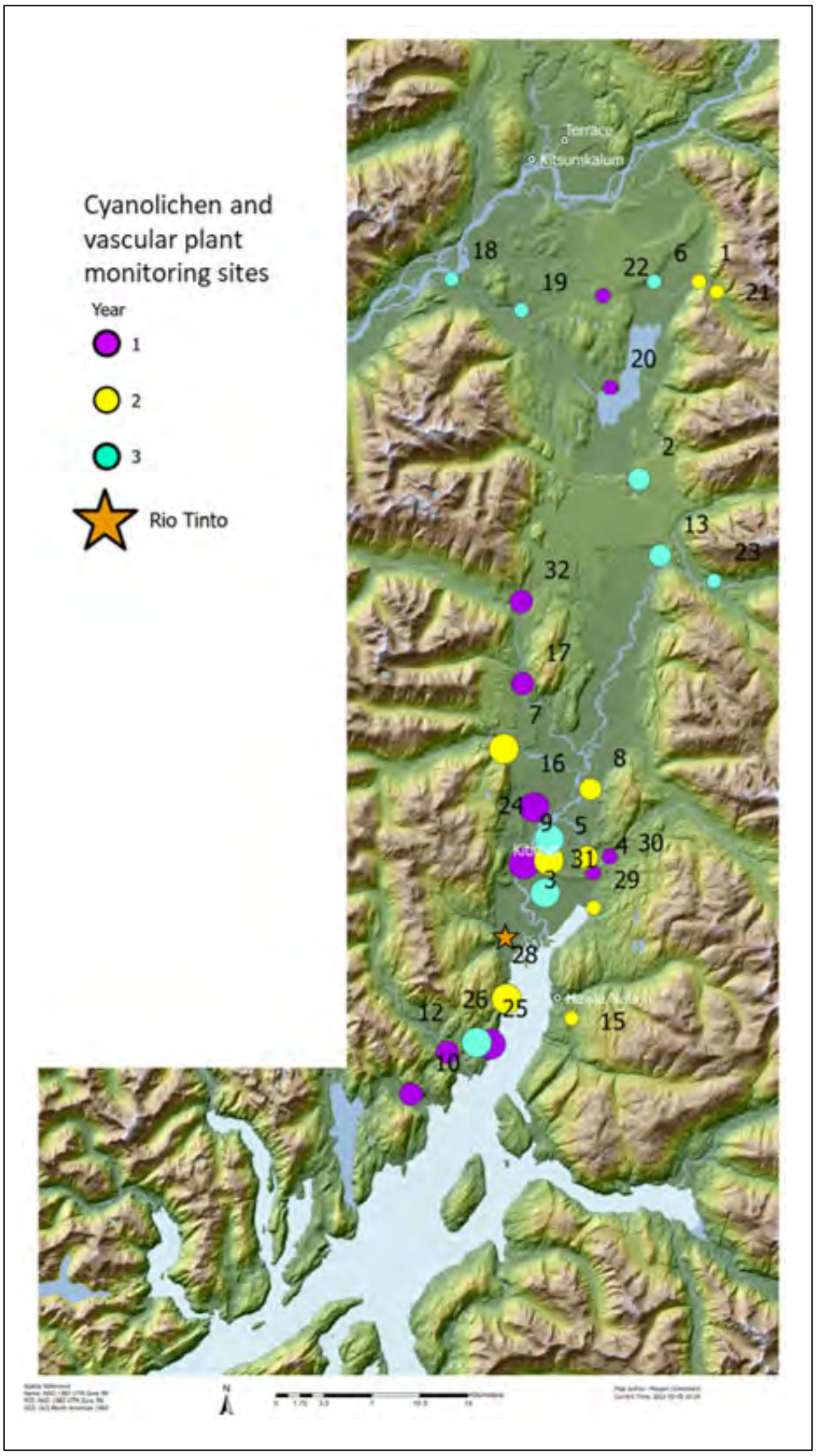


Figure 3. Location of cyanolichen and vascular plant monitoring sites. The plots are colour-coded by cohort (i.e., the year of initial assessment). The size of the dots represents whether the site is located within a high, medium or low deposition zone, as per Table 9.

Table 9. Three year monitoring cycle of cyanolichen and vascular plant monitoring plots

Plot #	Easting	Northing	BEC Subzone and Variant		Deposition Zone	Year
30	527179	5990884	CWH	vm1	L	1
22	526676	6031777	CWH	ws1	L	1
4	525944	5989784	CWH	vm1	L	1
20	527222	6025103	CWH	ws1	L	1
32	520702	6009460	CWH	ws1	M	1
10	512679	5973563	CWH	vm1	M	1
12	515291	5976609	CWH	vm1	M	1
17	520801	6003473	CWH	ws1	M	1
26	518455	5977210	CWH	vm1	H	1
16	521631	5994495	CWH	vm1	H	1
9	520895	5990386	CWH	vm1	H	1
15	524377	5979097	CWH	vm1	L	2
21	535012	6032054	CWH	ws1	L	2
1	533706	6032830	CWH	ws1	L	2
29	525991	5987150	CWH	vm1	L	2
3	525490	5990827	CWH	vm1	M	2
8	525764	5995821	CWH	vm1	M	2
TBD*			CWH			2
TBD*			CWH			2
28	519623	5980517	CWH	vm1	H	2
7	519432	5998784	CWH	vm1	H	2
5	522709	5990667	CWH	vm1	H	2
18	515594	6033009	CWH	ws1	L	3
23	534806	6010948	CWH	ws1	L	3
19	520698	6030688	CWH	ws1	L	3
6	530418	6032820	CWH	ws1	L	3
13	530863	6012801	CWH	ws1	M	3
2	529321	6018428	CWH	ws1	M	3
TBD*			CWH			3
TBD*			CWH			3
31	522437	5988257	CWH	vm1	H	3
25	517436	5977325	CWH	vm1	H	3
24	522742	5992140	CWH	vm1	H	3

*Reconnaissance for the additional four required sites (in years 2 and 3) will be undertaken in 2021.

3.2 Soil and Critical Loads Monitoring Components

Table 10. Timing of work plan activities to be completed in 2021 for the soils and critical loads component of the Terrestrial Ecosystems line of evidence. (C=consultation; R=review; D=delivery of final)

			Half-month periods in 2021																							
Topic	**#**	**Activity**	1-Jan	15-Jan	1-Feb	14-Feb	1-Mar	15-Mar	1-Apr	15-Apr	1-May	15-May	1-Jun	15-Jun	1-Jul	15-Jul	1-Aug	15-Aug	1-Sep	15-Sep	1-Oct	15-Oct	1-Nov	15-Nov	1-Dec	15-Dec
Planning	1.1	Initial preparation & coordination; update workplan if needed																								
Planning	1.2	Field operations																								
Planning	1.3	Coordinate any adjustments to the work plan																								
Planning	1.4	Field crew training																								
Field Work	1.5	Check / install field supplies, materials and/or equipment											Check permanent plots													
Field Work	2.1	Collect field samples and field data											Tag Kemano trees in 2022 or 2023													
Lab Work	2.2	Analyze field samples																								
Lab Work	3.1	Archival of field samples and lab data																								
Data Analysis	3.2	Data compilation and QA																								
Data Analysis	4.1	Data analysis and modelling																								
Reporting	4.2	Prepare draft and final technical report on field program																								
Reporting	5.1	Prepare draft and final technical memo on terrestrial results																								
Reporting	5.2	Prepare draft and final annual report for previous year									2020 Annual EEM Report															
Reporting	5.3	Prepare draft and final annual report for previous year									2020 Annual EEM Report															
Reporting	5.4	KPAC consultation on current year's field program								C																
Reporting	5.5	Reviews of draft report for previous year by Rio Tinto																		R		R				
Reporting	5.6	Reviews of draft report for previous year by ENV																			R		D			
Reporting	5.7	Presentation of previous year's results to KPAC								C											C	C				

Table 11. Schedule of work plan activities to be completed in 2022-2025 for the soils and critical loads component of the Terrestrial Ecosystems line of evidence. (C=consultation; R=review; D=delivery of final)

Planning	1.2	Field operations							Planning				Coordinating													
Planning	1.3	Coordinate any adjustments to the work plan																								
Planning	1.4	Field crew training																								
Field Work	2.1	Check / install field supplies, materials and/or equipment																								
Field Work	2.2	Collect field samples and field data																								
Lab Work	3.1	Analyze field samples																								
Lab Work	3.2	Archival of field samples and lab data																							Occurs after CR --->	
Data Analysis	4.1	Data compilation and QA																								
Data Analysis	4.2	Data analysis and modelling																							During 2026 CR ---->	
Reporting	5.1	Prepare draft and final technical report on field program																				Part of the 2026 Comprehensive Review --->				
Reporting	5.2	Prepare draft and final technical memo on terrestrial results																				Part of the 2026 Comprehensive Review --->				
Reporting	5.3	Prepare draft and final annual report for previous year				Annual EEM Report																				
Reporting	5.4	KPAC consultation on current year's field program								C																
Reporting	5.5	Reviews of draft report for previous year by Rio Tinto								R																
Reporting	5.6	Reviews of draft report for previous year by ENV								R	R	R	R	R												
Reporting	5.7	Presentation of previous year's results to KPAC								C	C	C														

Legend: C = Consultation with KPAC R = Review by Rio Tinto R = Review by ENV D = Delivery of final to ENV A = Acceptance by ENV

Table 12. Annual work plan activities for the soils and critical loads component of the Terrestrial Ecosystems line of evidence.

Topic	#	Component	Activity Description
Planning	1.1	Initial preparation and coordination	**Soils Monitoring** Long-term acidification: In 2023 or 2025, prepare and coordinate logistics for field monitoring program. Unless otherwise specified, all tasks in this work plan associated with the long-term acidification element apply *only to 2025*. **Critical Loads Monitoring** Wetland geochemistry: In 2021, establish project objectives, develop and document approach, and revise this work plan as appropriate for this additional study, as described in Section 5.3.7.1 (i.e., details not in current work plan). Aluminum solubility: In 2021, establish project objectives, develop and document approach, and revise this work plan as appropriate for this additional study, as described in Section 5.3.7.2 (i.e., details not in current work plan).
	1.2	Field operations	**Soils Monitoring** Long-term acidification: Select and/or confirm field crew. Liaise with Rio Tinto, field technicians, analytical laboratories, and QPs, as appropriate, throughout the field season, confirming that the work plan is being followed and making any required adjustments due to unexpected events. Locations within each subplot in each future sampling year are already identified.
	1.3	Coordinate any work plan adjustments	**Soils Monitoring** Long-term acidification: Coordinate between field technicians and the Terrestrial QPs regarding any required adjustments to the field program, and the implications of these adjustments.
	1.4	Field crew training	**Soils Monitoring** Long-term acidification: Field crew and/or students supporting the QPs will be trained on field protocols and soil sampling methodology as appropriate.
Field Work	2.1	Check / install field equipment	**Soils Monitoring** Long-term acidification: Starting in 2021, inspect plot staking (i.e., corner posts and centre stakes) for permanent plots annually, with expectation of requiring some replacements of posts/stakes every couple of years. In 2025 only, confirm that all required supplies and materials are available and ready for field visits, including checking that GPS, emergency communications and safety equipment are in proper working order. Confirm that all field equipment is functioning properly. Approximately 2 days are required per plot to start up work, collect the soil samples and measure the trees.
	2.3	Collect field samples and field data	**Soils Monitoring** Long-term acidification: In 2022 to 2025, tag and remeasure/reidentify trees in the Kemano plot, as done for the plots at Lakelse Lake and Coho Flats. In 2023 or 2025 only, resample the primary permanent soil plots at Coho Flats and Lakelse Lake. Collect 20 soil samples at 3 depths at each plot (120 total soil samples), following established methodology (see Section 5.3.2). Continue monitoring of trees on the plots – record the species/locations of trees and measure DBH (diameter at breast height) for all trees with DBH >10 cm. The plots will be resampled during summer 2025. Plot locations are shown in Figure 4.
Lab Work	3.1	Analyze field samples in laboratory	**Soils Monitoring** Long-term acidification: Conduct laboratory analyses on collected samples to assess organic matter content, exchangeable base cations, exchangeable acidity, and pH.
	3.2	Archive laboratory data	**Soils Monitoring** Long-term acidification: The analytical laboratory will record all measurements, note any equipment problems associated with particular analyses, and archive data reports. Once all laboratory and data analyses are complete and finalized, the soil samples are shipped to Rio Tinto for storage in the existing archive of soil samples.
Data Analysis	4.1	Compile data and do QA	**Soils Monitoring** Long-term acidification (2023 or 2025): All field observations, field measurements and laboratory analyses from annual sampling efforts are entered into a spreadsheet that includes past years' data. The analytical laboratory will follow standard QA/QC methods and compile the data for analyses.
	4.2	Data analysis and modelling	**Soils Monitoring** Long-term acidification: Conduct analyses of the changes in base saturation (see Section 5.3.2) as part of the 2026 Comprehensive Review including changes in base saturation, minimum detectable difference). Further details on the specific methods are provided in the 2019 Comprehensive Review. Calculate basal area increment for the trees measured.
Reporting	5.1	Prepare report on field program	**Soils Monitoring** In any year with field work prior to 2025, a basic summary of the field program – methods, implementation (including issues and adjustments, if applicable), data collected, and recommendations for following year's field program – will be developed and integrated into the annual SO_2 EEM Program report.

Topic	#	Component	Activity Description
	5.2	Prepare technical memo on terrestrial program	Prepare a technical memo summarizing terrestrial ecosystem actions, analyses, and results as per the Terms of Reference in Appendix B. **Biodiversity Monitoring** *[addressed separately in Table 8]* **Soils Monitoring** Long-term acidification: Summary of field and laboratory actions, results of laboratory analyses and data analyses, and discussion of the results will be included in the 2026 Comprehensive Review. **Critical Loads Monitoring** Wetland geochemistry: Summary of field actions, laboratory actions and resultant data in the 2022 and 2023 Annual Reports. Analyses of the data from this study, discussion of the results and recommendations will be included in the 2024 Annual Report. Aluminum solubility: Summary of laboratory actions and resultant data in the SO_2 EEM Program 2022 and 2023 Annual Reports. Analyses of the data from this study, discussion of the results and recommendations will be included in the SO_2 EEM Program 2024 Annual Report.
	5.3	Prepare chapter of annual report	Prepare the terrestrial chapter of the annual report, according to the Terms of Reference for the annual SO_2 EEM Program report in Appendix B.
	5.4	KPAC meeting	Consult with the KPAC on the intended plan for the field program in the current year, and revise if required.
	5.5	RT review	Rio Tinto reviews the technical memos and annual report; Terrestrial QPs makes revisions as required.
	5.6	ENV review	ENV reviews the technical memos and annual report; Terrestrial QPs makes revisions as required.
	5.7	Present results to KPAC	Present the results from the previous year's annual SO_2 EEM Program report. In 2021, task 5.7 is delayed due to work on finalizing the Phase III Plan.

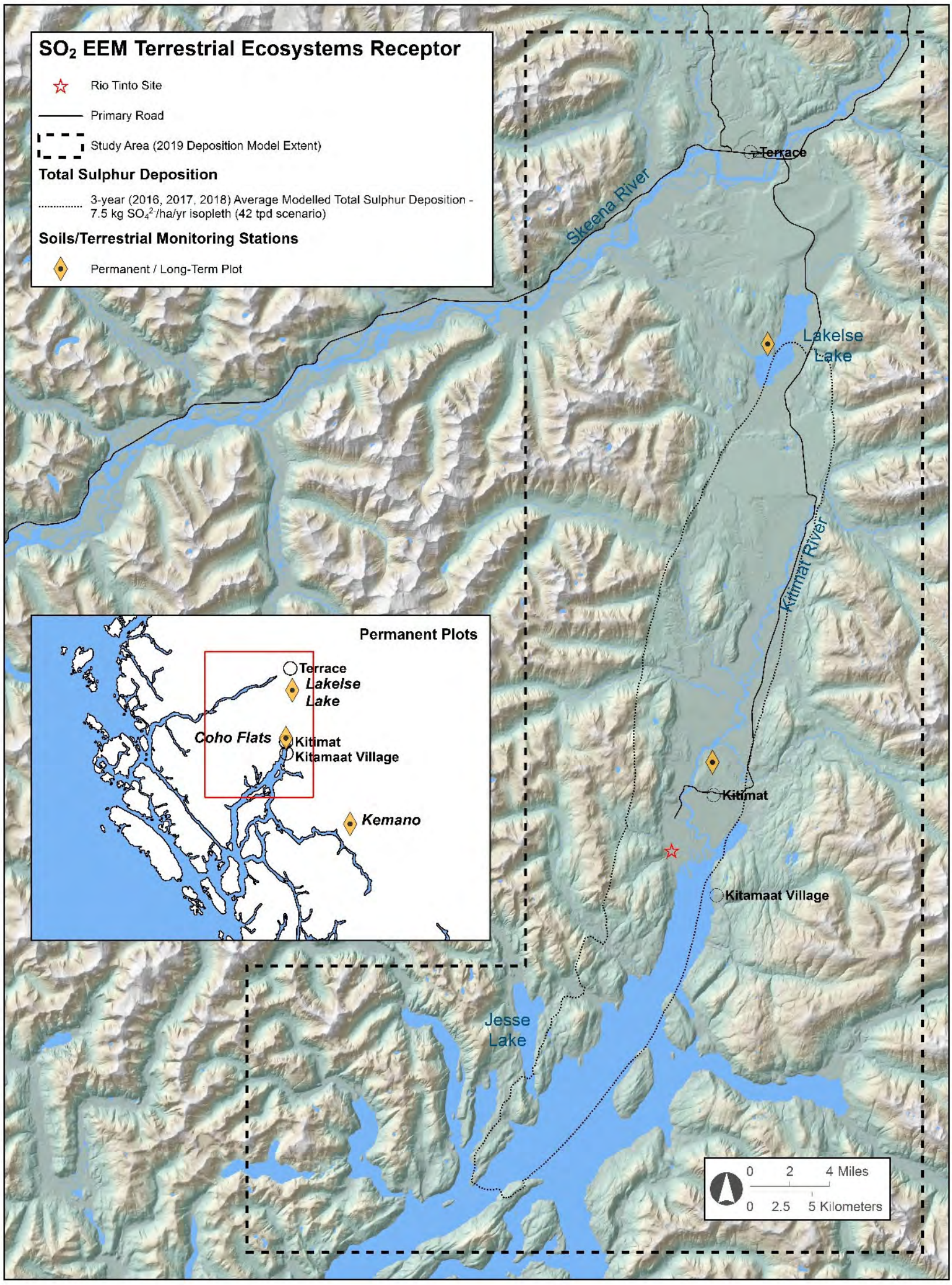


Figure 4. Location of the long-term monitoring plots (n = 3). The three long-term soil plots are at Coho Flats (latitude: 54.07660, longitude: –128.65117), Lakelse Lake (latitude: 54.37827, longitude: –128.57990) and Kemano (latitude: 53.53032, longitude: –127.97384). Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleth.

4 Aquatic Ecosystems

Section 6.4 in the Phase III Plan provides an overview of work activities for the Aquatic Ecosystems line of evidence over the period from 2019 to 2025. The target timing of EEM work plan activities to be completed in 2021 are illustrated in Table 13. The year 2021 includes some special activities which are not required in subsequent years. Activities to be completed over each year of the period from 2022 to 2025 are shown in Table 14. Timing of activities may be adjusted depending on circumstances. The specifics of each activity are described in Table 15. For detailed methods, see Limnotek (2020).

Table 13. Timing of work plan activities to be completed in 2021 for the Aquatic Ecosystems line of evidence. (C=consultation; R=review; D=delivery of final)

Topic	#	Activity	Half-month periods in 2021																							
			1-Jan	15-Jan	1-Feb	14-Feb	1-Mar	15-Mar	1-Apr	15-Apr	1-May	15-May	1-Jun	15-Jun	1-Jul	15-Jul	1-Aug	15-Aug	1-Sep	15-Sep	1-Oct	15-Oct	1-Nov	15-Nov	1-Dec	15-Dec
Planning	1.1	Initial preparation & coordination; update workplan if needed								R	R	R/A														
Planning	1.2	Direct field operations, liaise w Rio Tinto & labs																								
Planning	1.3	Coordinate any adjustments to the work plan per activity 1.2																								
Field Work	2.1	Install, inspect and/or prepare field equipment								LAK006, LAK028									Annual sampling							
Field Work	2.2	Calibrate field equipment										LAK006 & LAK028 in each window May-Aug									All lakes					
Field Work	2.3	Collect field samples and field data										LAK006 & LAK028 in each window May-Aug									All lakes					
Lab Work	3.1	Analyze field samples for water chemistry																								
Lab Work	3.2	Archival of field samples and lab data																								
Data Analysis	4.1	Data compilation and QA																								
Data Analysis	4.2	Data analysis and modelling																								
Reporting	5.1	Prepare draft and final technical report on field program	Technical report on 2020 field pgm																							
Reporting	5.2	Prepare draft and final technical memo on aquatics results									2020 EEM Technical Memos															
Reporting	5.3	Prepare draft and final annual report for previous year									2020 Annual EEM Report															
Reporting	5.4	KPAC consultation on current year's field program								C																
Reporting	5.5	Reviews of draft report for previous year by Rio Tinto																		R		R				
Reporting	5.6	Reviews of draft report for previous year by ENV																			R		D			
Reporting	5.7	Presentation of previous year's results to KPAC								C											C	C				

Table 14. Schedule of work plan activities to be completed in 2022-2025 for the Aquatic Ecosystems line of evidence. (C=consultation; R=review; D=delivery of final)

Topic	#	Activity	Half-month periods in 2022-2025																							
			1-Jan	15-Jan	1-Feb	14-Feb	1-Mar	15-Mar	1-Apr	15-Apr	1-May	15-May	1-Jun	15-Jun	1-Jul	15-Jul	1-Aug	15-Aug	1-Sep	15-Sep	1-Oct	15-Oct	1-Nov	15-Nov	1-Dec	15-Dec
Planning	1.1	Initial preparation & coordination; update workplan if needed							R	R	R/A															
Planning	1.2	Direct field operations, liaise w Rio Tinto & labs																								
Planning	1.3	Coordinate any adjustments to the work plan per activity 1.2																								
Field Work	2.1	Install, inspect and/or prepare field equipment								LAK006, LAK028									Annual sampling							
Field Work	2.2	Calibrate field equipment										LAK006 & LAK028 in each window May-Aug									All lakes					
Field Work	2.3	Collect field samples and field data										LAK006 & LAK028 in each window May-Aug									All lakes					
Lab Work	3.1	Analyze field samples for water chemistry																								
Lab Work	3.2	Archival of field samples and lab data																								
Data Analysis	4.1	Data compilation and QA																								
Data Analysis	4.2	Data analysis and modelling																								
Reporting	5.1	Prepare draft and final technical report on field program	Technical report on last year's field program																							
Reporting	5.2	Prepare draft and final technical memo on aquatics results				EEM Technical Memos																				
Reporting	5.3	Prepare draft and final annual report for previous year				Annual EEM Report																				
Reporting	5.4	KPAC consultation on current year's field program								C																
Reporting	5.5	Reviews of draft report for previous year by Rio Tinto								R																
Reporting	5.6	Reviews of draft report for previous year by ENV								R	R	R	R	R												
Reporting	5.7	Presentation of previous year's results to KPAC								C	C	C									D					

Legend: C = Consultation with KPAC R = Review by Rio Tinto R = Review by ENV D = Delivery of final to ENV A = Acceptance by ENV

Table 15. Annual work plan activities for the Aquatic Ecosystems line of evidence.

Topic	#	Activity	Activity Description
Planning	1.1	Initial preparation and coordination	Prepare and coordinate logistics for the annual field monitoring program based on this work plan. Update the work plan if there are any changes required based on the past year's results. ENV to review and approve the updated work plan.
	1.2	Field operations	Liaise with Rio Tinto, the helicopter company, field technicians in Terrace, and analytical laboratories including Biogeochemical Analytical Services Laboratory (BASL; U. Alberta, Edmonton) throughout the field season, confirming that the work plan is being followed and making any required adjustments due to unexpected events.
	1.3	Coordinate any work plan adjustments	Coordinate between field technicians and the Aquatic QP regarding any required adjustments to the field program, and the implications of these adjustments.
Field Work	2.1	Check / install field equipment	Confirm that all field equipment is working properly, including Onset pH and temperature loggers, water level and barometric pressure loggers (LAK006 and LAK028); WTW pH meter (all lakes); boats, vehicles, GPS, emergency communications and safety equipment. Install intensive monitoring stations in LAK006 and LAK028. Install/maintain temperature mooring in LAK028, which consists of a vertical line with 10 Onset temperature loggers at various depths from the lake surface to the bottom, continuously logging all four seasons. The temperature mooring in LAK028 is left in place year-round and the battery life is checked on each download visit. Two days are taken to start up work at each of LAK006 and LAK028 (one day for equipment set up and one day for first sampling). It has been standard practice to visit the lakes two weeks after the installation date to make sure the loggers are working properly.
	2.2	Calibrate field equipment	LAK006 and LAK028 intensive monitoring: Once monthly visits to calibrate Onset pH meters. Replace Onset pH sensors every month. In October, the pH meters are calibrated approximately weekly, during each sampling visit. The temperature loggers do not require calibration. Annual sampling in October: Calibrate WTW pH meter prior to each sampling day.
	2.3	Collect field samples and field data	LAK006 and LAK028 intensive monitoring: Monitor pH every half-hour and lake water levels according to methods described in section 6.3 of the Phase III Plan. While calibrating Onset pH meter every month, download past data and collect surface water (and bottom water, for LAK028 only) samples for WTW (field), and analytical laboratories (including BASL for Gran ANC). See description in section 6.3 of the Phase III Plan and Limnotek (2020). Field and laboratory pH probes should be kept in the water sample for at least 10 minutes to ensure a stable reading. Conduct CTD casts (i.e., water column sampling) during monthly visits to LAK006 and LAK028. LAK028 temperature profile monitoring: Download temperature data in May, August and October. Annual sampling: Collect samples in October from 7 sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044); 3 control lakes (NC184, NC194, DCAS14A); and 1 less sensitive lake (LAK016) (see map in Figure 5), description in section 6.3 of the Phase III Plan, and sampling methods in Limnotek (2020). Lake access for sampling is as follows: • All 11 lakes will be sampled once annually by helicopter at the end of September or the start of October • Six sensitive lakes (LAK006, LAK012, LAK023, LAK028, LAK042, LAK044) will be sampled 3 additional times / year in October through road access and hiking with an inflatable boat, except for LAK028 (where a boat is permanently stored) Samples should be shipped to the appropriate laboratories on the day after the day of sampling. When possible, the crew needs to avoid sampling late in the week because there is risk of samples being left in a warehouse or truck for an extended period over a weekend or holidays. Conduct photo-documentation of each lake during sampling visits.
Lab Work	3.1	Analyze field samples in laboratory	Laboratory analyses include pH, alkalinity and Gran ANC at BASL and a full scan of other analytes at an appropriate analytical laboratory (i.e., NH_4-N, NO_3-N, TN, TP, TDP, SRP, Cl, F, SO_4, DIC, DOC, specific conductance, TDS, dissolved Al, total Al, inorganic monomeric Al, and an ICP scan for total and dissolved cations). Laboratories also analyze blank, duplicate and spiked samples (see Limnotek 2020). The lab pH measurements will always exceed hold times, which emphasizes the importance of including a section in the aquatic data report on method effects on pH measurement.
	3.2	Archive laboratory data	BASL will archive the data from the Mantech PC automatic titrator to provide ancillary information for confirming ANC thresholds. BASL and/or other analytical laboratories will record all measurements, note any equipment problems associated with particular analyses, and archive data reports. Samples are discarded from the labs one month after analysis.
Data Analysis	4.1	Compile data and do QA	All field observations, field measurements and laboratory analyses from annual sampling efforts are entered into a spreadsheet that includes past years' data. Data from LAK006 and LAK028 (i.e., continuous pH, temperature, lake levels) are entered into separate worksheets. Multiple pH measurements using different equipment are compared (e.g., Limnotek 2020) to assess if there is an instrument effect, and to check the Onset pH sensor for drift. Analyses of blank samples are analyzed to determine if any exceed the detection limit (positive blanks), replicate samples are analyzed to determine laboratory precision, and spiked samples are analyzed to determine laboratory accuracy (Limnotek 2020).
	4.2	Data analysis and modelling	Conduct data analyses and modelling as outlined in section 6.3. Examine empirical changes in water chemistry. Apply Bayesian analysis to determine strength of evidence that changes in primary water chemistry metrics are greater than the thresholds associated with the KPI and informative indicators. Apply the simple evidentiary framework to assess the causal linkage of any observed changes in water chemistry to smelter emissions. Evaluate the differential trends between sensitive lakes and control lakes using the Bayesian BACI methods from the 2019 Comprehensive Review. Further details on the specific methods are provided in the 2019 Comprehensive Review, the SO_2 EEM Program 2021 Annual Report and previous annual SO_2 EEM Program reports.
Reporting	5.1	Prepare report on field program	Describe the methods and results of the field program, following the format of the terms of reference in Appendix B for the components described above.
	5.2	Prepare technical memo on aquatic program	Prepare a technical memo summarizing aquatic ecosystem actions, analyses, and results as per the Terms of Reference in Appendix B. In 2022 (for the 2021 Annual Report), the technical memo will include analyses of ANC metrics, and a re-evaluation of each lake for inclusion in future sampling.
	5.3	Prepare Aquatic Ecosystems chapter of annual report	Prepare the aquatic chapter of the annual SO_2 EEM Program report, according to the Terms of Reference for the Annual SO_2 EEM Program Report in Appendix B.
	5.4	KPAC meeting	Consult with the KPAC on the intended plan for the field program in the current year, and revise if required.
	5.5	RT review	Rio Tinto reviews the technical memos and annual SO_2 EEM Program report; Aquatic QP makes revisions as required.
	5.6	ENV review	ENV reviews the technical memos and annual SO_2 EEM Program report; Aquatic QP makes revisions as required.
	5.7	Present results to KPAC	Present the results from the previous year's annual SO_2 EEM Program report. In 2021, task 5.7 is delayed due to work on finalizing the Phase III Plan.

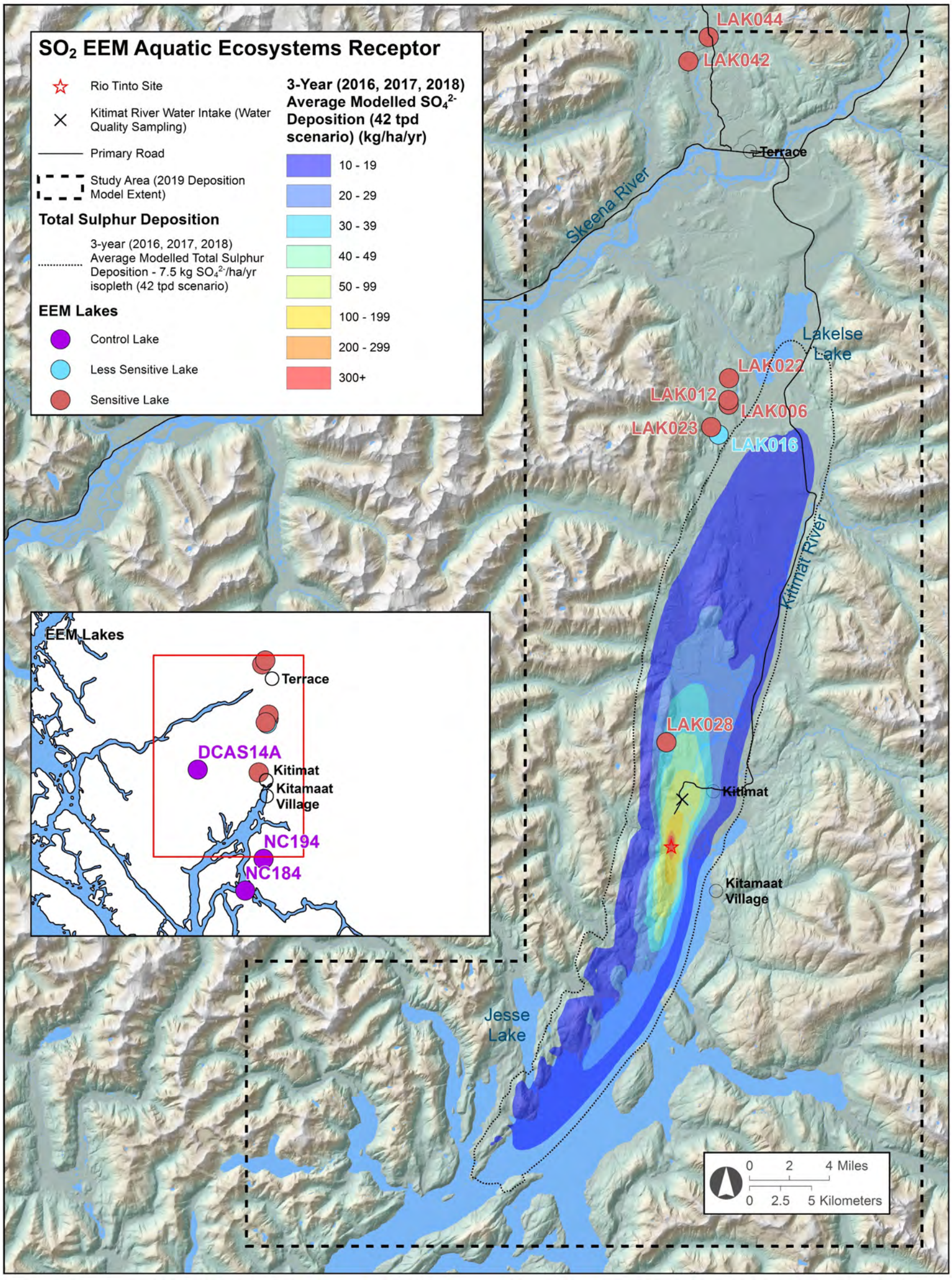


Figure 5. Lakes from which water chemistry samples will be taken (Activity #2.3).

Appendix D. Cyanolichen and Vascular Plant Biodiversity Monitoring Program

This appendix is the complete version of the Amanita Coosemans and John Laurence September 19th, 2022 document, *Field Manual – Vascular Plant Biodiversity and Cyanolichen Monitoring Program – Rio Tinto B.C. Works*.

It is provided on the following pages in its original PDF format.

Table 1. List of selected genera/species for inclusion in occurrence and abundance data collection. Bold lettering indicates those we believe will be most useful.

Genus	Species	Common Name	Ecological site type (M=moist; D=dry; R=rich; P=poor; 0=range across genus, mesic/medium, &/or versatile)	Predicted occurrence in forested plots (Low, Med, High frequency)	Criteria for Inclusion (S=sulphur response; W=high wildlife use Cultural Use: E=edible, MS=medicinal and/or spiritual, T=technology)
Actaea	*rubra*	baneberry	M, R	L	S
Anemone	*multifida*	cut-leaf anemone	0	L	S
Aquilegia	*formosa*	red columbine	M, R	L	S
Athyrium	***filix-femina***	**lady fern**	**M, R**	**M**	**S, E, W**
Campanula	*rotundifloia*	common harebell	0	L	S
Carex		sedge	M	L	S, W
Circaea	*alpina*	enchanter's nightshade	M	M	S
Clintonia	***uniflora***	**queen's cup**	**P**	**H**	**S**
Epilobium	*angustifolium*	fireweed	R	M	E, W
Galium	*triflorum*	sweet-scented bedstraw	M, R	M	S
Geum	*macrophyllum*	large-leaved avens	M, R	L	S
Goodyera	***oblongifolia***	**rattlesnake orchid**	**P**	**H**	**S**
Heracleum	*maximum*	cow parsnip	M, R	L	E, W
Lysichiton	***americanum***	**skunk cabbage**	**M, R**	**M**	**T, W**
Maianthemum	***racemosum***	**false solomon's seal**	**R**	**M**	**S**
Mentha	*arvensis*	field mint	M, R	L	E
Oplopanax	***horridus***	**devil's club**	**M, R**	**M**	**MS, T, W**
Osmorhiza	*chilensis/ purpurea*	sweet-cicely (mountain/purple)	M, R	L	S
Phegopteris	*connectilis*	narrow beech fern	M, R	L	S
Polypodium	*glycyrrhiza*	licorice fern	R (calcium)	L	S, E, M
Pteridium	*aquillinum*	bracken fern	0	L	S, E
Ranunculus		buttercup	0	L	S
Rubus		**raspberries, salmonberry, and thimbleberry**	**0**	**M**	**E, W**
Solidago	*Canadensis*	goldenrod	R	L	S, C (M)
Streptopus	***lanceolatus***	**rosy twistedstalk**	**M, R**	**M**	**S**
Symphyotrichum		aster	D	M	S
Thalictrum	*occidentale*	western meadowrue	M, R	L	S
Urtica	*dioica*	stinging nettle	M, R	L	E, MS, T
Vaccinium		**blueberries and huckleberries**	**P**	**H**	**E, W**
Veratrum	*viride*	Indian hellebore	M, R	L	MS, W
Viburnum	*edule*	highbush cranberry	M, R	M	E, MS, W
Viola		**violet species**	**0**	**M**	**S, E**

Modified Table 1 with Additional cultural species (green type) that could be expected within the plot environment:

Genus	Species	Common Name	Ecological site type (M=moist; D=dry; R=rich; P=poor; 0=range across genus, mesic/medium, &/or versatile)	Predicted occurrence in forested plots (Low, Med, High frequency)	Criteria for Inclusion (S=sulphur response; W=high wildlife use Cultural Use: E=edible, MS=medicinal and/or spiritual, T=technology)
Actaea	*rubra*	baneberry	M, R	L	S
Anemone	*multifida*	cut-leaf anemone	0	L	S
Aquilegia	*formosa*	red columbine	M, R	L	S
Athyrium	***filix-femina***	**lady fern**	**M, R**	**M**	**S, E, W**
Campanula	*rotundifloia*	common harebell	0	L	S
Carex		sedge	M	L	S, W
Circaea	*alpina*	enchanter's nightshade	M	M	S
Clintonia	***uniflora***	**queen's cup**	**P**	**H**	**S**
Epilobium	*angustifolium*	fireweed	R	M	E, W
Galium	*triflorum*	sweet-scented bedstraw	M, R	M	S
Geum	*macrophyllum*	large-leaved avens	M, R	L	S
Goodyera	***oblongifolia***	**rattlesnake orchid**	**P**	**H**	**S**
Heracleum	*maximum*	cow parsnip	M, R	L	E, W
Lysichiton	***americanum***	**skunk cabbage**	**M, R**	**M**	**T, W**
Maianthemum	***racemosum***	**false solomon's seal**	**R**	**M**	**S**
Malus	*fusca*	Pacific crab apple	M, R	L	E, T
Mentha	*arvensis*	field mint	M, R	L	E
Oplopanax	***horridus***	**devil's club**	**M, R**	**M**	**MS, T, W**
Osmorhiza	*chilensis/ purpurea*	sweet-cicely (mountain/purple)	M, R	L	S
Phegopteris	*connectilis*	narrow beech fern	M, R	L	S
Polypodium	*glycyrrhiza*	licorice fern	R (calcium)	L	S, E, M
Pteridium	*aquillinum*	bracken fern	0	L	S, E
Ranunculus		buttercup	0	L	S
Ribes	***bracteosum***	**stink (grey) currant**	**M, R**	**L**	**E, MS**
Rubus		**raspberries, salmonberry, and thimbleberry**	**0**	**M**	**E, W**
Sambucus	*racemosa*	red elderberry	M, R	M	E, MS, T
Solidago	*canadensis*	goldenrod	R	L	S, MS
Streptopus	***lanceolatus***	**rosy twistedstalk**	**M, R**	**M**	**S**
Symphyotrichum		aster	D	M	S
Taxus	*brevifolia*	western yew	0	L	MS, T
Thalictrum	*occidentale*	western meadowrue	M, R	L	S
Urtica	*dioica*	stinging nettle	M, R	L	E, MS, T
Vaccinium		**blueberries and huckleberries**	**P**	**H**	**E, W**
Veratrum	*viride*	Indian hellebore	M, R	L	MS, W

Viburnum	*edule*	highbush cranberry	M, R	M	E, MS, W
Viola		**violet species**	**0**	**M**	**S, E**

Field Manual:
Vascular Plant Biodiversity and Cyanolichen Monitoring Program for Rio Tinto B.C. Works

Prepared by Amanita Coosemans and John Laurence
29 April 2021

Version 2.2, January 25th, 20223

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Document Revision History		
Version	***Date***	***Comments***
Revision	May 26th, 2021	Internal review.
Revision	June 4th, 2021	Adjustments in response to ENV comments.
Version 2.0	July 28th, 2022	Added Document Revision History table and removed references to counts of individual plants within plots.
Version 2.1	September 19th, 2022	Replaced field form Page 1 with updated version that has additional fields for data collection (e.g., additional photos and soil sample depths). Minor formatting and wording improvements throughout document to improve clarity.
Version 2.2	January 25th, 2023	Minor formatting and wording improvements throughout document to improve clarity and correctness. Corrected use of "plot" vs. "site" throughout document (plot refers to a specific assessment of a site). Cyanolichen abundance category descriptions (p. 13 in Field Methods section, and on field form Page 4: Plot Cyanolichen Data, p.27, in Appendix A) reworded to improve clarity and to align directly with descriptions in SO_2 EEM document. Soil and Atmospheric Chemistry (Field Methods) section was modified to remove the sample analysis techniques. Use of the word "equivalent" was introduced to allow different analytical techniques to achieve the same goal as techniques used by Trent University (2018) for the soil analysis for the SO_2 EEM Program.

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Attachment 1_Example sample size_power analysis from Vaccinium cover.pdf

Introduction

The Vascular Plant and Cyanolichen Monitoring Program (PCMP / the Program) is designed to detect potential changes in the biodiversity (species richness and abundance) of vascular plants in the low shrub and forb layers and of cyanolichens in forest ecosystems of the Kitimat Valley and Lakelse Watersheds. The Program focuses on detecting mid-to-long-term effects on plants and cyanolichens due to acidification of soils or lichen substrates due to emissions of SO_2 from the Rio Tinto BC Works (RTBC) south of Kitimat. The details of the Program are found in Laurence *et al.* (2020).

This field manual establishes the methods and protocols that will be used in the PCMP.

Pre-Field Planning Activities and Methods

Annual Pre-Field Planning Meeting

Once the field crew is selected each year, a pre-field planning meeting will be undertaken with the crew and Rio Tinto program staff. During the annual pre-field meeting, expectations will be set with respect to all aspects of the field Program, at minimum including the following:

- health and safety briefing, planning, and documentation;
- review of previous season's Program results, issues encountered, lessons, etc.;
- confirmation of site selection for the season, including an updated plan for potentially inaccessible sites, addition of replacement sites, or other issues that may affect plot assessment during the field Program;
- identification of forms, documents, and materials required;
- scheduling (training, field session, etc.).

Training

Prior to commencing fieldwork, field team members must be trained and knowledgeable in the health, safety and environmental stewardship expectations; the field methods identified in this manual; and in vascular plant & cyanolichen identification. Training will include a mix of independent learning and group sessions and will encompass both office- and field- based learning.

A reference collection of cyanolichens has been provided by Patrick Williston of the British Columbia Ministry of Environment and Climate Change Strategy (BC ENV) and will be maintained and further developed as needed during the Program. No reference collection is currently planned for vascular plants, as their identification is not expected to be problematic and many resources are available for the species anticipated to occur at the sites.

Review of relevant updated information sources

Plants and Ecosystems at Risk

Prior to undertaking field sessions each year, the BC Conservation Data Centre (CDC) must be consulted to determine what plants and ecosystems are identified as "at risk," including provincially identified species or ecosystems, and federally identified species (through COSEWIC and/or SARA Schedule 1). Currently, the BC CDC offers the BC Species & Ecosystems Explorer to facilitate the search (available at https://a100.gov.bc.ca/pub/eswp/). Search criteria must include the following:

- BC List (Red: Extirpated, Endangered or Threatened; and Blue: Special Concern);
- COSEWIC Status (Endangered; Threatened; and Special Concern);
- Legal Designation (Federal Species at Risk Act (SARA); Provincial Forest and Range Practices Act (FRPA) – Previously Identified Wildlife; Provincial Wildlife Act; and Land Use Objectives (LUO)).

In addition, an Area (e.g., ecoregions) or Biogeoclimatic Unit (e.g., CWH zone) and/or Habitat Type (e.g., Forest—*for species only, not ecosystems) may be selected in order to reduce and refine the list. These spatial options should be selected with caution, recognizing that not all species information is spatially complete; results should be cross-checked with a non- area-based search of the CDC database prior to finalizing the list of potential plants and ecosystems at risk in the study area.

Invasive Plants

Prior to undertaking field sessions each year, the BC Invasive Species Council (ISC) should be consulted for a list of high priority species. Ideally, field crews will have the Report Invasives BC application downloaded and updated on their devices and can use it both to look up suspected weed species and report them to the ISC—particularly if any high priority species are observed.

Biogeoclimatic Ecosystem Classification (BEC)

Although unlikely to change from year to year, the Province updates BEC from time to time; site classification should be reviewed whenever a BEC update is released.

Field Methods

Health, Safety & Environmental Stewardship

Field teams must ensure they approach fieldwork in line with RTBC safety and environmental standards and following best practices for environmental stewardship.

Health and Safety Protocols

Health and Safety are paramount to the Program. All field activities will conform to RTBC standards using their risk assessment and mitigation methodology. Safety plans will be developed annually in collaboration with the RTBC project manager and reviewed during the Annual Pre-Field Planning Meeting. The plans will be reviewed and approved by RTBC before field activities commence for the year.

Environmental Stewardship Protocols

Invasive species management

Sites are located in rare and sensitive forest environments and are sometimes located adjacent to highly sensitive wetland or riparian ecosystems: The introduction of invasive species is a particular concern for this project.

Ideally, fieldwork will be undertaken prior to seed set for most weed species present in the study area (generally beginning in August and peaking in early September). Prior to starting the journey to any site, ensure that clothing, boots and vehicle are free of excess dirt, and that no seeds are present. If necessary, wash the vehicle, including the undercarriage and tires. When arriving at a site, avoid parking in weed-infested areas—particularly if weeds are setting seed. Avoid walking through weedy areas, and check clothing and footwear prior to entering uninfested areas—particularly older forests and wetlands—removing and securing any seeds found to ensure they do not spread to new areas. If the risk of introducing weed seeds is high, communicate this information to the project manager. Substitute the site with another and ensure future timing of fieldwork at the site will avoid the seeding period.

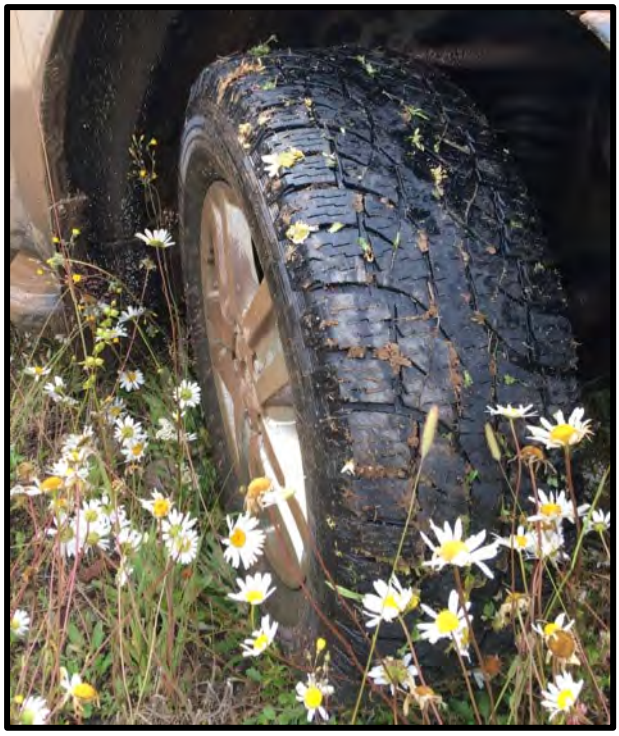


Photo 1: Tire showing potential transport of weed seeds (oxeye daisy and hawkweed) from infested area.

Avoiding Damage to Sensitive Areas, Wildlife, or Wildlife Habitat

In addition to managing the spread of invasive weeds, crews must be aware of other potential for disrupting habitat or wildlife.

All waterways, riparian areas and wetlands are sensitive areas, and field crews must conduct themselves in a manner that will not cause damage. For instance, it is not acceptable to drive through or park in sensitive areas, including small streams or seasonally wet meadows.

Most direct, human-caused wildlife mortality is associated with roads. Crews will drive at an appropriate speed to avoid collisions with wildlife and will avoid driving at dawn and dusk—when wildlife activity peaks and visibility is poor. If a wildlife migration is in progress across an access route (e.g., migration of juvenile western toads), the site(s) should not be visited unless or until access can be attained without harm to wildlife.

Human-wildlife conflicts represent another major—largely preventable—source of mortality for wildlife. Crews will follow established RTBC protocols to protect themselves and wildlife from dangerous encounters, including keeping food and waste secure (in trucks), and carrying bear spray.

Site Establishment

A total of 33 sites will be assessed in a three-year rotating panel, with approximately 11 plots measured in each given year. Sites have been classified into one of three deposition zone classes—Low, Medium, and High—based on the CALPUFF-modelled 42 TPD emissions scenario. (See Table 1).

In the fall of 2020, the 32 cyanolichen sites originally established by Patrick Williston (ENV; Williston and Perkins 2019) were assessed for potential use in this Program. At that time, a total of 29 sites at or near the original ENV locations were considered feasible (ENV-designated site numbers have been retained and are identified with these numbers in Table 1): All but one of these sites was marked at that time with temporary wire flags at the corners and flagging around a center tree (one site was not physically marked as it was located in Haisla territory). Site locations and any previously gathered data for these sites will be provided during the initial pre-field planning meeting, and will be updated during subsequent annual meetings.

Sites will be established as 20m x 20m, and (wherever practical) will be oriented along the cardinal directions.

Table 1: Schedule for Site Establishment (with location and deposition zone, where known)[1].

Plot #	Easting	Northing	BEC Subzone and Variant		Deposition Zone	Sulphur Deposition at Nearest Receptor (42 TPD scenario; kg SO4/ha/yr)	Year
30	527179	5990884	CWH	vm1	L	4.6	1
22	526676	6031777	CWH	ws1	L	4.6	1
4	525944	5989784	CWH	vm1	L	6.0	1
20	527222	6025103	CWH	ws1	L	7.0	1
32	520702	6009460	CWH	ws1	M	8.3	1
10	512679	5973563	CWH	vm1	M	8.6	1
12	515291	5976609	CWH	vm1	M	13.2	1
17	520801	6003473	CWH	ws1	M	17.0	1
26	518455	5977210	CWH	vm1	H	34.8	1
16	521631	5994495	CWH	vm1	H	39.0	1
9	520895	5990386	CWH	vm1	H	53.2	1
15	524377	5979097	CWH	vm1	L	3.4	2
21	535012	6032054	CWH	ws1	L	4.2	2
1	533706	6032830	CWH	ws1	L	4.6	2
29	525991	5987150	CWH	vm1	L	5.0	2
3	525490	5990827	CWH	vm1	M	7.7	2
8	525764	5995821	CWH	vm1	M	11.8	2
28	519623	5980517	CWH	vm1	H	55.6	2
7	519432	5998784	CWH	vm1	H	20.8	2
5	522709	5990667	CWH	vm1	H	34.4	2
TBD*			CWH				2
TBD*			CWH				2
18	515594	6033009	CWH	ws1	L	1.9	3
23	534806	6010948	CWH	ws1	L	2.2	3
19	520698	6030688	CWH	ws1	L	2.6	3
6	530418	6032820	CWH	ws1	L	5.4	3
13	530863	6012801	CWH	ws1	M	8.7	3
2	529321	6018428	CWH	ws1	M	10.1	3
31	522437	5988257	CWH	vm1	H	31.3	3
25	517436	5977325	CWH	vm1	H	27.2	3
24	522742	5992140	CWH	vm1	H	33.2	3
TBD*			CWH				3
TBD*			CWH				3

[1] This table has not been updated; refer to annual reports for updated site establishment.
*Reconnaissance for additional required sites TBD.

Permanent Plot [Re-]Monumenting

Sites will be permanently monumented to enable long-term re-measurements (see Figure 1). Metal rods will be used to mark the four corners, as well as plot centre; additional wooden stakes may be used to mark the midpoints of plot boundaries, and may also be added to the corners to increase visibility. Stakes will be marked with the site's unique identifier. Metal rods will have safety caps installed to reduce risk of injury, and caps will be labelled with the site's unique identifier and corner/center location. In most cases, rods and stakes will be flagged for visibility,

and the most central tree in each site will also be flagged and marked with the site identifier; however, flagging may not be used in locations where there are concerns around visual sensitivity. Monuments will be repaired or replaced as needed on an ongoing basis during the course of the PCMP study.

Temporary plot demarcations

When arriving at the site, the field team will locate plot center and the four corners of the plot (located ~14.1m northeast, southeast, southwest and northwest of center; Figure 1; note that idealized plot distances assume a planar surface, thus actual ground distances will vary somewhat). The team may hang temporary flagging at intervals along the outer plot boundary to provide a visual indication of plot edges. Further demarcation (e.g., marking the four quadrants of the plot) could be flagged with a different colour, and would assist in visual cover estimates of vegetation in more complex or diverse plots.

The crew may find it efficient to also place the measuring tape for the linear transects along the north and east plot boundaries at this time.

Prior to leaving the site, all temporary flagging/demarcations will be removed.

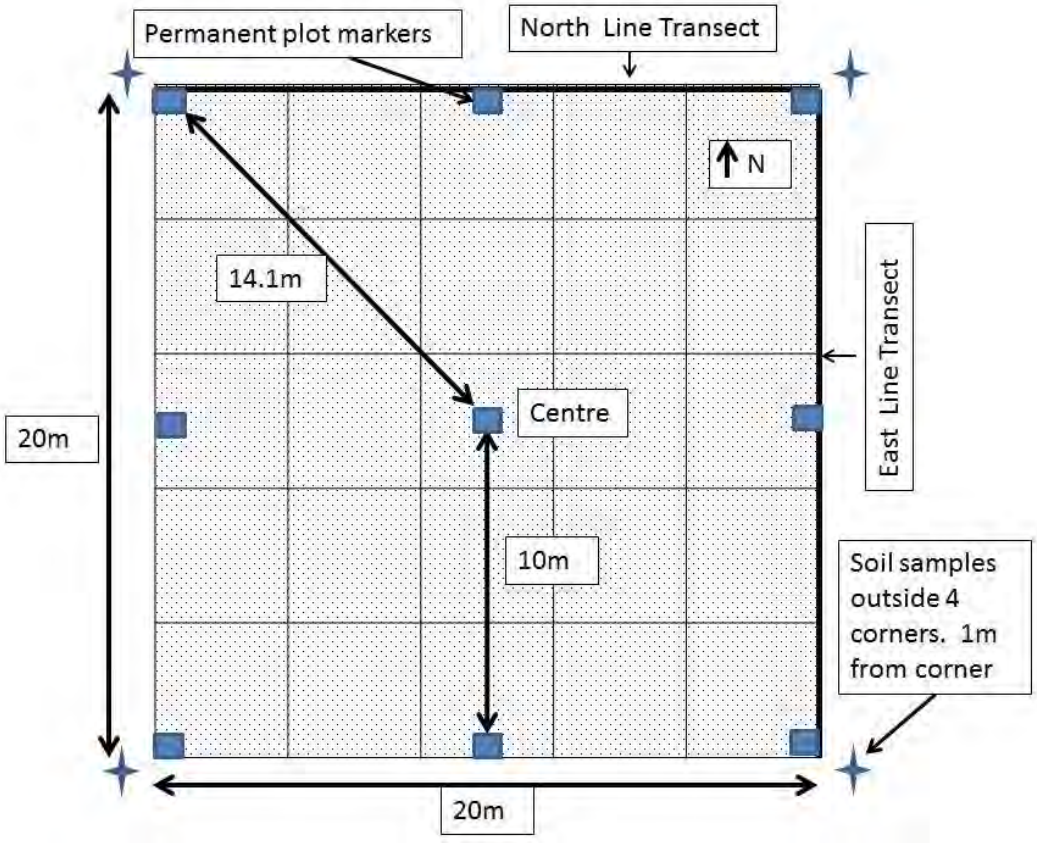


Figure 1: Plot design and orientation.

Plot Site Data

Basic ecological site data will be collected at each plot location during the initial assessment, and will reviewed, amended and updated (as needed) during subsequent visits. The ecological site data will provide essential information to understand—and allow comparisons between—plots.

A sample *Plot Site Data* form (a slightly modified version of the Province of BC's 2010 FS1333 form) is presented in Appendix A. The field crew will complete (or verify) all fields on the Plot Site Data form as per detailed direction in *Appendix B: Detailed Field Guide* (which in turn is based largely and directly on the methodology provided by the Province of BC in their guidance document, *Field Manual for Describing Terrestrial Ecosystems—2nd Edition* (2010)).

Vascular Plant Biodiversity

Vascular plant biodiversity will be assessed through measures of species richness and abundance described below.

All relevant data forms are presented in Appendix A, including the *Plot Site Data* form (which includes fields for the total percent cover of each vegetation layer), *Plot Vegetation Data* form, and *Line Transect Vegetation Data* form.

Species Richness

Species Richness refers to the number of distinct species present in a given area. Alone or in combination with a measure of species abundance, richness provides a measure of species diversity.

Low Shrub and Herb Layers

Crews will methodically search the plot for all vascular species assigned to the low shrub (B2) and herb (C) layers, recording each on the Plot Vegetation Data form, thus providing the metrics for each plot's Species Richness for those vegetation layers.

Additional Species of Importance

Regardless of the vegetation layer in which they occur, certain additional groups of species will be recorded if they occur in the plots, namely species listed by the BC CDC as "at risk," species known to be of cultural significance, and species classified by the BC ISC as "priority" weeds.

Naming/species coding

Species will be coded according to BC's most current version of the *BC Flora Checklist* (a 7-8 character code for all vegetation layers) and the *BC Tree Code List* (a 2-3 letter code for tree species) available through the Ministry of Forests and Range's Biogeoclimatic Ecosystem Classification Program website (last accessed

March 2021). As of the initial writing of this document, the most current version is Version 10 (2016).

Species Abundance

In combination with species richness, abundance data provide measures of plant and structural diversity. For the vegetation portion of the PCMP, abundance is measured primarily as percent cover.

Percent Cover

For the species described in Species Richness, above (*low shrubs*, *herbs* and *additional species of importance*), percent cover will be estimated during each plot assessment using two methods outlined below:

1. *Throughout plot*—Visual estimates of percent cover by species will be provided for the full 400m^2 area of each plot, using the methodology described in detail in Appendix A (based on Province of BC 2010).
2. *Linear (line) transect*—Using a measuring tape and plumb bob (as needed), crews will record precise (up to +/- 1 cm) measurements of the species that intersect the north and east boundary lines of each plot. These measures can then be used for an alternate percent cover measure of abundance at the plots, with the advantage of being directly [re]measurable and comparable between assessments.

Distribution, vigour and phenology coding

To better understand vegetation structure and potential change over time, distribution, vigour and phenology codes will be recorded for each species that is accounted for in vegetation richness and abundance data collection. Use of these codes is described in Appendix B and is based directly on Province of BC (2010).

Cyanolichen Biodiversity

Species Richness

Species Richness refers to the number of distinct species present in a given area. Alone or in combination with a measure of species abundance, richness provides a measure of species diversity. This lichen monitoring portion of the PCMP focuses on cyanolichens that use conifer trees as hosts, and species richness data will be collected only for this group of lichens. To ensure repeatable, comparable results, a one-hour timed search will be used. If present, dead (but not downed) tree hosts will be included in the search.

Host species group

For cyanolichens—species that often have specific host substrates—species richness is, in part, a function of host diversity. When collecting species richness data for cyanolichens, host species will be recorded.

Relative Abundance

In combination with species richness, abundance data provide measures of cyanolichen diversity. For the cyanolichen portion of the PCMP, relative abundance is recorded, according to the following categories for arboreal lichen loading (adapted from Province of BC 2010 in consultation with Patrick Williston, BC ENV):

0 None
1 Rare: 1 or 2 colonies per plot
2 Occasional: 3-5 colonies per plot
3 Common: 6 colonies to 20% cover of host tree(s) within plot
4 Very Common: 21-51% cover of host tree(s) within plot
5 Abundant: >51% cover of host tree(s) within plot

Visual Inspection and Assessment

Vascular Plants

When plots are measured to determine biodiversity, a visual inspection and assessment will be conducted to record the general condition of vascular plants (including any notable conditions for plants in the tree, tall shrub, moss/seedling and epiphyte layers), the presence of insects or diseases, or symptoms due to environmental factors (e.g., nutrient deficiencies, physical disturbance, drought, flooding, and other abiotic factors). The inspection and assessment will be conducted by a qualified professional (QP) in the plant sciences (e.g., plant ecologist, plant pathologist, forester, etc.).

General Site Conditions—At each plot an assessment of general conditions will be made. This assessment includes the general appearance of the site (e.g., green, healthy vegetation; droughty conditions; insect infestation; dusty; industrial activity such as logging, transmission line maintenance, construction, etc.). The prescribed photos taken at each site will support the description, and additional site photos will be taken if needed to better describe general site conditions with respect to the Visual Inspection and Assessment.

Survey of Signs and Symptoms—A survey of vegetation in the sampling plot is made. This survey notes the presence of symptoms or signs of pests, pathogens, and other stressors on any vegetation at the site. Symptoms are noted on the field data sheets (Appendix A). If symptoms are present, the affected area of individual leaves and the percentage of the plant that is affected are visually estimated for calculation of an injury or disease index (Laurence 2010). Standardized diagrams of affected leaf area (e.g., Duarte *et al*. 2013) are helpful for training the observer.

It is important to pay particular attention to species that are common to a large number of sites (e.g., western hemlock, western redcedar, Sitka spruce, elderberry, red-osier dogwood, balsam poplar, thimble berry, salmon berry, and others) as

widely distributed species will help determine the spatial pattern of any potential insect outbreak or disease epidemic.

Digital Images—Digital images are used to document the general conditions and any signs or symptoms of stressors such as insects, pathogens, air pollutants, physical injury, or other environmental stressors. Digital images should be geo-referenced, and date/time stamped to assure accurate site location information.

A digital image archive is maintained along with the report of the inspection by RTBC (see Data Archiving section, below).

Cyanolichens

At the time of plot measurement, observations will be made to document the health and condition of cyanolichens. Cyanolichens are affected directly by both wet and dry deposition. Symptoms to note include a general "off-color," bleaching of tissues, and reduced growth, and will be recorded on the field data sheets (Appendix A).

Soil and Atmospheric Chemistry

At the time of site establishment, soil samples will be taken and analyzed to help determine the potential acid sensitivity. Methods will be equivalent to those used in the SO_2 Environmental Effects Monitoring program (SO_2 EEM). The purpose of this sampling is to assess the sensitivity of the soils to acidification, not to measure and detect differential changes in soil chemistry over time.

Soil Chemistry

At each site, soil samples will be collected outside (minimum 1m from) the four plot corners. Mineral soil samples will be taken at a depth of 0-10 cm and 10-20 cm, where practical. Forest floor/organic material will not be included in the sample and will be removed prior to sampling. Samples from the four positions will be composited for analysis.

Following collection, the samples will be laboratory analyzed to determine pH, exchangeable cations, and exchangeable acidity.

Ion Exchange Resin Columns

Throughfall ion exchange resin columns may be used above ground at selected locations to quantify actual sulphur (S) deposition depending on the risk of soil acidification. These measurements will help characterize that risk. Although not currently scheduled, ion exchange resin columns will be planted vertically in the soil to measure SO_4^{2-}, base cations, and aluminum, *if necessary* to establish causality. Methods for ion exchange resin columns and their analysis will be those described by Blanchard (2019). Similarly, if needed to establish causality, Plant Root Simulator probes (PRS probes) may be installed to determine soil water concentrations of base

cations and Al^{3+}. If they are installed, the methodology of Watmough *et al*. (2013) will be used.

Data Management and Analysis

Data Collection

Emissions and Air Monitoring Data

Emissions, metal production, and air monitoring data will be provided by RTBC for use in data analysis. These data will be the same as those provided for the annual and summary SO_2 EEM Program reports.

Data Archiving

All data collected, analyses performed, images collected, and reports in the PCMP will be archived by RTBC and, where appropriate, made available on the RTBC internet.

Data Analysis

Monitoring Design.

The monitoring design is a type of rotating panel-design where sites are measured on a rotating schedule repeatedly over time. By measuring the same site repeatedly over time, other confounding factors (e.g., aspect) remain constant over time, which should reduce the amount of extraneous variation seen in the response.

An example of a rotating panel design is seen in Figure 2, showing a set of sites measured in a three-year rotation. For the purpose of this example, sites are classified into *high* and *reference* deposition classes.

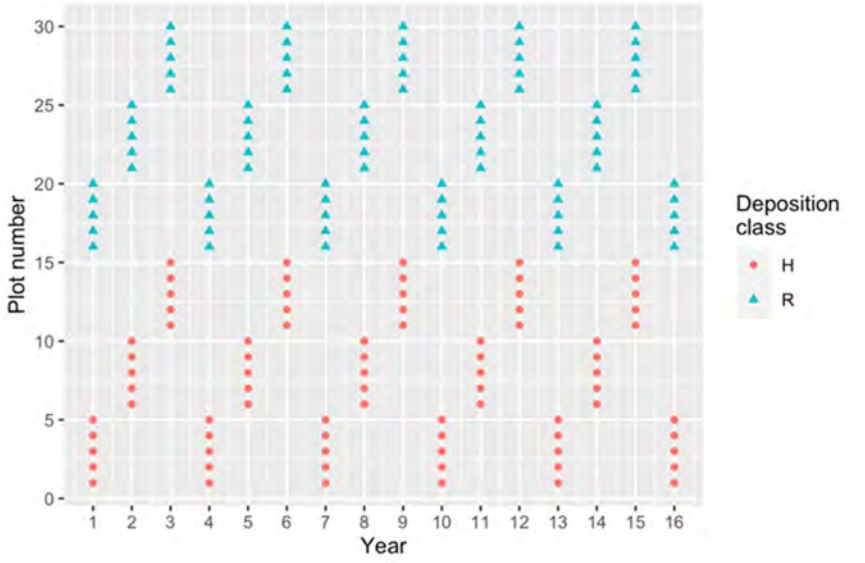


Figure 2. An illustration of a rotating panel design. Each site is measured every 3 years on a rotating schedule. Sites are classified in this example as being in a high deposition (H) or reference deposition (R) class.

While Figure 2 shows a nicely balanced design, this rotating panel design is very flexible, for example allowing for plot measurements on differing rotating schedules if a change is the existing plan is desired or required for any reason (e.g., some sites could be measured every 2 years or even every year). If a site becomes damaged or permanently inaccessible (e.g., land clearing, forest fire, landslide), it is simply "replaced" by a new site whose first measurement takes place when the new site is rotated in[1]. If a site is removed, the data prior to being removed are still included in the analysis.

Sample sizes in the deposition classes do not have to be equal, but power is highest to detect differential changes over time if the sample sizes in all deposition classes are equal, *and* power is also increased if contrast (i.e., between deposition classes) is maximized. The number of deposition classes is also not theoretically restricted, but if too fine a classification is used (i.e., a large number of deposition classes), then the number of sites within each deposition class may be too small to have any power to detect differential trends.

At the outset of this Project, we have 29 sites previously selected (ENV locations), and an additional four sites that will be selected in order to bring the total number of sample sites to 33 (Table 1). The additional sites will be preferentially selected to maximize statistical power (i.e., to achieve roughly equal numbers of sites in all deposition classes and to maximize contrast); however, field constraints (e.g., safety, access, and availability of suitable sites) may limit ability to achieve the "ideal" site composition. As well, additional locations will be assessed for their feasibility for use as alternate sites, in the event that a site needs to be replaced.

As shown in Table 1, plots will be undertaken in each of the deposition classes annually.

Measurements

Proposed response measurements will be the percent cover by species, or by species groupings (e.g., pooling all *Vaccinium* sp.).

Ideally, measurements will be available for every site in every year that it is measured, but the methods below provide a framework to deal with missing data. It is assumed that missing data are Missing Completely at Random (MCAR); that is , the missingness is unrelated to site characteristics or to the response value. For example, if a plot measurement was unavailable because the crew misplaced the raw data sheets, then the missingness is unlikely to be related to site characteristics or to the response value. However, if measurement could not be taken because the site

[1] While the new site "replaces" the old site, it should not use the same site number and the two sets of measurements should be kept separate from each other.

was so overgrown with vegetation that it would take too long to measure cover, then the missingness is related to the response value, and cannot be treated as MCAR.

Notice that if a species does not exist on the plot, the recorded value for cover/relative abundance for that species in that year should be 0 and not missing. In general, values for cover should be recorded for each plot in each year it is measured for *all* species of interest (e.g., all cyanolichens, low shrubs and herbs). Some care will be needed to deal with species that are new to sites: Assuming that crews could have recognized the species in earlier visits, values of 0 for cover/relative abundance of a new species will have to be imputed for past years. Similarly, if a species disappears from a site, value of 0 will have to be imputed for future years when the species is no longer present. If a species never appears in a site for all years it is measured, that site will not be included in the analysis of cover for that species, as there is no information available on changes in cover if a species never appears in a plot. In practice, during plot measurements, crews will not include values of 0 for species that are not present, but a zero value will be inferred during data analysis. Care will be taken, however, to ensure every species present is recorded, with extra efforts made to confirm absence (0) if a species previously recorded at a site is not found during a subsequent assessment.

An example of what the data could look like is shown in Figure 3.

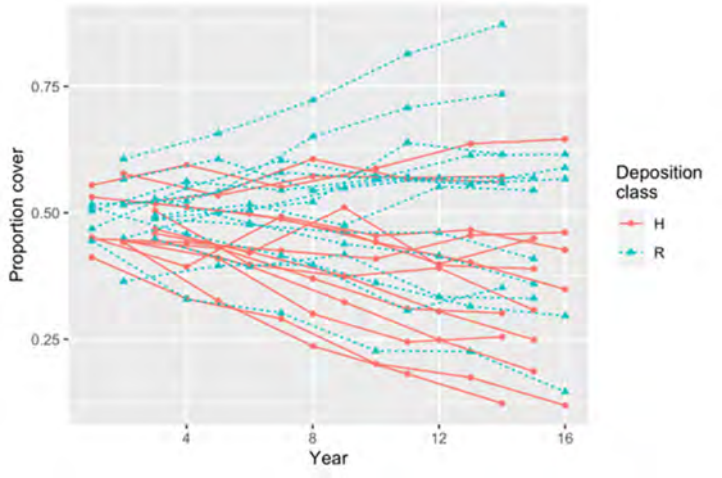


Figure 3. Hypothetical example of data collected from a rotating panel monitoring design. Plots are classified in this example as being in a high deposition (H) or reference deposition (R) class.

Data Analysis.

Annual Reports.

As data are accumulated over time, they will be examined on a yearly basis to correct any data recording errors, etc. For all plots examined in the current year, simple summary statistics (e.g. means and standard deviations of the cover values by deposition class) and—when sufficient data are available—

simple plots (e.g. similar to Figure 3) and the calculated trend line slopes will be presented in annual reports.

Prior to completion of the annual reports, these summaries will also be used as a secondary quality assurance, to help identify values that are anomalous, and if in error, correct them as soon as possible. Imputation of 0's for past years may be needed. Notice that not all anomalous values are necessarily erroneous—i.e., anomalous values do occur, but data should be examined carefully each year.

End-of-3-Year-Cycle Reports.

End-of-Cycle reports examining the impact of different deposition levels will occur at intervals due to the slow changes in the cover that may occur in response to deposition. In the first end-of-cycle report (3 years), all of the sites will have a single measurement. Simple analyses of the variability in the observation data across all of the sites and spatial distribution of values relative to levels of deposition will be conducted. At the end of Year 6, all sites will have been re-measured, and trends at high and medium deposition sites will be compared to those at low/reference sites. The analyses of comparative trends will be repeated every three (3) years.

There may be changes over time in the absence of effects of deposition, for example owing to climate change. Consequently, the analysis must account for these "natural" changes and look for differential changes in the trends between the deposition classes.

The statistical model to analyze this design will be a random slope and intercept model where evidence of impact would a difference in the mean trend among the deposition classes. In reference to Figure 3, the model will fit a separate line for each site, and then a comparison is made of the mean trend line among the deposition classes.

More formally, using a compact modelling notation used by many statistical packages, the statistical model is a linear mixed model:

$$Y \sim Year + DC + Year{:}DC + YearC(R) + Plot(R) + Year{:}Plot(R)$$

where:

. *Y* is the response value;
. *Year* is the common trend over time for all deposition classes;
. *DC* is the effect of deposition class on the initial mean response at the start of the study;
. *Year:DC* is the differential mean trend over time among the deposition classes;

. *Plot(R)* is a random effect associated with every individual plot;

. *YearC(R)* is a random effect associated with each (categorical) value of year reflecting year specific effects on cover (e.g., a particular year may be warmer than normal which could simultaneously affect the cover in all plots in that year in a similar fashion).

. *Year:Plot(R)* are random slopes around the respective mean trend for each deposition class for each plot.

. The *Year:DC* term represents the impact of deposition on the trend, i.e., the differential trend over time among the deposition classes and is the key term in the model to examine. An example of the model fitted to the hypothetical data is shown in Figure 4.

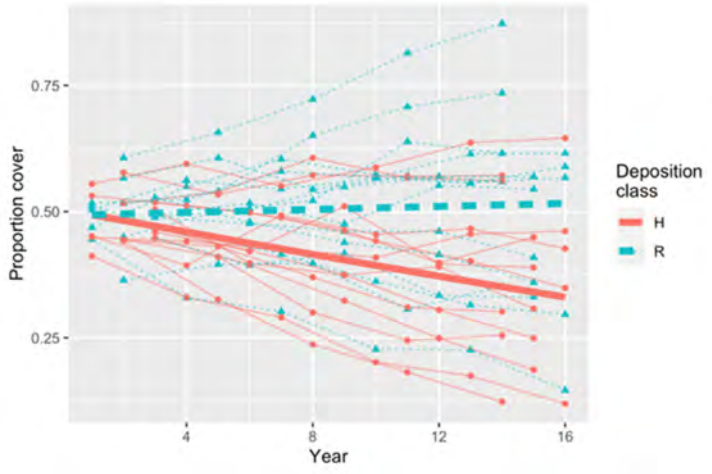


Figure 4. Example of fitted model to the hypothetical data. Sites are classified in this example as being in a high deposition (H) or reference deposition (R) class. The thicker lines are the mean trends over times for each deposition class.

This model is flexible enough that it can accommodate missing values (not zero, but actually missing), different numbers of sites within deposition classes, sites that are rolled out because of damage, or sites that are rolled in as replacements—without any required changes to the model. If a site is removed due to damage or access issues, data for the site until the time of removal are kept in the model. It is likely best to wait until all sites have been measured at least twice before running this model.

The response value could be the raw cover value for a plot, but Warton and Hui (2011) also suggest that the empirical logit transformation of the cover values (i.e., $\theta = \log(p/(1-p))$ where p is the cover value and log() is the natural logarithmic transformation may be more suitable for data that are proportions). This transformation would avoid the trend lines taking values below 0 or above 1. As noted previously, values of 0 for the cover may be present for species that

are absent, in which case the logit() transformation is undefined, but Warton and Hui suggest bounding low cover values from 0 using a small value (e.g., .001) rather than the raw value of 0. Some care will be needed to express the differential change in appropriate units (e.g., differential changes in log(odds)).

A standard hypothesis-testing framework can be used to examine if there is evidence of an effect for the *Year:DC* term. It is not necessary and not of interest to examine the other terms in the model. Estimates of effect sizes (e.g., the individual mean slopes for each deposition class and the difference in mean slopes among pairs of deposition classes) should also be computed.

The model can be extended through the use of site-level covariates (i.e., covariates that are constant for a site over time such as elevation), year-level covariates (i.e., covariates that affect all plots simultaneously in a year such as values representing the Pacific Decadal Oscillations), or plot-year covariates (i.e., covariates that vary by plot and year, such as actual rainfall in a plot in year), assuming that all covariates can be measured in each plot, year, or plot-year as needed.

An example of an analysis conducted using the *R* (R Core Team, 2020) statistical package is found in Attachment 1. The model could be fit using other statistical packages such as SAS or could be implemented in a Bayesian framework. The advantage of a Bayesian framework lies in the natural way the posterior beliefs about effects can be stated, for example, there is a 72% posterior belief that the differential slope is less than 1%/year. A Bayesian implementation is straightforward.

Quality Assurance

Quality assurance (QA) will be undertaken at several different stages, both for data collection and data archiving. QA for the planning process is presumed to be complete through the internal and external (ENV) reviews and ultimate acceptance of the PCMP proposal document (Laurence *et al.* 2020).

Data Collection

Data collection QA will be a layered, internal process, beginning with pre-field training and checklists to ensure the correct data will be collected, and continuing through end-of-day field data reviews, data entry data review and correction, and final QA when summarizing and reporting data.

Where taxonomically difficult or unusual plant/lichen species or damage agents have been tentatively identified during fieldwork, physical and/or photographic specimens will be retained until a qualified professional can verify them in the lab/office.

Laboratory specimens will be subjected to standard laboratory QA procedures.

All reporting will be subjected to an internal Project team review prior to distribution.

Data Archiving

Data, once entered, summarized, and presented in report form, will be given a final QA and will be archived in RTBC's internal servers.

Reporting

Annual Reporting

An annual report of activities in the PCMP will be submitted by December 31st of the current year except at the end of a 3-year measurement cycle when the annual report will be merged with the End-of-Cycle report. The terms of reference for the annual report are detailed in the 2021 Environmental Effects Monitoring (EEM) Phase III Plan (ESSA Technologies *et al*.), and will include implementation (including issues and adjustments, if applicable), summaries of all data collected, and recommendations for following year's field program.

End-of-Cycle Reporting

An End-of-Cycle report will be prepared at the end of each 3-year cycle of the PCMP will be submitted by March 31st of the following year to allow sufficient time to conduct the data analysis and interpret the results. The terms of reference for the annual report are detailed in the EEM Phase III Plan (ESSA Technologies *et al*. 2021).

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Appendix A: Data Collection Templates

Page 1: Plot Site Data Form

Plot Site Data

1	Project ID	RT_EEM_PCMP	Plot No.		Date		Surveyors		Deposition Category	L / M / H
2	Plot Location								Elevation	m
3	FS Region/District	RNI.DKM	UTM Zone	9U	Easting		Northing		GPS Accur.	± m
4	Plot Representing								Listed ecosystem?	Y / N
5	BGC (circle)	CWHws1 / CWHvm1	Site Series		SMR		SNR		Surface shape	ST / CC / CV
6	Slope	%	Aspect	°	Mesosl. Pos.		Exposure Type		Site Disturbance	
7	Canopy Composition				Densio. Cnt.	____/____/____/____	Struc. Stg.		Successional Status	
8	Total % Cover by Layer:	Tree (A)	%		Shrub (B)	%	Herb (C)	%	Moss/Lichen/Seedling (D)	%
9	Visual Inspection of veg. health (circle)	green healthy / drought / saturation (flood) / physical damage / insect infestation / disease / dust / nutrient deficiency / industrial activity / other (describe below)								
10	General Site Conditions (veg. health)	Inside plot / Near plot							Additional Survey Form?	Y / N
11	Photos	ID / N / E / S / W / Up	NE / SE / SW / NW		From corner to center:		NE / SE / SW / NW		Ph. Loc.	
	Other photos (describe):									
12	General site comments/notes								Sample Event (e.g. 1st, 2nd, etc.)	
13	Soil Samples Collected?	NE 0-10 ; 10-20 / SE 0-10 ; 10-20 / SW 0-10 ; 10-20 / NW 0-10 ; 10-20 / None / Other (comment)								
14	on Exchange Resin Column(s)	Y / N	Soil/IER comment							

Page 2: Plot Vegetation Data Form

Plot Vegetation Data

1	Layer (circle)	Species Code	% Cover (plot)	# Individuals (if countable)	Listed sp.?	Table 1 sp.?	ID Conf. Req'd?	Photo ?	Distrib Code (1-9)	Vigour Code (0-4)	Phenology Code* - Vegetative	Phenology Code* - Generative
2	B2 / C				□	□	□	□				
3	B2 / C				□	□	□	□				
4	B2 / C				□	□	□	□				
5	B2 / C				□	□	□	□				
6	B2 / C				□	□	□	□				
7	B2 / C				□	□	□	□				
8	B2 / C				□	□	□	□				
9	B2 / C				□	□	□	□				
10	B2 / C				□	□	□	□				
11	B2 / C				□	□	□	□				
12	B2 / C				□	□	□	□				
13	B2 / C				□	□	□	□				
14	B2 / C				□	□	□	□				
15	B2 / C				□	□	□	□				
16	B2 / C				□	□	□	□				
17	B2 / C				□	□	□	□				
18	B2 / C				□	□	□	□				
19	B2 / C				□	□	□	□				
20	B2 / C				□	□	□	□				
21	B2 / C				□	□	□	□				
22	B2 / C				□	□	□	□				
23	B2 / C				□	□	□	□				
24	B2 / C				□	□	□	□				
25	B2 / C				□	□	□	□				
26	B2 / C				□	□	□	□				
27	B2 / C				□	□	□	□				
28	B2 / C				□	□	□	□				
29	B2 / C				□	□	□	□				
30	B2 / C				□	□	□	□				
31	**Additional Species of Importance (other layers)**											At Risk (R) / Cultural (C) / Weed (W)
32	A / B1 / D / E				□	□	□	□				R / C / W
33	A / B1 / D / E				□	□	□	□				R / C / W
34	A / B1 / D / E				□	□	□	□				R / C / W
35	A / B1 / D / E				□	□	□	□				R / C / W
36	A / B1 / D / E				□	□	□	□				R / C / W
37	A / B1 / D / E				□	□	□	□				R / C / W

Distrib. Code	Description	# plants/400m2
1	Rare individual, single occurrence	1
2	A few sporadiclly occurring individuals	2-5
3	A single patch or clump of a species	1 patch (<25% of plot)
4	Several sporadically occurring individuals	≥6
5	A few patches or clumps of a species	2-5 patches, each <25% of plot
6	Several well-spaced patches or clumps	≥6 patches, each <25% of plot
7	Continuous uniform occurrence of well-spaced individuals	many
8	Continuous occurrence of a species with a few gaps in the distribution	many
9	Continuous dense occurrence of a species	many

Vigour Coding:		Decription
0	Species dead	All leaves dry, shriveled and/or necrotic.
1	Vigour poor	Severe necrosis or wilting.
2	Vigour fair	Some reduced vigour, possible browning of leaf tips, wilting, chlorosis or necrosis. Damage or disease agents may be impacting this species.
3	Vigour good	Relatively healthy, but growth not vigourous, plants are green but not deep green and lush. Damage or disease symptoms may be evident, but minor.
4	Vigour excellent	Deep green leaves, lush growth, and no chlorosis, wilting, or evidence of ongoing damage or disease.

* see Province of BC (2010) for Phenology Codes

Page 3: Line Transect Vegetation Data Form

Line Transect Vetatation Data

Segment 1: 20m	**N-bdry /other: _____**
POC:	**_____cm**

Distance	**Species Code**
cm - cm	
cm - cm	
cm - cm	

Page 4: Plot Cyanolichen Data Form

Plot Cyanolichen Data **Plot:**

1-Hour Timed Search Start	h		End time	h	(use 24-hour clock; e.g. 13h15)						
Did lichen search extend outside plot boundary?				Y / N	If yes, at what time did search begin outside plot?						h
Species Code	**Presence Inside Plot**	**Tally (individuals or colonies) Inside Plot**	**Abundance Rating***	**Presence in Search Area Outside Plot**	**Conifer Host Tree Spp. (circle all host spp.)**	**Listed sp.?**	**ID Conf. Req'd ?**	**Photo ?**	**Health: Normal (N), Injured (I) or Stressed (S)?**	**Comment**	
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		
	□			□ / n/a	Ba/Cw/Hw/Pl/Sx/Yc/__	□	□	□	N / I / S		

Overall comments on cyanolichen presence, abundance, or substrate/host(s)

Visual Inspection and Assessment of Cyanolichen Health (e.g., any symptoms such as "off-colour," bleaching of tissues, or notably reduced growth?):

*Abundance Rating Guide (adapted from Prov. of BC 2010)		
	Rating	**Criteria**
0	None (N)	Not present
1	Rare (R)	1 or 2 colonies per plot
2	Occasional (O)	3-5 colonies per plot
3	Common (C)	6 colonies to 20% cover of host tree(s) within plot
4	Very Common (VC)	21-51% cover of host tree(s) within plot
5	Abundant (A)	>51% cover of host tree(s) within plot

Page 5: Additional Vegetation Health Data Form

Additional Vegetation Health Data

Species Code	Symptom	Proportion of Affected Individuals in Plot	Average % of Leaf Area Affected	Average % of Plant Affected	Cause	Comments	Photo(s)?
							☐
							☐
							☐
							☐
							☐
							☐
							☐
							☐
Other comments:							

Appendix B: Detailed Field Guide

Field Equipment Checklist

Truck Gear:

- ☐ All Rio Tinto required truck-based safety gear (e.g., radio communication, wheel chocks)—to be established during pre-field planning meeting, annually
- ☐ First aid kit (Level 1)—include hard candy (e.g., tic-tacs), antihistamine, and extra medication (if needed)—and blanket
- ☐ Charging cables for tablets and other devices
- ☐ Saw and tow-rope (carry in truck for emergency use only)

Personal Safety Gear:

- ☐ All Rio Tinto required PPE (e.g., hard hat, safety boots, hi-viz vest, gloves, safety glasses)—to be established during pre-field planning meeting, annually
- ☐ inReach or other satellite communication system (for check-ins or emergencies in sites without cellular service)
- ☐ Handheld radios with local frequencies
- ☐ Contractor-grade garbage bag or emergency blanket (carry in field vest/bag for emergency cover/shelter)
- ☐ First aid kit (personal to carry; Level 1 in truck)—include hard candy (e.g., tic-tacs), antihistamine, and extra medication (if needed)
- ☐ Headlamp/flashlight

Suggested Minimum Personal Gear:

- ☐ Food/drink, including extra water and a hot drink for cold days
- ☐ Personal medication (if needed)
- ☐ Hip or chest waders (optional, for access to wetter sites)
- ☐ Rain gear
- ☐ Extra clothes in case you become wet or cold (e.g., spare layers, toque, mitts)

Special equipment for biodiversity plots:

- ☐ Metal rods (5-per plot), wooden stakes (up to 9-per plot) & rubber mallet (to install)
- ☐ Flagging tape (2 colours) and/or pin flags to delineate boundaries & quadrants (optional)
- ☐ Measuring tapes (2)(metric; minimum 25m)
- ☐ Measuring stick or ruler (ideally a folding 1m+ ruler)
- ☐ Stringline (optional)
- ☐ Plum-bob
- ☐ Tablet loaded with mapping program, Theodolite photo application, Field Form (if using digital), reference documents (e.g., this guide, DEIF, plant/lichen guides, etc.)
- ☐ Timer (timed search for cyanolichens)
- ☐ GPS (optional if using tablet)
- ☐ Extra batteries for everything (consider a battery pack that can charge all devices)
- ☐ Compass

- ☐ Clinometer
- ☐ Hand lens (10x)
- ☐ Sample bags
- ☐ Clippers
- ☐ Waterproof markers
- ☐ Densiometer (convex)
- ☐ Diameter (DBH) tape (optional)
- ☐ Set of forms for each plot, plus extras
- ☐ Clipboard or notebook to house forms
- ☐ Ducksback or Write-in-the-Rain paper for additional notes

Special Equipment for Soil Sampling:

- ☐ Rubbing alcohol to sanitize soil sampling equipment
- ☐ Nitrile gloves
- ☐ Spade, trowel
- ☐ Soil sample bags
- ☐ Permanent marker
- ☐ Soil auger

Suggested Minimum Reference Material:

- ☐ Previous plot information (if available)
- ☐ Annual instructions for field work (e.g., site list, alternate sites, sampling requirements, etc.)
- ☐ Laminated and/or digital copy of this Detailed Field Guidance document
- ☐ Copy of relevant sections of DEIF Manual (Province of BC 2010)
- ☐ Plant guide(s) (e.g., *Plants of Northern BC*, *Plants of Coastal BC*)
- ☐ Lichen guide(s) (e.g., *Macrolichens of the Pacific Northwest*)
- ☐ Invasive plant guide and/or Report Invasives BC application

Plot Site Data Card

The fields on the *Plot Site Data* card are described below; the numbers associated with the descriptions below correlate to line numbers on the data card. Many of the fields on this card are also described in Province of BC's (2010) *Field Manual for Describing Terrestrial Ecosystems*: Where this is the case, only a brief description is provided here, and the reader is directed to collect the data by referring to—and in accordance with—this essential reference.

For quick reference, boxed instructions detail whether/how these fields will be used between locations and years (assessments), and include the following coding: **I**=Record data at initial assessment and confirm during subsequent visits; **Δ**=Record when changed from initial assessment; **A**=Record data annually (during each assessment).

1. **Project ID, Plot No., Date, and Surveyors**

   Project ID: this will remain the same during each year of the PCMP, and will be recorded at each plot as **RT_EEM_PCMP** or as directed during the pre-field meeting.

A Pre-fill this provided ID (**RT_EEM_PCMP**) on your Site Data Card for each assessment.

   Plot number: this number will be unique for every assessment of every plot.

   Because plots will be visited over multiple years, *Plot Number* will be a unique *Plot Location Identifier* combined with a unique site visit code. *Plot Location Identifiers* identify a spatial site/location where plots will be located, and will be provided annually to the field team. For *Plot Number*, field teams will enter the *Plot Location Identifier*, followed by a two-letter crew-lead initials, and a two-digit year (e.g. L32AC21).

A Each assessment at each location will be given a unique Plot No.; these will be predetermined and confirmed at each annual pre-field planning meeting.

   Date: record the date in YY_MM_DD format.

A Record during each assessment.

   Surveyors: Record the first initial and last name of each member of the field team who is contributing to data collection. If teams are consistent, this could be reduced to initials on the field form, but should be expanded at the data entry phase.

A Record during each assessment.

Deposition Category: this will remain the same during each year of the PCMP. The category will be provided to field teams for each plot prior to assessment, and will be recorded as Low, Moderate or High.

I/Δ Record during initial assessment; confirm during subsequent assessments.

2. Plot Location and Elevation

Plot Location: a description of where the site is located at both regional and local scales. Reference features such as waterbodies, as well as roads (e.g. name and kilometer board), when describing how the site is accessed.

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

Elevation: Enter the elevation provided by your GPS device.

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

3. FS Region/District, UTM, and GPS Accuracy

***FS Region/District*:** This field is the Forest Region & District, and will be included in order to facilitate potential data-sharing in the future (at Rio Tinto's sole discretion). The study area lies entirely within the Northern Interior Forest Region and Kalum District, and will be recorded at each plot as **RNI.DKM**.

A Pre-fill this field with **RNI.DKM** on your Site Data Card for each assessment.

UTM Zone, Easting & Northing: Enter the precise location of plot center using UTM coordinates. Entire Project Area is located in Zone 9U. Plot UTM will remain the same from year-to-year, unless a correction is required.
*UTM is preferred to the Latitude/Longitude system for this Project; if Lat./Long. are collected, they should be converted to UTM during data entry.

I/Δ Record during initial assessment; confirm during subsequent assessments, and amend only if you believe you have more accurate location information.

GPS Accuracy: If determining the UTM of the plot for the first time or as a correction to a less accurate UTM collected previously, enter the GPS accuracy. If using UTM coordinates provided from previous plot visits to this location, leave this field blank.

Record during initial assessment; in subsequent assessments, only include if you have provided new UTM coordinates.

4. Plot Representing, and Listed Ecosystems

Plot Representing: Provide a description of the plot. If a description has been provided during a previous plot visit to this location, this field may be left blank—unless an adjustment is required owing to a change in plot dynamics or composition.

This field should include the dominant species present in each vegetation layer (A, B, C, and D), as well as a short description of vegetation stage and/or any special disturbance/edaphic/terrain or other prominent site features.

I/Δ Record during initial assessment; confirm or amend (if required) during subsequent assessments.

Listed Ecosystem: Circle yes (Y) if this Site Series (described in number 5, below) is currently a listed ecosystem per the BC Conservation Data Centre.

A Record during each assessment, per current BC CDC listing.

5. BGC, Site Series, SMR, SNR and Surface Shape

BGC: Record the BioGeoClimatic (BGC) Ecosystem Classification (BEC) by circling the zone/subzone/variant in which the plot occurs. Digital BEC mapping is available through BC's Data Catalogue, Data BC: https://catalogue.data.gov.bc.ca/dataset/bec-map.

I/Δ Record during initial assessment; confirm or amend during subsequent assessments. The BGC is unlikely to change, although the information is periodically reviewed and could be amended.

Site Series: Determine the Site Series using *A Field Guide to Site Identification and Interpretation for the Prince Rupert Forest Region (Part 1)*(Banner et al. 1993). If the site series has been determined during a previous plot at this location, leave this field blank.

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

SMR: Using the keys provided in Province of BC (2010), determine Soil Moisture Regime during initial soil sample collection. Enter the code (0-8). If SMR has been identified during a previous plot at this location, confirm SMR.

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

SNR: Using the keys provided in Province of BC (2010), determine Soil Nutrient Regime during soil sample collection. Enter the code (A-F). If SNR has been identified during a previous plot at this location, confirm SNR.

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

Surface Shape: Circle whether the overall surface of the plot is generally straight (ST), concave (CC) or convex (CV).

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

6. Slope, Aspect, Mesoslope Position, Exposure Type, and Site Disturbance

Slope: Using your clinometer, record the % slope (not degrees!). Remember, you are trying to give a good estimate of the average slope where your plot is located, not the slope of the small features inside the plot.

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

Aspect: Using a compass that has the correct declination, record aspect (in degrees). If your site doesn't face any particular direction (i.e., it's level), write "999".

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

Mesoslope Position: describes where your plot lies in a more local context (i.e., what you can see). Mesoslope position influences a suite of ecological information, helping us guess at moisture and nutrient inputs, what species likely grow here, and how wildlife may use the site. Refer to Province of BC (2010) to determine mesoslope position.

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

Exposure Type: If applicable, and using the codes presented in Province of BC (2010), crews should note "significant localized atmospheric and climate-related factors that are reflected in atypical soil and/or vegetation features" (e.g., Atmospheric Toxicity).

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

Site Disturbance: If applicable, and using the codes presented in Province of BC (2010), crews should "note events that have caused vegetation and soil characteristics to differ from those expected at climax for the site" (e.g., Wind, Forest Harvesting, etc.).

I/Δ Record during initial assessment; confirm or amend during subsequent assessments.

7. **Canopy Composition, Densiometer Counts, Structural Stage, and Successional Status**

Canopy Composition: Record the composition of the tree canopy using the 2-3 letter tree species codes separated by single digits representing decile proportion canopy closure (adding to 10 to make 100%), e.g.: Hw7 Act2 Cw1.

Densiometer Counts: Providing a metric similar to total % cover of the tree layer (see 8, below), desiometers provide an objective measure of overstorey cover; however, densiometer cover includes all cover above the height the densiometer is held, including the tall shrub layer and any topographic features that may overhang a site, as the instrument—unlike the human eye—cannot discern between layers or features.

Collect four densiometer counts in the cardinal directions at plot center during each assessment. (These will be converted into a % overhead cover metric by subtracting the average from 96, and multiplying the result by 1.04).

A Record during each assessment.

Structural Stage: Describes the stand using the characteristic life form (e.g., trees) and a number of physical attributes. Refer to Province of BC (2010) for Structural Stage codes and descriptions.

In the case of forests, structural stage infers a developmental trajectory from immediately post-disturbance towards an old-growth community, and describes the "typical" sequential steps of structural development. Keep in mind that human interference (e.g., stand management activities such as thinning or selective/partial cutting) can directly impact structural stage, sometimes circumventing or speeding up development the typical trajectory.

Successional Status: Describes the stand using species-related attributes. Refer to Province of BC (2010) for Successional Status codes and descriptions.

Even more than structural stage, successional status assumes a predictable, temporal development from "seral" to "climax." While structural stage focuses on the physical structure of species and the community, successional status describes species shifts over time (e.g., changing species composition, stature, dominance, relative age, and vigour).

A Record during each assessment.

8. **Total % Cover By Layer**

For each of the four major vegetation layers (A, B, C and D), estimate the total percent cover in the plot, using comparison charts for visual estimation (such as that provided in Province of BC 2010). Record whole numbers (no decimals) for these fields. (* 2m x 2m is 1% in our 400m^2 plots).
Note that if part of an individual shrub or small tree extends in height beyond the layer cutoff (e.g., 10m), the entire individual is assigned to the higher class.

A Record during each assessment.

9. Visual Inspection of Vegetation Health

Circle the condition(s) you observe for the site as a whole. (Circle all that apply).

A Record during each assessment.

10. General Site Conditions (Vegetation Health)

Comment on general site conditions with respect to vegetation health. For example,

- How does it look? Green and lush or dry and brown?
- If green and lush, does that apply to all plants?
- If dry and brown, is everything dry and brown?

If there is no damage to vegetation, OR if the damage is "universal" across species (e.g., dust covering all shrubs), OR if damage is "simple" (e.g., all cedar trees exhibiting columnar growth), no additional form is required—simply a description of such. However, if signs of vegetation damage are present, complete the *Additional Vegetation Health Data* form.

A Record during each assessment.

11. Photos Taken, and Photo Location

Photos Taken: Crews will aim to take a minimum total of ten specific photographs during each assessment at each location. Photos will be taken consistently at each plot, in the same order. Ideally, an application such as Theodolite is used to take the photos, recording location and direction on each photograph.
As a marker, the first photograph in each sequence will include a Plot ID—ideally a photo of the first page of the completed field form. Remaining photos to be taken from plot center: North, east, south, west, up (canopy), and four "down" (oblique, showing ground) photographs to NE, SE, SW and NW plot corners (and, from 2022, from each corner toward plot center). On the Field Card, circle all photos that have been taken.

Other photos should be taken as needed to document site conditions, vegetation health, disturbance, for specimen identification, etc. If other photos are taken, include a brief description.

A Record during each assessment.

Photo Location: Record what camera/device the photos are stored in.

A Record during each assessment.

12. General Site Comments/Notes, and Sample Year

General Site Comments/Notes: Record any site notes you feel may be relevant.

A Record during each assessment.

Sample Year: Record whether this is a location's initial (1st) assessment, or a subsequent assessment (2nd, 3rd, etc.) for the PCMP.

A Record during each assessment; the Sample Year will increase by one for each new assessment.

13. Soil Samples

Soil Samples Collected: Circle all locations at which soils samples were collected (~1m outside of plot corners—without disturbing vegetation at plot boundary), or circle "None" if none taken from the site during the current assessment.
Mineral samples will be taken at a depth of 0-10 cm & 10-20 cm, when practical. Humus or other organic layers will not be included in the sample. Samples will be collected using sterilized equipment (including gloves), and will be placed in sample bags labeled with the date, time, plot, location, crew and Project ID. Samples will be stored and shipped following the directions provided annually (based on laboratory recommendations). Samples from the four positions will be composited for analysis.
Soil samples to be collected during initial year, and then again only as directed. Comment as required (e.g., samples taken at different location in/near plot).

A Record during each assessment (but sample soil only during initial year and as directed).

14. Ion Exchange Resin Columns (IERC)

Are IERCs installed at the plot? Comment if/as needed (and only if "yes").

A Record during each assessment (but install only as directed).

Plot Vegetation Data Card

This data card will be completed in full during each plot [re-]assessment. Each row on this form represents a species (in some cases, related species that cannot be reliably distinguished in the field may be combined). For each new species, complete each of the fields, as described below:

Layer: Circle the appropriate vegetation layer for the species. Vegetation layers are as described in detail in Province of BC (2010), and are summarized as follows:

- A—Tree Layer—Includes all woody plants >10m tall.
- B1—Tall Shrub Layer—All woody plants 2-10m tall.
- **B2—Low Shrub Layer—All woody plants <2m tall, except low or trailing species (see Province of BC's (2010) *List of low woody species and species of uncertain life form assigned to the herb layer*).**
- **C—Herb Layer—All herbaceous species and low woody species described above**
- D—Moss, Lichen, Liverwort and Seedling Layer—All bryophytes, terrestrial lichens and liverworts, and tree seedlings less than 2 years old, occurring on mineral soil and humus. Subcategory "Dr" includes such species occurring on rock, and "Dw" occurring on wood.
- E—Epiphyte Layer—All species which grow on other living plants.

***Categories A, B1, D and E will only be included if identified as an "Additional Species of Importance" (i.e., it is at risk, a weed, or of cultural importance).**

% Cover (plot): Estimated as the percentage of the ground surface covered when the crowns are projected vertically: Follow the outside perimeter of the projected crown (small gaps in the canopy that are not fully covered can be ignored). If a plant is only partially in the plot (example the stem is outside but part of the plant vertically projects on the inside of the plot), include the % cover that occurs inside the plot boundaries.

Some tips for ensuring cover estimates are reliable:

- Walk around and view all areas of the plot from above—viewing obliquely can cause you to overestimate.
- For species with high cover values, mentally move the plants to a corner of the plot to estimate if they represent one-quarter, one-third, or one-half, or more of the plot.
- For species that almost cover the plot, mentally move them together and estimate how much of the area is not covered by the plants.

- For species with low cover, break the plot into subsections and add up the cover in the subsections.
- Work semi-independently with a partner and see if your estimates agree.
- Most importantly, use a ruler, and re-calibrate yourself with it at each plot. Equating percent cover with equivalent dimensions relative to plot area can be very helpful. These sample dimensions are applicable in our 400m^2 plots:

Dimensions	Area (m^2)	% Cover
10m x 10m	100.0	25.0
5m x 8m	40.0	10.0
5m x 5m	25.0	6.25
4m x 4m	16.0	4.0
2m x 2m	4.0	1.0
1m x 1m	1.0	0.25
63cm x 63cm	0.4	0.1
20cm x 20cm	0.04	0.01 ("1H")
6.3cm x 6.3cm	0.004	0.001 ("1T")

Record to the number of decimals you feel confident about, to a maximum of thousandths (you may record these as "xT," for example 3 thousandths would be recorded as "3T"; hundredths similarly may be recorded as "xH").

 # Individuals: [This metric has been removed]

Listed sp.?: Check the box if the species is identified as at risk (current BC CDC listing, provided annually during pre-field planning). If unsure, circle the box to flag it for follow-up.

Table 1 sp.?: Check the box if the species is a *Table 1* species (provided annually during pre-field planning). If unsure, circle the box to flag it for follow-up.

ID Conf. Req'd?: Check the box if you are not certain about correct identification of this plant (i.e. confirmation is required). Photograph the species. Do not collect a specimen from inside the plot, but do collect a specimen if you can find one nearby—and be sure to label it with species (can be "unknown 1," etc.), Plot ID, Date, and any other pertinent information.

Photo?: Take photo(s) and check the box IF the species identification is uncertain, or if you have specially taken additional photographs of this species (for any reason).

Distrib Code (1-9): Use the Distribution Codes (Province of BC 2010) to describe the spatial distribution pattern in the plot of individuals of each species.

Vigour Code (0-4): Use the Vigour Codes (Province of BC 2010) to describe individual species' vigour within the plot. As the coding does not elaborate on how to differentiate between the codes, the following is meant to provide guidance and clarity:

- ☐ 0—Dead—All leaves dry, shriveled and/or necrotic.
- ☐ 1—Poor—Severe necrosis or wilting.
- ☐ 2—Fair—Some reduced vigour, possible browning of leaf tips, wilting, chlorosis or necrosis. Damage or disease agents may be impacting this species.
- ☐ 3—Good—Relatively healthy, but growth not vigourous, plants are green but not deep green and lush. Damage or disease symptoms may be evident, but minor.
- ☐ 4—Excellent—Deep green leaves, lush growth, and no chlorosis, wilting, or evidence of ongoing damage or disease.

Phenology Codes (Vegetative/Generative): Use the appropriate Phenology Codes (Province of BC 2010) to describe the Vegetative (non-reproductive) AND Generative Stages in the plot for each species. Note that different species groups have different codes.

At Risk/Cultural/Weed: For Additional Species of Importance, indicate the reason this species was included by circling the appropriate category.

Line Transect Vegetation Data Card

The methods for the Line Transect Vegetation Data collected for the PCMP are adapted (to include herbs) from the Province of BC's (2018) *Vegetation Resource Inventory Ground Sampling Procedures'* Line-Intersect Method for Shrubs.

The object of this exercise is to quickly and reliably estimate cover by vertically projecting the "canopy" of low shrubs (B2) and herbs (C) onto a "two-dimensional" horizontal line, measuring the length of the line that intersects with the canopy.

Two connected ~20m transects will be established: One along the northern plot boundary, and the other along the eastern plot boundary (wherever practical; however, field crews may choose a different boundary if it is justified, but must then highlight this on the form and ensure a note is attached to the plot information for future re-assessments).

1) Stretch a measuring tape at a consistent, reasonable height (e.g., 30cm) along the transect lines (one at a time), attaching the tape tightly to the corner at either end.
2) Record the starting (POC) distance as read on the strung measuring tape (it does not need to begin at 0—simply read the centimeter mark off the tape where the transect begins (the corner)).
3) Identify and record the distances covered for each B2 and C layer species whose "vertical projection" intercepts the sampling line (see Figure 5*):
    a. Record distance along transect to the nearest 1cm.
    b. Ignore any gaps less than 5cm in an individual plant's "canopy" cover.
    c. Especially on slopes, remember to measure the horizontal distance: Use the plumb bob to help accuracy (i.e., project the canopy vertically, using gravity!).
    d. If the canopies of different species overlap, record the plants separately (including any area of overlap)
    e. If the canopies of the same species overlap, record them as one occurrence.
    f. It doesn't matter how you organize the data on the form (by species or by distance) so long as the distances are correctly recorded.
4) Use an additional page if you require more space to record data.
5) Record the ending (POT) distance as read on the strung measuring tape (it does not need to be at 20m—simply read the meter & centimeter marks off the tape where the transect ends (the corner)).
   It does not matter if the transect is slightly longer or shorter than 20m—given topography and other field conditions, plot corners will rarely (if ever) be precisely 20m apart.

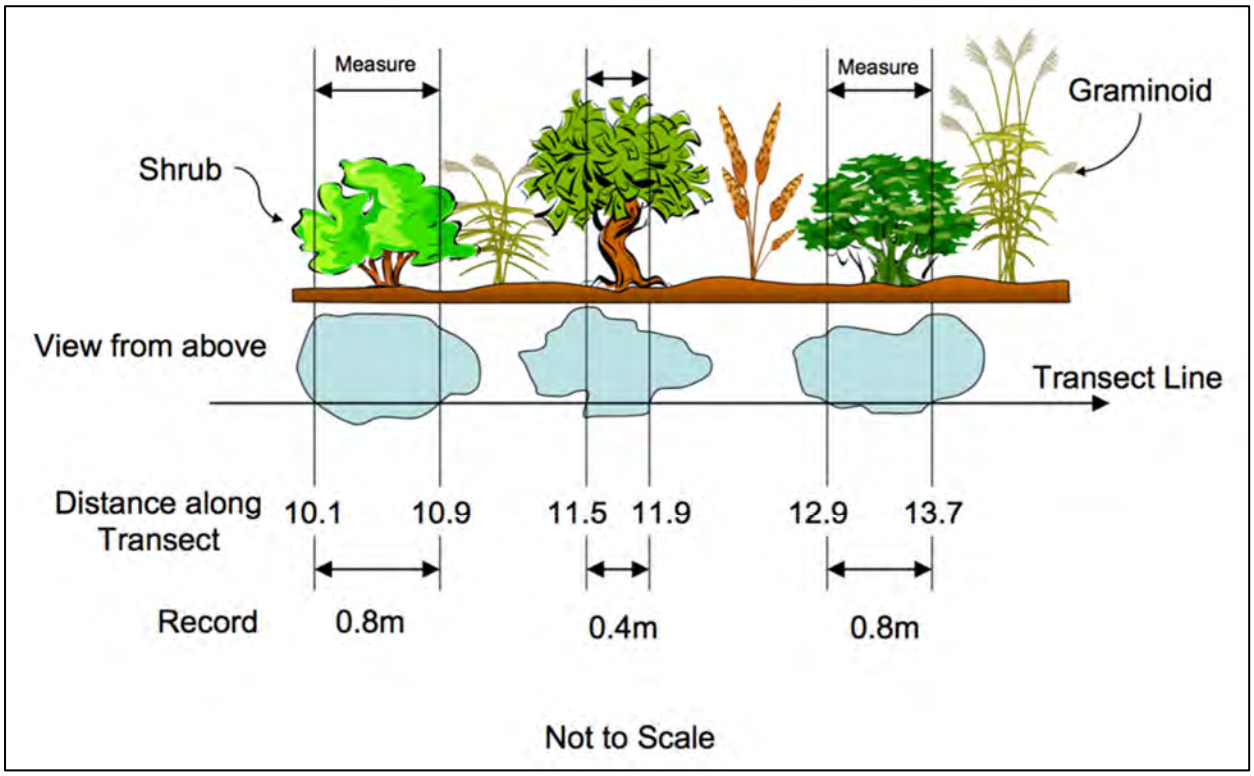


Figure 5: Line-intercept method for shrubs, taken from Province of BC (2018).

*Figure 5 shows the use of the method for shrubs only, excluding herbaceous species; however, for this project, all shrubs and herbs in the B2 and C layer will be included and measured as per the shrub cover shown in Figure 5.

Plot Cyanolichen Data Card

A one-hour timed search for cyanolichens is to be undertaken at each plot, during each assessment. A timer with an alarm should be used for this activity.

Using the 24-hour clock, record the start time for the search, and, when complete, the end time. If the search extends beyond the plot boundary (i.e. because the plot search area has been fully exploited), record the start time for this activity and continue searching until the one-hour total time limit is complete.

For each cyanolichen species encountered on a coniferous host tree (living, or dead but standing), record the following:

- Species code.
- Tick the box if it was encountered inside the plot boundaries.
- Tally the number of individuals/colonies that occur inside the plot **to a maximum of 15 (indicate more with a "+"),** and assign a corresponding abundance rating based on the tally within the plot when the timed search is completed.
- If the timed search continued outside the plot boundaries, tick the box if the species was encountered outside the plot during the timed search. Circle "n/a" only if the timed search did not continue beyond the plot boundaries.
- For each lichen species, record all coniferous host species observed during the timed search.
- Tick the box if the species is listed (at risk).
- Tick the box if identification of this species requires confirmation. If this is the case, do not take a physical sample (unless one can be obtained from outside the plot), but do take a set of good quality photographs of upper and lower surfaces.
- Tick the box if photos were taken of this species.
- For Health, circle Normal, Injured, or Stressed.
- Record a comment (optional).

Do not include cyanolichens found on downed trees or deciduous hosts in the table: Instead, provide this information in comments section.

When the timed search is complete, record any overall comments (e.g., presence, abundance, substrate, host species, etc.). It is helpful to add comments about distribution: e.g., is there one specific tree that is host to all/most of a species' occurrences?

Provide a comment on Cyanolichen Health. For example, are there any symptoms of poor health in plot cyanolichen community? Describe. If yes, is it affecting all members, or are the effects differentiated between locations, species, etc.?

Additional Vegetation Health Data Card

This is an optional data form, to be filled in only at plots when the vegetation and/or cyanolichen inspection and assessment indicate its necessity.

For each species with symptom(s), be sure to take photographs, and ensure they are labeled with date, location and species information.

- record the symptom(s) (i.e., what you see that suggests health is being negatively affected);
- record the proportion of individuals of this species present in the plot that show the symptom(s);
- for individual leaves that are affected, record the average percentage of affected leaf area;
- for individual plants that are affected, record the average percent of plant affected;
- record the suspected cause of symptom(s), and provide a comment; and
- note whether photographs have been taken.

Sample size/power analysis from measuring vascular cover - Vaccinium

Carl Schwarz

2020-09-03

- 1 Introduction
  - 1.1 Illustration of a sampling design
  - 1.2 Simulated data
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  - 2.4 Cover for **Vaccinium** genus.
  - 2.5 Change in cover
- 3 Power/sample size analysis
  - 3.1 Impact of a reduced sd in the trend

1 Introduction

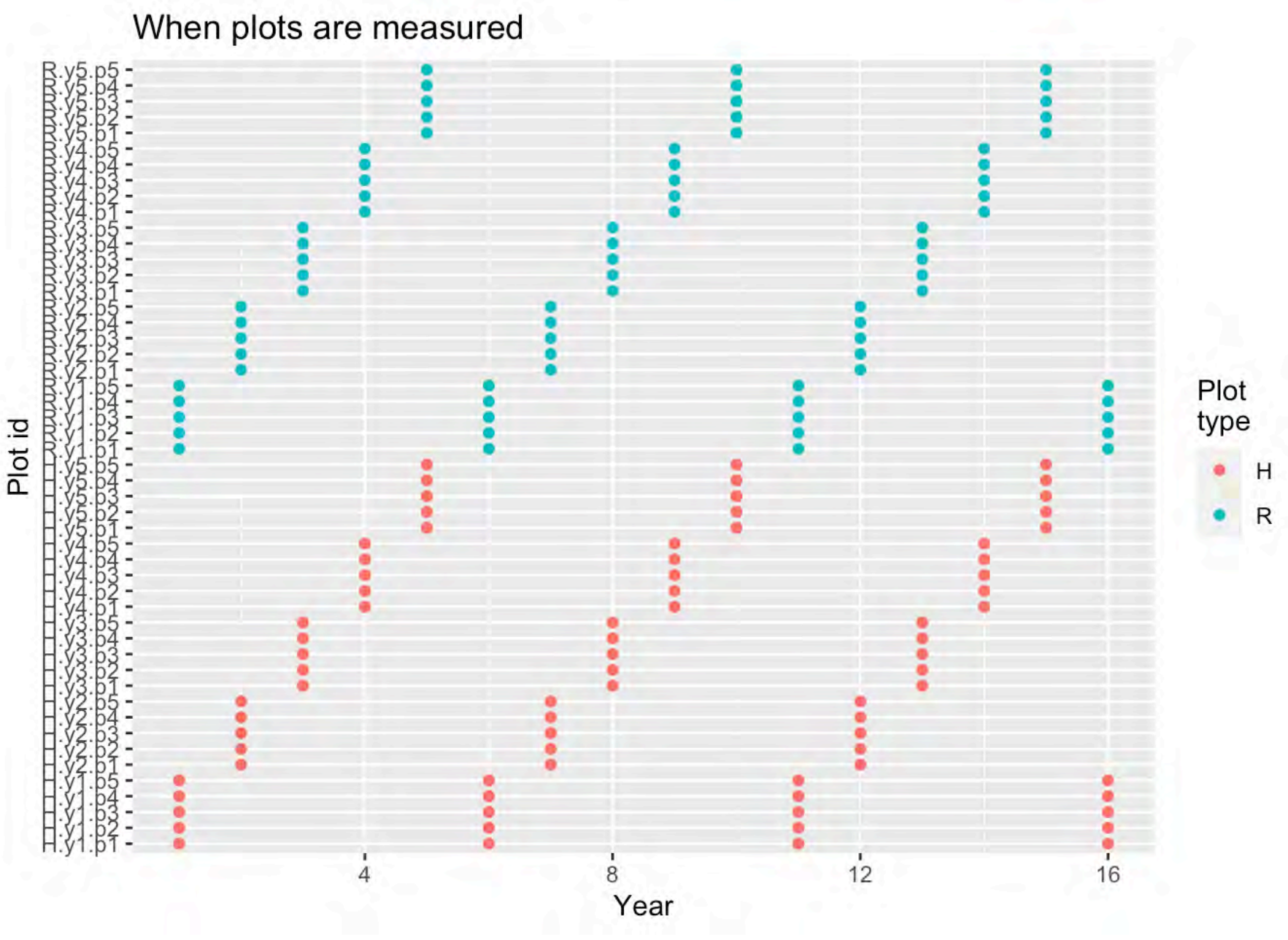
This document will illustrate the sample size requirements/power analysis for detecting changes in % cover in the long term monitoring plan for Rio Tinto.

The basic design is rotation panel design with staggered entry with most plot allocated to high and reference deposition levels.

1.1 Illustration of a sampling design

For example, here is a sample design, where there are 5 monitoring plots established per year in each of the high deposition and reference areas. Each plot is measured every 5 years after initiation. Monitoring continues to year 16.

An illustration of when plots are measured is:



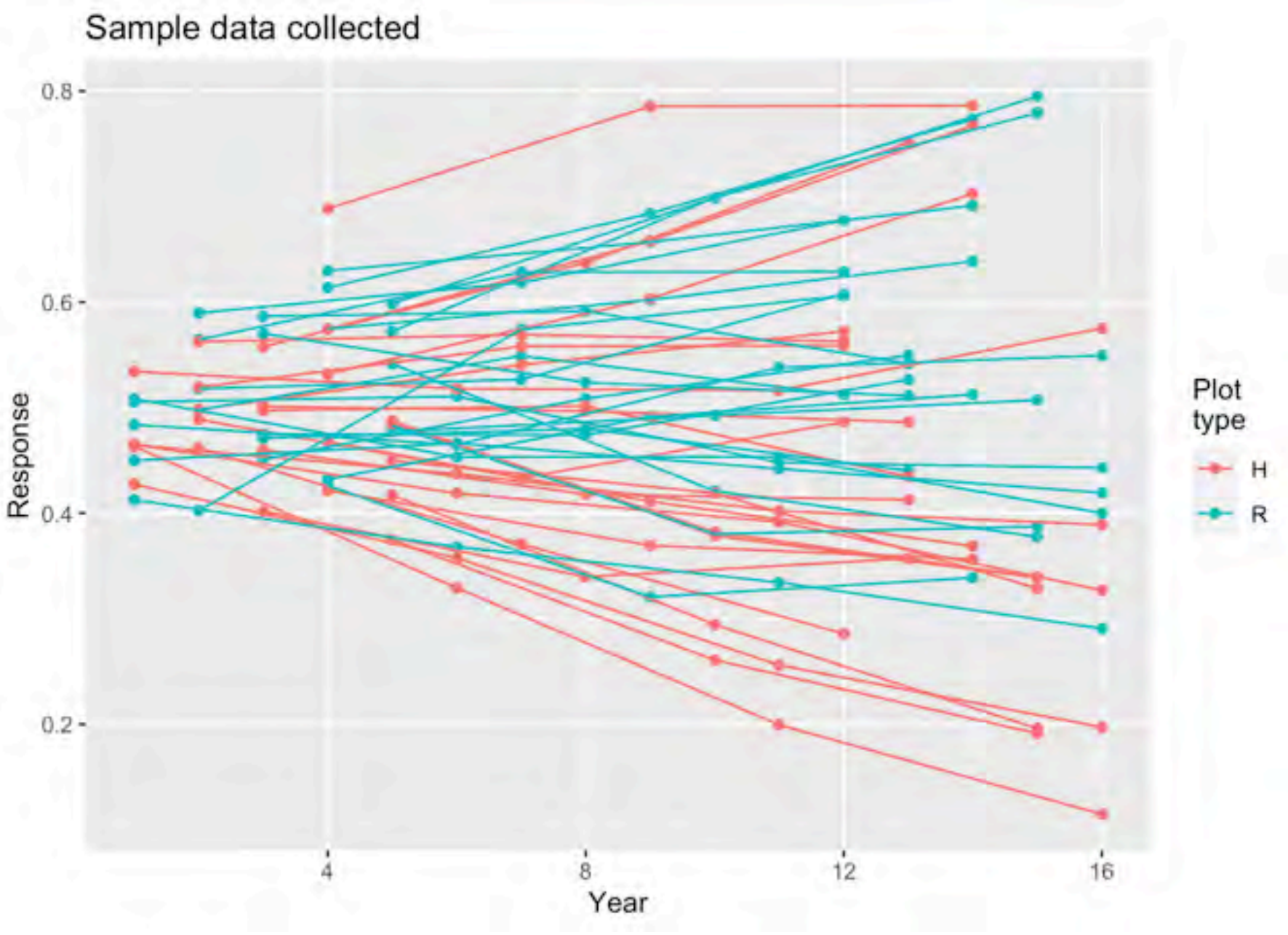
As noted in earlier documents, a key determinant of power/sample sizes is the variability in the trend across plots.

1.2 Simulated data

We generated some simulated data with the following characteristics

- The reference plots have an AVERAGE slope in the data values of 0 per year (this is arbitrary and does not change the analysis or power computations).
- The high deposition plots have an AVERAGE trend of -0.02 per year. Consequently, the differential trend is 0.02 per year.
- The actual slope for a plot varies (randomly) around the corresponding mean slope. This allows for each plot to have a separate trend line around the average for each group.
- The intercept for each plot also varies (spatial variation) among plot.
- The observed response at each measuring year also varies around the predicted response from the corresponding trend line for that plot.

Here is an illustration of what the simulated data looks like:



We see the generally plots in the high deposition area (H) have negative trend, but plots in the reference area have no trend. However, not all plots behave in exactly the same way, and there is variation in the response value in each measured year around the trend for each plot.

1.3 Illustration of analysis

A BACI-type analysis is used except rather than a step-change assumed for a BACI-design, we wish to see if the average slope is different for the reference and high deposition plots.

The analysis code is:

```
#fit1 <- lmerTest::lmer( Y ~ year + plot.type + year:plot.type + (1|plot.id) + (1|yea
rC)+ (year|plot.id), data=all.data)
# Mathematically, this is the same model, but has fewer convergence problems
fit <- lmerTest::lmer( Y ~ year + plot.type + year:plot.type + (1|yearC)+ (1+year|plo
t.id), data=all.data)
```

The terms in the model are:

- *year* representing a common slope for the reference and high deposition areas
- *plot.type* representing (potentially) different starting points for the reference and high deposition area (control vs impact)

- *year:plot.type* representing the DIFFERENTIAL slope for the reference and high deposition areas (the BACI effect)
- *(1|yearC)* a random effect representing year-specific effects that affect all plots simultaneously. For example, a “wet” year may cause the response in all plots to be above their respective trend line, while a “dry” year may cause the response in all plots to be below their respective trend line.
- *(1|plot.id)* a random effect representing the different initial conditions (year 0) for each plot
- *(year|plot.id)* a random effect representing random variation in the slopes in plots within each of the reference and high deposition area.

Notice that the last two terms can be combined in *R* to read *(1+year|plot.id)* which results in a more numerically stable fit.

The model was fit and the ANOVA table is

```
## Type III Analysis of Variance Table with Kenward-Roger's method
##                  Sum Sq  Mean Sq NumDF  DenDF F value  Pr(>F)
## year           0.001249 0.001249     1 46.918  0.1454 0.70469
## plot.type      0.000115 0.000115     1 47.436  0.0134 0.90843
## year:plot.type 0.047980 0.047980     1 47.969  5.5848 0.02222 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The statistical test for differential trend is found in the last line of the ANOVA table. The p-value is small, indicating that a differential trend was detected.

The estimated average slopes for the reference and high deposition areas is:

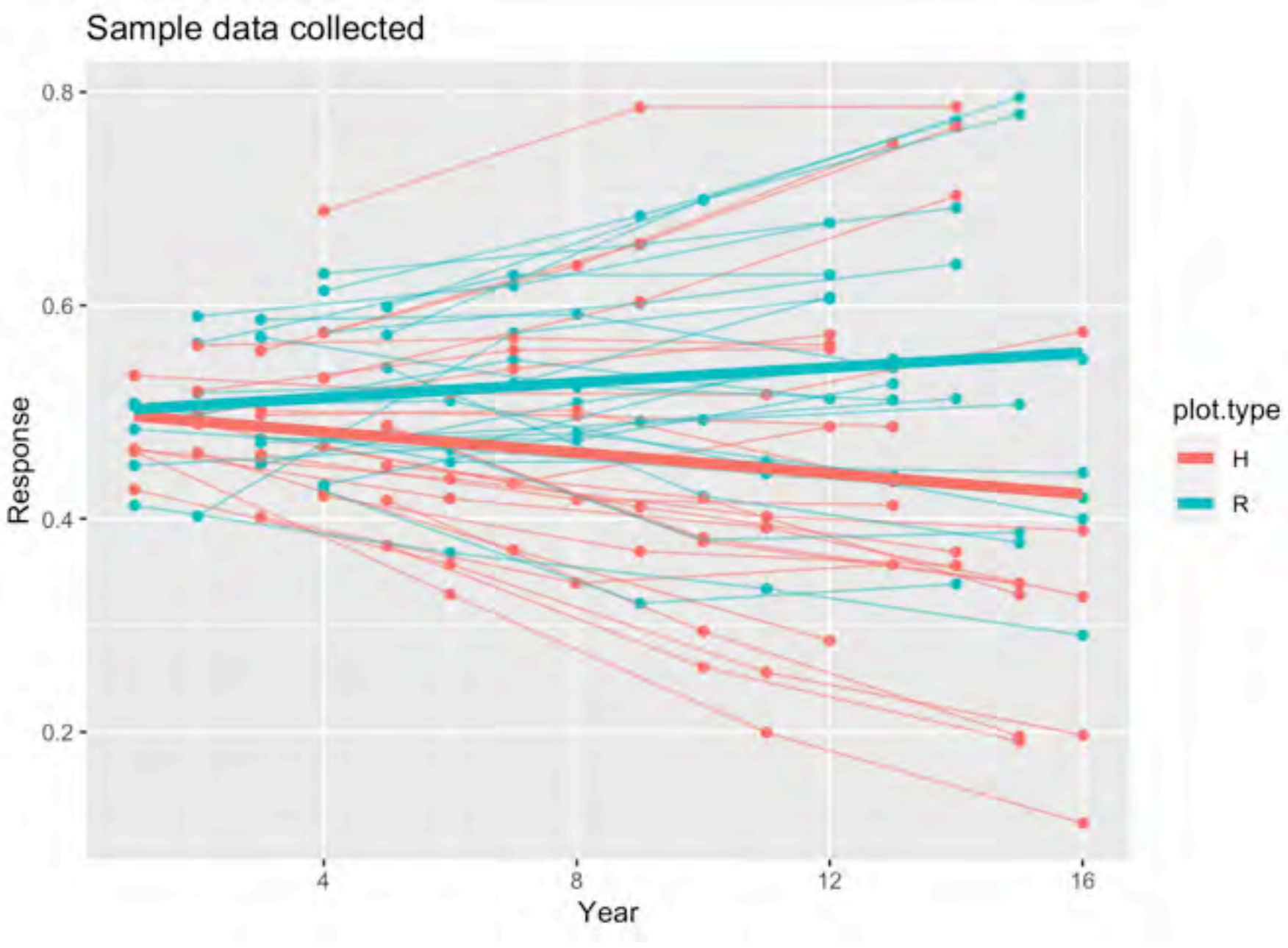
```
##  plot.type year.trend     SE   df lower.CL upper.CL .group
##  H             -0.0197 0.0101 47.8 -0.04002 0.000713  1
##  R              0.0142 0.0101 47.8 -0.00617 0.034557   2
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## significance level used: alpha = 0.05
```

The estimated differential trend (i.e. difference of the slopes) is:

```
##  contrast estimate     SE df lower.CL upper.CL t.ratio p.value
##  H - R     -0.0338 0.0143 48  -0.0626 -0.00505 -2.363  0.0222
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
```

The 95% confidence interval for the differential trend includes the true value of -0.02 per year.

A plot of the fitted AVERAGE trend lines and the raw data is



1.4 Sample size and power

How plots are needed for this monitoring design? The sample size/power of a design to detect effects will depend on

- number of plots. As the number of plots increases, the power to detect an effect increases.
- the biologically important effect size. A larger differential trend is easier to detect (higher power) than a smaller differential trend. THIS IS HARD TO DETERMINE!
- noise (variation) in the response. There are several sources of variation in this design
    - spatial variation in starting position for each plot
    - temporal variation in response around the plots trend line when measured
    - variation in the slope for a plot around the average slope for the reference or high deposition groups.

Generally speaking, spatial variation is less of a concern because each plots is repeatedly measured over time and so serves as a block. Temporal variation is caused by year specific effects, e.g. a wet or dry year and plot specific temporal effects. This is less of a concern with a large number of plots measured because when you average over plots, temporal variation is averaged out.

The key variation that affects power is the **variation in the slope for plots within each of the groups**. A low variation implies that all plots consistently move in the same direction; a large variation implies that some plots may see an increase in the response over time, while other plots may see a decrease over time. This makes it

difficult to measure the average slope with any precision.

We will use the US Forestry Inventory and Analysis monitoring program (https://www.fia.fs.fed.us/ (https://www.fia.fs.fed.us/)) to estimate what this variation in the slope among plots might be for selected genus or species cover data.

2 Using US Forestry Inventory and Analysis monitoring program

2.1 What is the US FIA

Briefly, the US FIA monitoring program (https://www.fia.fs.fed.us/ (https://www.fia.fs.fed.us/)) consists of a set of field sample locations distributed across the US landscape with approximately one sample location (FIA plot) every 6,000 acres. These are known as Phase 2 plots. Forested sample locations are visited by field crews who collect a variety of forest ecosystem data. Non forest locations are also visited as necessary to quantify rates of land use change.

Phase 3 plots consists of a subset of the phase two plots (approximately 1 every 96,000 acres) which are visited during the growing season in order to collect an extended suite of ecological data including full vegetation inventory, tree and crown condition, soil data, lichen diversity, coarse woody debris, and ozone damage. We will use the vegetation inventory data to try and estimate variation in trends in cover.

2.2 Plot selection

We downloaded the phase 2 and phase 3 data from the FIA website in August 2020. We tried to select plots from OR, WA and AK that matched as close as possible the Coastal Hemlock ecoregion found around Kitimat BC. Of course, data from OR and WA is based on regions that are “warmer” than northern BC, and unfortunately (as you will see later), the data from AK is very sparse. Despite these limitations, we hope that the estimates of variation in the trend will be similar.

Note that the variable *PLOT* is, unfortunately, not a unique identifier (see Section 1.3 of the P2 User Guide). We created a variable, *PLOT.ID*, that is a combination of state-county-plot that will be used to link records from various data sources.

We extracted plot level information using the M241, M242 ecological provinces in the states of OR, WA, and AK as defined in the FIA database:

```
## # A tibble: 2 x 2
##   Province Province_name
##   <chr>    <chr>
## 1 M241     Coastal Rainforest Province - Mountains
## 2 M242     Cascade Mixed Forest - Coniferous Forest - Alpine Meadow
```

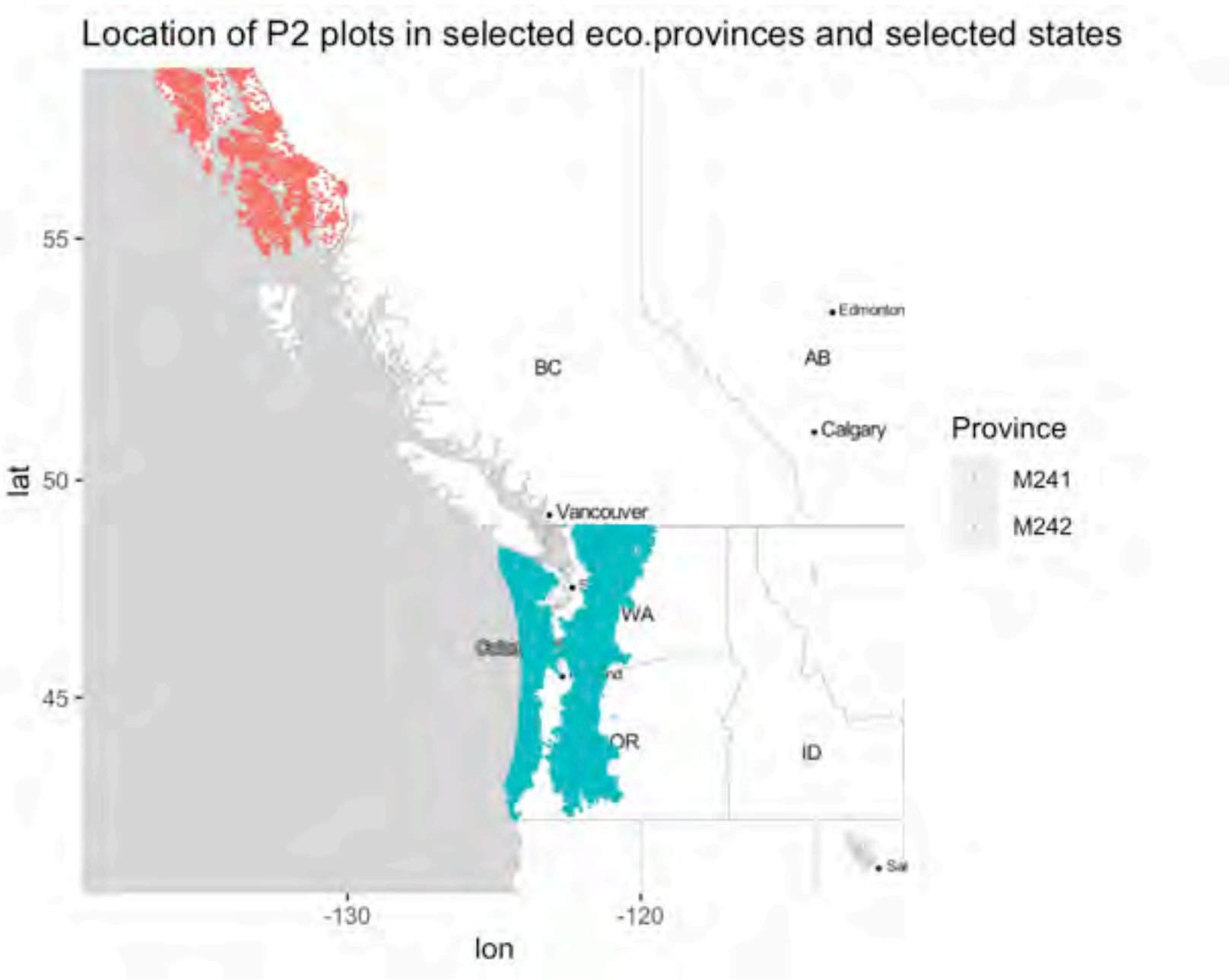
The plot level information contains information about each plot at each inventory year including latitude and longitude. Unfortunately, the FIA “fuzzifies” and “swaps” location information with other plots for privacy considerations so that a particular plot can “appear” to change locations over time. We used the location

(latitude, longitude, state) of a plot at its first measurement as the “fixed” location for the plot.

This gives the following number of phase 2 plots by state and ecological province:

```
##                                                                STATEAB
## paste0(Province, ".", Province_name)                              AK   OR   WA
##   M241.Coastal Rainforest Province - Mountains                  5110    0    0
##   M242.Cascade Mixed Forest - Coniferous Forest - Alpine Meadow    0 5468 4885
```

A map of the location of the Phase 2 plots is:



Not all Phase 2 plots have vegetation collected (Phase 3 plots). We downloaded the vegetation cover data base and restricted it to the phase 2 plots. We again create a *PLOT.ID* variable as a combination of state-county-plot as indicated in P2 User Guide.

```
##     STATECD              CN COUNTYCD  PLOT INVYR SUBP CONDID         PLT_CN SUBPCO
ND_PROP MICRCOND_PROP MACRCOND_PROP HECTCOND_PROP NONFR_INCL_PCT_MACRO NONFR_INCL_PCT
_SUBP CYCLE SUBCYCLE UNITCD
## 81         2 188425805020004      150 67802  2012    4      3 63491002010760      0
.163545      0.000000             NA             NA                    NA
NA     2        9      1
## 86         2  36599662010497      201 45400  2004    3      1 21975434010497      0
.582859      1.000000             NA             NA                    NA
NA     2        1      1
## 155        2  36599648010497      201 24905  2004    1      2 21974962010497      0
.466697      0.000000             NA             NA                    NA
NA     2        1      1
## 254        2  36599610010497      201 26160  2004    1      2 21974547010497      0
.400396      0.000000             NA             NA                    NA
NA     2        1      1
## 258        2  36599614010497      201 26160  2004    4      2 21974547010497      0
.414651      0.239191             NA             NA                    NA
NA     2        1      1
##     RGN_FLG RGN_TYP STATENM STATEAB      PLOT.ID
## 81       NA      NA  Alaska      AK 67802.AK.150
## 86       NA      NA  Alaska      AK 45400.AK.201
## 155      NA      NA  Alaska      AK 24905.AK.201
## 254      NA      NA  Alaska      AK 26160.AK.201
## 258      NA      NA  Alaska      AK 26160.AK.201
```

```
##       CONDID
## INVYR      1     2     3     4     5     6
##   2001  1990   391    57     4     0     0
##   2002  3633   738   122    12     0     0
##   2003  3538   672   120     7     1     0
##   2004  4469   786   123     8     1     0
##   2005  4765   776    99     4     0     0
##   2006  4409   848    97    10     0     0
##   2007  3640   734   109    11     1     0
##   2008  3610   699   142    14     1     0
##   2009  3548   742   116     8     0     0
##   2010  4247   754   129    13     0     0
##   2011  4293   773   105     8     3     0
##   2012  4381   887   164    10     0     0
##   2013  4336   845   180    20     1     0
##   2014  3672   729   122     3     1     2
##   2015  4358   844   101     6     0     0
##   2016  4399   892   105    13     0     0
##   2017  4397   901   149    22     0     0
##   2018  3575   688   152    13     2     0
##   Sum  71260 13699  2192   186    11     2
```

```
##       DSTRBCD1
## CONDID     0    10    11    12    20    21    22    30    31    32    40    41
42    43    44    45    46    50    51    52    53    54    60    70    80    90    9
1    92    94    95  <NA>
##       1 52138  1543    68  1621  3005    51  3663   147   900   866   116    53
99   108   218     4   515   430   106   840    56   109   230   302   140     7   11
8   162    11    50  3584
##       2  8082   134     3   202   181     3   260    14   110    69    12    12
3    12     6     4    54    37    10    59    23    15    15    15    25     4    14
44     3    25  4249
##       3  1297    29     2    40    34     1    34     1    15     9     0     0
1     4     4     0     0     5     4     7     6     2     1     0     5     0     3
8     0     2   678
##       4    87     1     0     7     2     0     2     0     0     0     0     0
0     0     0     0     3     0     0     4     0     0     1     0     0     0     0
1     0     0    78
##       5     6     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     5
##       6     2     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
```

```
##       disturbed
## INVYR  FALSE  TRUE  <NA>
##   2001  1612   314   138
##   2002  2564   905   327
##   2003  2648   777   259
##   2004  3382   803   495
##   2005  3554   751   671
##   2006  3172   858   602
##   2007  2370   845   561
##   2008  2464   754   554
##   2009  2472   782   458
##   2010  3167   741   556
##   2011  3087   978   475
##   2012  3181  1059   384
##   2013  2892  1330   374
##   2014  2612   963   273
##   2015  3146  1134   332
##   2016  3136  1149   383
##   2017  3071  1149   440
##   2018  2311  1035   410
##   Sum  50841 16327  7692
```

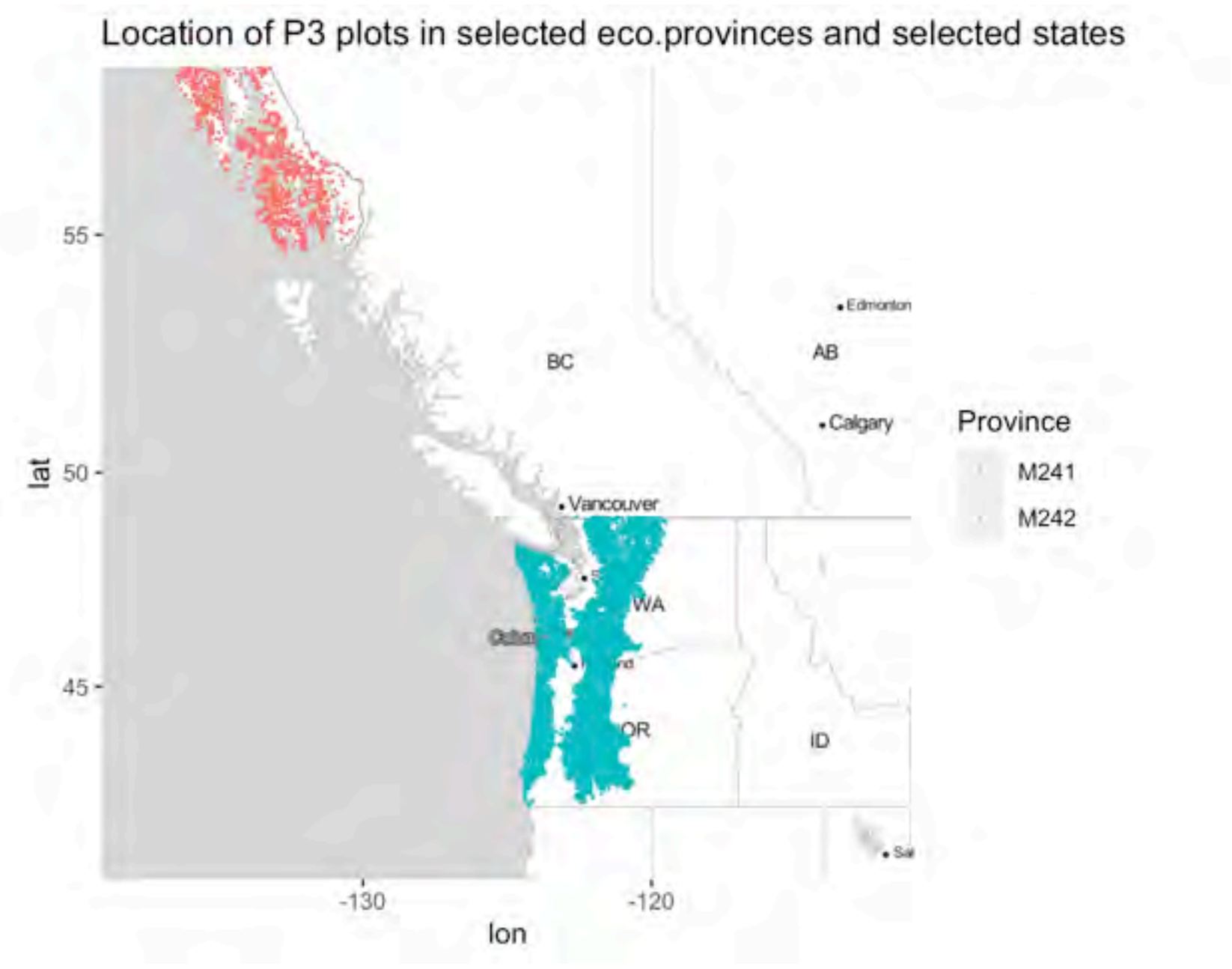
This gives the following number of phase 3 plots with vegetation information by state and ecological province:

```
##                                                                STATEAB
## paste0(Province, ".", Province_name)                              AK   OR   WA
##   M241.Coastal Rainforest Province - Mountains                  1574    0    0
##   M242.Cascade Mixed Forest - Coniferous Forest - Alpine Meadow    0 5114 4275
```

The total number of plot-years measured by state and ecological province is:

```
##                                                                STATEAB
## paste0(Province, ".", Province_name)                              AK   OR   WA
##   M241.Coastal Rainforest Province - Mountains                  2224    0    0
##   M242.Cascade Mixed Forest - Coniferous Forest - Alpine Meadow    0 9210 7281
```

These P3 plots are located at:



2.3 Cover data

Vegetation cover data is measured at up to 4 sub-plots in each of the P3 plots in each inventory year. In most cases, all four sub-plots are measured at each P3 plot in each inventory year:

```
## How many sub-plots are measured in the P3 plots each year?
```

```
##       n.subplots
## INVYR      1     2     3     4
##   2001     1     6    20   477
##   2002    11    14    54   845
##   2003     5    14    55   835
##   2004     4    15    60   869
##   2005    12    17    56   914
##   2006     6    21    59   827
##   2007    11    17    51   838
##   2008    16    21    41   847
##   2009    13    23    56   836
##   2010    12    23    72  1009
##   2011    10    28    70   972
##   2012    19    29    52  1035
##   2013    17    22    81  1012
##   2014     8    17    52   868
##   2015    17    21    77  1021
##   2016    18    25    74  1029
##   2017    21    29    85  1001
##   2018    17    20    59   799
##   Sum    218   362  1074 16034
```

The data is stored with a separate record for each plot-subplot-inventory-year-species combination. Notice that missingness implies 0 percent cover for a species on a sub-plot for an inventory year.

The vegetation cover data is measured in several layers:

```
## # A tibble: 5 x 2
##   LAYER LAYER_HEIGHT
##   <dbl> <chr>
## 1     1 0 to 2.0 feet
## 2     2 2.1 to 6.0 feet
## 3     3 6.1 to 16.0 feet
## 4     4 Greater than 16 feet
## 5     5 Aerial: Canopy cover for all layers
```

We restricted cover data to layer codes 1 and 2, i.e. from 0 to 6.0 feet (approximately 2 meters).

2.4 Cover for **Vaccinium** genus.

The complete plant species database was downloaded from PLANTS database (https://plants.sc.egov.usda.gov/ (https://plants.sc.egov.usda.gov/)) which provides standardized information about the vascular plants, mosses, liverworts, hornworts, and lichens of the U.S. and its territories. **Are there Canadian species that are not present in this database?**

We will compute the TOTAL cover of all plants in the **Vaccinium** genus (blueberry and similar plants). The genus consists of 122 different species (and sub-species) (not all of which are present in the P3 plots). The common names of the selected species include:

```
##       [,1]                          [,2]
##  [1,] "Alaska blueberry"            "cranberry"
##  [2,] "lowbush blueberry"           "thinleaf huckleberry"
##  [3,] "farkleberry"                 "velvetleaf huckleberry"
##  [4,] "blueberry"                   "whortleberry"
##  [5,] "northern blueberry"          "shiny blueberry"
##  [6,] "sea bilberry"                "oval-leaf blueberry"
##  [7,] "New Jersey blueberry"        "California huckleberry"
##  [8,] "ohelo kau la'au"             "red huckleberry"
##  [9,] "dwarf bilberry"              "Blue Ridge blueberry"
## [10,] "highbush blueberry"          "ohelo 'ai"
## [11,] "creeping blueberry"          "grouse whortleberry"
## [12,] "Darrow's blueberry"          "upland highbush blueberry"
## [13,] "ohelo"                       "deerberry"
## [14,] "Elliott's blueberry"         "small black blueberry"
## [15,] "southern mountain cranberry" "bog blueberry"
## [16,] "southern blueberry"          "lingonberry"
## [17,] "black highbush blueberry"    "smallflower blueberry"
## [18,] "Mexican blueberry"           "northern mountain cranberry"
## [19,] "hairy blueberry"             "Alaska blueberry"
```

The range of cover for *Vaccinium* in each sub-plot of the P3 plots in the selected eco.province of WA, OR, and AK is:

```
## [1]   0 180
```

Notice that total cover on a sub-plot can exceed 100% given the number of different species and two layers to the data.

Finally, we find the mean percent cover over the sub-plots measured in a P3 plot in an inventory year.

The range of mean percent total cover (over subplots) is:

```
## [1]   0 116
```

We notice that if the percent cover is very small, it tends to occur only in one subplot, and so the mean total percent cover (including the sub-plots with 0 total cover) is reduced.

2.5 Change in cover

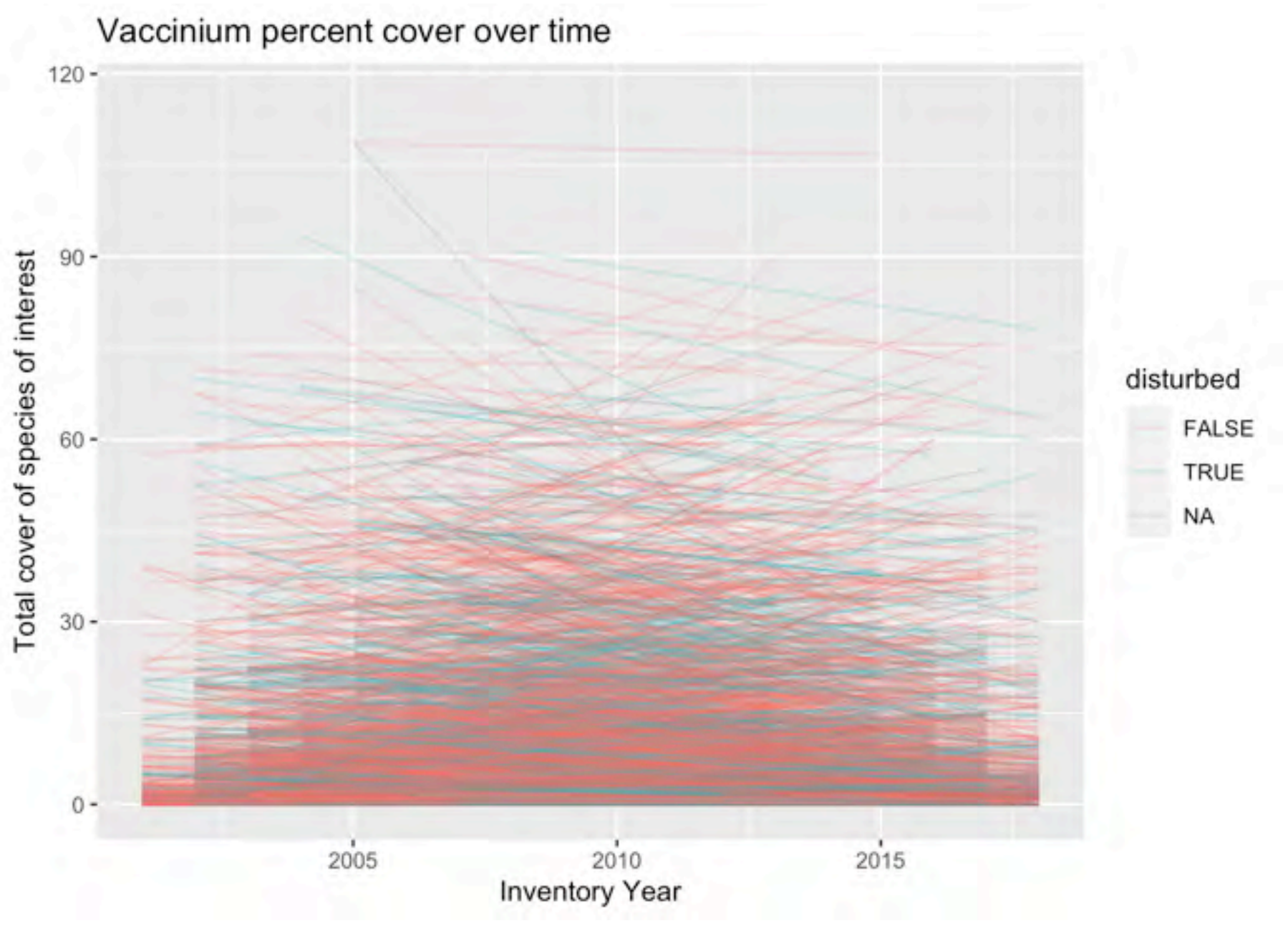
Not all P3 plots in the FIA database have been measured for multiple years and not all plots have the species of interest. A breakdown of the number of inventory years for plots with the species of interest is:

```
## Distribution of P3 plots by the number of inventory years
```

```
##        n.years
## STATEAB    1    2
##      AK 1574    0
##      OR 1226 3888
##      WA 1438 2837
```

Unfortunately, the majority of plots have only been measured for 1 year and so provide no information on changes in mean total percent cover for this species over time. In particular, there are very no plots in AK with repeated measurements at this time.

We can now plot the mean total percent cover over time for those plots with multiple measurements. If a disturbance is recorded for any of the subplots we code the plot as “disturbed”. For some plots, disturbances are not recorded (typically in areas that are not-forested).



For each plot with multiple measurements, we found the yearly increase in the total percent cover as

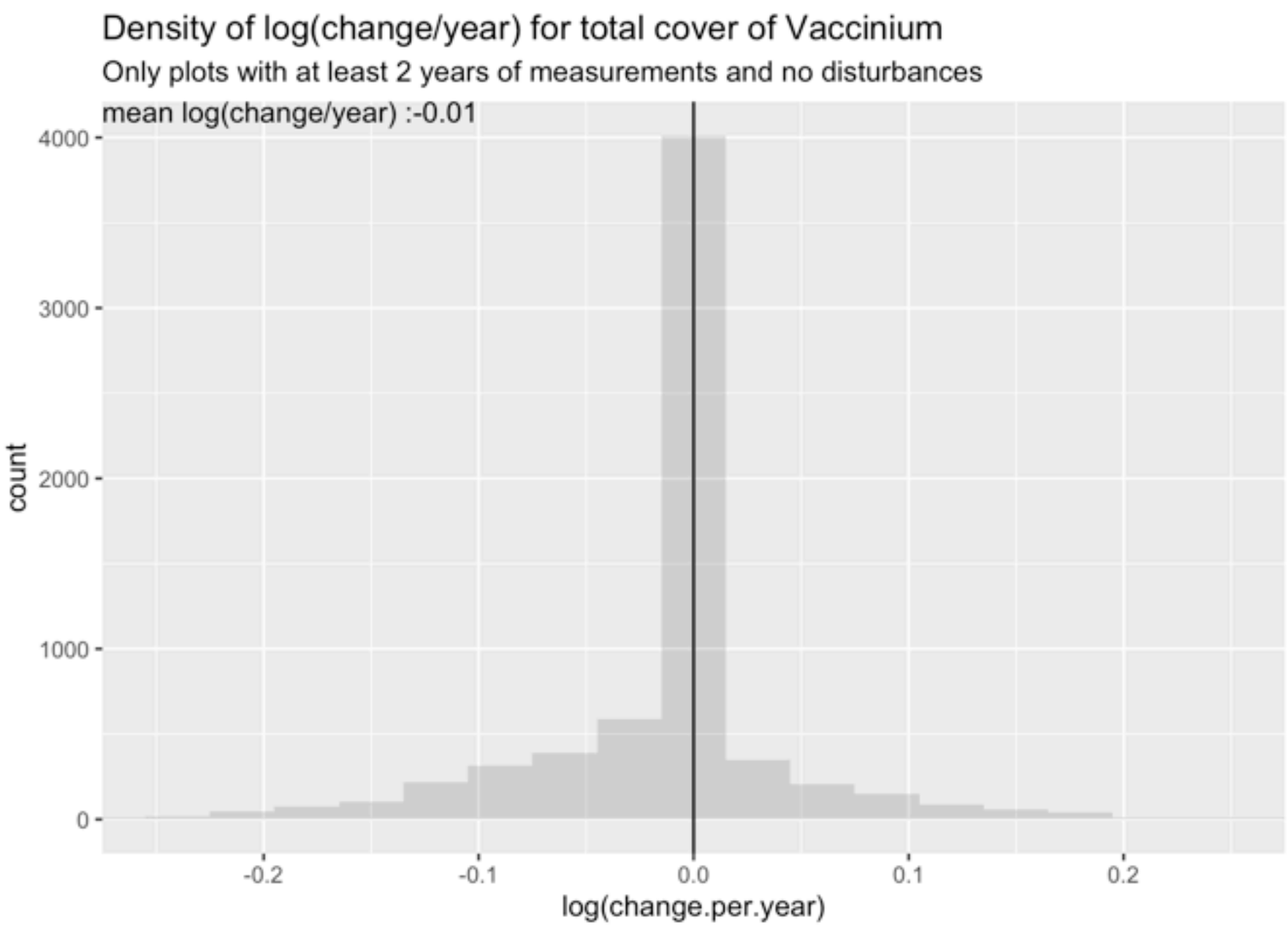
$$(final.cover/intial.cover)^{1/year.span}$$

For example, if the total percent cover in year 1 was 50% and the total percent cover in year 6 was 75%, this corresponds to an average yearly increase of

$$(75/50)^{1/5} = 1.0845$$

or about an 8.45% increase per year compounded over 5 years. If one of the initial or final cover is 0%, we arbitrarily change it to 1% to avoid divisions by 0.

A plot of the distribution of the log(annual change) for plots with at least two inventory measurements is:



The mean annual log(change/year) is NA and it appears that most plots are near steady state (little change per year), but the standard deviation in the trends is 0.064.

WHEW! This final number (the standard deviation of the $log(annual.change))$ is the value needed for a power analysis!

3 Power/sample size analysis

We can now estimate the power of a design to estimate a certain trend over the monitoring time spans of interest.

How many plots are needed for this monitoring design? The sample size/power of a design to detect effects will depend on

- number of plots. As the number of plots increases, the power to detect an effect increases.
- the biologically important effect size. A larger differential trend is easier to detect (higher power) than a smaller differential trend. THIS IS HARD TO DETERMINE!
- noise (variation) in the response. There are several sources of variation in this design

    - spatial variation in starting position for each plot
    - temporal variation in response around the plots trend line when measured
    - variation in the slope for a plot around the average slope for the reference or high deposition groups.

Generally speaking, spatial variation is less of a concern because each plots is repeatedly measured over time and so serves as a block. Temporal variation is caused by year specific effects, e.g. a wet or dry year and plot specific temporal effects. This is less of a concern with a large number of plots measured because when you average over plots, temporal variation is averaged out. The key variation that affects power is the variation in the slope for plots within each of the groups. A low variation implies that all plots consistently move in the same direction; a large variation implies that some plots may see an increase in the response over time, while other plots may see a decrease over time. This makes it difficult to measure the average slope with any precision.

The effect size of interest (biologically important effect size) is NOT a statistical question, but generally speaking effect sizes that are small fractions of the noise levels will require enormous sample sizes!

The power of a particular design to detect a specified effect size (and given estimates of the variance components) is evaluated using simulation methods. Briefly, simulated data is generated with the specified effect sizes and variance components. The simulated data is analyzed. The proportion of times that the effect is detect is then an estimate of the power.

We examined the following scenarios

- three or five plots measured per year in each of the high or reference deposition areas
- plots measured every five years. The combination of five plots per year in the two deposition areas with a five year skip interval implies a total of 50 plots; three plots per year in the two deposition areas with a five year skip interval implies a total of 30 plots.
- a 16 and 26 year program. In a 16 year program, plots established in year 1 will have been measured 4 times in years 1, 6, 11, and 16 (other plots will have been measured 3 times) and in a 26 year program, plots established in year 1 will have been measured 6 times (and other plots will have been measured 5 times)
- standard deviation of log(annual.change) from the previous analysis
- alpha = 0.05
- differential trends in percent cover between reference and control areas of 0 (no impact of deposition),-2%/year or -4%/year. Note that this is a percent change of a percentage. For example, if the initial total cover was 50%, then a -2% change/year, implies that the percent cover would decrease from 50% to 49% (a reduction of 1 percentage point out of 50% or a 2% change in total cover). These yearly increases, while seeming small, will be compounded so a -2% change per year yields an approximate 27% decline over 16 years, and a 41% decline over 26 years. Similarly, a 4% decline/year yields an overall decline of 48% over 16 years and an overall decline of 65% over 26 years.

Here is are the resulting estimates of power for the various effect sizes:

```
##
## Estimated power for differential slope of  -0.04  per year with sd log(trend) of
0.064
## Corresponding to total effect over the end.years in study of  -0.48 -0.65  reducti
on
##             end.year
## nplots.year    16    26
##           3 0.368 0.372
##           5 0.571 0.579
##
## Estimated power for differential slope of  -0.02  per year with sd log(trend) of
0.064
## Corresponding to total effect over the end.years in study of  -0.28 -0.41  reducti
on
##             end.year
## nplots.year    16    26
##           3 0.129 0.139
##           5 0.191 0.188
##
## Estimated power for differential slope of  0  per year with sd log(trend) of  0.06
4
## Corresponding to total effect over the end.years in study of  0 0  reduction
##             end.year
## nplots.year    16    26
##           3 0.055 0.052
##           5 0.047 0.060
```

Normally, a suggested power of 0.80 at alpha=.05 is preferred.

In this case, the standard deviation of the trend may be overstated because no adjustment has been for disturbances (e.g. forest fires) that would normally cause a plot to be rotated out of the design. A reduction in the sd would cause the estimated power to increase, but rotating plots out of the design will cause a slight reduction in power until the new plot receives multiple measurements.

There are a number of way to increase the power for a given sample size.

- Start more plots in year 1. One problem with a staggered entry design is that it takes 5 years to get the first measurement on all of the plots and 10 years before 2 measurements are available on all plot. But even in year 10, some plots have only been “monitored” for 5 years (those started in year 5). Power can be increased by starting more plots in year 1 (i.e. a big push to establish plots in year 1) and then staggering monitoring in years 6 onwards.
- Increase the number of plots established and monitored in each year. More plots is always better, but simply increasing the number of plots still leaves unresolved the problem that some plots are not started until year 5.

3.1 Impact of a reduced sd in the trend

The variation in trend seen above excluded plots that were disturbed between the measurements but has not been adjusted for year-specific effects. For example, with only 2 measurements, the fitted trend line will go through the two points exactly. If, for example, one of the years was wetter than normal, perhaps growth of the plants was improved and the percent cover will be increased compared to a normal year. The fitted trend line through the two data points will then affected by these year specific effects. If three or more years of data are available, the fitted trend will NOT go through the exact data points and so will be less affected by year-specific effects.

The net effect of these year specific effects will be to increase the variation in the observed trend lines. Unfortunately, with only two measurement years, it is not possible to adjust for these year specific effects.

Here is an illustration of the impact in reducing the standard deviation in the trend on the power analysis by 20% (arbitrarily chosen) to account for these year specific effects:

Here is are the resulting estimates of power for the various effect sizes with the reduced standard deviation:

```
##
## Estimated power for differential slope of  -0.04  per year with sd log(trend) of
0.051
## Corresponding to total effect over the end.years in study of  -0.48 -0.65  reducti
on
##             end.year
## nplots.year    16    26
##           3 0.533 0.532
##           5 0.766 0.781
##
## Estimated power for differential slope of  -0.02  per year with sd log(trend) of
0.051
## Corresponding to total effect over the end.years in study of  -0.28 -0.41  reducti
on
##             end.year
## nplots.year    16    26
##           3 0.174 0.180
##           5 0.257 0.255
##
## Estimated power for differential slope of  0  per year with sd log(trend) of  0.05
1
## Corresponding to total effect over the end.years in study of  0 0  reduction
##             end.year
## nplots.year    16    26
##           3 0.042 0.070
##           5 0.042 0.060
```

As expected the power is higher with this reduced standard deviation in the trends.

Appendix E. 2019 SO_2 EEM Comprehensive Review

This appendix contains the Wind Correction Addendum to the 2019 Comprehensive Review and the complete version of the 2019 Comprehensive Review for the SO_2 EEM Program.

It is provided on the following pages in its original PDF format.

Sulphur Dioxide Environmental Effects Monitoring for B.C. Works

Wind Correction Addendum to the 2019 Comprehensive Review, V.2 Final

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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.

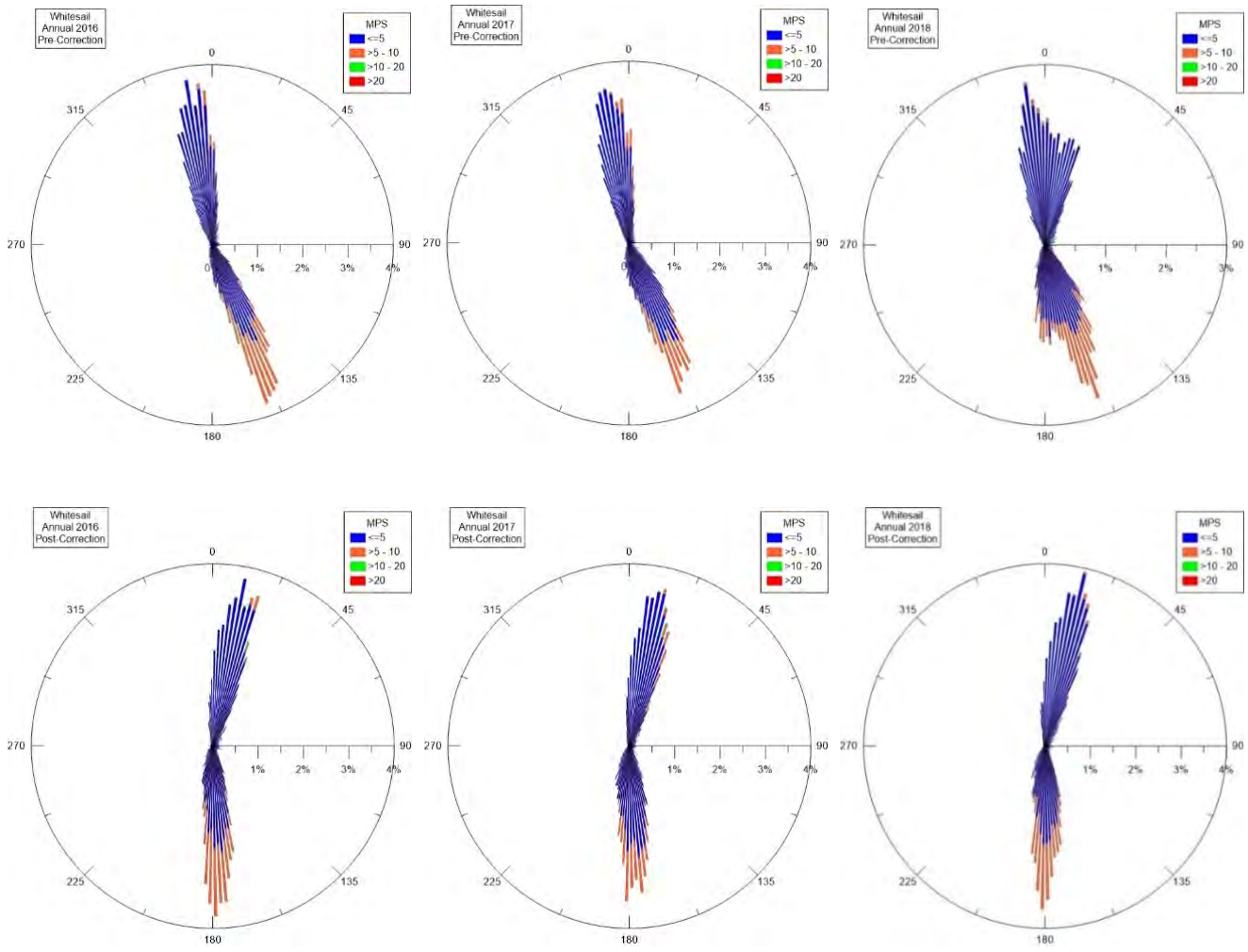


Figure 2-1. Whitesail Wind Rose Comparison.

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.

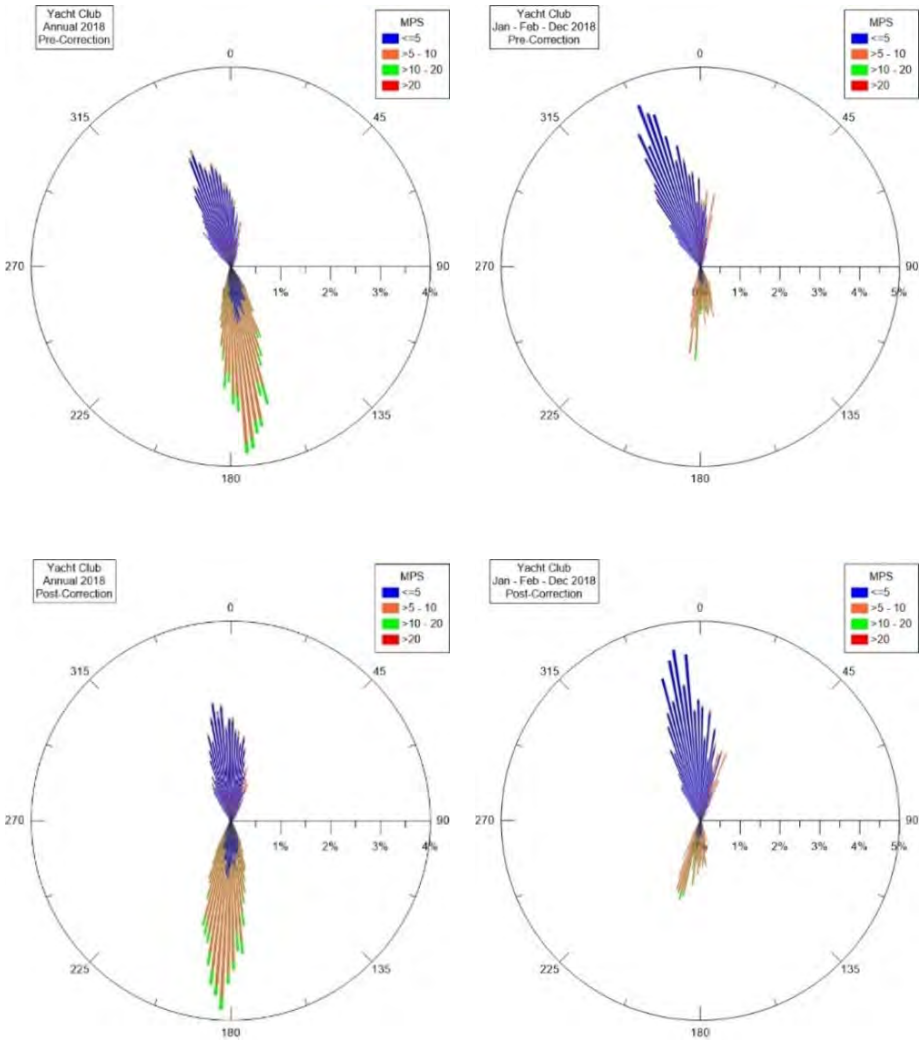


Figure 2-2. Yacht Club Wind Rose Comparison for 2018.

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.

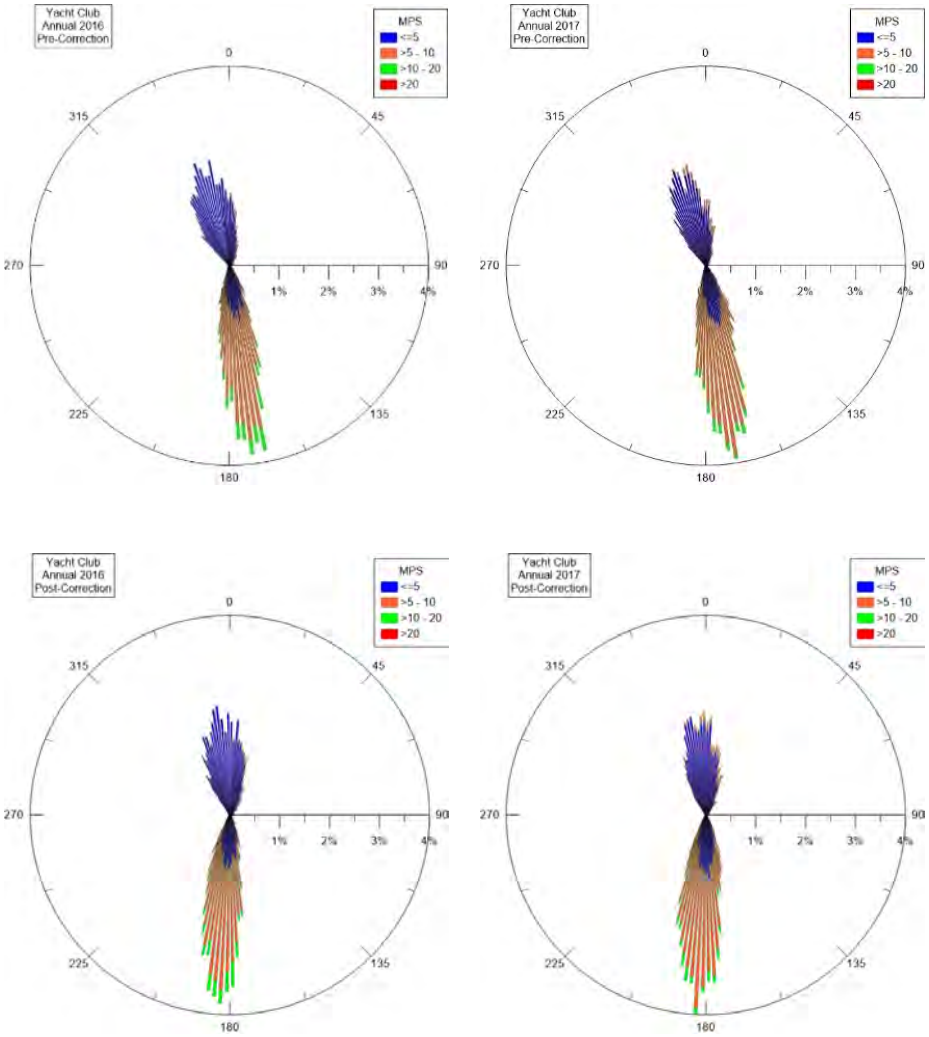


Figure 2-3. Yacht Club Wind Rose Comparison for 2016 and 2017.

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 files used as input to CALMET rounds wind direction to the nearest 10 degrees.[3] 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.

[3] The file format used as CALMET input is CD144, which includes only two digits for wind direction, so each wind direction data point is rounded to the nearest 10 degrees. For example, 214 degrees would be represented by 21. The meteorological data posted on ENVISTA by ENV does not contain 10-degree rounding.

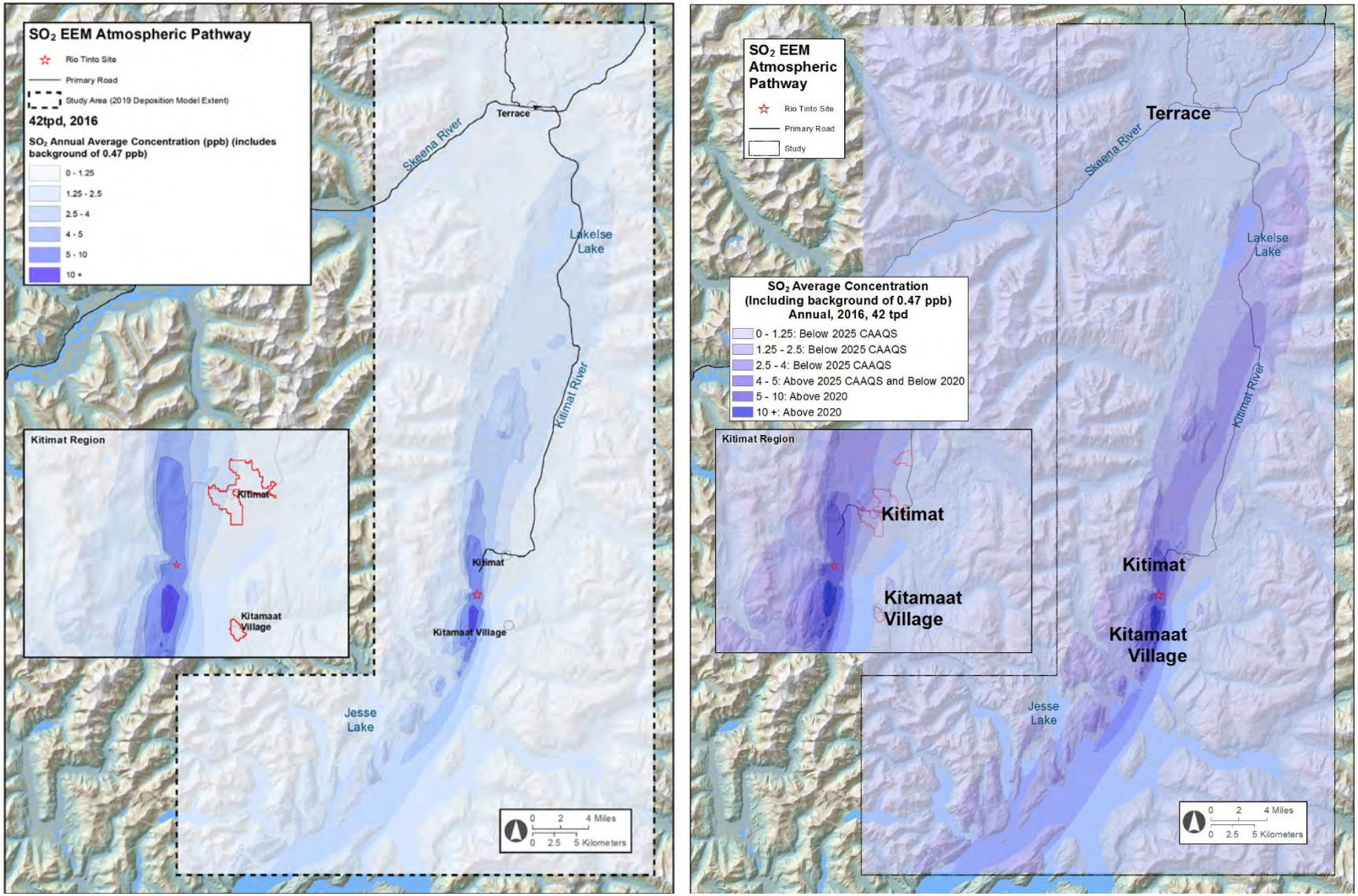


Figure 2-4. SO_2 Annual Concentration Comparison – 2016. The map on the left is pre-correction, the map on the right is post-correction.

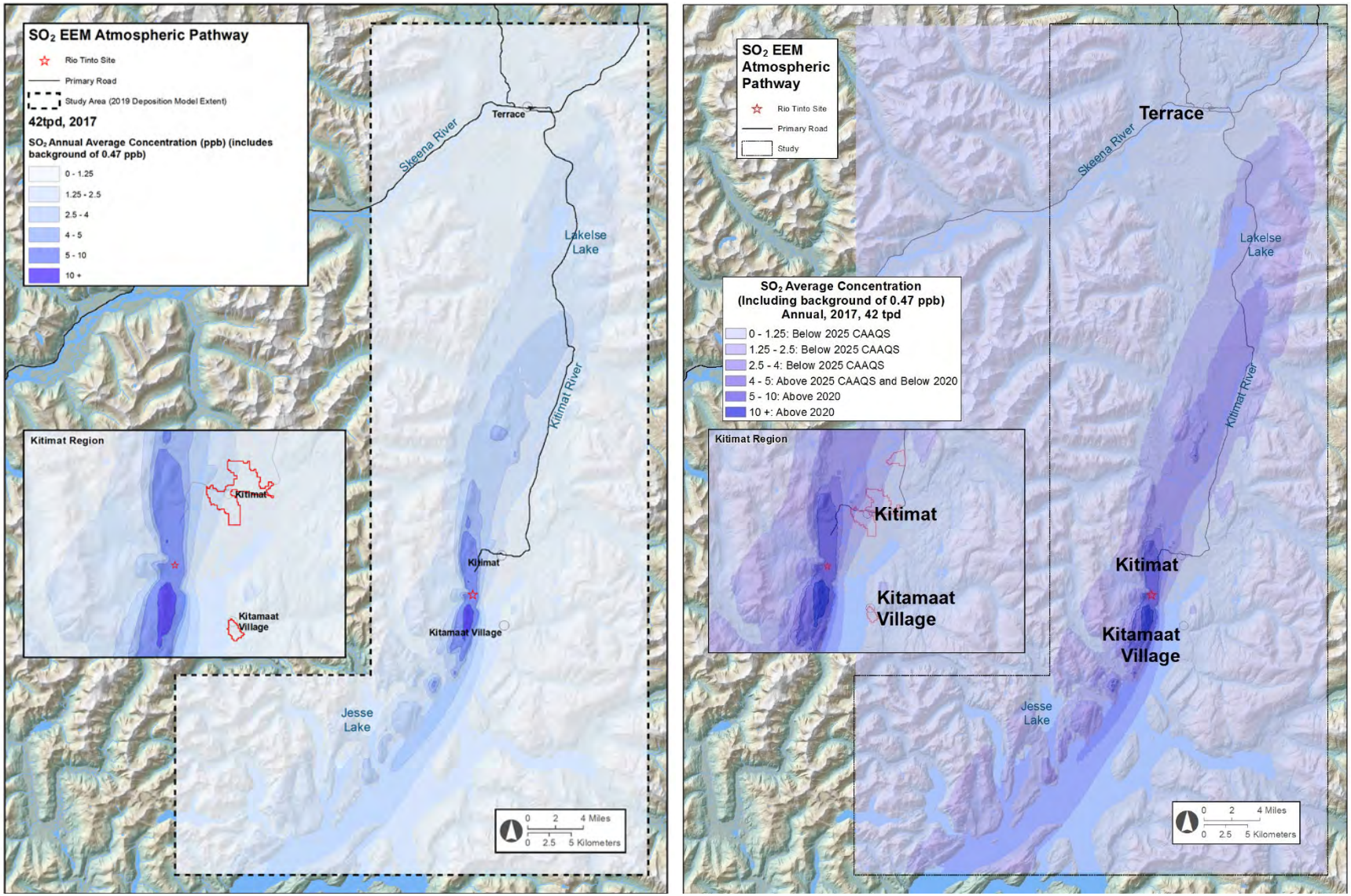


Figure 2-5. SO_2 Annual Concentration Comparison – 2017. The map on the left is pre-correction, the map on the right is post-correction.

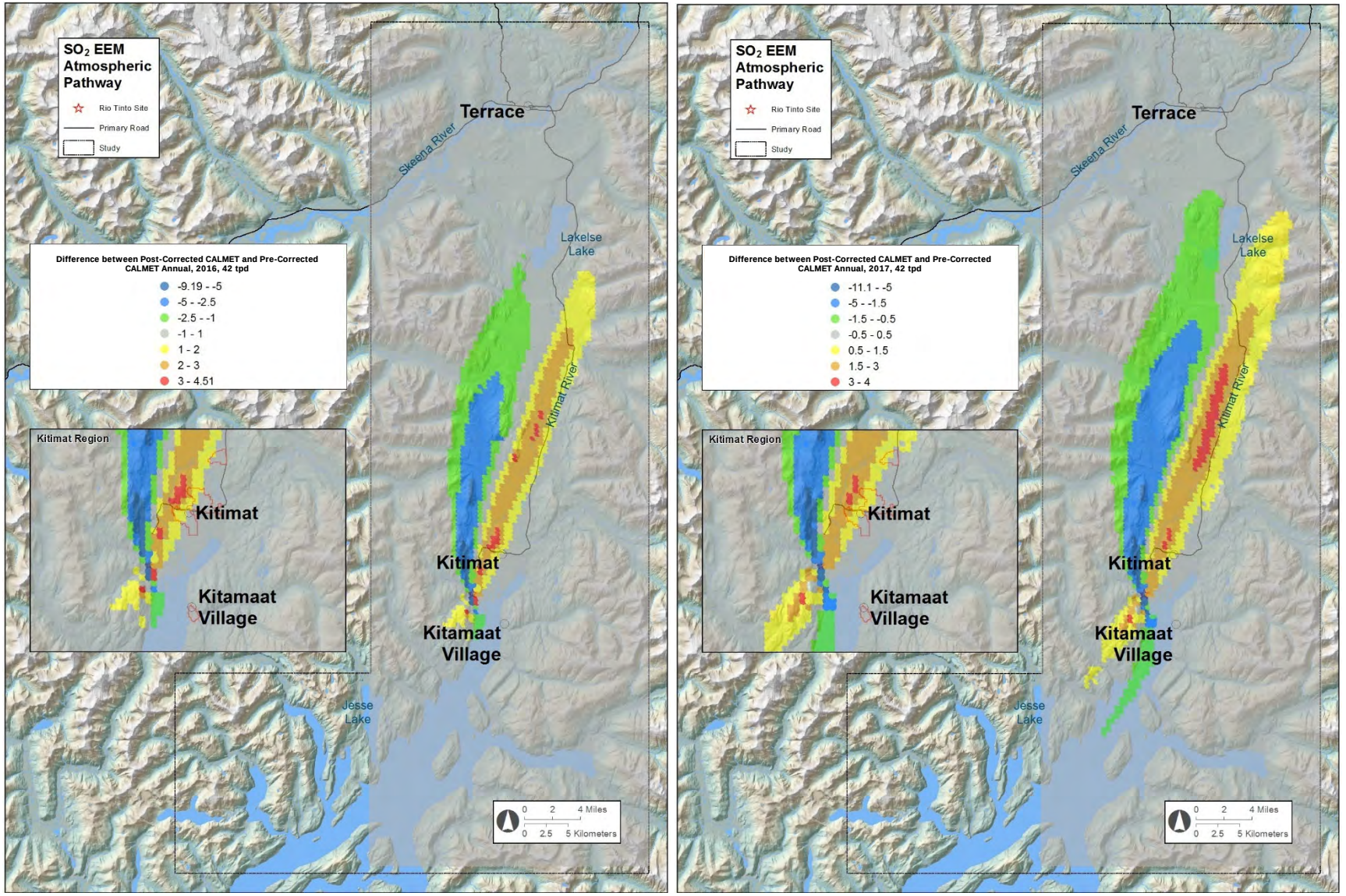


Figure 2-6. SO_2 Annual Difference – 2016 and 2017.

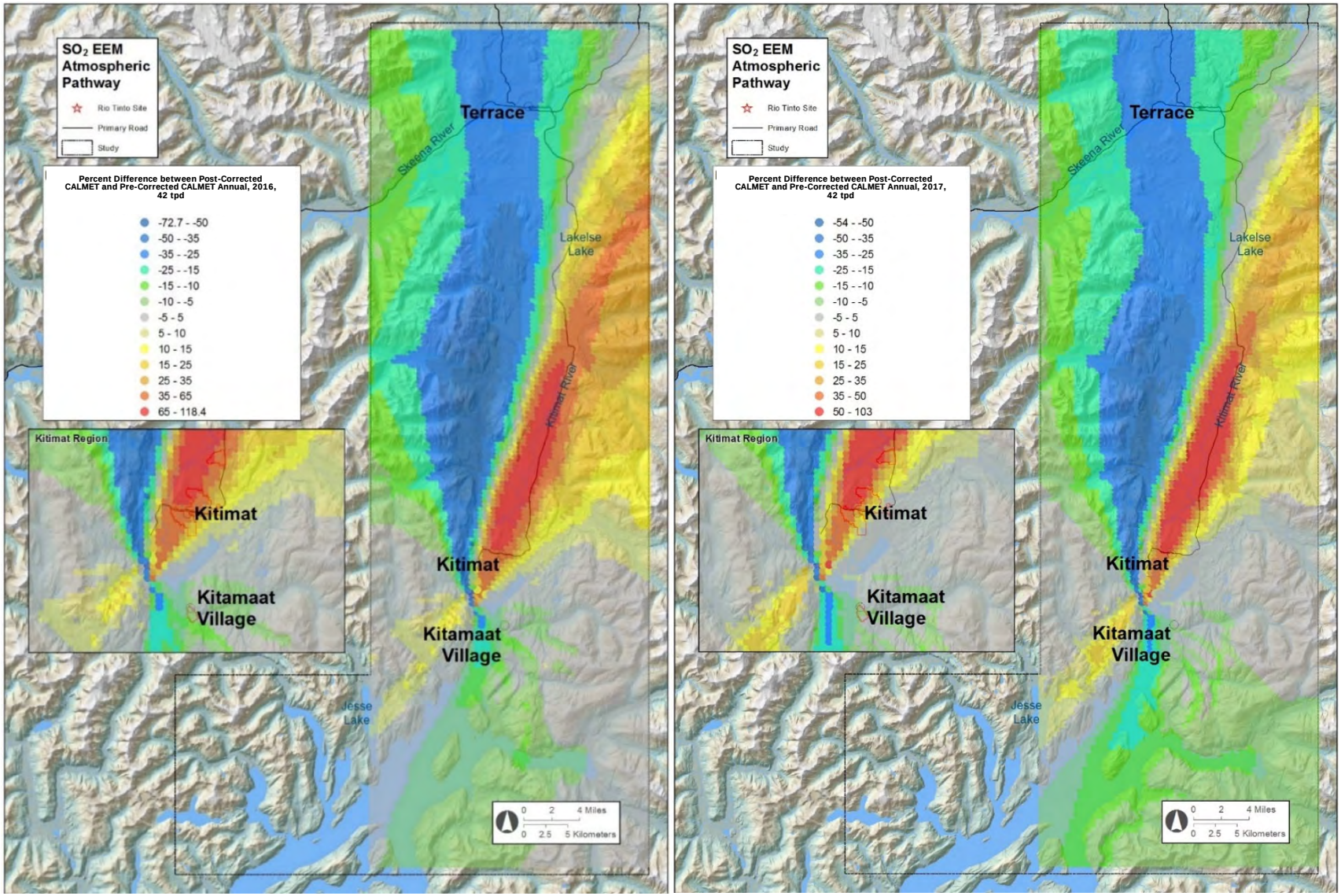


Figure 2-7. SO_2 Annual Percent Difference – 2016 and 2017.

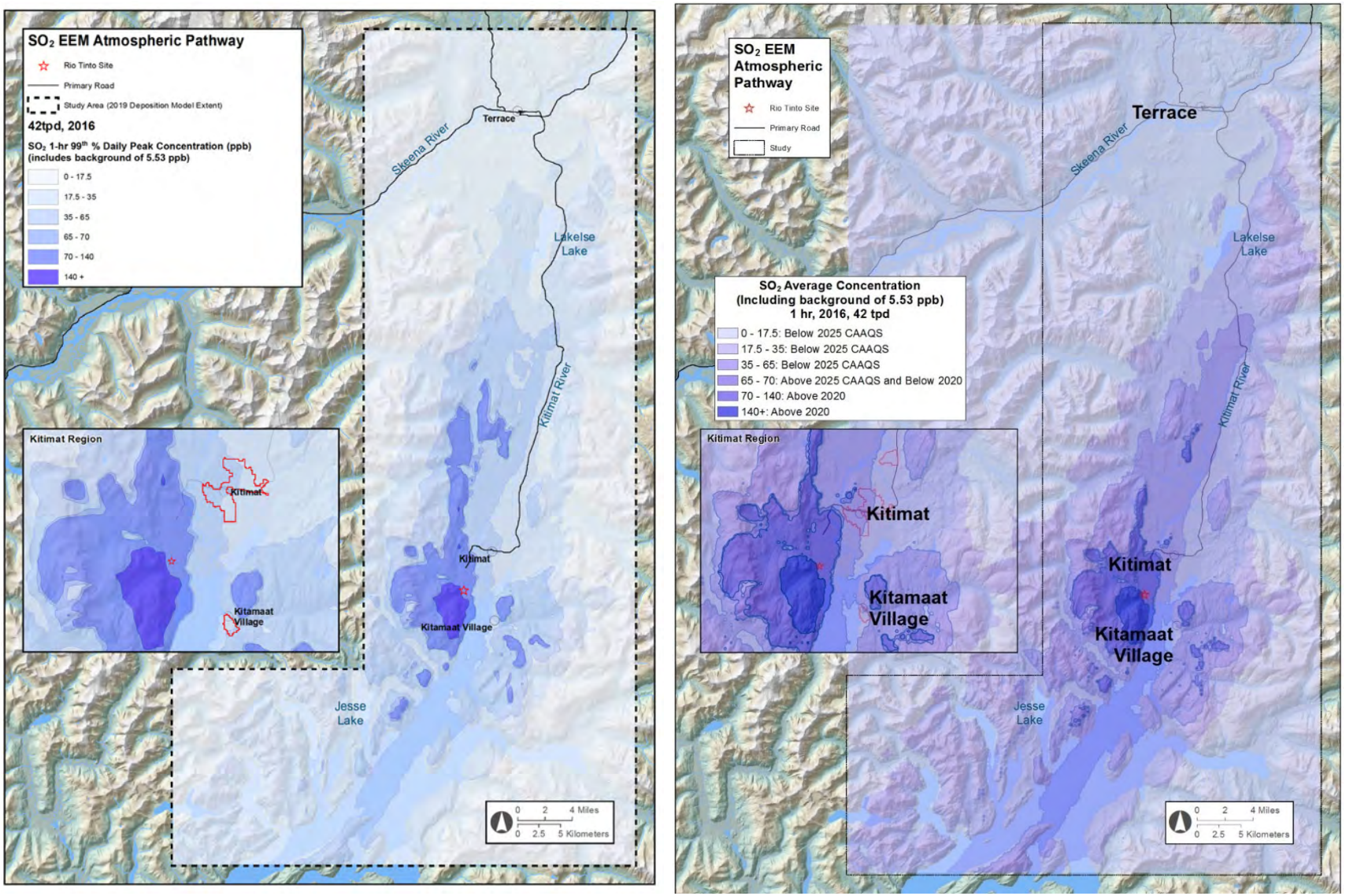


Figure 2-8. SO_2 99% Daily 1hr Peak Concentration Comparison – 2016. The map on the left is pre-correction, the map on the right is post-correction.

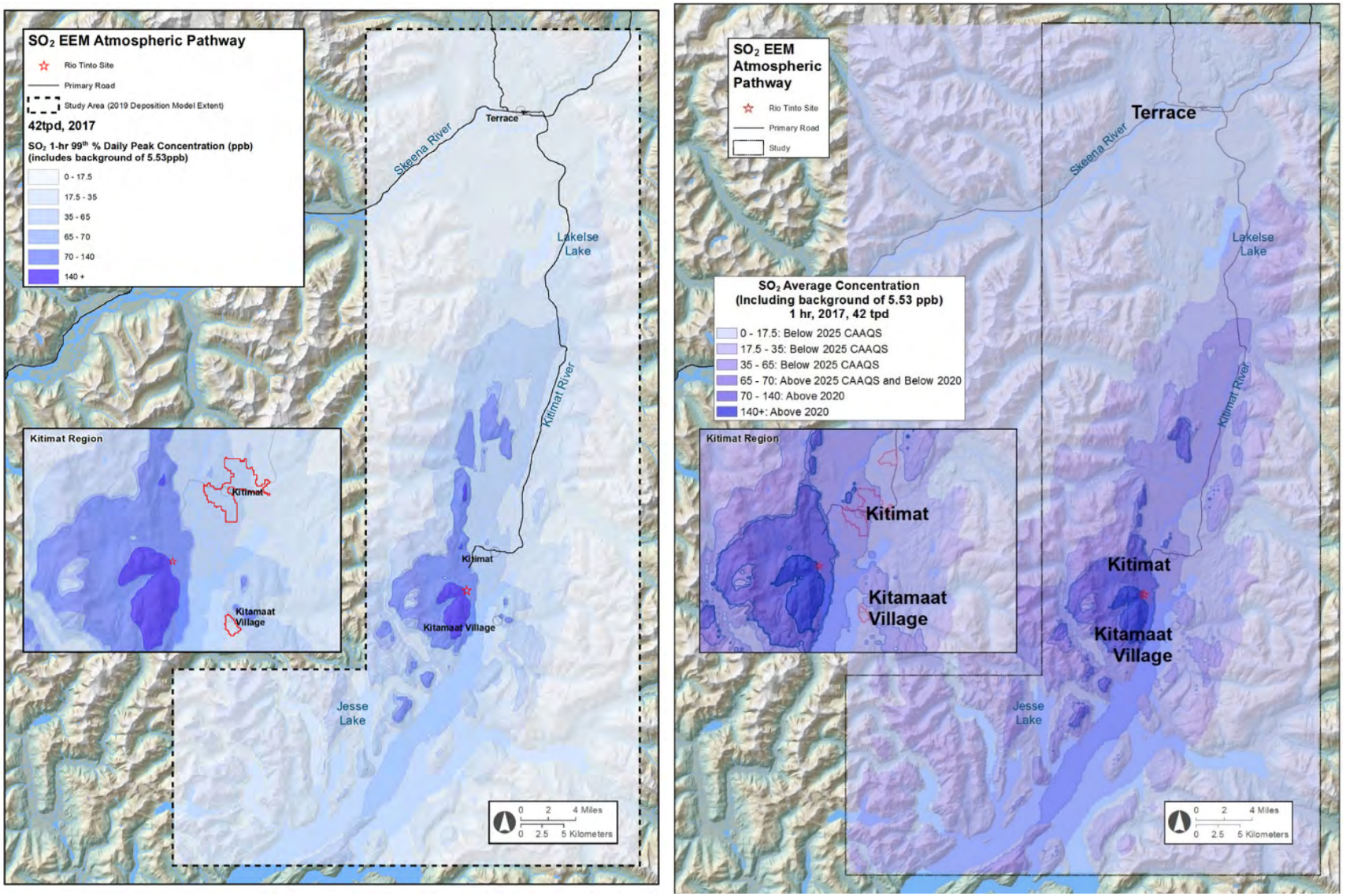


Figure 2-9. SO_2 99% Daily 1hr Peak Concentration Comparison – 2017. The map on the left is pre-correction, the map on the right is post-correction.

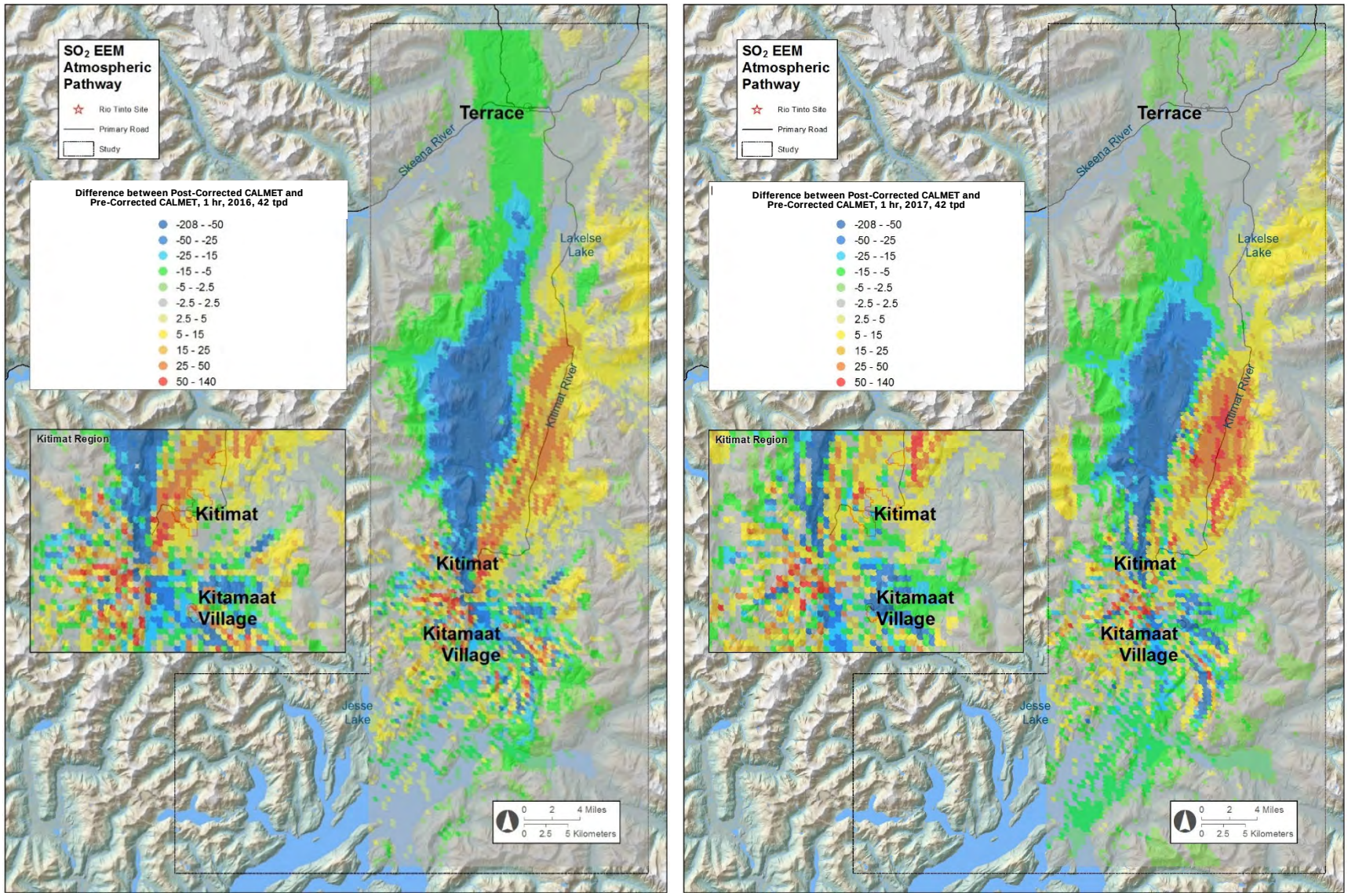


Figure 2-10. SO_2 99% Daily 1hr Peak Difference – 2016 and 2017.

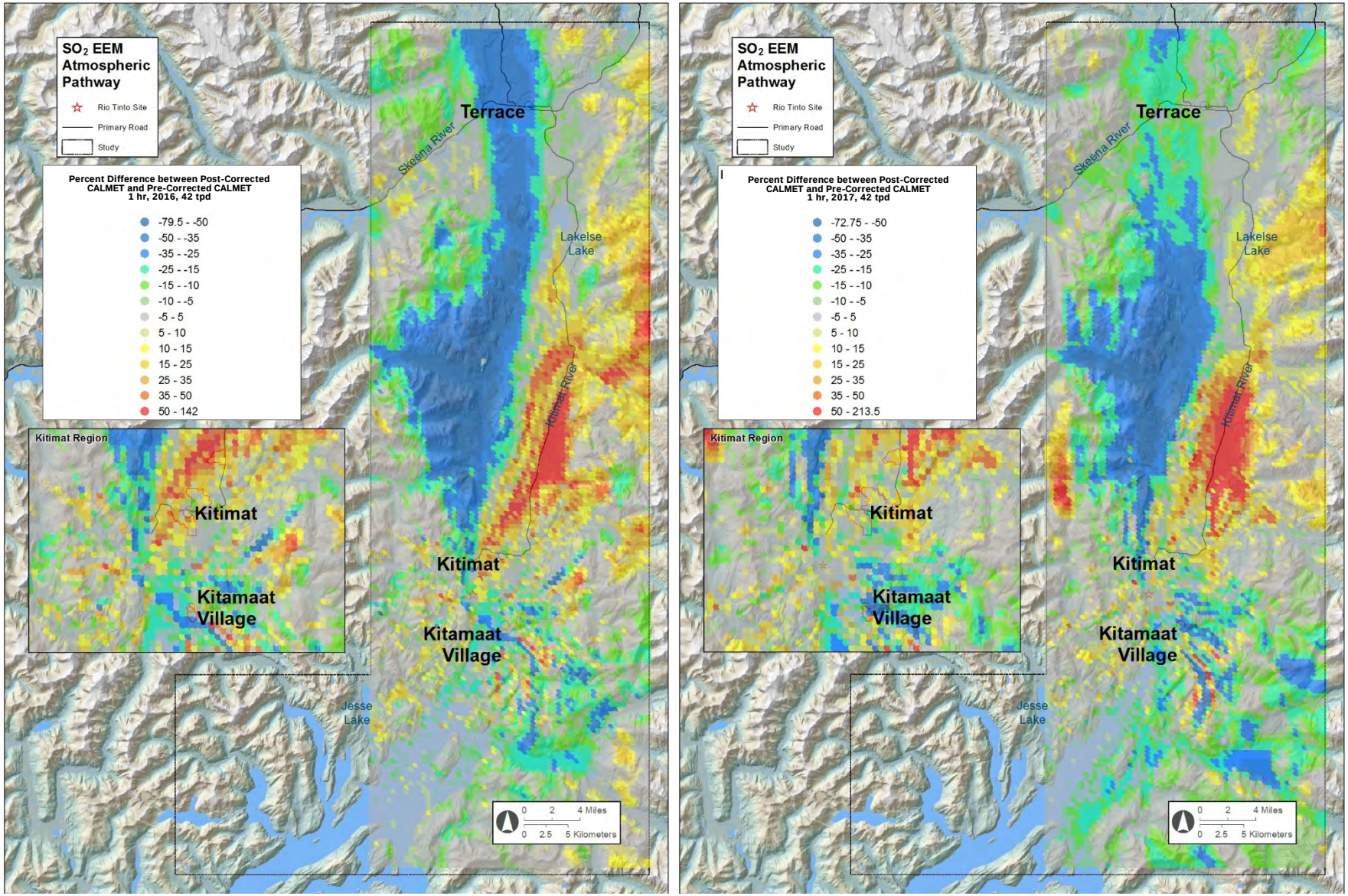


Figure 2-11. SO_2 99% Daily 1hr Peak Percent Difference – 2016 and 2017.

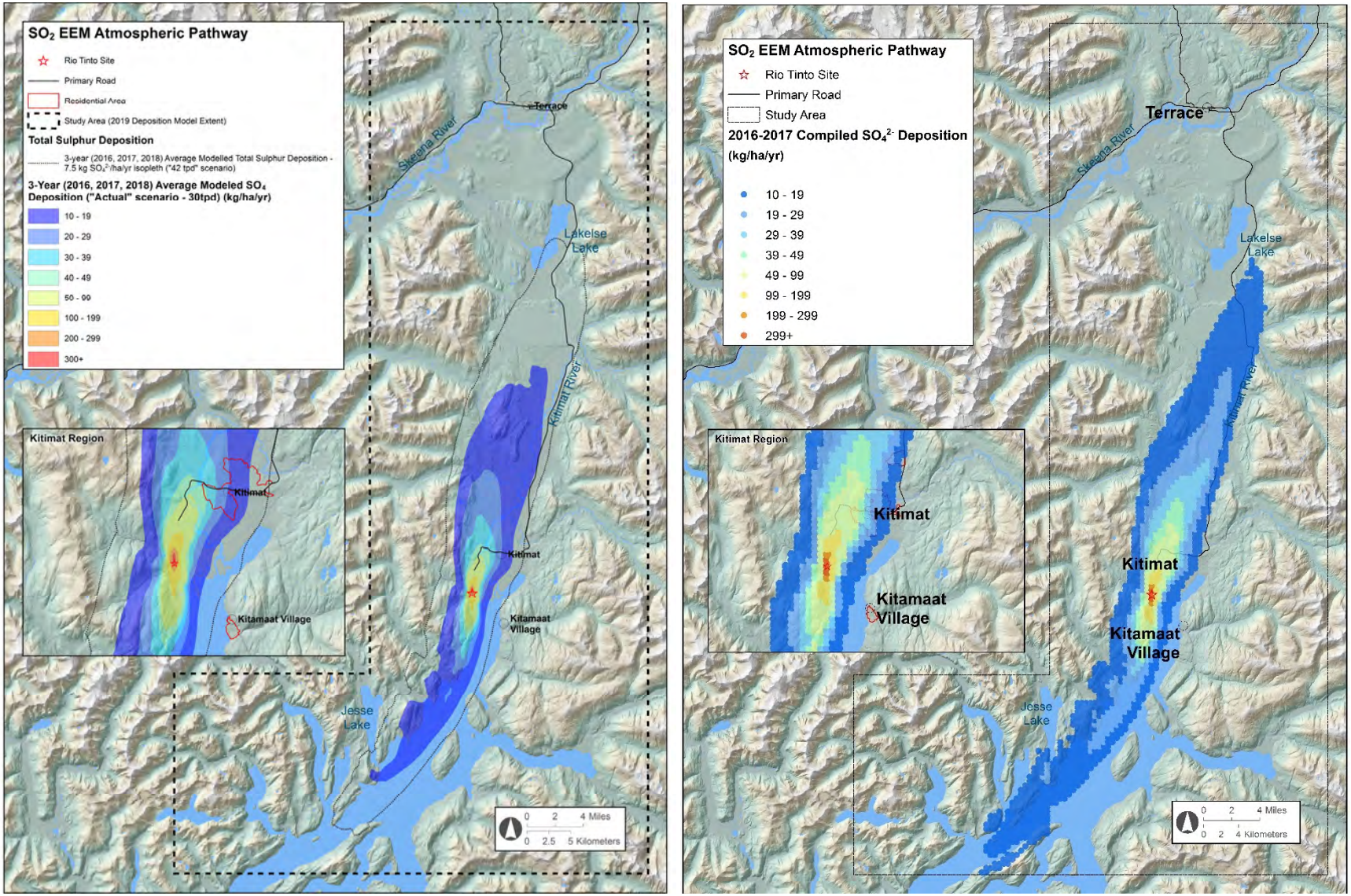


Figure 2-12. Sulfur Deposition Comparison – CR 2016-2018 (map on the left) v. updated 2016-2017 (map on the right).

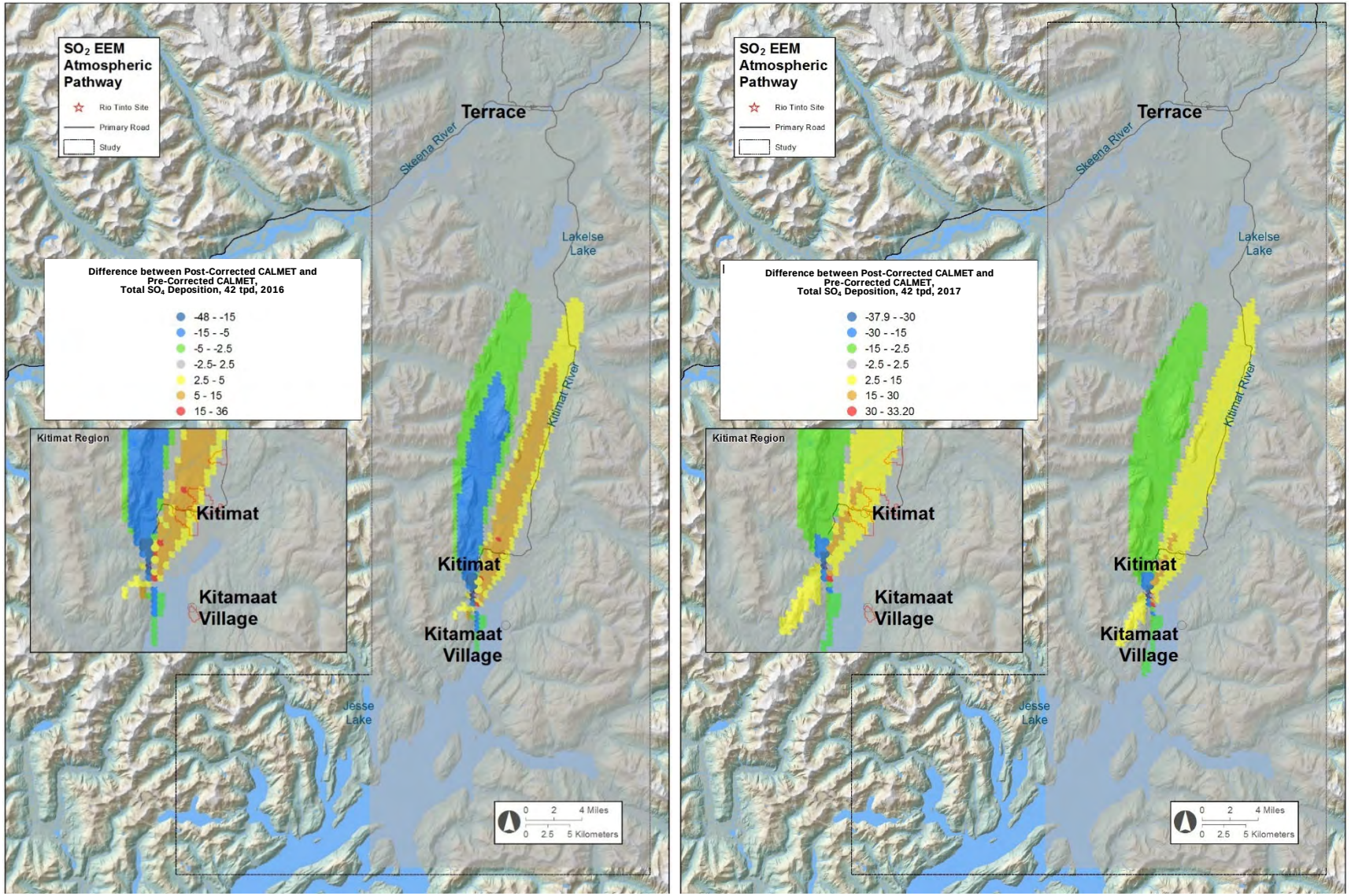


Figure 2-13. Sulfur Deposition Difference – 2016 and 2017.

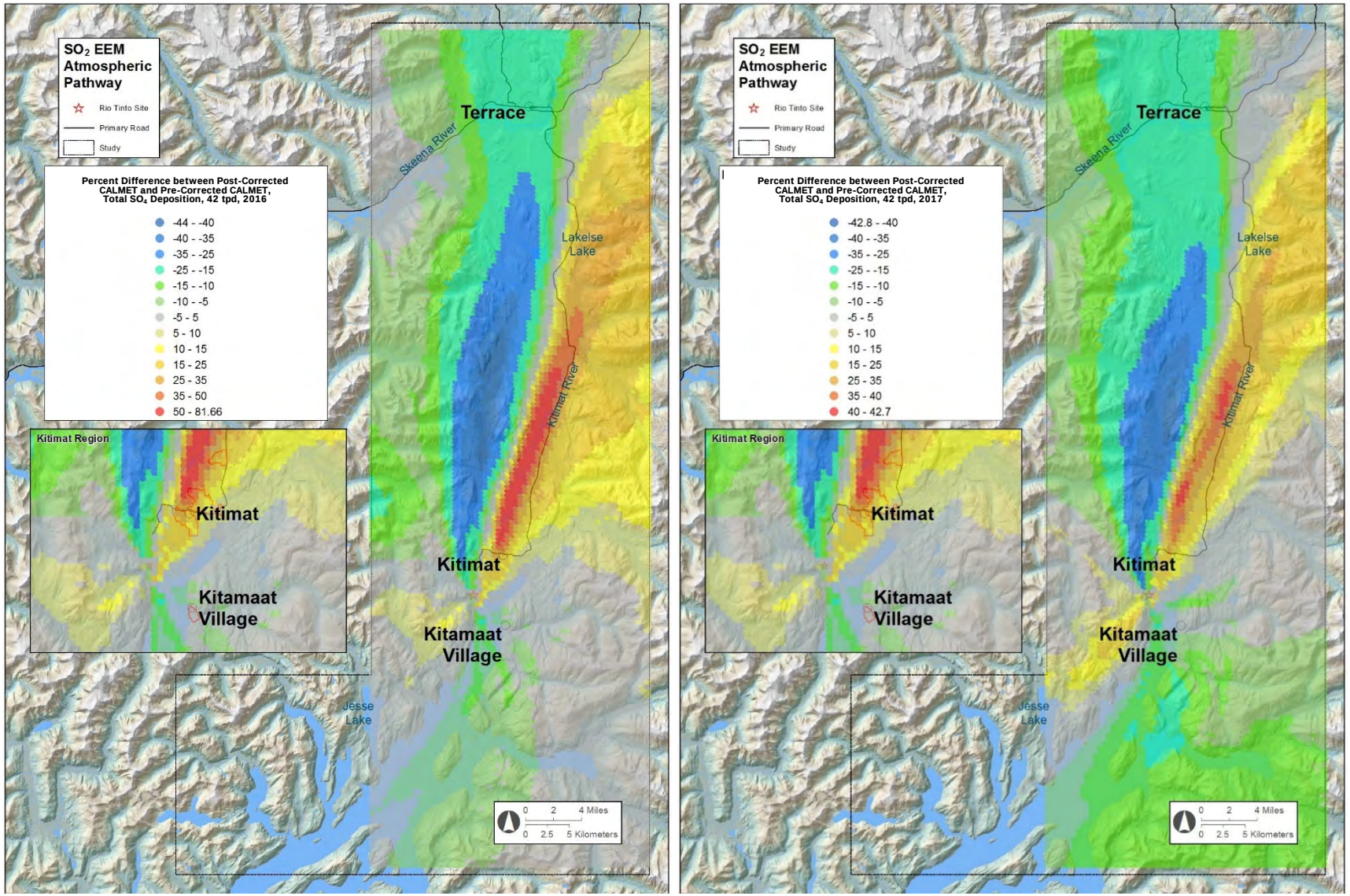


Figure 2-14. Sulfur Deposition Percent Difference – 2016 and 2017.

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/m³ 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/m³ 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/m³ 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/m³ 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/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 20 µg/m³ 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.

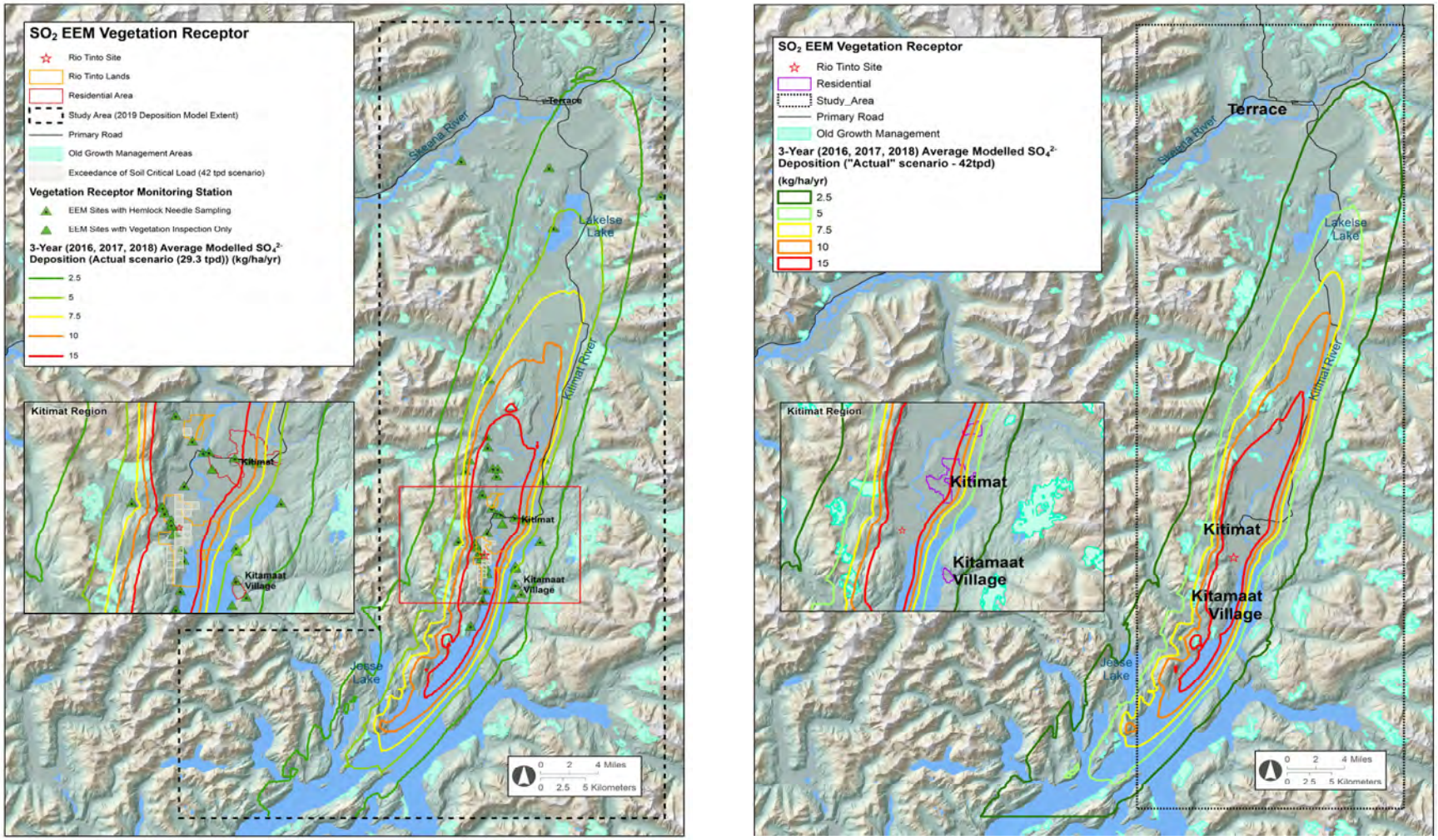


Figure 3-1. The map on the left shows the CR-modelled SO_4^{2-} deposition and the location of old growth management areas. The map on the right shows the wind-corrected modelled SO_4^{2-} deposition and the location of old growth management areas.

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

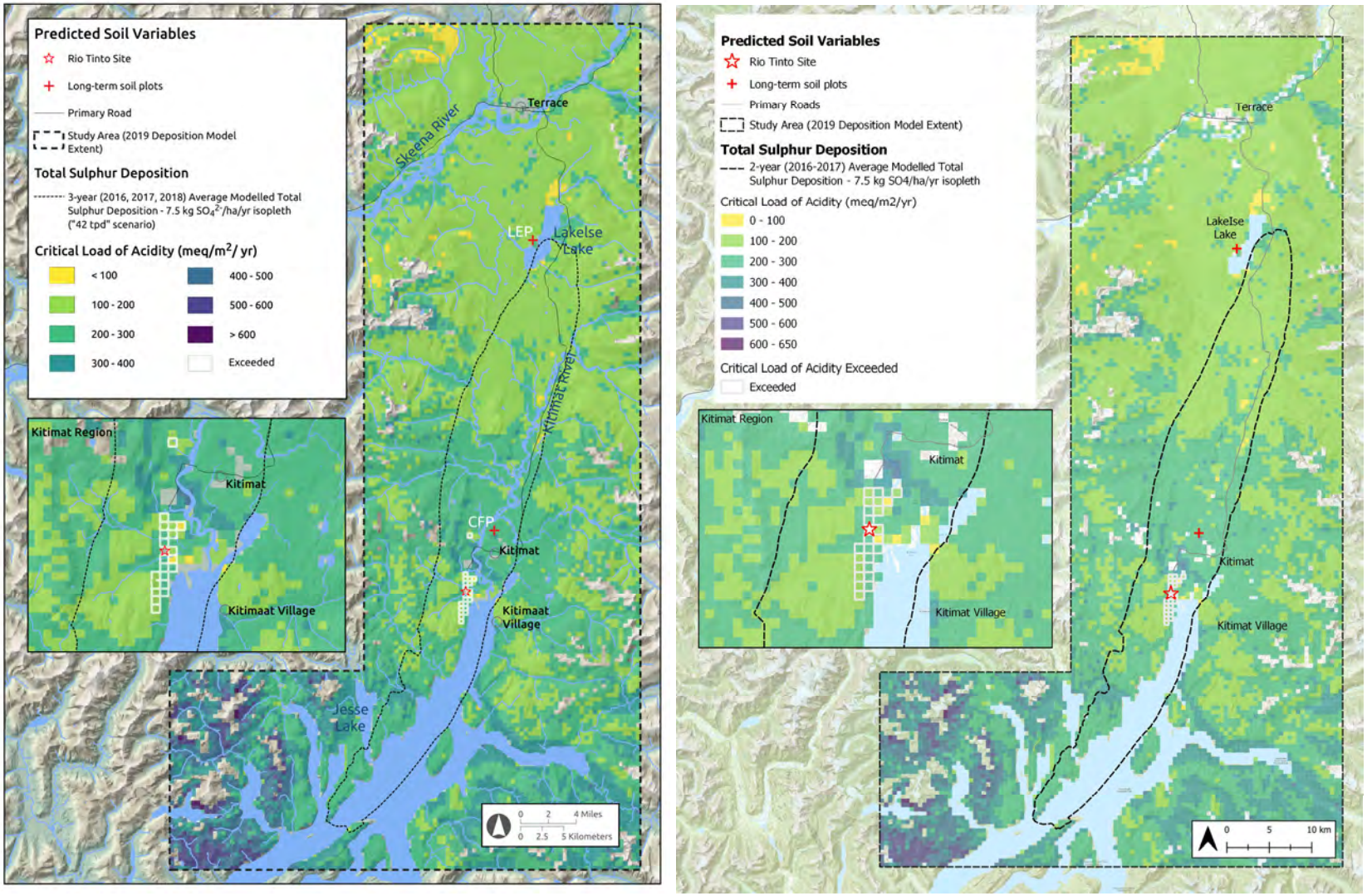


Figure 4-1. Comparison of grid squares with CL exceedance (white squares) under the original CR estimates of deposition for 2016-2018 (left, CR Figure 6-5) vs the revised deposition estimates for 2016-2017 (right). The same estimated CLs are used for both maps.

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

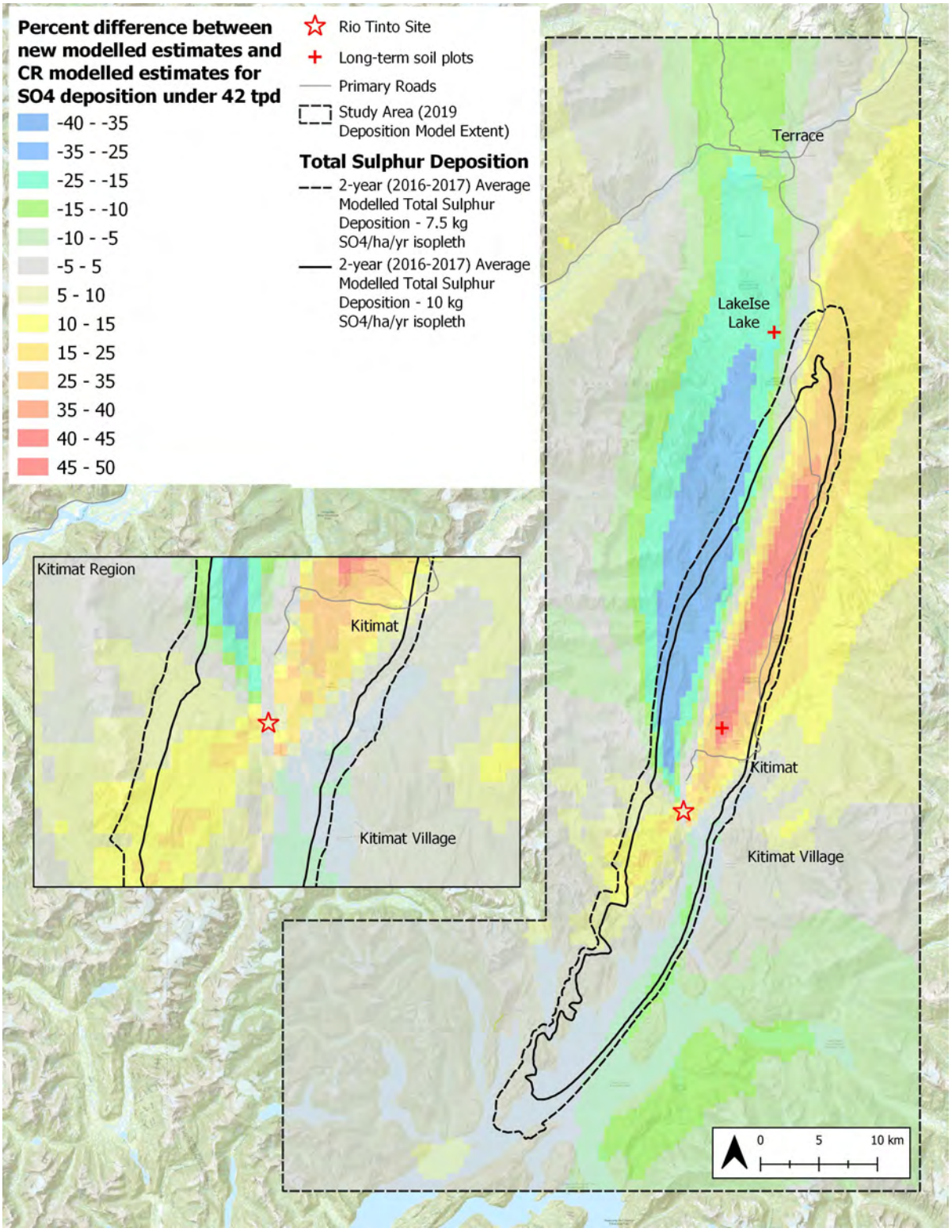


Figure 4-2. Percent difference between revised estimates of sulphate deposition under 42 tpd for meteorological years 2016-2017 and the estimates in the CR for meteorological years 2016-2018. The revised deposition isopleths (7.5 kg/ha/yr and 10 kg/ha/yr) are also shown.

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.

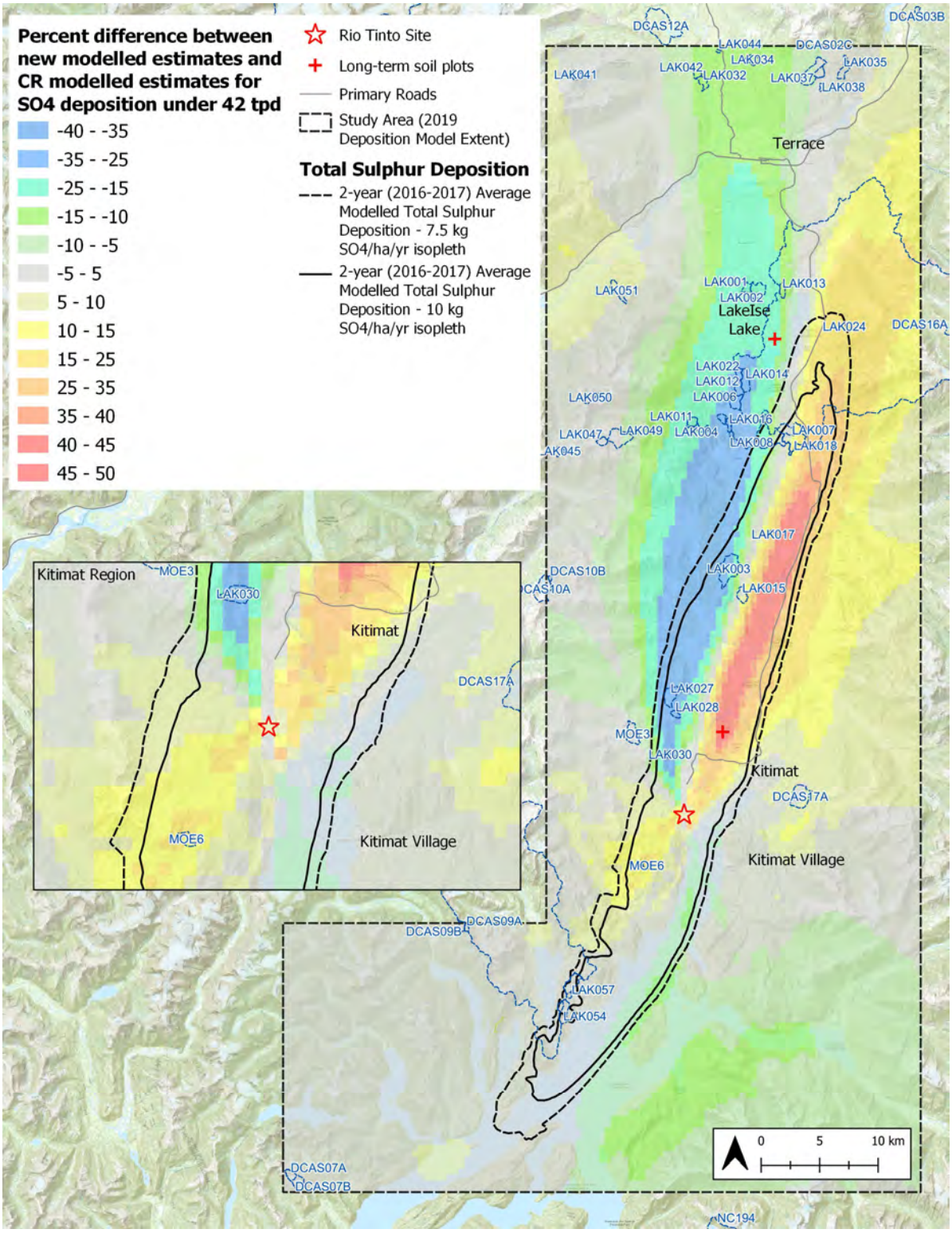


Figure 5-1. Percent difference between new modelled estimates and CR modelled estimates for SO_4 deposition under 42 tpd. The watersheds of all STAR and KAA lakes within the study area are shown.

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%
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%
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%
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 5-2 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.

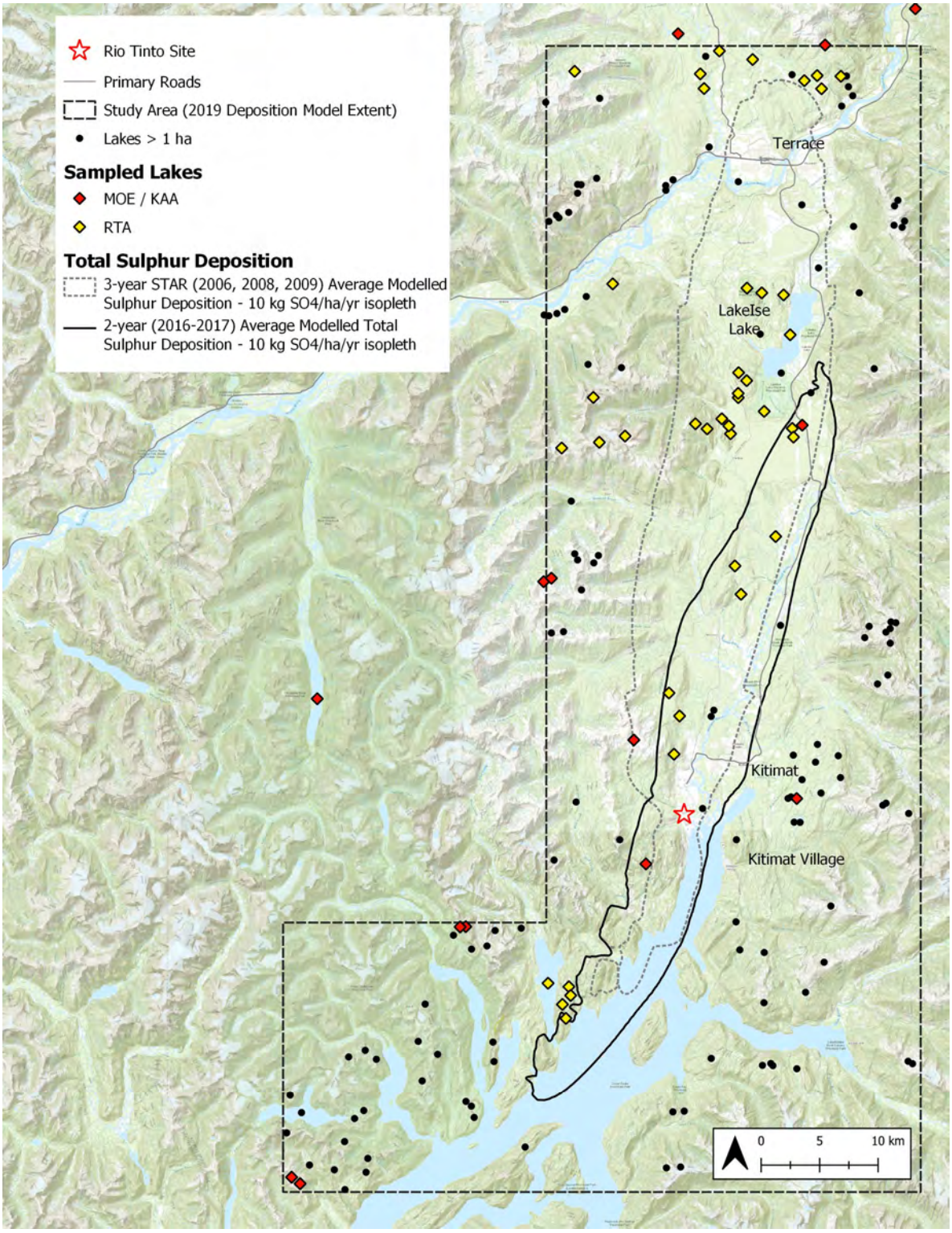


Figure 5-2. Location of the 10 kg/ha/yr isopleths for SO_4 deposition from the STAR and from the new deposition modelling. All of the lakes (>1 ha) in the study area are shown. Lakes that are located within the STAR isopleth but were not sampled during the STAR were excluded based on violating one or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

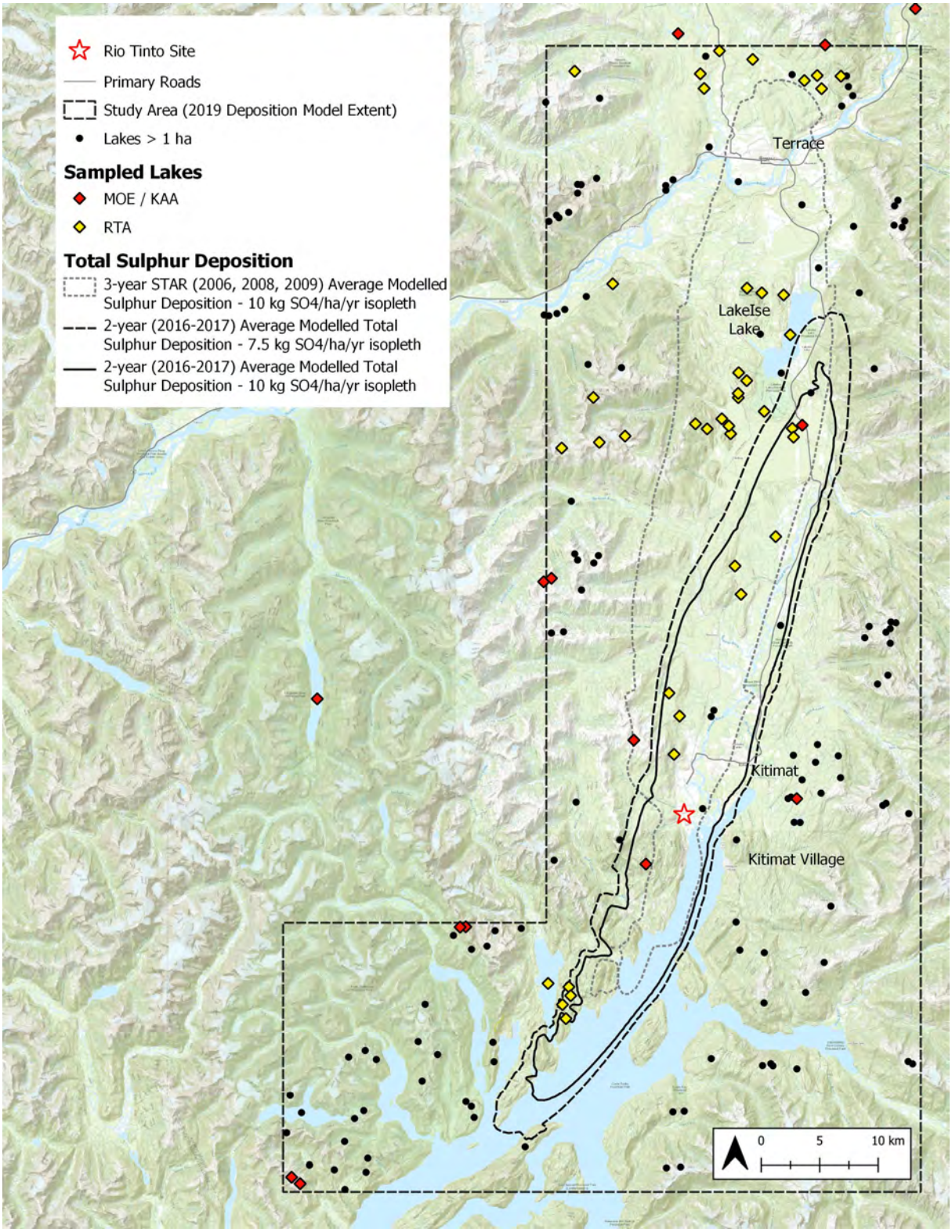


Figure 5-3. Location of the 10 kg/ha/yr isopleths for SO_4 deposition from the STAR and the 10 kg/ha/yr and 7.5 kg/ha/yr from the new deposition modelling. All of the lakes (>1 ha) in the study area are shown.

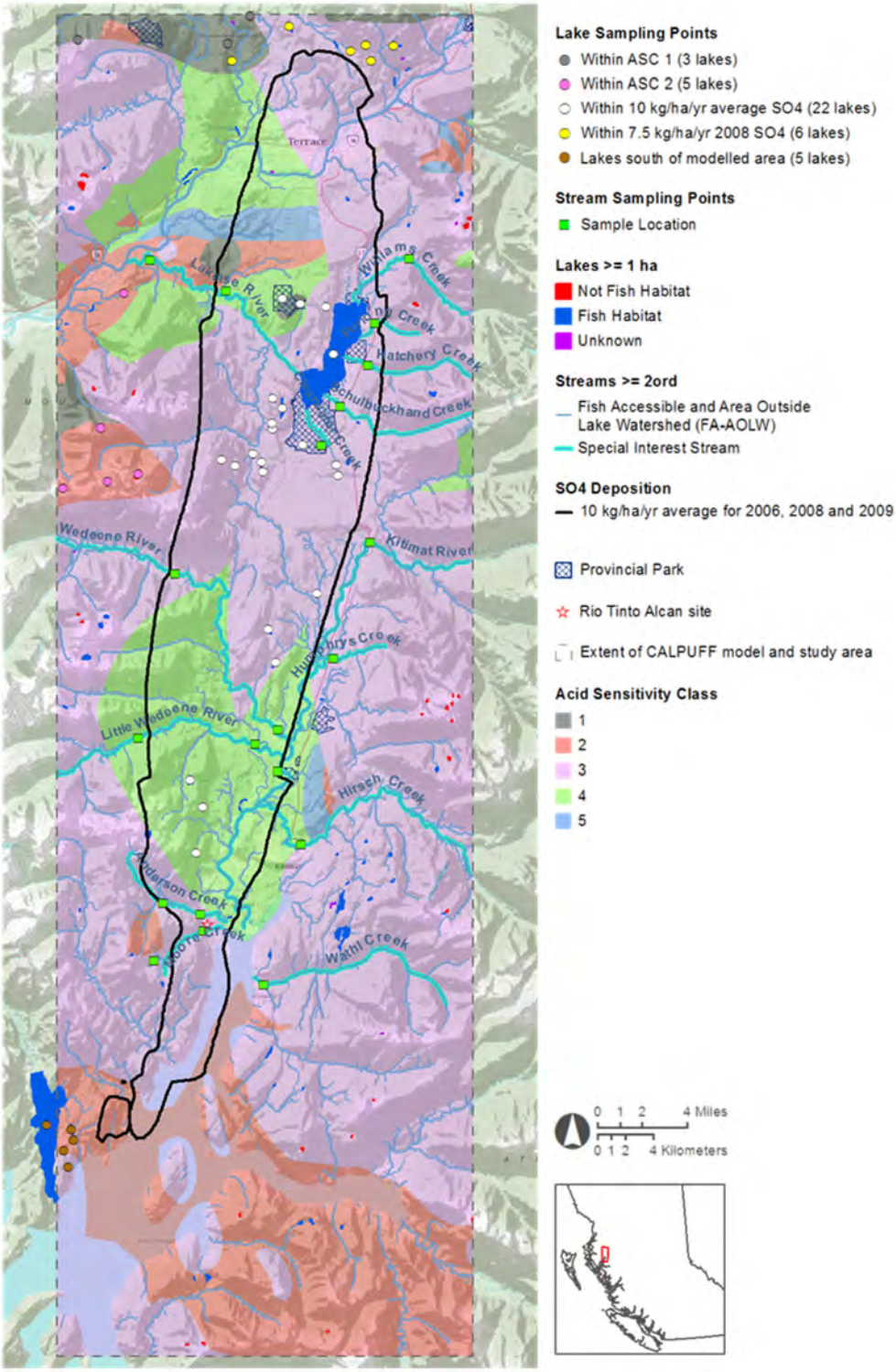


Figure 5-4. Overlay of STAR sampling sites and acid sensitivity classes (ASC). Grey and pink points show sampled lakes within ASC 1 and ASC 2, the two most sensitive sites. Source: Figure 8.6-4 in STAR Volume 2.

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.

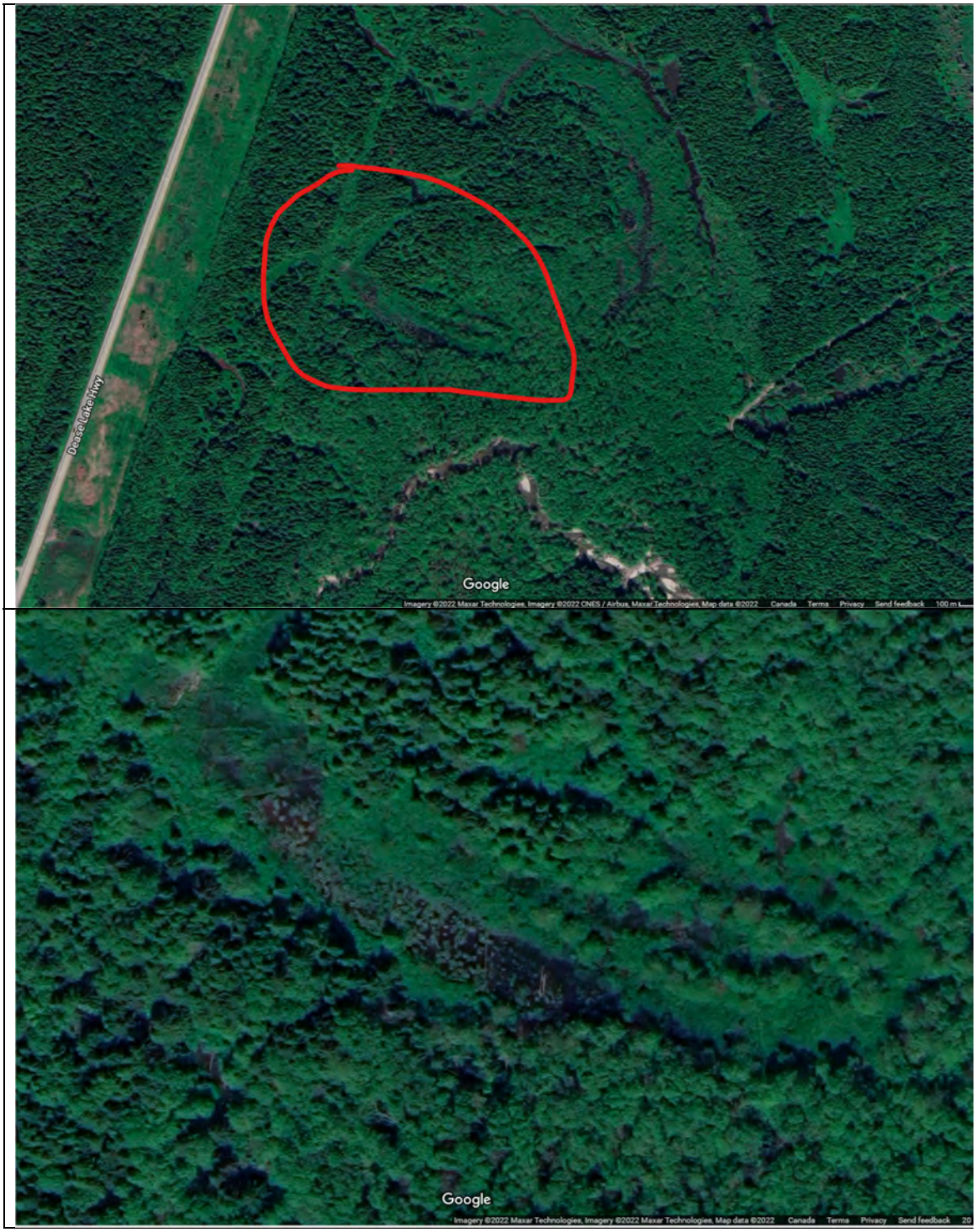


Figure 5-6. Satellite images of potential candidate lake at two different scales (source: Google Maps).



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/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 20µg/m^3 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.

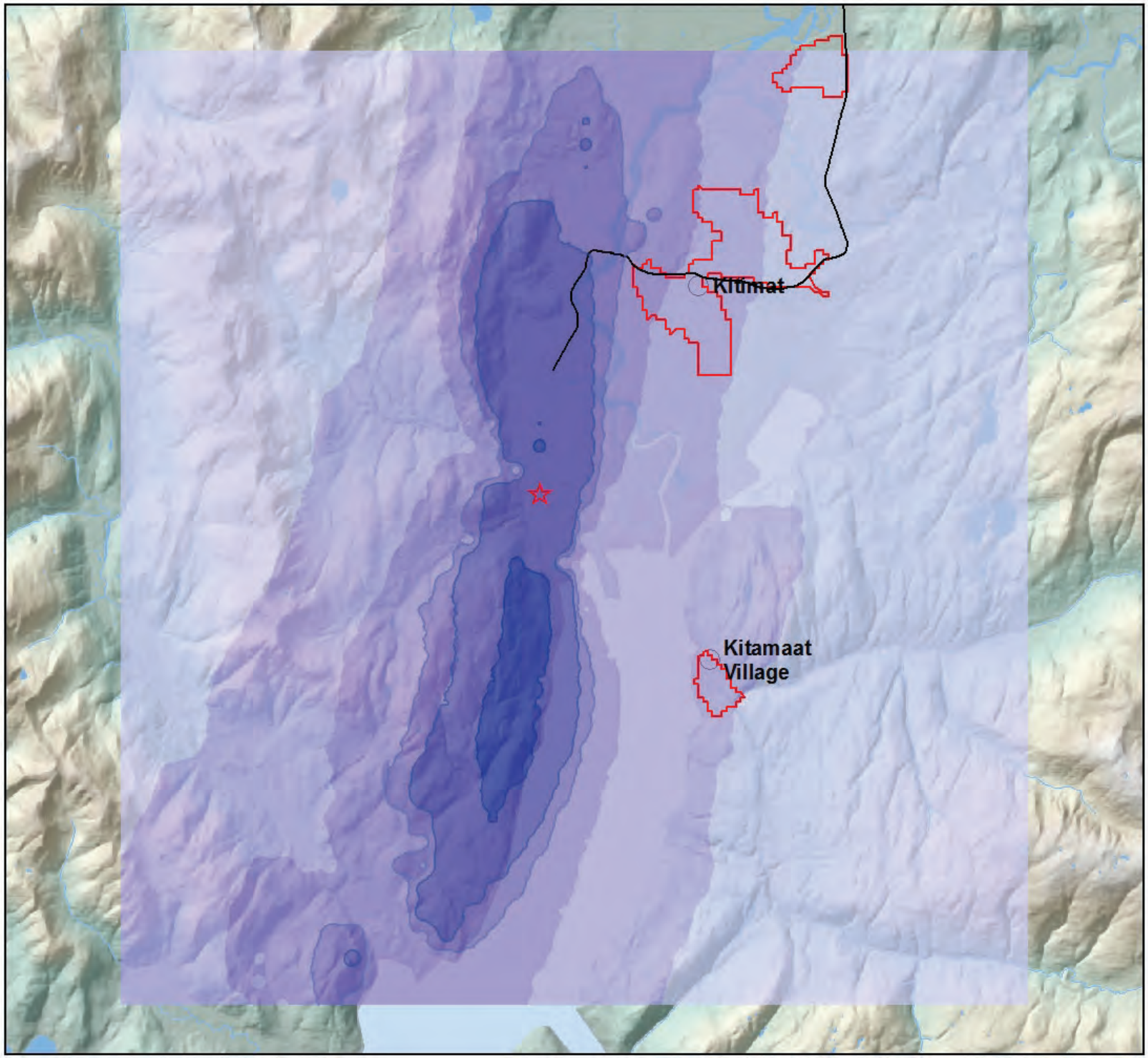
8 References

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.

Attachment 1
Model Result Plots

Local Scale – 42 TPD Scenario
Regional Scale – Actual Scenario
Local Scale – Actual Scenario



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

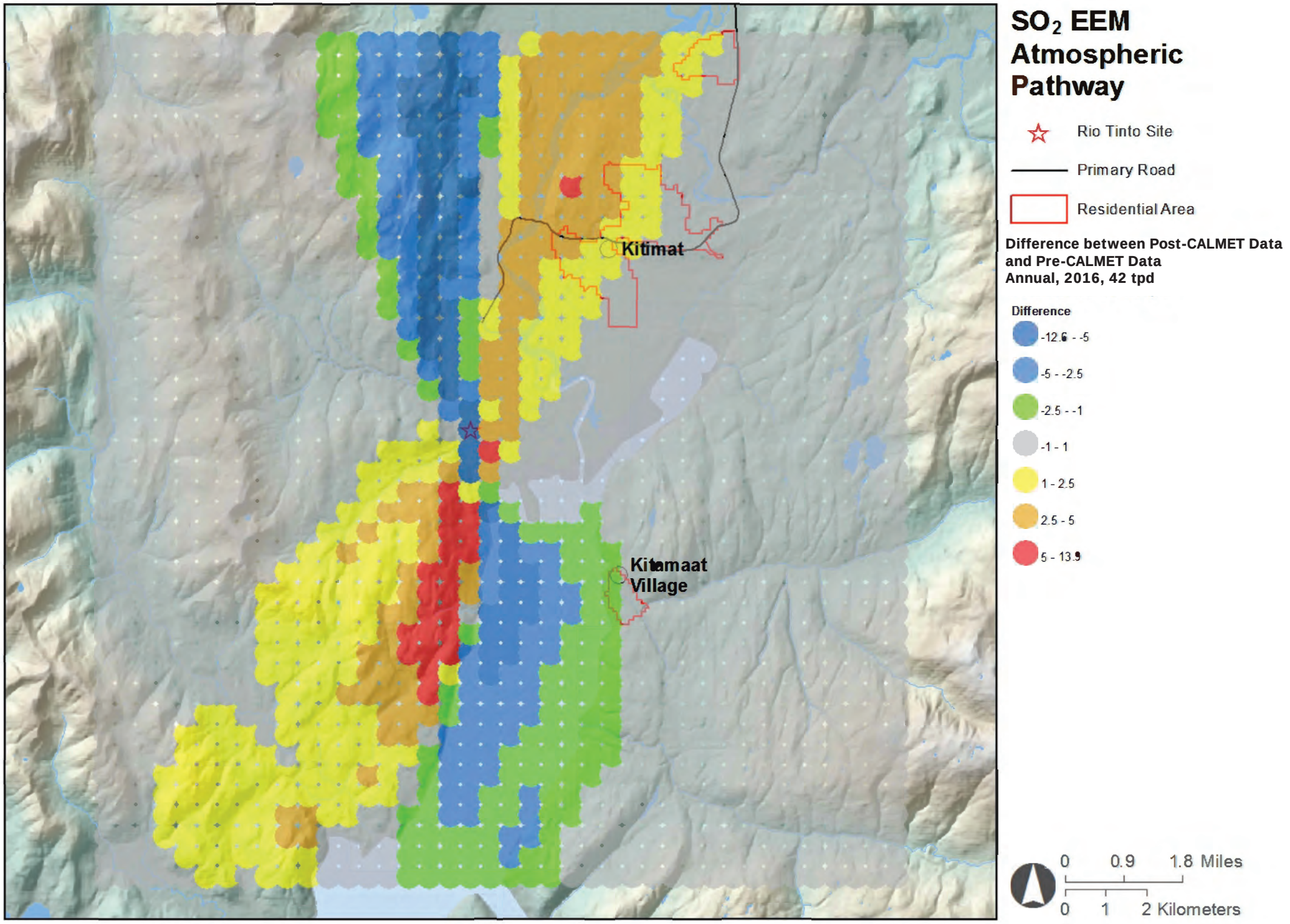
SO2 Annual Average Concentration (ppb) (Includes background of 0.47 ppb)

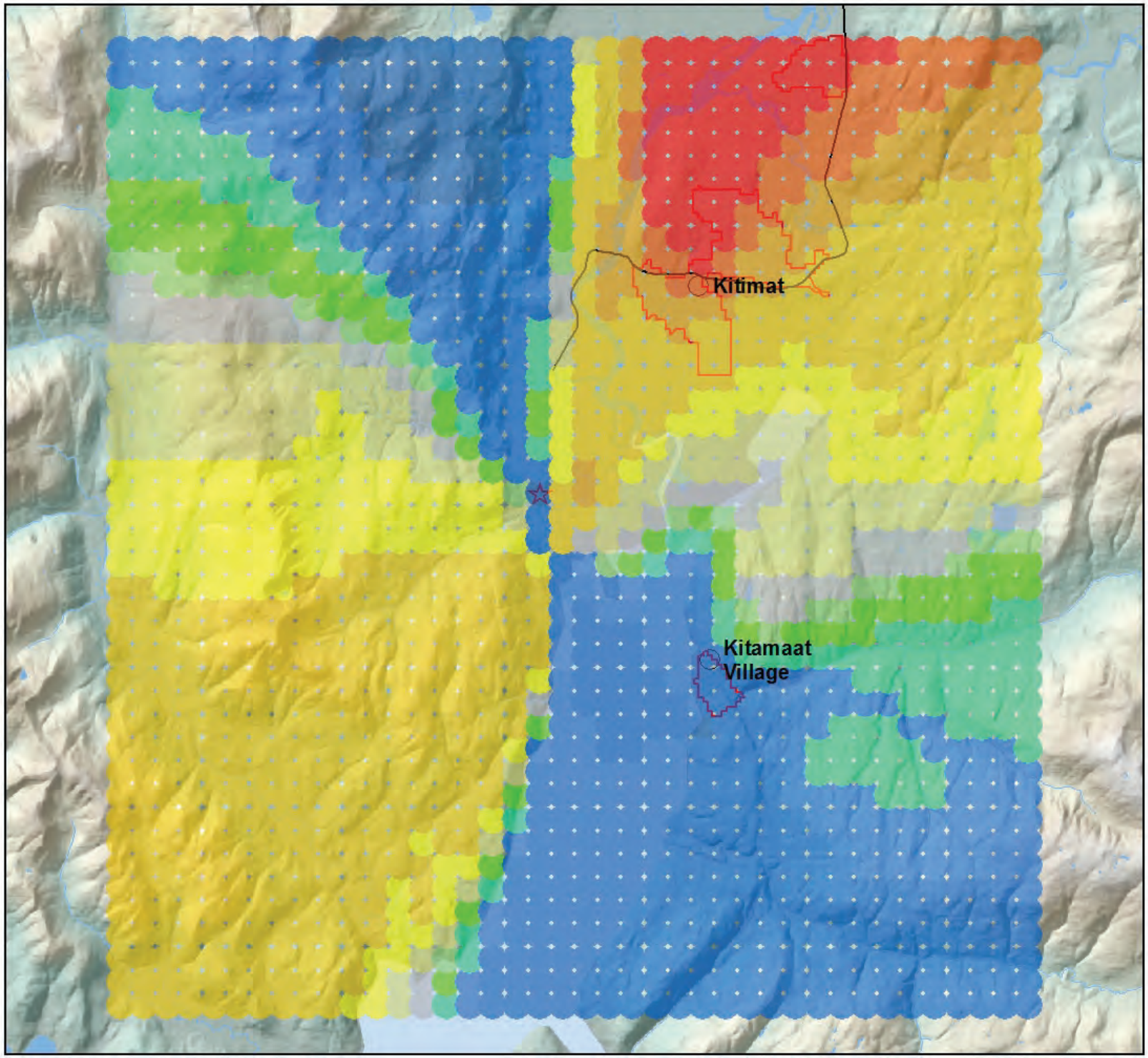
42 tpd, 2016

- 0 - 1.25: Below 2025 CAAQS
- 1.25 - 2.5: Below 2025 CAAQS
- 2.5 - 4: Below 2025 CAAQS
- 4 - 5: Above 2025 CAAQS and Below 2020
- 5 - 10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Residential Area
Difference between Post-CALMET Data and Pre-CALMET Data
Annual, 2016, 42 tpd
Difference
-12.6 - -5
-5 - -2.5
-2.5 - -1
-1 - 1
1 - 2.5
2.5 - 5
5 - 13.9
Kitimat
Kitamaat Village
0 0.9 1.8 Miles
0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

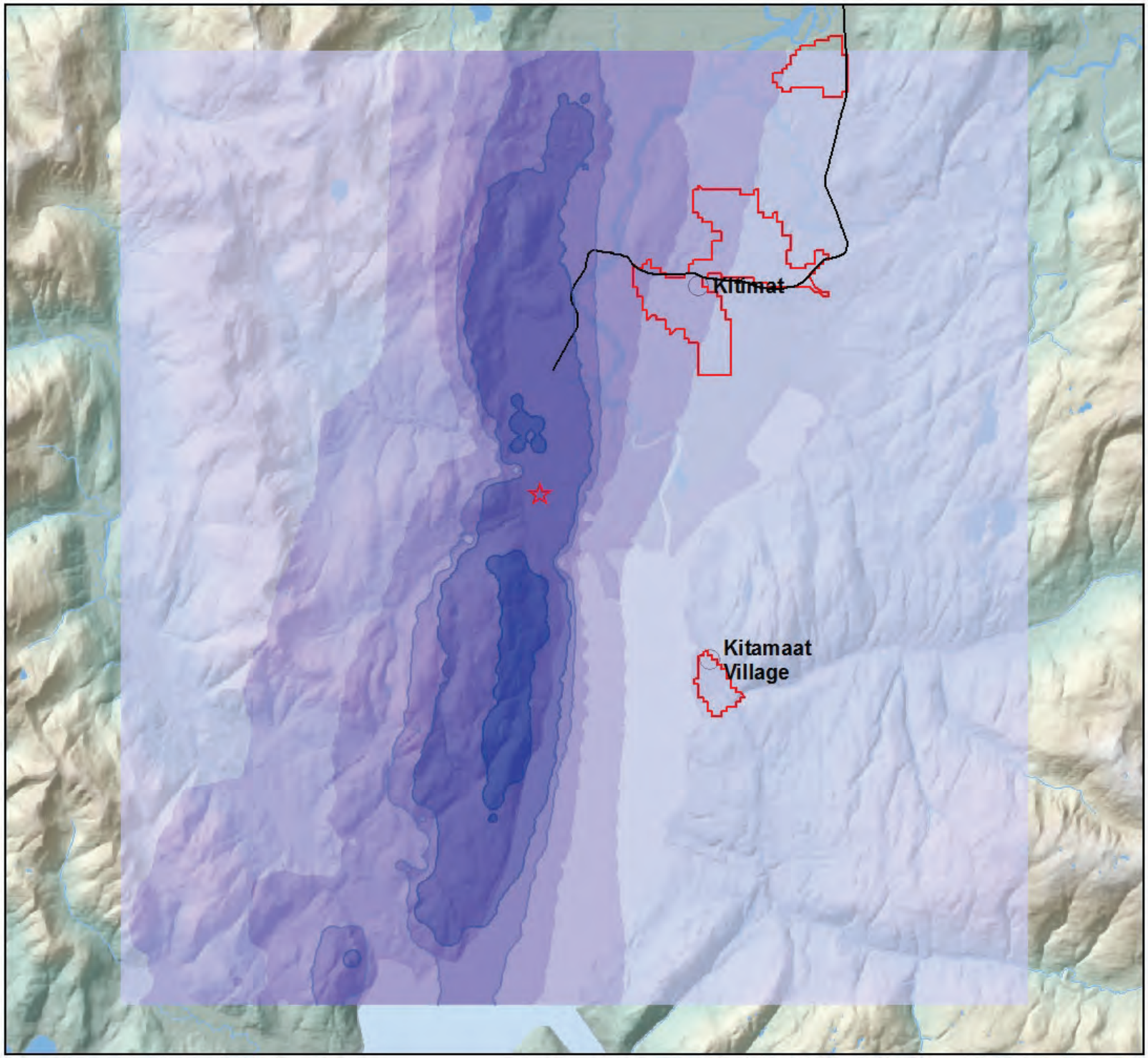
Residential Area

Percent Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2017, 42 tpd

- -60 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 295

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

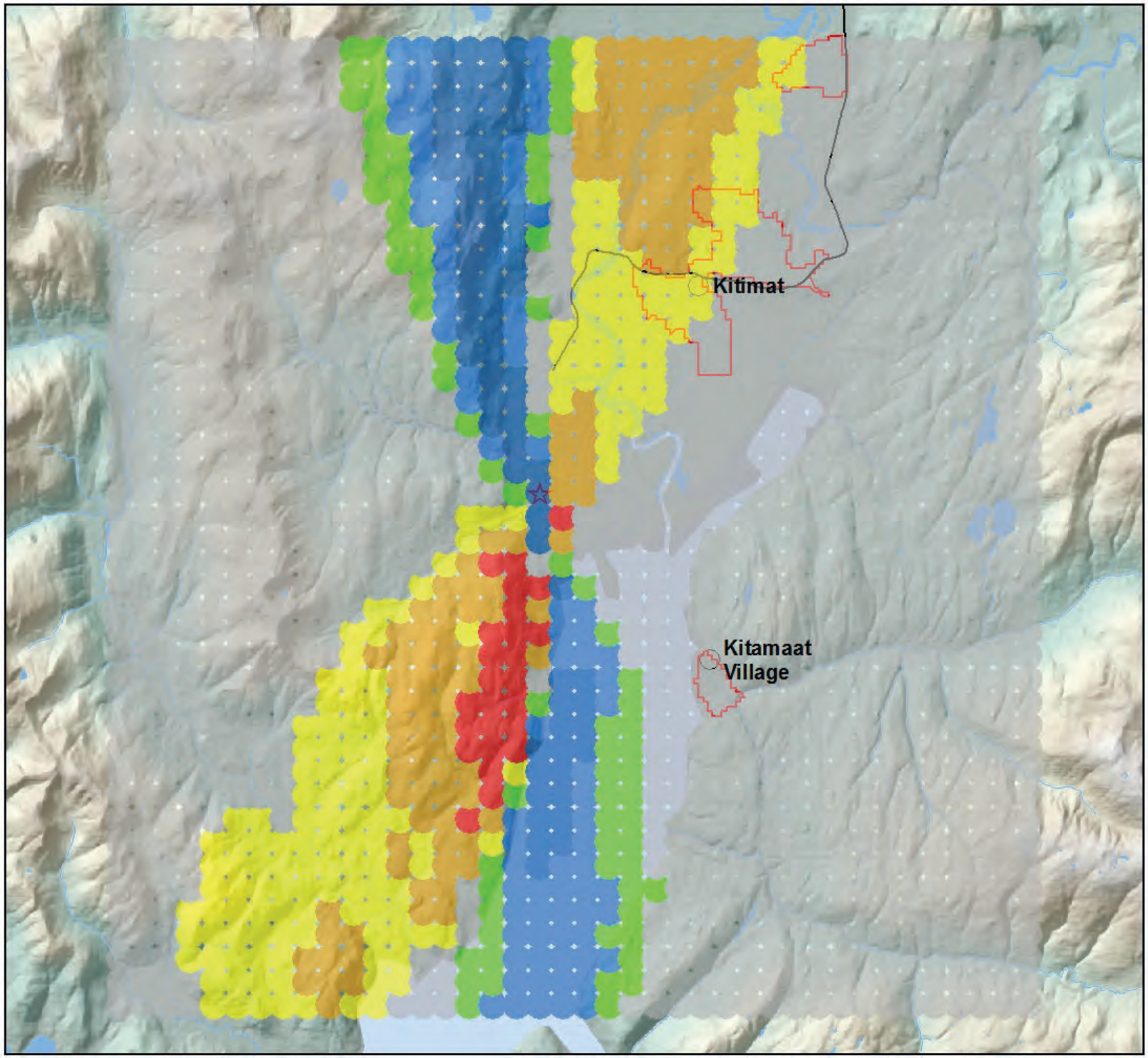
SO2 Annual Average Concentration (ppb) (Includes background of 0.47 ppb)

42 tpd, 2017

- 0 - 1.25: Below 2025 CAAQS
- 1.25 - 2.5: Below 2025 CAAQS
- 2.5 - 4: Below 2025 CAAQS
- 4 - 5: Above 2025 CAAQS and Below 2020
- 5 - 10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

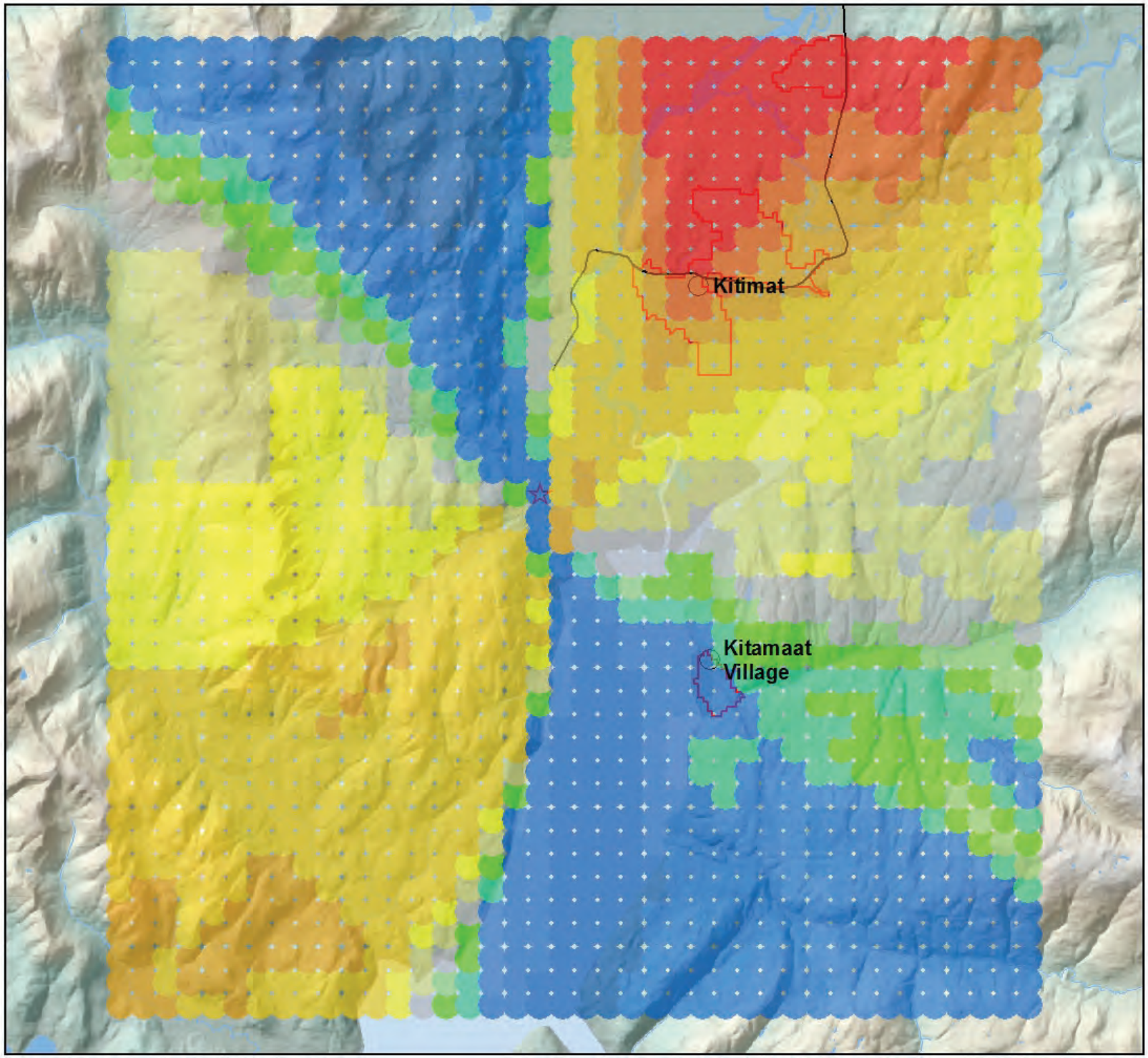
Percent Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2017, 42 tpd

Difference

- -15.5 - -5
- -5 - -2.5
- -2.5 - -1
- -1 - 1
- 1 - 2.5
- 2.5 - 5
- 5 - 11.4

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

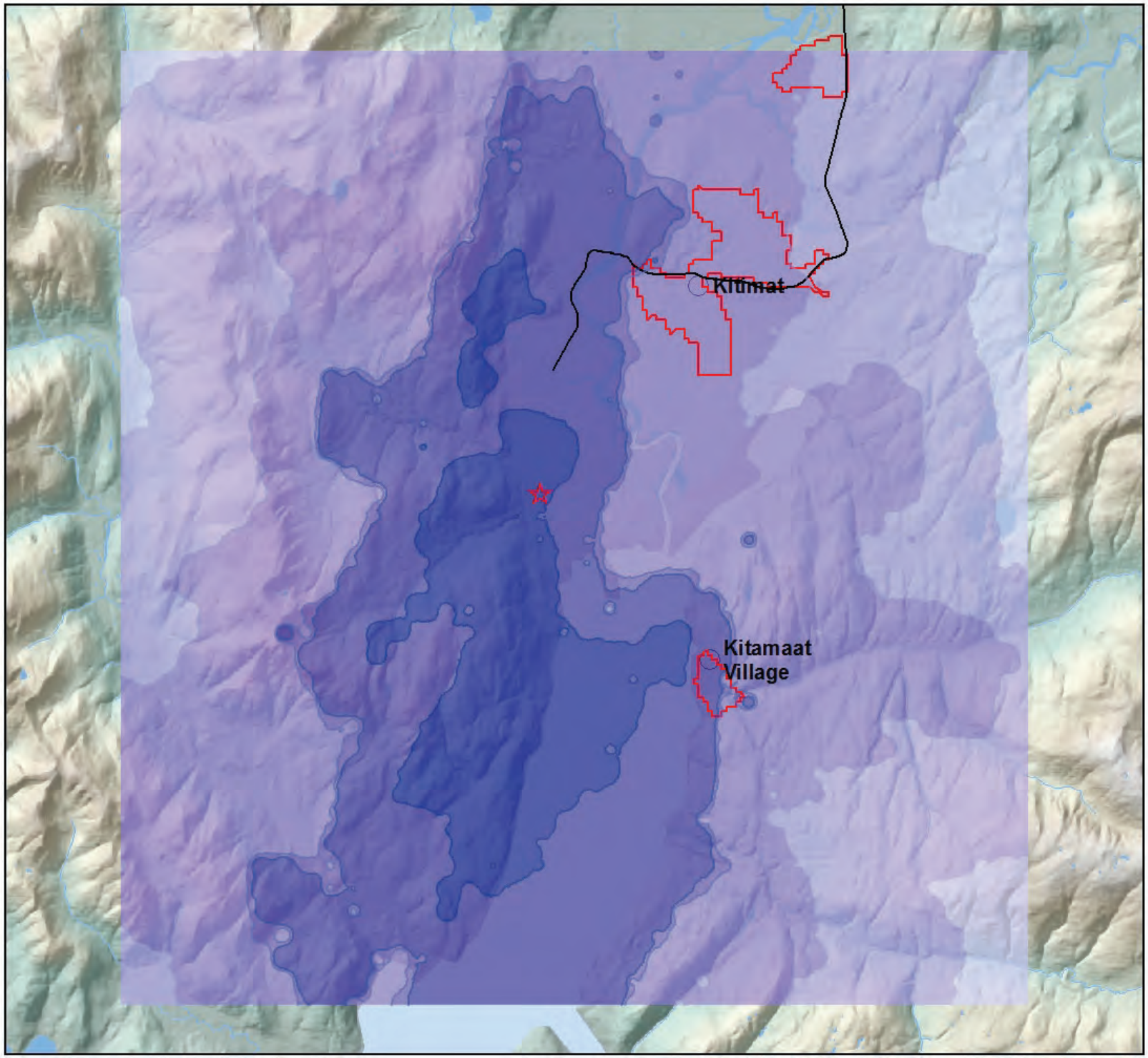
Residential Area

Percent Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2017, 42 tpd

- -61.63 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 351

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

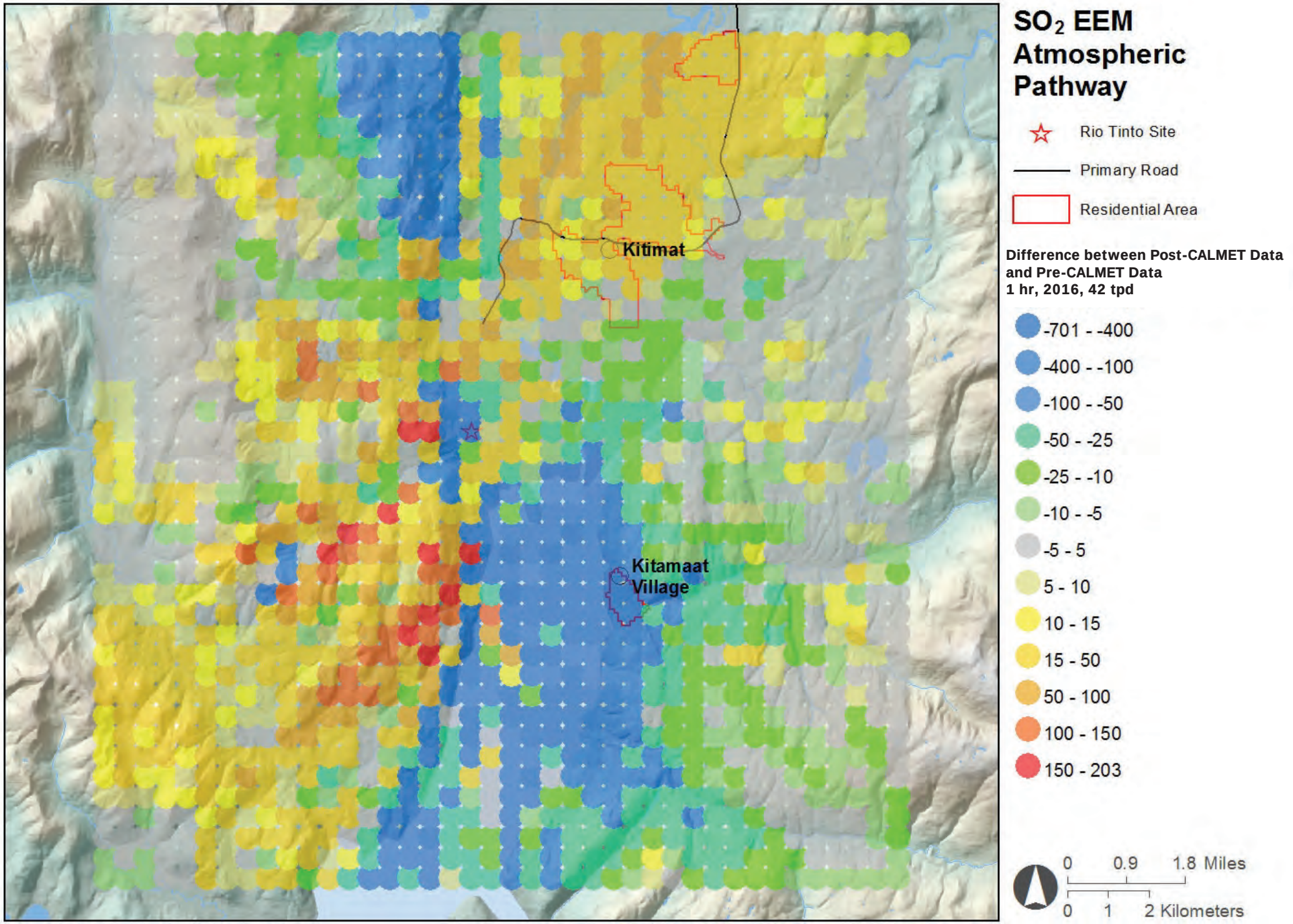
SO2 1 hr Average Concentration (ppb) (Includes background of 5.53 ppb)

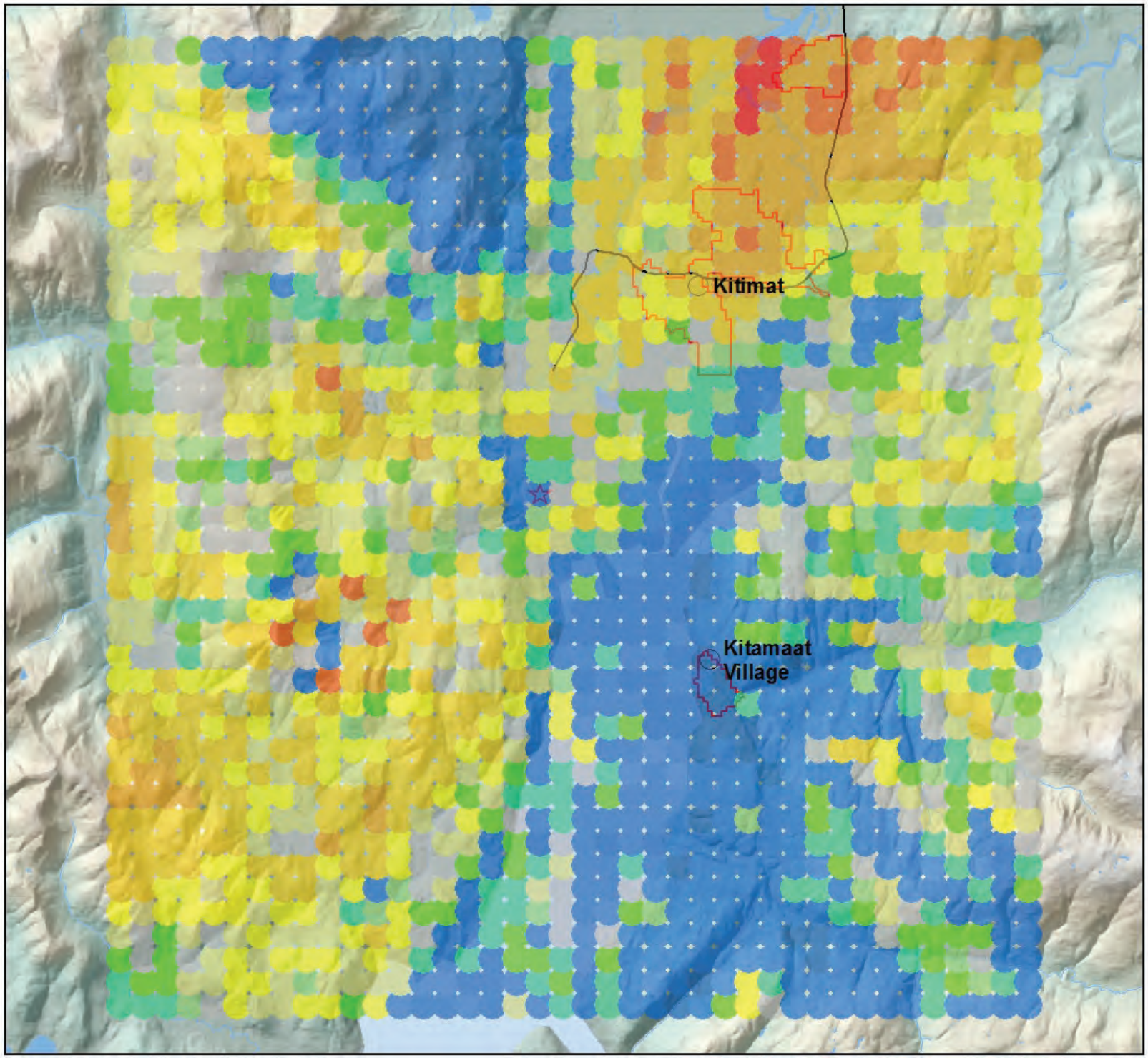
42 tpd, 2016

- 0 - 17.5: Below 2025 CAAQS
- 17.5 - 30: Below 2025 CAAQS
- 30 - 65: Below 2025 CAAQS
- 65 - 70: Above 2025 CAAQS and Below 2020
- 70 - 140: Above 2020 CAAQS
- 140+: ABove 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Residential Area
Kitimat
Kitamaat Village
Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2016, 42 tpd
-701 - -400
-400 - -100
-100 - -50
-50 - -25
-25 - -10
-10 - -5
-5 - 5
5 - 10
10 - 15
15 - 50
50 - 100
100 - 150
150 - 203
0 0.9 1.8 Miles
0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

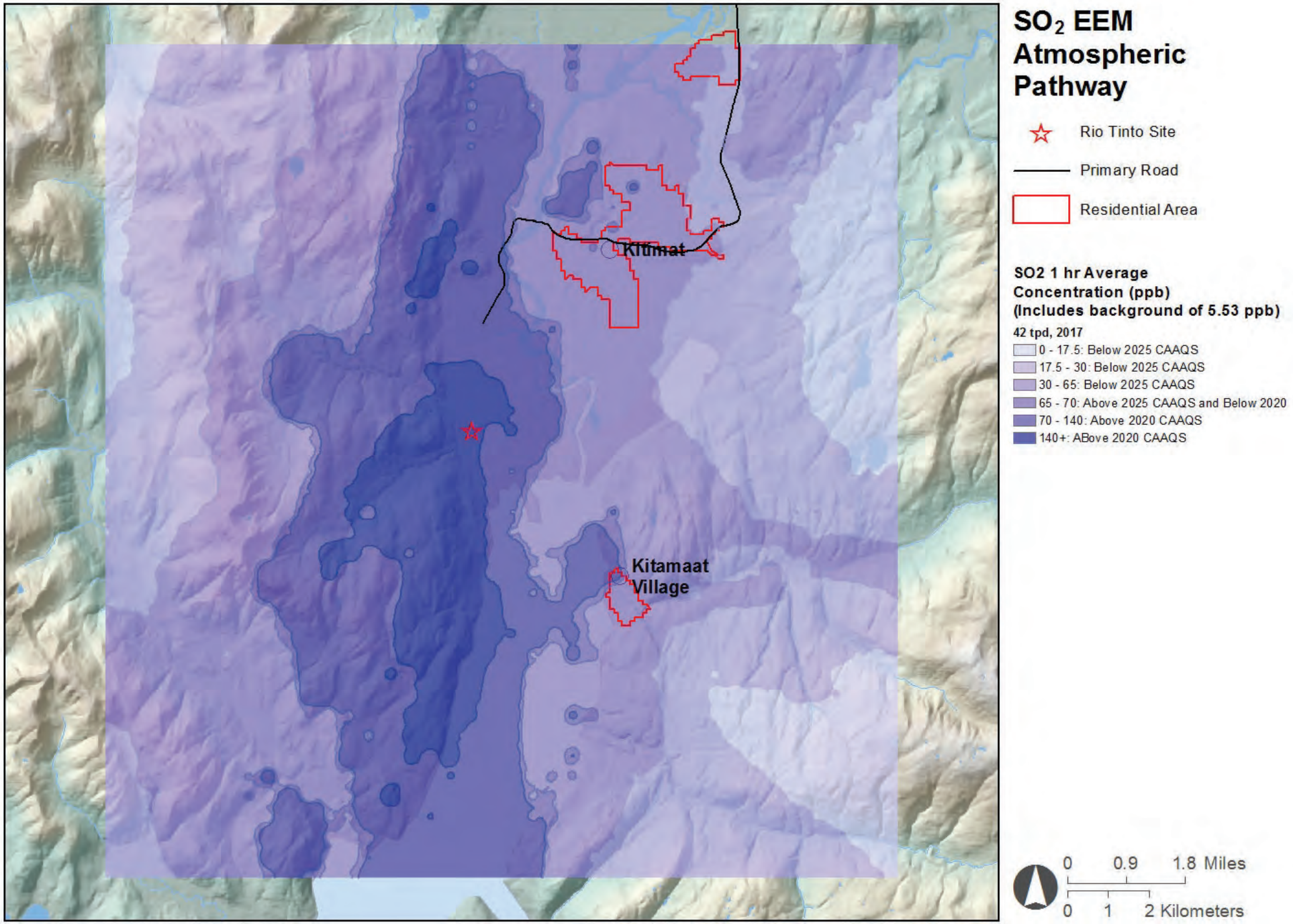
Residential Area

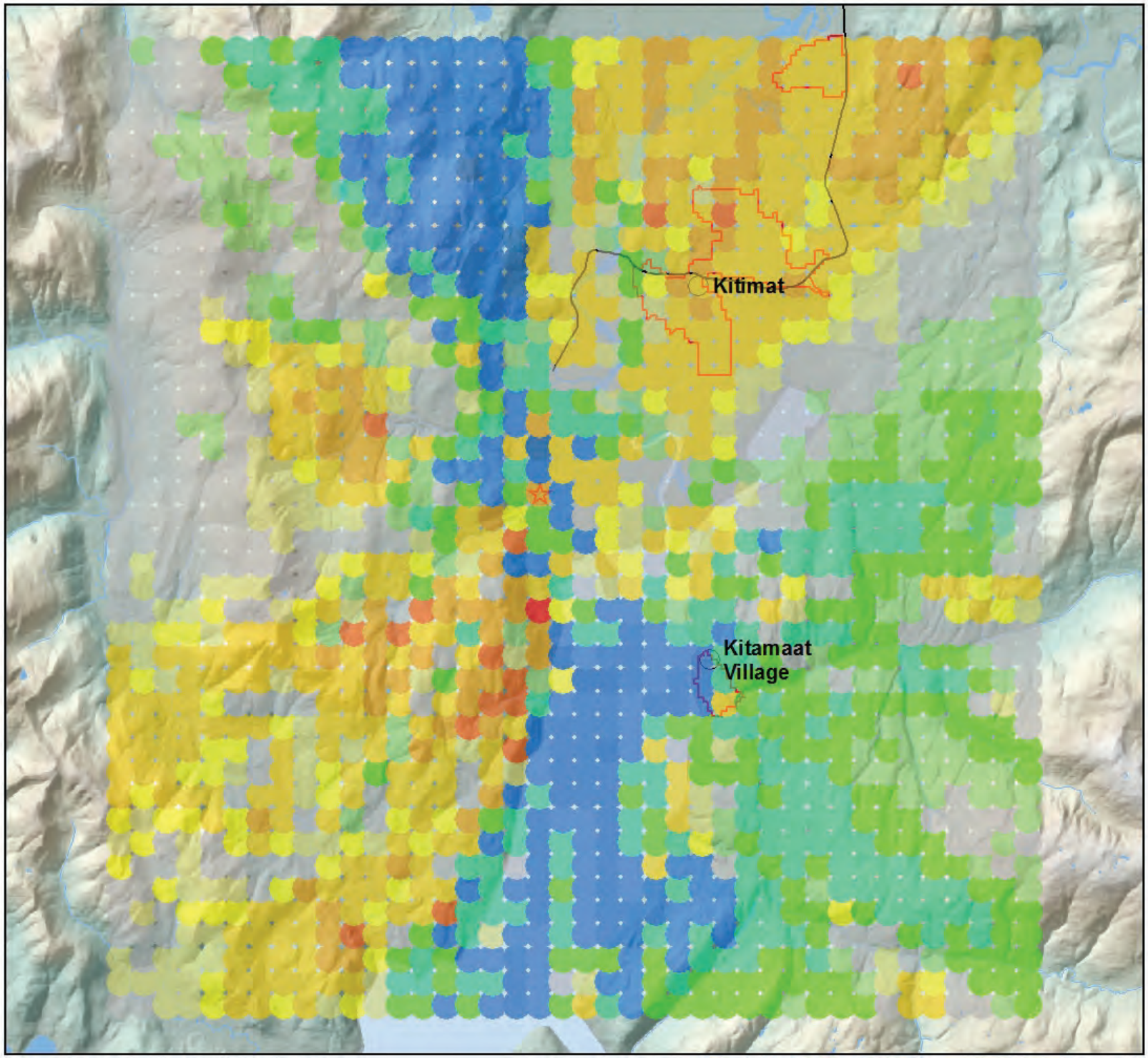
Percent Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2016, 42 tpd

- -73.2 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 179.59

0 0.9 1.8 Miles

0 1 2 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Residential Area
Kitimat
Kitamaat Village
SO2 1 hr Average Concentration (ppb)
(Includes background of 5.53 ppb)
42 tpd, 2017
0 - 17.5: Below 2025 CAAQS
17.5 - 30: Below 2025 CAAQS
30 - 65: Below 2025 CAAQS
65 - 70: Above 2025 CAAQS and Below 2020
70 - 140: Above 2020 CAAQS
140+: ABove 2020 CAAQS
0 0.9 1.8 Miles
0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

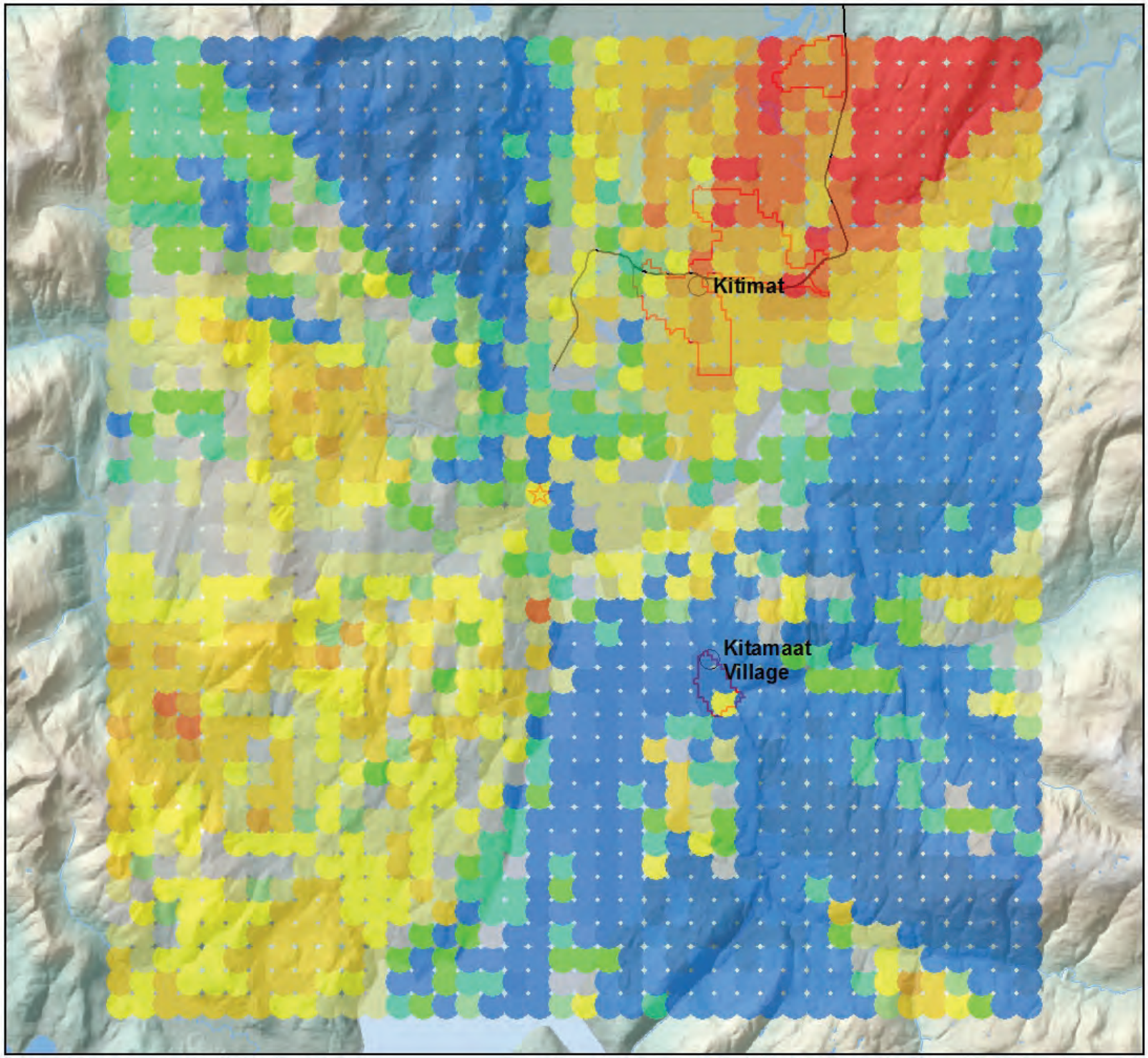
Residential Area

Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2017, 42 tpd

- -701 - -200
- -200 - -100
- -100 - -50
- -50 - -25
- -25 - -10
- -10 - -5
- -5 - 5
- 5 - 10
- 10 - 15
- 15 - 50
- 50 - 100
- 100 - 150
- 150 - 334

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

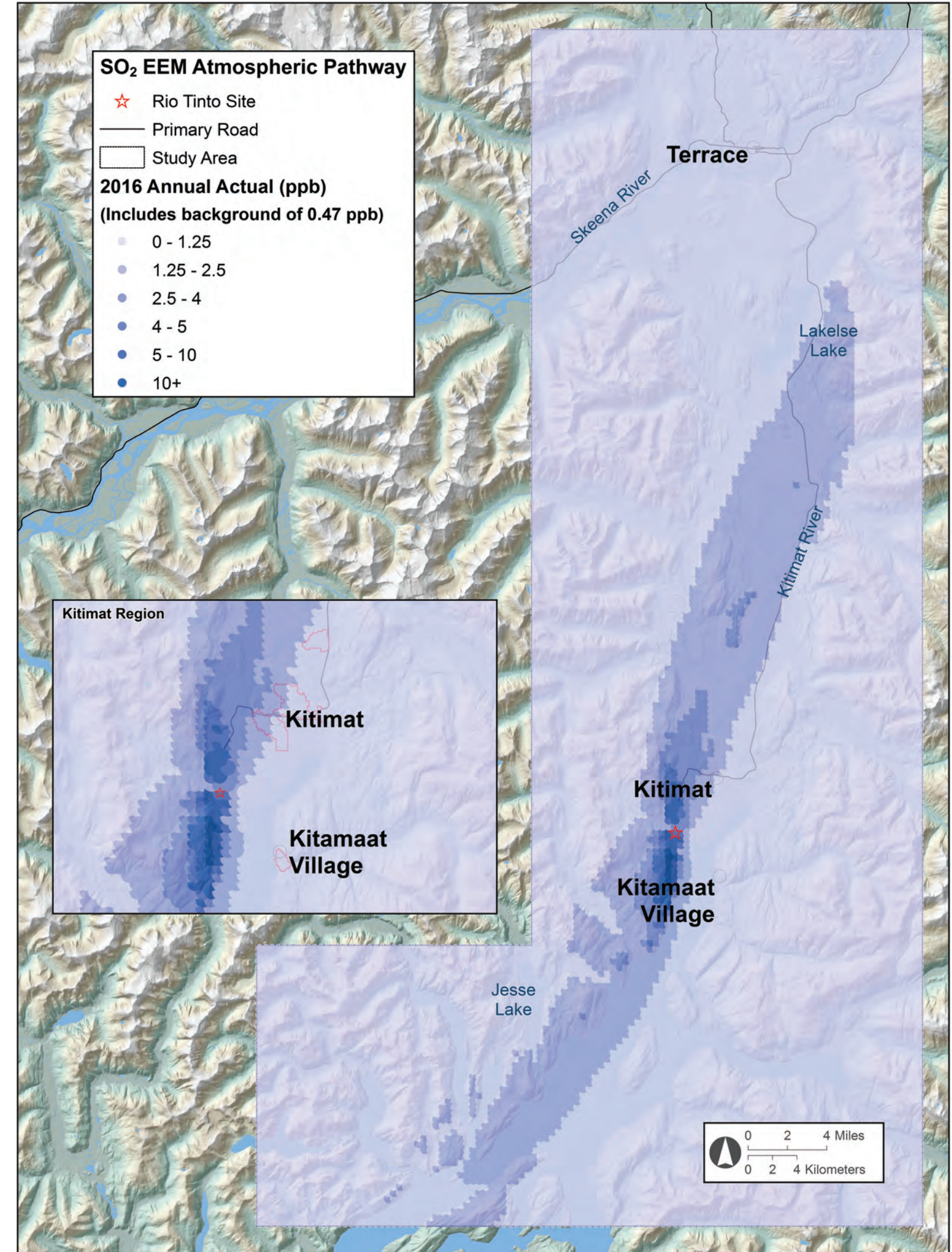
Residential Area

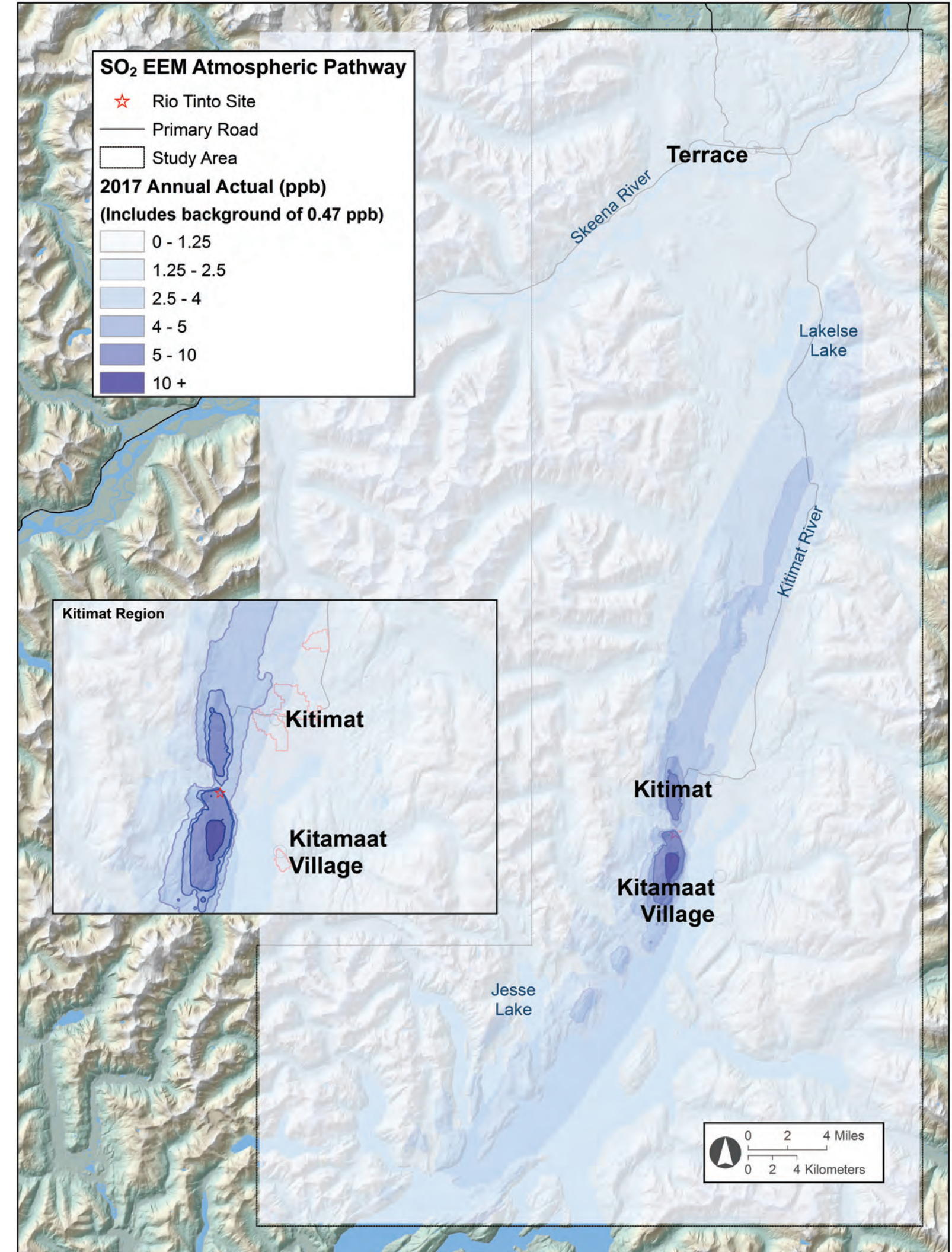
Percent Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2017, 42 tpd

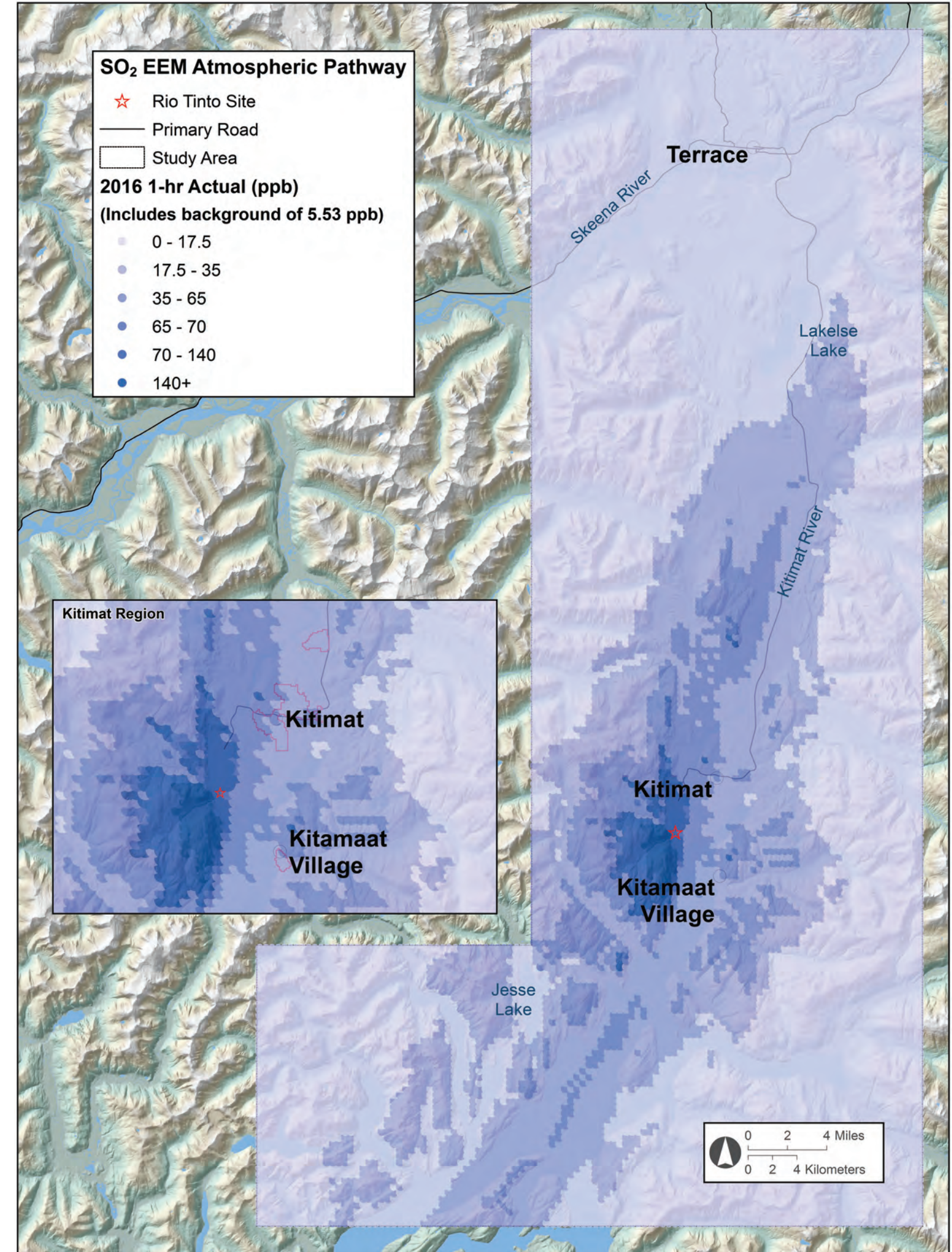
- -64.77 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 480.41

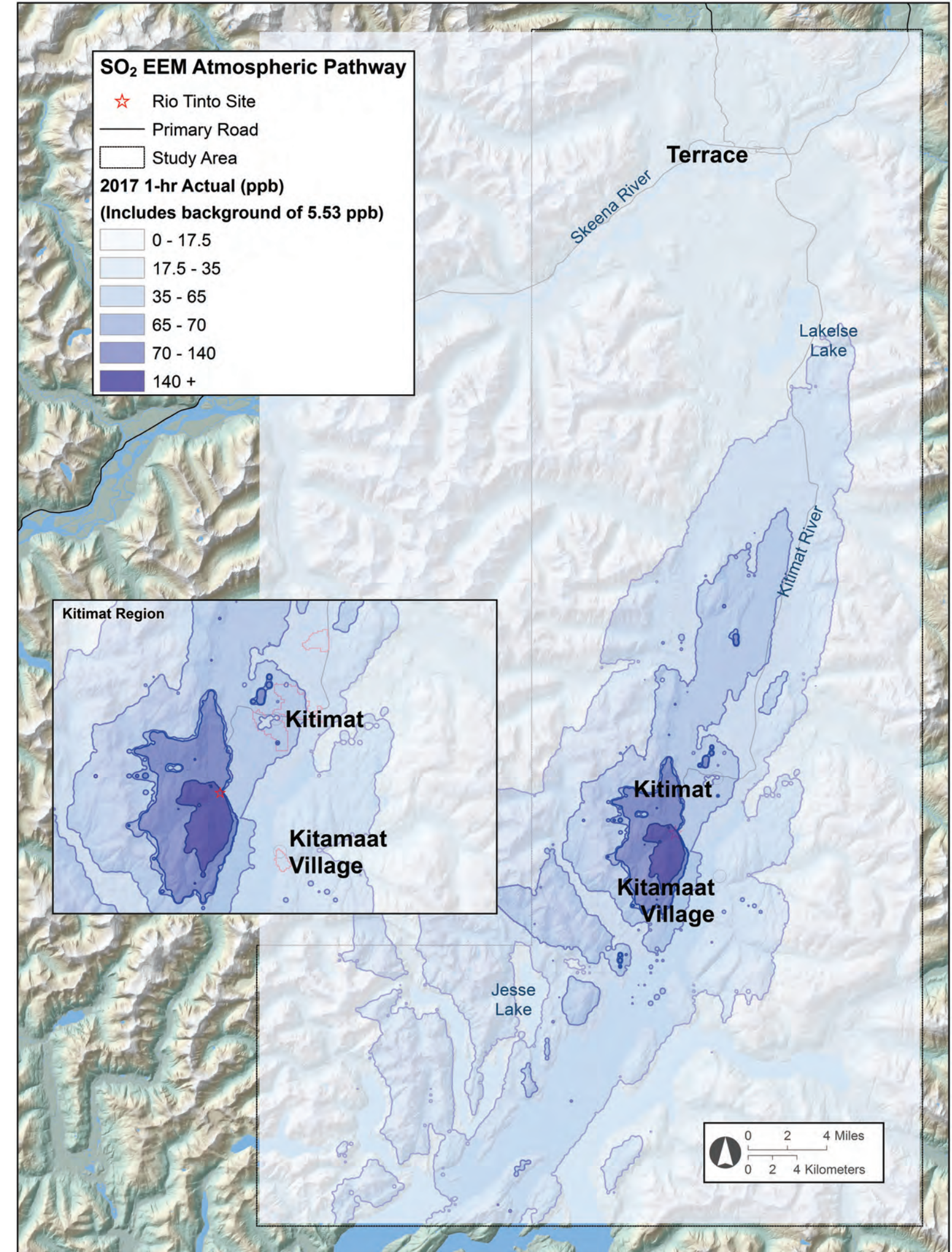
0 0.9 1.8 Miles

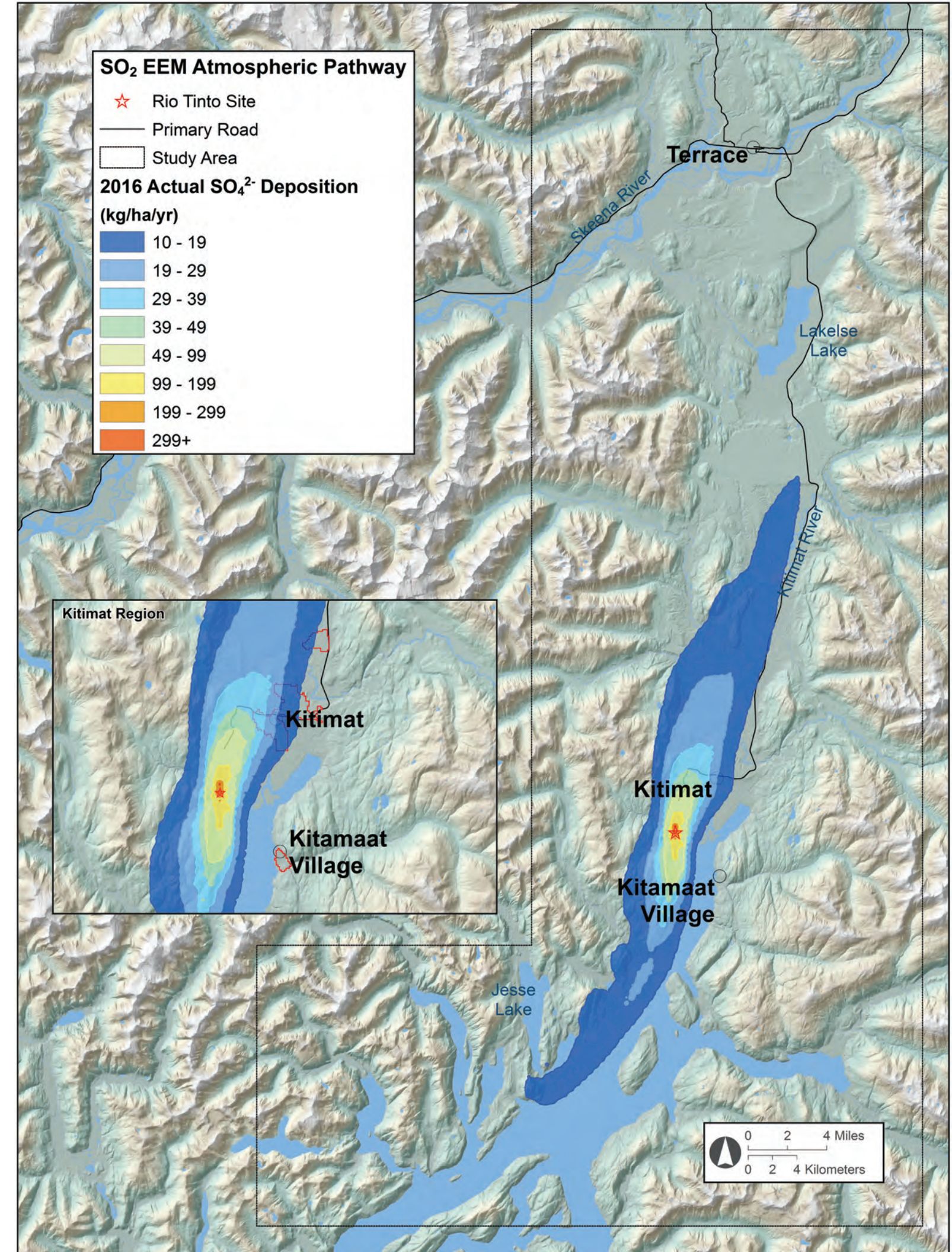
0 1 2 Kilometers

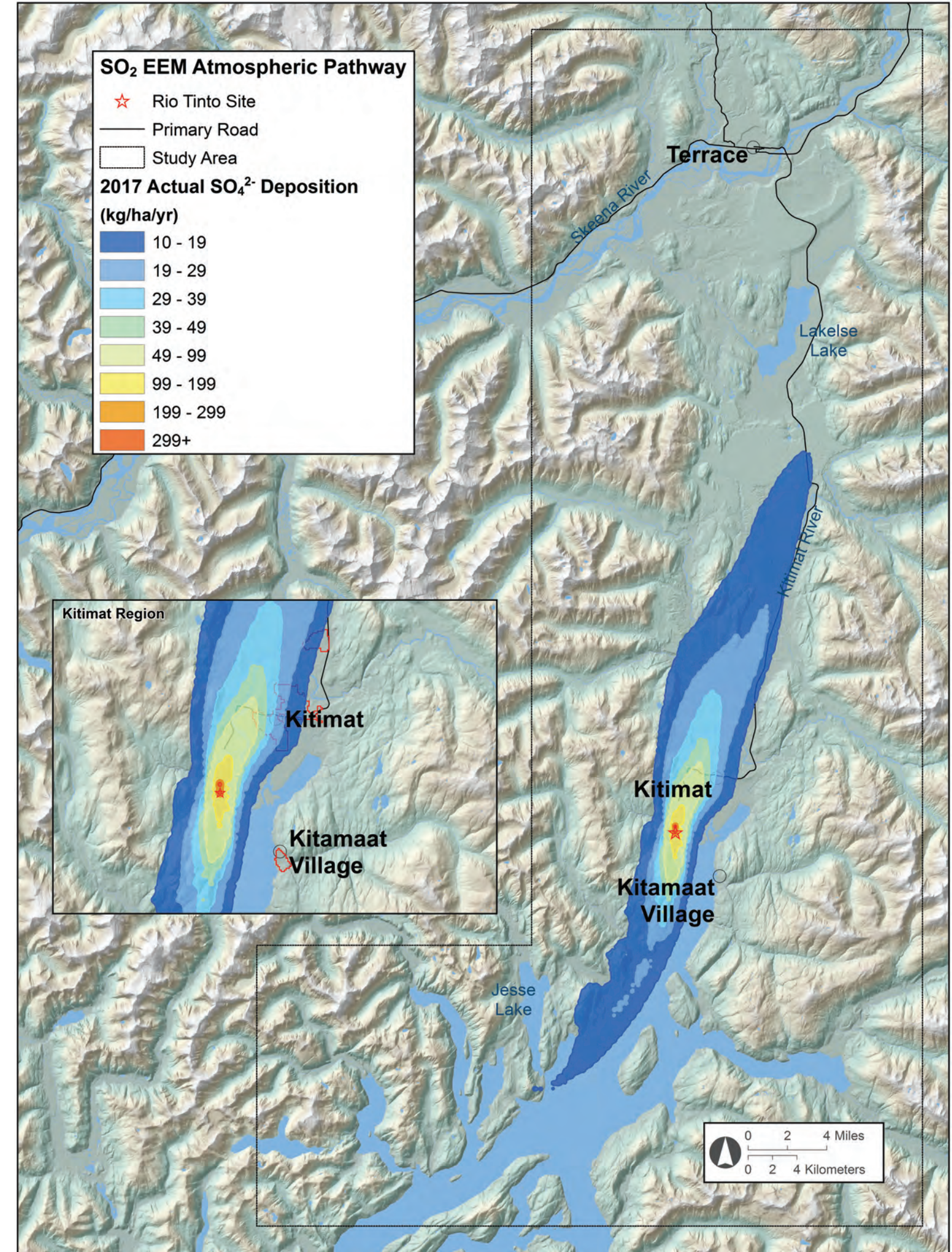

SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2016 Annual Actual (ppb)
(Includes background of 0.47 ppb)
0 - 1.25
1.25 - 2.5
2.5 - 4
4 - 5
5 - 10
10+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers

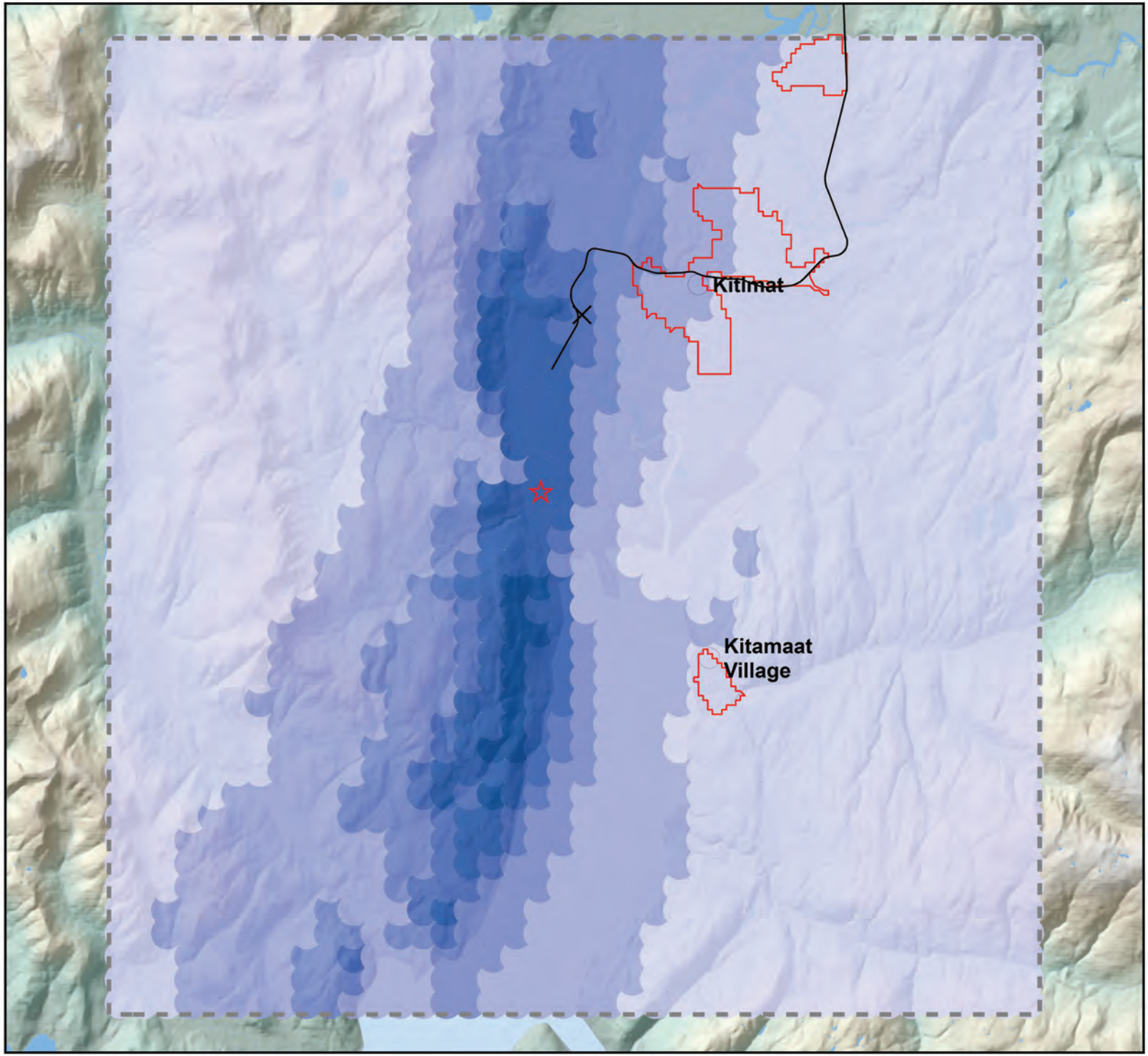

SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2017 Annual Actual (ppb)
(Includes background of 0.47 ppb)
0 - 1.25
1.25 - 2.5
2.5 - 4
4 - 5
5 - 10
10 +
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2016 1-hr Actual (ppb)
(Includes background of 5.53 ppb)
0 - 17.5
17.5 - 35
35 - 65
65 - 70
70 - 140
140+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2017 1-hr Actual (ppb)
(Includes background of 5.53 ppb)
0 - 17.5
17.5 - 35
35 - 65
65 - 70
70 - 140
140 +
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2016 Actual SO_4^{2-} Deposition
(kg/ha/yr)
10 - 19
19 - 29
29 - 39
39 - 49
49 - 99
99 - 199
199 - 299
299+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2017 Actual SO_4^{2-} Deposition
(kg/ha/yr)
10 - 19
19 - 29
29 - 39
39 - 49
49 - 99
99 - 199
199 - 299
299+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

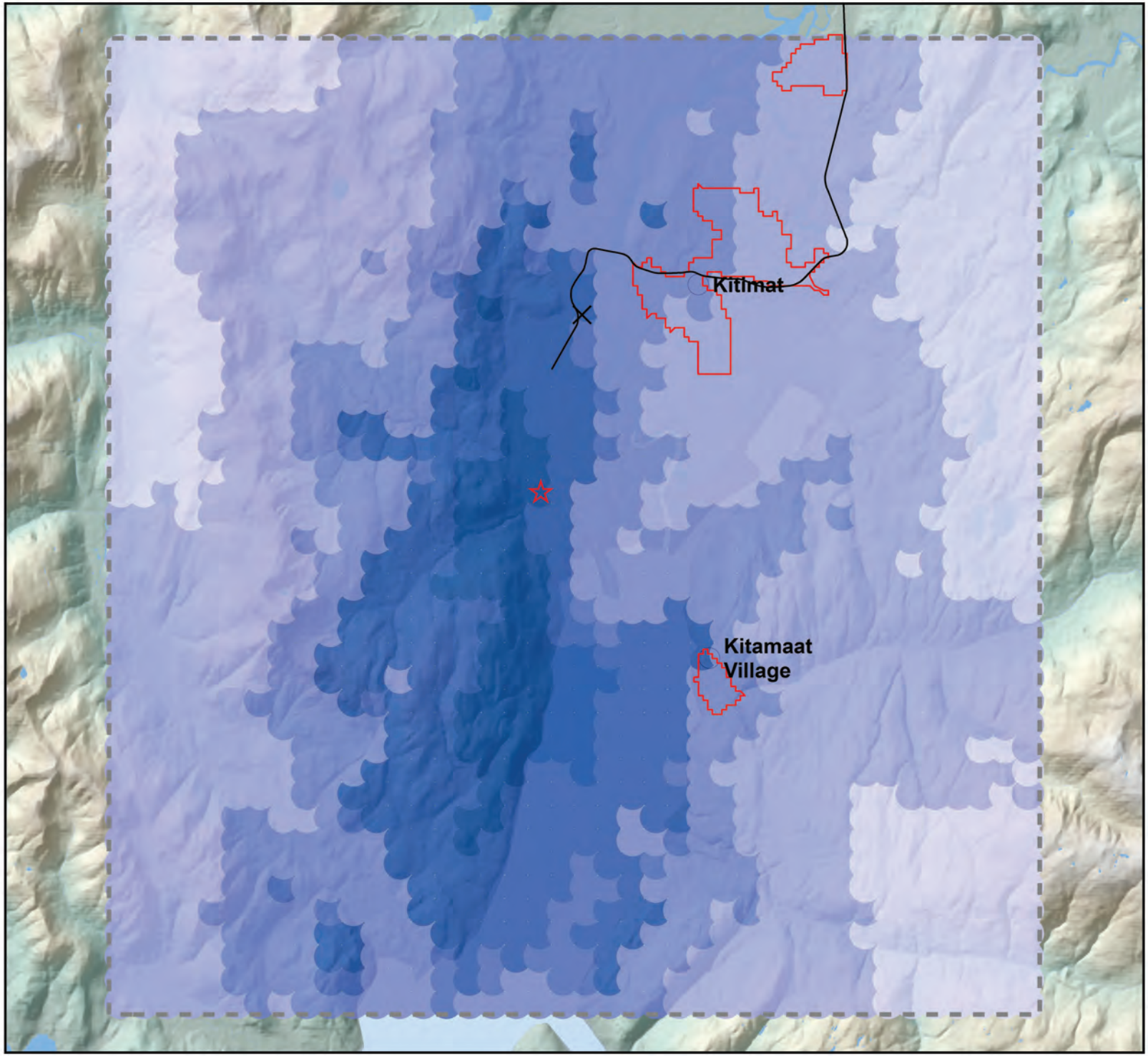
2016 Annual Actual (ppb)

(Includes background of 0.47 ppb)

- 0 - 1.25
- 1.25 - 2.5
- 2.5 - 4
- 4 - 5
- 5 - 10
- 10+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

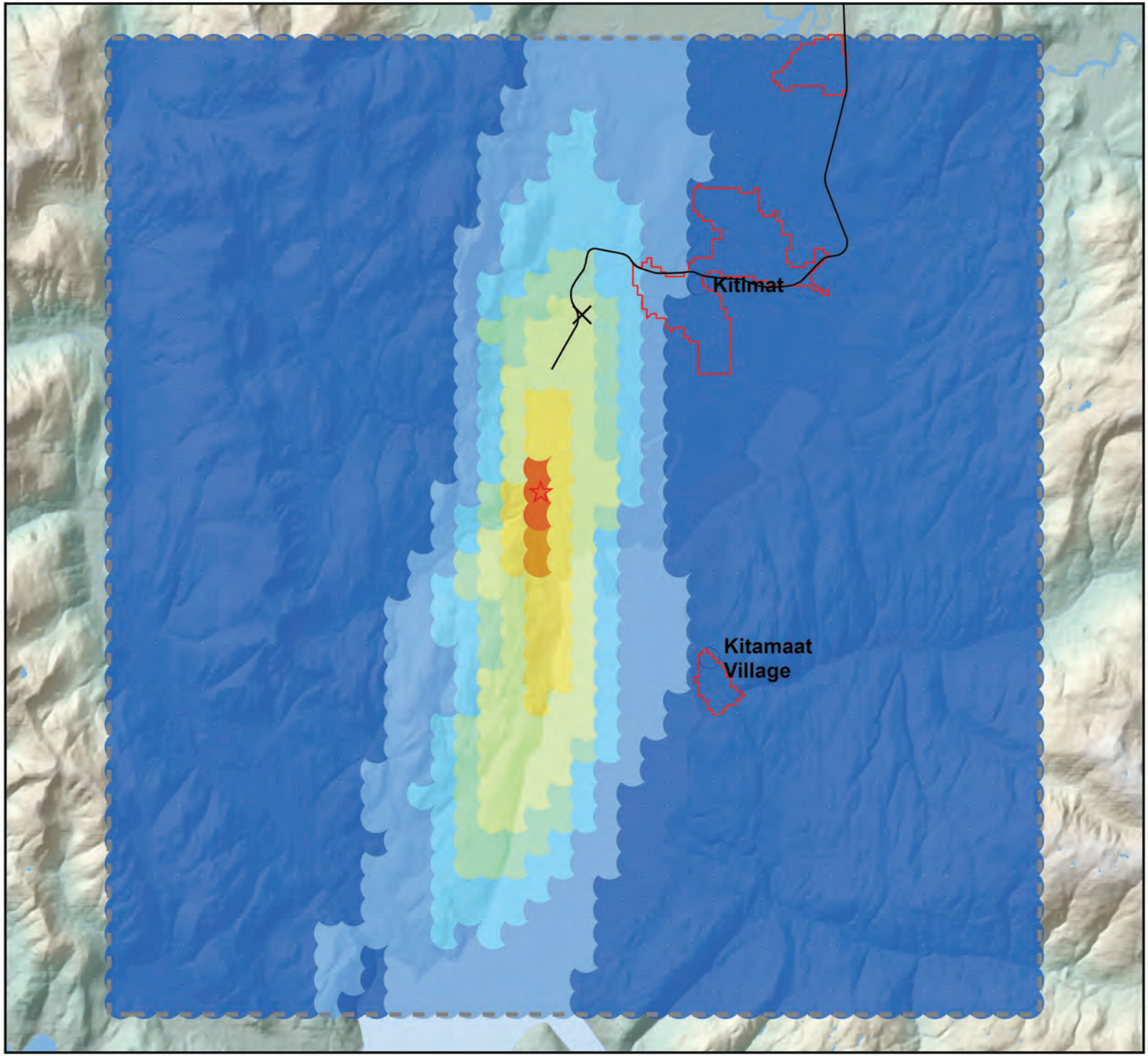
2016 1-hr Actual (ppb)

(Includes background of 5.53 ppb)

- 0 - 17.5
- 17.5 - 35
- 35 - 65
- 65 - 70
- 70 - 140
- 140+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

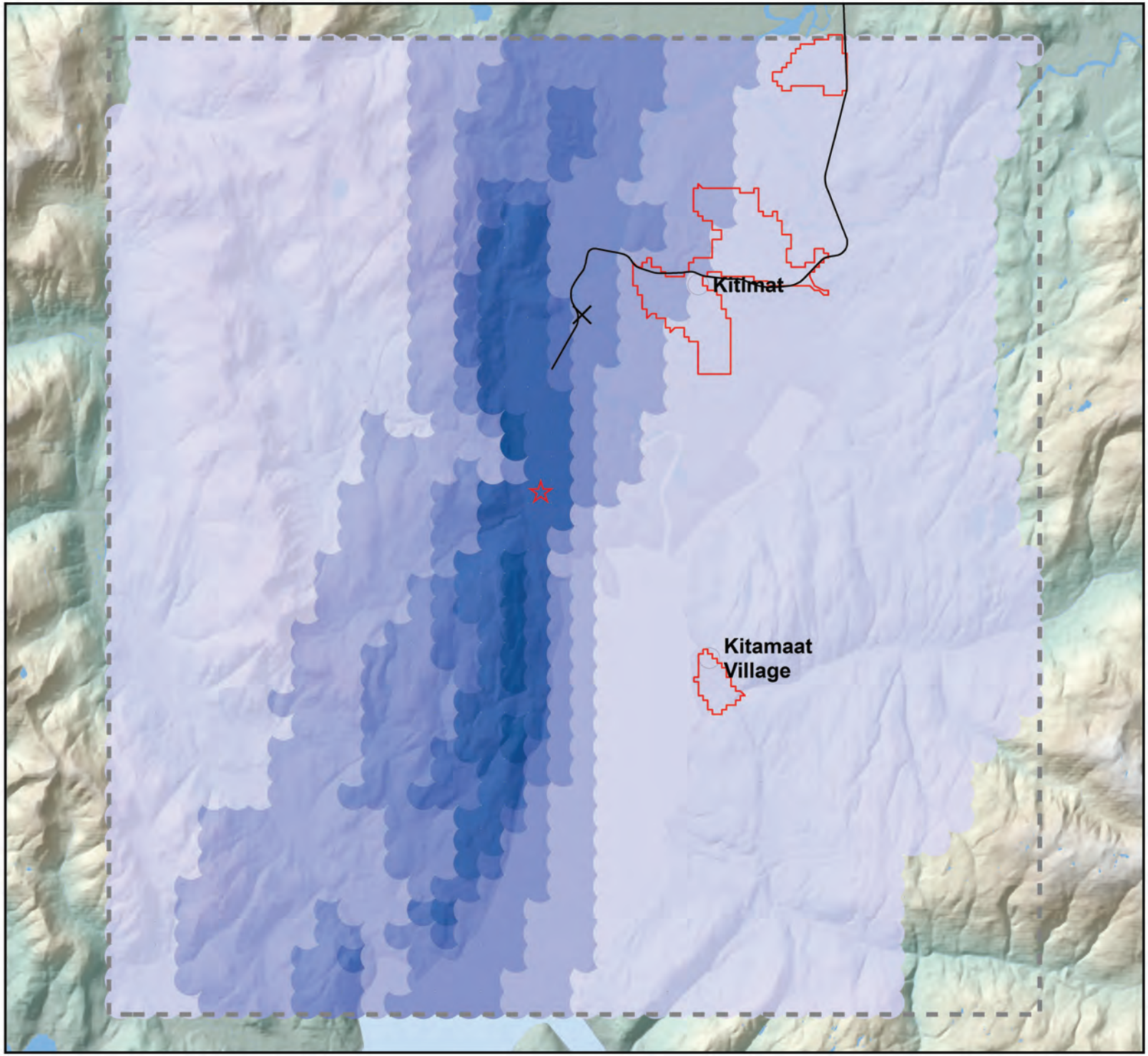
2016 Actual SO_4^{2-} Deposition

(kg/ha/hr)

- 10 - 19
- 19 - 29
- 29 - 39
- 39 - 49
- 49 - 99
- 99 - 199
- 199 - 299
- 299+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

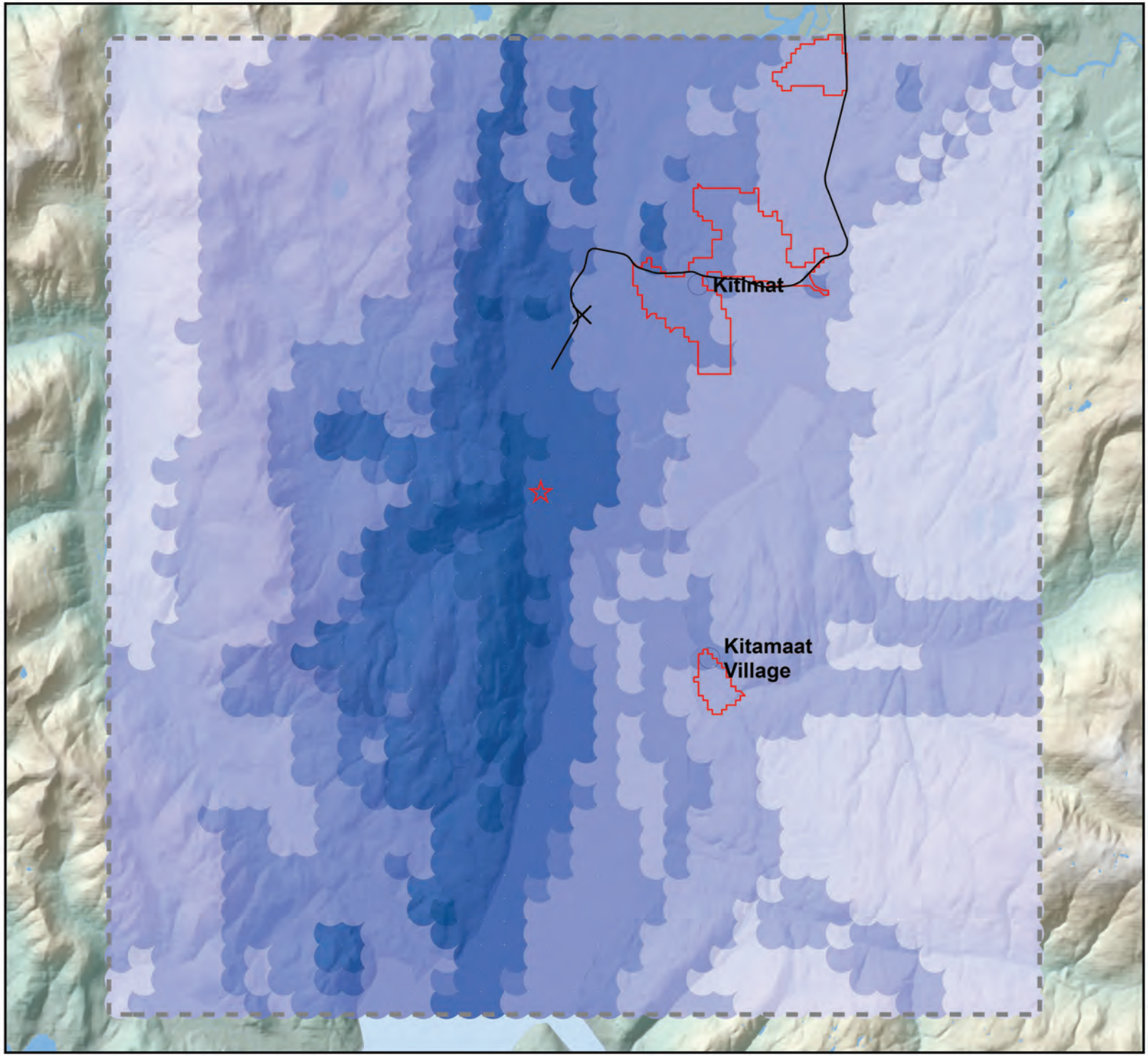
2017 Annual Actual (ppb)

(Includes background of 0.47 ppb)

- 0 - 1.25
- 1.25 - 2.5
- 2.5 - 4
- 4 - 5
- 5 - 10
- 10+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

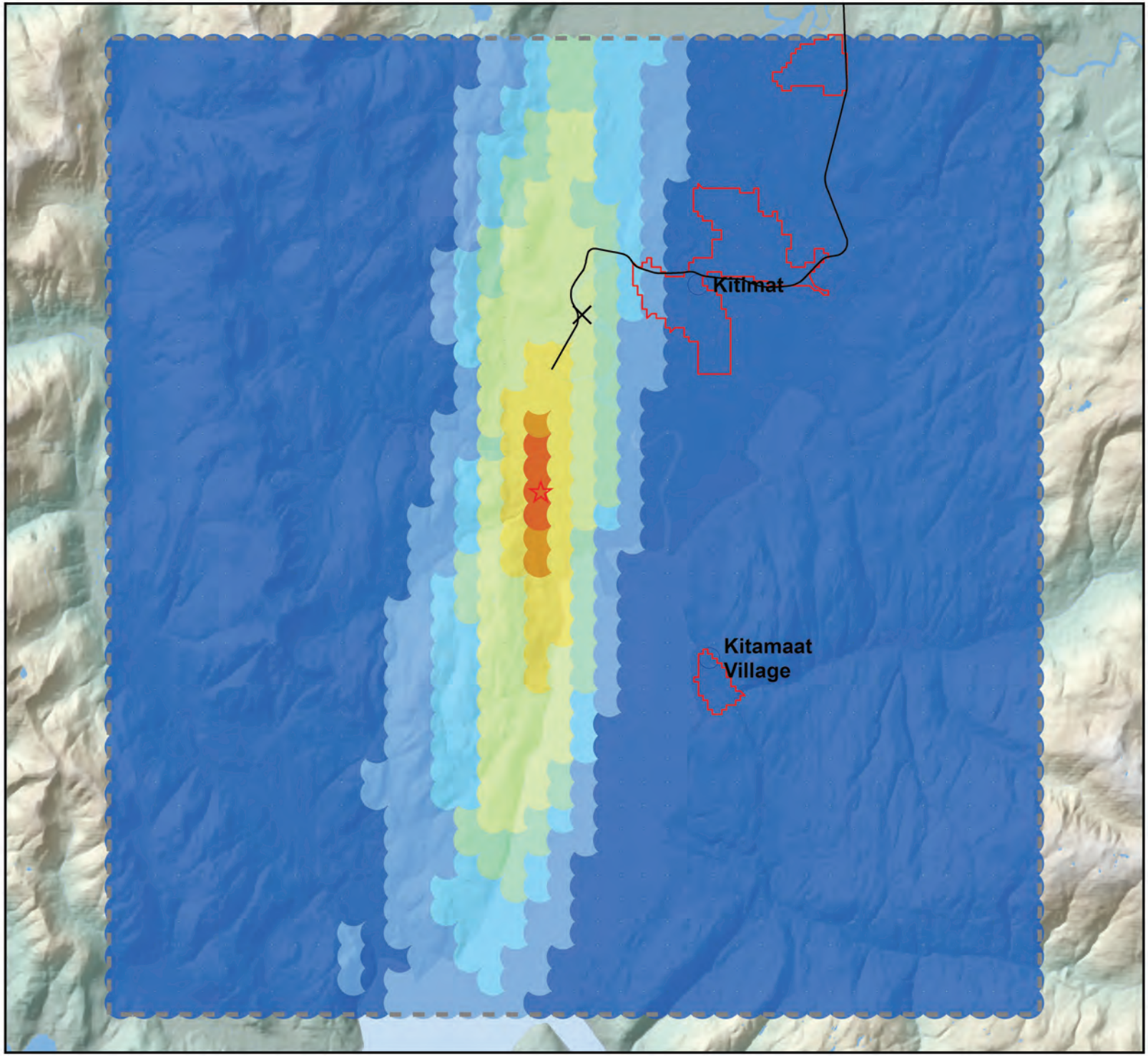
2017 1-hr Actual (ppb)

(Includes background of 5.53 ppb)

- 0 - 17.5
- 17.5 - 35
- 35 - 65
- 65 - 70
- 70 - 140
- 140+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

Residential Area

Study Area

2017 Actual SO_4^{2-} Deposition

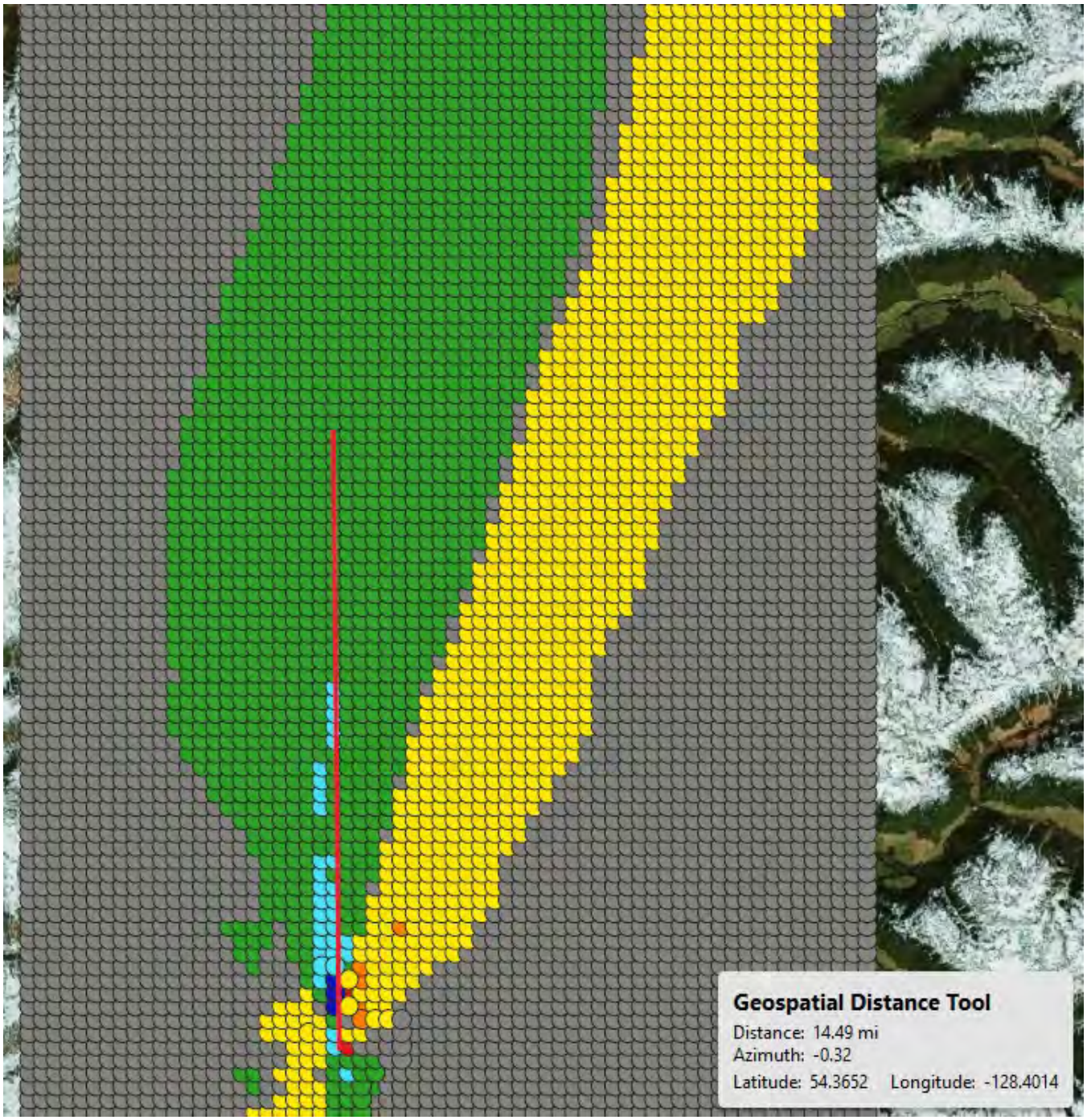
(kg/ha/yr)

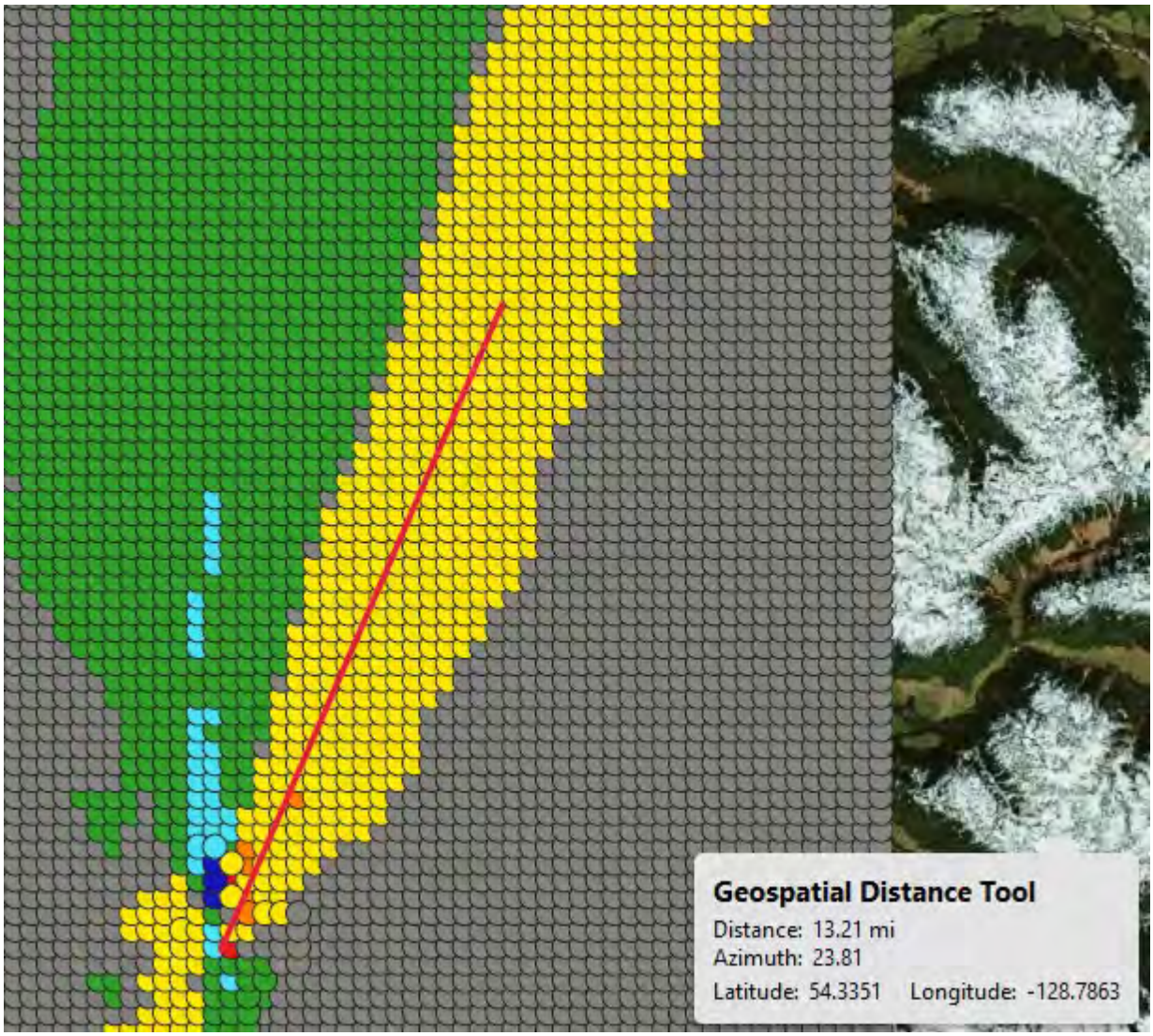
- 10 - 19
- 19 - 29
- 29 - 39
- 39 - 49
- 49 - 99
- 99 - 199
- 199 - 299
- 299+

0 0.9 1.8 Miles

0 1 2 Kilometers

Attachment 2
2018 Initial Model Measurements


Geospatial Distance Tool
Distance: 14.49 mi
Azimuth: -0.32
Latitude: 54.3652 Longitude: -128.4014


Geospatial Distance Tool
Distance: 13.21 mi
Azimuth: 23.81
Latitude: 54.3351 Longitude: -128.7863

Attachment 3
Model Performance Evaluation

MODEL PERFORMANCE EVALUATION

Regional scale model performance evaluation

The SO_2 concentrations predicted by the updated CALPUFF model for the actual scenario (actual emission rates, varying monthly) are compared to monitoring data to understand and evaluate the CALPUFF model performance. Only 2016 and 2017 are evaluated due to the Yacht Club missing wind speed data in 2018. For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data. The lower, more realistic background values are needed for model evaluation, so we can better understand model performance in areas with low SO_2 concentrations. If the Terrace-Skeena background used for effects assessments had been used for model evaluation, the model results in low concentration areas would be skewed. For example, even if the model result had been zero, the comparison using Terrace-Skeena for background would have shown the model over-predicted annual average concentrations at Kitamaat Village and Whitesail, because the Terrace-Skeena annual average SO_2 concentrations were higher than the Kitamaat Village and Whitesail annual average concentrations.[2]

SO_2 concentration results are calculated by CALPUFF in units of micrograms per meter cubed ($\mu g/m^3$). However, this appendix often presents SO_2 results in units of parts per billion (ppb) in order to stay consistent with the monitoring data and the CAAQS. It is possible to move between ppb and $\mu g/m^3$ by a factor of 2.614 $(\mu g/m^3)/(ppb)$.[3]

Evaluation of annual and individual hourly results and maximum hourly summary results are performed and summarized in Table A-1 and A-2 below. For annual average results, the updated model slightly improved over-prediction at Haul Road and Kitamaat Village and slightly increased over-prediction at Riverlodge and Whitesail. The model continues to over-predict the 99th percentile of daily 1-hour peak concentration at all stations and years, except now 2016 shows a slight under-prediction at Kitamaat Village. This one under-prediction was only slightly lower (19 ppb model result compared to 20 ppb), and previous 2018 CR results had also slightly under-predicted at Kitamaat Village. For all other comparisons, the model over-predicted by 20% (2017 Kitamaat Village) to 47% (2016 Whitesail), aligning fairly closely to CR comparisons which had a maximum 1-hour 99% over-prediction of 51% (also at Whitesail in 2016).[4]

[2] The Terrace-Skeena annual average concentrations were 0.4 to 0.5 ppb in 2016 – 2018. The Kitamaat Village annual average concentrations were 0.20 to 0.38 ppb, and Whitesail annual average concentrations were 0.41 ppb in 2017 and 0.35 ppb in 2018.

Based on 2017 and 2018 data, the Williams Lake background concentrations are 1.8 ppb for the 1-hour, 99th percentile daily peak SO_2: 1.8 ppb; and 0.26 ppb for annual average.

[3] The 2.614 $(\mu g/m^3)/(ppb)$ factor converts from a mass concentration basis to a volume concentration basis of SO_2 based on the molecular weight of SO_2 and standard atmospheric conditions. In this case, standard conditions are 1 atm and approximately 25 C, precisely corresponding to the 1-hour SO_2 B.C. AQO levels listed of 70 ppb and 183 $\mu g/m^3$ (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/aqotable.pdf).

[4] Percentage under-prediction or over-prediction calculated as the difference between the CALUFF result and observation, as a percent of the CALPUFF result.

Table A3-1. Summary of CALPUFF Model Comparison to Continuous Monitoring Data, Annual Average SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	0.38	0.58	0.54	0.29	0.52	0.51
Haul Road	4.22	7.12	6.78	3.77	7.33	7.20
Riverlodge	0.50	1.49	2.15	0.43	1.54	2.02
Whitesail	0.53	0.82	1.17	0.41	0.86	1.15

[1] Monitoring data annual average for 2016, 2017.

[2] CALPUFF results for actual scenario, regional-scale using actual smelter emission rates from 2016 to 2018, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO2 for 2016 – 2018 actual conditions. Results with a higher background are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments. The annual average background concentration used for the new 2016 -2018 model is 0.47 ppb based on monitoring at Terrace-Skeena Middle School.

Table A3-2. Summary of regional scale CALPUFF model comparison to continuous monitoring data, 99th percentile of daily 1-hour peak SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	20	25	19	12	17	15
Haul Road	75	99	108	66	100	105
Riverlodge	22	34	40	28	37	42
Whitesail	15	30	28	21	41	35

[1] Monitoring data 1-hour average for 2016, 2017.

[2] CALPUFF results for actual scenario, regional-scale using actual smelter emission rates from 2016 to 2017, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (1.8 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background (5.53 ppb based on monitoring at Terrace-Skeena Middle School) are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments.

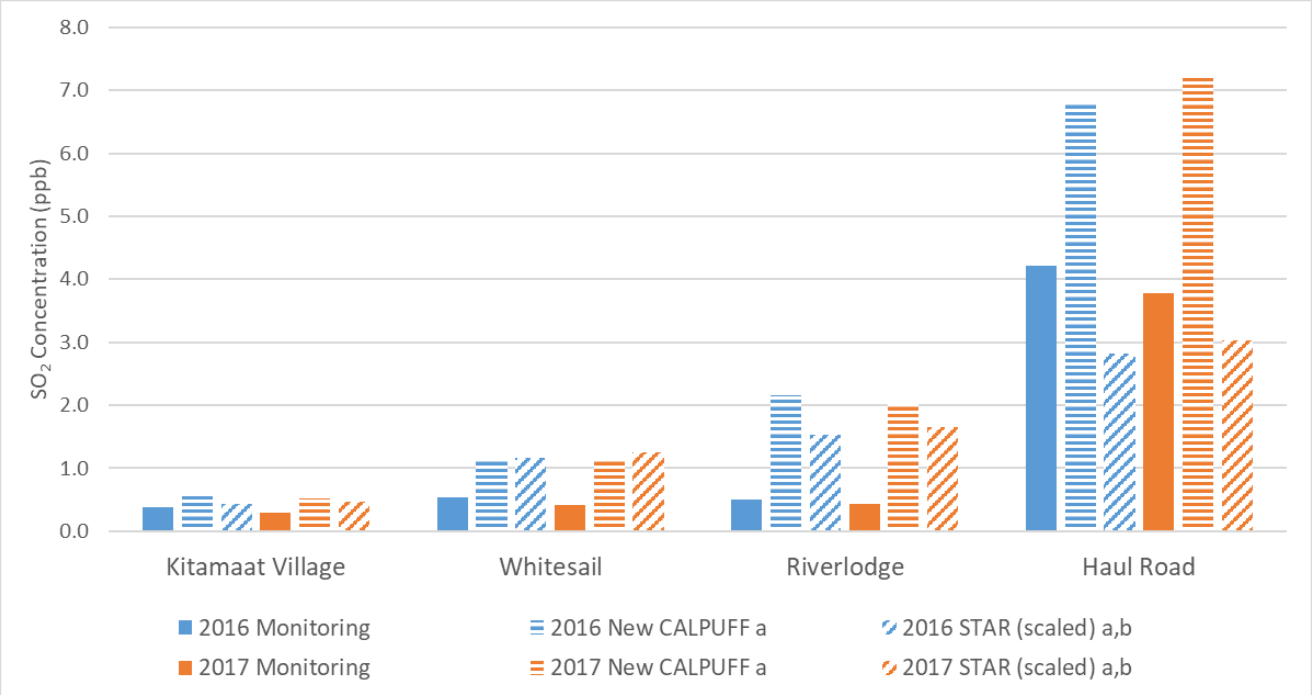


Figure A3-1. Continuous SO_2 (ppb) monitoring concentrations compared to updated CALPUFF model results and scaled STAR model concentrations, 99% of 1-hour daily peak, regional-scale (Williams Lake 1-hour background of 1.8 ppb applied).

Table A3-3 below provides the performance statistics for the regional-scale model for both the original CR model and the updated model. The original CR model statistics are provided in gray text as reference. Overall, the performance statistics are similar between the two models, with some slight improvements for Kitimaat Village and Haul Road and slightly higher error for Riverlodge and Whitesail. The root mean squared error (RMSE), mean bias error (MBE), and mean absolute error (MAE) represent the difference (or error) between the model result versus the observation at each monitor for each hour (paired in space and time as illustrated in Figure A3-2). The MBE represents the same differences seen when comparing the annual average concentrations. The MBE values indicate that the updated model overall slightly under-predicts at Kitamaat Village, slightly over-predicts Whitesail and over-predicts moderately at Haul Road and Riverlodge. The MAE indicates the mean error is larger when looking at absolute error for each hour, averaged over the two model years. For example, the model over-predicts some hours and under-predicts some hours, which averages out to only -0.2 $\mu g/m^3$ for Kitamaat Village, but the average over-prediction or under-prediction is approximately 1.22 $\mu g/m^3$ when looking at the absolute difference. The percentages are provided to demonstrate that while the Haul Road has the largest MBE and MAE on an absolute basis, the 18.9 $\mu g/m^3$ error put in context as a percentage of the monitored concentration is lower than Whitesail, which has an MAE of only 2.7 $\mu g/m^3$.

Table A3-3. Regional scale model performance evaluation statistics. Williams Lake annual background of 0.27 ppb, (0.69 µg/m^3) is applied.

Model	Monitor	RMSE (µg/m^3)	MBE (µg/m^3)	MAE (µg/m^3)	MBE% [1]	MAE% [1]
Original CR Model	Kitamaat Village	3.60	0.66	1.27	87%	167%
	Haul Road	34.06	8.49	17.72	83%	174%
	Riverlodge	9.47	2.86	3.71	235%	304%
	Whitesail	6.16	1.21	2.10	109%	189%
Updated Model (Corrected for Wind Direction)	Kitamaat Village	3.26	-0.20	1.22	-23%	139%
	Haul Road	35.69	7.08	18.86	68%	181%
	Riverlodge	10.93	3.49	4.68	287%	385%
	Whitesail	7.28	1.12	2.72	91%	222%

[1] MBE% and MAE% are expressed as MBE and MAE divided by the annual average observed concentrations, respectively, at each receptor.

Dispersion models are not expected to agree perfectly when paired in time and space (as done for the Table A3-3 performance statistics). In addition, the ability to predict an accurate annual average and 99th percentile daily peak (even if the day is not the same) is the most important metric for evaluating the model's ability to accurately predict future concentrations or deposition rates to assess risk of impacts to receptors. As such, quantile-quantile plots (Q-Q plots) are commonly used to evaluate model performance. Figure A3-2 illustrates the comparison paired in time (max hour each day from 2016 to 2018 for visualizing), while Figure A3-3 compares the hourly model data (all hours from 2016 to 2018) versus monitoring data sorted highest to lowest (Q-Q plot). The comparisons illustrate that the model predicts concentrations and distribution similar to monitoring data at each station (e.g., Kitamaat Village concentrations are low (below 10 ppb) most days with a few (5 to 10) occurrences of 1-hour peaks in the 20 – 30 ppb range for both datasets). However, while the model's overall predictions compare closely to the monitored concentrations, the model results do not generally predict the peaks on the same day or hour.

The Q-Q plots in Figure A3-3 and A-4 illustrate that the model generally predicts concentrations between 100% and 200% of the monitored concentrations, with the exception of slight under-prediction at Kitamaat Village for the two highest hours over and some over-prediction above 200% at the lowest quantile concentrations, particularly for Riverlodge and Haul Road. The updated model performance is about the same at all stations with some slight improvements at Haul Road.

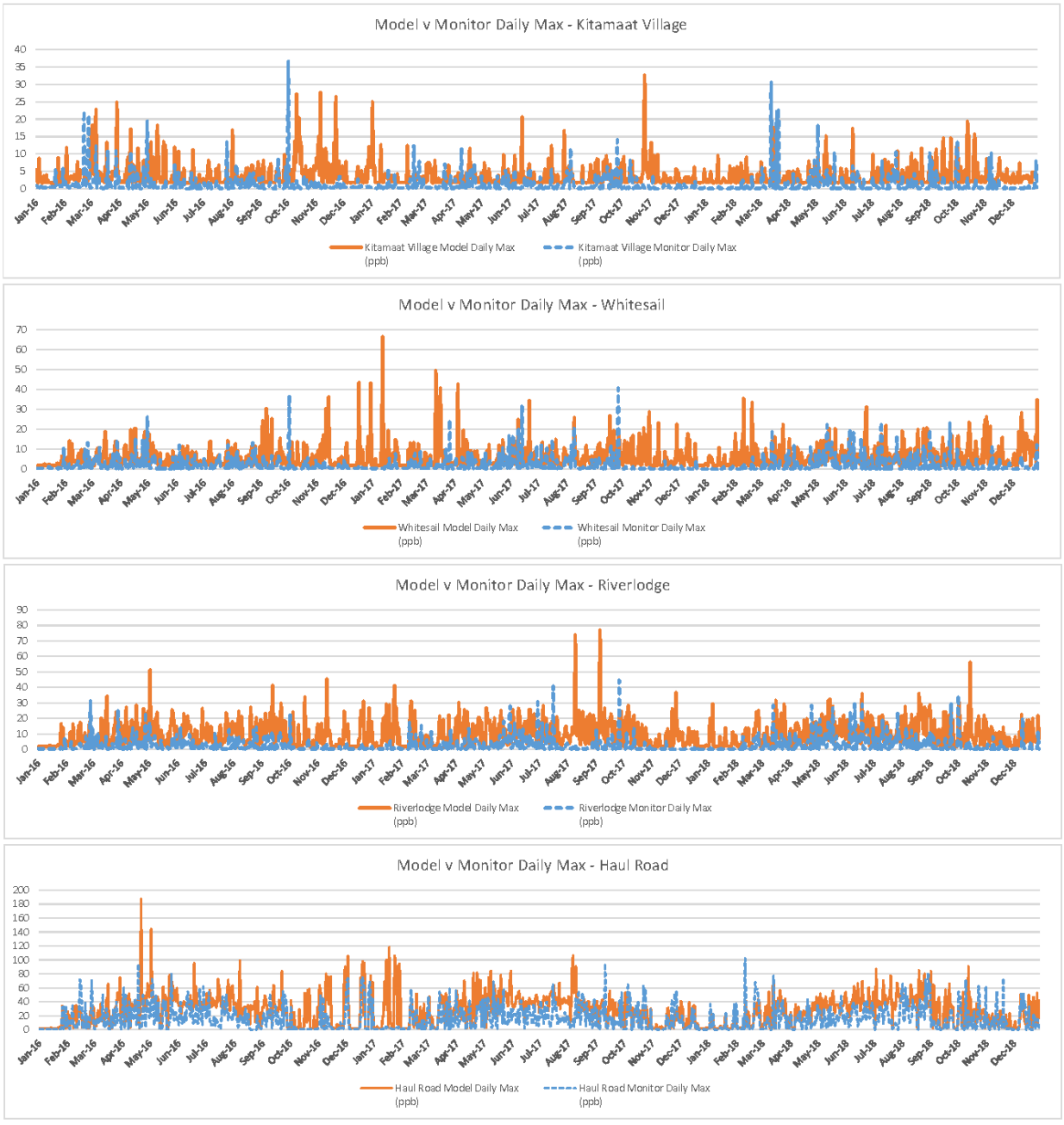


Figure A3-2. Comparison of modelled SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, timeseries (paired in time). The model data include the 1-hour background concentration (1.80 ppb).

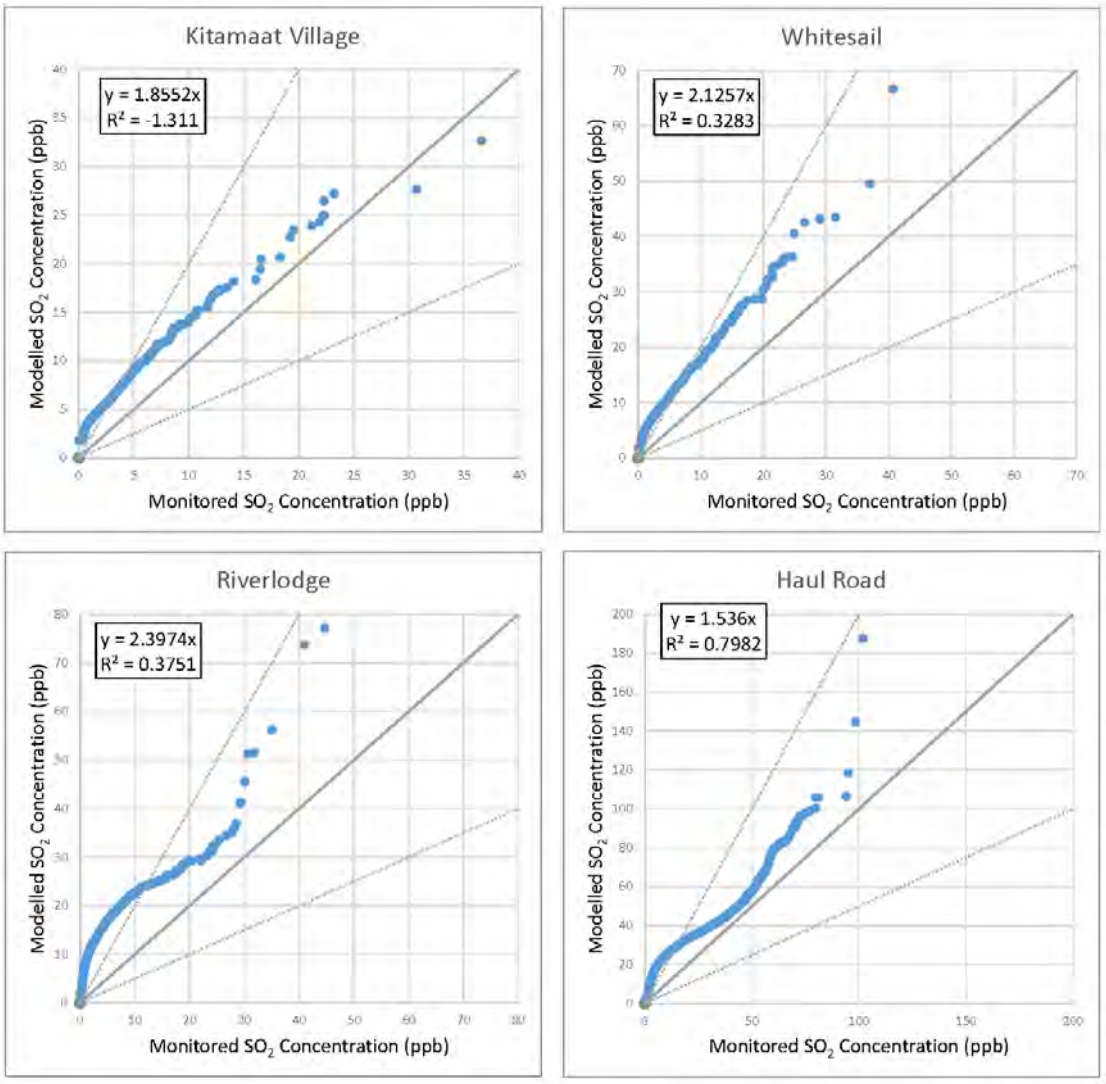


Figure A3-3. Comparison of original CR model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

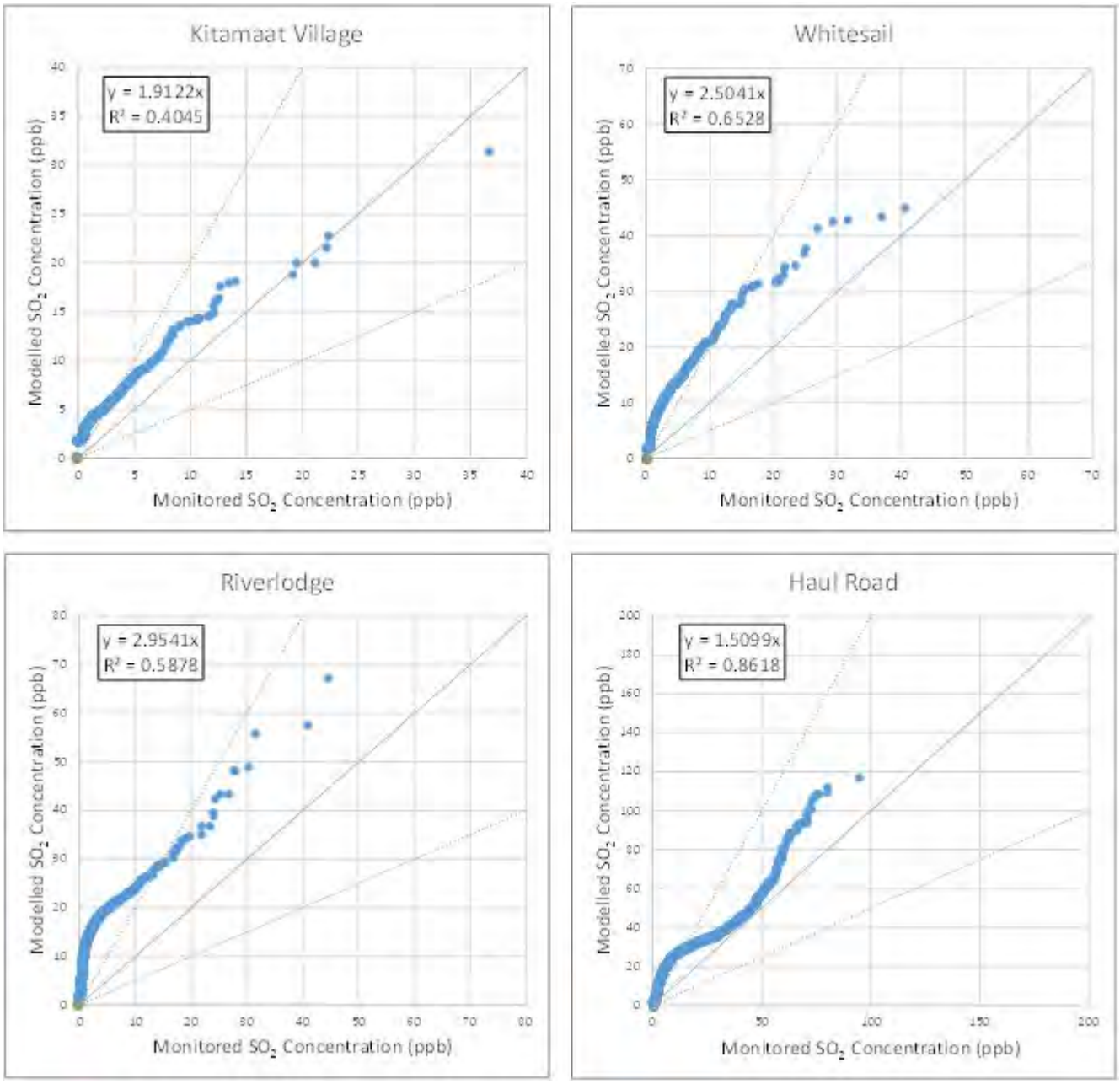


Figure A3-4. Comparison of updated model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

We also used the passive sampling measurements to evaluate the 2016–2017 CALPUFF model performance. Model data were averaged over the same periods as measured by the passive samplers for each sampling period at each site. As shown in the following tables and figures, the updated regional CALPUFF model performance is similar to the CR model performance. Both models over-predict long term (June – October) average concentrations in most locations (model results 150% to 500% of monitored concentrations). For the comparison that over-predicted at the highest rate, the corrected model over-predicts more-so: at V00 on the east side of the valley the updated model predicts 7 µg/m^3 versus 5 µg/m^3 modelled in the CR

compared to 0.34 µg/m^3 measured (only monitored in 2016). Model concentrations at the few sites to the south of the smelter (V11 - V13) remained generally lower than the monitored concentrations (under-predictions), ranging from 69% (V13 in 2017) to 127% (V12 in 2016) of monitored concentrations. Site V10 near the smelter's west boundary, maintained fairly good agreement with model results, but changed from agreeing very closely (model/monitor of 101%, 121%, and 102%) to slight under-predictions (78% and 77%). Overall, the updated model over-predicts to a lesser degree at the majority of the valley network sites compared to the original CR model and results in higher over-prediction at the urban sites.

Table A-4. Regional scale model CALPUFF compared to passive monitoring data - 2016.

Sensor ID	UTM X (m)	UTM Y (m)	Passive Average [a] (µg/m^3)	CALPUFF Original Average [b] (µg/m^3)	CALPUFF Original/ Passive	CALPUFF Corrected Average [b] (µg/m^3)	CALPUFF Corrected/ Passive
V00	530,167	6,016,477	0.34	5.02	1457%	7.02	2039%
V01	524,948	6,017,458	1.80	5.38	300%	3.81	212%
V02	523,130	6,015,390	1.47	5.49	373%	3.30	224%
V03	520,931	6,009,416	2.99	5.73	192%	2.79	93%
V04	520,767	6,003,740	0.92	8.80	959%	4.69	511%
V05	520,539	5,999,300	3.17	11.29	356%	6.63	209%
V06	520,944	5,996,297	2.27	9.22	406%	9.10	401%
V07	521,361	5,993,907	1.35	6.54	483%	8.99	663%
V08	519,935	5,992,321	3.94	13.05	331%	11.44	290%
V09	518,980	5,989,246	4.68	24.03	513%	18.51	395%
V10	519,028	5,985,441	7.13	7.23	101%	5.59	78%
V11	519,426	5,979,635	7.53	5.79	77%	5.46	72%
V12	518,339	5,977,238	4.96	6.45	130%	6.28	127%
V14/U12	520,488	5,990,243	2.11	8.10	384%	10.01	475%
A01	519,527	5,986,823	8.78	23.43	267%	24.48	279%
A02	521,538	5,989,580	0.81	4.61	572%	6.69	830%
A03	523,619	5,991,025	0.64	2.82	439%	3.66	569%
A04	527,457	6,025,573	0.61	4.02	656%	3.48	569%
U01	522,026	5,988,725	0.62	3.72	602%	4.42	714%
U02	522,781	5,989,708	0.60	3.29	545%	3.80	630%
U03	524,345	5,989,883	0.59	2.51	428%	2.87	490%
U04	524,362	5,990,295	0.57	2.51	440%	2.88	505%
U05	525,606	5,993,817	0.31	2.23	724%	2.58	837%
U06	522,947	5,989,308	0.73	3.02	413%	3.45	471%
U07	522,841	5,988,229	0.55	2.96	542%	3.27	598%
U08	522,866	5,991,066	0.76	3.86	509%	5.01	662%
U09	523,917	5,990,370	0.52	2.33	449%	2.39	460%
U10	523,807	5,991,260	0.65	2.96	456%	3.75	579%
U11	523,311	5,989,855	0.70	3.20	457%	3.81	544%
U13	524,981	5,989,675	0.67	2.29	341%	2.54	379%
U14	522,286	5,989,250	0.68	3.57	522%	4.25	621%
U15	523,232	5,980,798	0.47	2.05	436%	1.96	418%

[a] The passive data in this table is not adjusted for calibration with the continuous SO_2 analyzers.

[b] The following background value from Williams Lake is added to account for non-modelled sources of SO_2.

30-day Average Background: 0.46 ppb 1.21 (µg/m^3)

(2nd High over 2017-2018, 96th%) (1ppb = 2.614 µg/m^3 SO_2)

Table A-5. Regional scale model CALPUFF compared to passive monitoring data - 2017.

Sensor ID	UTM X (m)	UTM Y (m)	Passive Average [a] (µg/m³)	CALPUFF Average [b] (µg/m³)	CALPUFF/ Passive	CALPUFF Corrected Average [b] (µg/m³)	CALPUFF Corrected/ Passive
V01	524,948	6,017,458	1.97	5.53	280%	3.66	185%
V02	523,130	6,015,390	1.52	5.05	332%	3.11	204%
V03	520,931	6,009,416	4.24	7.27	171%	3.75	88%
V04	520,767	6,003,740	2.05	10.48	512%	5.85	286%
V04B	520,436	6,003,249	2.15	10.74	500%	2.07	97%
V05	520,539	5,999,300	5.41	11.75	217%	7.36	136%
V06	520,944	5,996,297	3.89	10.74	276%	9.63	247%
V07	521,361	5,993,907	2.08	8.60	413%	9.64	463%
V07B	520,285	5,993,190	3.48	13.26	381%	2.79	80%
V08	519,935	5,992,321	6.18	13.38	216%	11.65	188%
V09	518,980	5,989,246	7.88	29.54	375%	21.82	277%
V10	519,028	5,985,441	10.40	12.59	121%	7.97	77%
V11	519,426	5,979,635	7.91	6.06	77%	6.06	77%
V12	518,339	5,977,238	5.36	5.84	109%	6.05	113%
V13	516,405	5,976,686	5.50	3.61	66%	3.29	60%
V14/U12	520,488	5,990,243	3.28	11.93	364%	12.57	384%
A01	519,527	5,986,823	10.73	24.32	227%	23.70	221%
A02	521,538	5,989,580	1.01	5.42	538%	6.90	684%
A03	523,619	5,991,025	0.83	3.08	370%	3.59	431%
A04	527,457	6,025,573	0.76	4.39	580%	3.42	452%
U01	522,026	5,988,725	0.91	3.82	419%	4.17	457%
U02	522,781	5,989,708	0.76	3.23	427%	3.48	461%
U03	524,345	5,989,883	0.77	2.69	350%	2.66	346%
U04	524,362	5,990,295	0.85	2.68	313%	2.69	314%
U05	525,606	5,993,817	0.33	2.34	716%	2.52	773%
U06	522,947	5,989,308	0.88	2.97	339%	3.05	348%
U07	522,841	5,988,229	0.81	2.84	352%	2.86	353%
U08	522,866	5,991,066	0.76	3.95	520%	5.22	688%
U09	523,917	5,990,370	0.87	2.84	326%	2.98	342%
U10	523,807	5,991,260	0.78	3.03	390%	3.54	455%
U11	523,311	5,989,855	0.93	3.17	339%	3.38	363%
U13	524,981	5,989,675	0.72	2.43	338%	2.35	328%
U14	522,286	5,989,250	0.89	3.64	409%	4.01	451%

[a] The passive data in this table is not adjusted for calibration with the continuous SO_2 analyzers.

[b] The following background value from Williams Lake is added to account for non-modelled sources of SO_2.

30-day Average Background: 0.46 ppb 1.21 (µg/m³)

(2nd High over 2017-2018, 96th%) (1ppb = 2.614 µg/m³ SO_2)

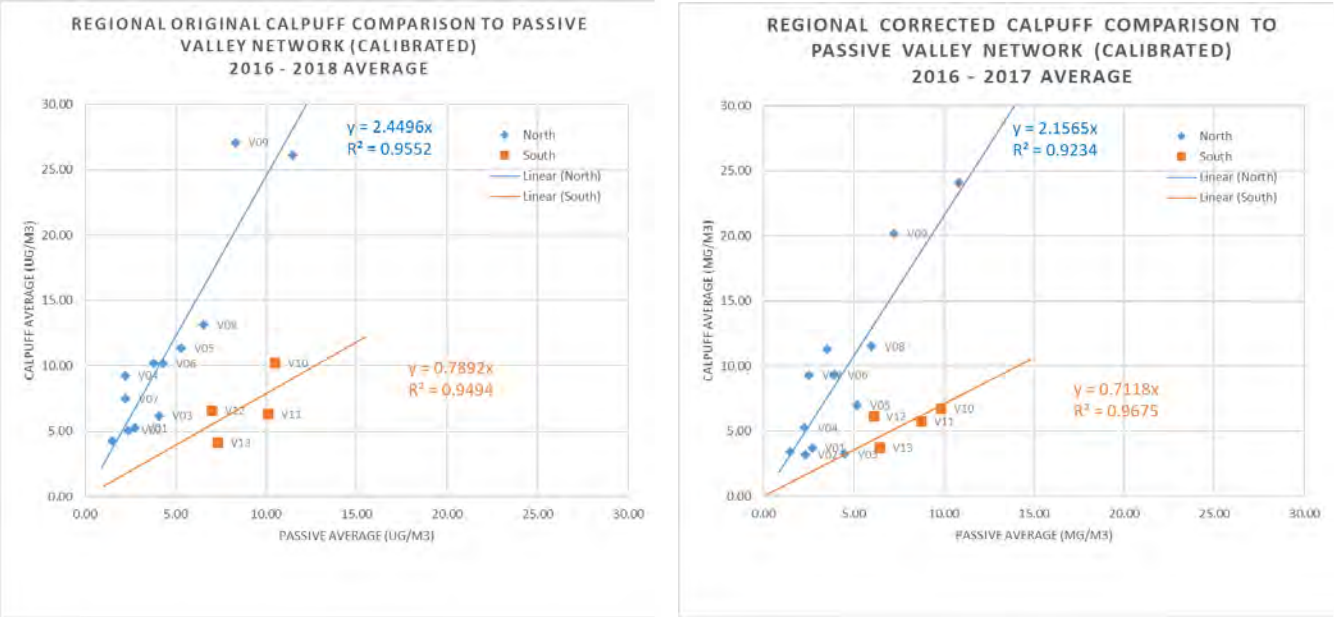


Figure A3-5. Comparison of modelled SO_2 concentrations (actual scenario) against average passive sample data in the valley network (calibrated passive data and background included in model results).

Figure A-16 compares model to monitor data for the original CALPUFF analysis (left) compared to the updated CALPUFF analysis (right). The updated model over-predicts to a lesser degree for the sites to the north (updated model prediction about 2.16 times measured levels compared to 2.45 times for the original CR model) and has slightly lower linear agreement (R^2 of 0.92 compared to 0.95). The sites to the south have a slightly lower under-prediction and slightly improved linear agreement in the updated model.

Local scale model performance evaluation

The local scale model performance evaluation followed the same approach as the regional scale evaluation with the exception that the passive monitoring data comparison is not used.

- Actual scenario (actual emission rates, varying monthly) CALPUFF results are compared to continuous monitoring data.
- For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data.

Table A3-6 and Figure A3-6 summarize comparison of annual average modelled concentrations estimated at each monitoring station compared to the monitoring data each year. Table A3-7 and Figure A3-7 summarize the 1-hour 99th percentile of daily peak concentrations. The local-scale model over-predicted both annual average and 99th percentile of daily 1-hour peak concentrations at all stations and years. The updated model over-predicted annual average concentrations by 16% (2016 Whitesail) to 74% (2016 Kitamaat Village) and 99th percentile of daily 1-hour peak at similar levels from 44% (2016 Haul Road) to 79% (2016 Riverlodge).[5] The local-scale updated (and original CR) model generally over-predicted concentrations more than the regional scale model, particularly at the Riverlodge monitor for annual average and the Kitamaat Village monitor for 1-hour.

Table A3-6. Summary of local scale CALPUFF model comparison to continuous monitoring data, annual average SO_2 (ppb).

	Monitoring Data[1] (SO_2 ppb)	Original CR CALPUFF[2] (SO_2 ppb)	Corrected CALPUFF[2] (SO_2 ppb)	Monitoring Data[1] (SO_2 ppb)	Original CR CALPUFF[2] (SO_2 ppb)	Corrected CALPUFF[2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	0.38	1.43	0.98	0.29	0.63	0.54
Haul Road	4.22	7.92	7.56	3.77	8.14	7.85
Riverlodge	0.50	1.64	2.40	0.43	1.49	1.99
Whitesail	0.53	0.63	1.16	0.41	0.53	0.97

[1] Monitoring data annual average for 2016, 2017.

[2] CALPUFF results for actual scenario, local-scale using actual smelter emission rates from 2016 to 2017, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments. The annual average background concentration used for the new 2016 -2018 model is 0.47 ppb based on monitoring at Terrace-Skeena Middle School.

[5] Percentage under-prediction or over-prediction calculated as the difference between the CALUFF result and observation, as a percent of the CALPUFF result.

Table A3-7. Summary of local scale CALPUFF model comparison to continuous monitoring data, 99th percentile of daily 1-hour peak SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	20	157	63	12	52	25
Haul Road	75	97	107	66	119	118
Riverlodge	22	42	45	28	43	44
Whitesail	15	18	34	21	26	43

[1] Monitoring data 1-hour average for 2016, 2017.

[2] CALPUFF results for actual scenario, local-scale using actual smelter emission rates from 2016 to 2017, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (1.8 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2017 actual conditions. Results with a higher background (5.53 ppb based on monitoring at Terrace-Skeena Middle School) are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments.

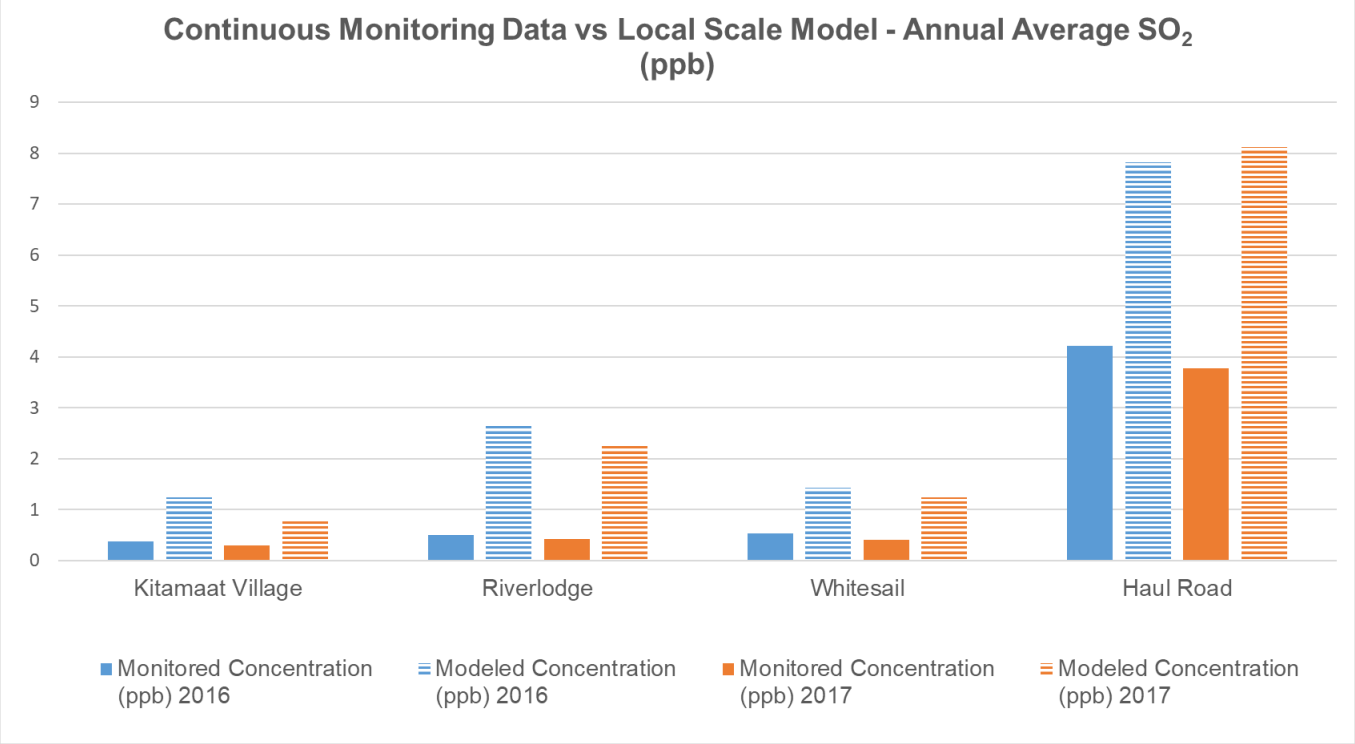


Figure A3-6. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, annual average, local-scale (Williams Lake annual background of 0.26 ppb applied).

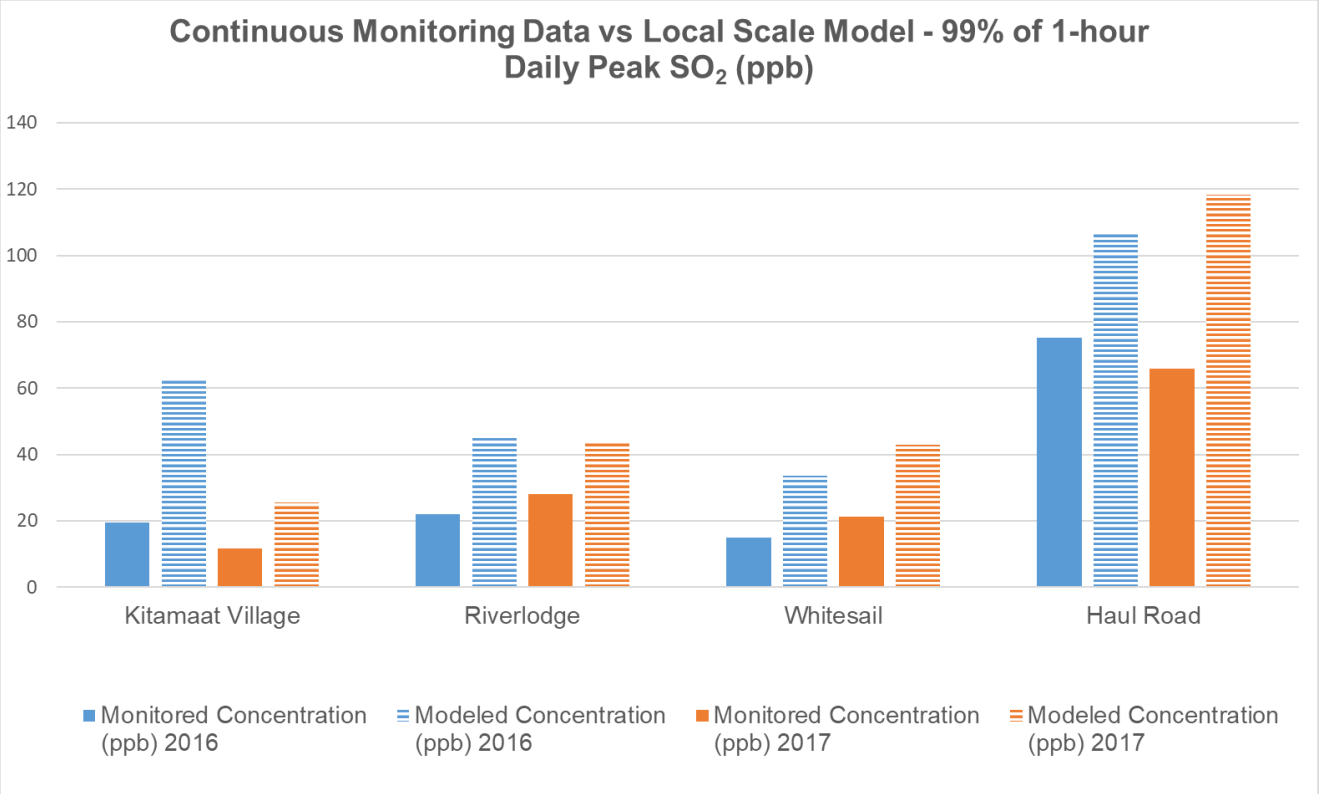


Figure A3-7. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, 99% of 1-hour daily peak, local-scale (Williams Lake annual background of 1.8 ppb applied).

Table A3-3 below provides the performance statistics for the regional-scale model. The RMSE, MBE, and MAE represent the difference (or error) between the model result versus the observation at each monitor for each hour (paired in space and time). The MBE represents the same differences seen when comparing the annual average concentrations (illustrated in Figure A3-6). Like the regional scale performance, the MBE values indicate that the local-scale model overall slightly over-predicts at Kitamaat Village and Whitesail and over-predicts moderately at Haul Road and Riverlodge. The MAE and RMSE values are also similar to the regional scale evaluation, except the Kitamaat Village error is noticeably higher (meaning the local scale does not estimate as well at Kitamaat Village) and the Whitesail error values are noticeably lower (the local-scale model predicts better at Whitesail). The wind correction model update improved local scale performance at Kitamaat Village and performance at Riverlodge declined somewhat.

Table A0-8. Local scale model performance evaluation statistics. Williams Lake annual background of .27 ppb, (0.69 µg/m3) is applied.

Model	Monitor	RMSE (µg/m3)	MBE (µg/m3)	MAE (µg/m3)	MBE% [1]	MAE% [1]
Original CR Model	Kitamaat Village	10.54	1.51	2.12	199%	279%
	Haul Road	37.95	10.29	19.04	101%	187%
	Riverlodge	10.89	2.83	3.86	232%	316%
	Whitesail	4.92	0.43	1.49	38%	133%
Updated Model (Corrected for Wind Direction)	Kitamaat Village	7.02	1.09	1.75	124%	199%
	Haul Road	39.68	9.67	19.81	93%	190%
	Riverlodge	12.54	4.51	5.31	371%	437%
	Whitesail	7.70	1.57	2.52	128%	205%

[1] MBE% and MAE% are expressed as MBE and MAE divided by the annual average observed concentrations, respectively, at each receptor.

The Q-Q plots in 8 below illustrate the over-prediction at Kitamaat Village and relatively good performance at Whitesail as noted above, giving a more complete picture of how the values compare across the range of concentrations. Haul Road modelled concentrations generally fall within the 100% to 200% of monitored values for all but the highest and lowest concentrations. Riverlodge model results also show relatively good performance at the higher concentrations but over-predicts the annual average nearly three times and lower to mid range concentrations over three times. The updated model (Figure A3-9) shows similar patterns at all four monitoring stations.

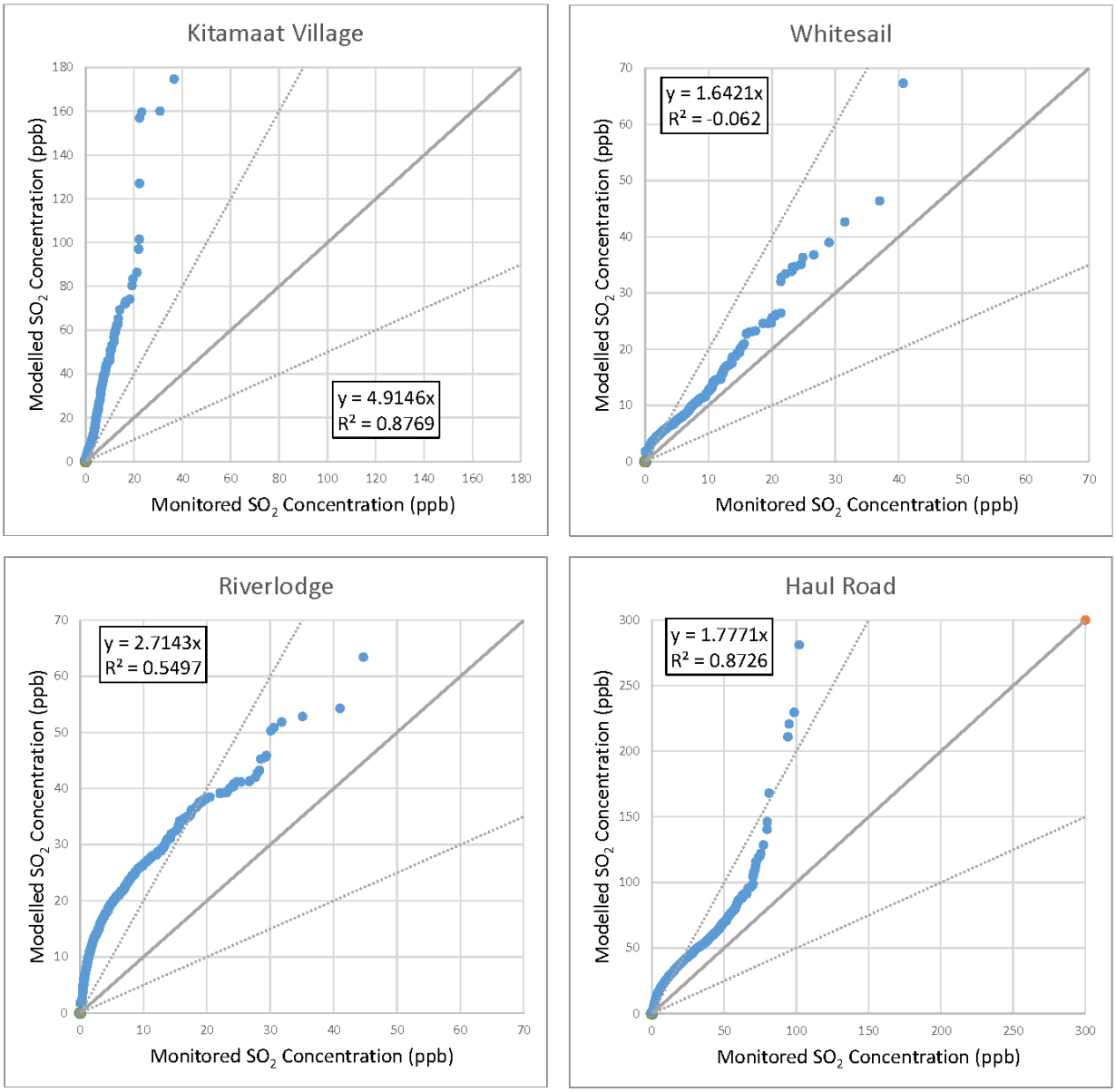


Figure A3-8. Comparison of local-scale original CR model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

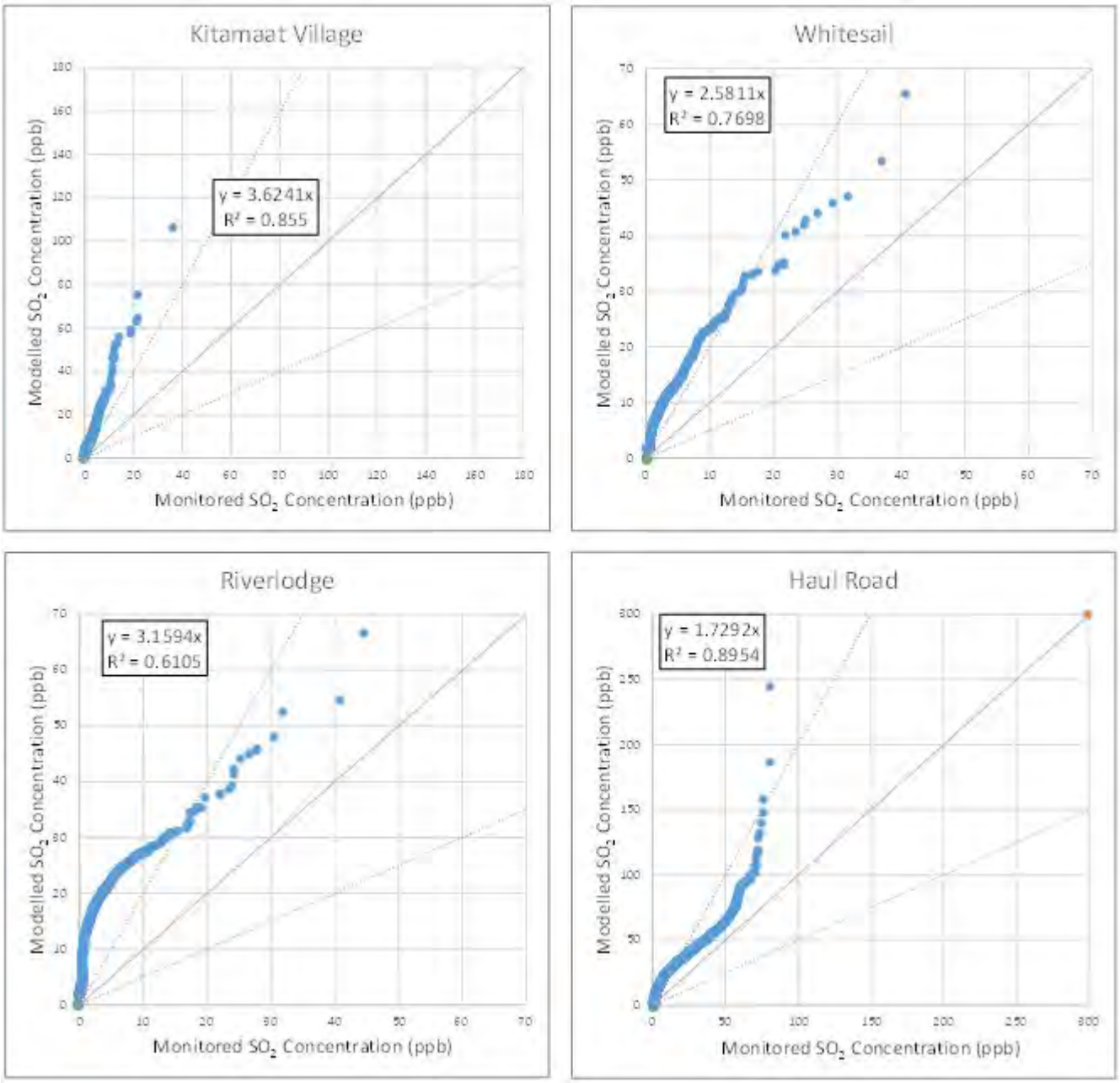
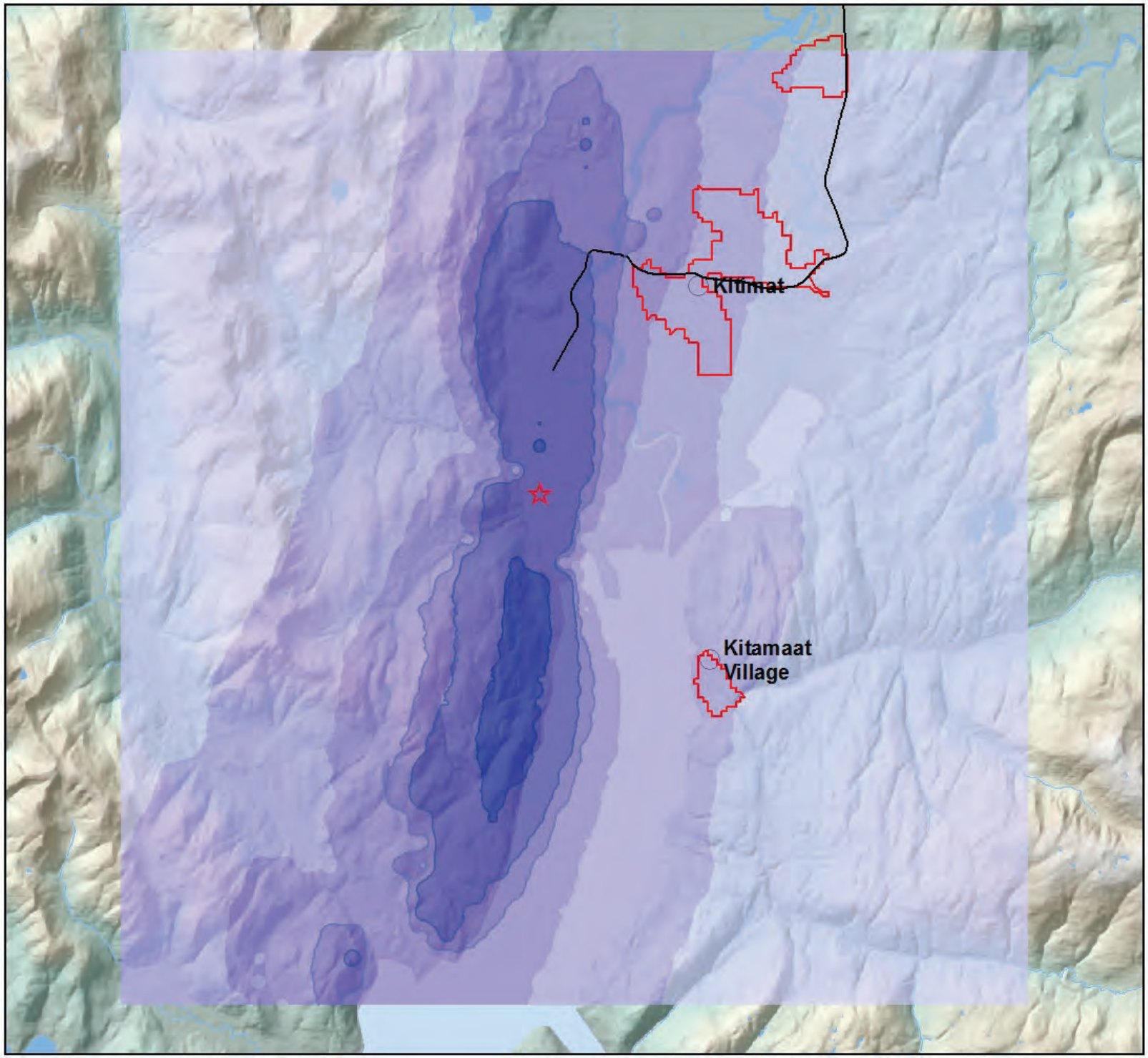


Figure A3-9. Comparison of local-scale updated model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

Attachment 1
Model Result Plots

Local Scale – 42 TPD Scenario
Regional Scale – Actual Scenario
Local Scale – Actual Scenario



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

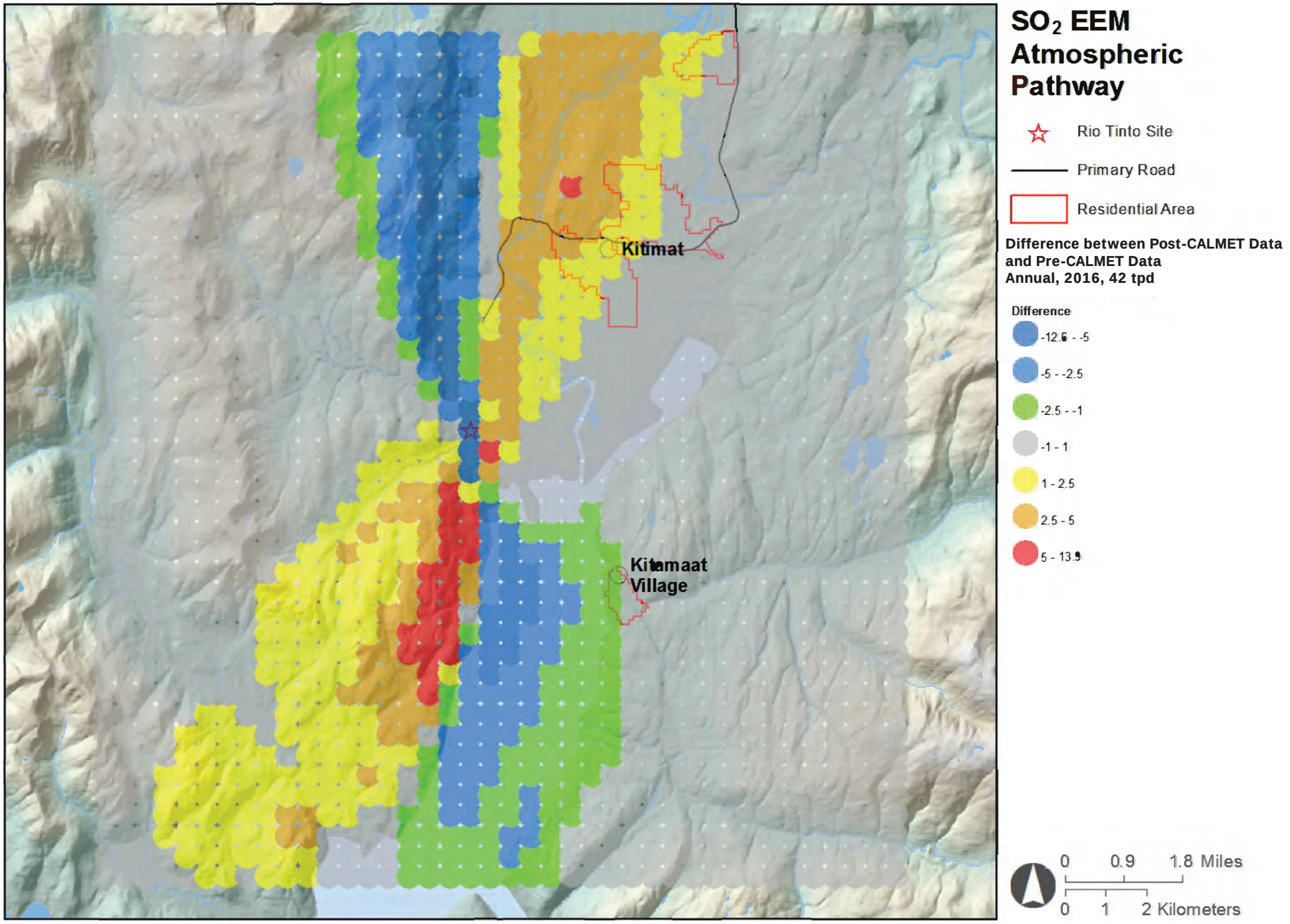
SO2 Annual Average Concentration (ppb) (Includes background of 0.47 ppb)

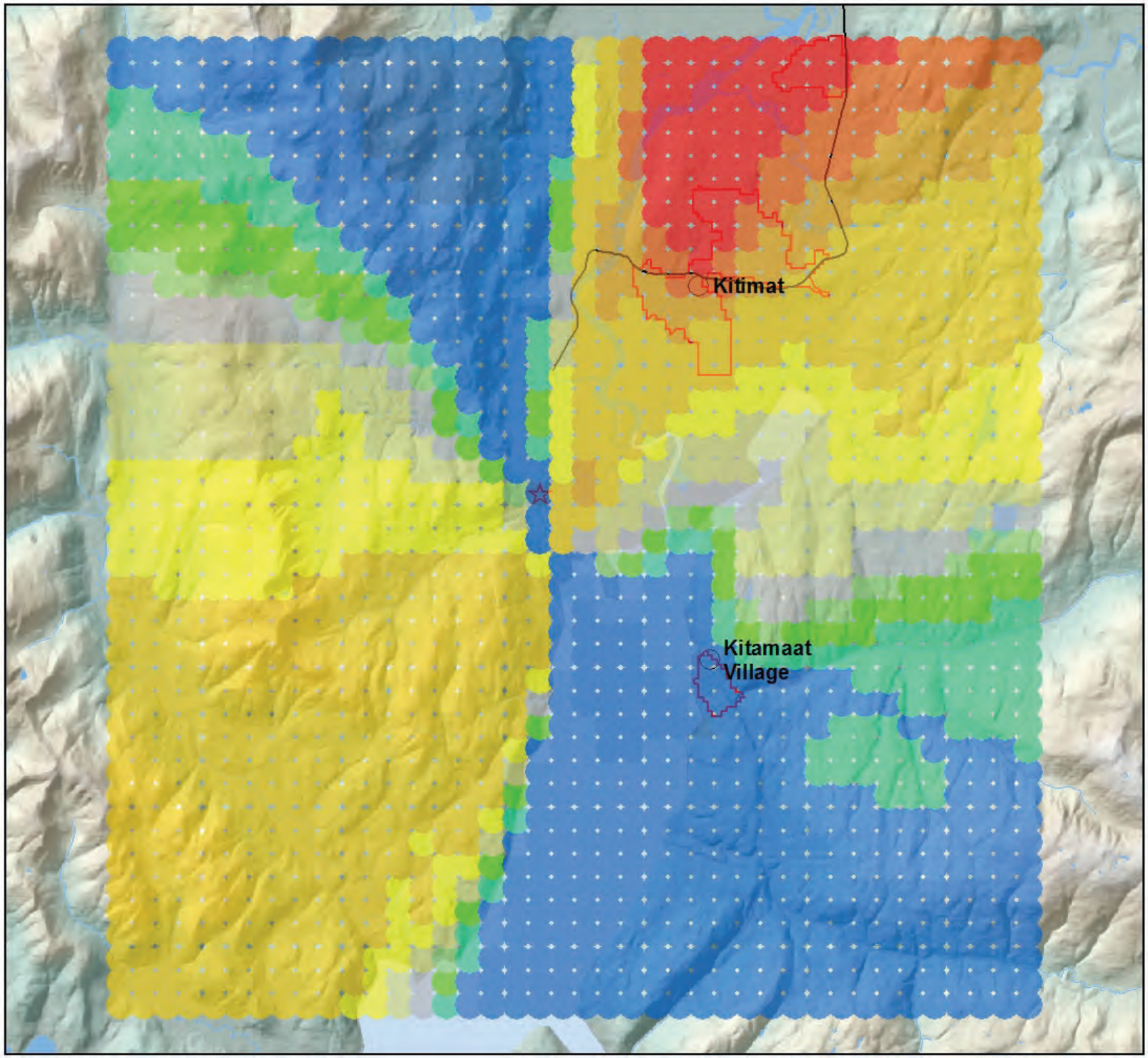
42 tpd, 2016

- 0 - 1.25: Below 2025 CAAQS
- 1.25 - 2.5: Below 2025 CAAQS
- 2.5 - 4: Below 2025 CAAQS
- 4 - 5: Above 2025 CAAQS and Below 2020
- 5 - 10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Residential Area
Difference between Post-CALMET Data and Pre-CALMET Data
Annual, 2016, 42 tpd
Difference
-12.6 - -5
-5 - -2.5
-2.5 - -1
-1 - 1
1 - 2.5
2.5 - 5
5 - 13.9
Kitimat
Kitamaat Village
0 0.9 1.8 Miles
0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

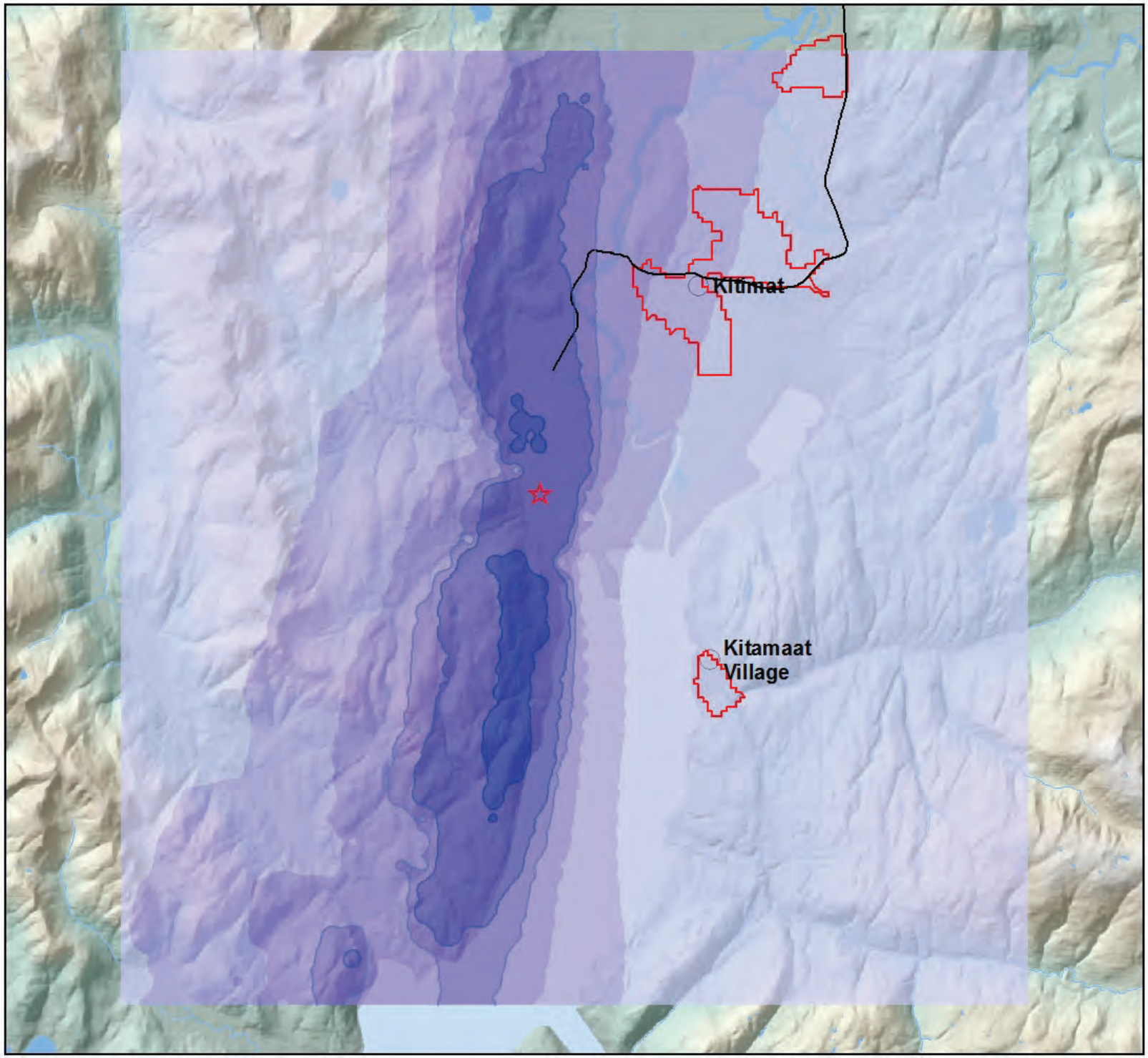
Residential Area

Percent Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2017, 42 tpd

- -60 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 295

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

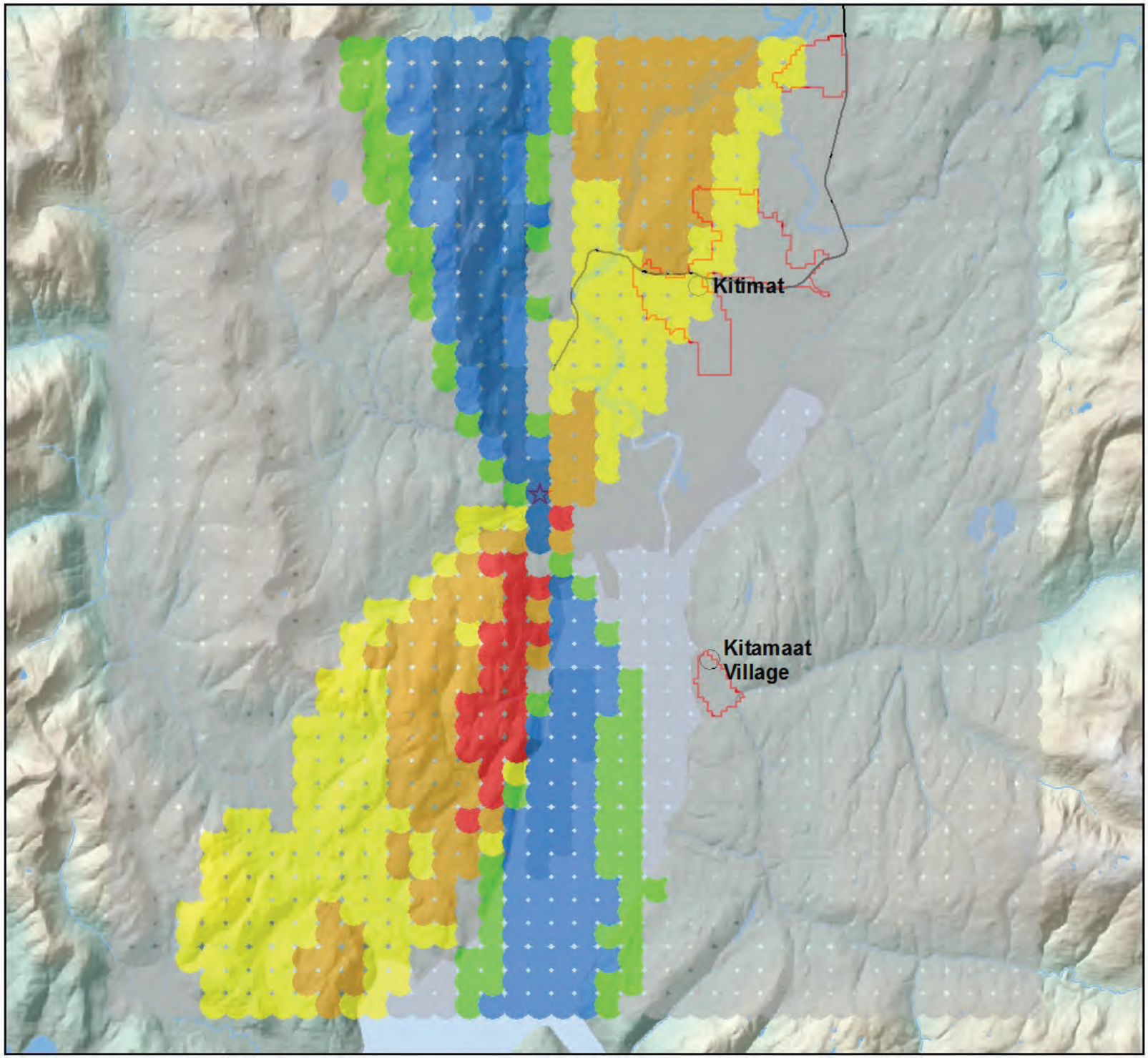
SO2 Annual Average Concentration (ppb) (Includes background of 0.47 ppb)

42 tpd, 2017

- 0 - 1.25: Below 2025 CAAQS
- 1.25 - 2.5: Below 2025 CAAQS
- 2.5 - 4: Below 2025 CAAQS
- 4 - 5: Above 2025 CAAQS and Below 2020
- 5 - 10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

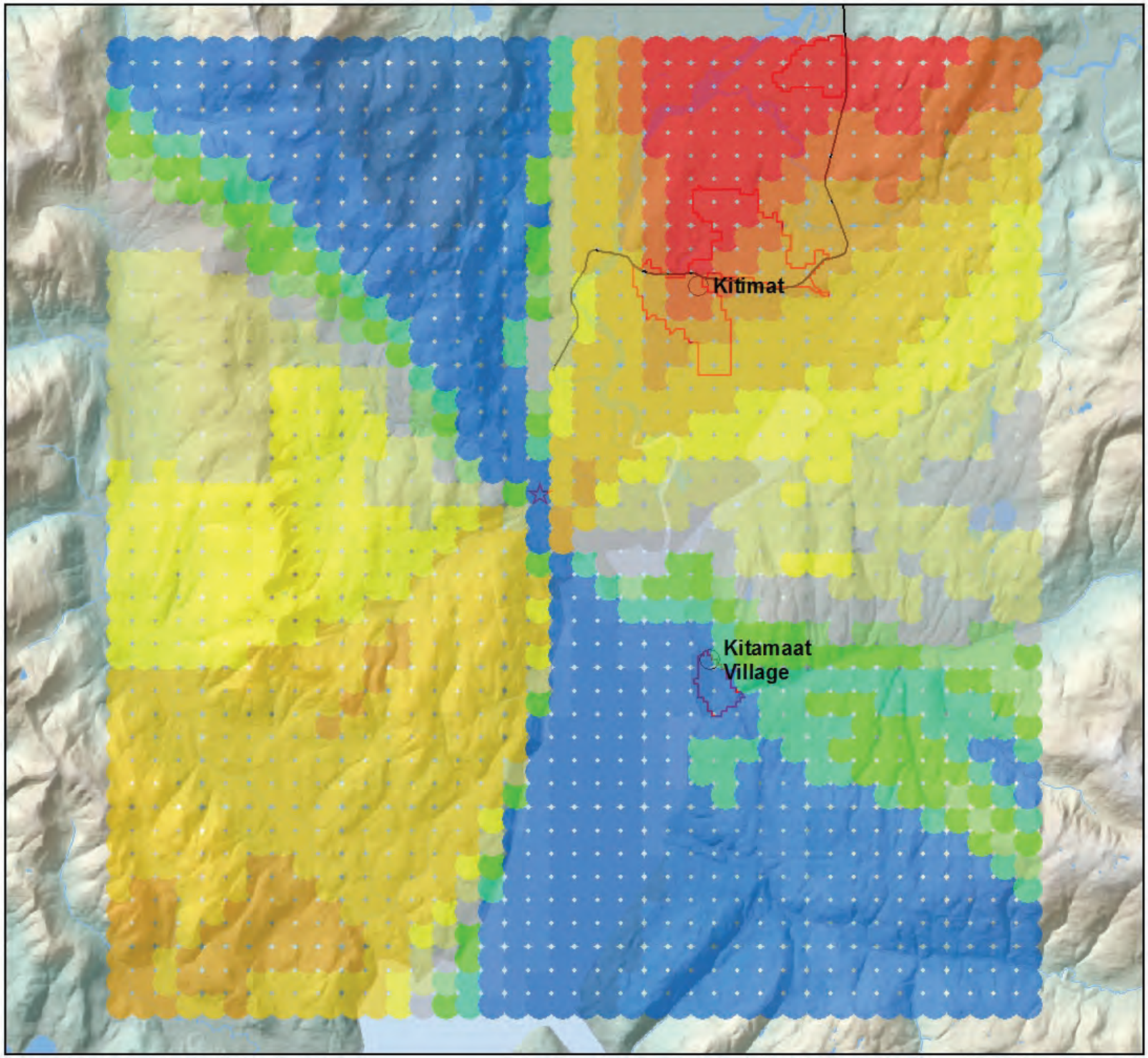
Percent Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2017, 42 tpd

Difference

- -15.5 - -5
- -5 - -2.5
- -2.5 - -1
- -1 - 1
- 1 - 2.5
- 2.5 - 5
- 5 - 11.4

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

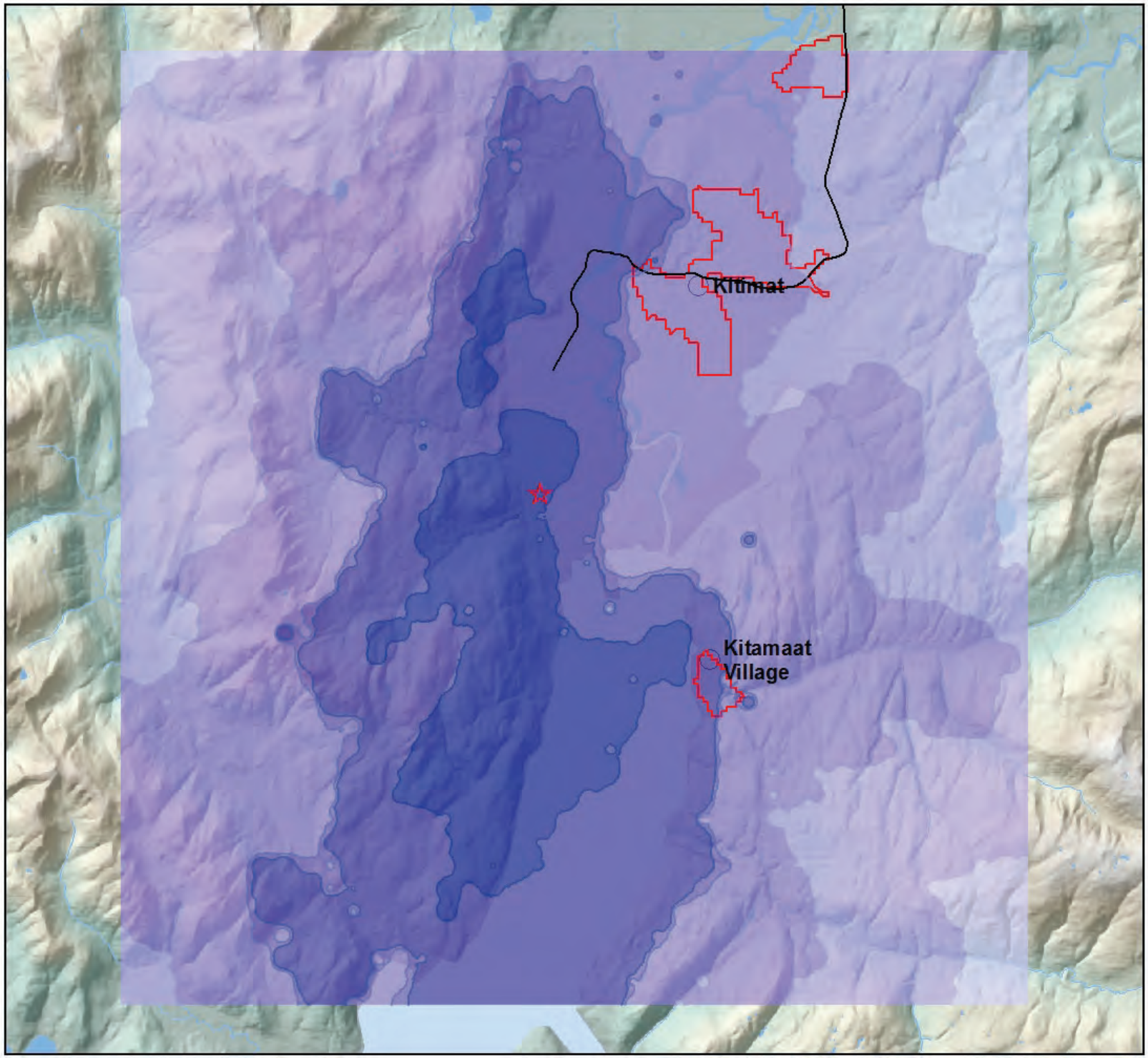
Residential Area

Percent Difference between Post-CALMET Data and Pre-CALMET Data Annual, 2017, 42 tpd

- -61.63 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 351

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

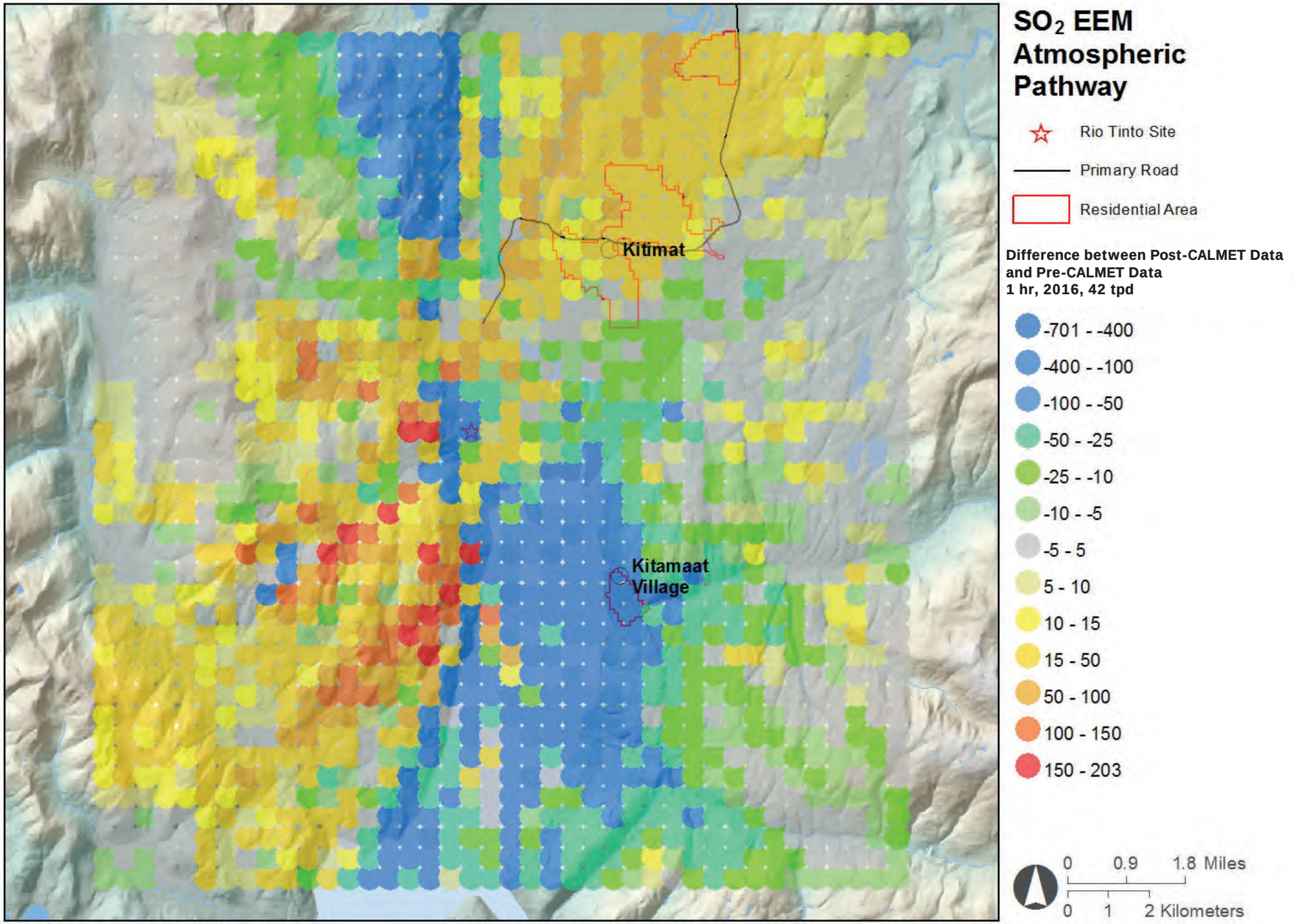
SO2 1 hr Average Concentration (ppb) (Includes background of 5.53 ppb)

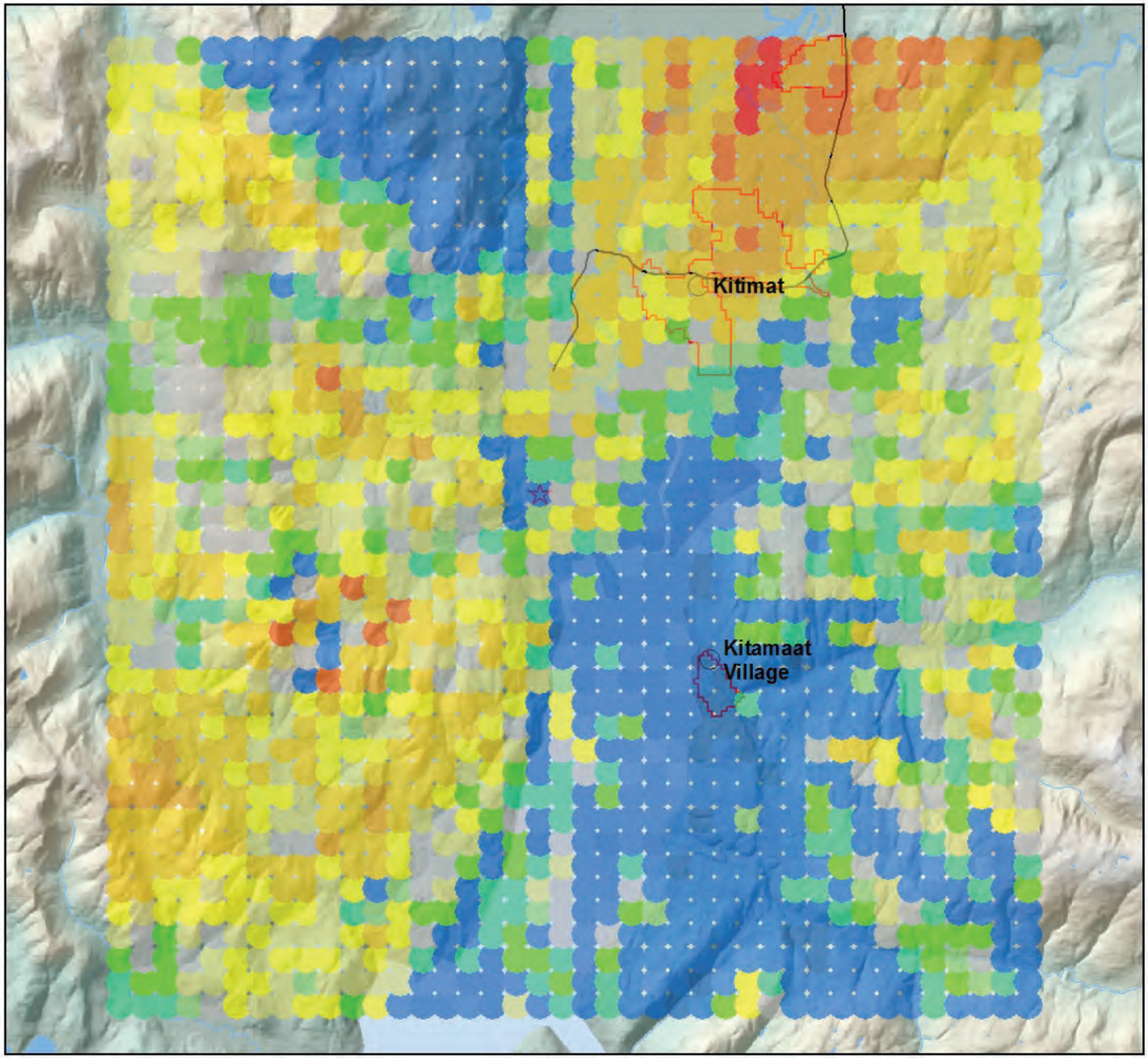
42 tpd, 2016

- 0 - 17.5: Below 2025 CAAQS
- 17.5 - 30: Below 2025 CAAQS
- 30 - 65: Below 2025 CAAQS
- 65 - 70: Above 2025 CAAQS and Below 2020
- 70 - 140: Above 2020 CAAQS
- 140+: ABove 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Residential Area
Kitimat
Kitamaat Village
Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2016, 42 tpd
-701 - -400
-400 - -100
-100 - -50
-50 - -25
-25 - -10
-10 - -5
-5 - 5
5 - 10
10 - 15
15 - 50
50 - 100
100 - 150
150 - 203
0 0.9 1.8 Miles
0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

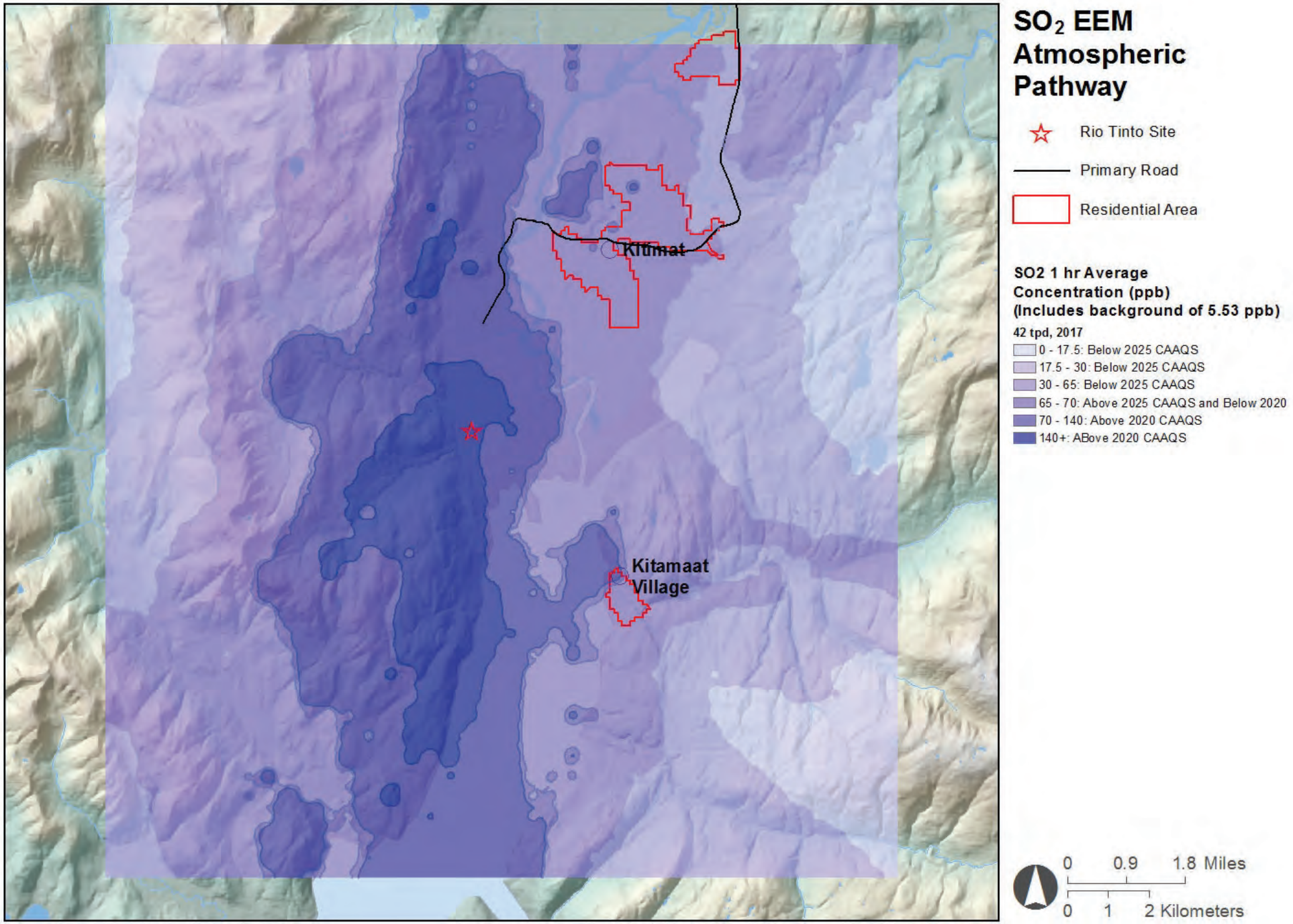
Residential Area

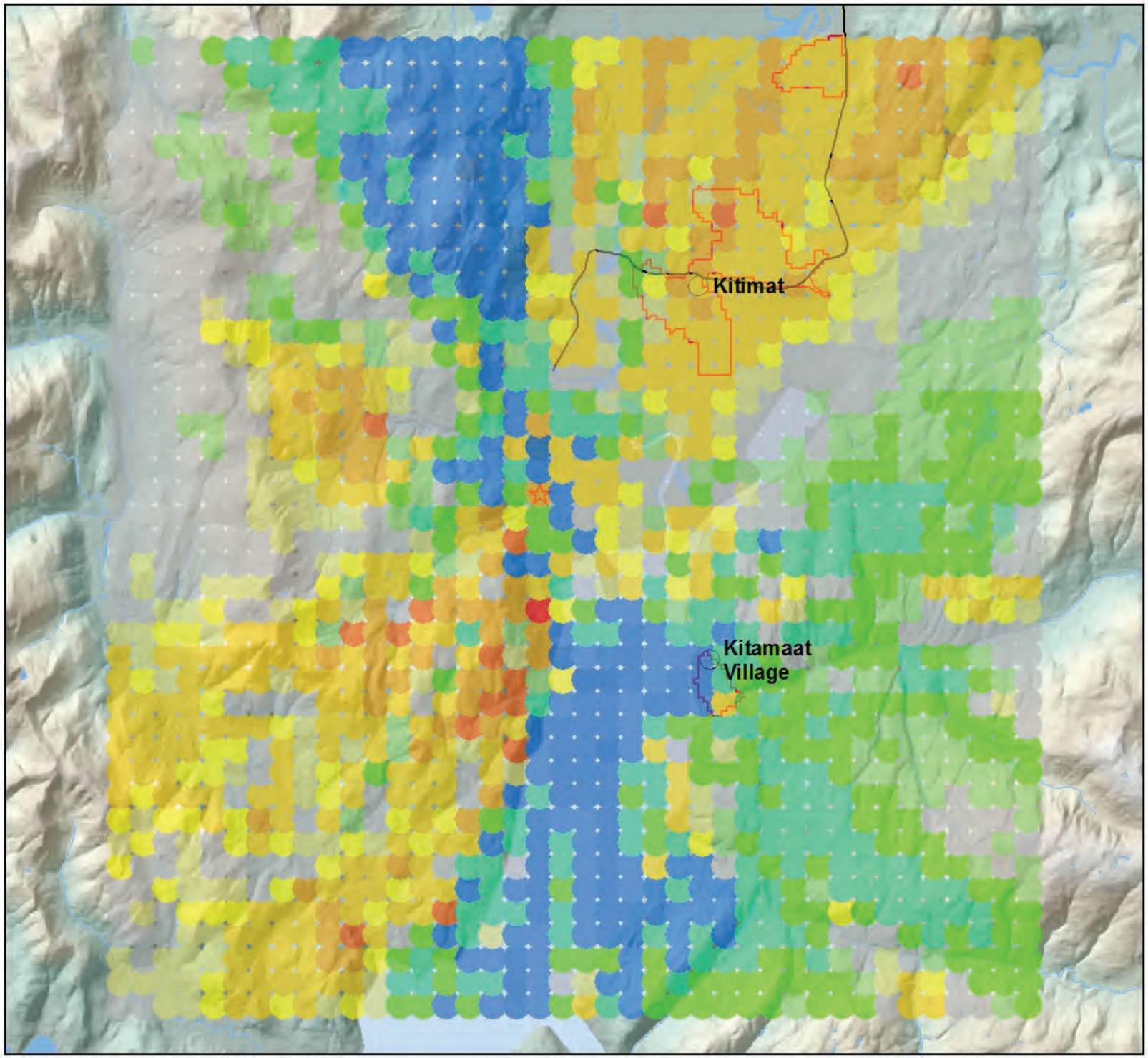
Percent Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2016, 42 tpd

- -73.2 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 179.59

0 0.9 1.8 Miles

0 1 2 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Residential Area
Kitimat
Kitamaat Village
SO2 1 hr Average Concentration (ppb)
(Includes background of 5.53 ppb)
42 tpd, 2017
0 - 17.5: Below 2025 CAAQS
17.5 - 30: Below 2025 CAAQS
30 - 65: Below 2025 CAAQS
65 - 70: Above 2025 CAAQS and Below 2020
70 - 140: Above 2020 CAAQS
140+: ABove 2020 CAAQS
0 0.9 1.8 Miles
0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

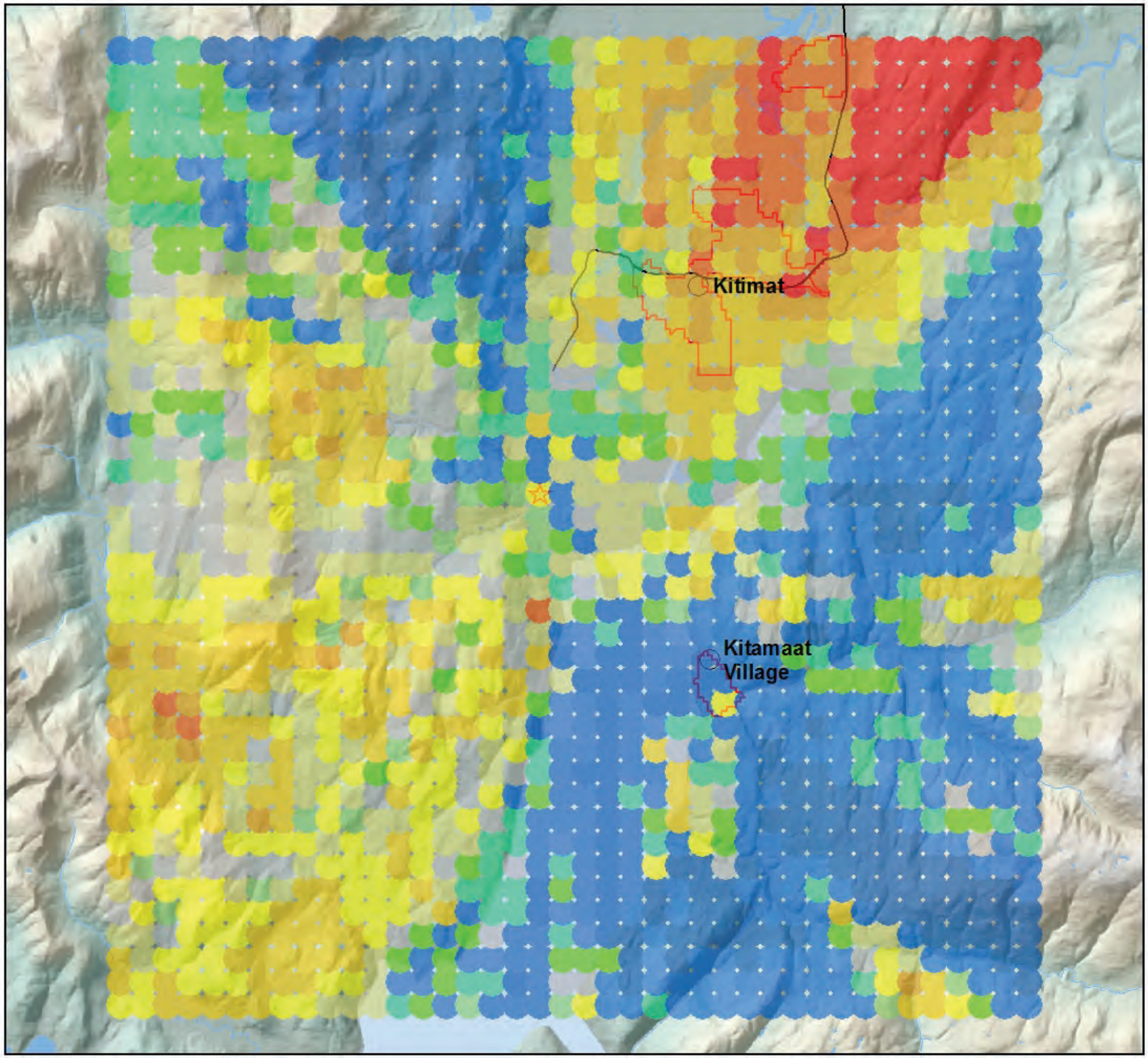
Residential Area

Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2017, 42 tpd

- -701 - -200
- -200 - -100
- -100 - -50
- -50 - -25
- -25 - -10
- -10 - -5
- -5 - 5
- 5 - 10
- 10 - 15
- 15 - 50
- 50 - 100
- 100 - 150
- 150 - 334

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

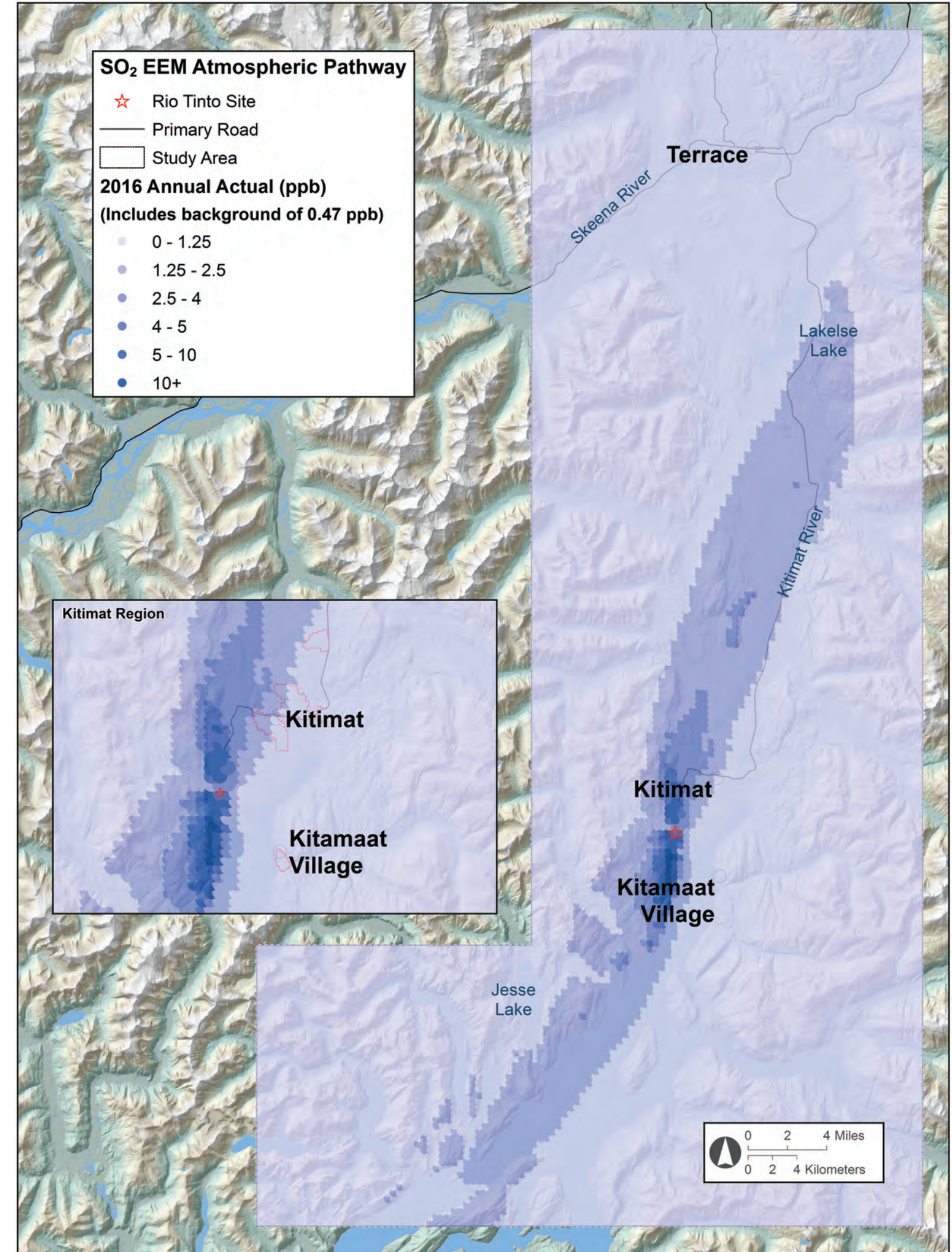
Residential Area

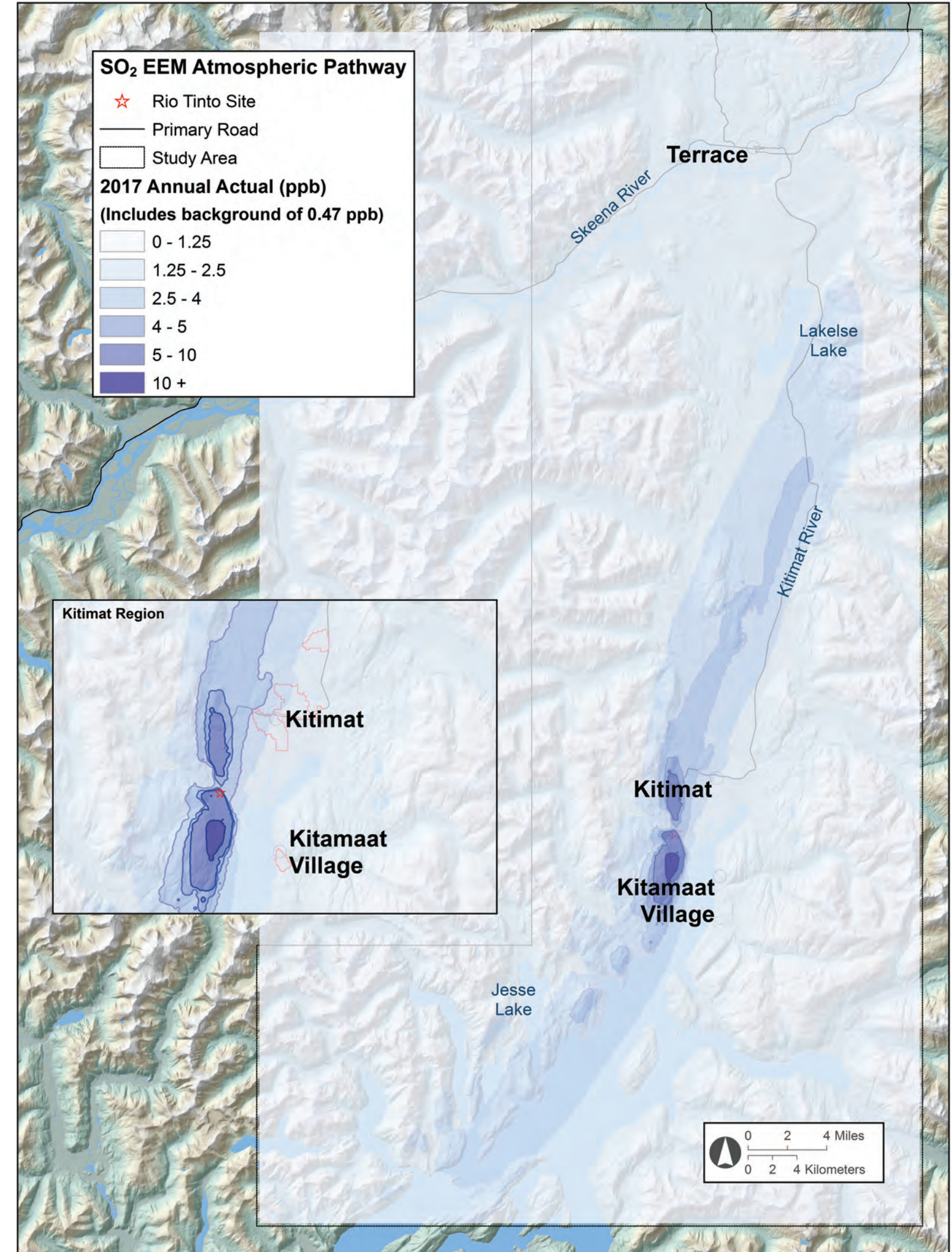
Percent Difference between Post-CALMET Data and Pre-CALMET Data
1 hr, 2017, 42 tpd

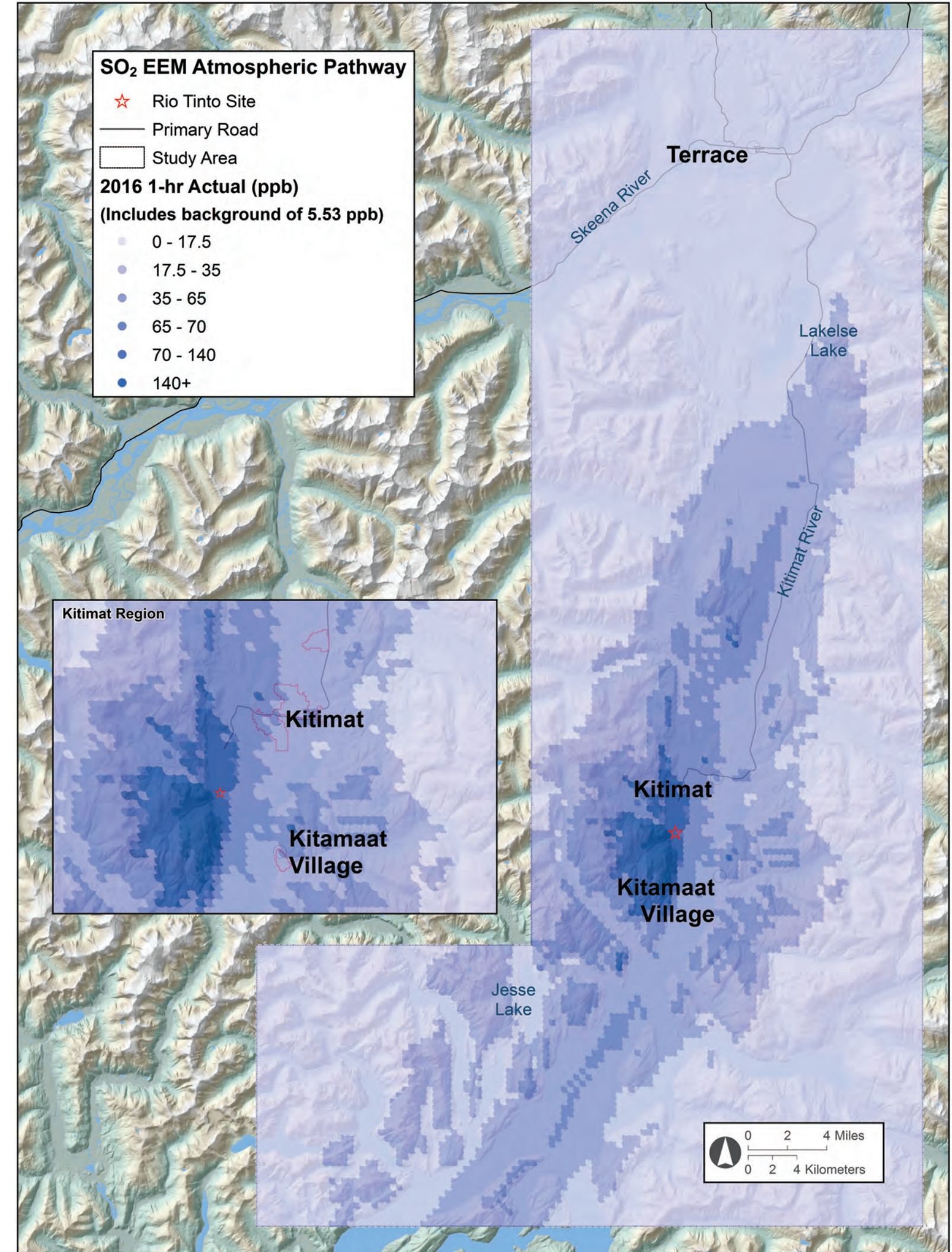
- -64.77 - -40
- -40 - -20
- -20 - -15
- -15 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - 2.5
- 2.5 - 10
- 10 - 20
- 20 - 50
- 50 - 80
- 80 - 120
- 120 - 480.41

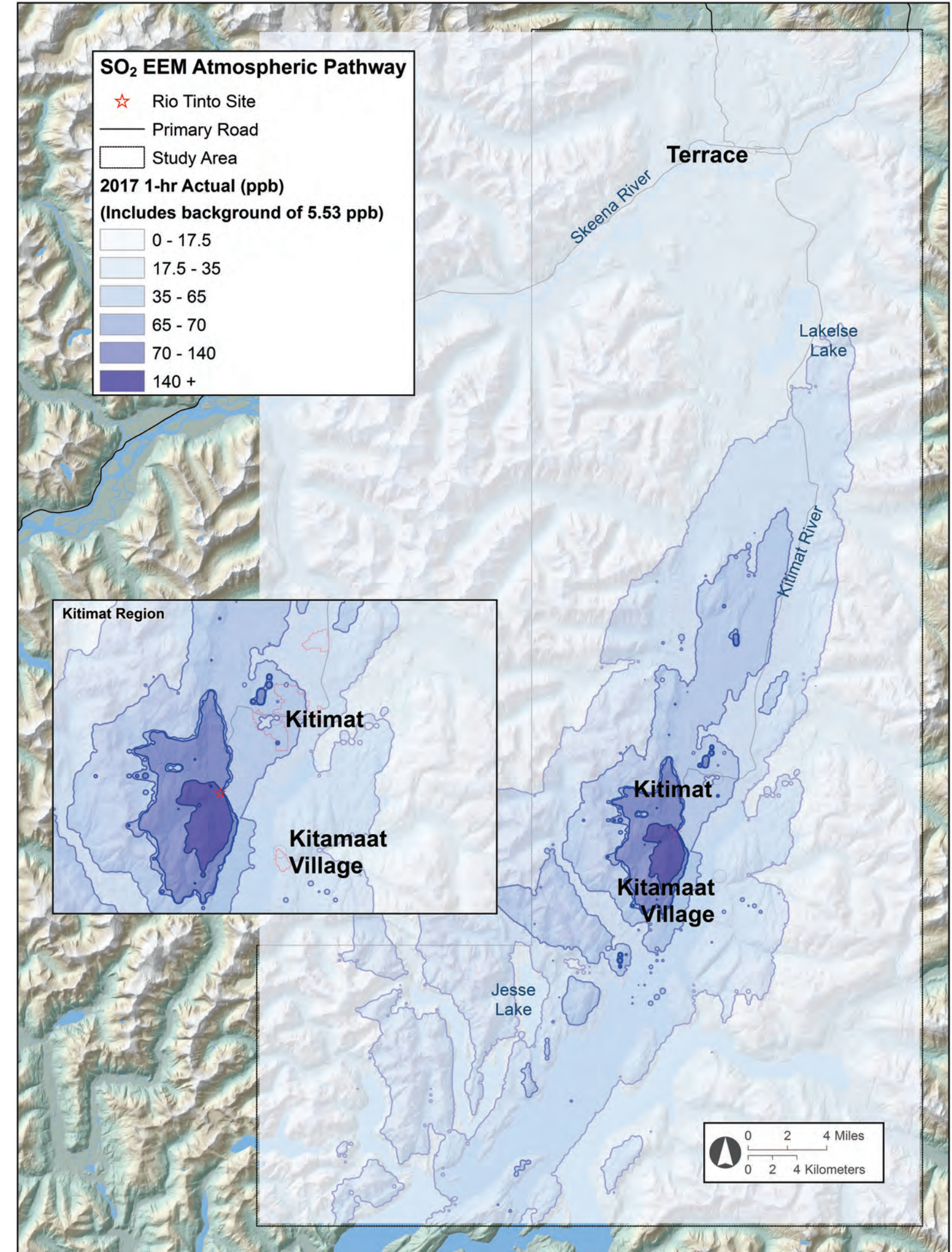
0 0.9 1.8 Miles

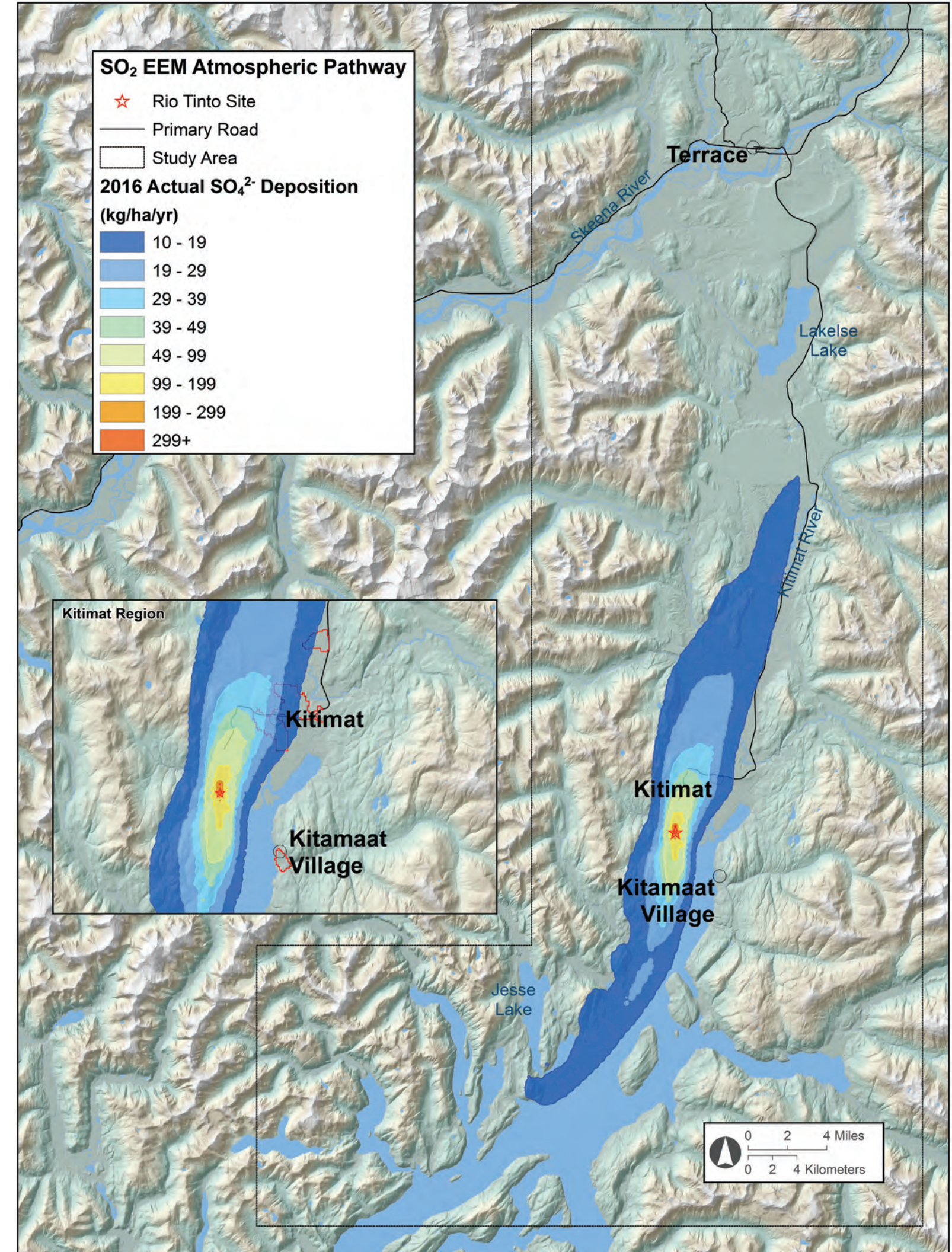
0 1 2 Kilometers

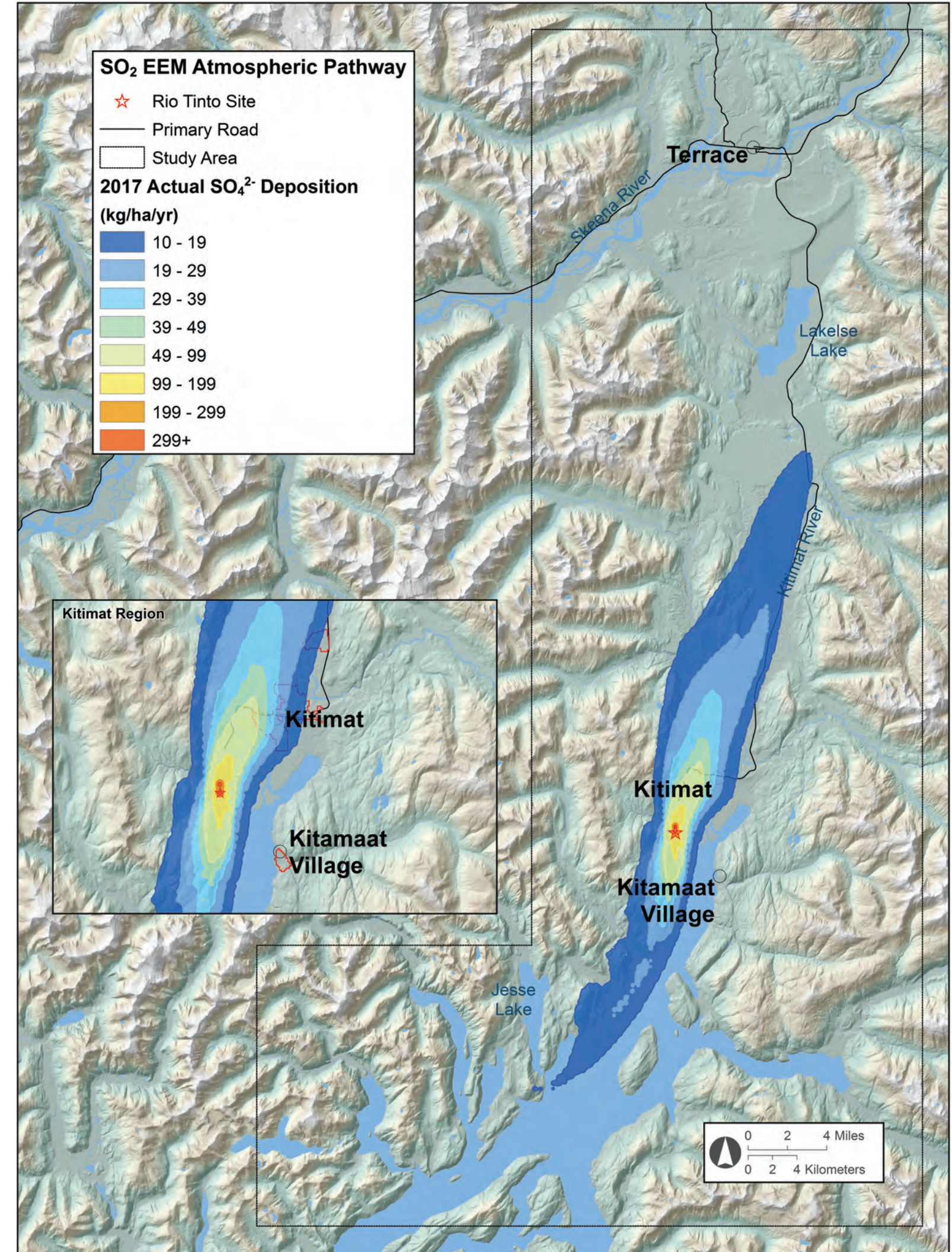

SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2016 Annual Actual (ppb)
(Includes background of 0.47 ppb)
0 - 1.25
1.25 - 2.5
2.5 - 4
4 - 5
5 - 10
10+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers

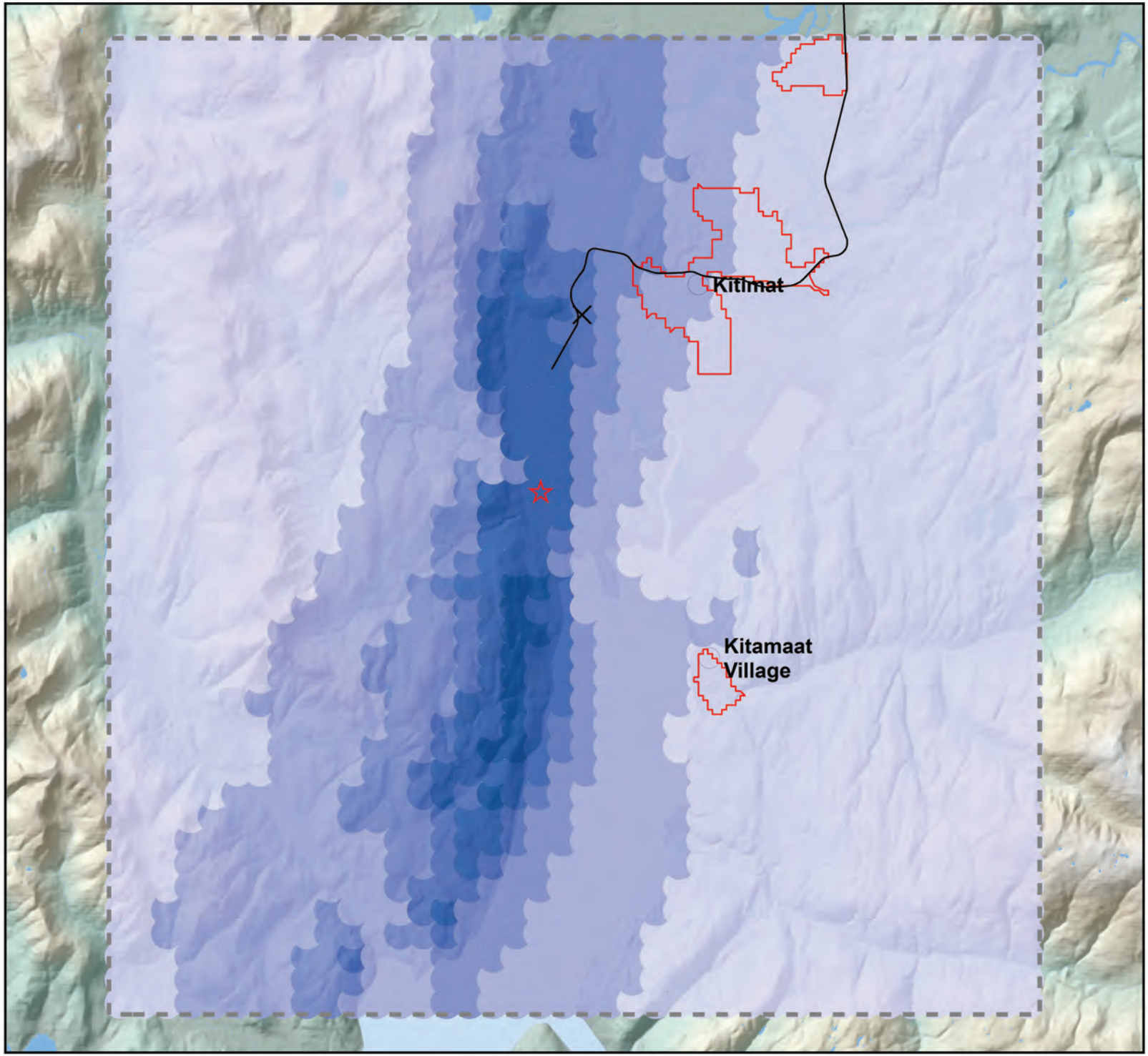

SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2017 Annual Actual (ppb)
(Includes background of 0.47 ppb)
0 - 1.25
1.25 - 2.5
2.5 - 4
4 - 5
5 - 10
10 +
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2016 1-hr Actual (ppb)
(Includes background of 5.53 ppb)
0 - 17.5
17.5 - 35
35 - 65
65 - 70
70 - 140
140+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2017 1-hr Actual (ppb)
(Includes background of 5.53 ppb)
0 - 17.5
17.5 - 35
35 - 65
65 - 70
70 - 140
140 +
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2016 Actual SO_4^{2-} Deposition
(kg/ha/yr)
10 - 19
19 - 29
29 - 39
39 - 49
49 - 99
99 - 199
199 - 299
299+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area
2017 Actual SO_4^{2-} Deposition
(kg/ha/yr)
10 - 19
19 - 29
29 - 39
39 - 49
49 - 99
99 - 199
199 - 299
299+
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat Region
Kitimat
Kitamaat Village
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2 4 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

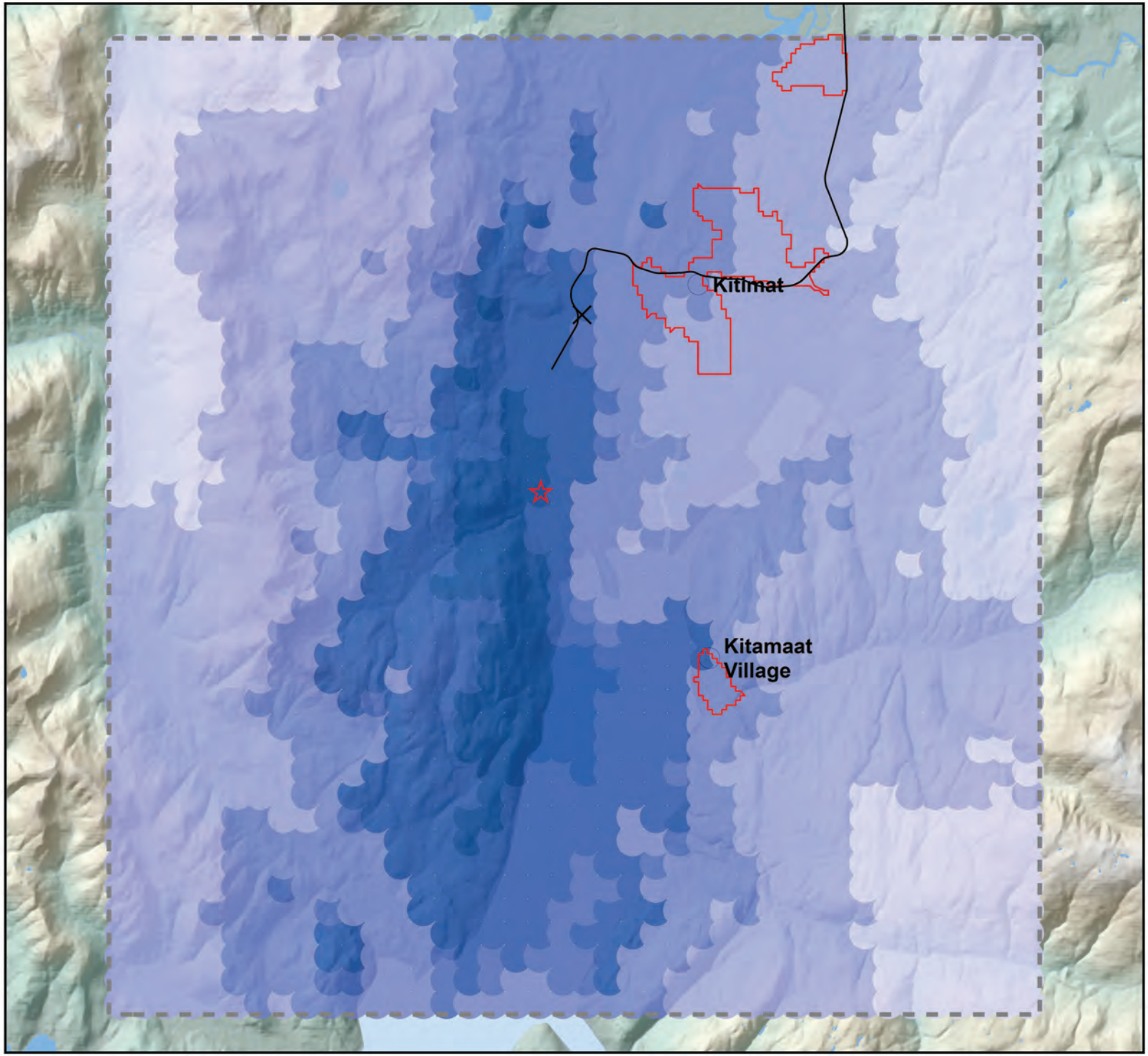
2016 Annual Actual (ppb)

(Includes background of 0.47 ppb)

- 0 - 1.25
- 1.25 - 2.5
- 2.5 - 4
- 4 - 5
- 5 - 10
- 10+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

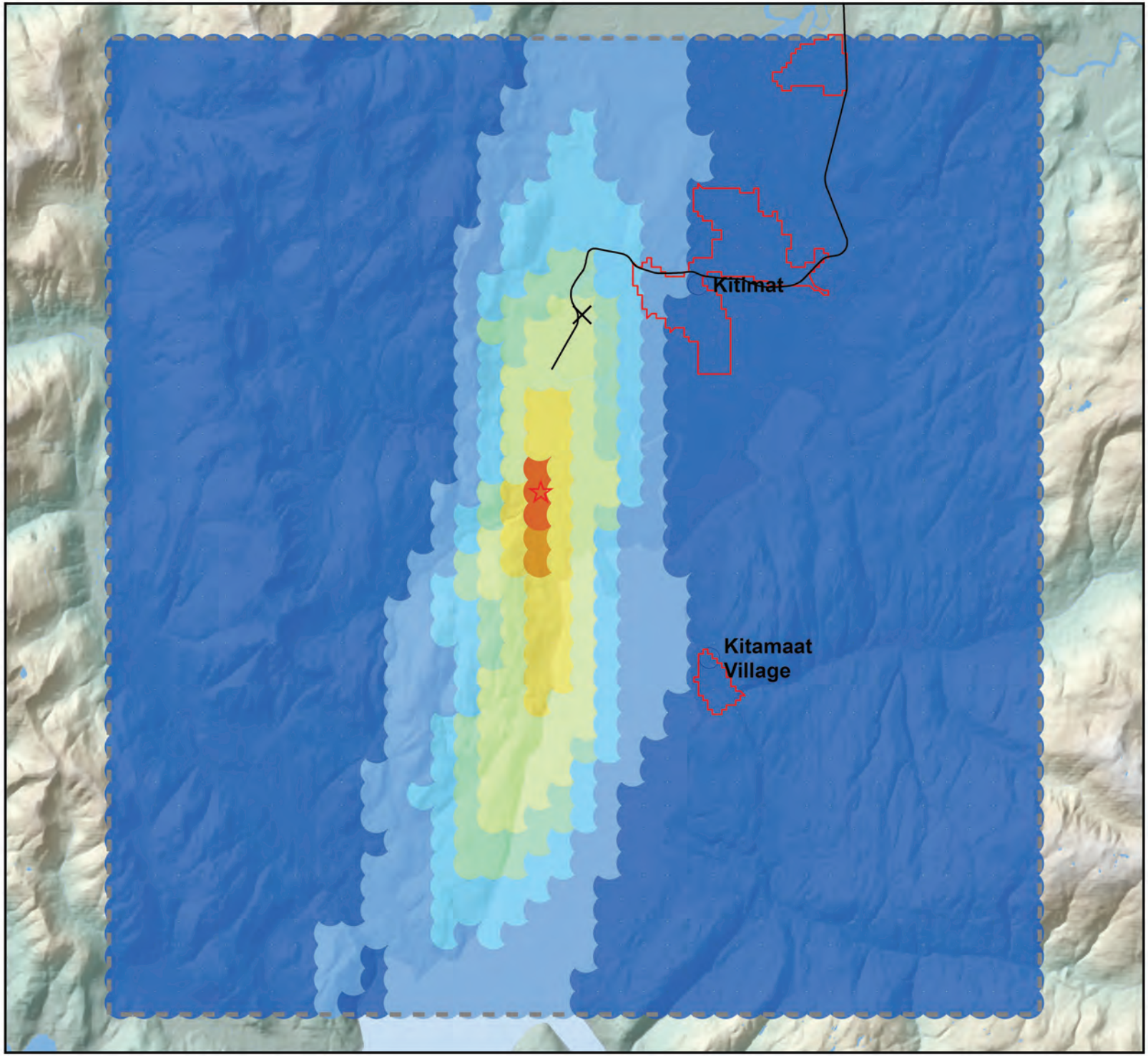
2016 1-hr Actual (ppb)

(Includes background of 5.53 ppb)

- 0 - 17.5
- 17.5 - 35
- 35 - 65
- 65 - 70
- 70 - 140
- 140+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

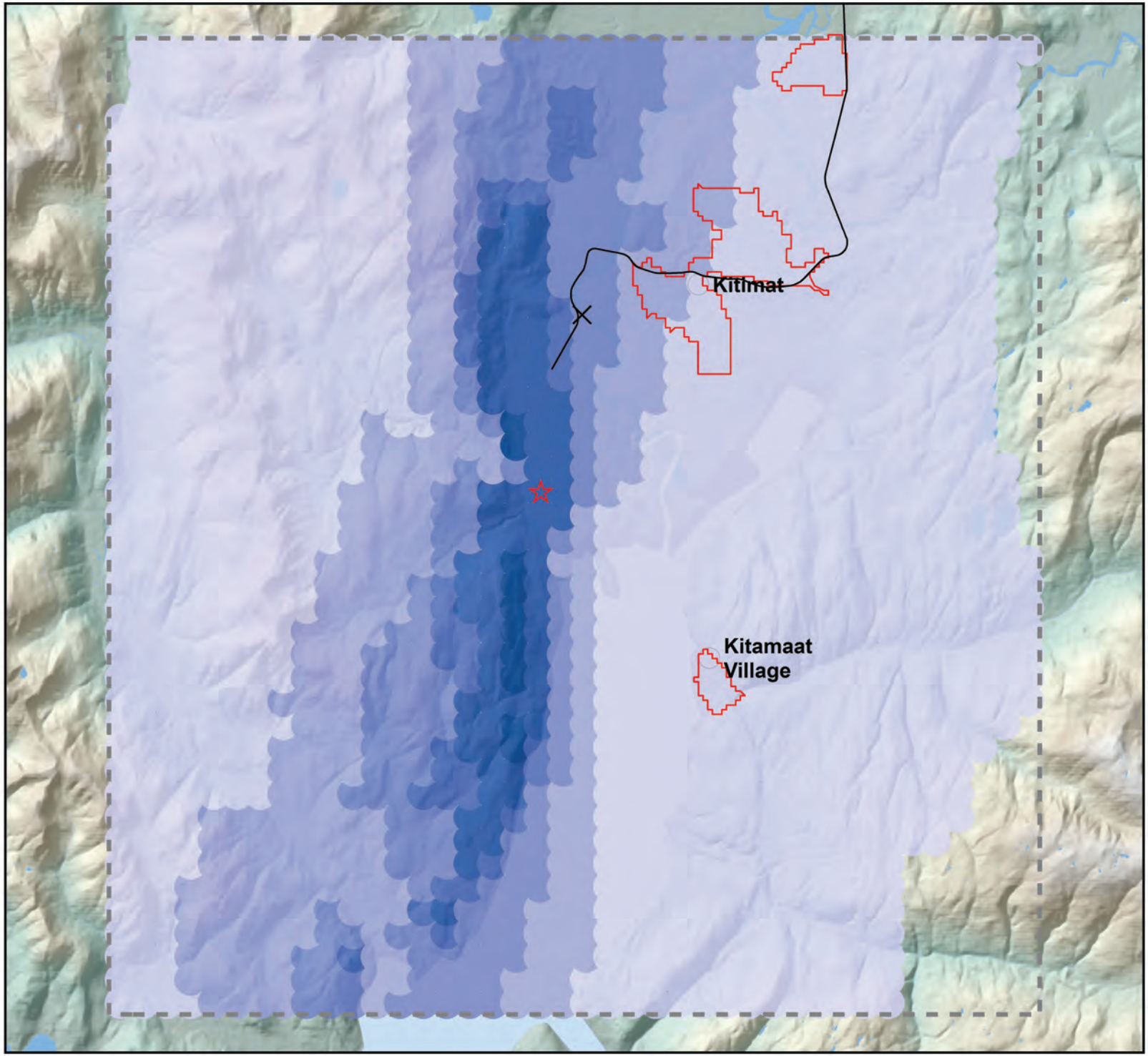
2016 Actual SO_4^{2-} Deposition

(kg/ha/hr)

- 10 - 19
- 19 - 29
- 29 - 39
- 39 - 49
- 49 - 99
- 99 - 199
- 199 - 299
- 299+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

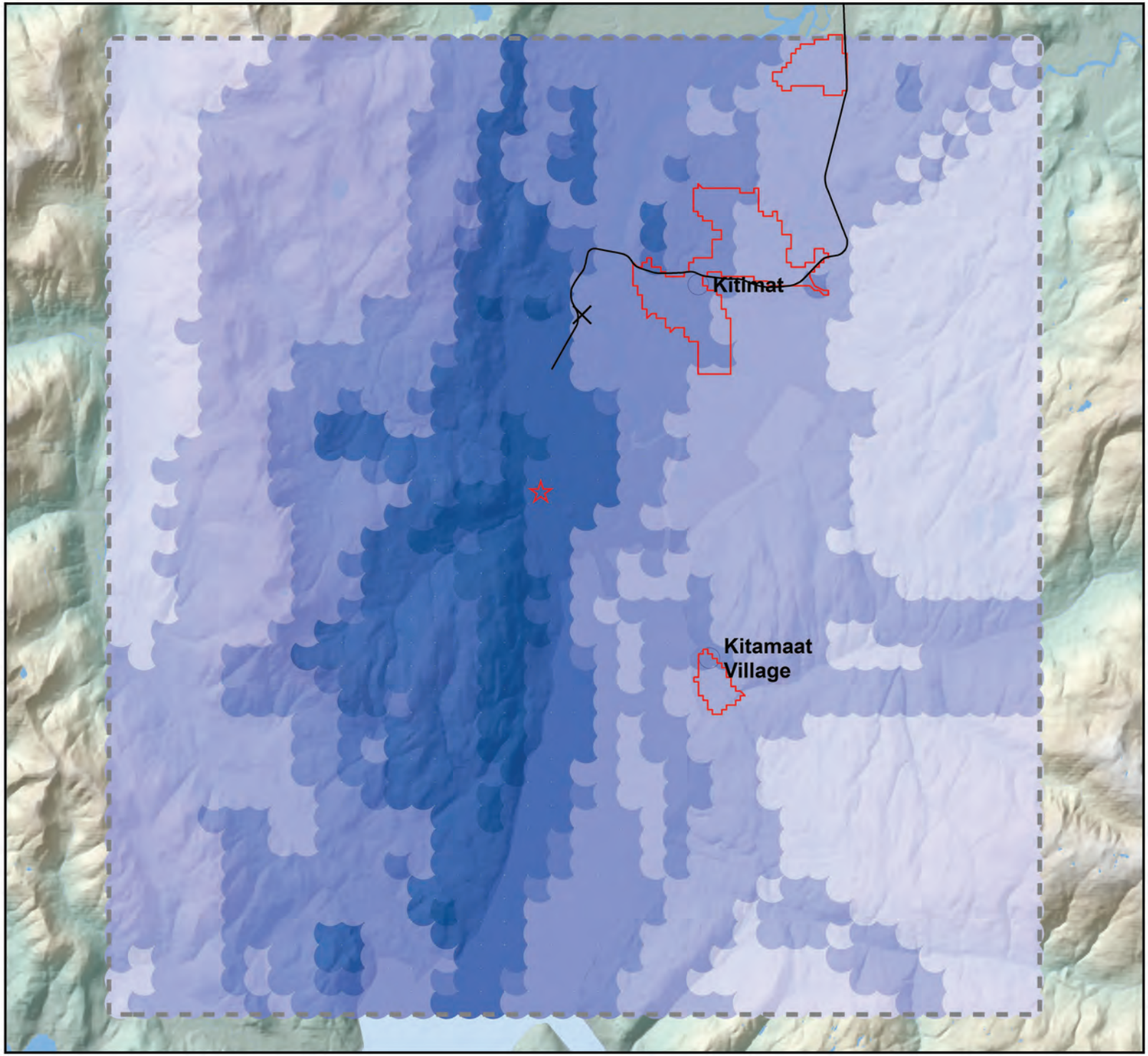
2017 Annual Actual (ppb)

(Includes background of 0.47 ppb)

- 0 - 1.25
- 1.25 - 2.5
- 2.5 - 4
- 4 - 5
- 5 - 10
- 10+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area

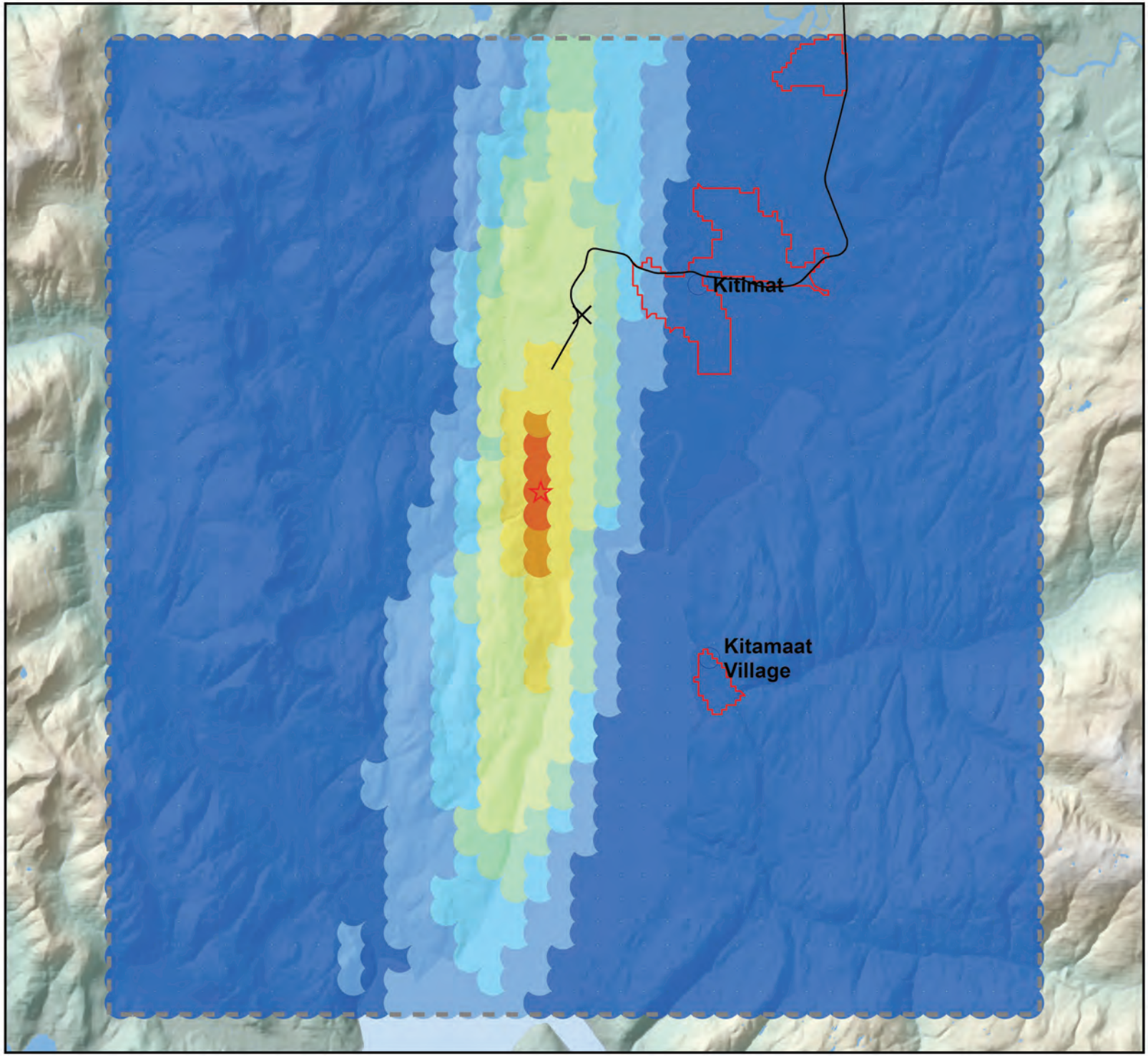
2017 1-hr Actual (ppb)

(Includes background of 5.53 ppb)

- 0 - 17.5
- 17.5 - 35
- 35 - 65
- 65 - 70
- 70 - 140
- 140+

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

Residential Area

Study Area

2017 Actual SO_4^{2-} Deposition

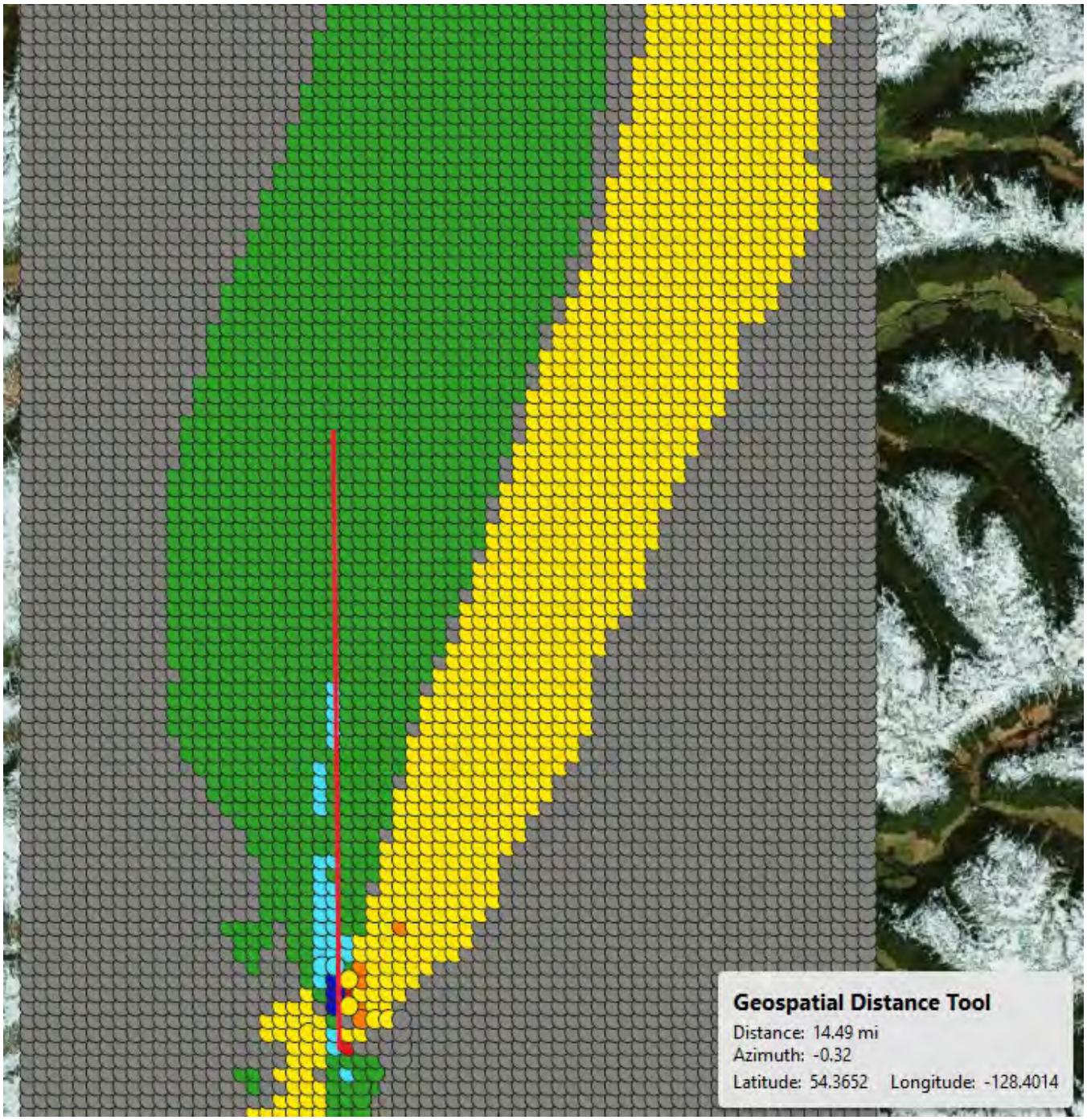
(kg/ha/yr)

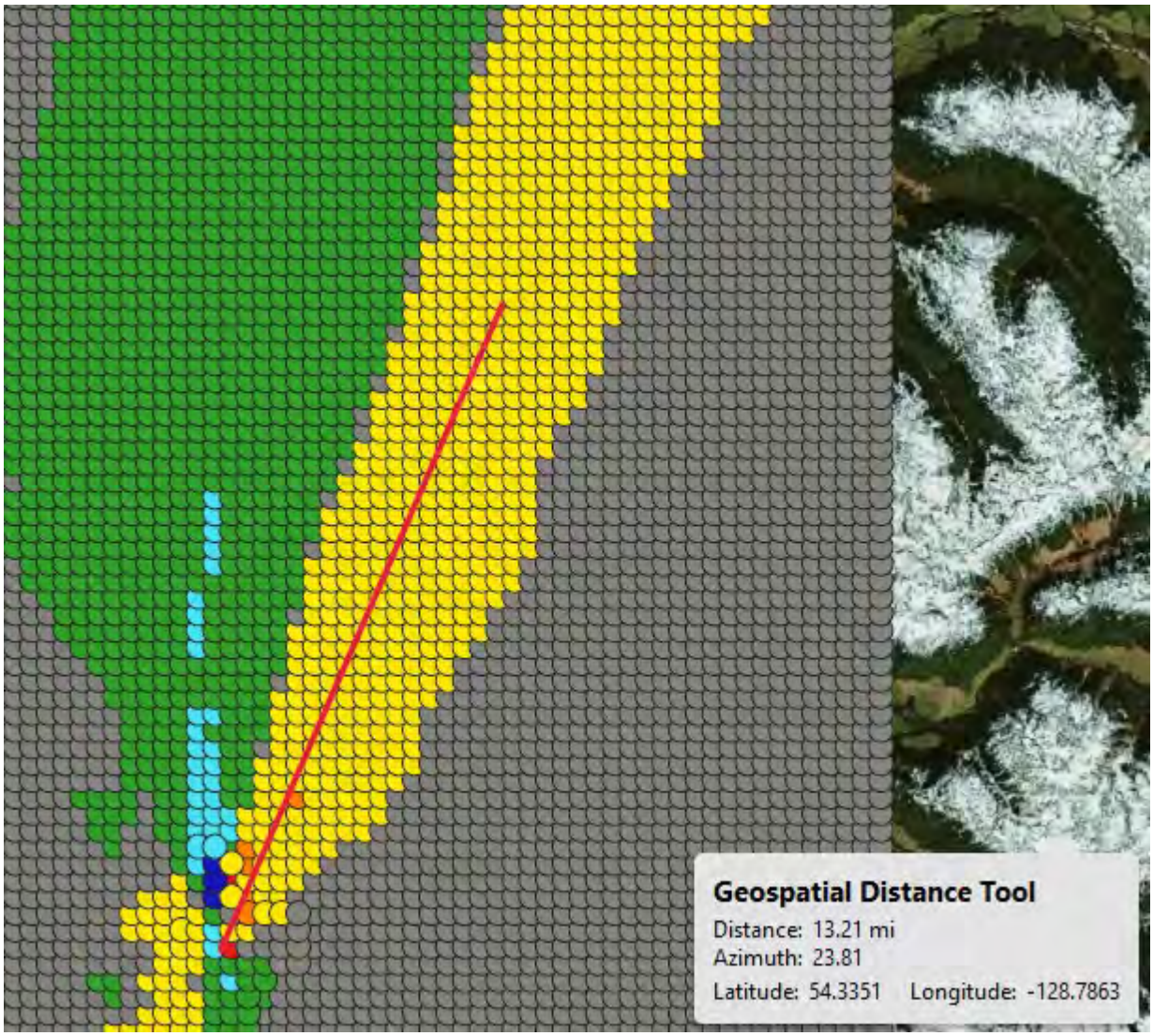
- 10 - 19
- 19 - 29
- 29 - 39
- 39 - 49
- 49 - 99
- 99 - 199
- 199 - 299
- 299+

0 0.9 1.8 Miles

0 1 2 Kilometers

Attachment 2
2018 Initial Model Measurements


Geospatial Distance Tool
Distance: 14.49 mi
Azimuth: -0.32
Latitude: 54.3652 Longitude: -128.4014


Geospatial Distance Tool
Distance: 13.21 mi
Azimuth: 23.81
Latitude: 54.3351 Longitude: -128.7863

Attachment 3
Model Performance Evaluation

MODEL PERFORMANCE EVALUATION

Regional scale model performance evaluation

The SO_2 concentrations predicted by the updated CALPUFF model for the actual scenario (actual emission rates, varying monthly) are compared to monitoring data to understand and evaluate the CALPUFF model performance. Only 2016 and 2017 are evaluated due to the Yacht Club missing wind speed data in 2018. For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data. The lower, more realistic background values are needed for model evaluation, so we can better understand model performance in areas with low SO_2 concentrations. If the Terrace-Skeena background used for effects assessments had been used for model evaluation, the model results in low concentration areas would be skewed. For example, even if the model result had been zero, the comparison using Terrace-Skeena for background would have shown the model over-predicted annual average concentrations at Kitamaat Village and Whitesail, because the Terrace-Skeena annual average SO_2 concentrations were higher than the Kitamaat Village and Whitesail annual average concentrations.[2]

SO_2 concentration results are calculated by CALPUFF in units of micrograms per meter cubed ($\mu g/m^3$). However, this appendix often presents SO_2 results in units of parts per billion (ppb) in order to stay consistent with the monitoring data and the CAAQS. It is possible to move between ppb and $\mu g/m^3$ by a factor of 2.614 $(\mu g/m^3)/(ppb)$.[3]

Evaluation of annual and individual hourly results and maximum hourly summary results are performed and summarized in Table A-1 and A-2 below. For annual average results, the updated model slightly improved over-prediction at Haul Road and Kitamaat Village and slightly increased over-prediction at Riverlodge and Whitesail. The model continues to over-predict the 99th percentile of daily 1-hour peak concentration at all stations and years, except now 2016 shows a slight under-prediction at Kitamaat Village. This one under-prediction was only slightly lower (19 ppb model result compared to 20 ppb), and previous 2018 CR results had also slightly under-predicted at Kitamaat Village. For all other comparisons, the model over-predicted by 20% (2017 Kitamaat Village) to 47% (2016 Whitesail), aligning fairly closely to CR comparisons which had a maximum 1-hour 99% over-prediction of 51% (also at Whitesail in 2016).[4]

[2] The Terrace-Skeena annual average concentrations were 0.4 to 0.5 ppb in 2016 – 2018. The Kitamaat Village annual average concentrations were 0.20 to 0.38 ppb, and Whitesail annual average concentrations were 0.41 ppb in 2017 and 0.35 ppb in 2018.

Based on 2017 and 2018 data, the Williams Lake background concentrations are 1.8 ppb for the 1-hour, 99th percentile daily peak SO_2: 1.8 ppb; and 0.26 ppb for annual average.

[3] The 2.614 $(\mu g/m^3)/(ppb)$ factor converts from a mass concentration basis to a volume concentration basis of SO_2 based on the molecular weight of SO_2 and standard atmospheric conditions. In this case, standard conditions are 1 atm and approximately 25 C, precisely corresponding to the 1-hour SO_2 B.C. AQO levels listed of 70 ppb and 183 $\mu g/m^3$ (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/aqotable.pdf).

[4] Percentage under-prediction or over-prediction calculated as the difference between the CALUFF result and observation, as a percent of the CALPUFF result.

Table A3-1. Summary of CALPUFF Model Comparison to Continuous Monitoring Data, Annual Average SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	0.38	0.58	0.54	0.29	0.52	0.51
Haul Road	4.22	7.12	6.78	3.77	7.33	7.20
Riverlodge	0.50	1.49	2.15	0.43	1.54	2.02
Whitesail	0.53	0.82	1.17	0.41	0.86	1.15

[1] Monitoring data annual average for 2016, 2017.

[2] CALPUFF results for actual scenario, regional-scale using actual smelter emission rates from 2016 to 2018, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO2 for 2016 – 2018 actual conditions. Results with a higher background are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments. The annual average background concentration used for the new 2016 -2018 model is 0.47 ppb based on monitoring at Terrace-Skeena Middle School.

Table A3-2. Summary of regional scale CALPUFF model comparison to continuous monitoring data, 99th percentile of daily 1-hour peak SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	20	25	19	12	17	15
Haul Road	75	99	108	66	100	105
Riverlodge	22	34	40	28	37	42
Whitesail	15	30	28	21	41	35

[1] Monitoring data 1-hour average for 2016, 2017.

[2] CALPUFF results for actual scenario, regional-scale using actual smelter emission rates from 2016 to 2017, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (1.8 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background (5.53 ppb based on monitoring at Terrace-Skeena Middle School) are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments.

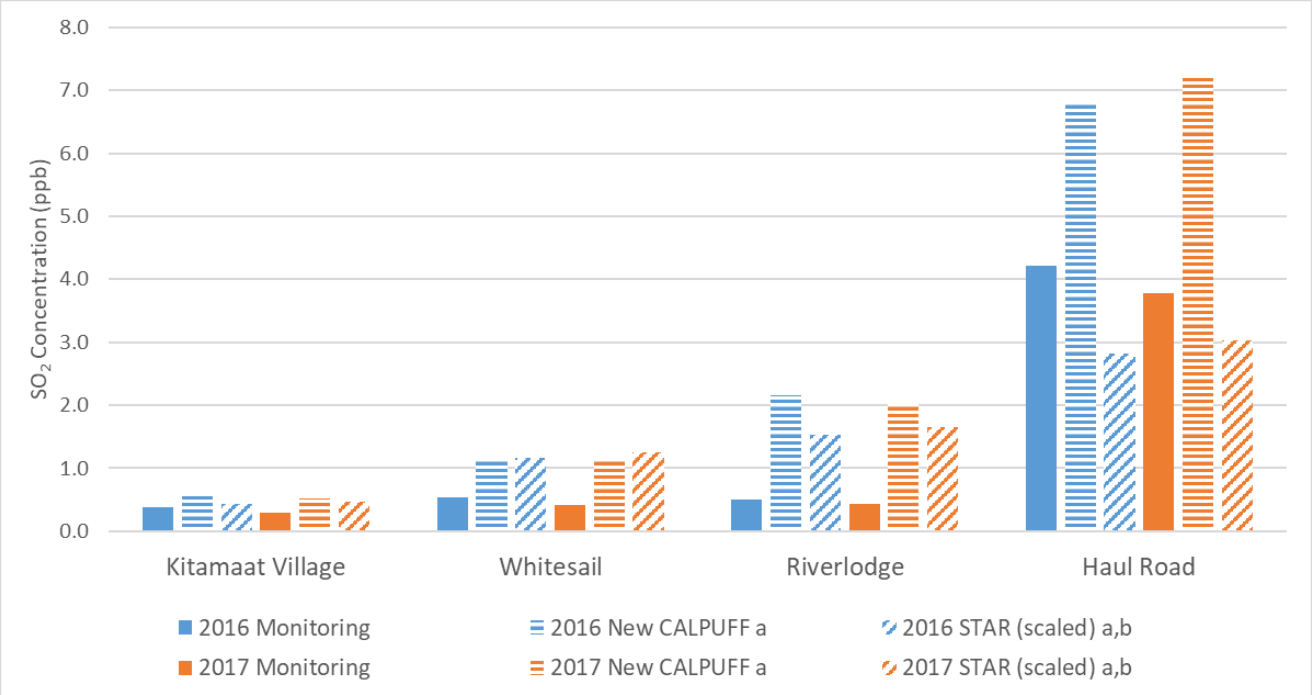


Figure A3-1. Continuous SO_2 (ppb) monitoring concentrations compared to updated CALPUFF model results and scaled STAR model concentrations, 99% of 1-hour daily peak, regional-scale (Williams Lake 1-hour background of 1.8 ppb applied).

Table A3-3 below provides the performance statistics for the regional-scale model for both the original CR model and the updated model. The original CR model statistics are provided in gray text as reference. Overall, the performance statistics are similar between the two models, with some slight improvements for Kitimaat Village and Haul Road and slightly higher error for Riverlodge and Whitesail. The root mean squared error (RMSE), mean bias error (MBE), and mean absolute error (MAE) represent the difference (or error) between the model result versus the observation at each monitor for each hour (paired in space and time as illustrated in Figure A3-2). The MBE represents the same differences seen when comparing the annual average concentrations. The MBE values indicate that the updated model overall slightly under-predicts at Kitamaat Village, slightly over-predicts Whitesail and over-predicts moderately at Haul Road and Riverlodge. The MAE indicates the mean error is larger when looking at absolute error for each hour, averaged over the two model years. For example, the model over-predicts some hours and under-predicts some hours, which averages out to only -0.2 $\mu g/m^3$ for Kitamaat Village, but the average over-prediction or under-prediction is approximately 1.22 $\mu g/m^3$ when looking at the absolute difference. The percentages are provided to demonstrate that while the Haul Road has the largest MBE and MAE on an absolute basis, the 18.9 $\mu g/m^3$ error put in context as a percentage of the monitored concentration is lower than Whitesail, which has an MAE of only 2.7 $\mu g/m^3$.

Table A3-3. Regional scale model performance evaluation statistics. Williams Lake annual background of 0.27 ppb, (0.69 µg/m^3) is applied.

Model	Monitor	RMSE (µg/m^3)	MBE (µg/m^3)	MAE (µg/m^3)	MBE% [1]	MAE% [1]
Original CR Model	Kitamaat Village	3.60	0.66	1.27	87%	167%
	Haul Road	34.06	8.49	17.72	83%	174%
	Riverlodge	9.47	2.86	3.71	235%	304%
	Whitesail	6.16	1.21	2.10	109%	189%
Updated Model (Corrected for Wind Direction)	Kitamaat Village	3.26	-0.20	1.22	-23%	139%
	Haul Road	35.69	7.08	18.86	68%	181%
	Riverlodge	10.93	3.49	4.68	287%	385%
	Whitesail	7.28	1.12	2.72	91%	222%

[1] MBE% and MAE% are expressed as MBE and MAE divided by the annual average observed concentrations, respectively, at each receptor.

Dispersion models are not expected to agree perfectly when paired in time and space (as done for the Table A3-3 performance statistics). In addition, the ability to predict an accurate annual average and 99th percentile daily peak (even if the day is not the same) is the most important metric for evaluating the model's ability to accurately predict future concentrations or deposition rates to assess risk of impacts to receptors. As such, quantile-quantile plots (Q-Q plots) are commonly used to evaluate model performance. Figure A3-2 illustrates the comparison paired in time (max hour each day from 2016 to 2018 for visualizing), while Figure A3-3 compares the hourly model data (all hours from 2016 to 2018) versus monitoring data sorted highest to lowest (Q-Q plot). The comparisons illustrate that the model predicts concentrations and distribution similar to monitoring data at each station (e.g., Kitamaat Village concentrations are low (below 10 ppb) most days with a few (5 to 10) occurrences of 1-hour peaks in the 20 – 30 ppb range for both datasets). However, while the model's overall predictions compare closely to the monitored concentrations, the model results do not generally predict the peaks on the same day or hour.

The Q-Q plots in Figure A3-3 and A-4 illustrate that the model generally predicts concentrations between 100% and 200% of the monitored concentrations, with the exception of slight under-prediction at Kitamaat Village for the two highest hours over and some over-prediction above 200% at the lowest quantile concentrations, particularly for Riverlodge and Haul Road. The updated model performance is about the same at all stations with some slight improvements at Haul Road.

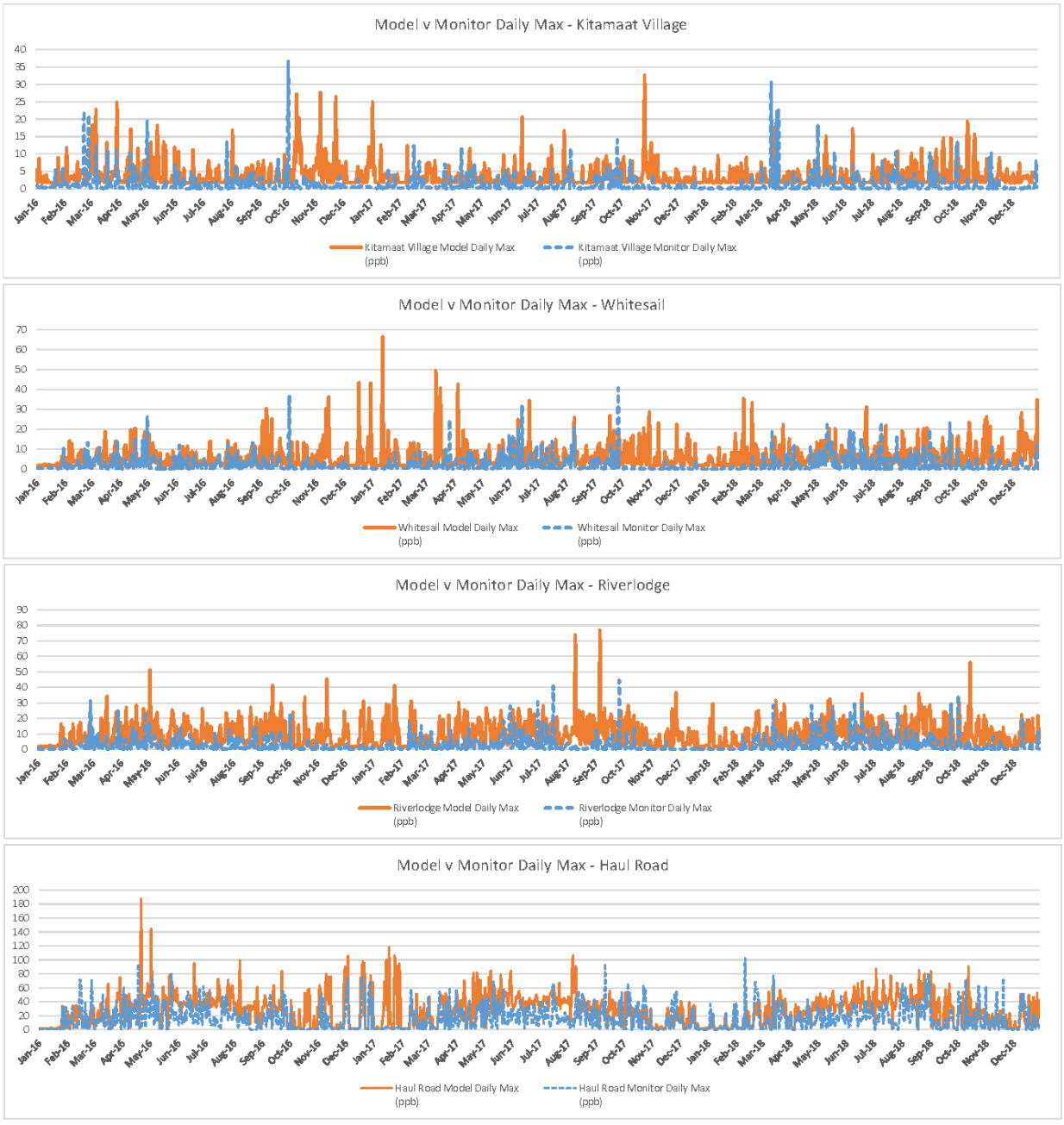


Figure A3-2. Comparison of modelled SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, timeseries (paired in time). The model data include the 1-hour background concentration (1.80 ppb).

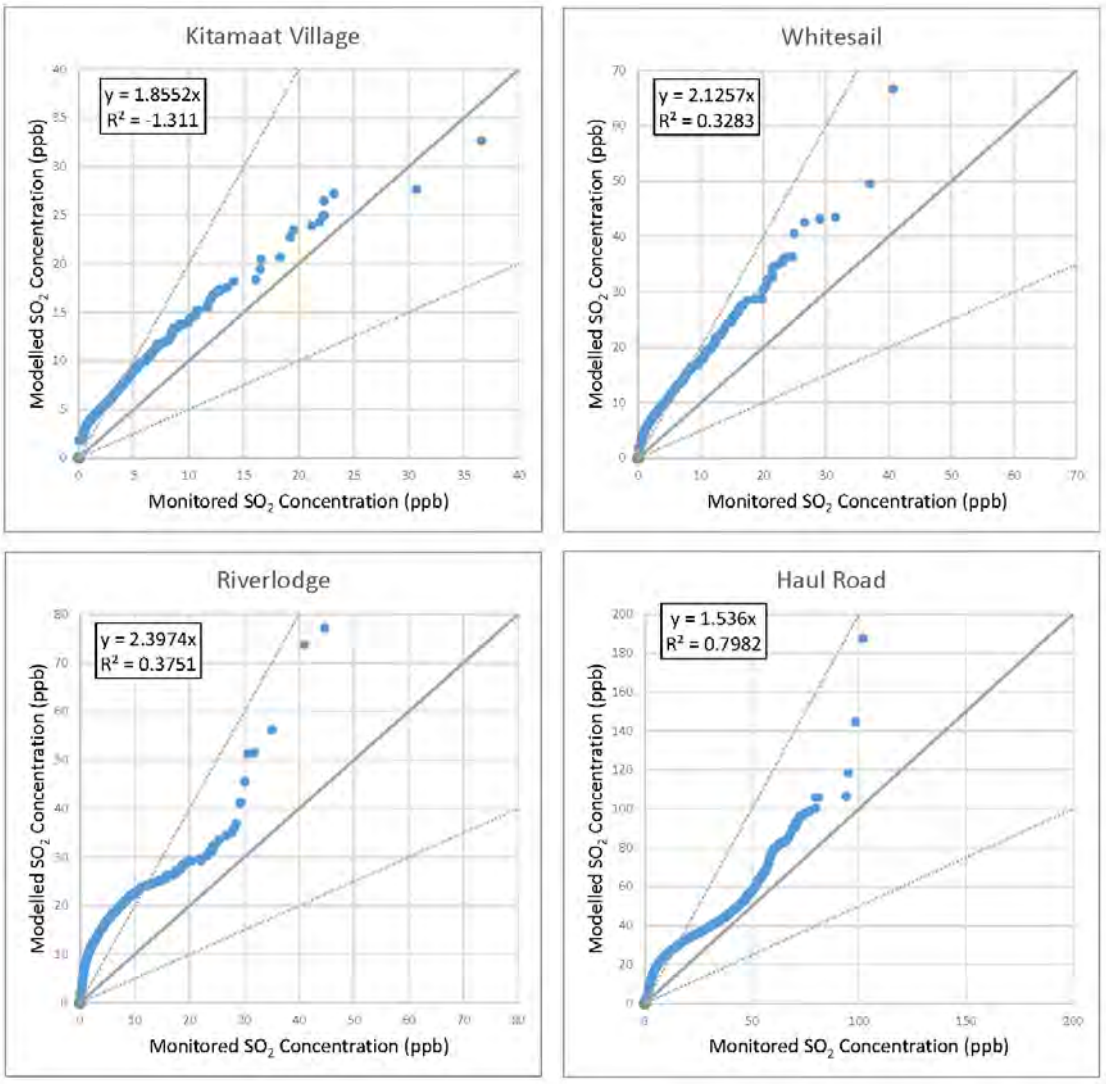


Figure A3-3. Comparison of original CR model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

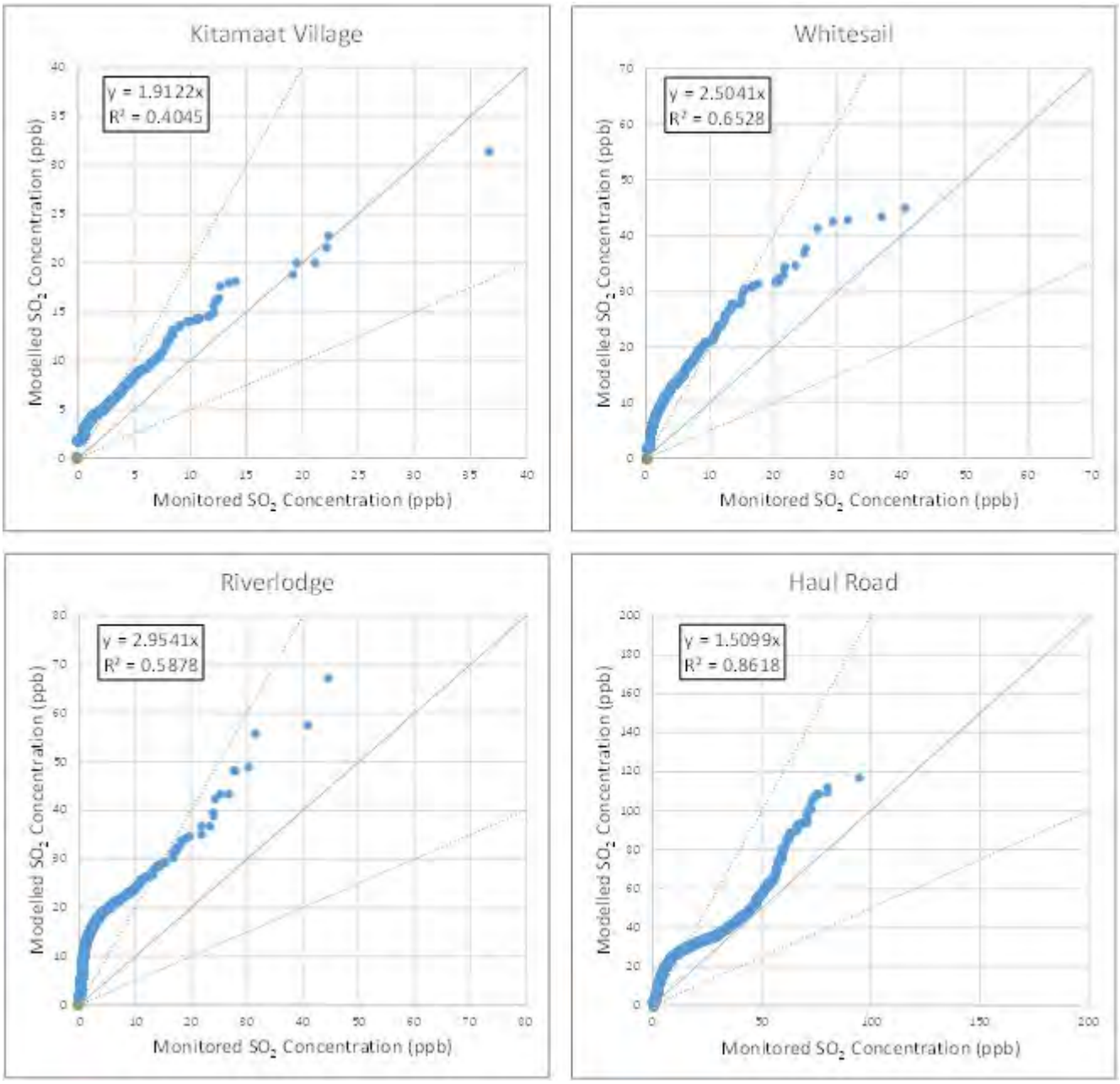


Figure A3-4. Comparison of updated model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

We also used the passive sampling measurements to evaluate the 2016–2017 CALPUFF model performance. Model data were averaged over the same periods as measured by the passive samplers for each sampling period at each site. As shown in the following tables and figures, the updated regional CALPUFF model performance is similar to the CR model performance. Both models over-predict long term (June – October) average concentrations in most locations (model results 150% to 500% of monitored concentrations). For the comparison that over-predicted at the highest rate, the corrected model over-predicts more-so: at V00 on the east side of the valley the updated model predicts 7 µg/m^3 versus 5 µg/m^3 modelled in the CR

compared to 0.34 µg/m^3 measured (only monitored in 2016). Model concentrations at the few sites to the south of the smelter (V11 - V13) remained generally lower than the monitored concentrations (under-predictions), ranging from 69% (V13 in 2017) to 127% (V12 in 2016) of monitored concentrations. Site V10 near the smelter's west boundary, maintained fairly good agreement with model results, but changed from agreeing very closely (model/monitor of 101%, 121%, and 102%) to slight under-predictions (78% and 77%). Overall, the updated model over-predicts to a lesser degree at the majority of the valley network sites compared to the original CR model and results in higher over-prediction at the urban sites.

Table A-4. Regional scale model CALPUFF compared to passive monitoring data - 2016.

Sensor ID	UTM X (m)	UTM Y (m)	Passive Average [a] (µg/m^3)	CALPUFF Original Average [b] (µg/m^3)	CALPUFF Original/ Passive	CALPUFF Corrected Average [b] (µg/m^3)	CALPUFF Corrected/ Passive
V00	530,167	6,016,477	0.34	5.02	1457%	7.02	2039%
V01	524,948	6,017,458	1.80	5.38	300%	3.81	212%
V02	523,130	6,015,390	1.47	5.49	373%	3.30	224%
V03	520,931	6,009,416	2.99	5.73	192%	2.79	93%
V04	520,767	6,003,740	0.92	8.80	959%	4.69	511%
V05	520,539	5,999,300	3.17	11.29	356%	6.63	209%
V06	520,944	5,996,297	2.27	9.22	406%	9.10	401%
V07	521,361	5,993,907	1.35	6.54	483%	8.99	663%
V08	519,935	5,992,321	3.94	13.05	331%	11.44	290%
V09	518,980	5,989,246	4.68	24.03	513%	18.51	395%
V10	519,028	5,985,441	7.13	7.23	101%	5.59	78%
V11	519,426	5,979,635	7.53	5.79	77%	5.46	72%
V12	518,339	5,977,238	4.96	6.45	130%	6.28	127%
V14/U12	520,488	5,990,243	2.11	8.10	384%	10.01	475%
A01	519,527	5,986,823	8.78	23.43	267%	24.48	279%
A02	521,538	5,989,580	0.81	4.61	572%	6.69	830%
A03	523,619	5,991,025	0.64	2.82	439%	3.66	569%
A04	527,457	6,025,573	0.61	4.02	656%	3.48	569%
U01	522,026	5,988,725	0.62	3.72	602%	4.42	714%
U02	522,781	5,989,708	0.60	3.29	545%	3.80	630%
U03	524,345	5,989,883	0.59	2.51	428%	2.87	490%
U04	524,362	5,990,295	0.57	2.51	440%	2.88	505%
U05	525,606	5,993,817	0.31	2.23	724%	2.58	837%
U06	522,947	5,989,308	0.73	3.02	413%	3.45	471%
U07	522,841	5,988,229	0.55	2.96	542%	3.27	598%
U08	522,866	5,991,066	0.76	3.86	509%	5.01	662%
U09	523,917	5,990,370	0.52	2.33	449%	2.39	460%
U10	523,807	5,991,260	0.65	2.96	456%	3.75	579%
U11	523,311	5,989,855	0.70	3.20	457%	3.81	544%
U13	524,981	5,989,675	0.67	2.29	341%	2.54	379%
U14	522,286	5,989,250	0.68	3.57	522%	4.25	621%
U15	523,232	5,980,798	0.47	2.05	436%	1.96	418%

[a] The passive data in this table is not adjusted for calibration with the continuous SO_2 analyzers.

[b] The following background value from Williams Lake is added to account for non-modelled sources of SO_2.

30-day Average Background: 0.46 ppb 1.21 (µg/m^3)

(2nd High over 2017-2018, 96th%) (1ppb = 2.614 µg/m^3 SO_2)

Table A-5. Regional scale model CALPUFF compared to passive monitoring data - 2017.

Sensor ID	UTM X (m)	UTM Y (m)	Passive Average [a] (µg/m³)	CALPUFF Average [b] (µg/m³)	CALPUFF/ Passive	CALPUFF Corrected Average [b] (µg/m³)	CALPUFF Corrected/ Passive
V01	524,948	6,017,458	1.97	5.53	280%	3.66	185%
V02	523,130	6,015,390	1.52	5.05	332%	3.11	204%
V03	520,931	6,009,416	4.24	7.27	171%	3.75	88%
V04	520,767	6,003,740	2.05	10.48	512%	5.85	286%
V04B	520,436	6,003,249	2.15	10.74	500%	2.07	97%
V05	520,539	5,999,300	5.41	11.75	217%	7.36	136%
V06	520,944	5,996,297	3.89	10.74	276%	9.63	247%
V07	521,361	5,993,907	2.08	8.60	413%	9.64	463%
V07B	520,285	5,993,190	3.48	13.26	381%	2.79	80%
V08	519,935	5,992,321	6.18	13.38	216%	11.65	188%
V09	518,980	5,989,246	7.88	29.54	375%	21.82	277%
V10	519,028	5,985,441	10.40	12.59	121%	7.97	77%
V11	519,426	5,979,635	7.91	6.06	77%	6.06	77%
V12	518,339	5,977,238	5.36	5.84	109%	6.05	113%
V13	516,405	5,976,686	5.50	3.61	66%	3.29	60%
V14/U12	520,488	5,990,243	3.28	11.93	364%	12.57	384%
A01	519,527	5,986,823	10.73	24.32	227%	23.70	221%
A02	521,538	5,989,580	1.01	5.42	538%	6.90	684%
A03	523,619	5,991,025	0.83	3.08	370%	3.59	431%
A04	527,457	6,025,573	0.76	4.39	580%	3.42	452%
U01	522,026	5,988,725	0.91	3.82	419%	4.17	457%
U02	522,781	5,989,708	0.76	3.23	427%	3.48	461%
U03	524,345	5,989,883	0.77	2.69	350%	2.66	346%
U04	524,362	5,990,295	0.85	2.68	313%	2.69	314%
U05	525,606	5,993,817	0.33	2.34	716%	2.52	773%
U06	522,947	5,989,308	0.88	2.97	339%	3.05	348%
U07	522,841	5,988,229	0.81	2.84	352%	2.86	353%
U08	522,866	5,991,066	0.76	3.95	520%	5.22	688%
U09	523,917	5,990,370	0.87	2.84	326%	2.98	342%
U10	523,807	5,991,260	0.78	3.03	390%	3.54	455%
U11	523,311	5,989,855	0.93	3.17	339%	3.38	363%
U13	524,981	5,989,675	0.72	2.43	338%	2.35	328%
U14	522,286	5,989,250	0.89	3.64	409%	4.01	451%

[a] The passive data in this table is not adjusted for calibration with the continuous SO_2 analyzers.

[b] The following background value from Williams Lake is added to account for non-modelled sources of SO_2.

30-day Average Background: 0.46 ppb 1.21 (µg/m³)

(2nd High over 2017-2018, 96th%) (1ppb = 2.614 µg/m³ SO_2)

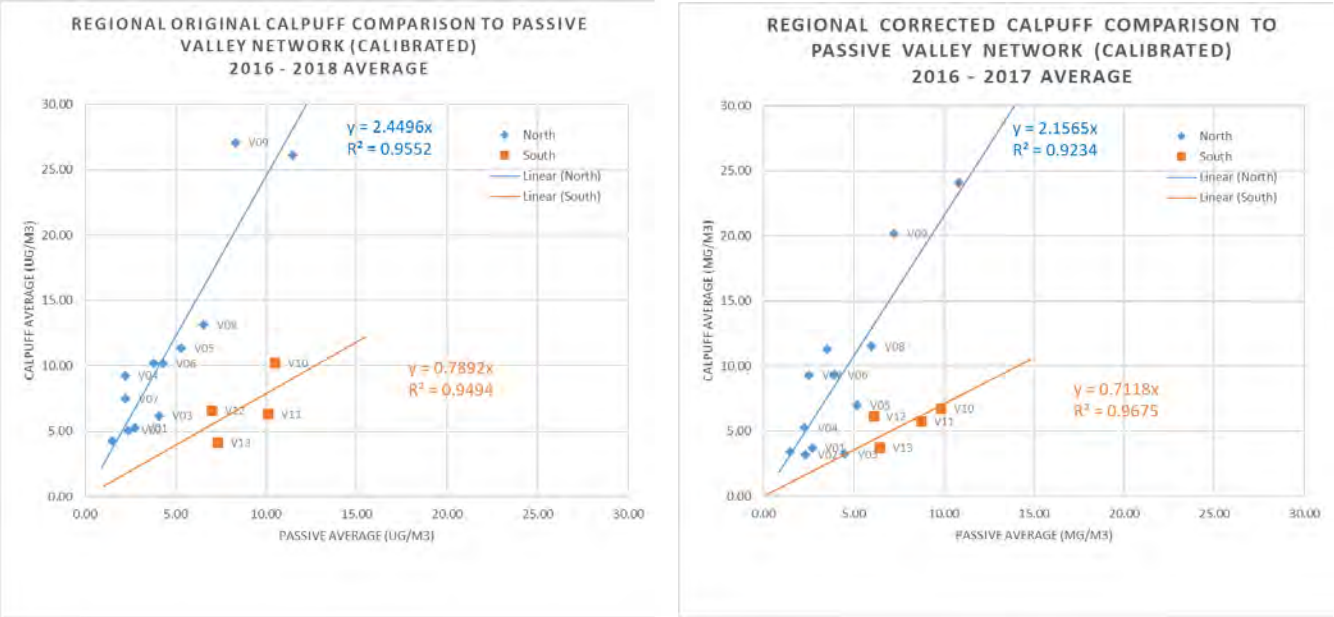


Figure A3-5. Comparison of modelled SO_2 concentrations (actual scenario) against average passive sample data in the valley network (calibrated passive data and background included in model results).

Figure A-16 compares model to monitor data for the original CALPUFF analysis (left) compared to the updated CALPUFF analysis (right). The updated model over-predicts to a lesser degree for the sites to the north (updated model prediction about 2.16 times measured levels compared to 2.45 times for the original CR model) and has slightly lower linear agreement (R^2 of 0.92 compared to 0.95). The sites to the south have a slightly lower under-prediction and slightly improved linear agreement in the updated model.

Local scale model performance evaluation

The local scale model performance evaluation followed the same approach as the regional scale evaluation with the exception that the passive monitoring data comparison is not used.

- Actual scenario (actual emission rates, varying monthly) CALPUFF results are compared to continuous monitoring data.
- For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data.

Table A3-6 and Figure A3-6 summarize comparison of annual average modelled concentrations estimated at each monitoring station compared to the monitoring data each year. Table A3-7 and Figure A3-7 summarize the 1-hour 99th percentile of daily peak concentrations. The local-scale model over-predicted both annual average and 99th percentile of daily 1-hour peak concentrations at all stations and years. The updated model over-predicted annual average concentrations by 16% (2016 Whitesail) to 74% (2016 Kitamaat Village) and 99th percentile of daily 1-hour peak at similar levels from 44% (2016 Haul Road) to 79% (2016 Riverlodge).[5] The local-scale updated (and original CR) model generally over-predicted concentrations more than the regional scale model, particularly at the Riverlodge monitor for annual average and the Kitamaat Village monitor for 1-hour.

Table A3-6. Summary of local scale CALPUFF model comparison to continuous monitoring data, annual average SO_2 (ppb).

	Monitoring Data[1] (SO_2 ppb)	Original CR CALPUFF[2] (SO_2 ppb)	Corrected CALPUFF[2] (SO_2 ppb)	Monitoring Data[1] (SO_2 ppb)	Original CR CALPUFF[2] (SO_2 ppb)	Corrected CALPUFF[2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	0.38	1.43	0.98	0.29	0.63	0.54
Haul Road	4.22	7.92	7.56	3.77	8.14	7.85
Riverlodge	0.50	1.64	2.40	0.43	1.49	1.99
Whitesail	0.53	0.63	1.16	0.41	0.53	0.97

[1] Monitoring data annual average for 2016, 2017.

[2] CALPUFF results for actual scenario, local-scale using actual smelter emission rates from 2016 to 2017, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments. The annual average background concentration used for the new 2016 -2018 model is 0.47 ppb based on monitoring at Terrace-Skeena Middle School.

[5] Percentage under-prediction or over-prediction calculated as the difference between the CALUFF result and observation, as a percent of the CALPUFF result.

Table A3-7. Summary of local scale CALPUFF model comparison to continuous monitoring data, 99th percentile of daily 1-hour peak SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	Original CR CALPUFF [2] (SO_2 ppb)	Corrected CALPUFF [2] (SO_2 ppb)
	2016			2017		
Kitamaat Village	20	157	63	12	52	25
Haul Road	75	97	107	66	119	118
Riverlodge	22	42	45	28	43	44
Whitesail	15	18	34	21	26	43

[1] Monitoring data 1-hour average for 2016, 2017.

[2] CALPUFF results for actual scenario, local-scale using actual smelter emission rates from 2016 to 2017, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (1.8 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2017 actual conditions. Results with a higher background (5.53 ppb based on monitoring at Terrace-Skeena Middle School) are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments.

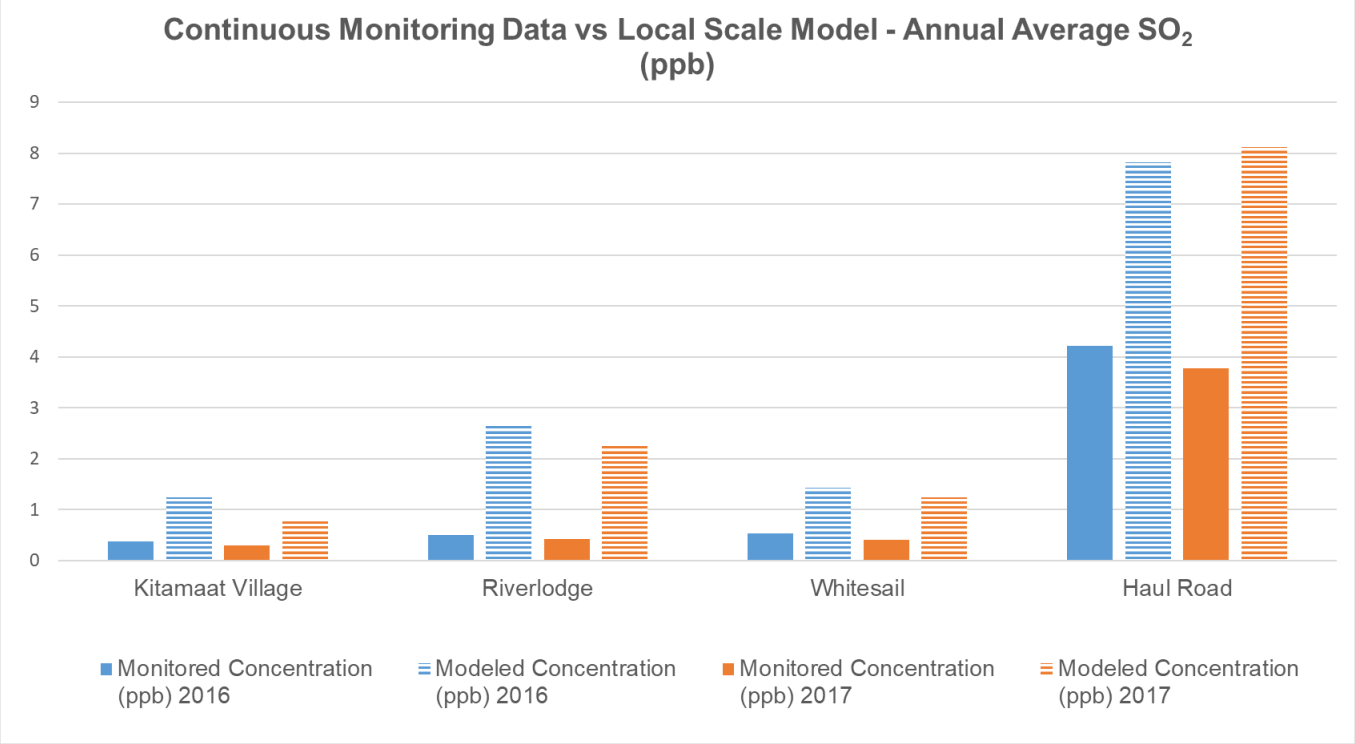


Figure A3-6. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, annual average, local-scale (Williams Lake annual background of 0.26 ppb applied).

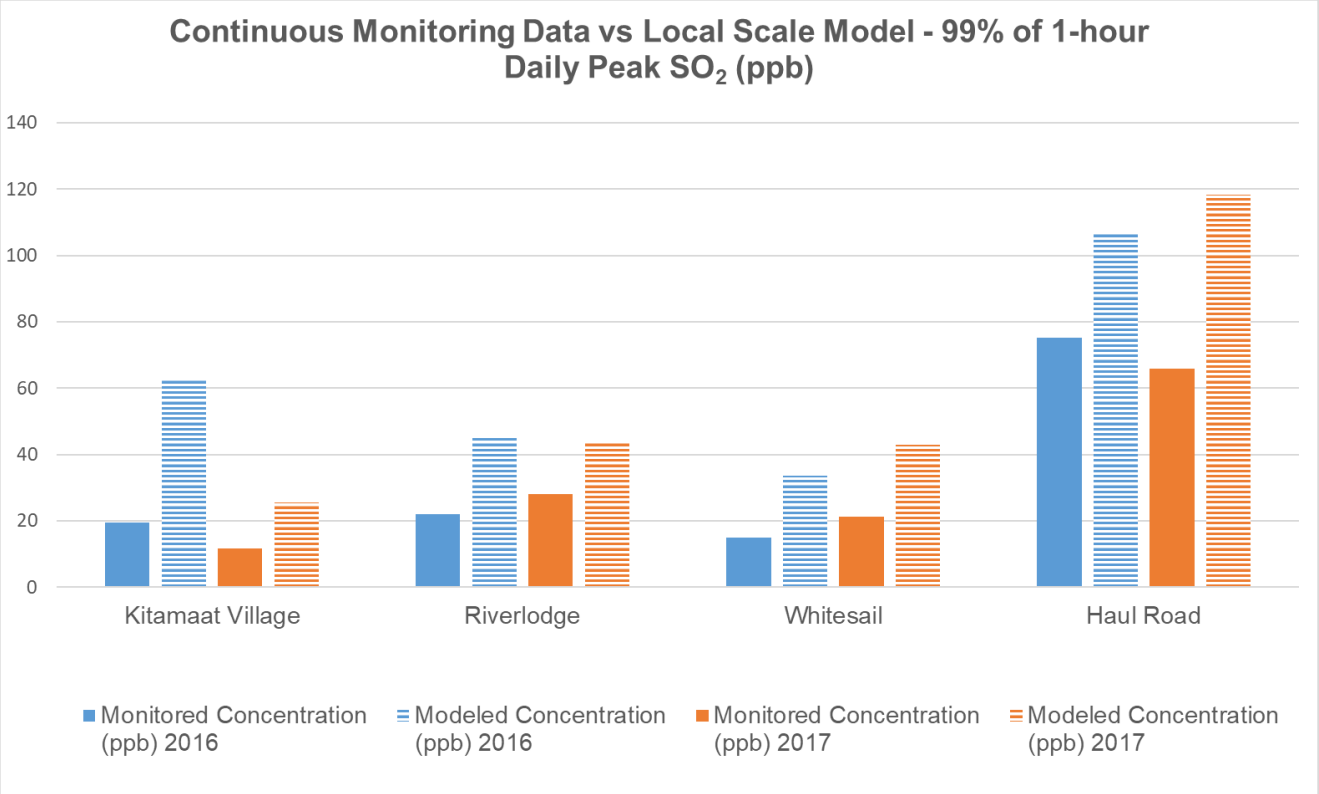


Figure A3-7. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, 99% of 1-hour daily peak, local-scale (Williams Lake annual background of 1.8 ppb applied).

Table A3-3 below provides the performance statistics for the regional-scale model. The RMSE, MBE, and MAE represent the difference (or error) between the model result versus the observation at each monitor for each hour (paired in space and time). The MBE represents the same differences seen when comparing the annual average concentrations (illustrated in Figure A3-6). Like the regional scale performance, the MBE values indicate that the local-scale model overall slightly over-predicts at Kitamaat Village and Whitesail and over-predicts moderately at Haul Road and Riverlodge. The MAE and RMSE values are also similar to the regional scale evaluation, except the Kitamaat Village error is noticeably higher (meaning the local scale does not estimate as well at Kitamaat Village) and the Whitesail error values are noticeably lower (the local-scale model predicts better at Whitesail). The wind correction model update improved local scale performance at Kitamaat Village and performance at Riverlodge declined somewhat.

Table A0-8. Local scale model performance evaluation statistics. Williams Lake annual background of .27 ppb, (0.69 µg/m3) is applied.

Model	Monitor	RMSE (µg/m3)	MBE (µg/m3)	MAE (µg/m3)	MBE% [1]	MAE% [1]
Original CR Model	Kitamaat Village	10.54	1.51	2.12	199%	279%
	Haul Road	37.95	10.29	19.04	101%	187%
	Riverlodge	10.89	2.83	3.86	232%	316%
	Whitesail	4.92	0.43	1.49	38%	133%
Updated Model (Corrected for Wind Direction)	Kitamaat Village	7.02	1.09	1.75	124%	199%
	Haul Road	39.68	9.67	19.81	93%	190%
	Riverlodge	12.54	4.51	5.31	371%	437%
	Whitesail	7.70	1.57	2.52	128%	205%

[1] MBE% and MAE% are expressed as MBE and MAE divided by the annual average observed concentrations, respectively, at each receptor.

The Q-Q plots in 8 below illustrate the over-prediction at Kitamaat Village and relatively good performance at Whitesail as noted above, giving a more complete picture of how the values compare across the range of concentrations. Haul Road modelled concentrations generally fall within the 100% to 200% of monitored values for all but the highest and lowest concentrations. Riverlodge model results also show relatively good performance at the higher concentrations but over-predicts the annual average nearly three times and lower to mid range concentrations over three times. The updated model (Figure A3-9) shows similar patterns at all four monitoring stations.

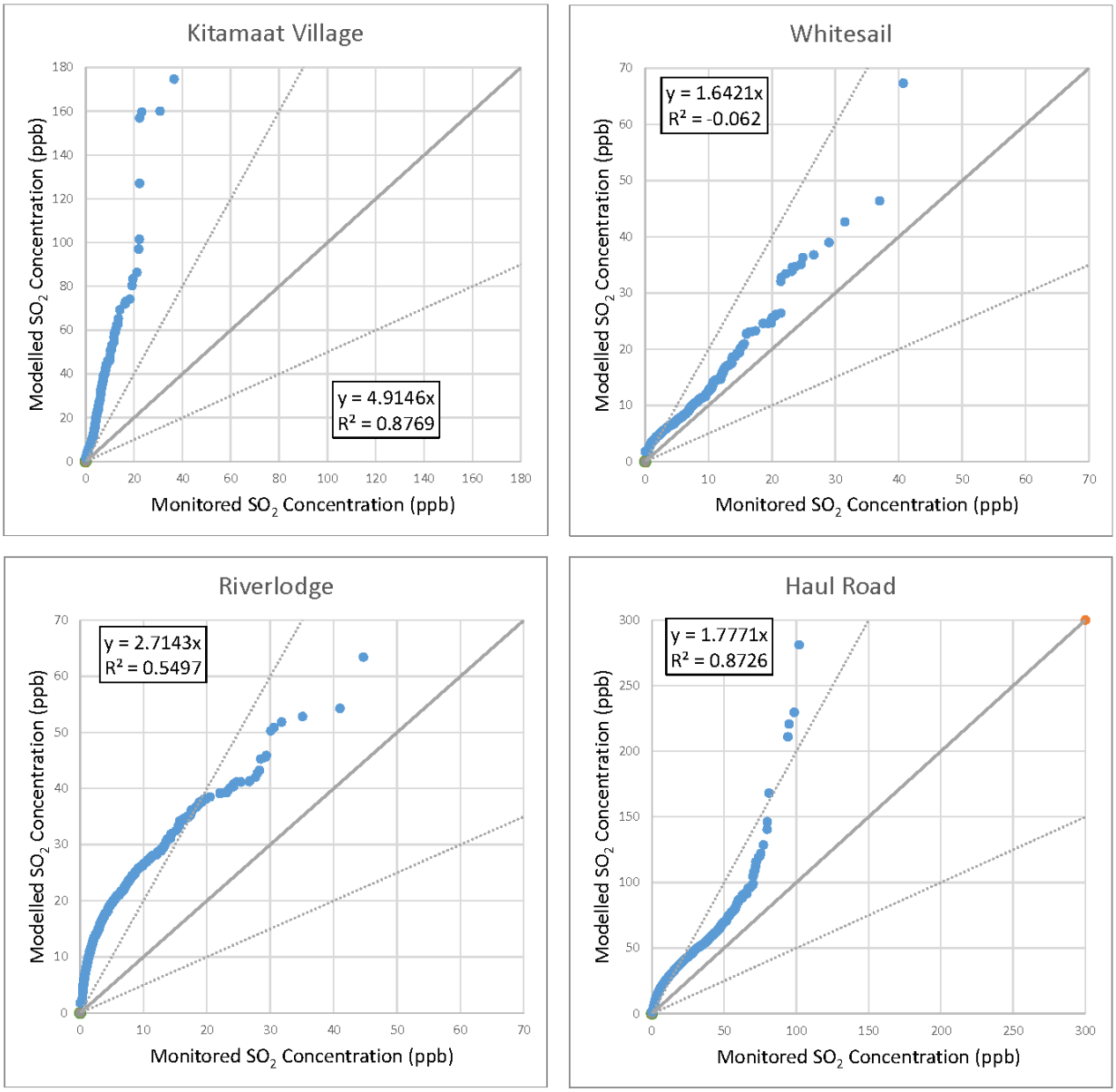


Figure A3-8. Comparison of local-scale original CR model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

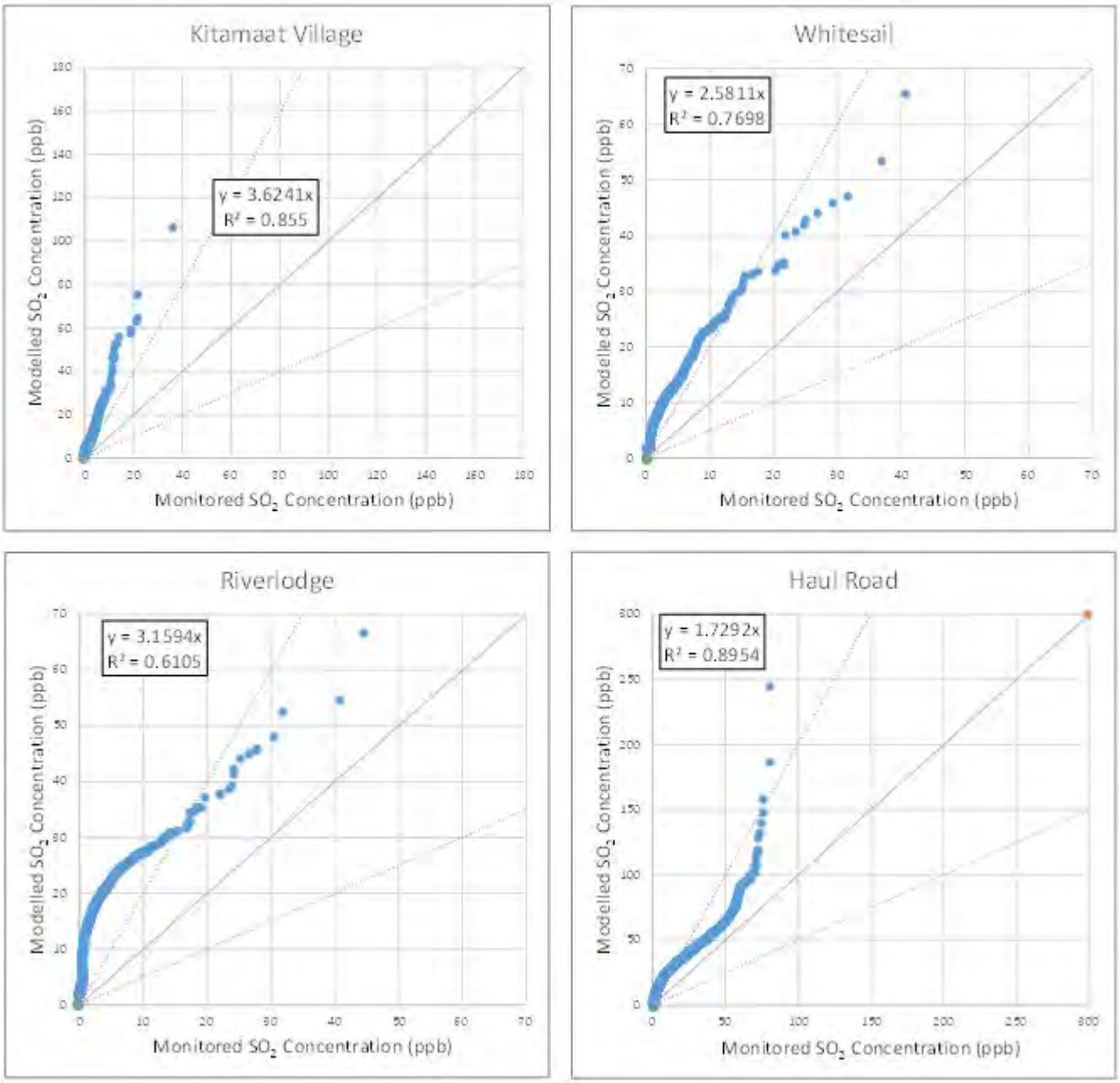


Figure A3-9. Comparison of local-scale updated model SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project

Volume 1: 2019 Comprehensive Review Report, V.3 Final

October 15, 2020

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Version Tracking Table

No.	Date	Summary of content /changes
V.1	October 31, 2019	Draft report for review by the B.C. Ministry of Environment and Climate Change Strategy
V.2	June 30, 2020	Draft report for KPAC review
V.3	October 15, 2020	Final report

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Executive Summary and KPI Report Card

Overview

In 2012 and 2013 a technical assessment was conducted for the Kitimat Modernization Project (KMP) to determine the potential impacts of sulphur dioxide (SO_2) emissions along four lines of evidence: effects on human health, effects on vegetation, effects on terrestrial ecosystems (soils), and effects on aquatic ecosystems (lakes and streams, and aquatic biota). Results were detailed in an SO_2 Technical Assessment Report (STAR)[1].

An SO_2 Environmental Effects Monitoring (EEM) Program was then developed to answer questions that arose during the technical assessment, and to monitor effects of SO_2 along these lines of evidence. Results from the SO_2 EEM Program inform decisions regarding the need for changes to the scale or intensity of monitoring, as well as decisions regarding the need for mitigation.

Section 9.2 of the 2013-2018 SO_2 EEM Plan[2] calls for a comprehensive review of the program in 2019. The purpose of the review is to :

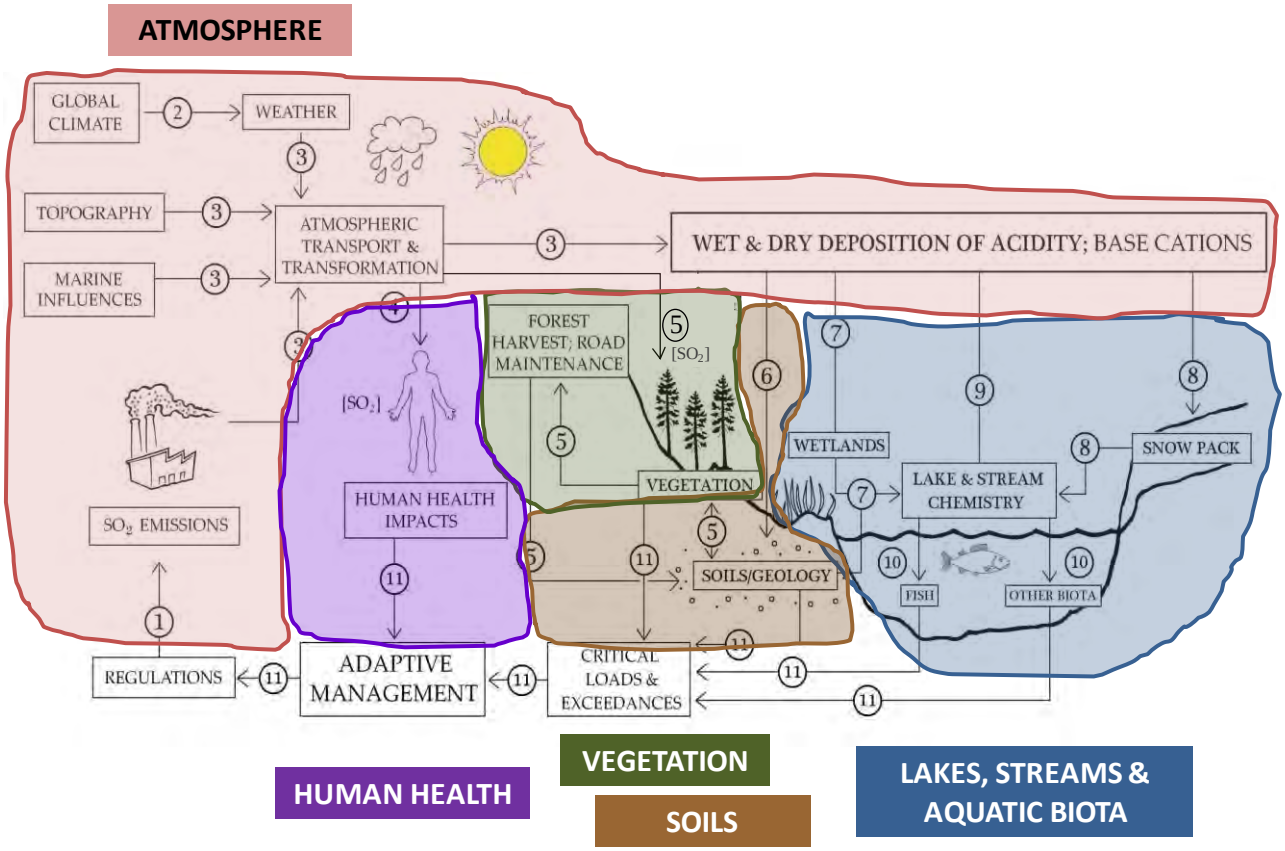
- Summarize what has been learned, and what questions have been answered,
- Describe which if any of the key performance indicator (KPI) thresholds have been reached, and if so, what actions were taken,
- Describe any modifications to KPIs, methods or thresholds that have been made based on annual results to date, and why,
- Look across the data sets of the four lines of evidence to develop an holistic understanding of KMP SO_2 effects on the environment and human health,
- Recommend changes if/as needed to: the suite of KPIs to be continued post-2018, their measurement methods, and/or their thresholds – along with the rationale for these recommended changes, and
- Recommend a date for the next comprehensive review.

The draft terms of reference for the comprehensive review were developed collaboratively by the team of scientists who led the design and implementation of the STAR and EEM Program. The draft terms of reference went through multiple cycles of review and revision with input from Rio Tinto and the Ministry of Environment and Climate Change Strategy (ENV).

This report presents the methods and results of the 2019 comprehensive review. The results and recommendations from the comprehensive review will inform adjustments to the ongoing SO_2 EEM Program, which could include modifications to some KPIs, modifications to how they are monitored, reductions in the overall set of KPIs, or reductions in monitoring effort for some KPIs. Discussions of these and other potential adjustments to the program (many of which are proposed in the comprehensive review) will occur during the development of the next SO_2 EEM Plan in 2020.

[1] ESSA et al. 2013
[2] ESSA et al. 2014a

The SO_2 EEM Program is designed around a source-pathway-receptor conceptual model that represents how SO_2 emissions from the smelter are transported and transformed in the atmosphere, and pathways of exposure for four receptors: human health, vegetation, terrestrial ecosystems (soils) and aquatic ecosystems (lakes, streams and aquatic biota). The conceptual model is shown in the figure below.



Source-pathway-receptor conceptual model for the SO_2 EEM Program.

Each receptor has at least one KPI, and KPIs have quantitative thresholds for action. The KPIs and their thresholds are listed in the table below.

The remaining pages of this section provide a brief summary of the comprehensive review results for atmospheric pathways and each of the four receptors. These are followed by a KPI Report Card that summarizes KPI performance and any adjustments that were made to the program during the first six years or are recommended for the program post-2019. This section ends with a brief summary of the holistic conclusions looking across all lines of evidence.

KPIs and KPI thresholds Receptors in the 2014 SO_2 EEM Plan:

	KPI	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation
Human Health	British Columbia Air Quality Objective measured at residential air monitoring stations	NA – there is no threshold for increased monitoring for this KPI	NA – there is no threshold for receptor-based mitigation for this KPI	3-yr average of 97th percentile of the daily one-hr average maximum (D1HM) for 2015-2017; 97.5th percentile for 2016-18; 98th percentile for 2017-2019 There is an allowance of a one-time exceedance of the 75 ppb threshold to a maximum concentration of 85 ppb over 2017-2019
Vegetation	Visible vegetation injury caused by SO_2	More than occasional symptoms of SO_2 injury outside of Rio Tinto Alcan Kitimat properties, causally related to KMP	NA – there are no reasonable receptor-based mitigations	Severe & repeated symptoms of SO_2 injury outside Rio Tinto properties causally related to KMP, including species of economic or social/ traditional importance, or symptoms of SO_2 injury causally related to KMP at long-distance (>15km) monitoring locations
Terrestrial Ecosystems (Soils)	Atmospheric S deposition and critical load exceedance risk	S deposition causally related to KMP emissions exceeding CL in > 1% (~20 km^2) of semi-natural upland forest soils in the study area	S deposition causally related to KMP exceeding CL in >5% (~100 km^2) of semi-natural upland forest soils in the study area within 200 years	S deposition causally related to KMP emissions exceeding CL in >5% (~100 km^2) of semi-natural upland forest soils in the study area within 100 years (based on projected change in base cations)
	Long term soil acidification attributable to S deposition	For one plot: a 40% decrease in 5 years or a 20% decrease in 10 years in exchangeable cation pools for at least one element, and decrease is causally related to KMP emissions	For one or more plots: a 40% decrease in 5 years or a 20% decrease in 10 years in exchangeable cation pools for at least 1 element and in >1% (~20 km^2) of the area of semi-natural upland forest soils	Decrease in the magnitude of exchangeable cation pool of >20% in 10 years, and in > 5% (~100 km^2) of the area of semi-natural upland forest soils, based on modelling, and decrease is causally related to KMP
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)	Water chemistry - acidification	Observed decrease in pH ≥ 0.30 pH units below mean baseline pH level measured pre-KMP in one or more of the 7 acid-sensitive lakes, and other evidence	More intensive sampling confirms a decrease causally related to KMP of> 0.30 pH units below mean baseline pH level pre-KMP and liming is feasible	More than 2 lakes rated Medium or High (based on relative lake rating) with decrease causally related to KMP of> 0.30 pH units below measured baseline pre-KMP (prior to liming)

Atmospheric Pathways Summary

The CALPUFF dispersion model used in the STAR predicted post-KMP SO_2 concentrations and total sulphur deposition throughout the Kitimat Valley. These atmospheric SO_2 and total sulphur deposition predictions were used to complete receptor-specific impact assessments along the four lines of evidence. In this comprehensive review, we set out to learn how accurate the STAR model predictions were. We also set out to develop more accurate model predictions of current and future post-KMP atmospheric SO_2 and total sulphur deposition using a new CALPUFF model analysis. The new CALPUFF results are used to complete updated receptor-specific impact assessments to vegetation, and terrestrial and aquatic ecosystems.

We use SO_2 atmospheric concentrations to assess the risk of direct impacts on human health and vegetation. Measured SO_2 atmospheric concentrations are used to assess health impact; modelled and measured SO_2 concentrations are used to evaluate the risk of direct injury to vegetation. We use predictions of atmospheric deposition under different emission scenarios to assess the risk of impacts on vegetation, terrestrial, and aquatic ecosystems. Since the effects of SO_2 concentrations and sulphur deposition on receptors are assessed in receptor-specific evaluations, there are no KPIs for atmospheric concentrations or atmospheric deposition. The atmospheric pathway has one atmospheric concentration informative indicator: atmospheric SO_2 concentrations, which is measured through three types of equipment: continuous SO_2 analyzers, passive SO_2 monitors, and filter packs (to assess what fraction of sulphur is in particulate form), and modelled using the CALPUFF model. There are also two atmospheric deposition informative indicators: atmospheric sulphur deposition and base cation deposition, which is measured at two NADP monitoring sites within the study area; sulphur deposition is modelled using the CALPUFF model.

Three SO_2 emission scenarios were modelled: actual emissions from the smelter during 2016-2018 which averaged 29.3 tonnes per day (tpd), a 42 tpd scenario representing the highest level of SO_2 emissions allowed under the permit, and a 35 tpd scenario representing SO_2 emissions of a magnitude that is midway between actual emissions and the maximum allowable.

What did we learn during the first six years of the SO_2 EEM Program?

The updated regional-scale 2016–2018 CALPUFF modelling reduced uncertainty in post-KMP model predictions. We used as-built source parameters and actual 2016–2018 SO_2 emission rates from the smelter, combined with corresponding 2016–2018 meteorological data, to evaluate the model performance. We learned that this new regional-scale 2016-2018 model is more accurate overall than the STAR model. In particular, the new model aligns with observations better than the STAR model at all residential monitors. In addition, the STAR model under-predicted slightly at the Haul Road monitor, while the new model over-predicts at the Haul Road monitor at a level similar to over-prediction at the other continuous monitors (the regional-scale model predicted 3-year average SO_2 at Haul Road of 1.8 times the 3-year average monitored SO_2 concentration). In addition to its value for evaluating CALPUFF model accuracy, the continuous SO_2 monitoring data also show monthly average trends indicating the Haul Road (fenceline) concentrations have generally increased with increasing SO_2 emissions from the smelter, while SO_2 concentrations in residential areas are influenced more by meteorological conditions than by changes in SO_2 emission rates.

We used the local-scale CALPUFF model to evaluate the SO_2 monitoring network. The CALPUFF results indicate that the Riverlodge monitor station is located near the highest concentrations within the town of Kitimat, and that the most suitable locations for measuring the highest concentrations within Kitamaat Village are along the western shoreline of Kitamaat Village. This analysis is preliminary based on new CALPUFF results only. The formal conclusions for the continuous SO_2 monitoring network evaluation and optimization will be made in the Phase 2 monitoring network optimization report.

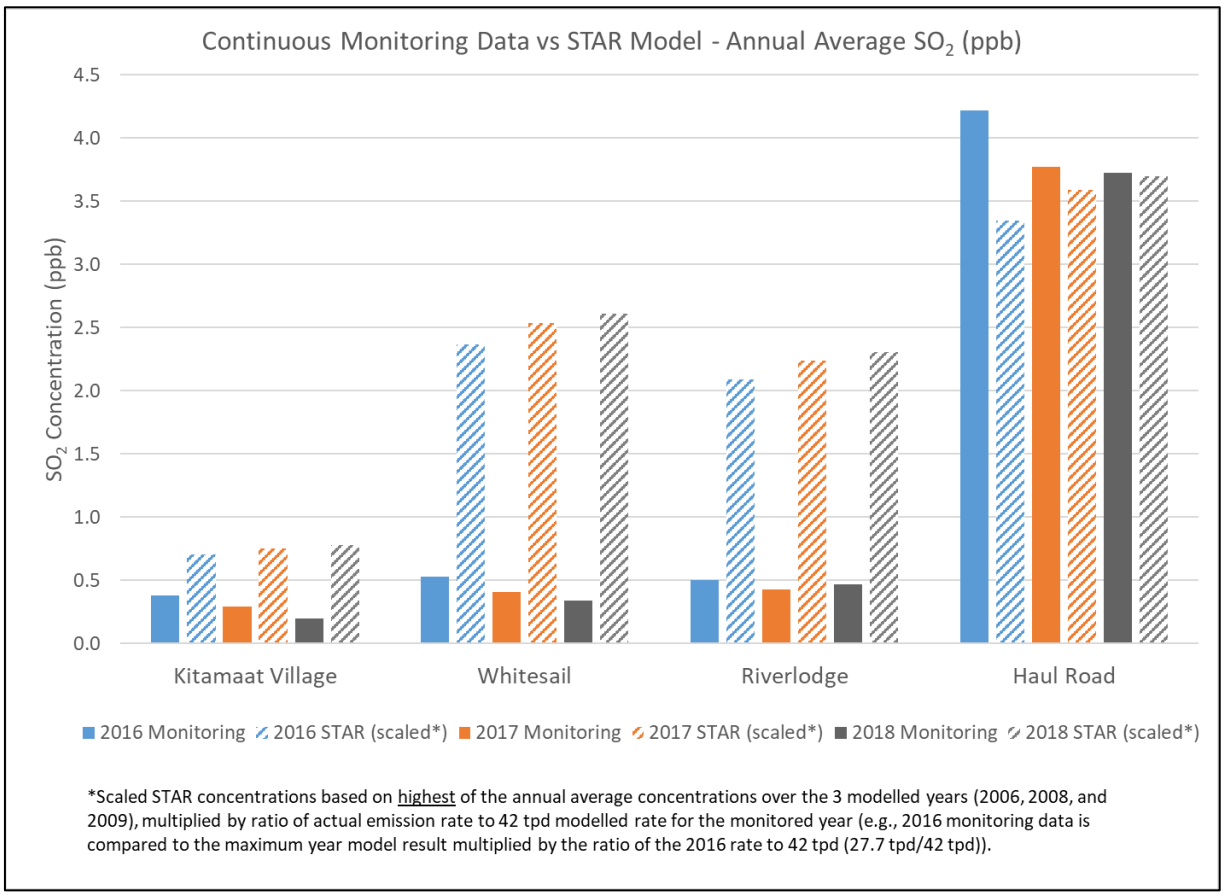
The passive sampling urban network study confirmed the entire Kitimat urban area has low SO_2 concentrations. Passive sampling at sites co-located with existing monitoring stations demonstrated that there was a strong linear relationship between estimates of the average monthly concentration of SO_2 from the passive samplers and monthly averages based on the continuous SO_2 analyzers. The network of passive samplers along the Kitimat Valley revealed that average monthly concentrations of SO_2 were highest close to and south of the smelter (about 12 $\mu g/m^3$), and then declined exponentially with distance from the smelter (reaching < 2 $\mu g/m^3$ at Lakelse Lake). A short study of particulate sulphate sampling using filter packs also confirmed that only a very small fraction of total sulphur in the atmosphere is particulate sulphate.

The new 2016–2018 CALPUFF model predicts a similar spatial distribution of deposition as was predicted in the STAR, however some differences are notable; the 7.5 kg SO_4^{2-}/ha/yr isopleth extends farther to the southwest, and does not extend as far to the north.

Only a small fraction of SO_2 emitted from the smelter is deposited through wet or dry deposition within the study area. This fraction is 8.1% for the 42 tpd scenario based on the 3-year average new 2016–2018 CALPUFF model results. The remaining SO_2 stays in the atmosphere and eventually exits the model domain. Deposition rates beyond the CALPUFF domain are well below levels we use to define the effects domain for terrestrial ecosystems (7.5 kg/ha/yr), and the primary area used to select lakes for study in the STAR (10 kg/ha/yr).

STAR question A1: Does the CALPUFF model accurately predict post-KMP SO_2 air concentrations?

As detailed in the annual EEM reports, comparisons performed each year between continuous SO_2 monitoring data and CALPUFF model results showed that the actual measured SO_2 concentrations were substantially lower than model predictions of post-KMP SO_2 concentrations from the STAR at most locations, and near model predictions at Haul Road. This comparison confirmed expectations based on the STAR CALPUFF model comparison of pre-KMP model results to pre-KMP monitoring data: that CALPUFF model results in the STAR over-predicted post-KMP SO_2 concentrations at most locations. Annual average STAR SO_2 concentration over-predictions at residential continuous SO_2 monitoring sites ranged from 1.9 times (compared to 2016 at Kitamaat Village) to 7.7 times (compared to 2018 at Whitesail); while the concentrations were slightly under-predicted at Haul Road as shown in the figure below (which includes the background concentration used in the STAR of 0.4 ppb).



The updated 2016–2018 CALPUFF model reduces uncertainty in post-KMP model predictions by using as-built source parameters and updated meteorological data. The new 2016–2018 model aligns with observations better than the STAR model at all residential monitors, and the new model over-predicts at the Haul Road monitor by 1.8 times compared to a slight under-prediction at Haul Road by the STAR model.

Analysis of data from the passive samplers revealed that the amount of CALPUFF over-prediction by the new CALPUFF model was relatively uniform in the Kitimat Valley to the north, with under-prediction to the south of the smelter (comparison based on only a few passive samplers south of the smelter).

STAR question D1: Does the CALPUFF model accurately predict post-KMP total sulphur deposition?

Overall, the new CALPUFF model predictions of total sulphur deposition compare well to the monitored results. When considering that the model results do not include background deposition (which may be up to 3.6 kg SO_4^{2-}/ha/yr), the new model over-estimates actual deposition rates at Haul Road by 24% to 29% and predicts actual deposition at Lakelse Lake from 16% under-estimation to 47% over-estimation (three-year average comparison of observed to modelled without background and to modelled with maximum background).

STAR question D2: What are the base cation deposition values in the study region?

We evaluated annual base cation (BC = Ca^{2+} (calcium) + Mg^{2+} (magnesium) + K^+ (potassium) + Na^+ (sodium)) precipitation chemistry at three NADP stations (Haul Road, Lakelse Lake and Port Edward) during 2014–2018 (2013–2018 for Haul Road). Following correction for sea salts, Mg^{2+} and Na^+ were zero at both stations (i.e., there was no observed non-sea salt deposition of Mg^{2+} and Na^+). Long-term $Ca^{2+}$and K^+ in precipitation were almost equal at Lakelse Lake and Port Edward. In contrast, the precipitation concentrations at Haul Road were 1.5 (K^+) to >2 (Ca^{2+}) times larger than the other two sites. It was assumed that precipitation chemistry at Haul Road was influenced by anthropogenic sources; as such, regional base cation precipitation was set to the average for Lakelse Lake and Port Edward. Average base cation concentration in precipitation was estimated as 0.8 µeq/L.

Did we make any adjustments to the SO_2 EEM Program during 2013-2018?

We added a new informative indicator to the SO_2 EEM Program: contribution of dry deposition to total deposition. This indicator is not used to assess impacts due to sulphur deposition, but provides valuable information to understand the factors that could lead to variation in deposition rates.

What changes do we recommend to the SO_2 EEM Program going forward?

Overall, we recommend continuing the atmospheric monitoring within the SO_2 EEM Program. The Phase 1 monitoring network evaluation indicated that the Riverlodge monitor site is in the most suitable location for measuring the highest concentrations within the town of Kitimat, and that the Kitamaat Village monitoring station is in the best location for Kitamaat Village. The Kitimat Haul Road station should also be continued because it serves as a fenceline monitor with a long historic record. The Phase 2 network evaluation is planned to start in the second quarter of 2020. Therefore, no changes should be made to these monitoring stations until and unless the Phase 2 network evaluation recommends changes. Lastly, we recommend establishing a temporary or fixed continuous SO_2 monitoring station within the Service Centre commercial area to provide information on model performance in this area. These recommendations are preliminary and may change as a result of the final Phase 2 network optimization effort.

We also recommend continuing the passive sampling network in the Kitimat Valley because it adds value for understanding the spatial distribution of SO_2. In particular, the passive sampling network added substantial value for evaluating CALPUFF model performance. Accurate CALPUFF prediction of SO_2 (and sulphur deposition) reduces uncertainty when using the CALPUFF output for evaluating impacts to receptors. However, the number of sites and frequency of monitoring should be reviewed. For example, in order to gain a better understanding of the plume position and extent in the east-west direction, we recommend adding passive sampling sites to the east and west of current sites located the north of the smelter, where possible based on access and British Columbia (B.C.) air monitoring site selection guidelines for passive sampling for passive sampling. The current north to south network could be reduced to accommodate the proposed east to west expansion. Two or three cross sections over two to three years will be sufficient for model evaluation needs. Additionally, we recommend evaluating whether additional passive sampling sites can be established in locations south of the smelter. Lastly, the passive sampling site locations should be assessed for whether some sites should be moved to align with the proposed vegetation biodiversity assessment plots (or vice versa).

The passive sampling urban network study has been successful in confirming the entire Kitimat urban area has low SO_2 concentrations. There are no plans to continue the study beyond 2019, and no benefit in continuing the study has been identified through the comprehensive review. Similarly, the short study of particulate sulphate sampling using filter packs was successful in confirming that only a very small fraction of total sulphur in the atmosphere is particulate sulphate. There are no plans to continue particulate sulphate study, and no benefit in continuing the study has been identified through the comprehensive review.

For the deposition monitoring program, we recommend continuing the Lakelse Lake monitor and considering discontinuing the Haul Road wet deposition monitor. The monitoring of wet deposition at Haul Road provides no ecological value (i.e., for the assessment of impacts) owing to its fence line location and because it provides limited value for model (CALPUFF) evaluation.

Human Health Summary

The STAR was prepared in 2013. At that time the Province of British Columbia did not have an Air Quality Objective for sulphur dioxide that was based on recent human health evidence. As a result, the STAR included predictions of the annual number of restricted airway events based on the ambient air concentrations in residential areas. The ambient air concentrations were predicted by the air dispersion modelling that was conducted as part of the STAR, similar in structure to the modelling done for this comprehensive review.

The contents of the STAR informed the SO_2 EEM Program. The 2013-2018 SO_2 EEM Plan included an informative performance indicator for human health based on updated predictions of the annual number of restricted airway events based on each year's actual emissions and meteorological observations.

In the time between the preparation of the STAR and this comprehensive review, the Province of British Columbia adopted an Interim Air Quality Objective (IAQO) and modified the SO_2 EEM Program to apply the IAQO as a KPI. The KPI is based on measurements at residential monitoring stations. Starting in the year 2020, the B.C. IAQO for SO_2 becomes equivalent to the Canadian Ambient Air Quality Standards (CAAQS) adopted by the Canadian Council of Ministers of the Environment (CCME). During the development of the terms of reference for this comprehensive review, it was determined that the informative indicator was no longer necessary for the SO_2 EEM Program or the comprehensive review.

Did we exceed a KPI threshold as calculated starting in 2017 under the 2014 SO_2 EEM Plan?

The human health KPI is based on maintaining concentrations of SO_2 below a threshold value for a significant proportion of the year at three residential monitoring stations: Riverlodge, Whitesail and Kitamaat Village. Annual calculation of the KPI for Human Health began in 2017. It has one threshold, for facility-based mitigation, and this threshold has not been exceeded.

What did we learn during the first six years of the SO_2 EEM Program?

The levels of SO_2 in the residential areas of Kitimat and Kitamaat Village change on an hourly basis. Despite being variable, the levels of SO_2 are below 1 ppb in more than half of the hours of each year, at all three sites. Even when considering only the worst hour of each day, the average concentration in that worst hour is less than 1 ppb in more than half of the days at each site in each year.

Due to the nature of meteorological conditions and other variables, there are relatively infrequent excursions of the SO_2 concentration above 10 ppb. For the period from 2016 to 2018, the maximum hourly averaged concentration for all stations (44.7 ppb) occurred at Riverlodge Station (Lower Kitimat) in 2017.

Did we make any adjustments to the SO_2 EEM Program during 2013-2018?

In 2016, the Province of British Columbia adopted an IAQO. This objective was established as 75 ppb for hourly averaged concentration of SO_2 and applies in the SO_2 EEM Program for the years 2017-2019. From the year 2020 forward, the IAQO value will be replaced by the CAAQS values of 70 ppb, and 65 ppb (starting in 2025).

What changes do we recommend to the SO_2 EEM Program going forward?

There are no recommendations for changes to the existing KPI since it is in the process of changing in alignment with the adoption and further adjustment of the CAAQS.

Vegetation Summary

The SO_2 EEM Vegetation Program was designed to monitor the potential effects of the modernized smelter on plants in the Kitimat Valley. The vegetation program centered around two measures: a visual inspection of plants at an array of sites throughout the valley, and the sulphur (S) content of western hemlock needles collected at those same sites.

The KPI for vegetation is based on visible injury of sensitive vegetation due to SO_2. Although the modelling results from the STAR indicated that visible injury was unlikely to occur, modelled concentrations were high enough to warrant such a KPI, particularly given that the sensitivity of most vegetation in the valley has not been documented through controlled exposure studies. Sulphur content in hemlock needles was used as an informative indicator.

Did we exceed a KPI threshold as identified in the 2014 SO_2 EEM Plan?

No KPI thresholds were exceeded. No visible injury due to SO_2 was observed at any location post-KMP. Visible injury due to SO_2 has not been reported in the results of the vegetation monitoring program since before 1999.

What did we learn during the first six years of the SO_2 EEM Program?

Given the results of air monitoring and dispersion modelling, the KPI will not be an effective tool as visible injury due to SO_2 seems highly unlikely to occur. From the results of measurements and observations to date, the risk to higher vegetation remains unlikely or very unlikely and of minor consequence.

STAR question V1: Validation of the dispersion model – are we looking in the right place?

For the most part, the locations of vegetation sampling and inspection sites align well with the predicted path of the plume. Additional sites are well outside the areas of projected deposition and provide reference information. The areas off the Rio Tinto B.C. Works site where the highest concentrations are projected to occur are not safely accessible from the ground or the air. The predicted 1-hour maximum concentrations at some of those locations exceed the 1-hour threshold used in the STAR but other thresholds are not exceeded. Aerial survey of the area doesn't reveal any indication of change in forest condition. The vegetation informative indicator of sulphur concentration in western hemlock needles did not help verify model predictions as there was a poor correlation between sulphur in needles and measured or modelled air concentration of SO_2 or deposition of SO_4^{2-}.

STAR question V2: How healthy is vegetation in sites with predicted exceedance of critical loads of soil and/or lakes and streams south of Lakelse Lake?

No significant differences in plant heath throughout the Kitimat Valley have been observed post-KMP. There were no significant insect outbreaks or plant disease epidemics during the period under review. The greatest stress to vegetation during the period was associated with drought in 2018. No differences were observed in vegetation in the areas of soil critical load exceedance under actual emissions. On-the-ground or aerial inspection of vegetation in the area of predicted soil critical load exceedance under the maximum permitted level (42 tpd) did not reveal differences in the health of vegetation compared to sites located at distance, including reference sites.

STAR question V3: Are plants of public importance showing symptoms in areas with the highest exceedances of soil critical loads?

No symptoms associated with emissions from the smelter were observed.

STAR question V4: Do plants at Kitimat that have unknown sensitivity to SO_2 and associated pollutants (acidic deposition) fall within the range of variation in the literature?

It appears that plants in the Kitimat Valley are within the range of sensitivities reported in the scientific literature. Given the low ambient concentrations of SO_2, injury would not be expected to occur, and it did not.

Did we make any adjustments to the SO_2 EEM Program during 2013-2018?

No adjustments were made to the SO_2 EEM Program.

What changes do we recommend to the SO_2 EEM Program going forward?

We recommend that a terrestrial ecosystem line of evidence be established to integrate the vegetation and soils lines of evidence. The current KPI for vegetation should be discontinued and measures of plant health and plant biodiversity should be developed to replace the current KPI and informative indicators. A plant biodiversity pilot project needs to be conducted to develop appropriate thresholds and related measures of variability to assure success.

We recommend establishing informative indicators of changes in plant biodiversity and changes in plant health due to emissions from the B.C. Works. These should be based on plant biodiversity field plots (to be established) and a triennial inspection to assess and document plant and ecosystem health, and will support the soil critical load KPI. Documented changes in plant and ecosystem health would trigger increased measurement and inspection frequency.

We also recommend changing the focus of the vegetation sampling and inspection program to detecting mid- to long-term effects related to Rio Tinto's B.C. Works on terrestrial ecosystems. This could be done by implementing a set of biodiversity plots to detect changes in plant communities, revisiting lichen plots at appropriate intervals to document changes in lichen communities, conducting a triennial inspection to document changes in plant and ecosystem health, and discontinuing sampling and chemical analysis of western hemlock foliage in favor of maintaining a valley passive sampler network and measuring more informative endpoints of vegetation health.

Terrestrial Ecosystems (Soils) Summary

The soils component of the SO_2 EEM Program set out to reduce uncertainty and fill information gaps that were identified in the STAR regarding the regional coverage of soils data, the use of bedrock type to regionalise soil weathering rates, and lack of empirical observations for soil base cations.

There are two KPI for soils: atmospheric sulphur deposition and critical load exceedance, and long-term soil acidification (rate of change of base cations) attributable to sulphur deposition. The first KPI is prediction-based and uses measured soil physical and chemical data from regional surveys to model and map the spatial distribution, magnitude and the level of exceedance of critical loads of acidity for soils. The second KPI is observation-based and uses measured soil chemistry data at two long-term monitoring plots to track changes in soil base cations over time.

Did we exceed a KPI threshold as identified in the 2014 SO_2 EEM Plan?

The thresholds for the two terrestrial KPIs were not reached. The area of critical load exceedance was < 1% and there was no statistical change (decrease) in soil base cations at the two long-term soil plots between 2015 and 2018. Long-term soil plots show no statistically significant decrease in any soil property between 2015 and 2018 in the 0-30 cm depth.

What did we learn during the first six years of the SO_2 EEM Program?

In general, the areal extent of critical load exceedance was similar to that reported in the STAR: areas with exceedance under the 42 tpd scenario were close to the smelter. If exceedance is limited to areas outside the fence line, then areal exceedance drops by 55%. Exceedance is not driven by sensitive soils; it is driven by high modelled sulphur deposition close to the smelter.

Regarding the long-term soil plots, in general, the Minimum Detectable Difference (i.e., the percent change in base saturation that can be detected with high statistical reliability, given the number of samples and the variability in soil properties) is lower for soil base cation concentrations compared with base cation pools. In addition, base cation pools have the added requirement to measure bulk density. Soil base saturation is the only soil property (related to base cations) that provides a reliable detectable difference of 40% in top 0-30 cm of mineral soil.

STAR question S1: Are estimates of average weathering rates by bedrock type valid for vulnerable areas (i.e. where lakes have low base cations)?

STAR question S2: What is the current buffering capacity (base cation pool) of the soils in the exceeded areas, and when would this base cation reservoir be used up?

STAR question S3: What is the rate of soil acidification measured as loss of base cations owing to acidic deposition?

These three questions, identified under the STAR, are no longer relevant as soil weathering rates are now mapped using regression kriging rather than 'averaged by bedrock type' (S1), the current buffering capacity of soils in exceeded areas is only addressed if the KPI for critical loads is exceeded (S2) and long-term soil plots were established to assess changes in soil base cation pools (S3).

Did we make any adjustments to the SO_2 EEM Program during 2013-2018?

No adjustments were made to the SO_2 EEM Program.

What changes do we recommend to the SO_2 EEM Program going forward?

We recommend maintaining both of the KPIs (atmospheric sulphur deposition and critical load exceedance, and long-term soil acidification attributable to sulphur deposition) going forward as they are both well-established and widely used indicators of the impacts from sulphur deposition. We also recommend establishing plant biodiversity plots (a recommendation in the vegetation section) located within the accessible exceeded areas south of the smelter to increase monitoring of the potential effects of sulphur deposition. Further, as noted in the vegetation section, a terrestrial ecosystem line of evidence should be established to integrate the vegetation and soil lines of evidence.

We recommend no changes to the critical loads KPI and suggest that critical loads only be revised if new data or revised critical limits become available; however, exceedance should continue to be routinely estimated for any updated sulphur [and nitrogen] deposition scenarios. To address several uncertainties in the regional assessment of impacts to terrestrial receptors, we recommend that a survey of wetland geochemistry and sulphur storage be carried out, since wetlands make up almost 25% of the exceeded area yet there is no chemical information on

wetlands in the Kitimat valley. We recommend an assessment of aluminium solubility in mineral soils be carried out; aluminium solubility is a key parameter in the determination of critical loads, associated with the critical limit and $ANC_{leaching}$.

For the long-term soil plot KPI, we recommend using a change (decrease) in base saturation (%) to calculate the KPI rather than a change in exchangeable base cation pools, since base saturation was the most sensitive parameter in detecting a change of 40% in exchangeable cations between two sampling periods (accommodating the variability in soil chemistry during both sampling events). We recommend using soil concentrations in the top 0-30 cm of mineral soil rather than pools to assess changes in soil chemistry. We recommend further analysing the minimum detectable difference, to evaluate the potential of an early warning change in soil base saturation using a lower level of significance and/or lower power. We also recommend carrying out the next sampling of long-term plots during 2025 (to return to a 5-year sampling period), and measuring trees (diameter at breast height) at time of soil sampling.

Aquatic Ecosystems (Lakes, Streams and Aquatic Biota) Summary

The STAR predicted that under the maximum post-KMP emissions of 42 tpd, pH would decrease by greater than 0.1 pH units in 7 of the 41 lakes that were sampled and modelled. Five of these lakes with potential significant declines in pH were also predicted to exceed their critical loads under such deposition conditions. The rest of the 34 sampled lakes (including Lakelse Lake) and all the 20 sampled stream sites were predicted to decline by less than 0.1 pH units in response to KMP. The STAR concluded that there would be a moderate impact on aquatic ecosystems (lakes, streams and associated aquatic biota) within the study area post-KMP if emissions reach the maximum permitted amount of 42 tpd. The moderate impact was deemed acceptable but requiring monitoring through the SO_2 EEM Program.

The KPI for aquatic ecosystems is based on the risk of biological effects due to lake acidification, as measured through a decrease in pH. Seven informative indicators provide evidence to support the lake acidification KPI. Some of these are prediction-based, such as the risk of exceeding critical loads which uses measured water chemistry data and measured sulphur deposition data as inputs for updated modelling of critical loads. Others are observation-based, such as the comparison of measured pH in selected lakes with the predicted steady state pH predicted in the SO_2 technical assessment.

Did we exceed a KPI threshold as identified in the 2014 SO_2 EEM Plan?

There have been no exceedances of the KPI thresholds.

What did we learn during the first six years of the SO_2 EEM Program?

We have learned that pH is more highly variable than anticipated. Our expectations were based on literature and data from other regions. We have also learned that it is difficult to measure pH well in lakes with low ionic strength. The low ionic strength means that a long time is needed to get stable readings – longer than factory settings for some instruments or laboratory protocols at some facilities. Not allowing sufficient time for readings to stabilize results in less reliable pH data. Furthermore, even when allowing sufficient time for stabilization (as with the laboratory

measurements that comprise the primary pH data set used in the analyses of the KPI), the measurement error for the different instruments is still high relative to the effect size of interest.

The results of the water quality sampling at the Rio Tinto intake on the Kitimat River showed no exceedances of the B.C. water quality objectives. The maximum measured sulphate concentration was less than 1% of the B.C. Drinking Water Guideline.

STAR question W1: How do assumptions in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post-KMP?

In general, the model results are robust to wide variation in assumptions.

STAR question W2: How many of the 7 to 10 potentially vulnerable lakes actually acidify, and to what extent?

Of the 14 lakes in the SO_2 EEM Program (7 acid-sensitive lakes, 4 less sensitive lakes, 3 control lakes), 12 lakes show no evidence of sulphur-induced acidification causally related to the Kitimat smelter. The sensitive lakes have shown considerably less response to increased emissions than was predicted in the STAR. LAK028, a 1 ha fishless lake close to the Kitimat smelter, shows some evidence of sulphur-induced acidification causally related to the smelter, evidence which also existed prior to the development of the new smelter. The trends in the chemistry of LAK028 show no support for a decline beyond its ANC threshold and low support for decline below the pH threshold. LAK012 (Little End Lake), a 2.3 ha lake to the southwest of Lakelse Lake, has shown increased concentrations of sulphate and some evidence of a decline in ANC, but no evidence of sulphur-induced acidification causally related to the smelter that exceeds the ANC or pH thresholds established in the EEM Plan to protect aquatic biota.

STAR question W3: What is the current status of the fish community in the potentially vulnerable lakes that can be safely accessed for fish sampling?

Four of the seven sensitive lakes, (West Lake (LAK023), End Lake (LAK006), Little End Lake (LAK012), Finlay Lake (LAK044)), were sampled for fish in 2013, and a fifth sensitive lake was sampled in 2017 (LAK028). No fish were caught in Finlay Lake (which has no inlets or outlets) or in LAK028 (which has no inlet and a blocked outlet). Threespine stickleback and coho salmon were present in West Lake, End Lake and Little End Lake. In West Lake the coho were confirmed to remain in freshwater for their entire life cycle, rather than going to sea. End Lake and Little End Lake also had coastal cutthroat trout and dolly varden char.

Three of the less sensitive lakes were sampled in 2015: Clearwater Lake (LAK007), LAK016 and LAK034. They generally had similar fish assemblages and numbers of fish species to the sensitive lakes with fish. Coastal cutthroat trout was common in all three lakes. Other species found included coho salmon and dolly varden char (in LAK007 and LAK016), threespine stickleback (in LAK007 and LAK034), and (in LAK007 only) rainbow trout and Chinook salmon. Altogether, six species were found in LAK007, three in LAK016, and two in LAK034.

STAR question W4: If some of the potentially vulnerable lakes that can be safely accessed for fish sampling show an acidifying trend, then do these lakes also show changes in their fish communities?

None of the lakes have shown an acidifying trend beyond the SO_2 EEM thresholds requiring them to be resampled.

We also learned the answers to a number of additional questions that arose during 2013 to 2018.

How do the observed changes in SO_4, Gran ANC and pH compare to the steady-state predictions from the STAR?

The observed changes in SO_4, Gran ANC and pH have generally been much less than the steady-state predictions from the STAR (adjusted to reflect actual emissions rather than maximum emissions). The only exceptions have been LAK024 (which increased in sulphate more than predicted); LAK028 (which increased in sulphate much more than predicted); LAK007 (a lake with a very high level of Gran ANC that is not sensitive to acidic deposition which decreased in Gran ANC despite a prediction of no change); and LAK034 (which decreased in pH, not associated with smelter emissions) despite a prediction of no change.

Can we estimate F-factors from the empirical sampling results?

We can only estimate an empirically-based F-factor for LAK028, where there was a sufficient change in lake sulphate to permit an estimate of the F-factor. The revised empirically-based estimates of the F-factor are in the range from 0.65 to 0.85, compared to an initial estimate of 0.44 in the STAR, indicating that over the period of the EEM Program approximately 65% to 85% of the deposited acidity associated with sulphur deposition was neutralized by exchanges for base cations in the watershed of LAK028. Thus, LAK028 was able to neutralize a larger fraction of the deposited acidity than had been assumed in the STAR.

Do we see any evidence of regional acidification if we analyze the lakes as a group rather than individuals?

No. There is a spatial pattern to changes in lake sulphate, with lakes closer to the smelter being more likely to show an increase in sulphate, but none of the lakes have acidified beyond the established thresholds for pH and Gran ANC.

Is there a benefit to adding appropriate control lakes to the SO_2 EEM?

Yes. The control lakes provide insights and statistical inferences on natural variability in water chemistry unrelated to the smelter (e.g., year-to-year variation in regional weather patterns and longer term changes in climate), and can be used in statistical analyses to detect changes in the sensitive lakes that differ from the control lakes. The power analysis completed in 2016 demonstrated that inclusion of control lakes increases statistical power. Inclusion of the control lakes also permits statistical analyses using a Before-After-Control-Impact (BACI) design, in addition to Before-After comparisons.

Is there a benefit to more intensive water sampling?

Yes. Intensive water sampling provides a better estimate of within-year variability in water chemistry, allows for a more precise estimate of lake chemistry for the fall period, and provides an additional data set for examining long term trends in pH. It is sufficient to have data from just one intensively monitored lake rather than three.

Is there a benefit to collecting other data on the SO_2 EEM lakes?

Yes. The bathymetric analyses have provided a much more accurate estimate of lake volume and therefore improved our initial estimates of water residence time so we can better understand the temporal lag (or lack of) in lake chemistry responses to changes in deposition levels. The lake

level data have provided information by which to examine the extent to which intra-annual changes in lake chemistry may be associated with hydrologic events. The lake level data provide information specific to the watershed rather than general regional patterns that are represented by weather stations or flow data from major rivers.

Will increased emissions result in immediate (i.e., same year) changes to lake chemistry or will there be a lag?

Reductions in sulphur emissions from the smelter, and therefore decreases in SO_4^{2-} deposition, from 2013 to 2014 resulted in apparent responses of the lakes' chemistry. Most of the sensitive lakes showed increases in both lake pH and lake ANC from 2012 to 2013 and 2013 to 2014. Lake chemistry has not shown a consistent response to the increase in sulphur emissions after 2015, most likely reflecting spatial variation in the path of the plume as well as differences in lake sensitivity to acidification. Improved estimates of water residence time suggest that all seven sensitive lakes should respond within a year or two to changes in watershed inputs.

Did we make any adjustments to the SO_2 EEM Program during 2013-2018?

We made numerous adjustments to the EEM Program, including increasing the frequency of sampling 6 of the 7 sensitive lakes, from once per year in the fall to four times in the fall; adding intensive monitoring of pH to four lakes; adding three control lakes to the annual monitoring program; and sampling various streams downstream from LAK028.

What changes do we recommend to the SO_2 EEM Program going forward?

We recommend that ANC become the primary KPI for the EEM Program, with pH as an informative indicator, since ANC better fulfills the criteria for a KPI. We further recommend that the KPI include two components: a *level of protection* to prevent acidification of lakes that are currently not at risk of aquatic impacts (i.e., an absolute threshold); and a *change limit* (i.e., a relative threshold) which prevents further acidification (for lakes already below the level of protection due to natural organic acids or past acidic deposition).

We recommend that the seven sensitive EEM lakes should continue to be the core of the EEM Program, maintaining the current frequency for sampling full water chemistry (i.e., four samples within the fall index period for the six sensitive lakes that are accessible and one annual sample for LAK022, which is not accessible).

For the EEM less sensitive lakes, we recommend continuing the annual sampling of the full chemistry of LAK016 (which has an intermediate level of sensitivity) and we recommend discontinuing the annual sampling of LAK007 (Clearwater Lake), LAK024 (Lakelse Lake) and LAK034, as the EEM Program has shown these lakes to be insensitive under both *current* and *maximum future* levels of sulphur emissions.

Annual sampling of the full chemistry of the three control lakes should be continued, to provide reliable measures of year-to-year changes in lake chemistry, an assessment of regional factors such as changing weather patterns, and critical data for statistical analyses of changes in sensitive lakes relative to control lakes. We recommend including one year with multiple sampling visits of the three control lakes during October (added to the 2019 October lake sampling), so as to estimate the within-year variability in lake chemistry, and thereby improve statistical inferences.

We recommend that the EEM lakes be re-evaluated in the 2021 Annual Report with respect to their inclusion in the EEM Program going forward. Some of the EEM lakes (which were all identified in the STAR as being potentially sensitive to increased acidic deposition) are now not predicted to acidify under updated modelling based on additional years of data.

We do not recommend adding any additional lakes to the EEM Program. We examined the critical loads and exceedances in the context of the updated CALPUFF deposition modeling for all the original STAR lakes, KAA lakes located within the study area, and additional lakes sampled early in the EEM Program. These analyses did not provide evidence that any of the lakes excluded from EEM Program should be re-considered for inclusion in the program in light of newer information.

We recommend continuing intensive sampling of LAK006 (End Lake) with the new Onset continuous pH monitor, and continuing measurements of lake levels to assess pH changes associated with storm events. Continuous monitoring of LAK012 (Little End Lake) and LAK023 (West Lake) is no longer needed, as these lakes have shown very similar patterns to End Lake and provide no incremental value beyond the intensive monitoring of End Lake.

We recommend a thorough review of the report on Kitimat Valley streams prepared by Paul Weidman once it is released, as one input to discussions on potential next steps in stream monitoring. We recommend discontinuing the monitoring of Anderson Creek, which has not provided useful information to the EEM Program.

If additional fish sampling is required (i.e., additional sampling is triggered by specific conditions in the EEM design), we recommend exploring the use of eDNA sampling to estimate any changes in the presence of fish species and avoiding the potential population impacts of gill-net sampling.

The critical load of a particular lake is an inherent property of the lake based on the geochemical characteristics of its watershed and is not interpreted to be a property that changes over time. With seven years of water chemistry data, we now have greatly improved estimates of the critical loads of the EEM lakes. We have also greatly improved upon the modelling of critical loads that was done in the STAR by conducting extensive sensitivity analyses. The prediction of exceedances does not need to be updated again in the future unless actual or predicted SO_2 emissions are in excess of 42 tpd or if the emissions modelling framework is significantly modified. These two metrics will not be responsive to potential changes in deposition due to smelter operations over the next phase of monitoring and therefore do not satisfy a critical criterion for a good indicator.

We recommend that the SO_2 EEM Annual Report be significantly streamlined where possible. The Annual Report should focus on reporting the new data from the monitoring program and updating critical analyses. The Annual Report should not attempt to make interpretations or inferences with respect to year-to-year changes in water chemistry, but should update statistical evaluations of long term changes between pre-KMP and post-KMP periods. However, the scope of the future annual reports will be determined as part of the collaborative discussion and development of the next phase of the EEM Program with ENV.

Holistic Synthesis

The KPIs in the SO_2 EEM Program were chosen to provide early warning of potential impacts on the receptors, and thus far we see no cause for concern. None of the KPI thresholds have been reached, not even the thresholds for increased monitoring. No prediction-based KPI threshold exceedances are projected even under the 42 tpd scenario. Air concentrations of SO_2 at residential monitoring stations are well below the B.C. Air Quality Objective. The concentrations are also below the CAAQS which will become the B.C. Air Quality Objectives starting in 2020. Air concentrations of SO_2 in the valley are well below concentrations that would cause visible injury to vegetation. Soil plots show no evidence of acidification. One small lake near the smelter shows some evidence of sulphur-induced acidification causally related to the smelter (as it did prior to the construction and operation of the new smelter: it shows only low support for a decline below the pH threshold and no support for decline beyond its ANC threshold. Prediction-based KPIs for soils and lakes are not expected to reach mitigation thresholds even under SO_2 emissions at 42 tpd.

Looking across these lines of evidence we do not see signs of harm in the valley, under present or predicted future conditions. Through all of the analyses, discussions, and results of the comprehensive review we are confident in these conclusions and feel that it is warranted to go forward with a more consolidated, efficient program. We recommend that the next review occur in 2026.

SO_2 EEM KPI Report Card for 2013-2018

		Atmospheric Pathways	Human Health	Vegetation	Terrestrial Ecosystems (Soils)	Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)
Performance	KPI(s) below threshold for increased monitoring?	Not applicable	Not applicable	**Yes**	**Yes**	**Yes**
	KPI(s) below threshold for receptor-based mitigation?	Not applicable	Not applicable	**Yes**	**Yes**	**Yes**
	KPI(s) below threshold for facility-based mitigation?	Not applicable	**Yes**	**Yes**	**Yes**	**Yes**
Recommended Changes	Do we recommend changes to the KPI(s)?	Not applicable	**No**	**Yes**	**No**	**Yes**
	Do we recommend changes in how to calculate the KPI(s)?	Not applicable	**No**	**Yes**	**Yes/No***	**Yes**
	Do we recommend other changes to the SO_2 EEM Program?	**Yes**	**No**	**Yes**	**Yes**	**Yes**

* 'Yes' for the soil acidification KPI, 'No' for the critical loads KPI

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Glossary

acid deposition	Transfer of acids and acidifying compounds from the atmosphere to terrestrial and aquatic environments via rain, snow, sleet, hail, cloud droplets, particles, and gas exchange
acidification	The decrease of acid neutralizing capacity in water, or base saturation in soil, by natural or anthropogenic processes
acid neutralizing capacity	The equivalent capacity of a solution to neutralize strong acids; ANC and alkalinity are often used interchangeably; ANC includes alkalinity plus additional buffering from dissociated organic acids and other compounds
anion	An ion with more electrons than protons, giving it a negative charge, e.g., SO_4^{2-}
base cations	An alkali or alkaline earth metal (Ca^{2+}, Mg^{2+}, K^+, Na^+)
base cation exchange	The replacement of hydrogen ions in the soil water by base cations from soil particles
critical load	A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur, according to present knowledge
dissolved organic carbon	Organic carbon that is dissolved or unfilterable in a water sample (0.45 µm pore size in the National Surface Water Survey)
dry deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via gravitational settling of large particles and turbulent transfer of trace gases and small particles
environmental effects	Impacts on receptors from SO_2 emissions from the modernized smelter
facility-based mitigation	Sulphur dioxide (SO_2) emission reduction at B.C. Works
F-factor	A simple way to represent cation exchange processes, specifically the proportion of incoming acidity accompanying sulphate that is exchanged in the soil for base cations
Gran ANC	The capacity of a solution to neutralize strong acids, determined by titration to the inflection point of the pH-alkalinity titration curve
informative indicator	Indicators that will provide supporting information for key performance indicators, and may have quantitative thresholds triggering additional monitoring or modelling, but on their own will not trigger mitigation
key performance indicator	An indicator that have quantitative thresholds triggering additional monitoring or modelling, receptor-based mitigation, and/or facility-based mitigation

liming	The addition of any base materials to neutralize surface water or sediment or to increase acid neutralizing capacity
pH	A measure of how acidic or basic a solution is, on a scale of 0-14; the lower the pH value, the more acidic the solution; pH 7 is neutral; a difference of 1 pH unit indicates a tenfold change in hydrogen ion activity
pre-KMP	The period of the VSS smelter operations
post-KMP	The period from 2016 forward
receptors	Components of the environment assessed for potential impacts from SO_2 emissions from the modernized smelter: human health; vegetation; soils; and lakes, streams and aquatic biota
receptor-based mitigation	Receptor-specific actions to reduce exposure or effects, such as air quality advisories in local communities or liming of selected lakes
residential stations:	Air quality monitoring stations in the residential areas of Kitimat and Kitamaat Village, which are currently the Riverlodge, Whitesail and Kitamaat village stations
wet deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via precipitation (e.g., rain, snow, sleet, hail, and cloud droplets)
percentile	A statistical measure for the value below which a given percentage of observations fall within a data set

Abbreviations, Acronyms and Symbols

Δ	delta, meaning quantitative change (e.g. ΔANC or ΔSO_2)
<	is less than what follows
≤	is less than or equal to what follows
>	is greater than what follows
≥	is greater than or equal to what follows
[ ]	the concentration, e.g., $[SO_2]$ means the concentration of SO_2
AERMOD	AMS/EPA Regulatory Model Improvement Committee (AERMIC) working group Model; a dispersion model for predicting air pollutant concentrations from industrial sources
AERSCREEN	The screening version of AERMOD that predicts 1-hour air pollutant concentrations from a single source
Al	Aluminium
ANC	Acid neutralizing capacity
ANC_{limit}	Acid neutralizing capacity limit
ANC_{OAA}	Organic anion adjusted acid neutralizing capacity

AQO	Air quality objective
BACI	Before-after-control-impact
Bc	Base cations
BC	Base cations that include calcium, potassium, magnesium and sodium
B.C.	British Columbia
Bcu	Base cation uptake
BSe	Effective base saturation; the percentage of effective CEC made up of base cations
BCS	Base cation surplus
C	Ambient air concentration of a substance
Ca^{2+}	Calcium ion
CAAQS	Canadian Ambient Air Quality Standards
CALMET	Meteorological model that generates hourly three-dimensional meteorological fields
CALPOST	Post-processor model for CALPUFF that computes pollutant concentration and deposition
CALPUFF	California Puff model that simulates non-steady state transport, dispersion, and chemical transformation of air pollutants emitted from a source in "puffs"
CBANC	charge balance ANC
CCME	Canadian Council of the Ministers of the Environment
CDC	Conservation Data Centre
CEC	Cation exchange capacity
CECe	Effective cation exchange capacity
Cl^-	Chloride ion
CL	Critical load
CV	Coefficient of variation
D1HM	Maximum 1-hour average SO_2 concentration measured in a 24-hour calendar day
DBH	Diameter at breast height
DFO	Fisheries and Oceans Canada (formerly Canadian Department of Fisheries and Oceans)
DOC	Dissolved organic carbon
EEM	SO_2 environmental effects monitoring
ENV	British Columbia Ministry of Environment and Climate Change Strategy
F	Fluoride
F_{dry}	Dry deposition flux
F_s	Sulphur concentration ratio
H^+	Hydrogen ion
HF	Hydrogen fluoride
IAQO	Interim Air Quality Objective
K^+	Potassium ion
KAEEA	Kitimat Airshed Emissions Effects Assessment

K_{gibb}	Gibbsite equilibrium constant
KMP	Kitimat Modernization Project
KPAC	Kitimat Public Advisory Committee
KPI	Key performance indicator
LFH	Deep Organic Soil Layer
LOAEC	Lowest Observed Adverse Effect Concentration
LOI	Loss-on-ignition
MCT	Measure of central tendency
MDD	Minimum detectable difference
Mg^{2+}	Magnesium ion
MOD	Magnitude of difference
MW	Molecular weight
N	Nitrogen
Na^{+}	Sodium ion
NA	Not applicable
NAD	North American Datum
NADP	National Atmospheric Deposition Program
NaOH	Sodium hydroxide
N_{exp}	Number of exposures
NO_2	Nitrogen dioxide
O_3	Ozone
NO_3^-	Nitrate ion
ppb	Parts per billion
pSO_4^{2-}	Particulate sulphate
QA/QC	Quality assurance / quality control
QPs	Qualified professionals (for the SO_2 EEM Program)
Q-Q plot	Quantile-quantile plot
R^2	Coefficient of determination
RfC	Reference concentration
S	Sulphur (as in sulphur deposition)
SO_2	Sulphur dioxide
SO_4^{2-}	Sulphate ion
SO_2 EEM	Rio Tinto B.C. Works' SO_2 Environmental Effects Monitoring Program
SPR	Source-pathway-receptor (conceptual model)
SSWC	Steady State Water Chemistry (model)
STAR	SO_2 Technical Assessment Report (for KMP)
TOR	Terms of reference for the SO_2 EEM 2019 Comprehensive Review
tpd	Tonnes per day
UTM	Universal Transverse Mercator
V_d	Deposition velocity of a substance

VSS	Vertical stud Söderberg Smelter
WGS 84	World Geodetic System (1984)
WRF	Weather Research and Forecasting

List of Measurement Units

$eq/m^3/a$	equivalents per cubic metre per annum (year)
g/m^3	grams per cubic metre
ha	hectares
km	kilometre
kg/h	kilograms per hectare
keq/ha/yr	kiloequivalents per hectare per year
kg/ha/yr	kilograms per hectare per year (units of deposition flux)
kg S/ha/yr	kilograms sulphur per hectare per year
kg SO_4^{2-}/ha/yr	kilograms sulphate per hectare per year
L min^{-1}	litres per minute
m	metres
mm	millimetres
m/s	metres per second
m^3/s	cubic metres per second
mg/L	milligrams per litre
Mg/d	mega grammes per day, equivalent to metric tonnes per day
mg/m^3	milligrams per cubic metre
$meq/m^2/yr$	milliequivalents per square metre per year
ng/g	nanograms per gram
ng/m^3	nanograms per cubic metre
ppb	parts per billion
ppm	parts per million
tpd	tonnes per day
t/month	tonnes per month
t/yr	tonnes per year
$t/km^2/yr$	tonnes per square kilometer per year
µeq/L	microequivalents per litre
$µg/m^3$	micrograms per cubic metre (conversion: 1ppb = 2.614 $µg/m^3$ SO_2)
µm	micrometres (µ can also be shown as u)

1 Introduction

1.1 Background

Rio Tinto operates an aluminium smelter that is currently the only major source of SO_2 emissions in the Kitimat Valley. During 2015 and early 2016, the Kitimat Modernization Project (KMP) replaced the 60-year old vertical stud Söderberg smelter (VSS) with a state-of-the-art AP-40 pre-bake smelting technology.

In 2012 and 2013, we conducted a technical assessment for the KMP to determine the potential impacts of sulphur dioxide (SO_2) emissions from the modernized smelter along four lines of evidence: effects on human health, effects on vegetation, effects in terrestrial ecosystems (soils), and effects on aquatic ecosystems (lakes and streams, and aquatic biota). We used the CALPUFF modelling system to estimate atmospheric concentrations of SO_2 and to estimate sulphur deposition from the modernized smelter. These estimates were then used in the analyses for the four lines of evidence. We documented the assessment methods and results in the SO_2 Technical Assessment Report (STAR; ESSA et al. 2013).

An SO_2 Environmental Effects Monitoring (EEM) Program was then developed to answer questions that arose during the technical assessment, and to monitor effects of SO_2 along these lines of evidence. Results from the SO_2 EEM Program inform decisions regarding the need for changes to the scale or intensity of monitoring, as well as decisions regarding the need for mitigation. The Program Plan for 2013-2018 (ESSA et al. 2014a, provided in Appendix 1.1) describes the monitoring and modelling activities that were planned out for the first six years of the SO_2 EEM Program.

The SO_2 technical assessment and SO_2 EEM Program were structured according to the source-pathway-receptor (SPR) conceptual model shown in Figure 1-1. The numbered arrows in the diagram represent the pathways of potential effect that were considered in the technical assessment, and the shading represents the lines of evidence in the SO_2 EEM Program.

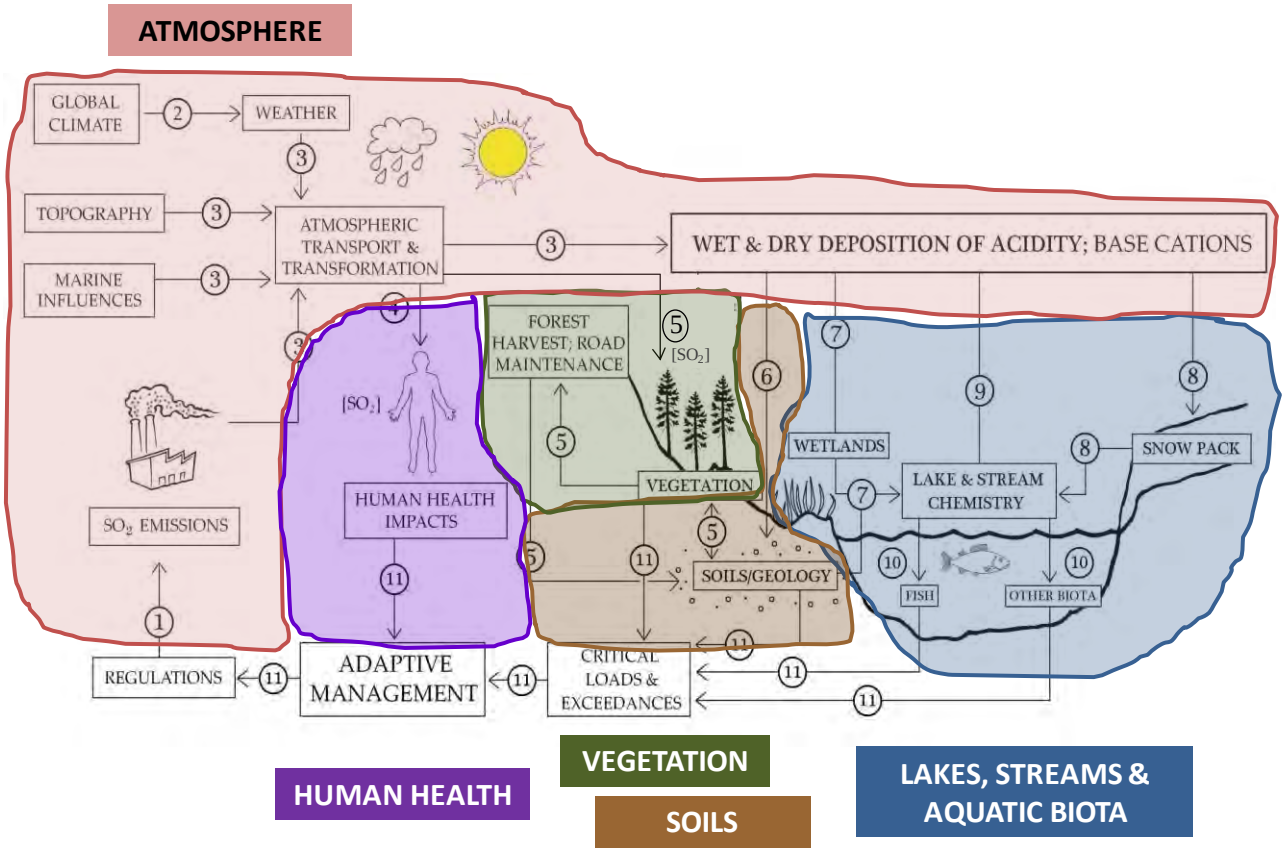


Figure 1-1. SO_2 Source-Pathway-Receptor conceptual model for the SO_2 EEM Program.

The SO_2 EEM Program follows a three-phase decision framework, presented in Figure 2 of the SO_2 EEM Program Plan for 2013-2018, and reproduced here in Figure 1-2. The first phase occurred in 2012-2013 and included the SO_2 Technical Assessment to predict whether there would be significant adverse human health and environmental effects from SO_2 emissions from the modernized smelter, and development of the SO_2 EEM Program. The second phase involved the implementation of the first six years of the SO_2 EEM Program, from 2013 to 2018. This phase spanned the final years of the 60-year old VSS smelter operations, the KMP period of ramping down production and transitioning the technology, and the period of ramping production back up with the modernized smelter. The third phase began in 2019 by reviewing results for the first six years, examining what we have learned from the first phase, and identifying new questions that have emerged. These results will inform the design of the SO_2 EEM Program for the next six years, which could include modifications to some Key Performance Indicators (KPIs), modifications to how they are monitored, and potentially reductions in the set of KPIs, or reductions in monitoring intensity for some KPIs.

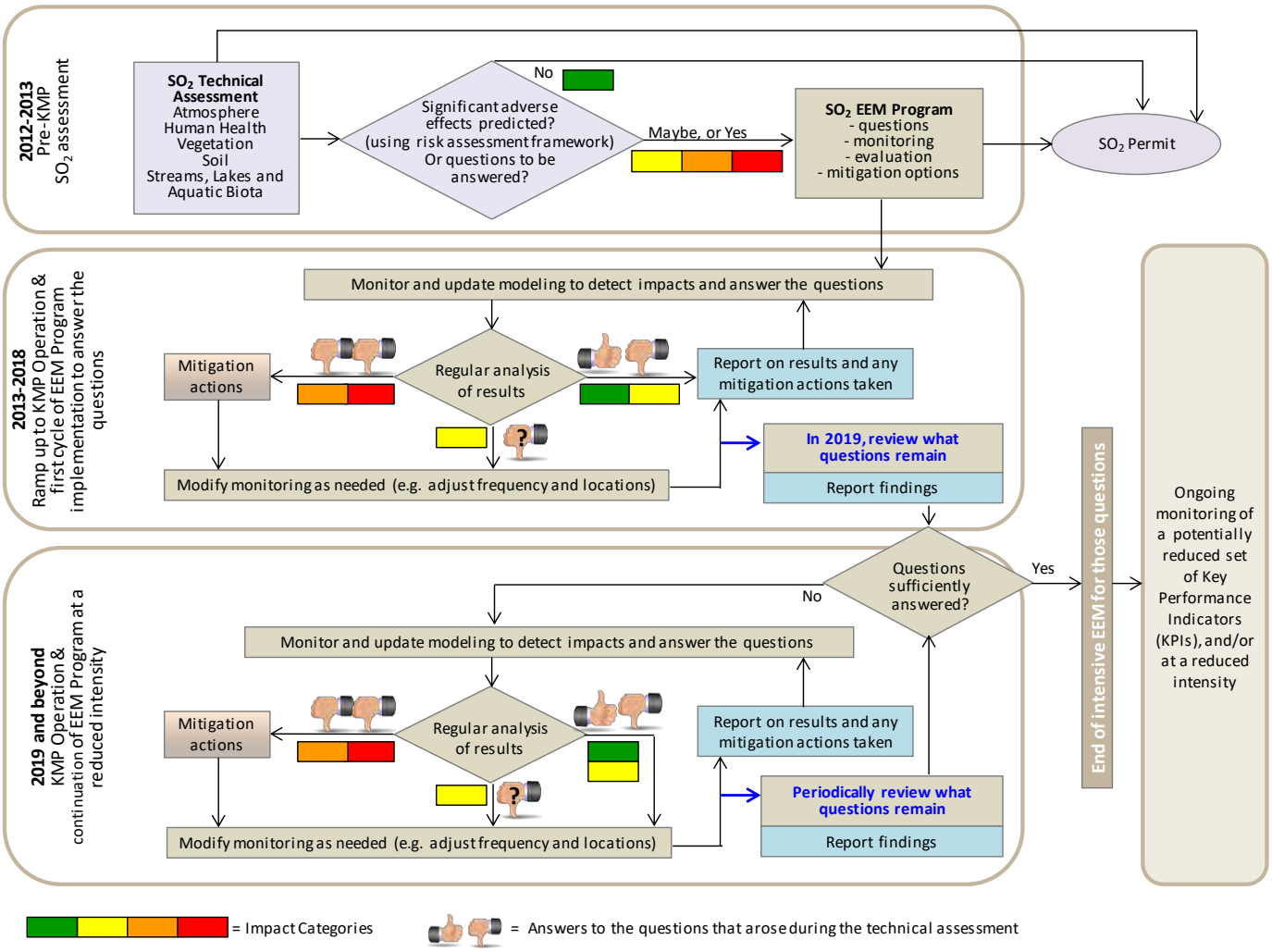


Figure 1-2. SO_2 EEM Framework for KMP.

1.2 Purpose and Scope of the Comprehensive Review

The SO_2 EEM Program calls for a comprehensive review in 2019 to examine results from the first six years, and preparation of a report that:

- Summarizes what has been learned, and what questions have been answered,
- Describes which, if any, of the KPI thresholds have been reached, and if so, what actions were taken,
- Describes any modifications to KPIs, methods, or thresholds that have been made based on annual results to date, and why,
- Looks across the data sets of the four lines of evidence to develop a holistic understanding of KMP SO_2 effects on the environment and human health,
- Recommends changes if/as needed to: the suite of KPIs to be continued post-2018, their measurement methods, and/or their thresholds – along with the rationale for these recommended changes, and
- Recommends a date for the next comprehensive review.

The purpose of this report is to present the methods, results and recommendations of the comprehensive review. The terms of reference (TOR) for the comprehensive review are provided in Appendix 1.2.)

For the comprehensive review, we modelled three SO_2 emission scenarios: actual emissions from the smelter during 2016 to 2018, which averaged to just under 30 tpd, a 42 tpd scenario representing the highest level of SO_2 emissions allowed under the permit, and a 35 tpd scenario representing SO_2 emissions of a magnitude midway between actuals and the maximum allowable. Further explanation about these scenarios is provided in Section 3.

The study area for the comprehensive review is shown in Figure 1-3. The figure shows two study area boundaries. The area within the light grey dashed line is the study area we used for the STAR. The area within the black dashed line is the study area we used for the comprehensive review. We have expanded the study area from that used in the STAR because S deposition under the highest emission scenario extended beyond the southwest boundary used in the STAR. This is explained further in Section 3.

Recommendations in this report are specific to the contents of the 2013-2018 SO_2 EEM Plan and will inform revisions to the next plan for SO_2 EEM Program post-2019. This report does not explore new indicators for the program going forward. Discussions of these and other potential adjustments to the program will occur during the development of the next SO_2 EEM Plan in 2020.



Figure 1-3. Map of the study area for the comprehensive review

1.3 Facility Production and Emissions from 2013 to 2018

Annual hot metal production from the Kitimat aluminium smelter is shown in Figure 1-4, and annual SO_2 emissions from the smelter are shown in Figure 1-5. Metal production from the smelter was low in 2013, 2014, and 2015 in preparation for the transition to the modernized smelter. The transition to AP-40 technology occurred in 2015 and the first quarter of 2016. Smelter stabilization took another 24 months. During the stabilization period, emissions of SO_2 increased from the 8.3 tpd rate in 2015 to 30.6 tpd in 2016.

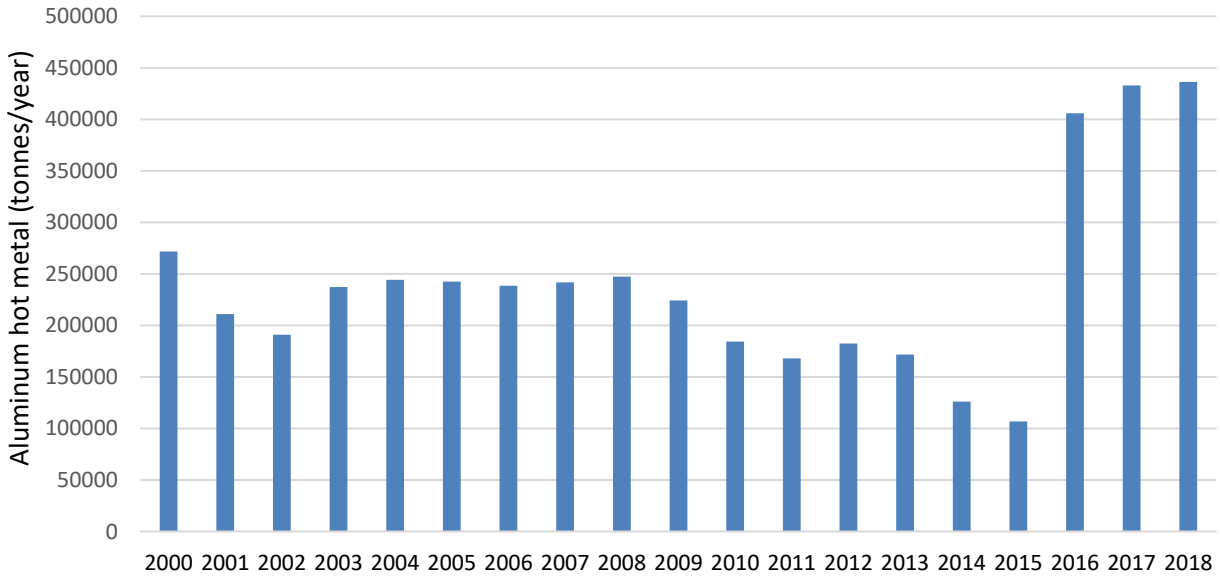


Figure 1-4. Annual hot metal production from the Kitimat smelter from 2000 to 2018. (Source: Rio Tinto)

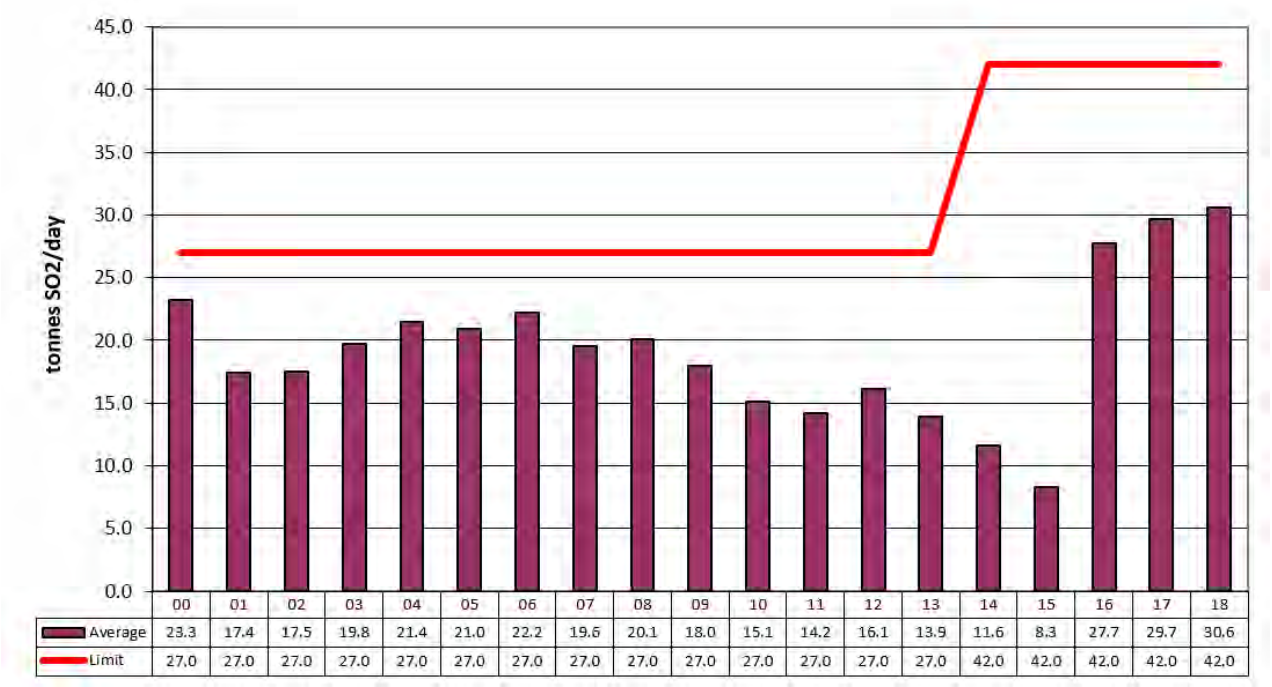


Figure 1-5. Annual SO_2 emissions from the Kitimat smelter for 2000-2018. (Source: Rio Tinto)

Post-KMP SO_2 emissions have varied over the 2016 to 2018 period of the SO_2 EEM Program. Emissions increased over that period as the smelter ramps up to the mid-term forecasted emission range of 33 to 35 tpd. Between 2016 and 2018, annual average emissions increased by 2.9 tpd. In 2016, emissions increased in the first quarter as the smelter was being commissioned. The last pot started at the end of March 2016.

Emissions fluctuate from month-to-month dependent on the sulphur content of green coke, imported calcined coke, and recycled carbon that are used to form the carbon anodes for the Al smelting process. Emissions will decrease twice per year due to the routine maintenance shutdowns of the coke calciner. During the typical 10 to 15 day shutdown periods, emissions from the coke calcining operation will cease. The tpd minimum, maximum, and range are provided in Table 1-1.

Table 1-1. Post-KMP SO_2 Emissions. (Source: Rio Tinto)

Year	Average tpd	Standard Deviation tpd	Minimum tpd	Maximum tpd	Range tpd
2016	27.7	2.4	22.2	31.4	9.2
2017	29.7	2.1	25.5	32.9	7.3
2018	30.6	3.1	25.3	36.2	10.9

1.4 Organization of this Report

This report is organized by the lines of evidence shown in Figure 1-6, which is a simplified version of the SPR model. Comprehensive review results for atmospheric pathways are provided in Section 3. Results for human health are provided in Section 4, results for vegetation are provided in Section 5, results for terrestrial ecosystems (soils) are provided in Section 6 and results for aquatic ecosystems (lakes, streams and aquatic biota) are provided in Section 7. Section 8 provides a holistic synthesis of what we have learned thus far in the SO_2 EEM Program across the lines of evidence.

Technical details underlying the analyses and results in this report are provided in a separate document (SO_2 EEM Comprehensive Review Report Volume 3: Technical Appendices). A summary report (Volume 1) is also available for a higher-level overview of the results of the comprehensive review.

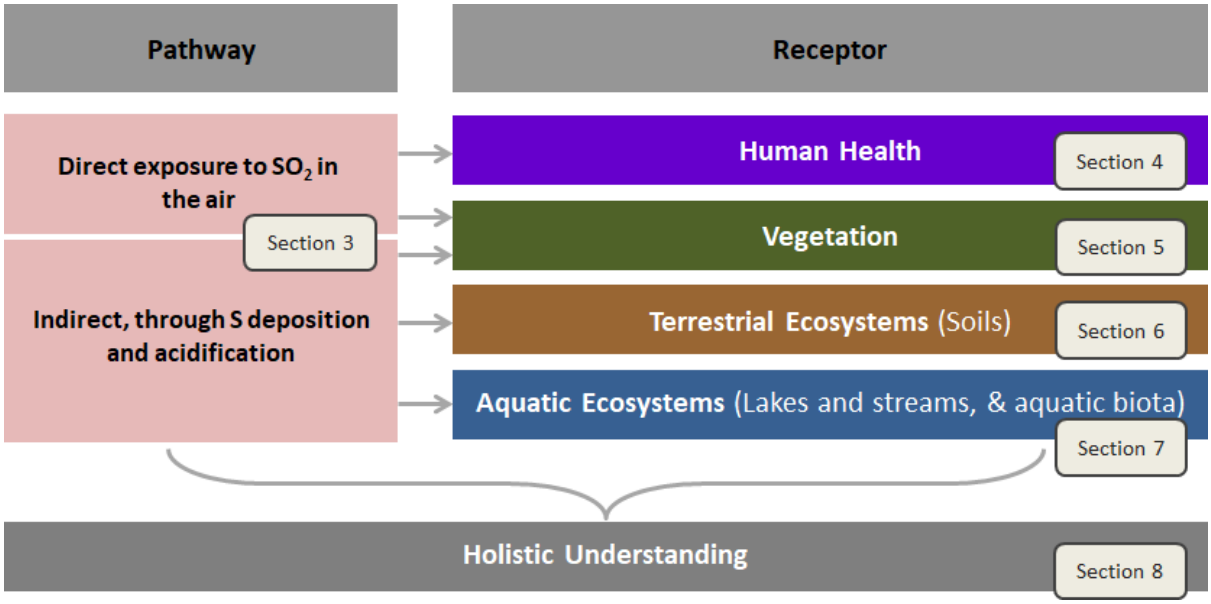


Figure 1-6. Framework for the organization of this report.

2 Evaluation of KPIs against Thresholds, Informative Indicators, & Synthesis of Results

This section provides a summary of comprehensive review results with a focus on KPI performance against thresholds, recommendations for KPIs and informative indicators going forward, learning under the STAR questions, and new questions to consider. Details for atmospheric pathways and the four receptors are provided in Sections 3 through 0, and a holistic synthesis across lines of evidence is provided in Section 8.

Table 2-1 summarizes whether KPIs where reached and whether any responses were needed, which KPIs or informative indicators were modified during the implementation of the 2013-2018 SO_2 EEM Plan, and our recommendations for modifying KPIs or informative indicators for the next phase of the SO_2 EEM Program. While still at a summary level, the table expands on the information conveyed in the KPI Report Card provided in the Executive Summary.

None of the thresholds for any of the KPIs were reached, therefore no responses (either increased monitoring or mitigation) were needed. Atmospheric SO_2 concentrations and atmospheric S deposition were informative indicators analysed under the Atmospheric Pathways component of the program. Measured concentrations of SO_2 were substantially lower than model predictions of post-KMP SO_2 concentrations from the STAR at most locations, and near model predictions at Haul Road. When considering that the model results do not include background deposition, the new CALPUFF model over-estimates actual deposition rates at Haul Road by 24% to 29%, and predicts actual deposition at Lakelse Lake from 16% under-estimation to 47% over-estimation (3-year average comparison of observed to modelled without background and to modelled with maximum background).

The only KPI modification we made during the first six years of the SO_2 EEM Program was for the human health component. When the STAR was prepared in 2013, the Province of British Columbia (B.C.) did not have an Air Quality Objective for sulphur dioxide that was based on recent human health evidence. Since then, the Province of British Columbia adopted an Interim Air Quality Objective (IAQO) and we modified the SO_2 EEM Program to apply the IAQO as a KPI. Starting in 2020, the IAQO value will be replaced with the CAAQS value of 70 ppb, and will be lowered to 65 ppb in 2025. During the development of the terms of reference for the comprehensive review, it was determined that the informative indicator for human health was no longer necessary for the SO_2 EEM Program or the comprehensive review.

We added a new informative indicator to the atmospheric pathways: contribution of dry deposition to total deposition. This indicator is not used to assess impacts due to sulphur deposition, but provides valuable information to understand the factors that could lead to variation in deposition rates. We also added three control lakes to the aquatic ecosystems (lakes, streams and aquatic biota) receptor.

We have several recommendations for modifying KPIs and informative indicators, and modifying the methods for monitoring and calculating them. For the atmospheric pathways component of the program, we recommend minimal changes to the continuous monitoring, and a review of the number and location of passive samplers that were deployed during the first six years of the program. For the deposition monitoring program, we recommend continuing the Lakelse Lake monitoring and considering discontinuing the Haul Road wet deposition monitor.

We recommend establishing a terrestrial ecosystem line of evidence to integrate the vegetation and soils lines of evidence, developing a KPI based on soil chemistry, and developing measures of plant health and biodiversity. We recommend monitoring these new indicators at appropriate locations including areas where critical loads (CLs) for soils or lakes are predicted to be exceeded under the 42 tpd emission scenario. For long-term soil plots, we recommend using % base saturation to calculate the KPI, focusing detection of change on the 0-30 cm soil layer, and returning to a 5-year sampling period.

For aquatic ecosystems (lakes, streams and aquatic biota), we recommend changing the KPI to ANC (acid neutralizing capacity), and using pH as an informative indicator. We also recommend discontinuing annual sampling of LAK007 (Clearwater Lake), LAK024 (Lakelse Lake) and LAK034, and we also believe that continuous monitoring of LAK012 (Little End Lake) and LAK023 (West Lake) is no longer needed. A complete list of recommendations for the next phase of the SO_2 EEM Program is provided in Section 9.

The SO_2 EEM Program also set out to reduce a number of critical uncertainties that were identified in the STAR and reiterated in Appendix A of the 2014 EEM Plan (provided in Appendix 1.1 of this comprehensive review). Four of these uncertainties are no longer relevant and the rest are answered in summary form in Table 2-2 with further details provided in the subsequent sections of this report. The table also lists several new uncertainties that have arisen, which should be considered during the design of the EEM Program going forward.

Table 2-1. Summary of results pertaining to KPIs or informative indicators.

	Atmospheric Pathways	Human Health	Vegetation	Terrestrial Ecosystems (Soils)	Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)
KPI	Not applicable (NA)	British Columbia (B.C.) Air Quality Objective measured at residential air monitoring stations	Visible injury to vegetation caused by SO_2	Critical load (CL) exceedance risk Long-term soil acidification	Water chemistry - acidification
Informative indicators	• SO_2 concentrations • S deposition • Base cation deposition	None	• S content in hemlock needles	• Magnitude of exchangeable cation pools • Time to depletion of exchangeable cation pools • Base cation weathering rates	• Atmospheric CL exceedance risk • Predicted steady stage pH vs current pH • Estimates of natural variability in pH and other indicators • Evidence that pH decrease is causally related to KMP • Aquatic biota • Episodic pH change • Amphibians
Were any KPI thresholds reached? If so, what was the response?	NA	There is only one threshold, for facility-based mitigation, and this threshold has not been reached.	None of the thresholds for the vegetation KPI have been reached.	None of the thresholds for the two KPIs for terrestrial ecosystems have been reached.	None of the KPI thresholds for aquatic ecosystems have been reached.
Were any KPIs or informative indicators modified? Are any modifications recommended to KPIs, informative	No modifications were made to the three informative indicators. We added a new informative indicator: contribution of dry deposition to total deposition, to help us	An IAQO was adopted as the KPI in December 2016, and annual calculation of the KPI began in 2017. The informative indicator of 'predicted annual number of	No modifications were made to the KPI or the informative indicator. We recommend that a terrestrial ecosystems line of evidence be established to integrate	No modifications were made to the KPI or the informative indicators. For long-term soil plots, we recommend using %base saturation to calculate the KPI which can detect a change <	No modifications were made to the KPI or the informative indicators. We recommend that ANC be the primary KPI, and that pH be an informative indicator.

	Atmospheric Pathways	Human Health	Vegetation	Terrestrial Ecosystems (Soils)	Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)
indicators that support KPIs, or the methods for monitoring and calculating them?	understand the factors that could lead to variation in deposition rates. No modifications were made to the informative indicator methods. We recommend continuing the continuous SO_2 monitoring with minimal changes, and reviewing the passive sampling Valley Network frequency and locations with a focus on increased number of passive samplers in east-west transects and (if possible) to the south of the smelter. We also recommend considering discontinuing the Haul Road wet deposition monitoring.	SO_2-associated respiratory responses' was removed from the program. Starting in 2020 the IAQO value for the KPI will be replaced by the CAAQS value of 70 ppb and will change to 65 ppb starting in 2025.	the vegetation and soils lines of evidence. We recommend informative indicators of changes in plant biodiversity and plant health due to emissions to support a terrestrial Ecosystems KPI that will be based on soil chemistry.	40% from baseline and focusing detection of change on the 0-30 cm layer (weighted). We recommend carrying out the next sampling of long-term plots during 2025 (to return to a 5-year sampling period). We recommend that a terrestrial ecosystems line of evidence be established to integrate the vegetation and soils lines of evidence.	We added 3 control lakes to the program. We recommend discontinuing the annual sampling of LAK007 (Clearwater Lake), LAK024 (Lakelse Lake) and LAK034. Continuous monitoring of LAK012 (Little End Lake) and LAK023 (West Lake) is also no longer needed.

Table 2-2. Summary of what questions from the SO_2 EEM Program have been answered thus far under, and whether any questions remain to be answered or new questions to be addressed under the next SO_2 EEM Plan.

	STAR questions the 2014 SO_2 EEM Program intended to answer	New questions for the SO_2 EEM Program
Atmospheric Pathways	*A1. Does CALPUFF accurately represent post-KMP SO_2 air concentrations?* Measured SO_2 concentrations were substantially lower than model predictions of post-KMP SO_2 concentrations from the STAR at most locations. *D1. Does CALPUFF accurately predict post-KMP total S deposition?* Overall, the new CALPUFF model predictions of total sulphur deposition compare well to the monitored results. *D2. What are base cation deposition values in the study region?* Following correction for sea salts, magnesium (Mg^{2+}) and sodium (Na^{+}) were zero. Long-term calcium (Ca^{2+}) and potassium (K^{+}) in precipitation were almost equal at Lakelse Lake and Port Edward. Precipitation concentrations at Haul Road were 1.5 (K^{+}) to >2 (Ca^{2+}) times larger than at the other two sites, and we assume that precipitation chemistry at Haul Road was influenced by anthropogenic sources. Average base cation concentration in precipitation was estimated as 0.8 µeq/L.	*What is the spatial extent of SO_2 concentrations and S deposition in the Kitimat Valley?*
Human Health	*HH1. How conservative is the CALPUFF model in predictions of SO_2 levels?* This is answered under question A1; however, the ability of CALPUFF to adequately represent residential SO_2 concentrations *is no longer applicable* for the human health component of the SO_2 EEM Program, as the KPI for human health is calculated using measured SO_2 concentrations at residential monitoring stations *HH2. What is the peak-to-mean relationship for shorter duration exposures?* The modelling approach employed in the human health analysis in the STAR is no longer being applied in the EEM Program or in this comprehensive review.	None
Vegetation	*V1. Are we looking for vegetation injury in the right places?* The array of sampling and inspection sites provided coverage of areas both inside and outside the path of the plume and area of deposition. Some areas could not be sampled safely. *V2. How healthy is vegetation in sites with predicted exceedance of critical loads of soil and/or lakes and streams south of Lakelse Lake?* No significant differences in plant heath throughout the Kitimat Valley have been observed post-KMP.	*What methods should be used to detect mid- to long-term indirect effects?*

	STAR questions the 2014 SO_2 EEM Program intended to answer	New questions for the SO_2 EEM Program
	V3. Are plants of public importance showing symptoms in areas with the highest exceedances of soil critical loads? No symptoms associated with emissions from the modernized smelter were observed. *V4. Do plants at Kitimat have unknown sensitivity to SO_2 and associated pollutants fall within the range of variation in the literature?* Plants in the Kitimat Valley appear to be within the range of sensitivities reported in the scientific literature. Given the low ambient concentrations of SO_2, injury would not be expected to occur, and it did not.	
Terrestrial Ecosystems (Soils)	*S1. Are estimates of average weathering rates by bedrock type valid for vulnerable areas?* This question is no longer relevant as soil weathering rates are now mapped using regression kriging rather than 'averaged by bedrock type. *S2. What is the current buffering capacity (base cation pool) of soils in the exceeded areas, and when would this reservoir be used up?* This question is no longer relevant as the current buffering capacity of soils in exceeded areas is only addressed if the KPI for critical loads is exceeded. *S3. What is the rate of soil acidification measured as loss of base cations owing to acidic deposition?* This question is no longer relevant as long-term soil plots were established to assess changes in soil base cation pools.	*What is the Al solubility in upland soils?* *How sensitive are wetlands to acidification?* *Is there evidence of acidification and associated impacts in exceeded areas?*
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)	*W1. How do assumptions in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post-KMP?* In general, the model results are robust to wide variation in assumptions. *W2. How many of the 7 to 10 potentially vulnerable lakes identified in the SO_2 technical assessment actually acidify, and to what extent?* Of the 14 lakes in the SO_2 EEM program (7 acid-sensitive lakes, 4 less sensitive lakes, 3 control lakes), 12 lakes show no evidence of sulphur-induced acidification causally related to the Kitimat smelter. LAK028 and LAK012 show some evidence of reductions in ANC or pH, but not exceeding the thresholds for these parameters that were established in the EEM Plan to protect aquatic biota.	*Has there been a statistically significant change in dissolved organic carbon (DOC) and organic anions over time?* *What is the within-year variability of the chemistry of the control lakes?* *How do the 3 metrics of ANC (i.e. Gran ANC, ANC_{OAA} and base cation surplus (BCS)) compare over time?*

	STAR questions the 2014 SO_2 EEM Program intended to answer	New questions for the SO_2 EEM Program
	W3. What species, age classes, and size of fish are present in the potentially vulnerable lakes that can be safely accessed for fish sampling? Across the six accessible lakes with fish, we found a total of six fish species: coho salmon, cutthroat trout, threespine stickleback, dolly varden char, rainbow trout and Chinook salmon. Two lakes (LAK028 and LAK 044) had no fish. *W4. If some of the potentially vulnerable lakes that can be safely accessed for fish sampling show an acidifying trend, then do these lakes also show changes in their fish communities?* None of the lakes have shown an acidifying trend beyond the SO_2 EEM thresholds requiring them to be resampled.	

3 Review Results for Atmospheric Pathways

3.1 Atmospheric Concentrations

3.1.1 What did we set out to learn?

The STAR identified an uncertainty within the atmospheric pathway, framed as a question to be addressed through the EEM program:

- STAR question A1: *Does the CALPUFF model accurately predict post-KMP SO_2 air concentrations?*

The CALPUFF dispersion model used in the STAR predicted post-KMP SO_2 concentrations and total sulphur deposition throughout the Kitimat Valley. These atmospheric SO_2 and total sulphur deposition predictions were used to complete receptor-specific effects assessments along the four lines of evidence. In this comprehensive review, we set out to learn how accurate the STAR model predictions were and to understand the base cation deposition levels in the study region. We also set out to develop more accurate model predictions of current and future post-KMP atmospheric SO_2 and total sulphur deposition using a new CALPUFF model analysis. The new CALPUFF results are used to complete updated receptor-specific effects assessments to vegetation, and terrestrial and aquatic ecosystems.

In addition, the new CALPUFF model, in combination with the 2012-2018 atmospheric monitoring data, provides information to understand the spatial and temporal variability of post-KMP SO_2 concentrations and total sulphur deposition.

3.1.1.1 *EEM informative indicators*

The atmospheric pathway has one atmospheric concentration informative indicator: *atmospheric SO_2 concentrations*. The atmospheric deposition informative indicators are discussed in Section 3.2.1.1. We use the SO_2 atmospheric concentrations to assess the risk of direct impacts on human health and vegetation in Section 4 and Section 5, respectively. Measured SO_2 atmospheric concentrations are used to assess the risk of health impacts; modelled and measured SO_2 concentrations are used to evaluate the risk of direct injury to vegetation. Since the effects from SO_2 concentrations on receptors are assessed in receptor-specific evaluations, there are no KPIs for atmospheric concentrations.

The measured SO_2 concentrations are an important informative indicator because the continuous SO_2 analyzers provide real-time, accurate, and reliable direct measurements, which can be directly tied to the smelter's current SO_2 emissions. In contrast, human health and vegetation effects are difficult to measure in real time and infeasible to measure on a continuous basis. The continuous SO_2 analyzers also provide hourly and sub-hourly data that can be used to understand how concentrations change over time and how 1-hour or 5-minute peak concentrations relate to long-term average concentrations (see Section 4.3.2 for a discussion of 5-minute peak versus 1-hour concentrations and Atmospheric Appendix Section 3.1.2 for 1-hour average versus 30-day average concentrations). The continuous SO_2 analyzer data combined with the passive sampling data also provide valuable information to understand the spatial distribution of the plume, including:

- the extent of the plume (how far away from the smelter elevated SO_2 concentrations occur),
- the position of the plume (in which direction elevated concentrations occur, i.e., north-northeast and south-southwest versus east or west); and
- the concentration gradient or relative concentration distribution (how high concentrations are at the highest levels close to the smelter versus at mid-point and lower concentrations)

The SO_2 concentration measurements also provide key information about the accuracy of the STAR model used for the STAR SO_2 effects assessments and to make decisions when developing the EEM. Learning whether the STAR over-predicted or under-predicted concentrations at various locations provides important information about whether the STAR SO_2 effects assessments over-predicted or under-predicted risk of impacts on receptors. Understanding the model accuracy at various locations (i.e., whether the model accurately predicted the extent and position of the plume) also provides valuable information about the design of the EEM program related to the locations selected for monitoring. Measured SO_2 concentrations are also used in the comprehensive review to evaluate the performance of the new CALPUFF model simulations, which in turn indicate the level of accuracy of the updated effects assessments that use the new CALPUFF model output.

3.1.2 What methods did we use?

This comprehensive review uses both monitoring data and the new CALPUFF model output of atmospheric SO_2 concentrations and sulphur deposition. The new CALPUFF model uses 2016–2018 meteorological data and includes three emissions scenarios: actual 2016–2018 (average 29.3 tpd), 35 tpd, and 42 tpd emissions.

- Actual emissions model results are compared to monitored data in order to evaluate model performance.
- 42 tpd model results are used to assess effects on vegetation, terrestrial and aquatic ecosystems under the permitted levels (maximum future SO_2 emission scenario).
- 35 tpd model results are included at the request of ENV[3] to assess a level midway between actual levels and maximum permitted levels.

The primary purpose of the new model analysis is to provide updated predictions of SO_2 concentrations and total sulphur deposition rates throughout the Kitimat Valley. These updated SO_2 and sulphur deposition predictions are then used for updating assessments of risk of impacts to vegetation, and terrestrial and aquatic ecosystems. We used the continuous SO_2 monitoring information directly to assess impacts to vegetation and human health and indirectly to evaluate the performance of the updated CALPUFF model. The passive SO_2 monitoring information was used to: (a) assess spatial and temporal changes, and (b) evaluate modelled concentration fields. Particulate sulphate (pSO_4^{2-}) was measured using a two-stage filter pack to assess its extent throughout the Kitimat Valley.

[3] During development of the comprehensive review report TOR for aquatic ecosystems, ENV requested a 35 tpd scenario. Members of the KPAC also expressed interest in a 35 tpd scenario.

3.1.2.1 *Data we collected: monitoring methods*

Atmospheric SO_2 concentrations were measured at four continuous SO_2 analyzers at Haul Road, Riverlodge, Whitesail, and Kitamaat Village. In addition, a fifth SO_2 monitoring location was added to the continuous SO_2 monitoring network at Lakelse Lake in 2018 to estimate dry deposition (Figure 3-1). While the measurements are continuous, the data are available on the British Columbia (B.C.) Air Data Archive webpage as 1-hour average concentrations.[4] ENV validates all data in this archive on an annual basis, with the previous year's data validated by June 30 of each year. The four complete 2018 datasets from the Kitimat area stations listed above were validated by ENV prior to using the data for the comprehensive review analyses. The Lakelse Lake data set is used for sulphur deposition and is not currently part of ENV's quality assurance program (i.e., ENV conducts audits on all monitors within their quality assurance program in addition to validating the data annually). In addition, the 2018 Lakelse Lake data set is not complete. Therefore, the SO_2 data from Lakelse Lake are not used in the comprehensive review analysis. Atmospheric Appendix Section 3.1.1 includes further details on the continuous monitoring network and equipment.

In addition to the primary SO_2 monitoring using the continuous analyzers, Rio Tinto established two other atmospheric monitoring networks: SO_2 passive sampling and pSO_4^{2-} monitoring using filter packs. The SO_2 passive sampler network began with a pilot program at three stations in 2015 (Technical Memo P03, 2016), and expanding to 16 sites throughout the Kitimat Valley in 2016 through 2018 (Technical Memo P04, 2017; Technical Memo P05, 2018). The SO_2 passive sampling program includes two networks:

- The Valley Network included 16 monitoring sites primarily located along the Wedeene and Bish roads (Figure 3-1) to capture the plume path.
- The second network was established in urban and residential areas of Kitimat to support the 'multi-seasonal air quality' and the 'air quality network optimization' studies. During 2016, the urban network included 17 sites but expanded to 22 sites during 2018 (Figure 3-1).

The passive sampler networks employed IVL passive SO_2 samplers (URL: diffusivesampling.ivl.se) with an exposure period of one month (see Technical Memo P03, 2016). In general, both networks operated between June and October, providing four one-month exposures. However, the urban network was extended to year-round sampling in 2018. Duplicate samplers were deployed ~25% of the time at varying locations (to assess variation in measurements). To evaluate the performance of the passive samplers, the networks also included co-location with four ambient stations (Haul Road, Riverlodge, Whitesail and Lakelse Lake[5]). Following deployment, all samplers were returned to IVL for laboratory analysis.

Further, SO_2 and pSO_4^{2-} were measured using a two-stage filter pack during several discrete campaigns throughout the Kitimat Valley in 2017–2018 (Rio Tinto Voluntary). These observations are used to assess what fraction of atmospheric sulphur is in the form of pSO_4^{2-} in

[4] https://envistaweb.env.gov.bc.ca/
[5] ENV is not currently validating Lakelse Lake SO_2 data. ENV will validate data if/when there is a data sharing agreement and if the analyzer is part of ENV's quality assurance program (including conducting audits).

the region. The two-stage filter pack network was established to monitor SO_2 and pSO_4^{2-} at several discrete locations (n = 9) during four campaigns throughout the Kitimat Valley (Figure 3-1). The two-stage filter holders were developed by the Norwegian Institute for Air Research (URL: www.innovation.nilu.no). The first stage holds a 47 mm Teflon (PTFE) filter to capture particulates, and the second stage holds a 47 mm cellulose filter impregnated with potassium hydroxide to capture SO_2. (see Technical Memo F01, 2018). The holder is connected to a diaphragm pump with a recommend flow rate of 15 L min^{-1} for daily sampling. Exposures ranged in duration from 24 to 48 hours (depending on the pump volume). All filter pack analysis was carried out at Trent University.

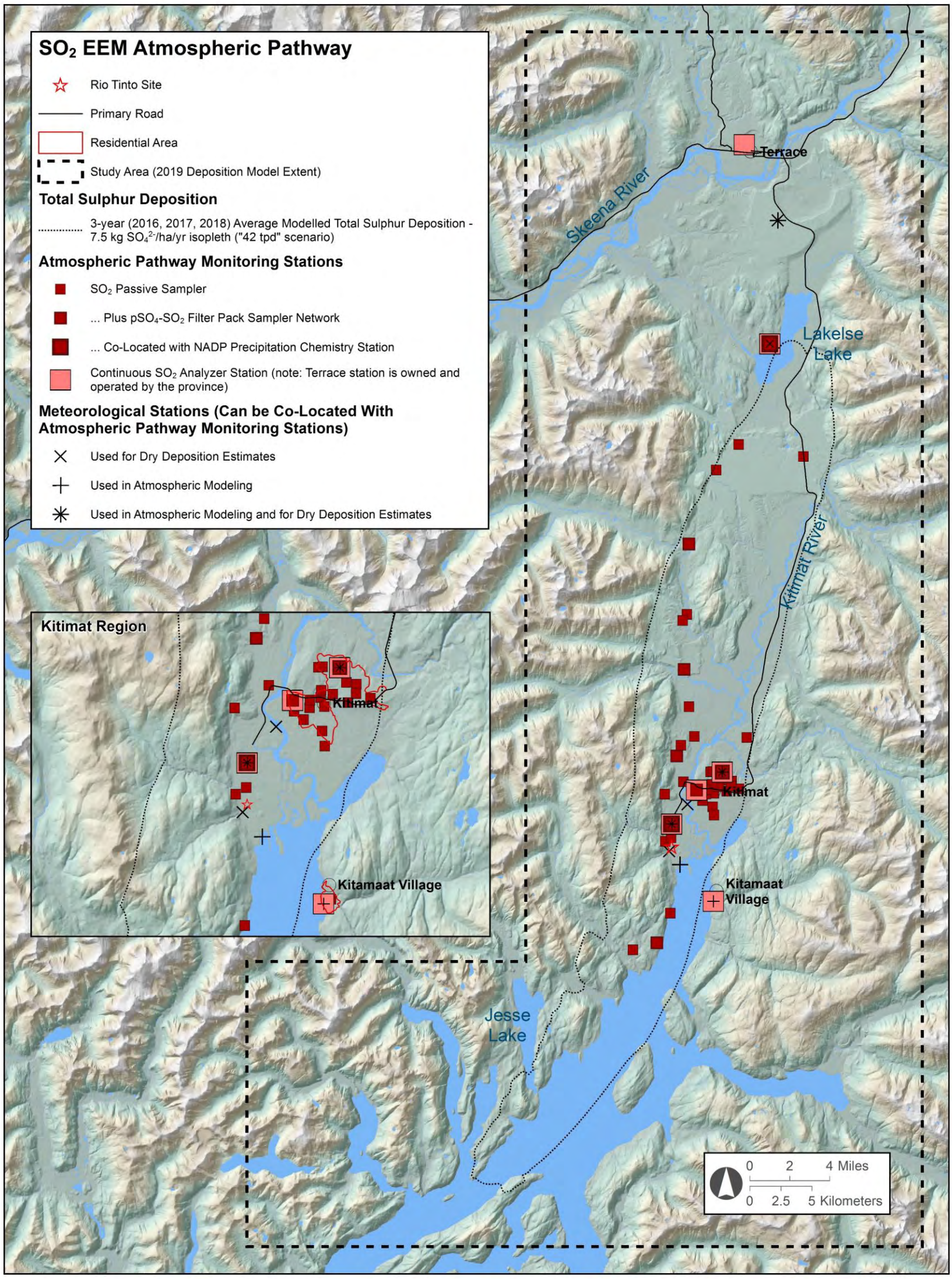


Figure 3-1. Locations of atmospheric SO_2 concentration and sulphur deposition monitoring for the SO_2 EEM Program. The location of meteorological stations is also shown.

3.1.2.2 *Atmospheric concentrations monitoring data analysis methods*

This section describes the methods used to analyze the atmospheric concentration monitoring data. Section 3.2.2 describes the monitoring data analysis of atmospheric deposition, including comparison of measured S deposition to modelled S deposition (results in Section 3.2.3.4).

SO_2 continuous monitor data analysis methods

As part of the EEM annual reporting, each year we compared the continuous analyzer measurements to modelled SO_2 air concentrations from the STAR for the 1-hour, 3-hour, 24-hour, and annual averaging periods, consistent with the objectives relevant during the STAR. As part of the comprehensive review, SO_2 continuous monitor data are used for model performance evaluation (see Section 3.1.3.5).

Multi-seasonal air quality study methods

We began development of a multi-seasonal air quality study on the seasonal and spatial variability of SO_2 concentrations in the residential areas of Kitimat. The study has been cancelled, but we plan to use the year-round data from the passive samplers deployed in the Urban Network (up to October 31, 2019) for the Kitimat air quality monitoring network optimization.

Air quality network optimization methods

Rio Tinto committed to evaluating the air monitoring network as part of the EEM program because KMP has changed the emissions profile from the smelter, which affects the spatial distribution of SO_2 ambient concentrations. Following U.S. EPA guidance,[6] Trinity analyzed the results from air dispersion modelling of the 42 tpd maximum permitted SO_2 emissions scenario (same source input as used for the STAR) using the 2006, 2008, and 2009 meteorological data similar to the data used for the STAR and post-KMP SO_2 monitoring data (Phase 1 network optimization[7]). The results of the Phase 1 analysis showed that the Riverlodge monitor is in a suitable location to represent the highest concentrations expected within the Kitimat residential area; that Whitesail monitor location does not provide added benefit for measuring the maximum SO_2 air concentrations within Kitimat; and that the Kitamaat Village monitor is in the most suitable location within Kitamaat Village.

Phase 2 of the air quality network optimization is planned to start in the second quarter of 2020, using the new 2016 to 2018 modelling results and incorporating the latest data from SO_2 concentration monitoring. In 2015, a draft TOR for the air quality monitoring network optimization was provided to ENV and other stakeholders for review and comment. Comments were received and discussed in January through June 2016, including at the June 2016 Air Quality workshop. The 2016 Air Quality Workshop provided detailed information to the Kitimat Public Advisory Committee (KPAC) on the continuous monitoring network, monitoring data, optimization process, and passive sampling program. As a key outcome of the workshop and public feedback received, the Urban Passive Sampler Network was established. Both Phase 1 and

[6] U.S. EPA technical assistance document for "source-oriented monitoring" for SO_2 available at: https://www.epa.gov/sites/production/files/2016-06/documents/so2monitoringtad.pdf
[7] Trinity Consultants. Air Quality Network Evaluation. April 2019.

Phase 2 network optimization efforts use the passive sampling data to better understand spatial patterns within urban and residential Kitimat.

Rio Tinto submitted a revised version of the TOR addressing the comments received and focused on Phase 2 of the optimization in April 2019. The TOR proposes using zoning maps[8] to define the study area rather than census data because the Kitimat residential network should represent any locations where people may reside now or in the near future. The zoning maps provide the best information to define current and future residential areas. In 2020, Rio Tinto will submit a revised version of the TOR submitted in April 2019 to reflect the most up to date status of the available monitoring and modelling data.

In addition to residential areas, the Kitimat SO_2 air quality monitoring network also represents commercial areas in Kitimat (e.g., City Centre Mall). However, the existing monitors may or may not sufficiently represent the Service Centre commercial area. Passive sampling data indicate that 30-day average concentrations in summer months are higher in the Service Centre area than measured at the nearby Riverlodge monitoring station. The new CALPUFF model predicts annual 1-hour concentrations are higher in the Service Centre than at Riverlodge. However, because of the uncertainty inherent in the CALPUFF model and the inconsistent relationship between 30-day average and 1-hour peaks, the available information is not sufficient to provide clear conclusions whether the peak 1-hour actual concentrations are higher in the Service Centre area than measured at the nearby Riverlodge monitoring station. As such, we may consider new continuous SO_2 monitoring in the Service Centre.

Monitoring data analysis that focuses on the Phase 2 network optimization will begin in 2020. Preliminary analysis of the local-scale CALPUFF results focused on the network evaluation has been completed as part of the comprehensive review. The preliminary model results are analyzed following the methods detailed in the draft TOR and similar to those outlined in the Phase 1 report (both in Atmospheric Appendix Section 3.1.9). The procedure follows the U.S. EPA guidance for the SO_2 national ambient air quality standard source oriented monitoring.[9] Equal weight is given to highest concentrations over the three model years (in the form of the standard) and frequency (locations that would most frequently measure the highest concentration in a given day versus other modelled locations). Following the guidance, the approach also excludes locations that cannot be accessed due to terrain or other impediments prior to the data analysis. A summary of the preliminary network optimization CALPUFF results are presented in Section 3.1.3.7 of this report. Details of the preliminary Phase 2 monitoring network evaluation (methods and results) are included in Atmospheric Appendix 3.1.3, and a copy of the Phase 1 network rationalization and draft Phase 2 network optimization TOR reports are included in Atmospheric Appendix 3.1.9.

[8] Kitimat Townsite Zoning Map and District of Kitimat Zoning Map, https://www.kitimat.ca/en/business-and-development/resources/Documents/Townsite-Zoning-Map.pdf, https://www.kitimat.ca/en/business-and-development/resources/Documents/District-of-Kitimat-Zoning-Map.pdf. Downloaded April 2019.
[9] Ibid.

SO_2 passive sampler data analysis methods

The SO_2 passive sampler results were used to evaluate the spatial and temporal changes in Kitimat Valley, and to evaluate CALPUFF modelled concentration data (under the actual emissions scenario).

The performance of the passive samplers was evaluated through duplicate exposures to estimate the variability (as percent difference) between samplers. Further, individual monthly passive sampler exposures were compared to average continuous SO_2 data (for the same period) at co-located sites: Haul Road and Smeltersite (2015 only) for the valley network, and Riverlodge and Whitesail for the urban network (2016 to 2018 only). The best-fit linear regression between passive samplers and continuous analyzers was used to calibrate the passive sampler data.

Individual exposures were summarised to produce annual Spring–Autumn (June–October) and long-term (2016–2018) averages (weighted by exposure period)[10] for each site. All data were adjusted (calibrated) to account for deviations between the passive and continuous SO_2 data. The spatial variation in SO_2 passive samplers in the Kitimat Valley was evaluated through spatial mapping of the three-year average concentrations and evaluation of the change in concentrations with distance from the smelter. The temporal variability between annual Spring–Autumn (June–October) averages was evaluated through coefficient of variation (also known as relative standard deviation), which was estimated as the standard deviation between the three years divided by the annual Spring–Autumn average (multiplied by 100 for units of percent). The three-year average SO_2 passive sampler concentrations for the Valley Network sites were compared against modelled (actual emissions scenario) SO_2 data summarised for the identical period to evaluate the performance of CALPUFF. We also evaluated if passive samplers could be scaled from Spring–Autumn (June–October) to annual values using the ratio (for the same period) observed at continuous stations; however, the approach was not used as we focused only on monitoring stations with full year continuous SO_2 data to estimate annual total deposition values (see Section 3.2).

We evaluated continuous SO_2 monitoring data at the 4 stations to assess if a peak-to-mean ratio (1-hour peak to 30-day average) can be established for use with the SO_2 passive sampler results. The analysis concluded that the 1-hour peak to 30-day average ratio is inconsistent and highly variable and should not be used to draw conclusions about 1-hour peak concentrations based on 30-day average passive sampling data. Details of the methodology and results are included in Atmospheric Appendix Section 3.1.2.

Filter pack monitoring data analysis of particulate sulphate methods

Filter pack results of pSO_4^{2-} and SO_2 collected under four campaigns during 2017–2018 were analysed first to evaluate the performance of filter pack SO_2 measurements by comparison to continuous station SO_2 (for all co-exposures). Second, the contribution (importance) of pSO_4^{2-} to

[10] The annual Spring–Autumn and long-term average concentrations were weighted by the exposure period (hours) for each individual sampler, i.e.,

$$\bar{x} = \frac{w_1 x_1 + w_2 x_2 + \cdots + w_n x_n}{w_1 + w_2 + \cdots + w_n}$$

where x is the individual exposure concentration and w is the exposure period duration.

total atmospheric sulphur was assessed using the pSO_4^{2-} to SO_2 plus pSO_4^{2-} ratio (F_s expressed as percent). We also evaluated whether this ratio may be used as a means to estimate pSO_4^{2-} from observations of SO_2. The sulphur concentration ratio (F_s) was calculated following Grosjean and Friedlander (1975):

$$F_s = \frac{[pSO_4^{2-}]}{[SO_2] + [pSO_4^{2-}]} \times 100$$

where [pSO_4^{2-}] is the sea-salt corrected particulate sulphate concentration, expressed as S (µg/m³), and [SO_2] is the average gaseous SO_2 concentration expressed as S (µg/m³). The measured F_s ratios were compared to the modelled F_s ratios to evaluate model performance. It should be noted that the measured F_s represent a small number of daily observations (max = 20) compared with modelled F_s based on annual data. Further, the modelled F_s do not include 'background' atmospheric sulphur contributions.

3.1.2.3 *Data we collected: modelling methods*

We performed CALPUFF modelling for three scenarios: actual emissions (varying by month), 35 tpd, and 42 tpd (permitted rate). As part of this analysis, we gathered SO_2 emission rate information from the smelter (using sulphur mass balance) to accurately estimate monthly average SO_2 emission rates from each emission source (electrolysis gas treatment centre and potline roof vents, anode baking furnace, fume treatment centre, and calciner). This same actual emissions dataset was used to update the 35 tpd and 42 tpd scenario to more accurately model the distribution of the SO_2 emissions among the sources at the smelter. In addition, we collected as-built source and building information for the new model analysis. Atmospheric Appendix Section 3.1.5 provides the monthly SO_2 emission rates and source parameters, and Section 1.3 describes the historic SO_2 emission rates from the smelter.

Data sets collected from local meteorological stations were also used in the CALPUFF model analysis. Complete details of all data inputs to the CALPUFF model system are included in Atmospheric Appendix Section 3.1.5 and 3.1.9.

3.1.2.4 *CALPUFF modelling analysis methods*

We conducted 2016–2018 CALPUFF modelling following a detailed model plan and B.C. Air Quality Dispersion Modelling Guideline (B.C. Ministry of Environment and Climate Change Strategy 2015), submitted to ENV May 13, 2019 and approved May 31, 2019. The model plan and approval are included in Atmospheric Appendix Section 3.1.9.

About dispersion models methods

Dispersion models serve as a tool to predict or estimate ambient air concentrations and deposition rates due to industrial or other anthropogenic sources of emissions. Dispersion models are most commonly used to predict air concentrations from industrial sources that have not yet been constructed. Predictions available from dispersion models allow stakeholders to gain an understanding of the changes to ambient air due to emissions changes from a project *before* the project begins operation. Most applications of source-oriented dispersion models compare modelled air concentrations or deposition rates to screening thresholds, air quality objectives, or air quality standards. It is rare to use these model outputs as inputs to other models.

Dispersion models are designed to be conservative, because their most common purpose is to provide a worst case estimate of air quality after a project to ensure the project will not result in violations of air quality requirements or detrimental impacts to human health or the environment. Typical levels of conservatism range from 50 percent over-prediction, up to over-predicting by a factor of four (400 percent over-prediction) when using maximum (permitted) emission rates. When model evaluations are performed using hourly actual emission rates and other methods to minimize reducible uncertainty, model accuracy is typically within about a factor of two (i.e., models often estimate between 50% and 200% of monitored concentrations).[11] The uncommon use of air dispersion model output as inputs to additional models (e.g., critical load models) causes uncertainties in each model to compound. The most commonly used dispersion models for predicting air pollutant concentrations from industrial sources are AERSCREEN, AERMOD, and CALPUFF.

About the CALPUFF dispersion model

While the CALPUFF model is more complex and technically challenging than its relatives, it offers several advantages. The modelling analysis presented in this report applies the CALPUFF dispersion model for a number of reasons, including the need to:

- determine long-range impacts (AERSCREEN and AERMOD are not recommended for distances over 50 kilometres);
- represent complex terrain conditions in the Kitimat area (AERMOD assumes winds do not change direction across the entire domain for each time step, while AERSCREEN does not consider wind direction at all);
- represent the influence of the land/sea boundary (e.g., land-sea breeze circulation and onshore fumigation); and
- represent calm wind conditions (AERMOD ignores hours with "calm" winds).

The CALPUFF model is a useful tool to inform decisions and generally errs on the conservative side.

The main components of the CALPUFF modelling system are the CALMET, CALPUFF, and CALPOST models. CALMET is the meteorological model that generates hourly three-dimensional meteorological fields such as wind and temperature. CALPUFF simulates the non-steady state transport, dispersion, and chemical transformation of air pollutants emitted from a source in "puffs". CALPUFF calculates hourly concentrations of specified pollutants at specified receptors in a modelling domain. CALPOST is the post-processor for CALPUFF that computes concentration and deposition from emissions sources based on the pollutant concentrations and deposition that are output by CALPUFF.

CALPUFF dispersion modelling methods summary methods

For the new 2016–2018 CALPUFF model analysis, we used model methods consistent with the methodologies used for the STAR dated April 2013, with the exception of some key changes:

[11] U.S. Environmental Protection Agency. Guideline on Air Quality Models (40 CFR 51, Appendix W): *The "irreducible" uncertainty associated with Gaussian plume models may be responsible for variation in concentrations of as much as +/- 50 percent. "Reducible" uncertainties can be on a similar scale.*

- As-built source and building parameters are used, including flow and temperature based on actual source test data where available.
- Meteorological years 2016–2018 are used.
- The regional-scale analysis used meteorological data processed using Weather Research and Forecasting (WRF)[12] data developed by Trinity rather than fifth-generation mesoscale regional weather model used in the STAR.
    - The CALMET model was run in the hybrid mode with WRF and local observation data consistent with the STAR approach. Note this approach is different from the CALMET method proposed in the original model plan. The hybrid approach yields improved model performance as detailed in a technical memorandum to ENV, included in Atmospheric Appendix Section 3.1.9.
- The initial domain for this meteorological data is nearly identical to the domain used in the STAR protocol but extended south 24 km to include better coverage of the final STAR receptor grid, which was also extended south.
    - The domain was expanded to the southwest as further described in the section below.
- The local-scale analysis uses meteorological data processed using only surface station data (also known as Obs-Only mode).
    - That is, the local scale analysis does not use WRF for gridded input.
    - However, a pseudo upper air station from WRF output is used to represent the upper air data because no upper air data are available within the Kitimat Valley. The location of the pseudo upper station is from the WRF grid cell closest to the Terrace Airport. This location is different from the location proposed in the original model plan (initially proposed the WRF cell closest to the gas treatment centre stacks). Using the new pseudo upper air station location yields improved model performance as detailed in a technical memorandum to ENV, included in Atmospheric Appendix Section 3.1.9.
- The UTM coordinate system, WGS 84 ellipsoid is used as opposed to the UTM NAD 27 used in the STAR approach, which will allow Qualified Professionals (QPs), ENV, and the public to better understand model inputs and outputs using readily available tools such as Google Earth.
- Hourly precipitation data are obtained from the Haul Road and Lakelse Lake wet deposition stations.
- SO_2 concentrations measured at the Terrace Skeena Middle School station, representing SO_2 background, are added to model results to predict total ambient SO_2 concentrations for effect assessments.
    - 1-hour, 99th percentile daily peak SO_2 for 2016, 2017 and 2018: 4.6, 5.9 and 6.1 ppb respectively, are added to each corresponding year for the actual emission scenario. 3-year average results and future scenarios use the average of three years: 5.53 ppb.
    - Annual average SO_2 for 2016, 2017 and 2018: 0.5, 0.5, and 0.4 ppb respectively, are added to each corresponding year for the actual emission scenario. 3-year average results and future scenarios use the average of three years: 0.47 ppb.

[12] WRF is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications (https://www.mmm.ucar.edu/weather-research-and-forecasting-model).

    - This approach of adding background concentrations based on Terrace monitoring is expected to over-predict SO_2 concentrations in non-populated areas because emissions of SO_2 from non-modelled sources (such as diesel burning engines) are much lower in non-populated areas. This approach would also double count any smelter emissions contributing to SO_2 at the Terrace monitor (however, smelter contribution of SO_2 at Terrace is expected to be very low).
- For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data: Based on 2017 and 2018 data, the Williams Lake background concentrations are:
    - 1-hour, 99th percentile daily peak SO_2: 1.8 ppb; and
    - Annual average SO_2: 0.26 ppb.

The regional-scale model S deposition outputs serve as input for CL modelling for terrestrial and aquatic ecosystems. The regional-scale model SO_2 concentration outputs (considered in conjunction with other information including measured SO_2) are used to evaluate the risk of direct injury to vegetation. The local-scale model results are used for the local monitoring network evaluation.

We evaluated model performance by comparing the actual scenario results to SO_2 monitoring data. This included comparing hourly data at the continuous monitoring stations and monthly data at the passive sampling sites. The primary purpose of the comparison to SO_2 passive sampling is to evaluate the spatial SO_2 gradient produced by CALPUFF to verify that it aligns with observations.

The initial model runs (actual scenario) following the original model plan resulted in an unexpected spatial distribution of the concentrations and deposition rates. The initial results did not align with expectations based on terrain and monitoring data. Therefore, we evaluated model improvement options, proposed updates to the model plan to ENV, and compared initial and updated CALPUFF results for the actual scenario to observations. The change made to the regional scale model was to run the regional CALMET model in the hybrid mode, rather than no-observations mode as originally proposed. The change made to the local scale-model was to use a different location to extract WRF data for the pseudo upper air station. Both these changes reduced the influence of WRF data and increased the influence of local observation data near the smelter. Both changes resulted in clear improvement in model performance (i.e., model concentrations align more closely with observations when using the updated methods). Copies of the model evaluation and proposed model plan updates provided to ENV and associated ENV approval are provided in Atmospheric Appendix Section 3.1.9.

Regional CALPUFF domain: All cases of industrial air emissions begin with relative high air concentrations at the point of release (e.g., at the top of the stack). Meteorological and terrain influences cause the emissions to disperse as the plume travels downwind. At some point downwind, ground level concentrations reach a dispersion level so dilute that concentrations are below levels of interest. The emissions from the smelter disperse to a level equivalent to half of the CAAQS (< 2.5 ppb on annual averaging period and < 35 for the 1-hour averaging period) approximately 30 km to the north and approximately 15 km to the southwest. The model domain proposed in the detail model plan adequately captures this level. The level of interest for total sulphur deposition is 7.5 kg SO_4^{2-}/ha/yr. The proposed model domain in the detail model plan did not include all areas with predicted deposition equal to or above 7.5 kg SO_4^{2-}/ha/yr. Therefore, the domain was extended to the southwest as shown in Figure 1-3.

3.1.3 What did we learn, and did we make any adjustments to the EEM Program?

3.1.3.1 *Overview of EEM monitoring program results – continuous SO_2 network*

The continuous SO_2 network provided valuable information to answer STAR question A1 (answered in the following sub-section) and to understand the overall spatial and temporal trends in the Kitimat area. The four monitoring locations provide limited spatial variability information but do confirm that the residential areas of Kitimat and Kitamaat Village continue to experience generally low concentrations of SO_2, while the area near the fenceline to the north of the smelter (represented by the Haul Road monitor) remains higher than residential areas. The passive SO_2 network results discussed in the next Section 3.1.3.2 provide more information on spatial variability. As presented in Figure 3-2 and Figure 3-3, the temporal trends of the continuous SO_2 monthly average data indicate the Haul Road (fenceline) concentrations have generally increased with increasing SO_2 emissions from the smelter, while SO_2 concentrations in residential areas do not show a noticeable trend of higher monthly SO_2 concentrations associated with the higher SO_2 emissions.. In particular, the charts show residential concentrations are similar or lower during the 2016 – 2018 post-KMP period than during the 2013 to 2015 period with lower SO_2 emissions. In contrast, the highest Haul Road monthly SO_2 concentrations in 2013 – 2015 are approximately 3 ppb and increase to 8 ppb during post-KMP. This difference may be influenced by residential areas being influenced more by meteorological conditions than at the Haul Road station. Figure 3-3 shows only the residential SO_2 monitoring data alongside the SO_2 emission rate data to see the changes (or lack thereof) more clearly for these relatively low concentrations.

- Riverlodge recorded the highest monthly average of 1.0 ppb in August 2013 (during low SO_2 emissions) compared to 0.80 ppb in July 2017.
- Kitamaat Village recorded the highest monthly average of 0.60 ppb and 0.56 ppb in August 2013 (during low SO_2 emissions) compared to 0.67 ppb in February 2016 (and below 0.5 ppb for all other 2016 – 2018 months).
- The Whitesail monitor was not operational for most of 2013 – 2015; however, it generally shows trends of relatively low post-KMP concentrations consistent with Riverlodge.

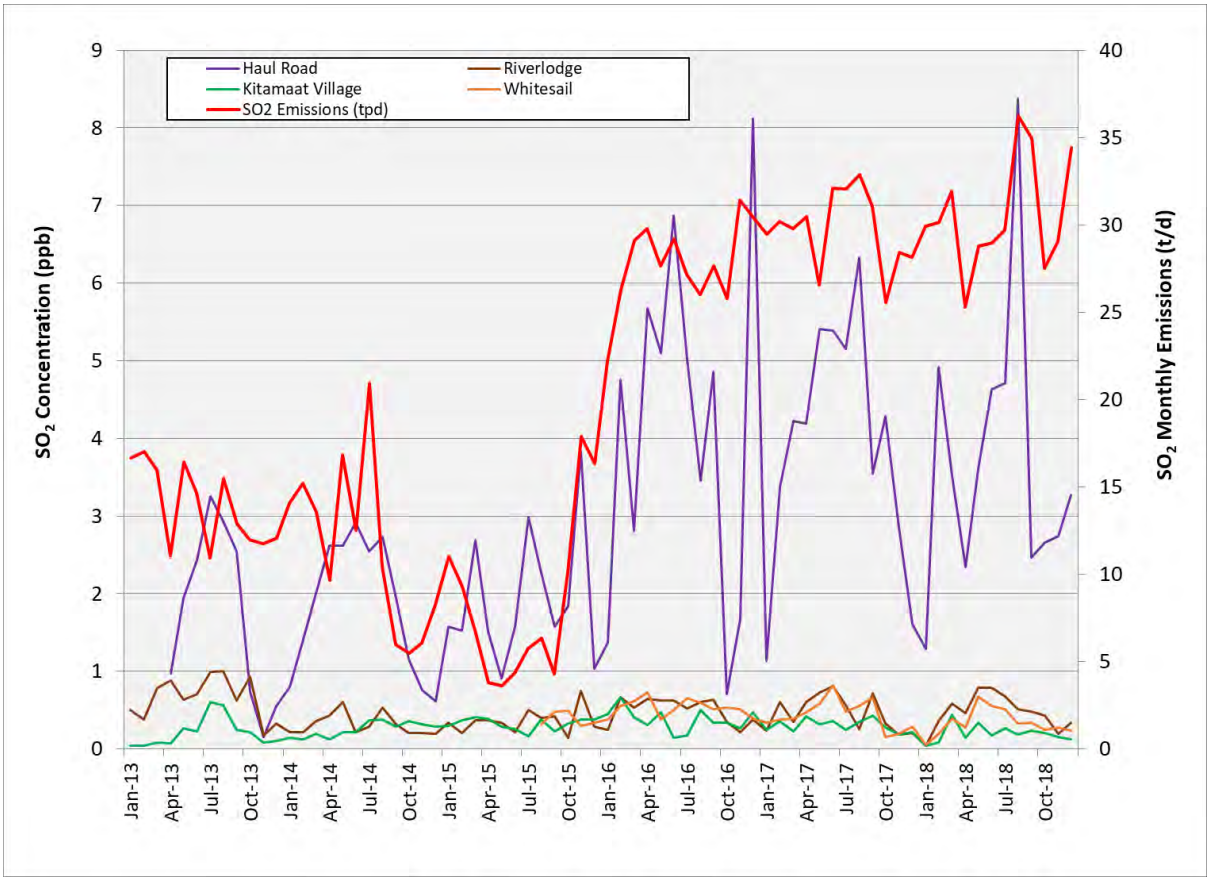


Figure 3-2. Monthly SO_2 emissions (red line) and monthly average ambient SO_2 concentrations at the four continuous monitoring stations (purple, brown, green and orange lines) for 2013 to 2018.

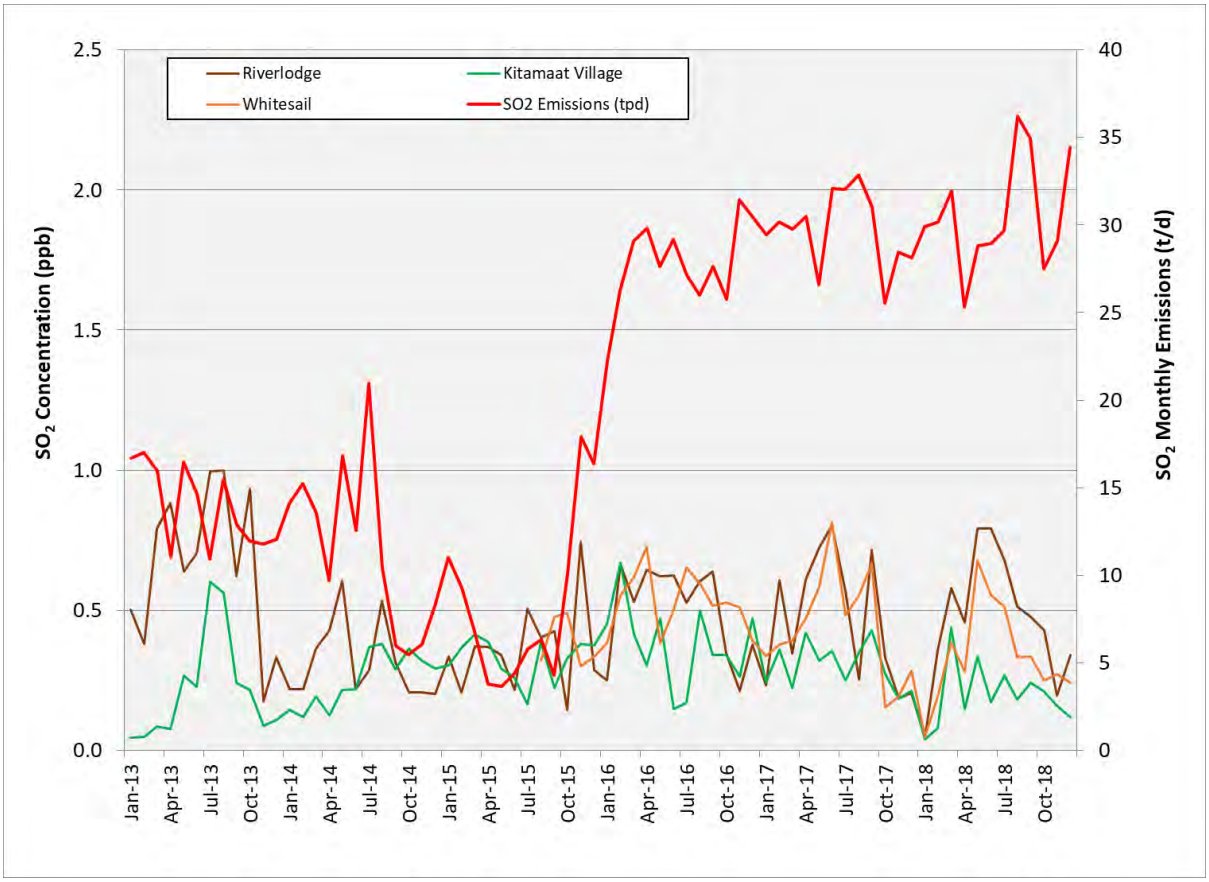


Figure 3-3. Monthly SO_2 emissions (red line) and monthly average ambient SO_2 concentrations at three residential continuous monitoring stations (brown, green and orange lines) for 2013 to 2018.

Charts of the residential annual averaging SO_2 and 1-hour SO_2 (99th percentile of daily 1-hour peak) in Figure 3-4 and Figure 3-5 show similar temporal trends. The residential concentrations remain relatively unaffected by the changes in SO_2 emissions; however, some increasing trend is noticeable for the 1-hour results in Figure 3-5. The Haul Road monitor is not shown in the CAAQS-comparison charts below because the CAAQS are not intended to be used for fenceline reporting.[13] Consistent with model results, these trends indicate that the post-KMP SO_2 plume infrequently affects the residential areas of Kitimat. In addition, as illustrated by comparison to the CAAQS air management levels on the chart background, the residential concentrations have remained in the "keep green areas green" management category under the Canadian Council of Ministers of the Environment (CCME) and well below the 2020 CAAQS levels indicated by the red management level (for "Reduce ambient pollutants below the CAAQS").[14]

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[13] ENV Air Quality Management System Information Sheet: New National Air Quality Standards for SO_2. November 2016. (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/fs_so2_caaqs.pdf).
While the CAAQS are not intended to be used for fenceline reporting, these standards will be used to characterize air quality and potential air quality impacts in areas where people live or where other sensitive receptors are likely to be found.

[14] https://www.ccme.ca/en/resources/air/air/sulphur-dioxide.html

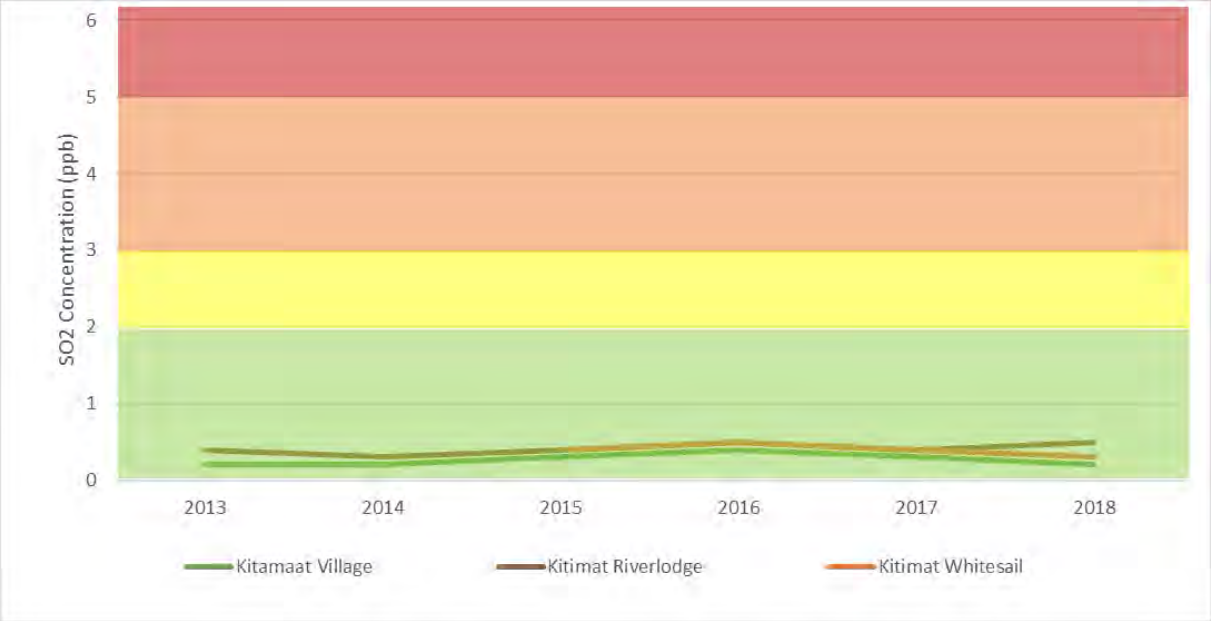


Figure 3-4. Annual average ambient SO_2 concentrations at the four continuous monitoring stations (purple, brown, green and orange lines) for 2013 to 2018. SO_2 CAAQS and CCME management levels shown in background: Red = Reduce below the CAAQS, Orange = Prevent CAAQS exceedance, Yellow = Prevent air quality deterioration, Green = Keep clean areas clean.

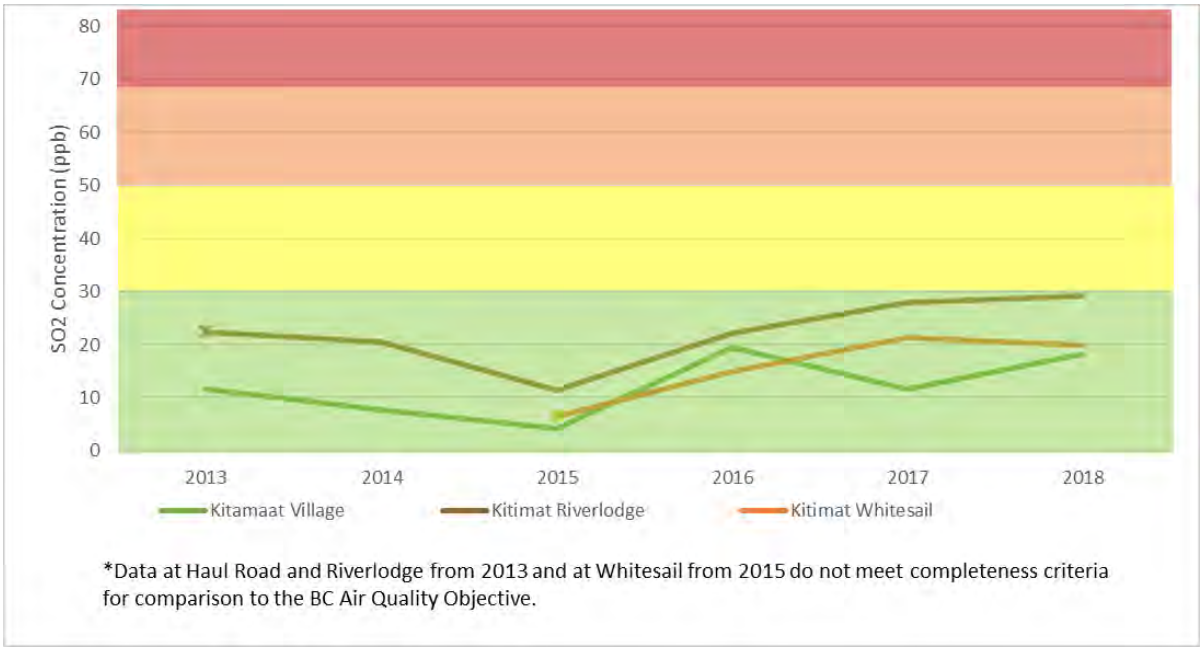


Figure 3-5. 99th percentile of daily 1-hour peak ambient SO_2 concentrations at the four continuous monitoring stations (purple, brown, green and orange lines) for 2013 to 2018. SO_2 CAAQS and CCME management levels shown in background: Red = Reduce below the CAAQS, Orange = Prevent CAAQS exceedance, Yellow = Prevent air quality deterioration, Green = Keep clean areas clean.

STAR question A1: Does the CALPUFF model accurately predict post-KMP SO_2 air concentrations?

As detailed in the annual EEM reports and summarized in Figure 3-6 below, comparisons performed each year between continuous SO_2 monitoring data and CALPUFF model results showed that the actual measured SO_2 concentrations were substantially lower than model predictions of post-KMP SO_2 concentrations from the STAR at most locations and near model predictions at Haul Road (most years the model slightly under-predicted at Haul Road when scaling STAR results using actual emission rates). Figure 3-7 comparing the 99th percentile of daily 1-hour peak also shows that the STAR model over-predicted concentrations at all three residential monitors and slightly under-predicted at Haul Road. This comparison confirmed expectations based on the STAR CALPUFF model comparison of pre-KMP model results to pre-KMP monitoring data (2006, 2008, 2009): that the STAR SO_2 predictions generally over-predicted concentrations, particularly in residential areas. In other words, the continuous SO_2 monitoring has provided the data needed to answer the question whether CALPUFF accurately represents post-KMP SO_2 concentrations: CALPUFF over-predicted post-KMP concentrations at most locations.

The continuous SO_2 data set also provides information for new CALPUFF model performance evaluation (see Section 3.1.3.5), which will answer the related question of how accurately the new CALPUFF model predicts post-KMP concentrations.

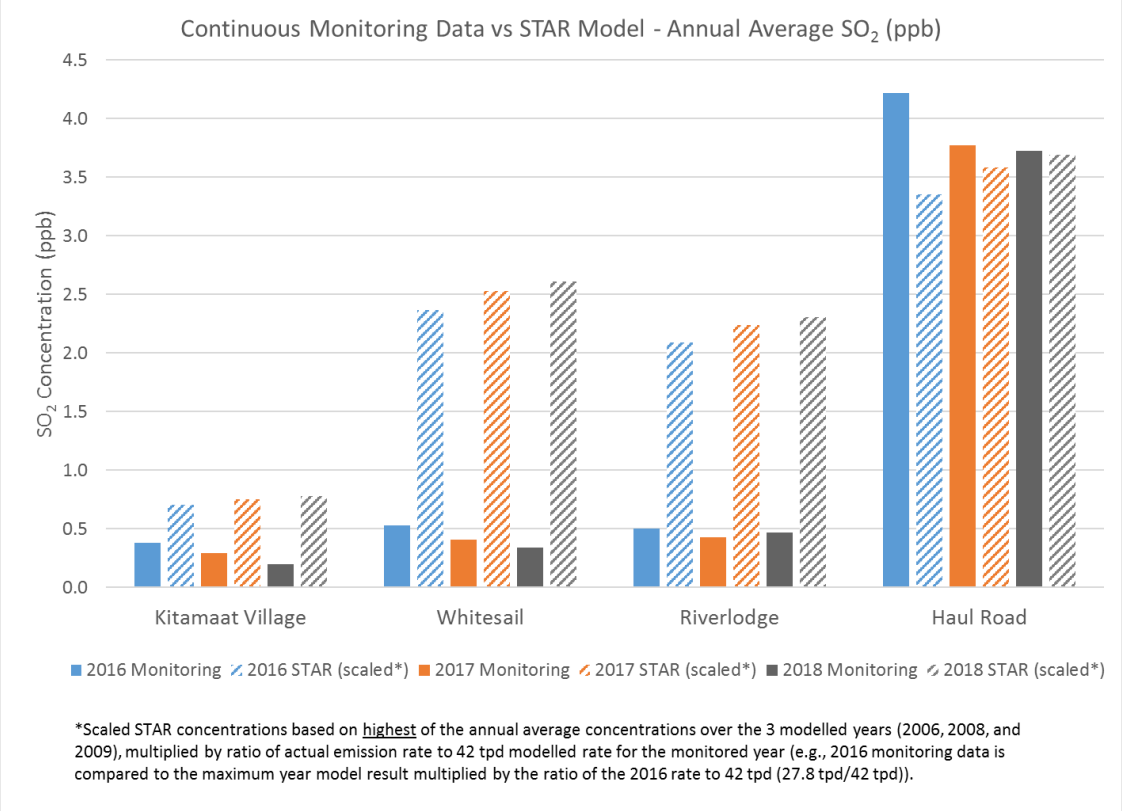


Figure 3-6. Continuous SO_2 monitoring concentration compared to scaled STAR model concentrations, annual average (background of 0.4 ppb used in STAR included).

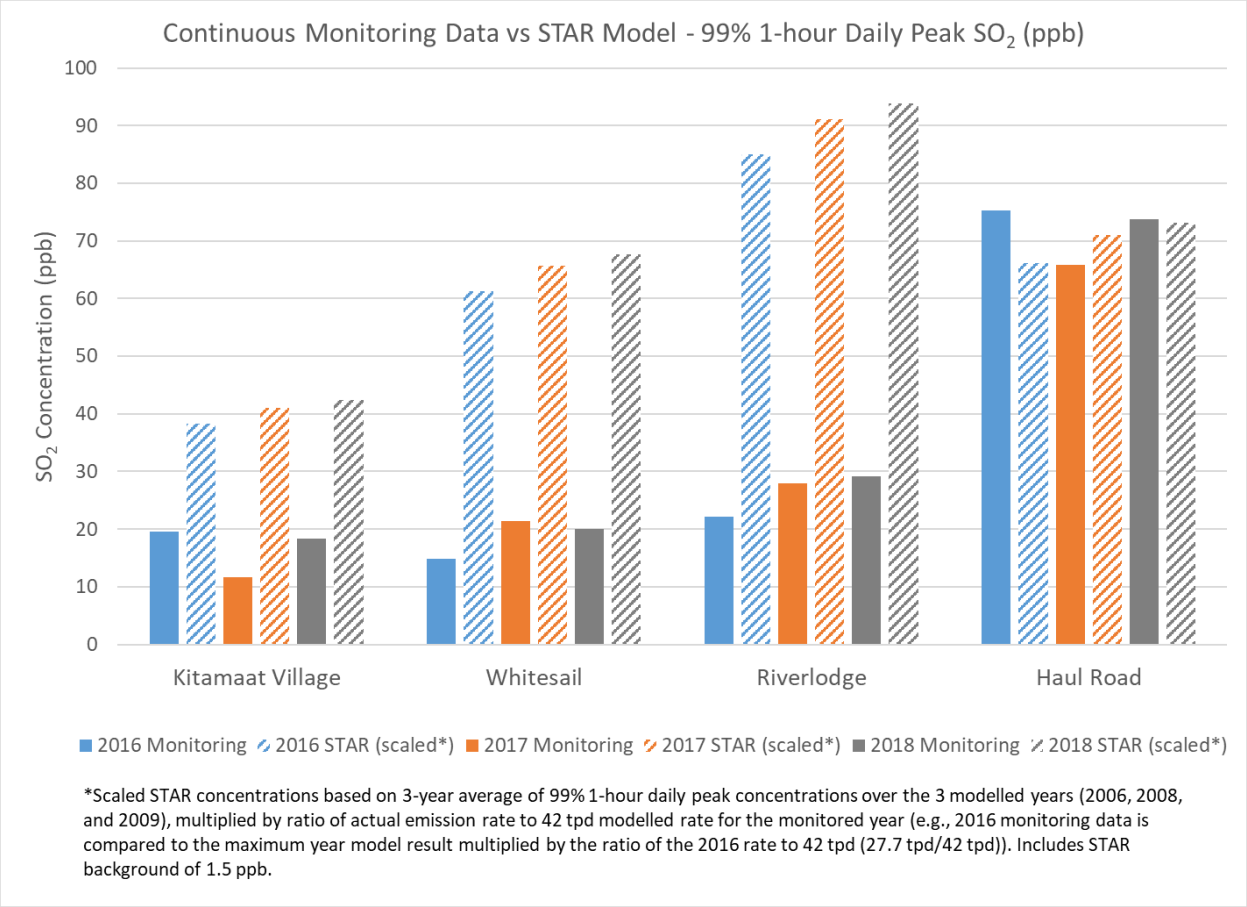


Figure 3-7. Continuous SO_2 monitoring concentration compared to scaled STAR model concentrations, 99th percentile of daily 1-hour peak (background of 1.5 ppb used in STAR included).

3.1.3.2 *Overview of EEM monitoring program results – passive SO_2 network*

During 2016–2018 (three years), there were 240 passive samplers deployed in the Kitimat Valley network, which included 50 duplicate exposures (>25% of sampler exposures were duplicates). The average percent difference between duplicate samplers was ~15% (median ~11%). There was a strong linear agreement between passive (individual monthly exposures) and continuous SO_2 observations (averaged over the same exposure period) in both the valley (coefficient of determination (R^2) of 0.90) and urban (R^2 = 0.67) networks; although, deployments at the continuous station in the valley network showed stronger statistical agreement than the agreement at the urban continuous stations (Figure 3-8). In general, passive samplers underestimated air concentrations compared with the continuous analyzers; as such all passive data were calibrated to the continuous analyzers based on the best fit lines shown in Figure 3-8 (see Atmospheric Appendix Section 3.1.4 for details on the calibration). All Valley sampler results

are calibrated using the best fit line for the Haul Road and Smeltersite (Figure 3-8(A) [15]) and all Urban sampler results apply the best fit for Whitesail and Riverlodge (Figure 3-8(B)).

The passive sampler SO_2 concentrations are reported in units of micrograms per meter cubed ($\mu g/m^3$). However, this chapter also frequently presents SO_2 results in units of parts per billion (ppb) in order to stay consistent with the continuous analyzer monitoring data and the CAAQS. It is possible to move between ppb and $\mu g/m^3$ by a factor of 2.614 $(\mu g/m^3)/(ppb)$.[16]

The average yearly Spring–Autumn (June–October) SO_2 concentrations ranged from 1.38 $\mu g/m^3$ (0.53 ppb) (A04: Lakelse Lake during 2016) to 13.51 $\mu g/m^3$ (5.17 ppb) (V11: Bish Road during 2017) in the valley network (Table 3-1). The highest SO_2 concentrations were generally observed close to and south of the smelter (Figure 3-9 and Table 3-1). In general, SO_2 concentrations in the valley followed a logarithmic decay with distance from the smelter (Figure 3-10). This spatial pattern was consistent between the three years of observations, with an average coefficient of variation < 20% (Table 3-1) ranging from 4.1% (Bish Road at Chevron) to 31.6% (Sandhill).

We also used the passive sampling measurements to evaluate the 2016–2018 CALPUFF model performance (see Section 3.1.3.5). The accuracy of spatial SO_2 dispersion patterns predicted in the STAR cannot be entirely assessed based on the coverage of the continuous SO_2 analyzers. As such, the passive sampling network implemented mid-way through the EEM program provided valuable information in locations where continuous SO_2 analyzers are not located. It is important to note that passive samplers provide a measure of average air concentration during their exposure, they cannot provide information on maximum concentrations (see Atmospheric Appendix Section 3.1.2). Nonetheless, they provide important information on the spatial variation in SO_2 air concentrations.

[15] Kitimat Valley network: Calibrated SO_2 $(\mu g/m^3)$ = uncalibrated SO_2 $(\mu g/m^3)$ × 1.034 + 0.749

[16] The 2.614 $(\mu g/m^3)/(ppb)$ factor converts from a mass concentration basis to a volume concentration basis of SO_2 based on the molecular weight of SO_2 and standard atmospheric conditions. In this case, standard conditions are 1 atm and approximately 25 C, precisely corresponding to the 1-hour SO_2 B.C. AQO levels listed of 70 ppb and 183 $\mu g/m^3$ (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/aqotable.pdf).

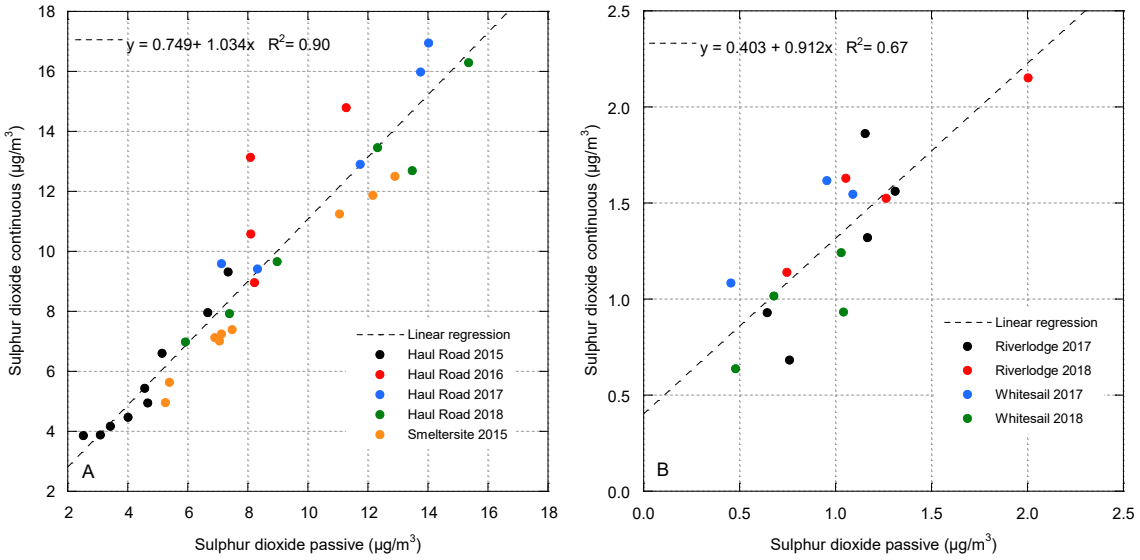


Figure 3-8. Concentration (µg/m³) of sulphur dioxide (SO_2) measured with passive samplers (monthly exposures) against average SO_2 from the continuous analyzers during the same exposure period in the (A) Valley and (B) Urban Kitimat networks. The best-fit linear regression between passive and continuous is also shown (as a dashed line). See Atmospheric Appendix Section 3.1.4 for details on the calibration of passive samplers to the continuous analyzers.

Table 3-1. Passive sulphur dioxide (SO_2) monitoring sites (Figure 3-9 for site locations), location (latitude, longitude), distance from smelter, number of exposures (N_{exp}), three-year average SO_2 (June–October), the coefficient of variation (CV) and yearly Spring–Autumn (June–October) average during 2016, 2017 and 2018. Passive samplers were calibrated against continuous SO_2 data (Figure 3-8).

Site¥	Latitude	Longitude	Distance §	N_{exp}	SO_2 2016 – 2018	SO_2 2016 – 2018	CV	SO_2 2016	SO_2 2017	SO_2 2018
			km	n	µg/m³	ppb	%	µg/m³	µg/m³	µg/m³
A01	54.02931	–128.70192	1.82	13	11.71	4.48	13.7	9.85	11.91	12.96
A04	54.37721	–128.57734	41.35	12	1.50	0.57	6.8	1.38	1.54	1.57
V01	54.30437	–128.61655	32.91	11	2.74	1.05	4.2	2.62	2.74	2.85
V02	54.28593	–128.64471	30.61	10	2.39	0.91	10.4	2.27	2.18	2.65
V03	54.23226	–128.67892	24.45	9	3.90	1.49	22.3	3.88	5.14	3.36
V04	54.18131	–128.68178	18.78	11	2.12	0.81	26.3	1.71	2.87	2.12
V05	54.14140	–128.68559	14.33	11	5.22	2.00	18.9	4.03	5.78	5.64
V06	54.11443	–128.67961	11.38	11	4.16	1.59	24.4	3.13	4.07	5.13
V07	54.09294	–128.67343	9.09	9	2.30	0.88	24.3	2.14	2.72	1.66
V08	54.07872	–128.69531	7.33	9	6.40	2.45	23.4	4.82	6.80	7.79
V09	54.05111	–128.71008	4.27	11	8.30	3.17	31.6	5.65	8.00	10.80
V10	54.01693	–128.70958	0.66	10	10.61	4.06	20.1	8.19	11.53	12.19
V11	53.96473	–128.70387	5.37	11	11.83	4.53	21.5	8.77	13.51	12.41
V12	53.94320	–128.72061	7.86	11	7.80	2.98	19.2	5.98	8.31	8.71
V13	53.93831	–128.75015	8.89	7	8.29	3.17	4.1		8.51	8.03
V14	54.05997	–128.68704	5.32	10	3.90	1.49	20.4	2.91	4.03	4.39

¥ A represents ambient stations, and V represents the valley network sites; A01 is Haul Road and A04 is Lakelse Lake.
§ Based on a smelter location of 54.01300, –128.70200

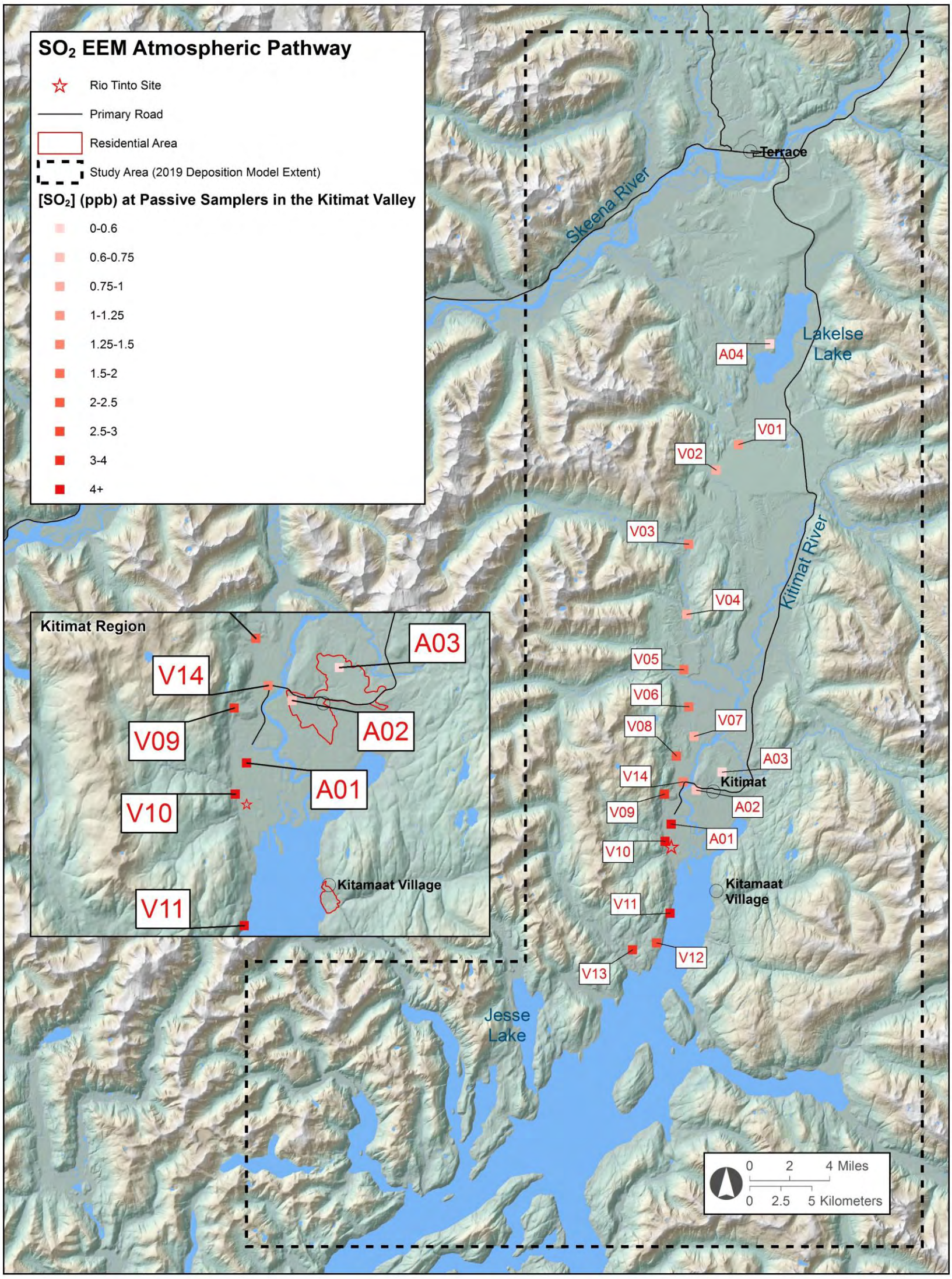


Figure 3-9. Average (2016–2018) sulphur dioxide (SO_2) concentrations at the passive sample sites during the June to October exposures. The site ID is also shown (see Table 3-1 for details on location). Passive samplers were calibrated against continuous SO_2 data (see Figure 3-8).

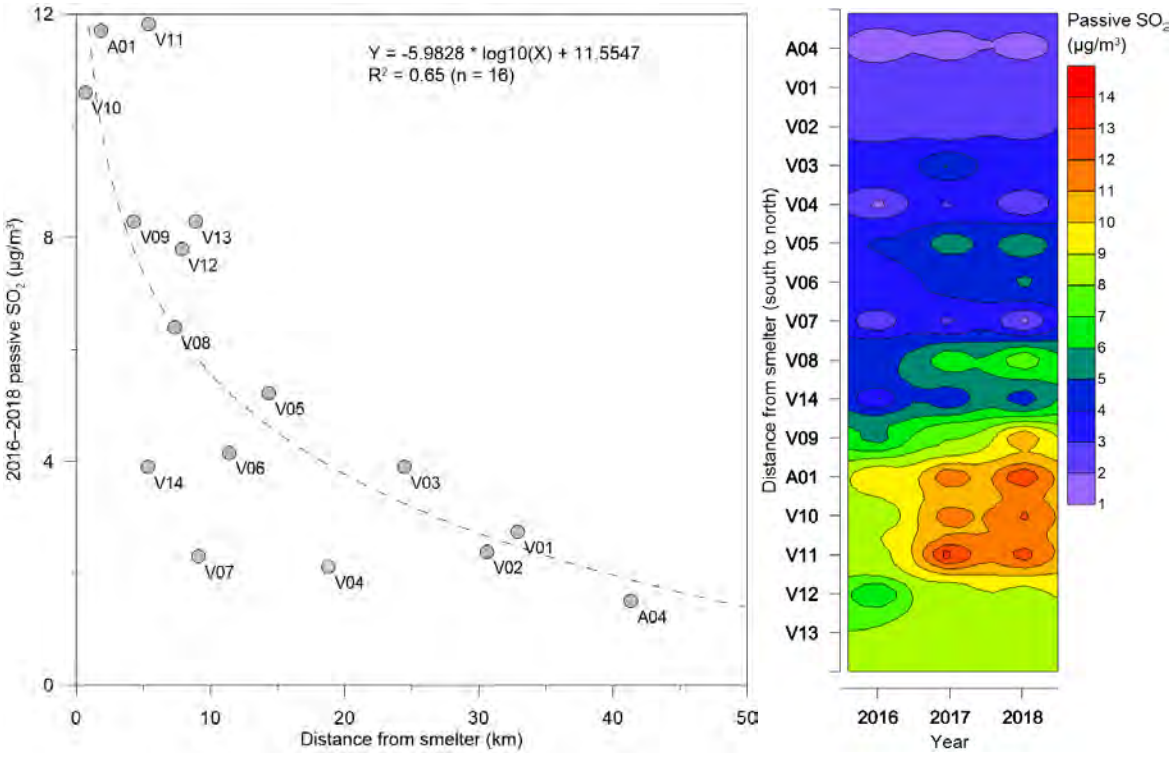


Figure 3-10. Left panel: average (2016–2018) passive sulphur dioxide (SO_2) concentrations observed in the valley network against their geographic (straight-line) distance from the smelter (km). The best-fit log regression line is also shown. Right panel: space-time plot showing the Spring–Autumn (June–October) passive SO_2 concentrations during 2016, 2017 and 2018 at each location in the Kitimat valley network ordered by distance (south to north) from smelter (see Figure 3-9 for exact site locations). Passive samplers were calibrated against continuous SO_2 data (see Figure 3-8).

The number of sites in the urban passive sampler network ranged from 15–16 during 2017–2016 and expanded to 20 during 2018. The 15 sites with consistent deployments during 2016–2018 (June–October) are described herein (Figure 3-11 and Table 3-2). There were 140 passive samplers deployed during the three years in the urban network; however, the hours of exposure at each site varied greatly (2924–9348 hrs), primarily due to physical disturbance of samplers (and that some sites only operated for two of the three years).

The average yearly Spring–Autumn (June–October) SO_2 concentrations ranged from 0.69 µg/m³ (0.26 ppb) (U05: Cable Car during 2016) to 1.53 µg/m³ (0.59 ppb) (A02: Riverlodge during 2018) in the urban network (Table 3-2). The highest Spring–Autumn (June–October) SO_2 concentrations were always observed at A02: Riverlodge (Figure 3-11 and Table 3-2). During 2016–2018 (three years), the next highest SO_2 concentration was observed at U06: Kitimat General Hospital, and the lowest at U05: Cable Car (Figure 3-11 and Table 3-2). Nonetheless, there was very little variation across all the stations; the average for all sites was 1.09 µg/m³ (0.42 ppb). In contrast, the average for the Valley Network for the same period was 5.82 µg/m³ (2.23 ppb). (Table 3-1). The spatial pattern in the urban network was consistent between the three years of observations (Figure

3-11), with an average coefficient of variation < 12% (Table 3-2), ranging from 3.2% (U13: St. Anthony's Elementary) to 20.8% (U9: Fulmar Street), although the latter is likely influenced by the low number of exposures.

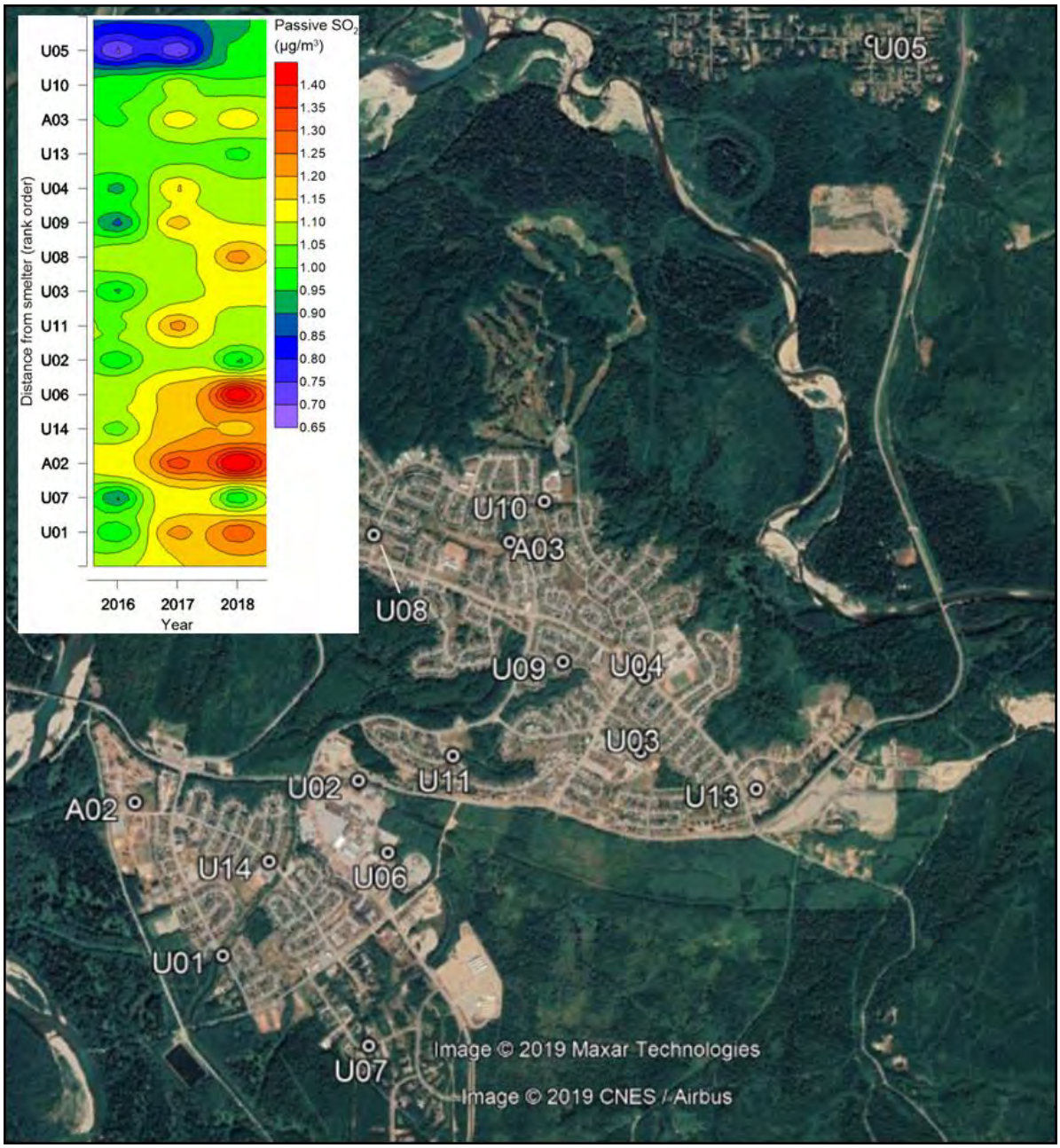


Figure 3-11. Location of passive sampler sites in the urban Kitimat network with monthly exposures during June–October between 2016 to 2018 (see Table 3-2 for exact site locations). Inset: space-time plot showing the Spring–Autumn (June–October) passive sulphur dioxide (SO_2) concentrations during 2016, 2017 and 2018 at each location in the Kitimat urban network ordered by distance from smelter. Passive samplers were calibrated against continuous SO_2 data (see Figure 3-8).

Table 3-2. Passive sulphur dioxide (SO_2) monitoring sites (Figure 3-12 for site locations), location (latitude, longitude), total hours and number of exposures, three-year average SO_2 (June–October), the coefficient of variation (CV) and yearly Spring–Autumn (June–October) average during 2016, 2017 and 2018. Passive samplers were calibrated against continuous SO_2 data (see Figure 3-8).

Site¥	Latitude	Longitude	Exposure		SO_2 2016–2018	SO_2 2016–2018	CV	SO_2 2016	SO_2 2017	SO_2 2018
			Hrs	n	µg/m³	ppb	%	µg/m³	µg/m³	µg/m³
A02	54.05396	-128.67101	9348	13	1.36	0.52	14.4	1.14	1.34	1.53
A03	54.06695	-128.63910	8192	11	1.09	0.42	7.7	0.99	1.14	1.14
U01	54.04629	-128.66356	7462	10	1.18	0.45	15.1	0.96	1.22	1.29
U02	54.05507	-128.65199	5757	8	1.00	0.38	8.1	0.95	1.08	0.93
U03	54.05655	-128.62810	7458	10	1.06	0.41	9.2	0.94	1.09	1.11
U04	54.06028	-128.62775	7457	10	1.05	0.40	11.3	0.93	1.16	1.05
U05	54.09192	-128.60854	6708	9	0.82	0.31	20.2	0.69	0.69	0.96
U06	54.05146	-128.64951	7460	10	1.29	0.49	17.0	1.08	1.19	1.49
U07	54.04179	-128.65115	7462	10	0.99	0.38	12.4	0.89	1.13	0.95
U08	54.06731	-128.65057	7456	10	1.15	0.44	7.3	1.09	1.08	1.23
U09	54.06102	-128.63463	2924	4	1.10	0.42	20.8	0.88	1.18	
U10	54.06897	-128.63620	4268	6	1.04	0.40	7.4	0.98	1.09	
U11	54.05635	-128.64391	7457	10	1.11	0.42	9.2	1.04	1.23	1.07
U13	54.05471	-128.61835	6568	9	1.01	0.39	3.2	1.02	1.04	0.98
U14	54.05101	-128.65961	7460	10	1.14	0.44	9.0	1.02	1.20	1.18

¥ A represents ambient stations, and U represents the urban network sites; A02 is Riverlodge and A03 is Whitesail.

3.1.3.3 *Overview of EEM monitoring program results – filter pack pSO_4^{2-} network*

The filter packs were deployed at nine locations; seven of these sites were part of the passive sampler Valley Network or co-located with continuous samplers. In total there were 56 discrete (24–48 hour) exposures at these seven sites between June 2017 and July 2018 (Table 3-3). There was strong linear agreement between the concentration of SO_2 measured with the filter pack (individual exposures) and the continuous SO_2 observations (averaged over the same exposure period) with an R^2 = 0.98 (Figure 3-12). The filter pack SO_2 concentrations were lower than continuous samplers; however, it is the relative concentrations of particulate to gaseous sulphur that is primarily of interest. The average pSO_4^{2-} [17] ranged from 0.4 (A04: Lakeslse Lake) to 0.19 (A05) µg S/m³. In comparison, average SO_2 ranged from 0.28 (A04) to 3.38 (A01: Haul Road) µg S/m³. On average, SO_2 is 10 times higher than pSO_4^{2-} across the measurement sites (Table 3-3).

[17] Conversion of units. Particulate sulphate: pSO_4^{2-}-S (µg S/m³) = pSO_4^{2-} (µg/m³) × $MW_{sulphur}$ / $MW_{sulphate}$ where MW is the molecular weight of sulphur (32.065 g/mol) and sulphate (96.06 g/mol); Gaseous sulphur dioxide: SO_2-S (µg S/m³) = SO_2 (µg/m³) × $MW_{sulphur}$ / $MW_{sulphur\ dioxide}$ where MW is the molecular weight of sulphur dioxide (64.066 g/mol).

The calibrated SO_2 from the filter packs (Table 3-3) is generally consistent with the longer-term (June–October) exposures for the passive samplers (Table 3-1 and Table 3-2) despite the limited duration of exposures.

The average F_s ratio of pSO_4^{2-} to total atmospheric sulphur was 8.7% and ranged from 4.1% (A01) to 18.2% (A02). In contrast, the average F_s estimated from CALPUFF was 1.4% (for the same sites). The CALPUFF estimates do not include background contributions and represent a full year; nonetheless the modelled and measured data both indicate that pSO_4^{2-} is a minor component of atmospheric sulphur in the Kitimat Valley. Moreover, a low F_s is expected because the rate of transformation of SO_2 to SO_4^{2-} in the atmosphere occurs on a longer timescale than transportation and dispersion (Warneck 1999); and these measurements corroborate this expectation. The relationship between SO_2 and F_s may provide a means to scale these observations to sites without pSO_4^{2-} measurements, albeit a minor component of atmospheric sulphur.

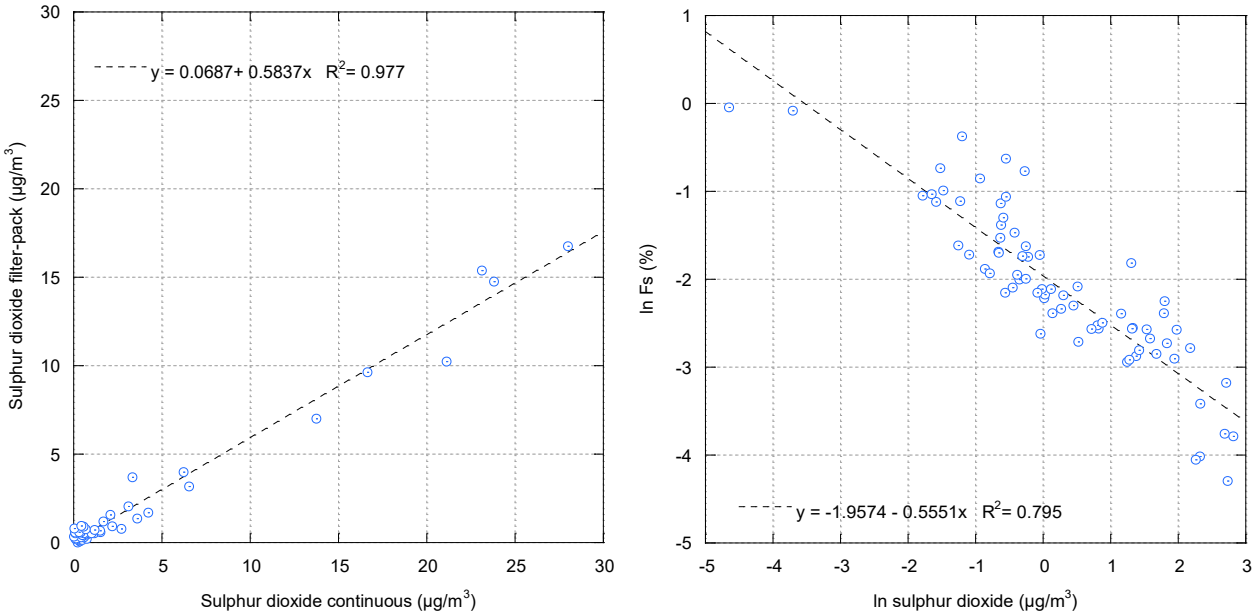


Figure 3-12. Left: concentration (µg/m³) of sulphur dioxide (SO_2) measured with filter pack samplers (24–48 hour exposures) against average SO_2 from the continuous analyzers during the same exposure period (both uncalibrated). The best-fit linear regression between filter-pack and continuous is also shown (as a dashed line). Right: Comparison of natural-log transformed SO_2 (µg/m³) and F_s (%) measured via filter pack sampler during sampling campaigns one through four. The line of best fit (dashed line) and corresponding linear equation is also shown.

Table 3-3. Average (uncalibrated) atmospheric concentrations (µg S/m³) of particulate sulphate (pSO_4^{2-}) and sulphur dioxide (SO_2) from the filter pack network during 2017–2018 across all exposures, average ratio (Fs expressed as a percentage) of pSO_4^{2-} to total ambient sulphur (SO_2 and pSO_4^{2-} as S), and calibrated SO_2 for comparison to passive samplers observations (Table 3-1 and Table 3-2).

Site ID ¥	Latitude	Longitude	Elevation	Exposures	pSO_4^{2-}-S	SO_2-S	SO_2 calibrated §	F_S
	decimal degrees		m	n	µg/m³	µg/m³	µg/m³	%
A01	54.0293	-128.7019	11	15	0.15	3.38	11.3	4.1
A02	54.0540	-128.6710	18	19	0.08	0.35	1.2	18.2
A04	54.3773	-128.5776	111	16	0.04	0.28	0.9	12.4
V03	54.2360	-128.6871	127	4	0.18	1.47	4.9	10.9
V05	54.1408	-128.6859	114	7	0.19	1.66	5.5	10.5
V08	54.0786	-128.6955	68	7	0.16	2.16	7.2	6.8
V12	53.9432	-128.7206	114	3	0.17	0.87	2.9	16.3
Average					0.14	1.45	4.83	8.7
Median					0.15	1.46	4.86	9.4

¥ A represents ambient stations, and V represents the valley network sites; A01 is Haul Road A02 is Riverlodge and A04 is Lakelse Lake.
§ Calibrated SO_2 (µg/m³) = 1.674 × filter-pack SO_2 (µg/m³) – 0.026 where filter-pack SO_2 (µg/m³) = filter-pack SO_2-S (µg S/m³) / $MW_{sulphur}$ × $MW_{sulphur\ dioxide}$ where MW is the molecular weight of sulphur (32.065 g/mol) and sulphur dioxide (64.066 g/mol).

3.1.3.4 *Summary of 2016-2018 CALPUFF model results*

The primary purpose of the new CALPUFF analysis is to provide updated SO_2 air concentrations and sulphur deposition rates for updated vegetation, soil, and aquatic ecosystem effects assessments.

For general information, the SO_2 model results are also presented in the form of the B.C. IAQOs for the 42 tpd scenario. As shown in Figure 3-13 through Figure 3-16, the areas exceeding the B.C. IAQOs are limited to areas close to the smelter. While viewing results in the form of the B.C. IAQOs provides helpful illustration short-term and annual average spatial distribution, model results compared to the B.C. IAQOs are not used for any effects assessments. This section focuses on the regional-scale model annual average SO_2 concentrations because the regional-scale annual average (and 3-year average) model results are used for assessing the risk of impacts on vegetation, soil, and aquatic ecosystems. The vegetation assessment also uses shorter-term averaging periods (also regional-scale), but the most stringent vegetation impact thresholds are assessed for annual averaging period. The human health assessment uses monitoring data (not model data). The local-scale model will be used for evaluating the ambient monitoring network, which will conclude in a separate future report. Atmospheric Appendix Section 3.1.8 provides additional figures for the actual and 35 tpd scenarios, individual years, and exceedance maps, and also provides tables of concentrations at locations of interest.

SO_2 concentration results are calculated by CALPUFF in units of micrograms per meter cubed ($\mu g/m^3$). However, this chapter generally presents SO_2 results in units of parts per billion (ppb) in order to stay consistent with the monitoring data and the CAAQS. It is possible to move between ppb and $\mu g/m^3$ by a factor of 2.614 $(\mu g/m^3)/(ppb)$.[18]

[18] The 2.614 $(\mu g/m^3)/(ppb)$ factor converts from a mass concentration basis to a volume concentration basis of SO_2 based on the molecular weight of SO_2 and standard atmospheric conditions. In this case, standard conditions are 1 atm and approximately 25 C, precisely corresponding to the 1-hour SO_2 B.C. IAQO levels listed of 70 ppb and 183 $\mu g/m^3$ (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/aqotable.pdf).

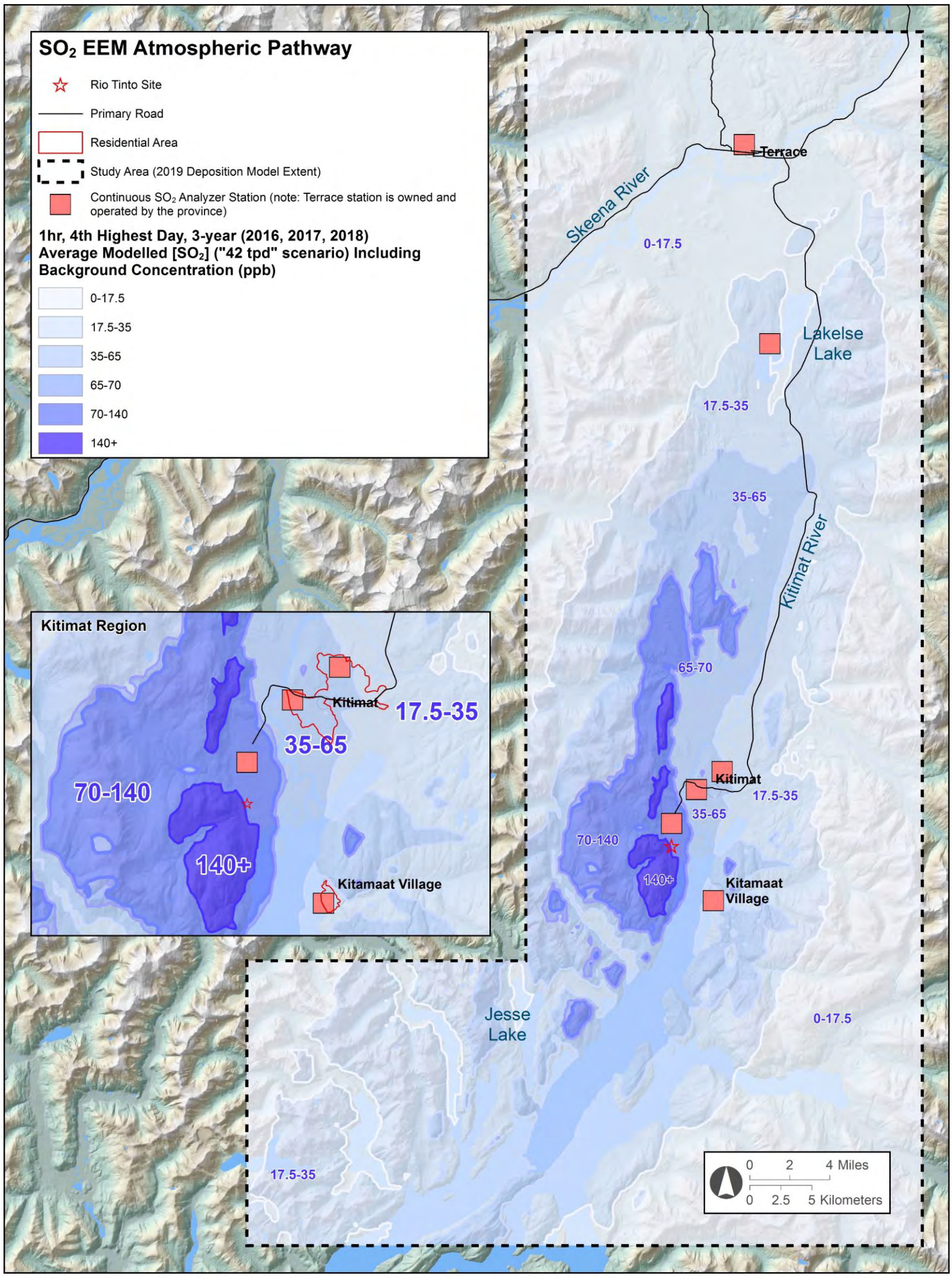


Figure 3-13. Modelled SO_2 concentrations (new 2016–2018 CALPUFF), 42 tpd, 99th percentile of daily 1-hour peak, 3-year average, regional (units of ppb, including background of 5.53 ppb).

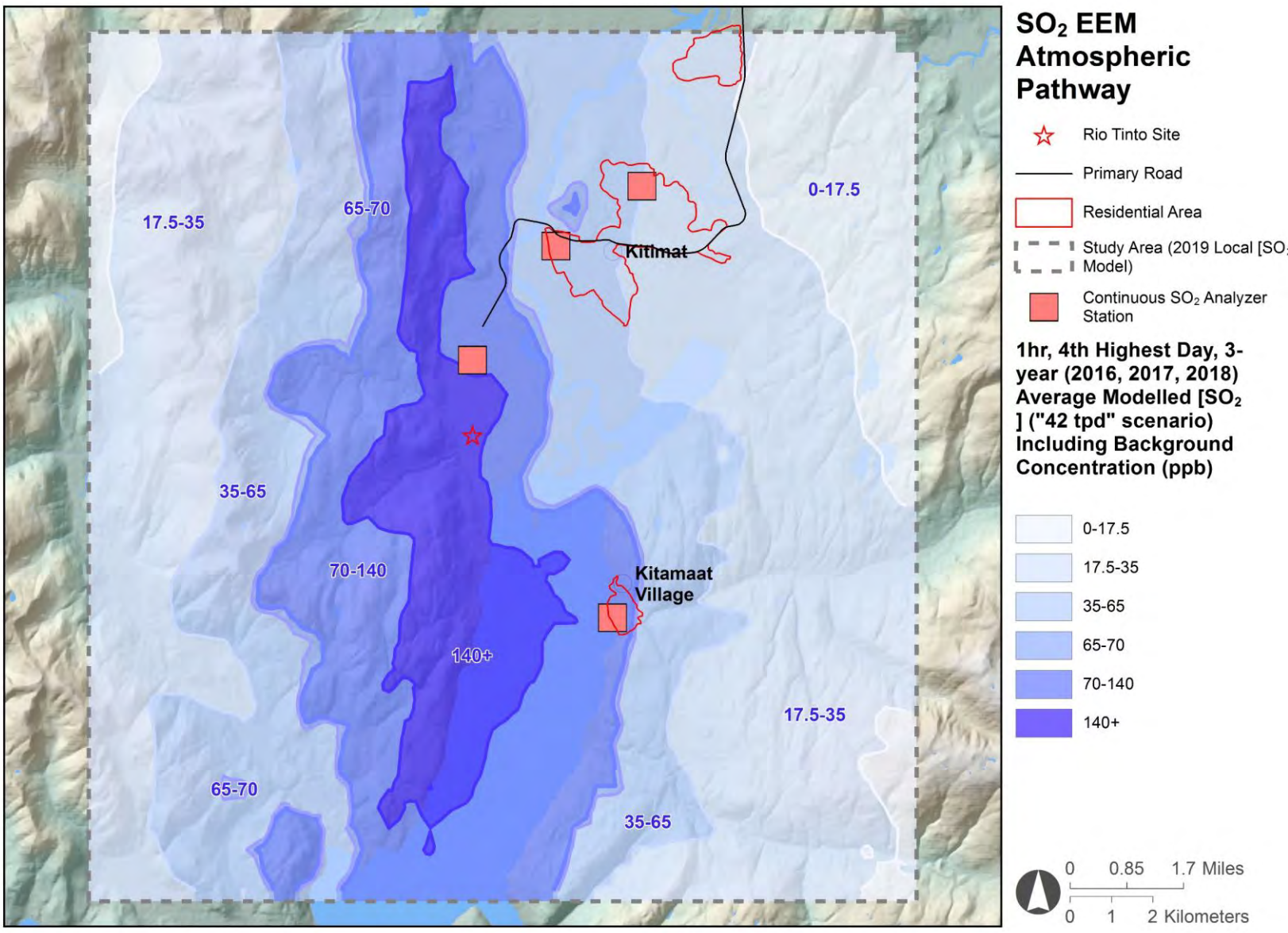


Figure 3-14. Modelled SO_2 concentrations (new 2016–2018 CALPUFF), 42 tpd, 99th percentile of daily 1-hour peak, 3-year average, local-scale (units of ppb, including background of 5.53 ppb).

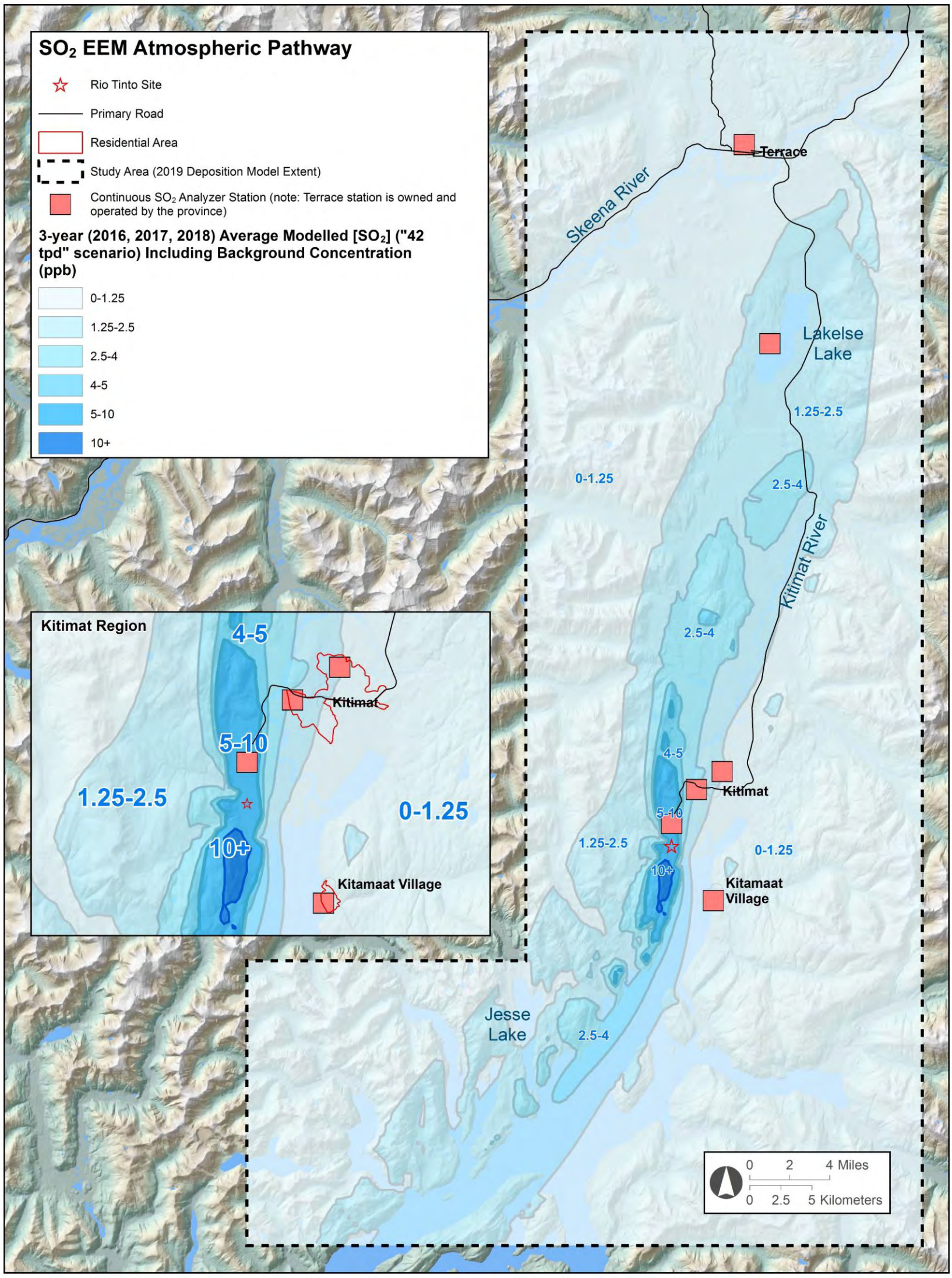


Figure 3-15. Modelled SO_2 concentrations (new 2016–2018 CALPUFF), 42 tpd, 3-year average, regional (units of ppb, including background of 0.47 ppb).

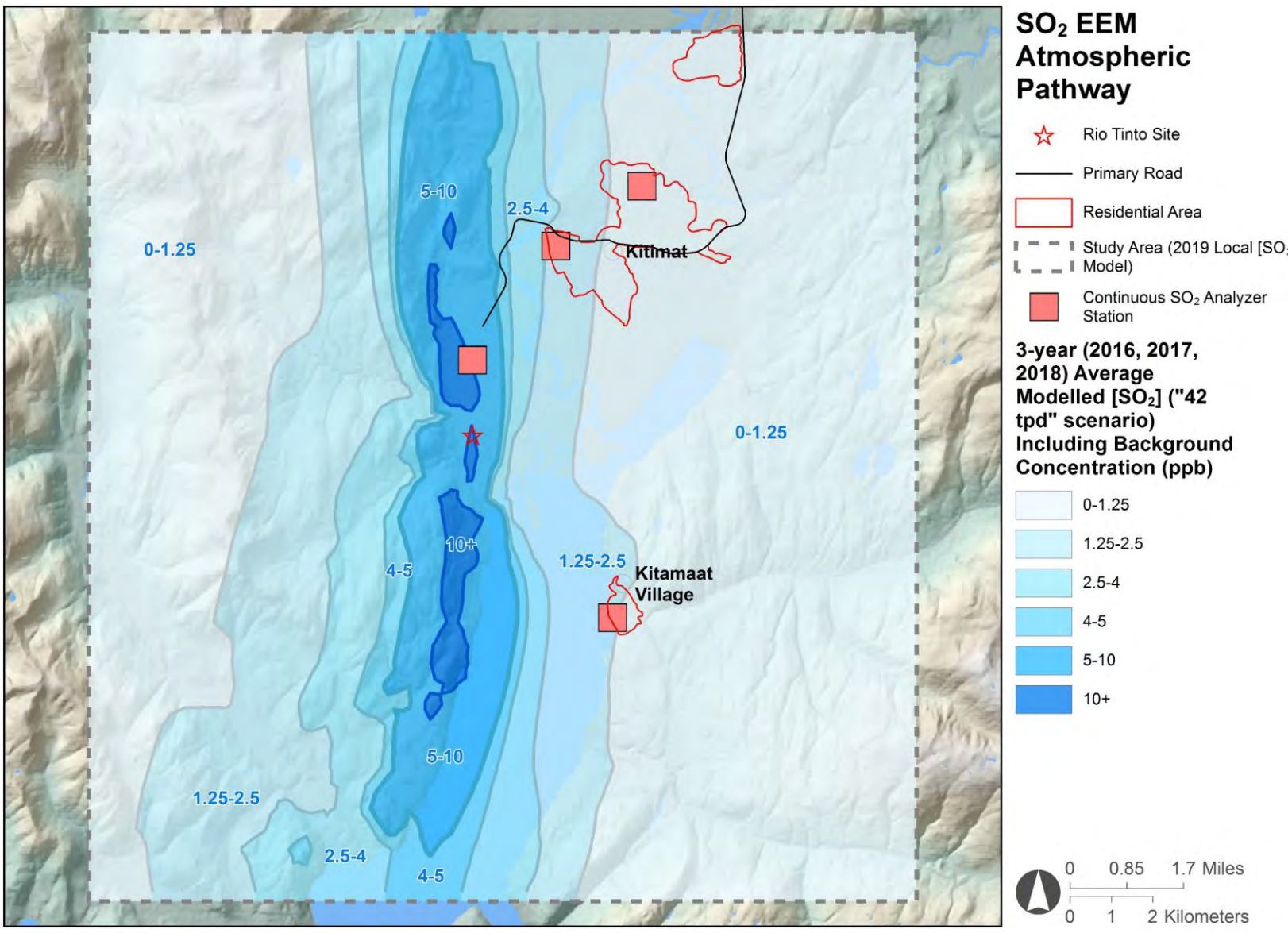


Figure 3-16. Modelled SO_2 concentrations (new 2016–2018 CALPUFF), 42 tpd, 3-year average, local (units of ppb, including background of 0.47 ppb).

The annual average concentration maps show a consistent spatial distribution for each of the modelled years (2016, 2017, and 2018, Atmospheric Appendix Section 3.1.8), with a slightly smaller extent for 2016 and slightly larger extent for 2018 (most notably to the south for the 2.5 ppb isopleth). The 1-hour SO_2 (99th percentile of daily 1-hour peak) plots show slightly more variation year to year, but all years show highest peak concentrations directly to the south and north-northwest of the smelter (Atmospheric Appendix Section 3.1.8). Modelled concentrations remain well below the CAAQS in Kitimat for all three years with a consistent distribution in the area. In contrast, the predicted concentrations near Kitamaat Village vary noticeably year to year and between the regional-scale model and local-scale model. Based on the regional-scale model, SO_2 concentrations remain below the CAAQS within the residential area with the 2016 and 2017 models predicting 1-hour concentrations exceeding 70 ppb directly to the north of Kitamaat Village, while 2018 shows concentrations below 65 ppb in the same area. The local-scale model shows even greater year-to-year variation of 1-hour results in Kitamaat Village, ranging from less than 65 ppb in 2018 to over 140 ppb in 2016 (Atmospheric Appendix pages 83-85).[19] Consistent with the annual average trends, 2018 shows the highest concentrations near the smelter (most noticeable directly to the north-northwest) and the farthest extent of the 17.5 ppb isopleth to the north. Table 3-4 also shows consistent year-to-year maximum concentrations in the form of the CAAQS, with slightly lower maximum concentrations in 2016. These year-to-year comparisons use the same 42 tpd SO_2 emissions and parameters for all years, so the variation is solely due to changes in the meteorological data used in the model.

[19] Based on the local-scale CALPUFF performance evaluation (Atmospheric Appendix Section 3.1.7), the local-scale model over-predicted SO_2 concentrations at Kitamaat Village more-so than at other locations and more-so than the regional-scale model, particularly in 2016 (1-hr, 99th% daily peak concentration of 157 ppb modelled compared to 20 ppb measured).

Table 3-4. Summary of New CALPUFF Regional-scale Model 42 tpd Maximum SO_2 Concentrations (ppb).

Year	Max Offsite [1] (SO_2 ppb)	Max Residential [2] (SO_2 ppb)
	1-hr, 99th% Daily Peak Concentration [3] (ppb)	
2016	599	43
2017	628	54
2018	834	53
3-Year Average	645	45
Objective [4]	70	70
	Annual Average Concentration [3] (ppb)	
2016	18.7	1.7
2017	19.1	1.7
2018	20.3	1.9
3-Year Average	19.0	1.7
Objective [4]	5.0	5.0

[1] Maximum offsite includes all receptors outside Rio Tinto's modelled fenceline (see Atmospheric Appendix Section 3.1.5 for figure).
[2] Maximum residential results include all results in Kitimat, Cable Car, and Kitamaat Village (see Atmospheric Appendix Section 3.1.9, detailed model plan for figure).
[3] Background concentrations are included based on average SO_2 concentrations measured at the Terrace Skeena Middle School station in 2016, 2017 & 2018. The background concentration applied for the annual averaging period is 0.47 ppb, while the background concentration for the 1-hr averaging period is 5.53 ppb. Model results are converted to ppb based on the ratio of [70 ppb]/[183 µg/m^3] per the 1-hr SO_2 British Columbia air quality objective.
[4] Objectives are based on British Columbia air quality objectives. Where both Interim Provincial IAQO and CAAQS are in place, the more stringent 2020 CAAQS is listed in this table.

While annual average spatial distribution is consistent among years, the position of the plume has shifted to predict higher concentrations to the south and extend a shorter distance to the north compared to the STAR model (Figure 3-17). The deposition spatial distribution shift from STAR results to the new model is similar (see Figure 3-29). As detailed further in Section 3.1.3.5 below and Atmospheric Appendix Section 3.1.6, this shift in plume position and extent from the north to the south aligns more closely with passive sampling measurements, which have recorded higher concentrations to the south.

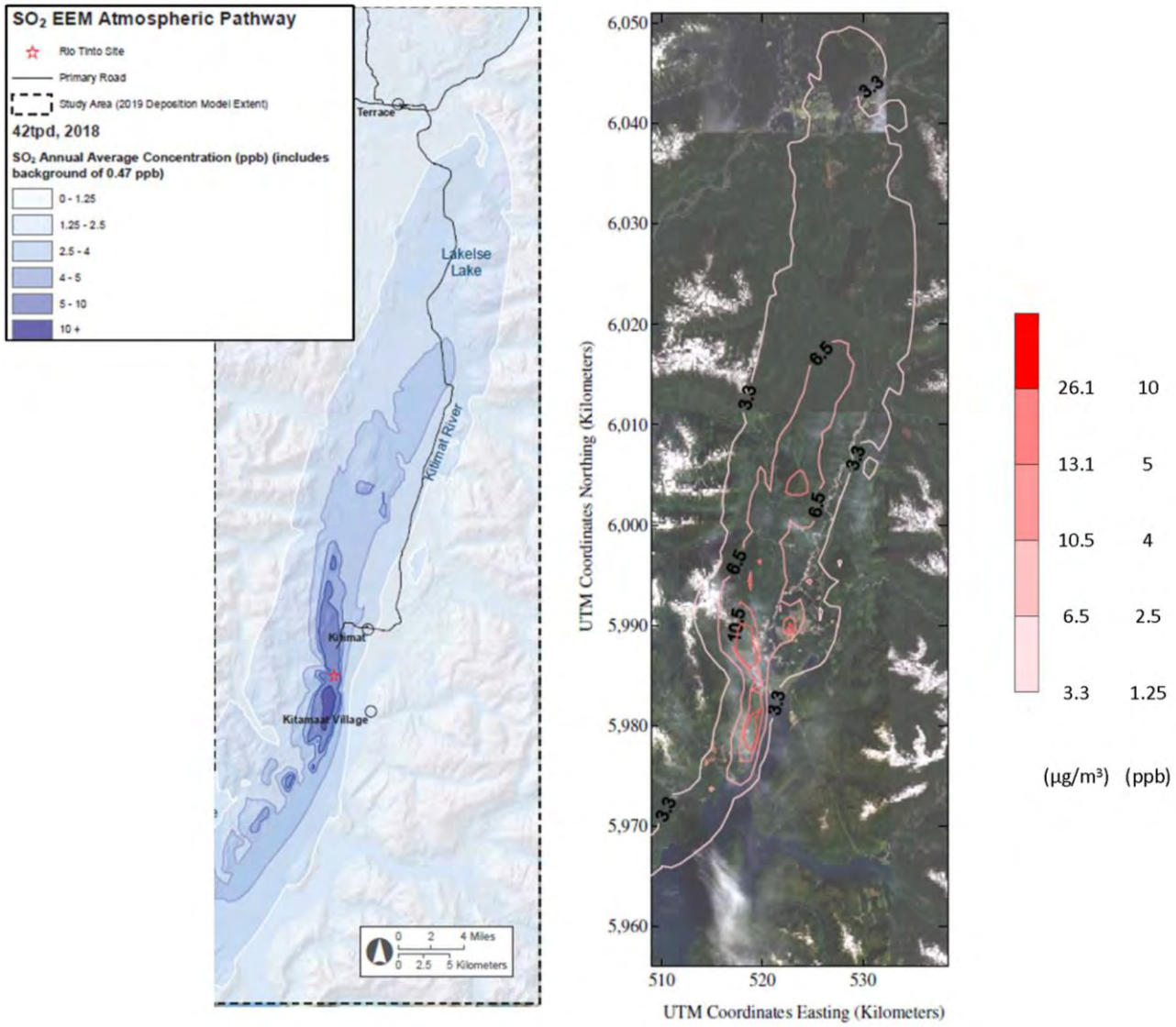


Figure 3-17. Modelled annual average SO_2 concentrations for new CALPUFF (left panel) versus STAR (right panel), 42 tpd, max year (2018 and 2006), regional-scale. New CALPUFF in units of ppb (including background of 0.47 ppb); STAR in units of µg/m³ with ppb equivalent scale, STAR scale set to identical levels (e.g., lowest for both is 1.25 ppb), including STAR background of 0.40 ppb.

3.1.3.5 *Summary of regional-scale CALPUFF model performance for SO_2 air concentrations*

The updated 2016–2018 CALPUFF modelling reduces uncertainty in post-KMP model predictions by using as-built source parameters and actual 2016–2018 SO_2 emission rates from the smelter combined with corresponding 2016–2018 meteorological data to evaluate the model performance. As detailed in Atmospheric Appendix Section 3.1.6, the regional-scale CALPUFF model shows good performance overall. The most important metric to evaluate for this

comprehensive review is the regional-scale model annual average SO_2 concentration because the regional-scale annual average (or 3-year average) model results are used for assessing the risk of impacts on vegetation, soil, and aquatic ecosystems. The vegetation assessment also uses shorter-term averaging periods, but the most stringent vegetation impact thresholds are assessed for annual averaging period. The human health assessment uses monitoring data (not model data). The local-scale model will be used for evaluating the ambient monitoring network, which will conclude in a separate future report.[20]

Model performance evaluation primarily relies on comparing modelled SO_2 to measured SO_2 taken at the continuous SO_2 monitoring stations and to measurements from the passive samplers. Table 3-5 shows the 2016–2018 CALPUFF model estimates compared to the monitoring data at each station; while Figure 3-18 illustrates the comparison and also includes the comparable STAR model results.

Table 3-5. Summary of New CALPUFF Model Comparison to Continuous Monitoring Data, Annual Average SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)
	2016		2017		2018	
Kitamaat Village	0.38	0.58	0.29	0.52	0.20	0.53
Haul Road	4.22	7.12	3.77	7.33	3.73	7.02
Riverlodge	0.50	1.49	0.43	1.54	0.47	1.69
Whitesail	0.53	0.82	0.41	0.86	0.34	0.99

[1] Monitoring data annual average for 2016, 2017, 2018.

[2] New CALPUFF results for actual scenario, regional-scale using actual smelter emission rates from 2016 to 2018, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments. The annual average background concentration used for the new 2016 -2018 model is 0.47 ppb based on monitoring at Terrace-Skeena Middle School.

[20] Since the local-scale model results are not used directly in conclusions of the EEM comprehensive review, the local-scale model evaluation is included only in Atmospheric Appendix Section 3.1.7.

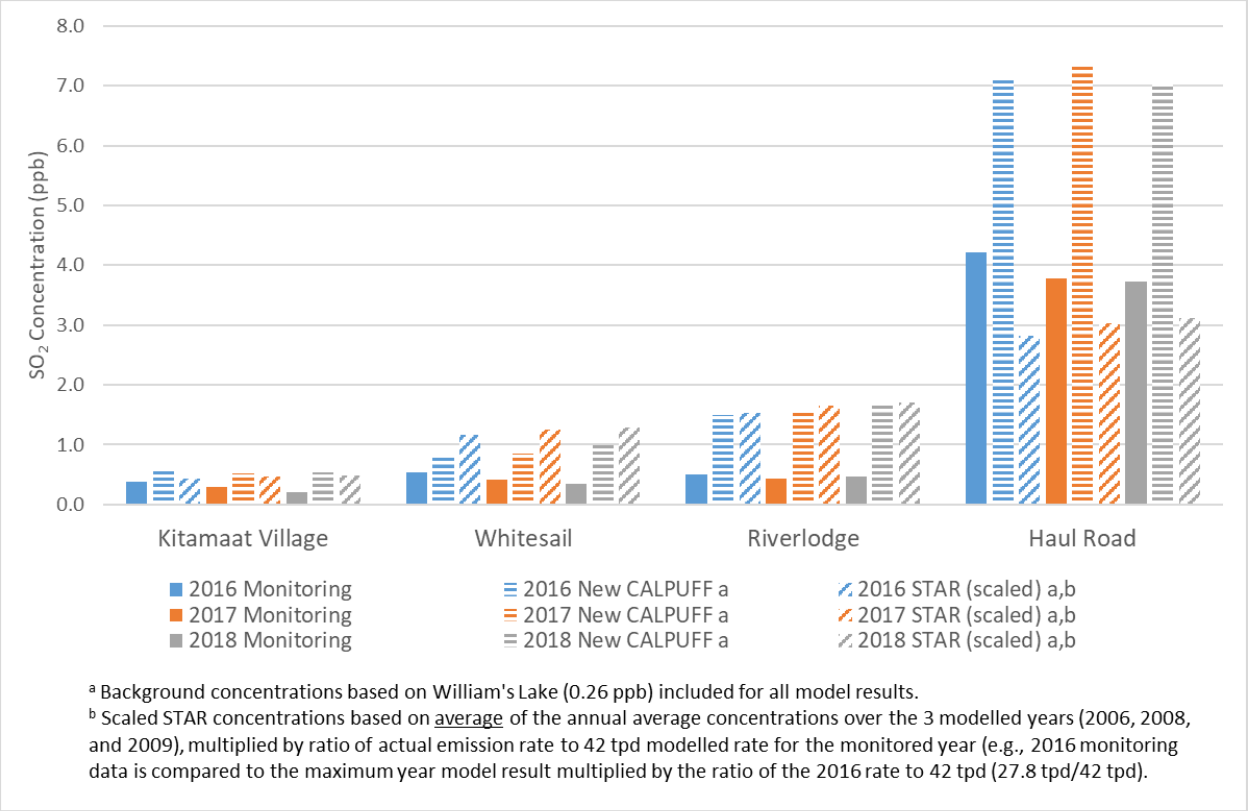


Figure 3-18. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, annual average (Williams Lake annual background of 0.26 ppb applied).[21]

As shown in Figure 3-18 and summarized in Table 3-6, the 2016–2018 regional-scale CALPUFF model is more accurate overall than the STAR model. In particular, the new 2016–2018 model aligns with observations better than the STAR model at all residential monitors. In addition, the STAR model under-predicted slightly at the Haul Road monitor, while the new model over-predicts at the Haul Road monitor by 1.8 times.

[21] Comparable STAR model results for model performance comparisons use 3-year average STAR results with Williams Lake background for model performance purposes. Figure 3-6 shows a similar comparison, but the STAR results show the maximum annual average over the three model years with STAR background for purposes of comparing model predictions used for impact assessment to monitored concentrations.

Table 3-6. Summary of new CALPUFF model comparison to continuous monitoring data, 3-year Average SO_2 (ppb).

Monitoring Station	Monitoring Data [1] (SO_2 ppb)	STAR CALPUFF, Scaled [2] (SO_2 ppb)	2016-018 CALPUFF [3] (SO_2 ppb)	Comment on comparisons to model results without background (values in parentheses)
Kitamaat Village	0.29	0.46	0.54	STAR and new CALPUFF over-predict very slightly (by less than the background value).
Whitesail	0.43	1.23	0.89	STAR over-predicted by nearly triple. New CALPUFF over-predicts by slightly more than double.
Riverlodge	0.47	1.63	1.57	STAR and new CALPUFF over-predict at similar levels: 3.5 and 3.4, respectively.
Haul Road	3.91	2.99	7.16	STAR slightly under-predicted. New CALPUFF over-predicts by 1.8 times.

[1] Monitoring data average over 2016-2018.
[2] STAR CALPUFF results are scaled to be comparable to actual 2016 – 2018 conditions by multiplying by the ratio of actual smelter emission rates in 2016–2018 (29.3 tpd) to permitted (modelled) emission rates of 29.3 tpd / 42 tpd or 69.8%. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background were used for STAR effects assessment in order to be cautious in assessments (the annual average STAR background concentration was 0.40 ppb based on monitoring at Whitesail).
[3] New CALPUFF results for actual scenario, using actual smelter emission rates from 2016 to 2018, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background are used for new model future 35 and 42 tpd effects assessment in order to be cautious in assessments. The annual average background concentration used for the new 2016 -2018 model is 0.47 ppb based on monitoring at Terrace-Skeena Middle School.

Figure 3-19 and Figure 3-20 show comparison between the hourly regional-scale model results and monitoring data over the three modelled years at each monitoring station. Figure 3-19 illustrates the comparison paired in time (max hour each day from 2016 to 2018 for visualizing), while Figure 3-20 compares the hourly model data (all hours from 2016 to 2018) versus monitoring data sorted highest to lowest (known as a quantile-quantile plot or Q-Q plot). The comparisons illustrate that the model predicts concentrations and distribution similar to monitoring data at each station (e.g., Kitamaat Village concentrations are low (below 10 ppb) most days with a few (5 to 10) occurrences of 1-hour peaks in the 20 – 30 ppb range for both datasets). However, while the model's overall predictions compare closely to the monitored concentrations, the model results do not generally predict the peaks on the same day or hour. For example, the Kitamaat Village monitor measured two peak concentrations in February 2016 (22.3 and 21.2 ppb on February 22nd and 27th), and the model predicted two peak concentration shortly after (18.3 ppb and 22.8 ppb on March 2nd and 6th), but the model did not predict the peaks on the same days. This outcome (i.e., the model resembling the monitor when comparing overall results (as in the Q-Q plots in Figure 3-20) and not agreeing perfectly when paired hour by hour) is expected for all air dispersion models. This expectation leads to common practice of placing more

emphasis on using Q-Q plots for model performance evaluation rather than on comparisons paired in time.[22]

[22] While expected to reveal lower agreement, comparisons paired in time are also valuable. The model performance statistics presented in Atmospheric Appendix Section 3.1.6 summarize the model result compared to monitor results paired in space and time using root mean squared error, mean bias error, and mean absolute error.

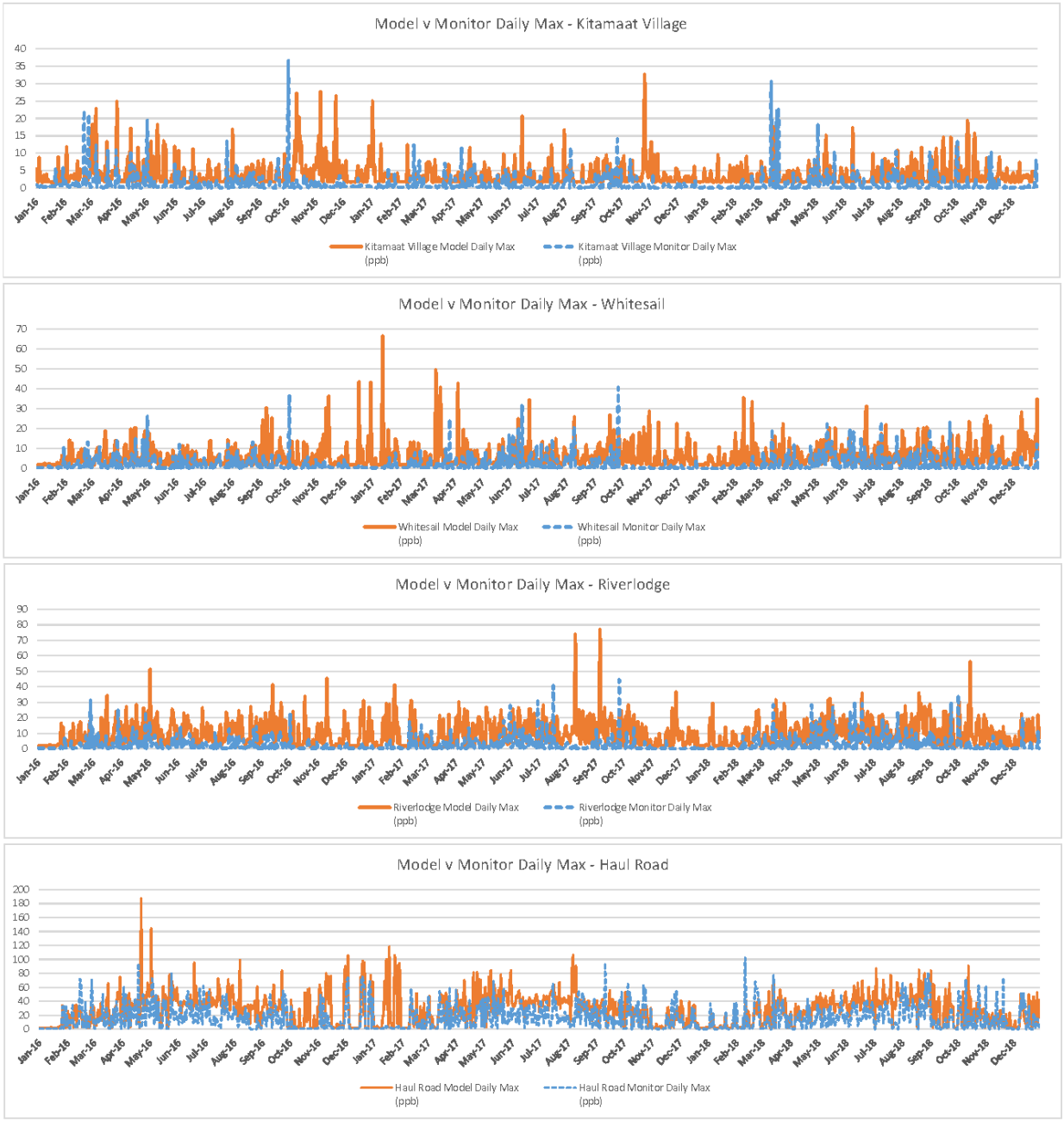


Figure 3-19. Comparison of modelled SO_2 concentrations (actual scenario) against continuous monitoring network SO_2., 2016-2018, timeseries (paired in time). The model data include the 1-hour background concentration (1.80 ppb).

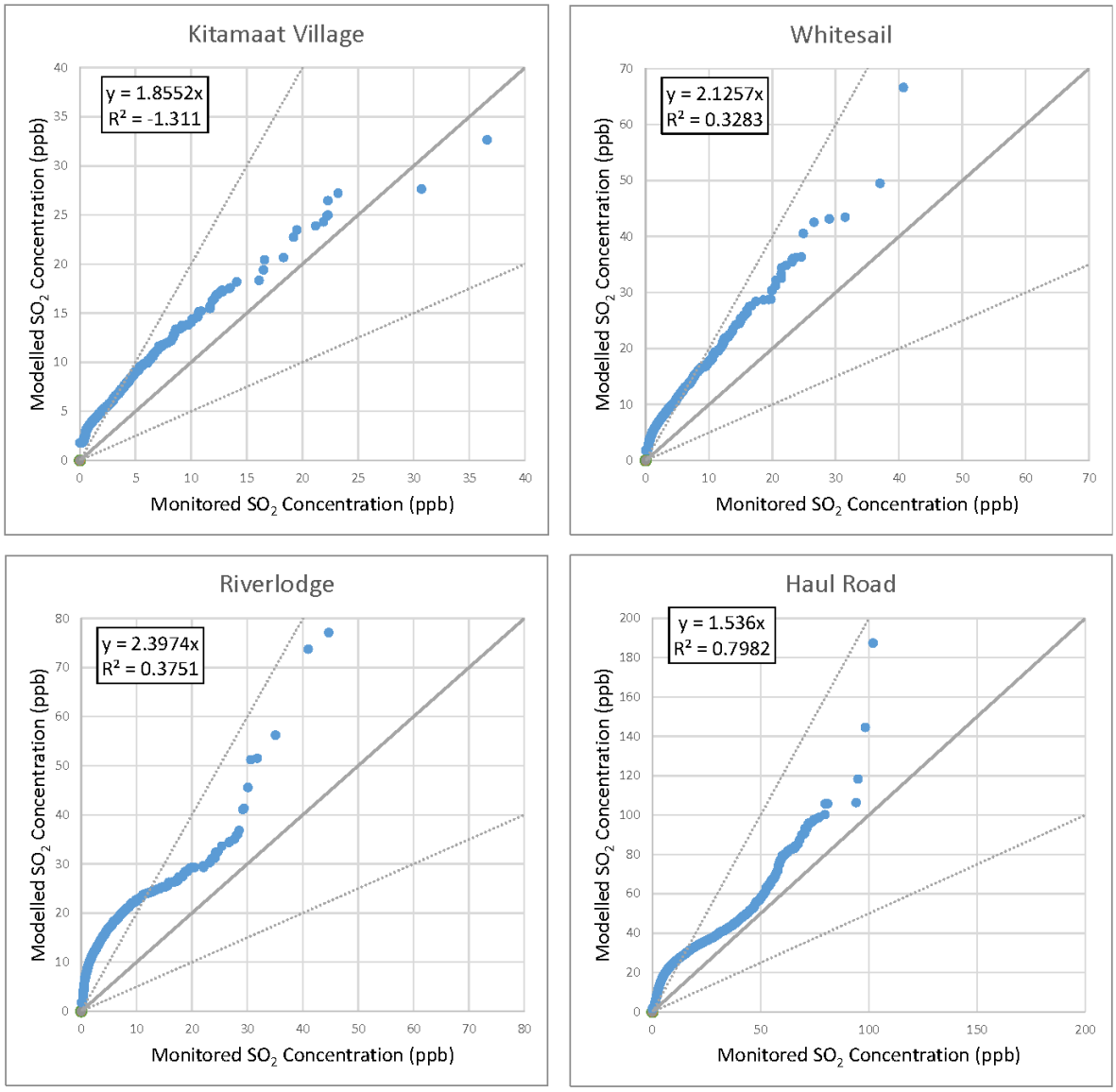


Figure 3-20. Comparison of modelled SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

The Q-Q plots in Figure 3-20 illustrate that the model generally predicts concentrations between 100% and 200% of the monitored concentrations, with the exception of slight under-prediction at Kitamaat Village for the two highest hours over three years and some over-prediction above 200% at the lowest quantile concentrations, particularly for Riverlodge and Haul Road.

Additional model performance evaluation data are included in Atmospheric Appendix Sections 3.1.6 and 3.1.7, including comparison of 1-hour model results in the form of the objective (99th percentile of the daily peak) and model performance statistics (comparing the model versus

monitor paired for each hour). The regional-scale model also over-predicts 1-hour 99th percentile concentrations at all continuous monitoring sites, with a ratio of model to monitor ranging from 1.18 at Kitamaat Village to 1.81 at Whitesail.

We also used the passive sampling measurements to evaluate the 2016–2018 CALPUFF model performance (Figure 3-21). There was strong linear agreement between the modelled and measured SO_2 concentrations; however, there was a different relationship to the north and south of the smelter (Figure 3-21). While the 2016–2018 model over-predicted by approximately 2.2 times at sites to the north, the over-prediction is consistent, indicating good model spatial performance to the north (R^2= 0.86). In contrast, the 2016–2018 CALPUFF model under-predicted SO_2 concentrations at sites to the south of the smelter (model results average 58% of passive sampler results). The confidence in this level and uniformity of under-prediction of concentrations to the south is limited by the fewer number of monitoring sites to the south (R^2 = 0.19 for n=4). Atmospheric Appendix Section 3.1.6 also includes tables and maps for each year comparing the regional scale CALPUFF model results to the passive sampling results.

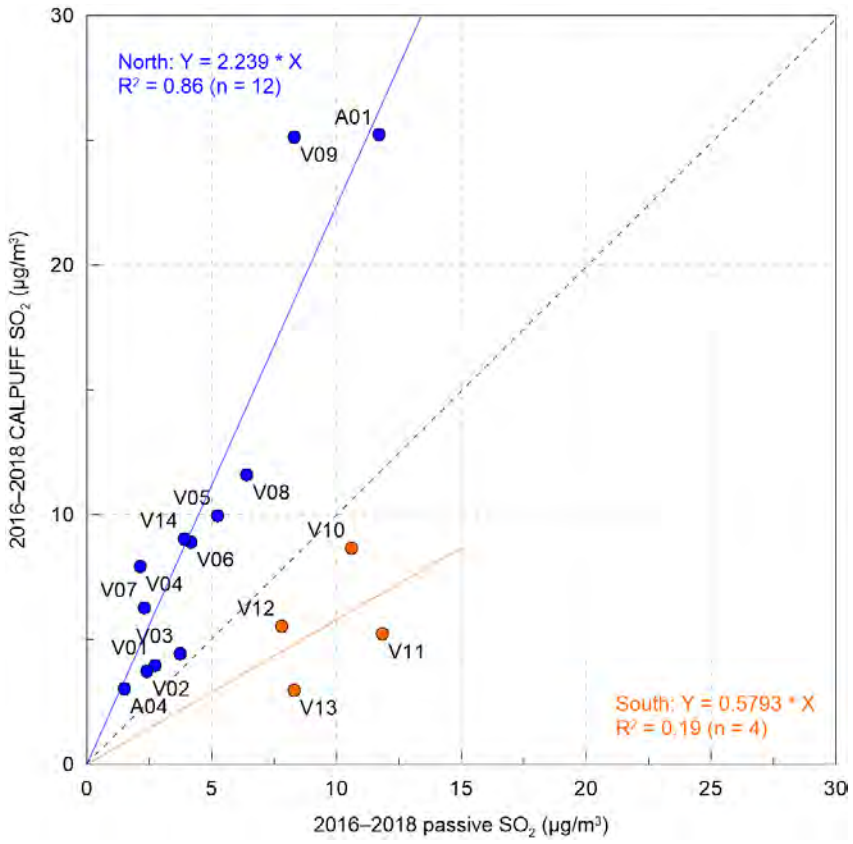


Figure 3-21. Comparison of modelled SO_2 concentrations (actual scenario) against average (2016–2018) passive sample data in the valley network. The 1-to-1 line is shown (dashed line), and best-fit linear regression for sites north and south of the smelter. Passive samplers were calibrated against continuous SO_2 data (see Figure 3-8). Note: the modelled data do not include estimates for residual background concentrations (1.21 µg/m³).

3.1.3.6 *Summary of regional-scale CALPUFF uncertainty*

As discussed in Section 3.1.2.4, dispersion models such as CALPUFF are generally accurate within about a factor of two (actual concentrations can be 50% to 200% of model results). The model performance evaluation described in the previous section also provides valuable information for quantifying the accuracy and uncertainty of the model data. A review of the annual average comparison at each continuous SO_2 monitoring station for each year allows a view of year-to-year and location-to-location variability in model over-prediction (or under-prediction). Table 3-5 (previous section) shows the 2016–2018 annual average CALPUFF model estimates compared to the monitoring data at each station. The model results at the four continuous SO_2 monitors range from 35% to 72% over-prediction of annual average SO_2 concentrations.[23] Based on this comparison, actual concentrations in the areas near the continuous SO_2 monitors are expected to have an uncertainty of approximately -75% to -25% (actual annual concentrations are expected to be 25% to 75% lower than modelled concentrations). However, this evaluation is limited to only four continuous monitoring locations. When also considering the comparison to passive sampling data (Figure 3-21), we can conclude more broadly that the actual annual average concentrations will likely be slightly lower to approximately half of CALPUFF results (actual concentrations likely 50% - 100% of model results) at any location north of the smelter or near Kitamaat Village, while actual concentrations south of the smelter along the western shores of the Douglas Channel are likely slightly higher to double those of CALPUFF results.

3.1.3.7 *SO_2 monitoring network evaluation results*

The local-scale CALPUFF model is used to evaluate the continuous SO_2 monitoring network (preliminary Phase 2 results). As detailed in Section 3.1.2.2, the CALPUFF results are used in the network evaluation by ranking receptors, giving equal weight to the receptor's highest concentration (99^{th} % 1-hour daily maximum concentration, form of the CAAQS) and to the frequency that the highest concentration occurs at that receptor compared to all receptors in the area of evaluation. As shown in Figure 3-22, the new CALPUFF results indicate that the Riverlodge monitor site is near the highest ranked locations within the town of Kitimat. The Whitesail monitor is not located near the highest rank locations; however, it may be located in the nearest site to the 9^{th} ranked location that meets siting criteria.

Note that the spatial SO_2 dispersion patterns predicted in the STAR within residential areas of Kitimat showed some higher concentrations that were suspected to be artifacts of the model's treatment of wind data from two different sources. Subsequent modelling and passive sampling (described in Phase 1 Network Evaluation in Atmospheric Appendix Section 3.1.9) showed spatial patterns consistent with the new model results – the highest concentrations within Kitimat are along the western boundary near Riverlodge.

Additionally, as shown in Figure 3-23, the model prediction of the most suitable location for measuring the highest concentrations within Kitamaat Village is along the western shoreline of

[23] Percentage under-prediction or over-prediction calculated as the difference between the CALPUFF result and observation, as a percent of the CALPUFF result. STAR results on the same basis (using Williams Lake background, STAR results vs. continuous monitors, Figure 3-18) gives an uncertainty of under-predicting by 50% to over-predicting by 74%.

Kitamaat Village. Additional maps showing individual years and individual metrics are included in Atmospheric Appendix Section 3.1.3.

The analysis in this section is preliminary, based on new CALPUFF results only. The formal conclusions for the continuous SO_2 monitoring network evaluation and optimization will be made in the Phase 2 monitoring network optimization report.

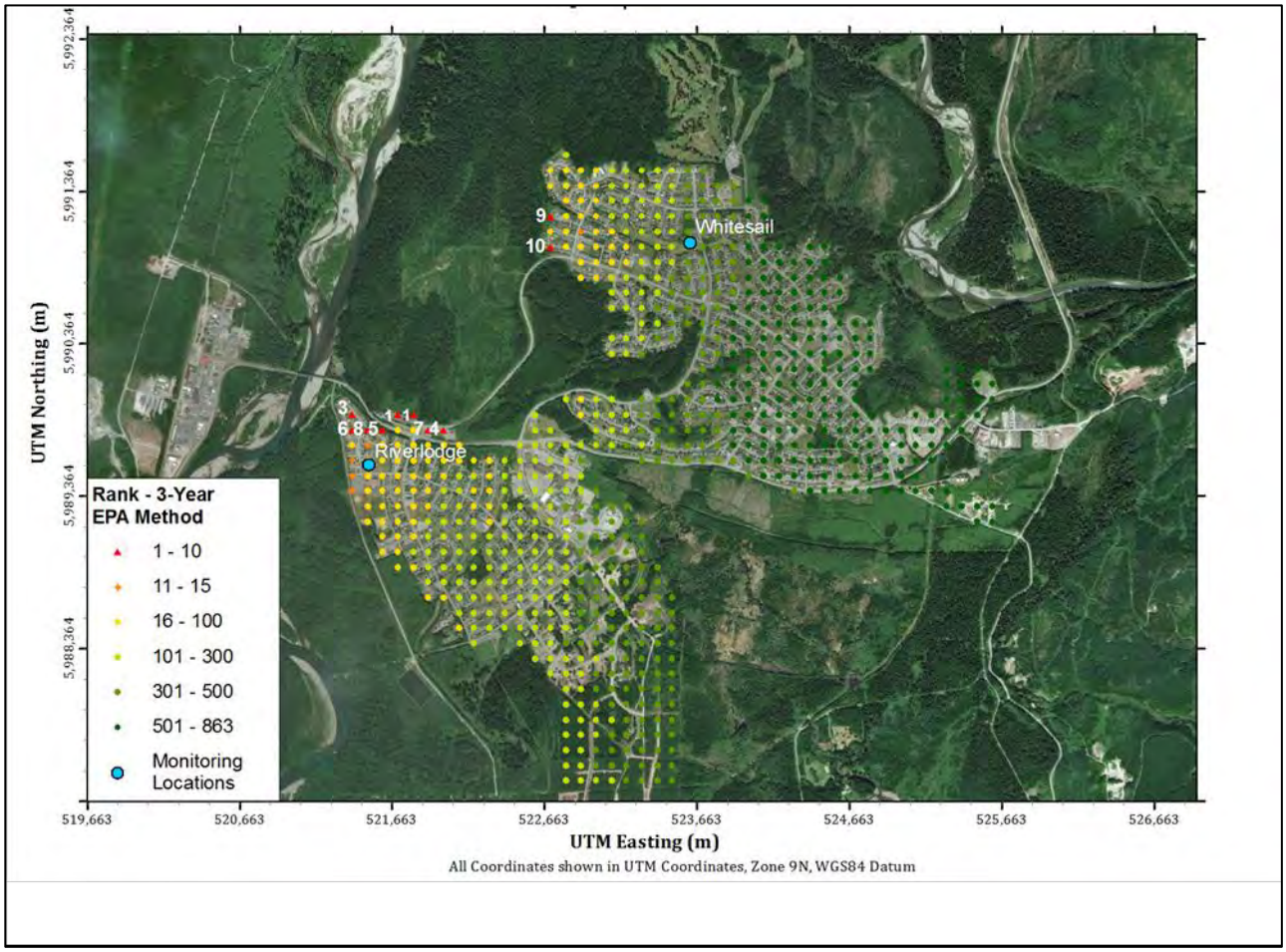


Figure 3-22. Network evaluation results, 2016-2018 met data for Kitimat, 42 tpd scenario, local-scale CALPUFF, considering equal weighting to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.

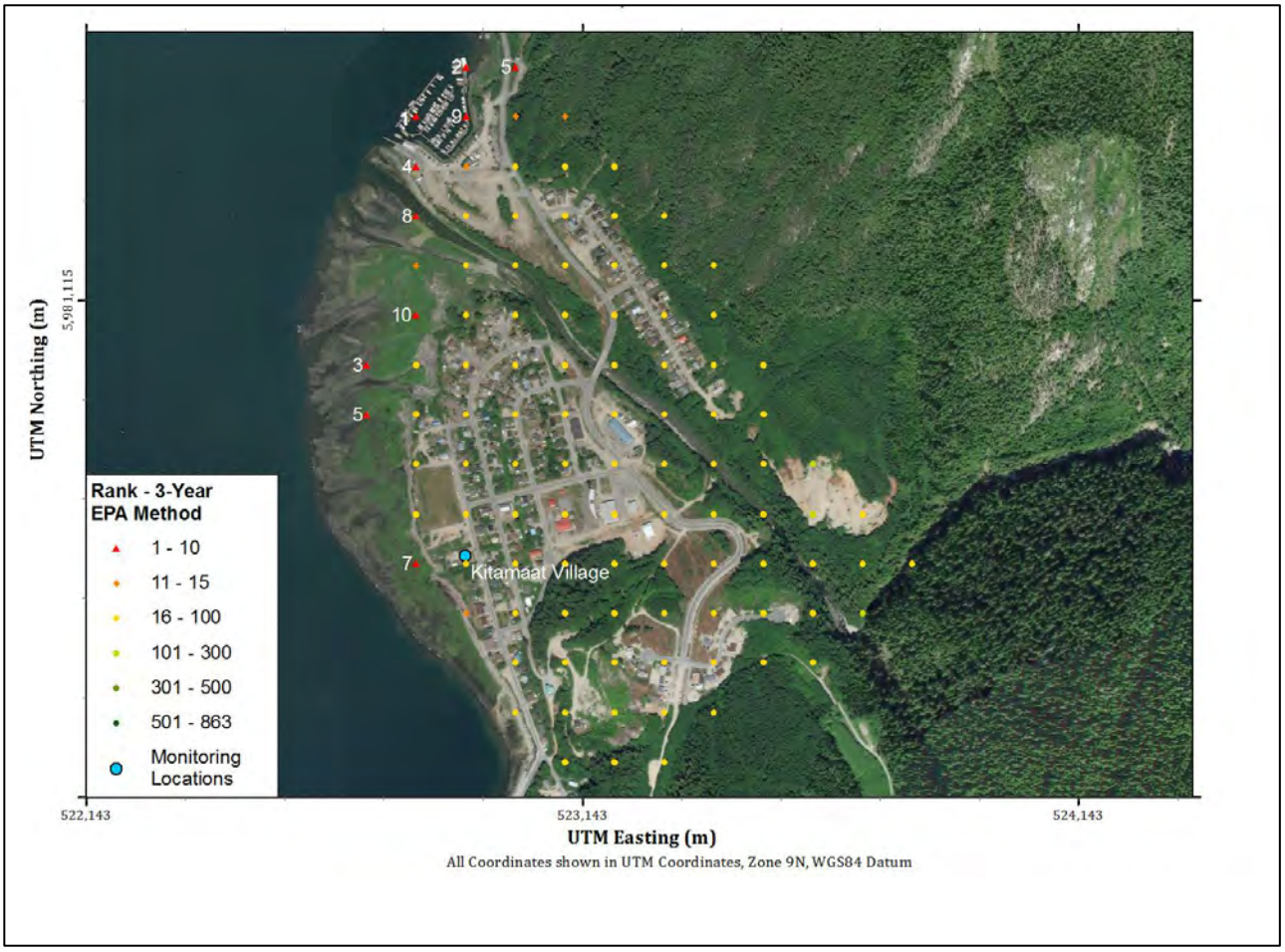


Figure 3-23. Network evaluation results for Kitamaat Village, 2016-2018 met data, 42 tpd scenario, local-scale CALPUFF, considering equal weighting to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.

3.2 Atmospheric Deposition

3.2.1 What did we set out to learn?

The STAR identified two uncertainties within the atmospheric deposition pathway, framed as questions to be addressed through the EEM program:

- STAR question D1: *Does the CALPUFF accurately predict post-KMP total sulphur deposition?*
- STAR question D2: *What are the base cation deposition values in the study region?*

As described in Section 3.1.1, the CALPUFF dispersion model used in the STAR predicted post-KMP SO_2 concentrations and total sulphur deposition throughout the Kitimat Valley. These atmospheric SO_2 and total sulphur deposition predictions were used to complete receptor-specific effects assessments along the four lines of evidence. In this comprehensive review, we set out to learn how accurate the STAR model predictions were and to understand the base cation deposition levels in the study region. We also set out to develop more accurate model predictions of current and future post-KMP atmospheric SO_2 and total sulphur deposition using a new CALPUFF model analysis. The new CALPUFF results are used to complete updated receptor-specific effects assessments to vegetation, and terrestrial and aquatic ecosystems.

The new CALPUFF model, in combination with the 2012-2018 atmospheric monitoring data, provides information to understand the spatial and temporal variability of post-KMP SO_2 concentrations and total sulphur deposition.

3.2.1.1 *EEM informative indicators*

We use the atmospheric deposition results to assess risk of impacts on vegetation, terrestrial, and aquatic ecosystems in Section 5, Section 6, and Section 7, respectively. Since the effects from sulphur deposition on receptors are assessed in receptor-specific evaluations, there are no KPIs for atmospheric deposition. The atmospheric pathway has two atmospheric deposition informative indicators: *atmospheric sulphur deposition* and *base cation deposition*.

We also added two new informative indicators to the EEM Program: *contribution of particulate sulphate to dry sulphur deposition* and *contribution of dry deposition to total deposition*. These indicators are not used to assess effects due to sulphur deposition, but provide valuable information to understand the factors that could lead to variation in deposition rates.

3.2.2 What methods did we use?

Sulphur dioxide is primarily removed from the atmosphere by two mechanisms. During dry periods, SO_2 and pSO_4^{2-} are removed through settling, impaction, and adsorption, termed as 'dry deposition'. SO_2 is also readily taken up by moisture in the air and becomes incorporated into rainfall along with pSO_4^{2-}; this removal mechanism is termed 'wet deposition'. Under the SO_2 EEM program, both wet and dry deposition were measured (modelled) to provide an estimate of total sulphur deposition, which was compared with CALPUFF modelled total sulphur deposition. It is difficult to directly measure dry deposition, as such it is generally estimated using a modelled dry deposition velocity. Therefore, although based on observations of air concentrations (of SO_2 and pSO_4^{2-}), dry deposition is modelled.

3.2.2.1 *Data we collected: wet deposition*

Sulphur wet deposition is measured by collecting samples of precipitation, including both rain and snow. Weekly major ion precipitation chemistry was measured at two stations within the Kitimat Valley. Both stations were incorporated into the National Atmospheric Deposition Program (NADP), which provided standardised equipment (electronic recording rain gauge and a wet deposition collector) and monitoring / measurement protocols. The wet deposition monitoring station at Haul Road (NADP site BC22) was established in September 2012, and the Lakelse Lake station (BC23) in March 2013.

3.2.2.2 *Analyses we conducted with these data: wet deposition*

Quality controlled monthly major ion precipitation chemistry and annual deposition data for Haul Road and Lakelse Lake were obtained directly for the NADP website (URL: nadp.slh.wisc.edu). Data quality and rainfall amount were evaluated for each station. The annual seasonality and long-term temporal trend between the two three-year periods 2013–2015 and 2016–2018 were evaluated. The changes in sulphate (SO_4^{2-}) deposition were compared with other NADP stations (BC24, WA19 and AK02). The monitoring data were also used to evaluate non-sea salt and non-anthropogenic base cation deposition, which is a required input for critical loads of acidity for soils.

3.2.2.3 *Data we collected: dry deposition*

Dry deposition measurements are difficult to make because of the requirements for highly sophisticated methods and instrumentation (Wesely and Hicks 2000). In general, dry deposition is modelled from air concentrations of gaseous and particulate species (e.g., SO_2 and p SO_4^{2-}) multiplied by a species-specific dry deposition velocity estimated using modeling techniques, i.e., 'inferential' models (Vet et al. 2014).

$$F_{dry} = C \times V_d$$

where F_{dry} is the dry deposition flux, C is the measured ambient air concentration, and V_d is the deposition velocity, which is influenced by factors such as wind speed, height of observation, heat flux, moisture availability, vegetation, and surface roughness (Wesely and Hicks 2000).

The 'big-leaf' model developed by Environment and Climate Change Canada (Zhang et al. 2001, 2003a, 2003b; Zhang and He 2014) was used to estimate hourly species-specific V_d at three stations in the Kitimat Valley (Haul Road, Whitesail and Terrace Airport [YXT]). The V_d model required meteorological forcing variables on an hourly resolution for the period of interest (2015–2018). The data sources for the big-leaf dry deposition velocity model at three stations are shown in Table 3-7. The model also required site-specific variables, such as latitude and land cover; deposition velocities were estimated for coniferous land cover only. For further details on the big-leaf model see Technical Memo D01 (2016) and Technical Memo D02 (2018).

Table 3-7. Data sources for meteorological variables required to model deposition velocity at Haul Road, Whitesail and Terrace Airport.

Variable	Kitimat: Haul Road	Kitimat: Whitesail	Terrace Airport
Temperature	Haul Road hourly	Whitesail hourly	Terrace Airport hourly
Wind speed	Haul Road hourly	Whitesail hourly	Terrace Airport hourly
Relative humidity	Whitesail hourly	Whitesail hourly	Terrace Airport hourly
Solar irradiance	Modelled from maximum and minimum daily temperature using Hargreaves method	Modelled from maximum and minimum daily temperature using Hargreaves method	Modelled from maximum and minimum daily temperature using Hargreaves method
Precipitation rate	NADP Haul Road	NADP Haul Road	Terrace Airport daily data, disaggregated by NADP Lakelse Lake hourly data
Surface pressure	2015 & 2016: estimated from Terrace A hourly data. 2017 & 2018: Haul Road	2015 & 2016: estimated from Terrace A hourly data. 2017 & 2018: Haul Road	Terrace Airport hourly
Snow depth	Environment Canada, Kitimat Hatchery, daily data applied to all hours	Environment Canada, Kitimat Hatchery, daily data applied to all hours	Terrace A / Terrace PCC daily snow depth, applied to all hours
Cloud fraction	3-hourly Terrace Airport	3-hourly Terrace Airport	3-hourly Terrace Airport

3.2.2.4 *Analyses we conducted with these data: dry deposition*

We estimated hourly dry deposition velocities for a range of atmospheric gaseous species and particle size classes (including SO_2 and pSO_4^{2-}). We evaluated the influence of meteorological variables on deposition velocity to assess the potential error in using multiple data sources for a single station (Table 3-7). We estimated dry deposition for SO_2 using modelled hourly dry deposition velocities.

3.2.2.5 *Analyses we conducted with these data: total deposition*

We produced observation-based estimates of total sulphur deposition at Haul Road and Lakelse Lake by combining:

- measured wet S deposition (obtained from the NADP precipitation),
- estimated dry SO_2 deposition (based on hourly modelled deposition velocity and air concentrations from continuous analyzers[24]), and
- estimated dry deposition of pSO_4^{2-} (based on the relationship in Figure 3-12).

3.2.2.6 *CALPUFF modelling methods*

We used the new 2016-2018 CALPUFF model described in Section 3.1.2.4 to update predictions of deposition rates throughout the Kitimat Valley for the three model scenarios (actual, 35 ptd,

[24] SO_2 concentrations at Haul Road are obtained directly from the Haul Road station analyzer from 2016-2018. At Lakelse Lake, SO_2 concentrations were obtained from passive sampling during June to October, which was scaled to annual concentrations using the ratio in air concentrations observed at Haul Road.

and 42 tpd). The resolution of the deposition results was 1 km spacing for the STAR, which has been refined to 0.5 km spacing for the current effort. Section 3.1.2.4 summarizes the model methods, and Atmospheric Appendix Section 3.1.5 describes the methods in more detail.

3.2.3 What did we learn, and did we make any adjustments to the EEM Program?

3.2.3.1 *Overview of EEM monitoring program results – wet deposition network*

The long-term (2014–2018) average annual rainfall volume at Haul Road (2408 mm) is approximately 1.7 times Lakelse lake (1423 mm). The pattern is generally consistent for every year of observations (Figure 3-24). The monthly ion balance for stations indicates an anion deficit (Figure 3-24), which is notably larger at Haul Road, this may be driven by missing anions (e.g., fluoride or organic ions) or by removal of outliers in monthly summaries. Only two of the major ions in deposition chemistry showed any large change between the periods 2013–2015 and 2016–2018 (both three-year periods). SO_4^{2-} and hydrogen ion (H^+) concentration in precipitation increased at both Haul Road and Lakelse Lake between these periods; sulphate (mg/L) increased by 63% at Haul Road and 72% at Lakelse Lake, and H^+ increased by 26% and 48%, respectively. We compared changes in sulphur deposition for the same period against three other NADP stations (one in B.C., one in Alaska and one in Washington state; (Table 3-8); there was an observed decrease in sulphur deposition at the other stations compared with the increase at BC22 and BC23 in the Kitimat Valley (Table 3-8). There was a decrease in sulphate deposition at Haul Road and Lakelse Lake in 2018 compared with 2017 (Table 3-8), this was caused by the low precipitation volume (Figure 3-25). Focusing on sulphur and pH (hydrogen ion concentration), sulphur did not show a consistent seasonal pattern between stations; in contrast, pH at Haul Road and Lakelse Lake showed minima during June–July (Figure 3-24). The long-term time-series for Haul Road and Lakelse Lake show a step change (increase) in the deposition of sulphur from 2013–2015 compared with 2016–2018 (Figure 3-24 and Figure 3-25; note that the scale for Haul Road is a factor of 10 higher than Lakelse Lake). The long-term time-series for pH showed a similar decrease (Figure 3-24; note a decrease in pH is equivalent to an increase in H^+ concentration). However, at Haul Road the pH of rainfall increased during the period 2013–2015, and subsequently decreased during 2016–2018.

STAR question D2: *What are the base cation deposition values in the study region?*

Base cation deposition is a required input for the determination of critical loads of acidity for terrestrial ecosystems (soils). Base cation deposition should be corrected for sea salts and excluded anthropogenic inputs, i.e., it should reflect ambient 'background' deposition of base cations. We evaluated annual base cation (BC = Ca^{2+} (calcium) + Mg^{2+} (magnesium) + K^+ (potassium) + Na^+ (sodium)) precipitation chemistry at three NADP stations, Haul Road [BC22], Lakelse Lake [BC23] and Port Edward [BC24] during the period 2014–2018 (2013–2018 for BC22). Following correction for sea salts, Mg^{2+} and Na^+ were zero, i.e., they had no non-sea salt sources at both stations. Long-term $Ca^{2+}$and K^+ in precipitation were almost equal at Lakelse Lake and Port Edward (, i.e., Ca^{2+} was 0.71 µeq/L at both sites, and K^+ was 0.09–0.10 µeq/L at Port Edward–Lakelse). In contrast, the precipitation concentrations at Haul Road were 1.5 (K^+) to >2 (Ca^{2+}) times larger than the other two sites. It was assumed that precipitation chemistry at Haul Road was influenced by anthropogenic sources; as such, regional base cation precipitation was set to the average for Lakelse Lake and Port Edward. Regional base cation deposition was estimated by multiplying mapped rainfall volume by average 'background' base cation precipitation = 0.8 µeq/L (Ca^{2+} = 0.71 µeq/L and K^+ = 0.09 µeq/L). See Terrestrial Ecosystems (Soils) Appendix 6.6 for a map of base cation deposition across the Kitimat Valley.

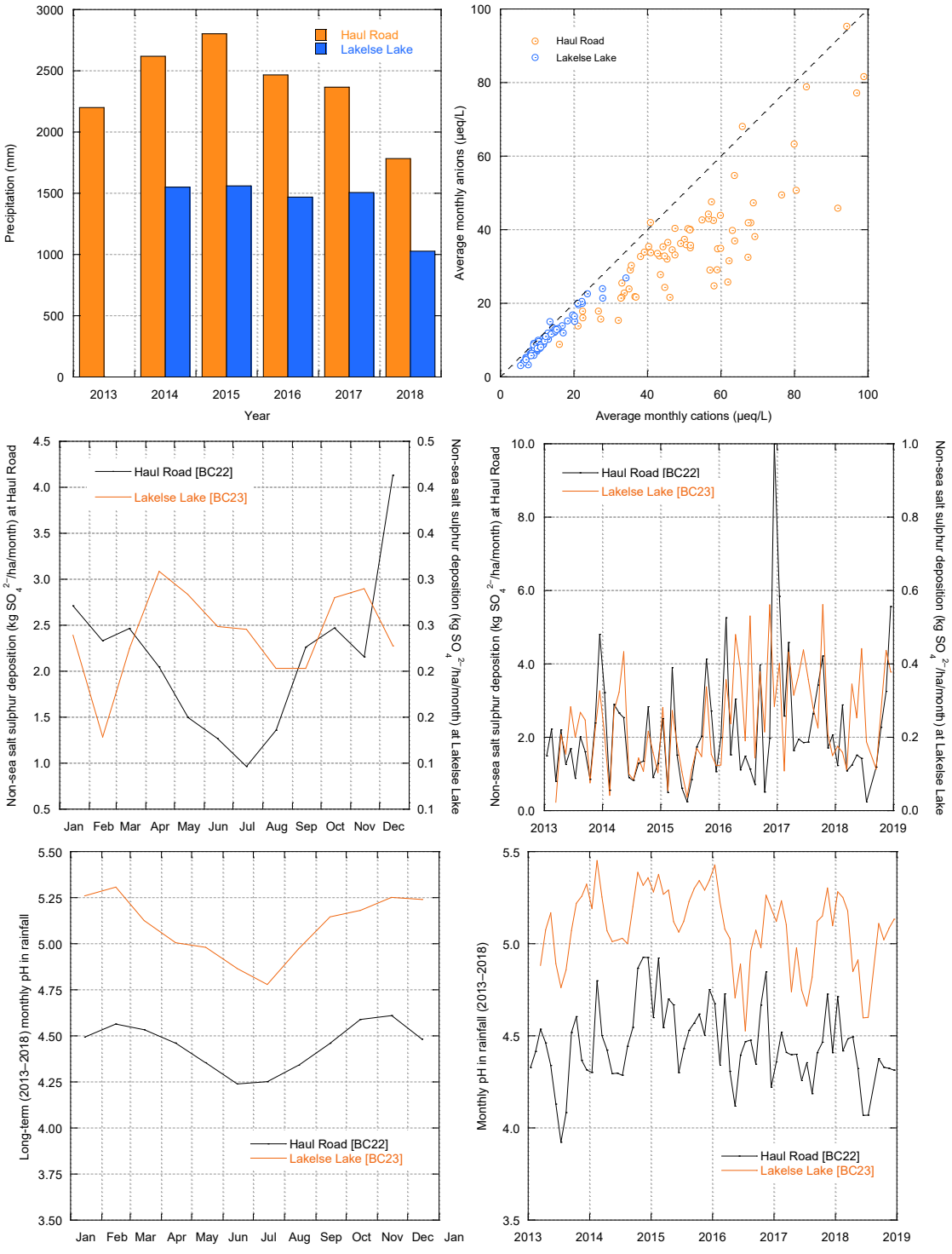


Figure 3-24. Comparison of precipitation chemistry at Haul Road and Lakelse Lake. Top row: Rainfall volume and ion balance. Middle row: Seasonal and long-term monthly non-sea salt sulphur deposition (kg SO_4^{2-}/ha/month); note different axis for Haul Road and Lakelse Lake. Bottom row: Seasonal and long-term monthly pH (see Atmospheric Appendix 3.2.1 for larger version).

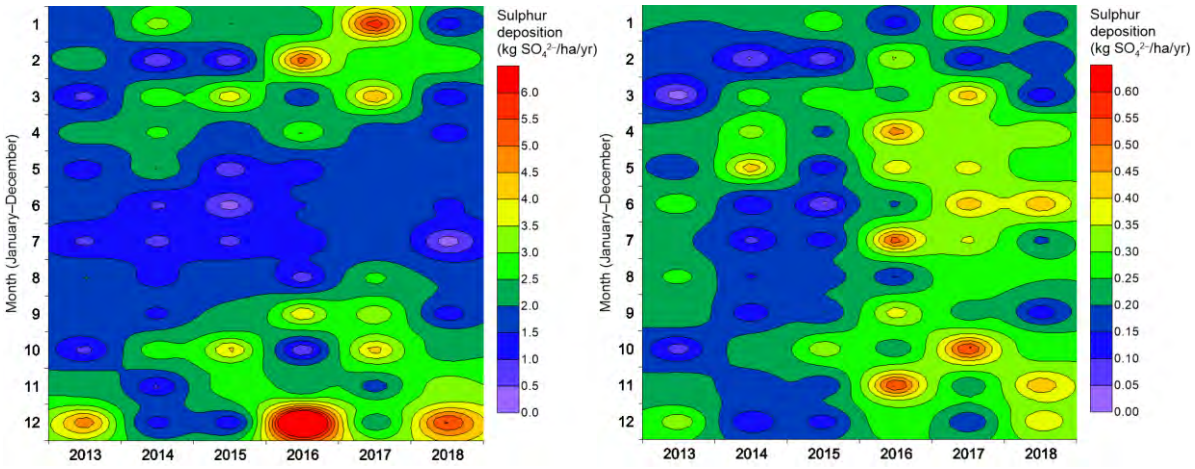


Figure 3-25. Year-month maps showing monthly deposition of non-marine sulphate at Haul Road (left) and Lakelse Lake (right) during the period 2013–2018 (six-years).

Table 3-8. Annual non-sea-salt (excess) sulphur deposition (kg SO_4^{2-}/ha/year) at wet-only monitoring stations within the National Atmospheric Deposition Program (NADP) network during 2013 to 2018. Also shown is the ratio between the two periods 2013–2015 and 2016–2018.

Station	Haul Road	Lakelse Lake	Port Edward	North Cascades	Juneau
Year	BC22	BC23	BC24	WA19	AK02
2013	21.83	2.38*	—	3.01	2.90
2014	20.41	1.95	3.65	2.81	2.55
2015	21.03	1.82	3.46	1.78	2.26
2016	32.38	3.37	2.45	2.30	1.89
2017	33.64	3.68	2.93	1.59	1.87
2018	21.17	3.00	2.33	1.72	1.91
Ratio ($^{16\text{-}18}/_{13\text{-}15}$)	1.38	1.63	0.72	0.74	0.74

* The 2013 annual average was based on 10 months of observations.

3.2.3.2 *Overview of EEM monitoring program results – dry deposition*

Annual modelled dry deposition velocity (V_d) for SO_2 during 2016–2018 ranged 0.49 cm/s at Haul Road (0.47–0.51 cm/s) to 0.83 cm/s at Terrace Airport (0.74–0.91 cm/s). The V_d for SO_2 is generally higher than other gases (e.g. nitrogen dioxide (NO_2) and ozone (O_3)) and particles ($PM_{2.5}$) within the Kitimat Valley (Table 3-9). The V_d for pSO_4^{2-} was assumed to be equivalent to $PM_{2.5}$, which is about one-third of the V_d for SO_2 (and lower than other gases and particles; Table 3-9). Daily V_d for SO_2 was highly variable within and between months (Figure 3-26) with no clear seasonal pattern across the three sites. Overall, modelled V_d for SO_2 were highest at Terrace Airport and lowest at Haul Road (Figure 3-18, also true for other gases and particles see Table 3-9). The monthly average V_d for SO_2 showed lower variation between summer exposure months

(Table 3-10; June to October exposure period for passive samplers); the average coefficient of variation was 20%, which ranged from 8.3% (2017 at Haul Road) to 30.3% (2016 at Haul Road). The average V_d at Haul Road is very similar to Whitesail during 2016–2018, i.e., 0.53 cm/s compared with 0.56 cm/s, respectively.

A one-at-a-time sensitivity analysis was carried out to assess the influence of input variables on modelled V_d. Gaining an understanding of which variable most influences V_d is valuable because a number of input variables were estimated or taken from nearby stations (Table 3-7) rather than those variables originating directly from observations at the same site. Temperature had the greatest influence, i.e., ±30% change in temperature resulted in a 56% decrease in V_d for SO_2 (a 30% increase in temperature resulted in a 56% decrease in V_d and a 30% decrease in temperature resulted in a 106% increase in V_d). Windspeed and relative humidity were the next sensitive (with windspeed being the most sensitive) and had a similar magnitude and direction of effect; i.e., a 30% increase resulted in a 20% increase in V_d and a 30% decrease resulted in a 20% decrease in V_d. A ±30% change in solar irradiance, precipitation, surface pressure, snow depth and cloud fraction had negligible influence on modelled V_d for SO_2. In the current study, temperature and windspeed were site-specific measurements; the only sensitive parameter that was infilled at Haul Road was relative humidity, which was taken from Whitesail (Table 3-7).

Given the low observed atmospheric concentration of pSO_4^{2-} compared with SO_2 (factor of 10 lower; see Table 3-3) and the lower V_d for pSO_4^{2-} compared with SO_2 (approximately one-third of the value, see Table 3-9), the estimated dry deposition of pSO_4^{2-} makes up a small fraction of total (pSO_4^{2-} + SO_2) dry deposition, and an even smaller fraction of total (wet plus dry) sulphur deposition.

Table 3-9. Annual average (hourly) dry deposition velocity of four common gases (sulphur dioxide, nitrogen dioxide, ozone, ammonia) and two particle size classes at three climate monitoring stations during 2016–2018. The deposition velocities assume coniferous landcover.

Station	Year	SO_2	NO_2	O_3	NH_3	$PM_{2.5}$	$PM_{2.5-10}$
		cm/s	cm/s	cm/s	cm/s	cm/s	cm/s
Haul Road	2016	0.48	0.27	0.30	0.55	0.13	0.49
Haul Road	2017	0.51	0.28	0.31	0.58	0.14	0.51
Haul Road	2018	0.47	0.25	0.27	0.54	0.14	0.51
Whitesail	2016	0.47	0.22	0.25	0.50	0.14	0.49
Whitesail	2017	0.56	0.28	0.32	0.61	0.17	0.51
Whitesail	2018	0.58	0.29	0.33	0.65	0.18	0.51
Terrace YXT	2016	0.91	0.51	0.59	0.99	0.33	1.62
Terrace YXT	2017	0.85	0.48	0.55	0.93	0.32	1.58
Terrace YXT	2018	0.74	0.43	0.49	0.81	0.29	1.41

Table 3-10. Monthly (June–October) average (hourly) dry deposition velocity (cm/s) for sulphur dioxide at three climate monitoring stations during 2016–2018. The five-month (June–October) average and variation between months (as coefficient of variation [CV]) is also shown.

Station	Year	Monthly Dry Deposition Velocity (cm/s)					Average	CV
		June	July	August	September	October	cm/s	%
Haul Road	2016	0.63	0.63	0.45	0.61	0.27	0.52	30.3
Haul Road	2017	0.62	0.59	0.64	0.52	0.64	0.60	8.3
Haul Road	2018	0.63	0.42	0.48	0.41	0.43	0.47	19.1
Whitesail	2016	0.50	0.53	0.43	0.56	0.29	0.46	23.1
Whitesail	2017	0.43	0.68	0.73	0.60	0.78	0.64	21.3
Whitesail	2018	0.73	0.52	0.60	0.54	0.52	0.58	15.3
Terrace YXT	2016	0.96	0.93	0.72	0.98	0.97	0.91	12.0
Terrace YXT	2017	0.85	0.78	0.86	0.77	1.00	0.85	10.6
Terrace YXT	2018	0.88	0.58	0.64	0.79	0.78	0.73	17.0

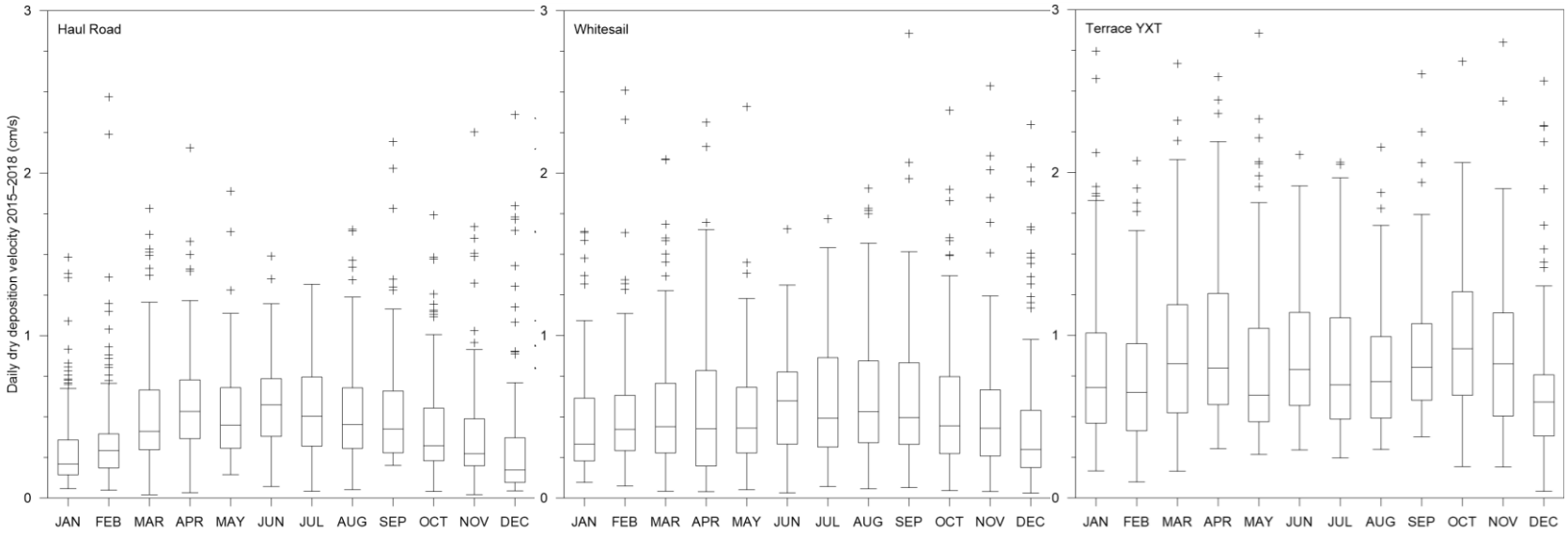


Figure 3-26. Box-plot showing the variation in daily dry deposition velocity (cm/s) for sulphur dioxide each month during the period 2015–2018 (four years) at Haul Road, Whitesail and Terrace airport.

3.2.3.3 *Summary of CALPUFF model results for total sulphur deposition*

Figure 3-27 and Figure 3-28 present the new 2016-2018 CALPUFF model deposition results. The model outputs deposition of total sulphur from SO_2 and SO_4^{2-} wet and dry deposition, which is presented in units of kg SO_4^{2-} /ha/yr. The new 2016–2018 CALPUFF model predicts a similar spatial distribution of deposition as was predicted in the STAR; however, some differences are notable. As shown in Figure 3-29, which compares the new CALPUFF deposition and the STAR CALPUFF deposition results, the 7.5 kg SO_4^{2-} /ha/yr isopleth extends farther to the southwest and does not extend as far to the north. The new CALPUFF model predicts a smaller area within the 7.5 kg SO_4^{2-} /ha/yr isopleth compared to STAR due to the change in extent to the north (Table 3-12).

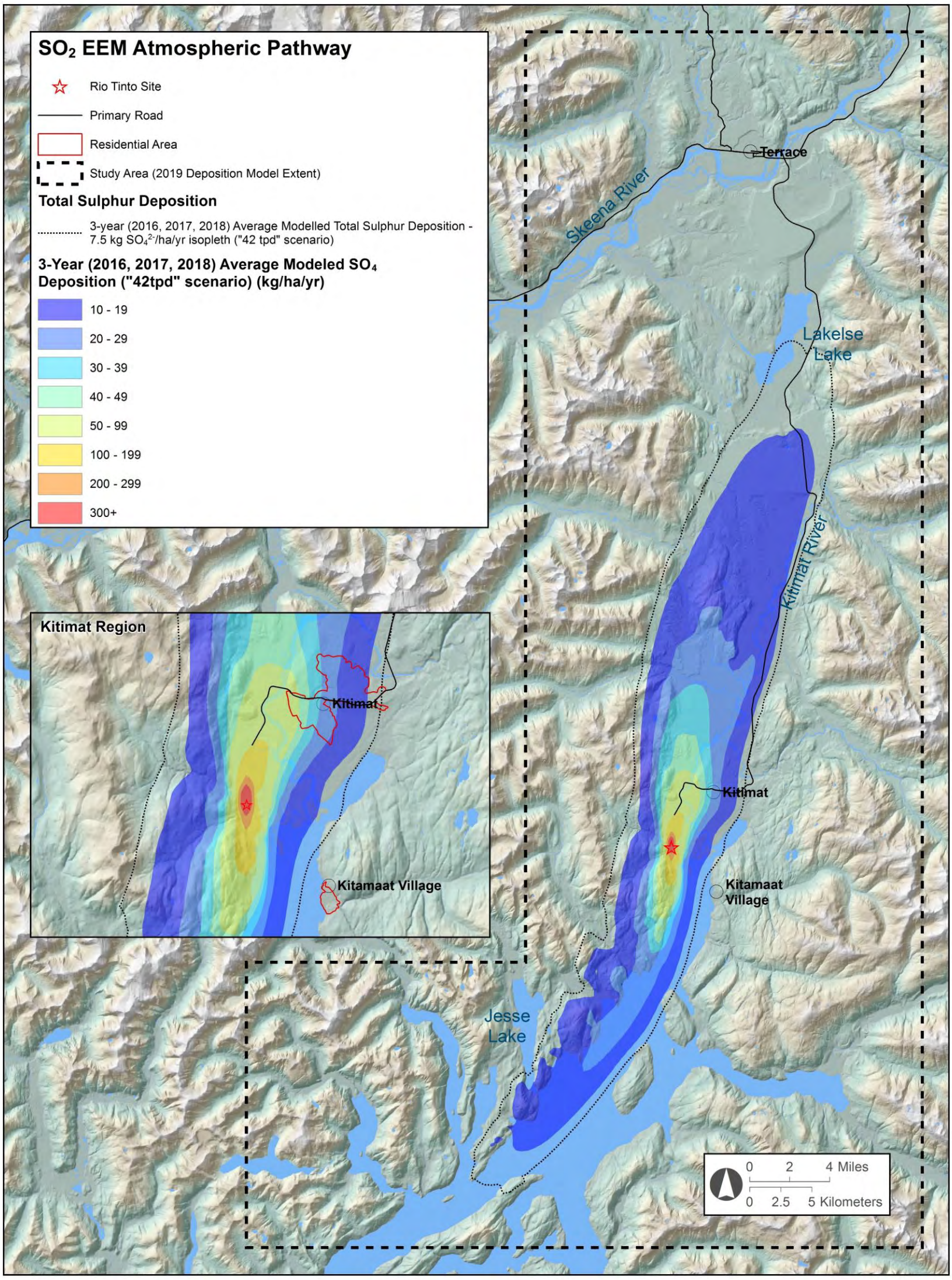


Figure 3-27. Modelled total sulphur deposition as SO_4^{2-} (kg/ha/yr SO_4^{2-}), 42 tpd scenario, 3-year average, regional (not including background).

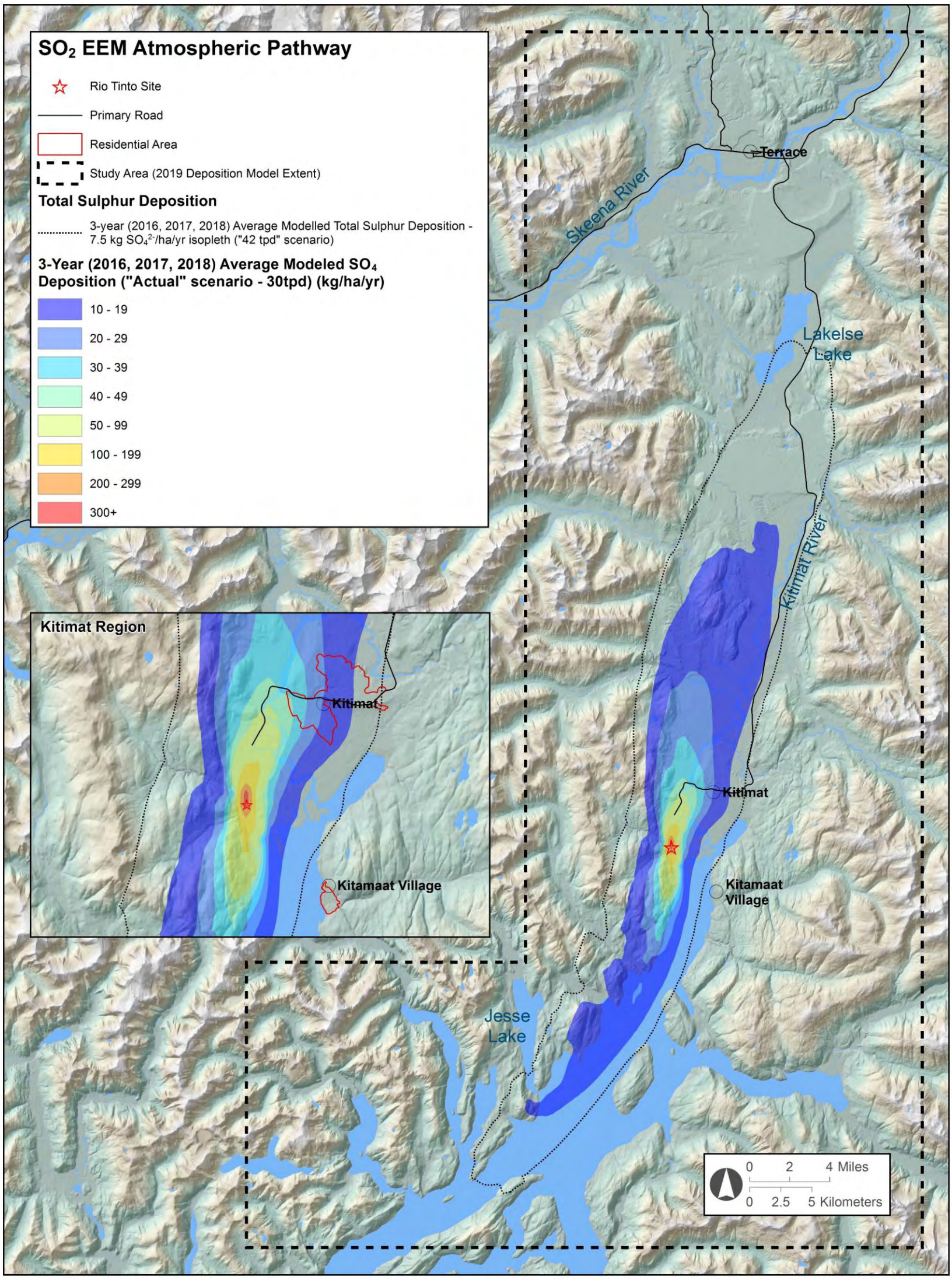


Figure 3-28. Modelled total sulphur deposition as SO_4^{2-} (kg/ha/yr SO_4^{2-}), actual scenario (29.3 tpd), 3-year average, regional (not including background).

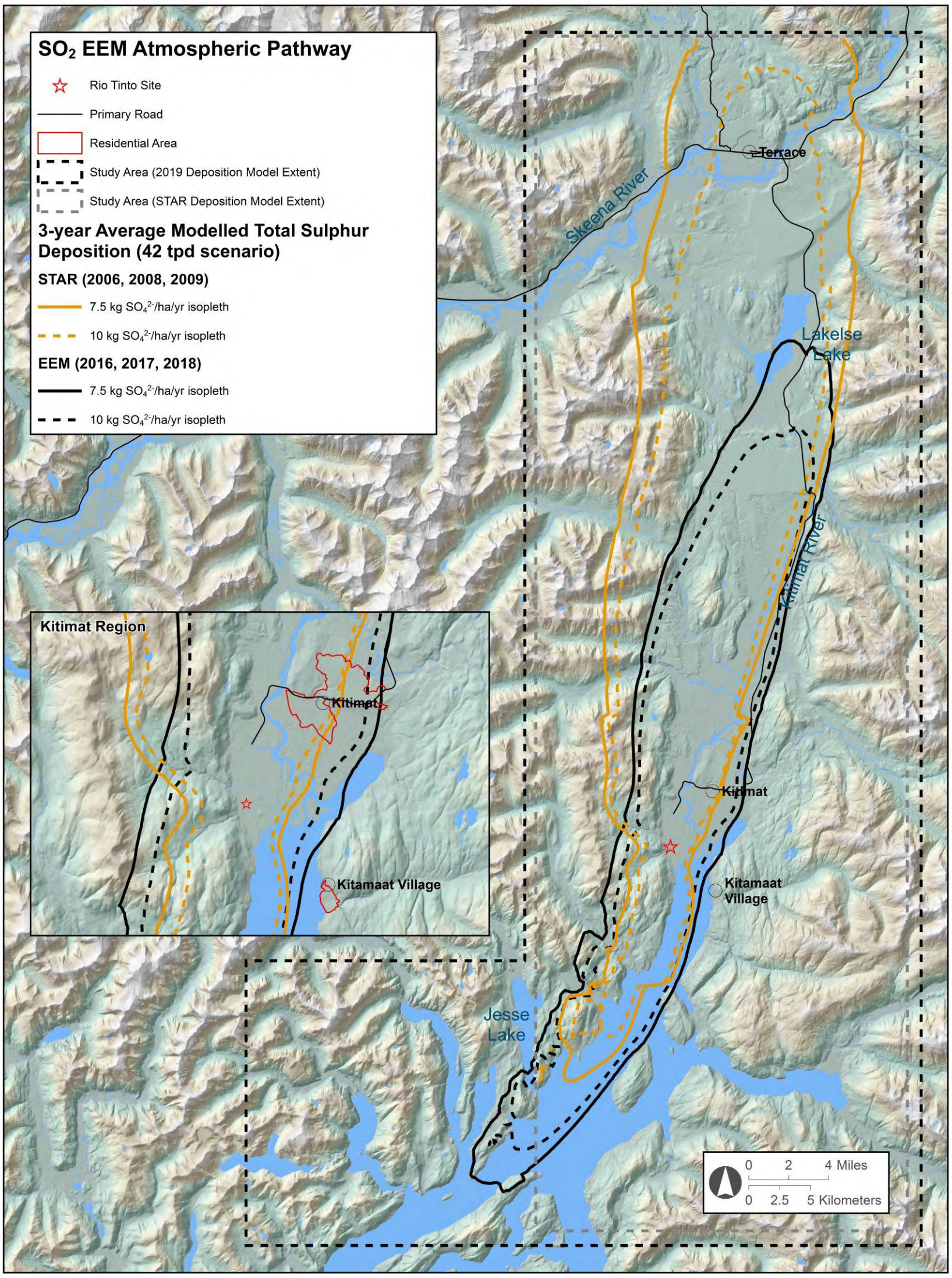


Figure 3-29. Modelled total sulphur deposition as SO_4^{2-} (kg/ha/yr SO_4^{2-}) for new CALPUFF versus STAR, 42 tpd scenario, 3-year average, regional (not including background).

Only a small fraction of SO_2 emitted from the smelter is deposited through wet or dry deposition within the study area (Table 3-11). This fraction is 8.1% for the 42 tpd scenario based on the 3-year average new 2016–2018 CALPUFF model results. The remaining SO_2 stays in the atmosphere and eventually exits the model domain. Deposition rates beyond the CALPUFF domain are well below levels we use to define the area within which deposition impacts may occur (7.5 kg/ha/yr).

Table 3-11. Percentage of SO_2 emitted from the smelter that is deposited through wet or dry deposition within the study area as predicted by CALPUFF (based on 42 tpd scenario).

Year	Deposited (ton/day (as SO_2))	Deposited (as % of emitted)	Not Deposited (as % of emitted)
2016	3.47	8.3	91.7
2017	3.55	8.4	91.6
2018	3.13	7.5	92.5
3-year Average	3.38	8.1	91.9

* Note that the amount 'deposited' is based on wet and dry deposition of total sulphur SO_2 and SO_4^{2-}. The number shown is total S deposited as SO_2, so it can be compared to the sulphur emitted.

Table 3-12. Sulphur deposition boundary area of new CALPUFF model compared to STAR CALPUFF model.

	Area of Plume (km^2)	
Deposition Scenario:	7.5 kg/ha/yr SO_4^{2-}	10 kg/ha/yr SO_4^{2-}
3-year average SO_4^{2-} deposition for 2006, 2008, 2009 - Post-KMP (STAR) - 42 tpd Scenario	1,012*	722
3-year average modelled SO_4^{2-} deposition for 2016, 2017, and 2018 (New CALPUFF) - 42 tpd Scenario	578	418
Difference	*-433*	*-304*
* The STAR "Post-KMP" deposition (7.5 kg/ha/yr SO_4^{2-}) is cut-off at the north end, leading to a restricted estimate of its area.		

3.2.3.4 *Summary of regional-scale CALPUFF model performance for total sulphur deposition*

STAR question D1: Does the CALPUFF accurately predict post-KMP total sulphur deposition?

Table 3-13 compares the annual and 3-year average wet, dry, and total deposition at the two NADP stations. Similar to the STAR model, the new CALPUFF model predicts that wet deposition dominates the total sulphur deposition; however wet deposition observations combined with the big-leaf model dry deposition estimates indicate that wet and dry deposition contribute approximately equal amounts, with dry contributing a slightly higher fraction than wet at Haul

Road, and wet contributing a slightly higher fraction than dry at Lakelse Lake. Overall, the new CALPUFF model predictions of total sulphur deposition compare well to the monitor results. When considering that the model results do not include background deposition (which may be up to 3.6 kg SO_4^{2-}/ha/yr; see Terrestrial Ecosystems (Soils) Appendix 6.7, the new model over-estimates actual deposition rates at Haul Road by 24% to 29% (3-year average comparison of observed to modelled without background and to modelled with maximum background), and predicts actual deposition at Lakelse Lake from 16% under-estimation to 47% over-estimation (3-year average comparison of observed to modelled without background and to modelled with maximum background).

Table 3-13. Annual and three-year average wet, dry and total observation-based deposition and CALPUFF modelled sulphur deposition (kg SO_4^{2-}/ha/yr) at Haul Road and Lakelse Lake during 2016 to 2018.

Station	Year	Observation			Model		
		wet	dry	total	wet	dry	total
Haul Road	2016	32.38	42.88	75.26	75.83	15.36	91.20
	2017	33.64	39.44	73.08	82.69	14.58	97.26
	2018	21.17	34.45	55.62	50.46	14.98	65.45
	Average	29.06	38.92	67.99	69.66	14.97	84.63
Lakelse Lake	2016	3.37	2.67	6.04	2.81	2.41	5.22
	2017	3.68	2.66	6.34	2.62	2.51	5.14
	2018	3.00	2.14	5.14	2.00	2.47	4.47
	Average	3.35	2.49	5.84	2.48	2.47	4.94

* Note: wet deposition is a direct measurement obtained from the NADP station; in contrast, dry deposition is estimated from measurements of atmospheric SO_2 and modelled deposition velocity (using the big-leaf model).

Under the STAR, observation-based estimates of total (wet and dry) sulphur deposition were compared with pre-KMP modelled total deposition (ESSA et al. 2013). CALPUFF total sulphur deposition at Haul Road under pre-KMP was ~93 kg SO_4^{2-} ha/yr. In comparison, the observation-based estimate of total deposition was ~65 kg SO_4^{2-} ha/yr during the period 2007–2011 (5-year annual average), composed of ~35 kg SO_4^{2-} ha/yr wet deposition and ~30 kg SO_4^{2-} ha/yr dry deposition. The pre-KMP comparison suggested that STAR CALPUFF simulations overestimated total sulphur deposition at Haul Road (consistent with the current study); however, both showed approximately the same proportion of dry deposition (42% CALPUFF and 46% observed data). Under the current study, observation-based estimates show a similar but higher proportion of dry deposition at 57% likely owing to the inclusion of site-specific high temporal resolution V_d and the low rainfall volume during 2018. In contrast, the 2016-2018 CALPUFF predicts a much lower proportion of dry deposition at 18% (compared with 42% under the STAR),

3.3 What do we recommend for the EEM Program going forward?

Overall, we recommend continuing the atmospheric monitoring within the EEM program with relatively few changes to the core monitoring programs (SO_2 continuous monitoring and Valley Network passive sampling).

We recommend continuing SO_2 continuous monitoring at all or most of the current sites. The Phase 1 monitoring network evaluation indicated that the Riverlodge monitor site is in the most suitable location for measuring the highest concentrations within the town of Kitimat, and that the Kitamaat Village monitoring station is in the best location for Kitamaat Village. The preliminary Phase 2 network evaluation does not contradict these conclusions, but the Phase 2 evaluation should be completed before making final conclusions. Therefore, final continuous network recommendations will be made as part of the Phase 2 network optimization report. In the interim, the continuous SO_2 monitoring should continue at the current sites pending the Phase 2 network evaluation completion.

We also recommend continuing the passive sampling network in the Kitimat Valley because it adds value for understanding the spatial distribution of SO_2. In particular, the passive sampling network added substantial value for evaluating CALPUFF model performance. Accurate CALPUFF prediction of SO_2 (and SO_4^{2-} deposition) reduces uncertainty when using the CALPUFF output for evaluating risk of impacts to vegetation, terrestrial, and aquatic ecosystems. However, the number of sites and frequency of monitoring should be reviewed. For example, in order to gain a better understanding of the plume position and extent in the east-west direction, we recommend adding passive sampling sites to the east and west of current sites located to the north of the smelter, where possible based on access, and in locations that meet the B.C. air monitoring site selection guidelines for passive sampling. The current north to south network could be reduced to accommodate the proposed east to west expansion. Two or three cross sections over two to three years will be sufficient for model evaluation needs. Additionally, we recommend evaluating whether additional passive sampling sites can be established in locations south of the smelter. Lastly, the passive sampling site locations should be assessed for whether some sites could be moved to align with the proposed biodiversity plots (or vice versa).

Note that the passive sampling urban network study has been successful in confirming the entire Kitimat urban area has low SO_2 concentrations. There are no plans to continue the study beyond October 2019, and no benefit in continuing the study has been identified through the comprehensive review. Similarly, the short study of particulate sulphate sampling using filter packs was successful in confirming that only a very small fraction of total sulphur in the atmosphere is particulate sulphate. There are no plans to continue particulate sulphate study, and no benefit in continuing the study has been identified through the comprehensive review.

For the deposition monitoring program, we recommend continuing the Lakelse Lake monitor and considering discontinuing the Haul Road wet deposition monitor. The monitoring of wet deposition at Haul Road provides no ecological value (i.e., for the assessment of impacts) owing to its fence line location, and it provides limited value for model (CALPUFF) evaluation.

4 Review Results for Human Health

4.1 What Did We Set Out to Learn?

4.1.1 How is the Human Health Receptor evaluated in the SO_2 EEM Program?

The purpose of the SO_2 EEM Program for human health is to characterize the levels of SO_2 in the ambient air in residential areas in the Kitimat area and to compare those levels with KPIs related to human health.

The human health aspects of the SO_2 EEM program are unique with respect to the role of the STAR (ESSA et al. 2013). When the STAR was prepared, the Province of British Columbia did not have an Air Quality Objective for sulphur dioxide that was based on recent human health evidence. As a result, the STAR included predictions of the annual number of restricted airway events based on the ambient air concentrations in residential areas. The ambient air concentrations were predicted by the air dispersion modelling that was conducted as part of the STAR, similar in structure to the modelling described in Section 3 of this report.

As part of the original SO_2 EEM Program, informed by the STAR, a performance indicator was included based on updated predictions of the annual number of restricted airway events based on each future year's actual emissions and meteorological observations. In the EEM, this indicator was described as an "informative" rather than a "key" indicator.

In the time between the preparation of the STAR and this comprehensive review, the Province of British Columbia adopted an IAQO and has modified the SO_2 EEM Program to apply the IAQO as a KPI. The KPI is based on measurements at residential monitoring stations. Starting with the year 2020, the B.C. IAQO for SO_2 becomes equivalent to the CAAQS adopted by the CCME.

This section primarily addresses the KPI which is based on the observations of the levels of SO_2 at residential monitoring stations in comparison to the levels specified in the B.C. IAQOs. The locations of the residential monitors ("Riverlodge" in Lower Kitimat, "Whitesail" in Upper Kitimat, and "Kitamaat Village") are shown in Figure 4-1.

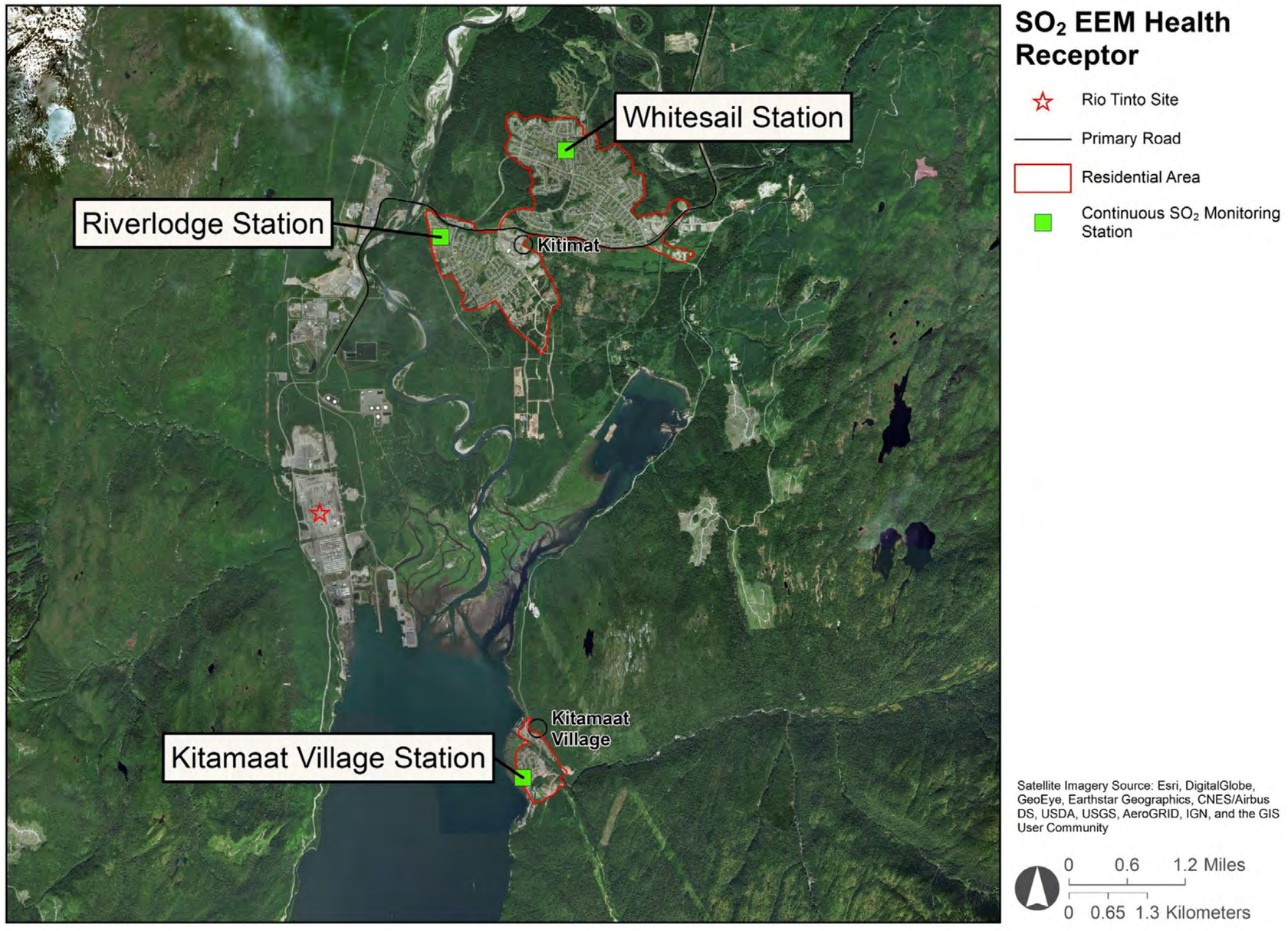


Figure 4-1. Locations of residential continuous SO_2 monitoring stations in the Kitimat region.

4.1.2 What is the basis for the B.C. IAQOs and the CAAQS?

The CAAQS constitute a set of pollutant-specific standards that place limits on and establish goals for the levels of pollutants in the air. The CAAQS values for SO_2 were announced in October, 2016[25]. They establish a specific SO_2 concentration limit (70 ppb) starting in 2020, and a lower limit starting in 2025 (65 ppb). A specific statistic of the observed air pollutant levels is employed to compare to the limit values ("The three-year average of the annual 99th percentile of the SO_2 daily-maximum of 1-hour-averaged concentrations.").

The CAAQS values of 70 ppb and 65 ppb, for 1-hour averaged concentrations, are compatible with, but not identical to, a value of 67 ppb derived by Health Canada (2016) for 10 minute averaged concentrations. Health Canada's report (2016), *Human Health Risk Assessment of Sulphur Dioxide: Analysis of Ambient Exposure to and Health Effects of Sulphur Dioxide in the Canadian Population,* describes the process of deriving an exposure limit, which Health Canada labels a Reference Concentration (RfC), for SO_2. The process is summarized below:

1. Causal analysis of relationships between various types and durations of exposure to SO_2 and human health effects. This answers the question: How likely is it that SO_2 causes each possible human health effect?
2. Selection of a Lowest Observed Adverse Effect Concentration (LOAEC) from human studies related to those health effects identified as known to be causally linked to SO_2 exposure. This answers the question: What is the lowest concentration of SO_2 at which the identified human health effects have been observed in studies of appropriate quality?
3. Downward adjustment of the LOAEC to account for human variability and uncertainties.
4. The result of this process (identifying the LOAEC and downward adjustment) is the RfC, which is understood to be an exposure level below which human health effects are not expected or would be very infrequent even in vulnerable populations.

In Health Canada's judgement, based on a weight-of-evidence approach, the human health effect which is known to be caused by SO_2 is the exacerbation of airway restriction events among asthmatics. This is based on clear evidence from highly controlled human studies in which asthmatics are exposed to specific concentrations (e.g. 100 ppb, 200 ppb, 400 ppb) of SO_2 while

[25] Canadian Ambient Air Quality Standards for SO_2. CCME, 2016.

exercising. The studies are conducted on exercising asthmatics in order to ensure some observed airway restrictions since these are considerably less likely for asthmatics breathing normally.

Health Canada selected a LOAEC of 400 ppb based on statistically significant increases in measurements of airway restriction and lung function among exercising asthmatics. The extent of downward adjustment of the LOAEC was described as being based on the following considerations:

1. That some exercising asthmatics responded below 400 ppb, even if the finding was not statistically significant
2. That some asthmatics may be more sensitive than the relatively healthy volunteers who participated in the controlled human studies
3. That it is possible that there are other health effects other than restricted airway events
4. That the controlled studies are done using indoor and room temperature air and there is evidence of increased incidence of restricted airway events in the presence of cold, dry air as might be experienced frequently in Canada

With these considerations, Health Canada selected an overall downward adjustment factor of 6. This is used to reduce the observed threshold value (the LOAEC) by a factor of 6 from 400 ppb down to 67 ppb. The resulting RfC is therefore 67 ppb. Specifically, Health Canada indicates "To account for the uncertainties mentioned above and considering the supporting evidence from the epidemiology, an uncertainty factor of 6 was applied to result in a 10-minute RfC of 67 ppb, which is expected to be protective of human health, including sensitive subpopulations like asthmatics."

The Health Canada approach is based on standard practice in regulatory toxicology that is applied in deriving exposure guideline values across multiple human exposure pathways (i.e., in air, water, soil, food and consumer products). This practice includes the weight-of-evidence evaluation, the selection of a lowest observed effect concentration, and the assignment of additional adjustment factors to account for uncertainties and human variability in response to SO_2 (i.e., those people who may be even more sensitive than those who participated in the controlled studies). By establishing an exposure threshold level that is deliberately chosen to be protective of the sub-population who is known to be most vulnerable to SO_2 effects, the understanding is that the rest of the population may be presumed to be protected.

Recently, the U.S. Environmental Protection Agency reaffirmed its standard of 75 ppb for SO_2 (US EPA 2019). This value is applied to the three-year average of the 99th percentile of the distribution of daily 1-hour maxima.

4.2 What Methods Did We Use?

In 2017, the indicators for the Human Health component of the SO_2 EEM Component permit were amended. The amendment added a KPI based on the newly adopted B.C. IAQOs. The B.C. IAQOs were formally adopted on December 15, 2016.

The B.C. IAQO of 75 ppb was applied in a phased approach within the EEM. As such, the percentile of comparison was increased gradually through the interim period. The resulting requirements and updated KPIs are captured in Table 4-1. For comparison, the CAAQS values, which will be adopted as the B.C. Air Quality Objectives as of 2020 are described in the last two rows of Table 4-1. Note that the CAAQS values are made more stringent (lowered to 65 ppb) starting in 2025.

Table 4-1. Characterization of the phased approach to the KPI for SO_2 for human health.

Exposure Year	KPI Threshold	KPI Percentile	KPI Averaging Time	"Plain language" KPI
2017	75 ppb	97th	3 years	The average of the 1-hour daily maximum on the 11th worst day in each of 2015, 2016, 2017
2018	75 ppb	97.5th	3 years	The average of the 1-hour daily maximum on the 10th worst day in each of each of 2016, 2017, 2018
2019	75 ppb	98th	3 years	The average of the 1-hour daily maximum on the 8th worst day in each of 2017, 2018, 2019
CAAQS 2020-2024	70 ppb	99th	3 years	The average of the 1-hour daily maximum on the 4th worst day in each of three consecutive years
CAAQS 2025+	65 ppb	99th	3 years	The average of the 1-hour daily maximum on the 4th worst day in each of three consecutive years

4.2.1 What levels of SO2 did we observe at residential air monitors?

The levels of SO_2 in the residential areas of Kitimat and Kitamaat Village change on an hourly basis. Despite being variable, the levels of SO_2 are below 1 ppb in more than half of the hours of each year, at all three sites. Even when considering *only the worst hour of each day*, the average concentration in that worst hour is less than 1 ppb in more than half of the days at each site in each year.

Due to the nature of meteorological conditions and other variables, there are relatively infrequent excursions of the SO_2 concentration above 10 ppb. For the period 2016-2018, the maximum hourly averaged concentration for all stations (44.7 ppb) occurred at Riverlodge Station (Lower Kitimat) in 2017.

The series of figures below (Figure 4-2 to Figure 4-7) show selected histograms of the hourly averaged concentrations at the three residential monitoring stations. For each station, the histograms are shown below for the most recent year (2018). Each histogram is first shown at the full scale, followed by the same histogram with a "zoomed in" view with y-axis, to allow a clearer view of the infrequent values above 1 ppb. The same types of histograms for the three stations for the years 2016 and 2017 are provided in Human Health Appendix 4.

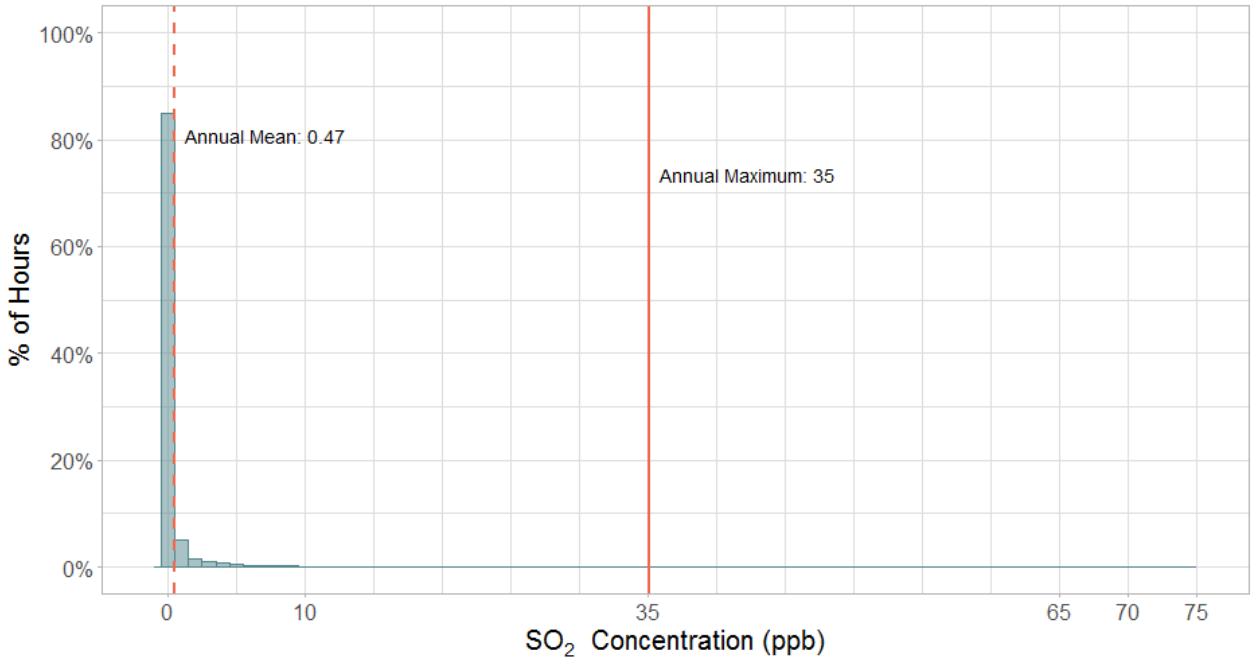


Figure 4-2. Histogram of hourly averaged SO_2 concentrations (Riverlodge, 2018).

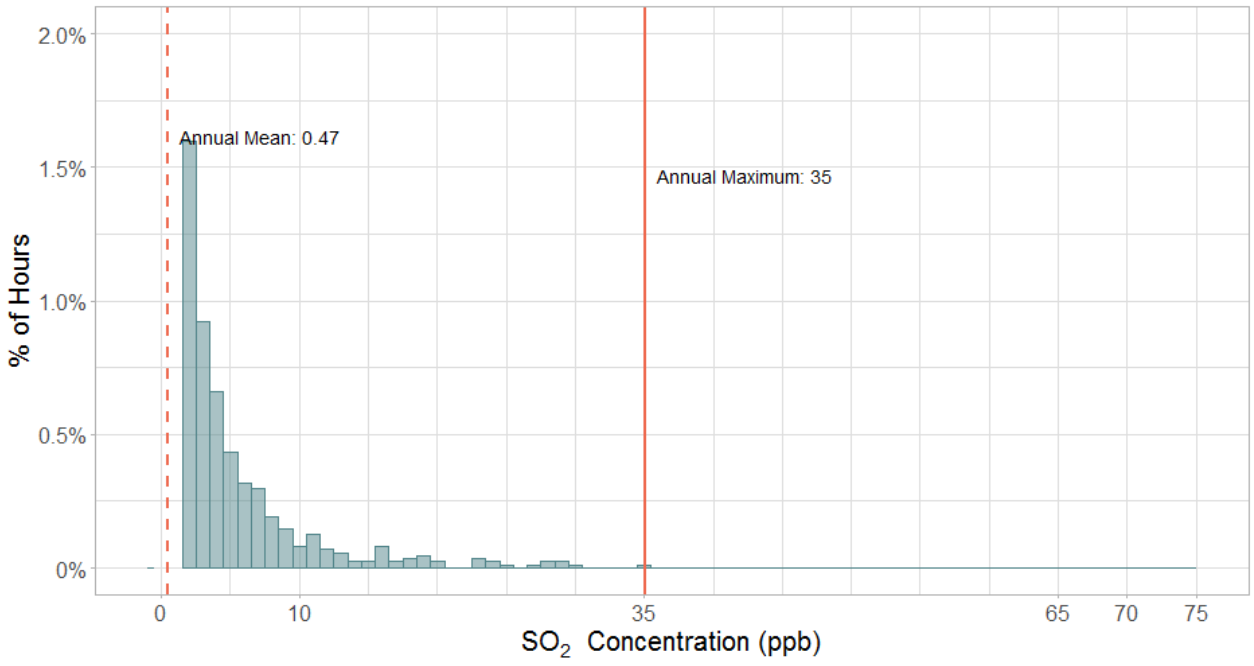


Figure 4-3. Histogram of hourly SO_2 concentrations with y-axis cut off at 2% (Riverlodge, 2018). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis.

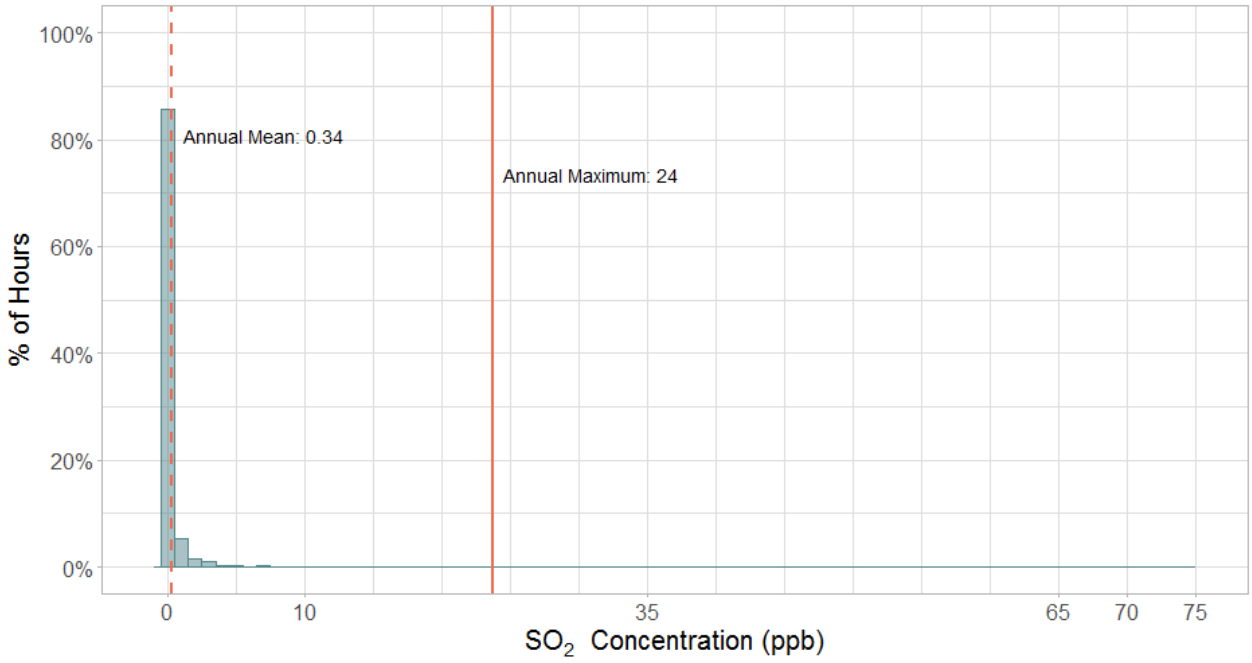


Figure 4-4. Histogram of hourly averaged SO_2 concentrations (Whitesail, 2018).

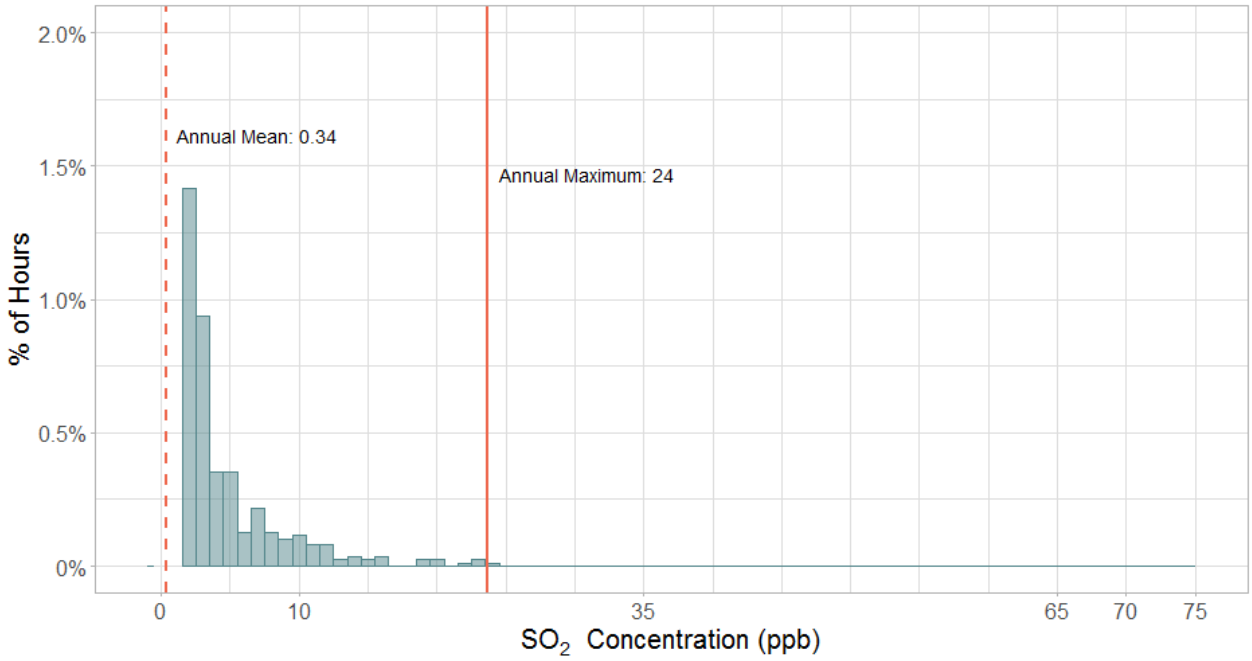


Figure 4-5. Histogram of hourly SO_2 concentrations with y-axis cut off at 2% (Whitesail, 2018). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis.

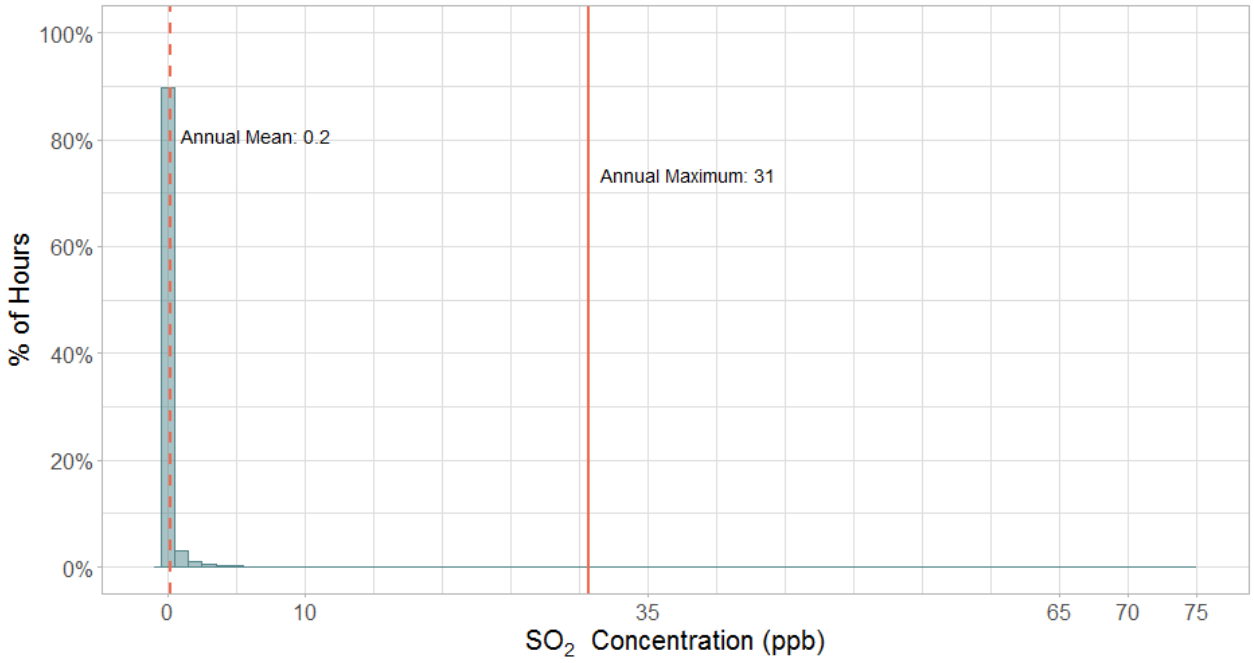


Figure 4-6. Histogram of hourly averaged SO_2 concentrations (Kitamaat Village, 2018).

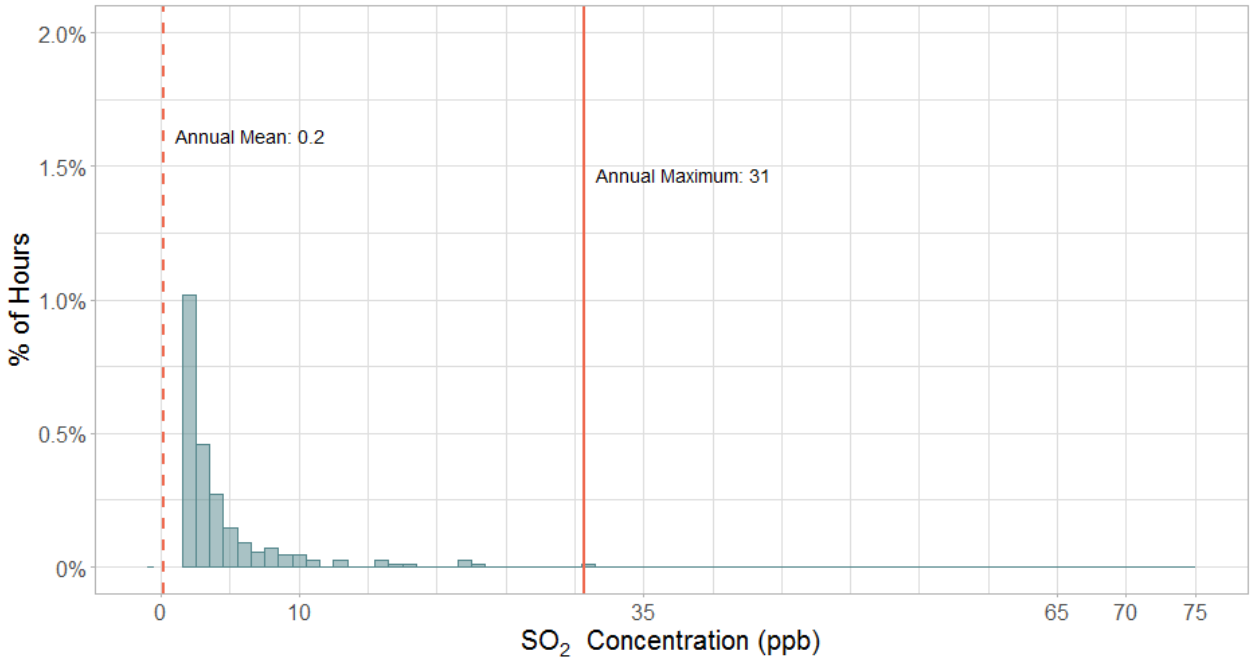


Figure 4-7. Histogram of hourly SO_2 concentrations with y-axis cut off at 2% (Kitamaat Village, 2018). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis.

For the purposes of the B.C. IAQOs, and the CAAQS, the relevant measurement of air concentration is the daily maximum of the 1-hour averages of each day (i.e., the worst hour of each day, as measured by its average concentration). For brevity, this is also known by the abbreviation D1HM (daily 1-hour maximum). The figures below (Figure 4-8 to Figure 4-13) show the histograms of the daily maxima values (the D1HMs) for each monitoring station for the year 2018. The 97.5th percentile value of the D1HMs is also shown for each station, but only for 2018. For the purposes of the KPI calculations, a three-year average is used. The same types of histograms for the years 2016 and 2017 are provided in Human Health Appendix 4.

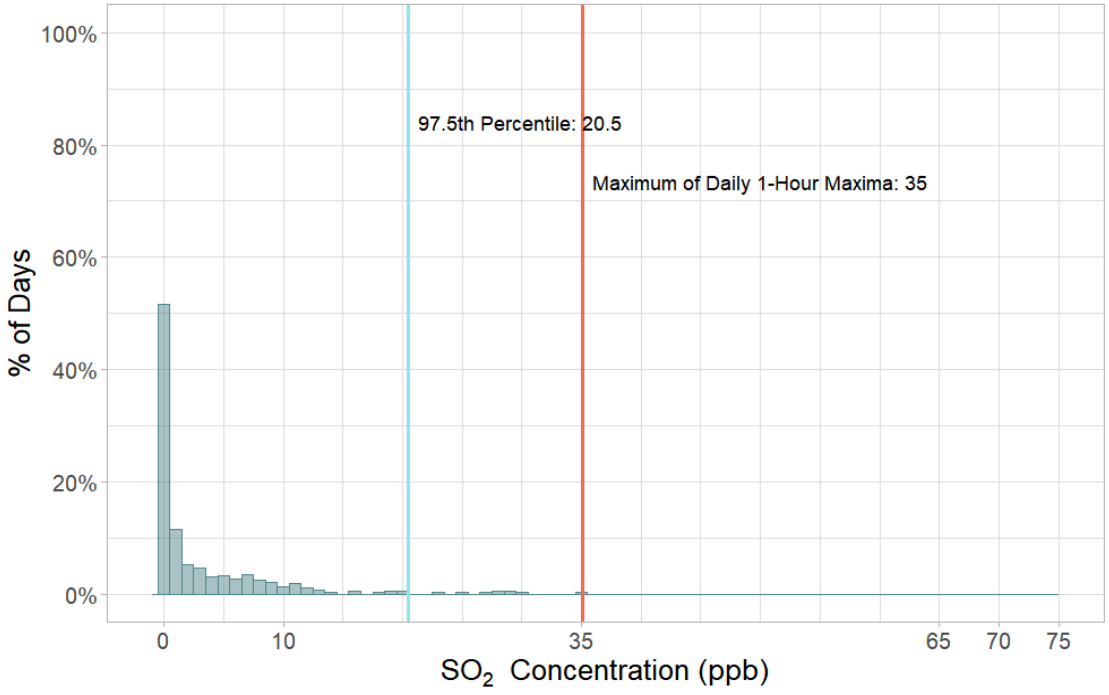


Figure 4-8. Histogram of D1HM SO_2 concentrations (Riverlodge, 2018).

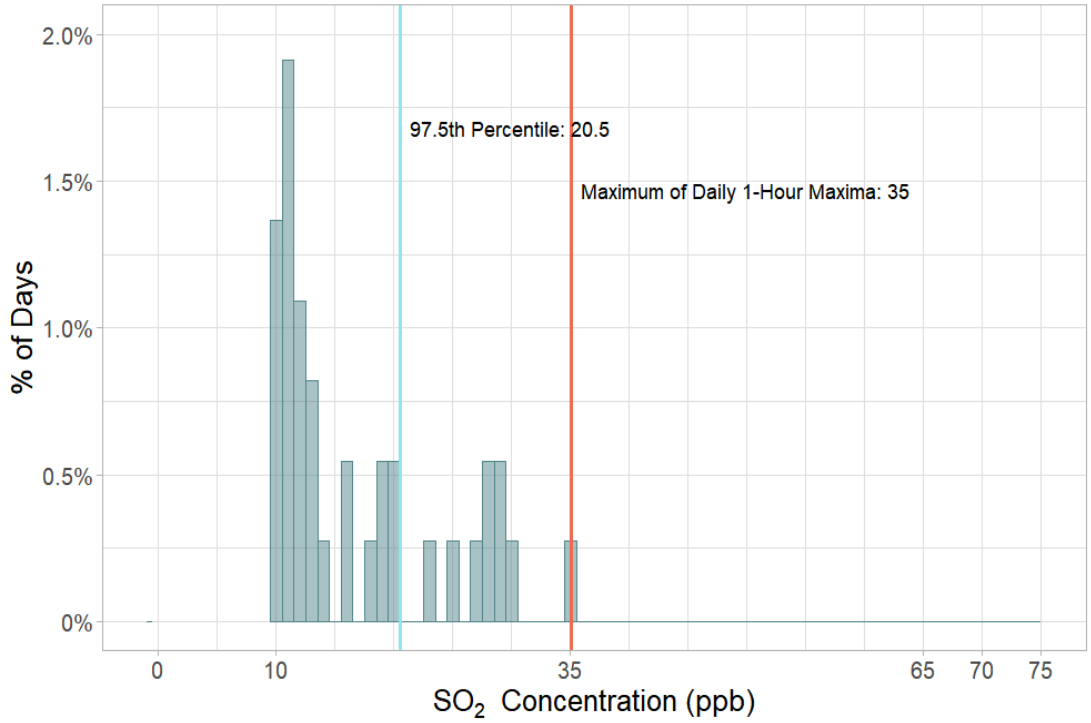


Figure 4-9. Histogram of D1HM SO_2 concentrations with y-axis cut off at 2% (Riverlodge, 2018). Note: The first ten histogram bars are not shown because they exceed the limit of the y-axis.

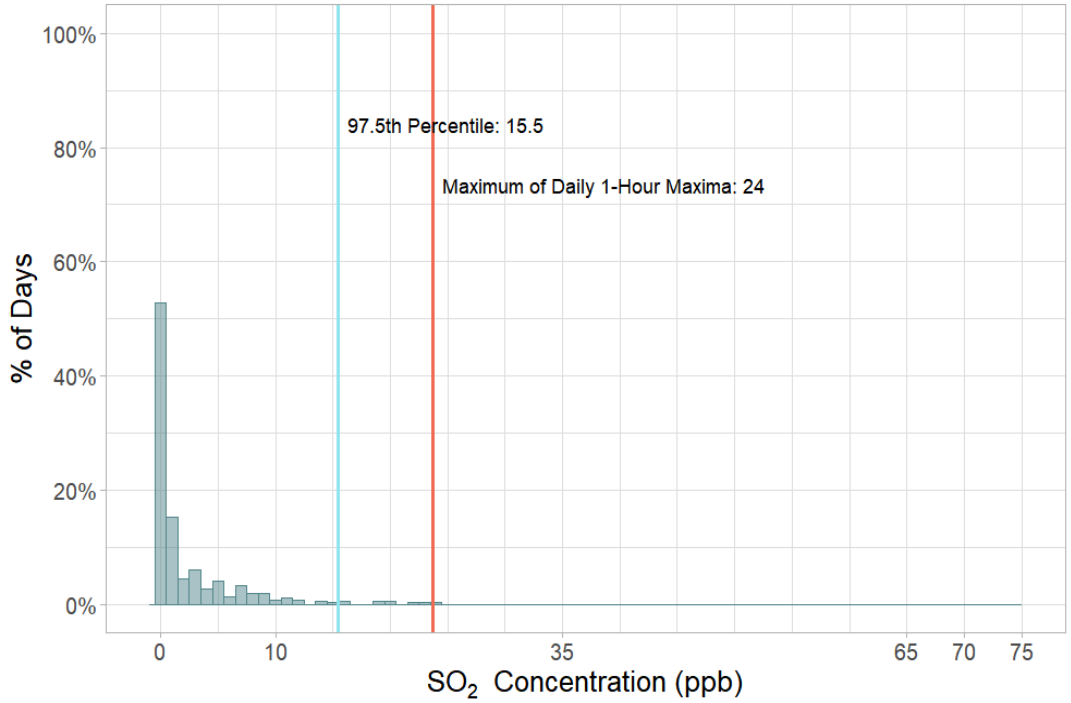


Figure 4-10. Histogram of D1HM SO_2 concentrations (Whitesail, 2018).

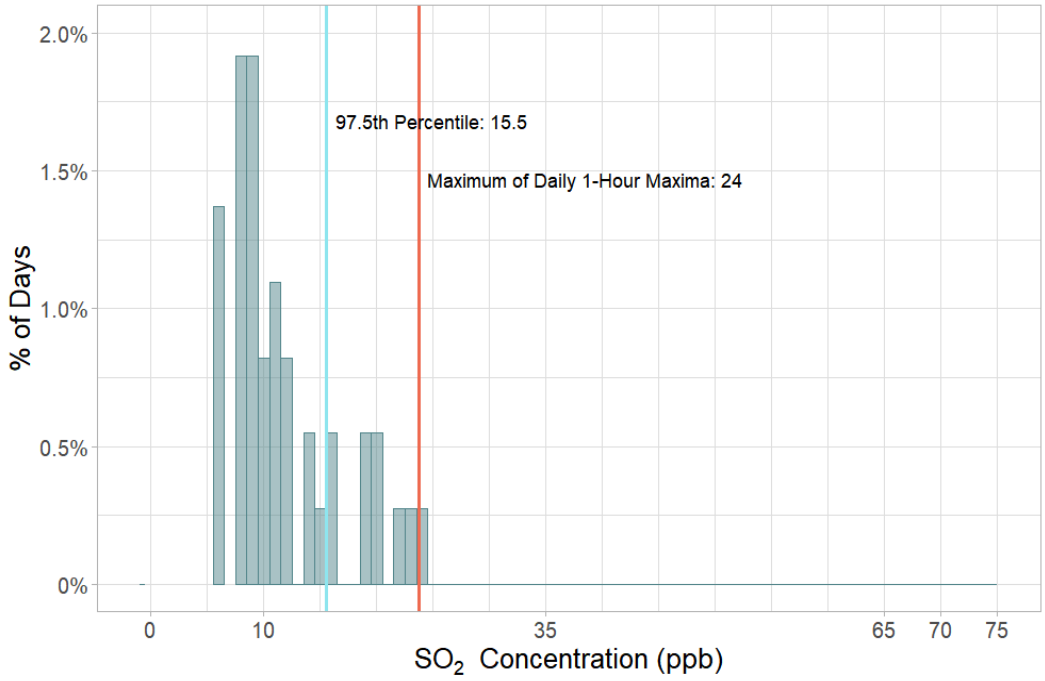


Figure 4-11. Histogram of D1HM SO_2 concentrations with y-axis cut off at 2% (Whitesail, 2018). Note: The first six and the eighth histogram bars are not shown because they exceed the limit of the y-axis.

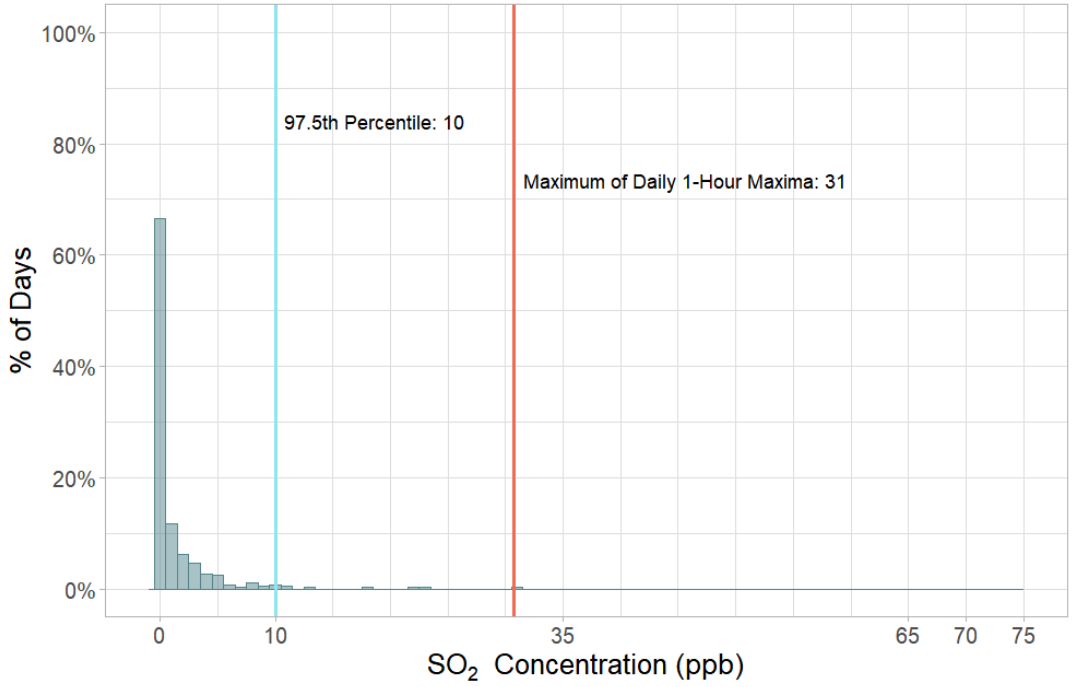


Figure 4-12. Histogram of D1HM SO_2 concentrations (Kitamaat Village, 2018).

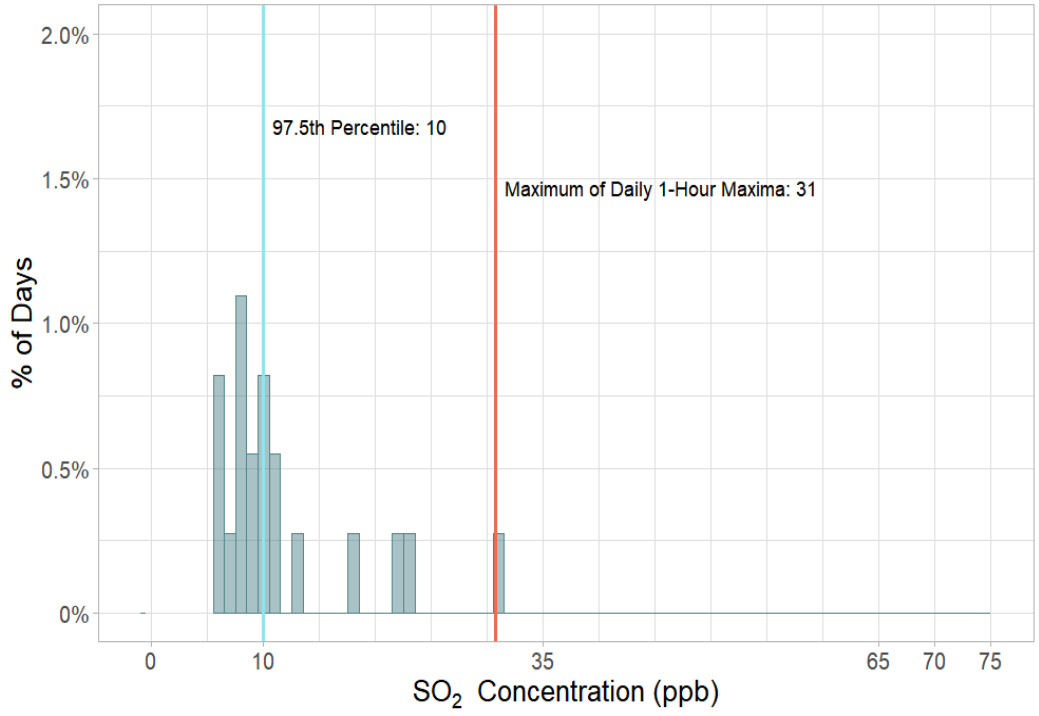


Figure 4-13. Histogram of D1HM SO_2 concentrations with y-axis cut off at 2% (Kitamaat Village, 2018). Note: The first six histogram bars are not shown because they exceed the limit of the y-axis.

Table 4-2, Table 4-3 and Table 4-4 demonstrate the upper percentiles of SO_2 concentrations (as reflected by the D1HM) for the years of 2015-2018, at all three sites.

Table 4-2. Riverlodge Monitoring Station: distribution (percentiles) of daily 1-hour maximum SO_2 concentrations.

Percentile	Xth Worst Day	SO_2 Concentrations (ppb)			
		2015	2016	2017	2018
95%	19th	4.3	9.9	11.0	13.0
97%	11th	6.3	12.9	15.5	19.7
97.5%	10th	6.4	13.8	16.8	20.5
98%	8th	7.1	14.4	17.0	24.7
99%	4th	11.4	22.1	28.0	29.2
100%	1st	20.7	31.8	44.7	35.1

Table 4-3. Whitesail Monitoring Station: distribution (percentiles) of daily 1-hour maximum SO_2 concentrations.

Percentile	Xth Worst Day	SO_2 Concentrations (ppb)		
		2016	2017	2018
95%	19th	7.7	8.7	10.6
97%	11th	11.0	12.1	14.2
97.5%	10th	12.2	12.7	15.5
98%	8th	13.2	14.9	16.0
99%	4th	14.9	21.4	20.0
100%	1st	37.0	40.7	23.7

Note: there were extensive missing data for 2015 at Whitesail monitoring station. As a result, the year 2015 is not included.

Table 4-4. Kitamaat Village Monitoring Station: distribution (percentiles) of daily 1-hour maximum SO_2 concentrations.

Percentile	Xth Worst Day	SO_2 Concentrations (ppb)			
		2015	2016	2017	2018
95%	19th	2.1	6.2	5.3	5.6
97%	11th	3.0	8.4	6.1	8.9
97.5%	10th	3.0	8.6	6.4	10.0
98%	8th	3.3	10.8	7.1	10.4
99%	4th	4.3	19.5	11.7	18.3
100%	1st	38.5	36.6	14.1	30.7

4.2.2 How do these observations compare to the Human Health Key Performance Indicator?

The human health KPI is based on maintaining concentrations of SO_2 below a threshold value for a significant proportion (i.e., 97% or 97.5%) of the year. This threshold value is applied to the worst

hour of the day (i.e., the hour with the highest average concentration of SO_2). The specific implementation is described as part of the B.C. IAQO specifications (B.C. Ministry of Environment and Climate Change Strategy 2018).

In 2017, the KPI requirement is that the worst hour of the day be below the threshold value 97% of the time, when averaged over the period 2015-2017. When converted to days, this means that the average of the worst hours on the 11th worst days of each year must be below 75 ppb.

In 2018, the KPI requirement is that the worst hour of the day be below the threshold value 97.5% of the time, when averaged over the period 2016-2018. When converted to days, this means that the average of the worst hours on the 10th worst days of each year must be below 75 ppb.

The tables below provide the relevant statistic for each site and for each year. The table also provides the three-year average of this statistic which is the value to be compared to the human health KPI threshold value. The three-year average is compared to the threshold for each monitoring location. The KPI applies to the three sites collectively, such that the KPI threshold must be met ***at all three sites***, for the human health KPI to be attained.

As seen in Table 4-5, the 97th percentile D1HM SO_2 concentration was below the KPI threshold in each of the included years (2015-2017) at each of the three sites. The year 2015 is not applied for the Whitesail monitoring station (Upper Kitimat) due to technical problems with the monitor leading to loss of valid data. For that station, the two-year average of 2016 and 2017 is compared to the KPI. As the averages are below the KPI threshold for all three sites, the KPI is attained for 2017.

Table 4-5. Comparison of monitoring results to the KPI for Human Health for 2017.

Station	Percentile (Xth Worst Day)	SO_2 Concentrations (ppb)					Three-Year Average Below Threshold?
		2015	2016	2017	Three-Year Average	KPI Threshold (2017)	
Riverlodge	97.0% (11th)	6.3	12.9	15.5	11.6	75.0	Yes
Whitesail	97.0% (11th)	n/a	11.0	12.1	11.6[a]	75.0	Yes
Kitamaat Village	97.0% (11th)	3.0	8.4	6.1	5.8	75.0	Yes
Overall Attainment of Human Health KPI for 2017 (all three residential sites met KPI)							Attained

[a] There were missing data in 2015 for Whitesail monitoring station. The extent of the missing data was such that the data were "invalid" for the purposes of applying the B.C. IAQO. As such, the KPI calculation for Whitesail in 2017 was based on the average of the values for 2016 and 2017. All three years were used for Riverlodge and Kitamaat Village.

As seen in Table 4-6, the 97.5th percentile D1HM SO_2 concentration was below the KPI threshold in each of the three years (2016-2018), and at each of the three sites. As a result, the average is below the KPI threshold and the KPI is attained for 2018.

Table 4-6. Comparison of monitoring results to the KPI for Human Health for 2018.

Station	Percentile (X^{th} Worst Day)	SO_2 Concentrations (ppb)					Three-Year Average Below Threshold?
		2016	2017	2018	Three-Year Average	KPI Threshold (2018)	
Riverlodge	97.5% (10^{th})	13.8	16.8	20.5	17.0	75.0	Yes
Whitesail	97.5% (10^{th})	12.2	12.7	15.5	13.5	75.0	Yes
Kitamaat Village	97.5% (10^{th})	8.6	6.4	10.0	8.3	75.0	Yes
Overall Attainment of Human Health KPI for 2018 (all three residential sites met KPI)							Attained

4.2.3 Spatial Representativeness of the Monitoring Network

As described in Sections 3.1.2.2 and 3.1.3.7, the Riverlodge monitor was sited to represent the highest SO_2 concentrations within the town of Kitimat. The Phase 1 monitoring network optimization concluded the Riverlodge monitor is in the most suitable location to continue to represent the highest SO2 concentrations in Kitimat under the post-KMP. The Phase 2 network optimization, based on 2016-2018 CALPUFF results and the latest SO_2 monitoring data, will reevaluate the conclusions of the monitoring network optimization. While further data analysis is needed to complete the phase 2 network evaluation, the new CALPUFF results indicate that the Riverlodge monitor site is near the highest ranked locations within the town of Kitimat (Figure 3-22).

The Phase 1 network evaluation concluded the Kitamaat Village monitor is in the most suitable location to represent the highest SO_2 concentrations in Kitamaat Village. The 2016-2018 CALPUFF model prediction of the most suitable location for measuring the highest concentrations within Kitamaat Village is along the western shoreline of Kitamaat Village, and the Kitamaat Village monitor is located along this western boundary.

4.2.4 Meteorological events giving rise to elevated levels of SO_2 in Kitimat and Kitamaat Village

Elevated SO_2 levels in Kitimat and Kitamaat Village are rare because typical meteorological conditions result in the SO_2 plume traveling north from the smelter (positioned west of the western boundary of Kitimat) or south from the smelter (positioned west of the western boundary of Kitamaat Village along the western shoreline of the Douglas channel). Certain meteorological conditions are required for elevated SO_2 concentrations to reach Kitimat or Kitamaat Village and their associated SO_2 monitors (Riverlodge and Kitamaat Village) such as stagnant wind conditions during temperature inversions, steady wind direction directly from the smelter to the monitor, and shifting wind direction. This last case of shifting wind direction beginning out of the south and shifting out of the north can result in the smelter SO_2 plume traveling north / northwest of Kitimat, then circling eastward (just north of Kitimat) and south into Kitimat. Wind directions beginning out of the north and then shifting to blow from the west or southwest can cause elevated concentrations at Kitamaat Village.

4.3 What Did We Learn, and Did We Make Any Adjustments to the EEM Program?

4.3.1 Uncertainty in the STAR: ability of CALPUFF to predict residential SO_2 concentrations

Due to the insertion of a new KPI (which is based on measurements at monitoring stations) and the determination to not further apply the informative indicator, the key uncertainty (HH-1 from Table 10.3-1) in the STAR related to the ability of CALPUFF to adequately represent residential SO_2 concentrations *is no longer applicable* for the human health component of the SO_2 EEM.

4.3.2 Uncertainty in the STAR: comparing the assumed peak-to-mean ratios to observations in 2016-2018

In the STAR, the approach to predicting the number of restricted airway events required the assumption of values for the peak-to-mean ratio. This ratio is used to extrapolate from hourly predictions (the output of the air dispersion modelling) to shorter-term peaks within each hour. The shorter-term peaks are expected to be more predictive of human health outcomes. The peak-to-mean ratio was defined as the ratio between the highest 5-minute average concentration within an hour, and the average concentration for the entire hour. During the period of development of the STAR, minute-by-minute data were only available for one monitoring location, Haul Road, which is within the industrial site and therefore is not considered to be a residential monitoring station. These data were used to provide predictions for the 5-minute peaks in the residential areas within the STAR. This assumption was identified in the STAR as a key uncertainty (HH-2 in Table 10.3-1 of the STAR) to be resolved. Resolution of this uncertainty would determine whether the use of data from Haul Road could systematically lead to under-prediction or over-prediction of the level of the peaks of SO_2 concentration at residential locations.

Although the modelling approach employed in the STAR is no longer being applied in the EEM or in this comprehensive review, the data to estimate the peak-to-mean ratio are now available. Table 4-7 provides various statistics of the peak-to-mean ratios at each of the three residential monitoring stations as well as the monitoring stations at Haul Road, for the years 2016-2018. The final rows of the table contain the three-year averages of each of the statistics at each site.

Table 4-7. Peak-to-mean ratios at residential stations and the Haul Road station.

Site	Year	Mean	95th Percentile	99th Percentile	Max
Riverlodge	2016	1.5	2.2	3.5	6.4
	2017	1.4	2.0	3.4	7.5
	2018	1.4	2.0	3.3	7.6
Whitesail	2016	1.4	1.8	2.8	7.7
	2017	1.5	2.2	3.0	5.5
	2018	1.4	1.7	2.9	7.2
Kitamaat Village	2016	1.4	1.7	2.5	6.2
	2017	1.4	1.7	2.3	4.7
	2018	1.4	1.8	2.4	5.4
Haul Road	2016	1.8	3.7	5.2	8.6
	2017	1.9	3.9	5.5	9.1
	2018	1.9	3.9	5.6	8.6
Riverlodge	3-Year Average	1.4	2.1	3.4	7.2

Site	Year	Mean	95th Percentile	99th Percentile	Max
Whitesail	3-Year Average	1.4	1.9	2.9	6.8
Kitamaat Village	3-Year Average	1.4	1.7	2.4	5.4
Haul Road	3-Year Average	1.9	3.8	5.4	8.7
Haul Road largest peak-to-mean ratio for all years and on average?		YES	YES	YES	YES

Based on Table 4-7, the distribution of peak-to-mean ratios for Haul Road yields consistently higher values for key statistics (mean, 95th percentile, 99th percentile, maximum) of the peak-to-mean ratio on a year-by-year comparison and when considering a three-year average of each of these statistics.

With this information for 2016-2018, it is reasonable to assume that the use of peak-to-mean ratios from the Haul Road monitoring station in the STAR led to some over-estimation of the distribution of peak concentrations in the residential areas when compared with using observed peak-to-mean ratios from the residential monitors. In over-estimating the peak concentrations, this assumption contributes to the potential to over-estimate the number of restricted airway events, whose likelihood was assumed to increase with increasing peak concentrations, based on the dose-response analysis applied in the STAR.

4.3.3 Adjustments to the SO_2 EEM Program

In 2016, the Province of British Columbia adopted an IAQO. This objective was established as 75 ppb for hourly averaged concentration of SO_2. This IAQO, adopted in December 2016, is applied in the EEM for the years 2017-2019. From the year 2020 forward, the IAQO value is replaced by the CAAQS values of 70 ppb and 65 ppb (starting in 2025).

Given the changes already implemented within the SO_2 EEM Program, and with the structure in place, there is no need to consider modifications to the SO_2 EEM Program or the health KPI as it will become aligned with the CAAQS starting in 2020 and become more stringent (65 ppb) in 2025.

4.3.4 Shift away from the informative indicator

Through the course of the SO_2 EEM Program, a shift occurred from relying upon an informative indicator to a KPI. The informative indicator used predictions based on air dispersion modelling, exposure assessment, and dose-response analysis.

The availability of a 2016 Human Health Risk Assessment of Sulphur Dioxide, conducted by Health Canada, for ambient SO_2, and the corresponding development of the CAAQS, allowed for the transition to a KPI that is aligned with the interim B.C. IAQO and the similar values that were adopted as part of the CAAQS process.

The use of the current KPI has the advantages of: a) being based on actual observations from monitoring data within the residential communities; and b) clear thresholds and protocols for determining attainment with the KPI. The informative indicator did not have these qualities.

4.4 What Do We Recommend for the EEM Program Going Forward?

Going forward, the KPI for the EEM Program will shift toward alignment with the CAAQS for SO_2. As such, there is no basis for a recommendation for changes to the quantitative basis for the existing KPI since it is in the process of changing according to the adoption and further adjustment of the CAAQS.

5 Review Results for Vegetation

5.1 What Did We Set Out to Learn?

The SO_2 EEM Vegetation Program was designed to monitor the potential effects of the modernized smelter on plants in the Kitimat Valley. The vegetation program centered around two measures—a visual inspection of plants at an array of sites throughout the valley and the sulphur content of current year western hemlock needles collected at those same sites. Visual inspections have been conducted every year or two since about 1970 and are designed to detect visible injury due to hydrogen fluoride (HF) and SO_2 emissions, as well as to document the general health of vegetation, the incidence and severity of diseases and insect pests, and the effects of other environmental stressors, such as drought, physical disturbance, and growing season conditions. Sampling of needles for fluoride (F) started at about the same time with S analysis added at a later date. The S content of needles was used in conjunction with F content to integrate the exposure to pollutants at the site, as mediated by uptake by vegetation. Concentrations of F and S in needles were also used as a method to map the dispersion of pollutants from the VSS smelter.

Based on air dispersion modelling in the STAR (ESSA et al. 2013), we developed a KPI related to visible injury of sensitive vegetation due to SO_2. Although the modelling results indicated that visible injury was unlikely to occur, modelled concentrations were high enough to warrant such a KPI, particularly given that the sensitivity of most vegetation in the valley has not been documented through controlled exposure studies. Sulphur content of current year needles of western hemlock was established as an informative indicator.

This comprehensive review will present data and analyses to inform the questions posed in the STAR and to make recommendations for changes in the next phase of the SO_2 EEM Program.

5.1.1 Hypotheses posed in the STAR

Upon implementation of the SO_2 EEM Program, data were collected through the visual inspections and sampling in order to address four hypotheses posed in the STAR.

5.1.1.1 *Question V1: Validation of the dispersion model—are we looking in the right place?*

Two hypotheses were posed under question V1:

- H_1 Post-KMP passive and continuous monitoring measurements show a similar SO_2 concentration distribution to that predicted by the model.
- H_2 Post-KMP passive and continuous monitoring measurements show a different SO_2 concentration distribution to that predicted by the model.

5.1.1.2 *Question V2: How healthy is vegetation in sites with predicted exceedances of critical loads of soil and/or lakes and streams south of Lakelse Lake?*

No hypotheses were proposed under question V2. Vegetation in the vicinity of predicted critical load exceedances was to be inspected.

5.1.1.3 *Question V3: Are plants of public importance showing symptoms in areas with the highest exceedances of soil critical loads?*

Three hypotheses were posed under question V3:

H_1 Negligible or no effects.
H_2 Indirect effects on plants via changes in soil base cations and Al are moderate.
H_3 Indirect effects on plants via changes in soil base cations and Al are significant.

5.1.1.4 *Question V4: Do plants at Kitimat with unknown sensitivity to SO_2 and associated pollutants (acidic deposition) fall within the range of variation in the literature*

Two hypotheses were posed under question V4:

H_1 Yes, the scientific literature accounts for the responses of the most sensitive plants.
H_2 No, symptoms indicate that plants at Kitimat may be more sensitive than those reported in the literature.

5.1.2 EEM Key Performance Indicator

We developed an SO_2 EEM KPI for Visible Injury to Vegetation because, although the modelled SO_2 concentrations in the STAR were below reported thresholds for direct effects on vegetation, they were high enough, given uncertainty in modelling, that the most sensitive of plants might have been injured. Also, if dispersion modelling was in error there could have been immediate acute effects on plants. Since most of the species present in the valley are of unknown sensitivity (through controlled exposure studies), it was possible that some would be more sensitive than what was reported in the scientific literature. The KPI threshold for increased monitoring was "More than occasional symptoms of SO_2 injury outside of Rio Tinto Alcan Kitimat properties, causally related to KMP" with associated actions of assess air monitoring and emissions data to identify potential causes and increase the frequency of visual inspection to annually. This threshold was not equalled or exceeded.

5.1.2.1 *Learning from the Key Performance Indicator*

This comprehensive review integrates the results of visual inspections to assess the effectiveness of the KPI vis-à-vis our understanding of the effects of smelter emissions on vegetation in the Kitimat Valley.

5.1.2.2 *Evaluation of the Key Performance Indicator*

Based on the analyses in this comprehensive review, we have assessed the KPI and made recommendations for change.

5.1.3 EEM informative indicator

The EEM informative indicator continued the historical collection and analysis of S concentrations in needles to try to detect spatial patterns associated with dispersion of the plume from the smelter. Because of the length of the analytical record, changes associated with increased emissions and new dispersion patterns could be compared to the patterns under the VSS smelter operational characteristics. The threshold for increased monitoring was "An increase of more than 1 standard

deviation (from pre-KMP baseline data) in 20% of the sites for 3 consecutive years, causally related to KMP. This threshold was not equalled or exceeded.

5.1.3.1 *Learning from the informative indicator*

The comprehensive review integrates the results from the informative indicator with other measures, such as dispersion model output, active and passive air sampling, and visual observations to assess potential effects of the smelter on vegetation.

5.1.3.2 *Evaluation of the informative indicator*

The informative indicator is evaluated with regard to its relationship with active and passive air monitoring and the spatial distribution of S concentration in needles in the Kitimat Valley.

5.1.4 Other questions that have emerged since the development of the EEM Program

5.1.4.1 *Evidence from the literature for more sensitive indicators of potential effects on vegetation*

Before considering the evidence for more sensitive indicators, it is important to consider the potential impact of climate change on vegetation in the area of interest as overall ecosystem health will be affected by changes in climate during the lifetime of the modernized smelter. By 2055, average temperatures in the Skeena region are expected to increase by up to 3.5C over the present during the growing season (Foord 2016), with increases in precipitation, primarily in the winter, but increases in evapotranspiration in the summer due to warmer temperatures. Extreme precipitation events, both in terms of excess (winter rain instead of snow) and deficit (summer drought) are expected to increase in frequency. Such changes will affect the vegetation of the Kitimat Valley, increasing stress on forested vegetation and changing habitat suitability. Geiser et al. (2019) point out that hot, dry temperatures will become an important driver of cyanolichen success.

Thresholds for impacts to understory and overstory vegetation

Although there is little active research on the sensitivity of plants to SO_2, and most of it addresses plants that are tropical or subtropical and/or agricultural plants, reviews of thresholds used by regulatory and advisory agencies have been conducted. No relevant new experimental or observational results have been reported since the STAR that have changed the threshold values or standards in use in the United States and Europe. Both the U.S. Environmental Protection Agency (2018) and the European Union (2008) have recently reviewed their standards set to protect natural ecosystems from the effects of SO_2. Both organizations have left their standards in place. The U.S. secondary National Ambient Air Quality Standard (NAAQS) to protect vegetation continues to be an exposure of 500 ppb averaged over three hours, not to be exceeded more than once per year. The European Union Air Quality Standard to protect vegetation of 20µg/m^3 (7.6 ppb) for both annual average and winter (October 1-March 31) average remains in effect. The EU continues to accept the recommendation of WHO (2000) of a critical level to protect lichens of 10 µg/m^3 annual average (3.8 ppb). The CAAQS have established a standard of an annual average of 5 ppb (changing to 4 ppb in 2025) to protect natural ecosystems (CCME, 2016 https://www.ccme.ca/en/resources/air/air/sulphur-dioxide.html). This standard replaced the B.C. Pollution Control Objectives cited in the STAR.

Controlled experimental studies of SO_2 effects on crop plants such as tomato (Padhi and Swain 2013), pomegranate (Swain and Padhi 2013), *Arabidopsis* (Choi et al. 2014), and grape (Considine and Fyer 2015) continue to expand knowledge of the direct effects of SO_2, however the concentrations used in the exposure studies far exceed those monitored at Kitimat.

Hu et al. (2016) used sap flow measurements to estimate whole tree stomatal conductance and estimated flux of four pollutants, including SO_2, to three species of urban trees, *Schima superba* (no English common name), *Eucalyptus citriodora* (lemon-scented gum) *and Acacia auriculaeformis* (earleaf acacia). The exposures were from ambient air; thus all four gases were present at the same time. They determined that under the climate conditions of southern China, uptake of SO_2 was greatest in the spring and least in the summer and autumn. The concentration of SO_2 was an annual average of about 12 μg/m^3 (4.6 ppb). Exposure to SO_2 did not injure the trees.

Baciak et al. (2015), offer a brief review of the effects of several air pollutants on woody plants, but do not report new, original research. Their conclusions are in concert with past findings.

Progress has been made in determining critical loads and associated effects on forests (e. g. Ouimet et al. 2006; Aherne and Posch 2013; Blett et al. 2014; Duarte et al. 2013; Fenn et al. 2011; Kosiba et al. 2018; Ouimet et al. 2001; Pardo et al. 2018; Williston et al. 2016).

Most recently, Horn et al. (2018) used forest inventory data for over 1.4 million trees and measurements of deposition of nitrogen (N) and S from the NADP to model the growth and survival relationship of 71 tree species in the US. The primary focus of the study was on the effects of N deposition; however, they did find that 31 of the 71 species showed decreasing growth with increasing S deposition; the other 40 showed no response. The survival of 40 species decreased with increasing S deposition, while 31 did not show a relationship between survival and S deposition. Their models were constrained to prevent an increase in growth or survival which the authors believe is consistent with the role S plays in acidification. Ten species that occur in the Kitimat Valley were included in the study (although trees from the Kitimat Valley were not part of the sample). Pacific silver fir, Douglas-fir, and paper birch showed a decline in growth with increasing S deposition (ranging from 0-5, 0-15, and 0-25 kg S/ha/yr respectively[26]). Lodgepole pine, paper birch, and quaking aspen showed decreased survival with increasing S deposition (ranging from 0-4, 0-15, and 0-30 kg S/ha/yr respectively). Subalpine fir, western larch, western redcedar, western hemlock, and mountain hemlock did not show any relationship between S deposition and growth or survival. Overall, they found growth decreased with S deposition at rates of -1.6% per kg change in deposition of S/ha/year. In the Pacific Northwest, growth effects were less than the overall rate. In the western US, tree survival did not change with S deposition. Analysis at the regional or national scale does remove factors such as climate, habitat suitability, and forest management that can be important locally, thus the results apply to regional trends but not necessarily to every locality.

Clark et al. (2019) used plant community data from over 14,000 plots across the U.S. along with deposition data and estimates from NADP and the U.S. EPA's Community Multi-scale Air Quality Modeling System[27] (CMAQ) (Schwede and Lear 2014) to calculate critical loads of N and S for 198 of the 348 herbaceous species examined (the remaining 150 species did not have sufficiently robust relationships to be included). Of the 198, 123 were found to have a decreased probability of

[26] Total S deposition expressed as SO_4^{2-} is three times the S deposition rate.
[27] For a description of CMAQ see https://www.epa.gov/cmaq

occurrence with increasing S deposition (ranging from 0 to about 42 kg S/ha/yr), 32 showed no response, and 43 species had an increased probability of occurrence with increasing S deposition. About 50% of the species that increased were from historically polluted areas leading the authors to postulate that where deposition is high, plant communities may have shifted to acid-tolerant species. They also conclude that the wide range of responses indicates that local environmental and edaphic factors are likely important in shaping the vulnerability of plant communities.

Thresholds for effects on lichens and mosses

Lichens and mosses have been recognized as sensitive indicators of air pollution for over 100 years (Nash 1971, 1976) and have been used as bioindicators of gaseous pollutants or bioaccumulators of metals in many locations around the world (e.g. Cowden and Aherne 2019; Geiser 2004; Leavitt and St. Clair 2019; Stolte et al. 1993). Pescott et al. (2015) provide an excellent review of the direct and indirect effects of air pollutants on lichens and bryophytes.

Lichens and mosses are sensitive to both wet and dry deposition associated with SO_2 exposure. Direct effects may center on the dry deposition of SO_2 gas or wet deposition (acidic deposition). However, indirect effects, such as acidification of substrates that support lichens and mosses, are also important, particularly to groups such as cyanolichens growing on naturally acidic substrates such as conifer boles and branches (Goward and Arsenault 2000). Cyanolichens growing on conifers are an important component of forests, particularly old growth forests, in places such as the Kitimat Valley, thus SO_2 exposure is of concern, as is habitat loss from logging and industrial development, or from possible changes in habitat suitability due to SO_2 exposure, SO_4^{2-} deposition, and climate change.

The Kitimat Valley has a long history of industrial and logging activity and it is likely that lichen populations have been affected for 60 years or more. Reid Collins and Associates (1978; 1986) conducted a lichen study in the Kitimat Valley in the 1970s and 1980s. They surveyed for the presence of lichens in three zones of pollution (control, light, and heavy, based on the F content of western hemlock needles at the sampling location). They demonstrated a significant relationship between F in western hemlock foliage and the average lichen occurrence per tree. Over 5 years of the detailed study (Reid Collins and Associates 1986) they noted little change in control plots, a continued decline in the main path of the plume, and an increase in lichen occurrence in the lightly polluted area, likely due to a concomitant decrease in F emissions from the VSS smelter that took place during the study. The map included in the 1978 report shows an area of impact on lichen richness and abundance that corresponds to the current plume path modelled by CALPUFF.

A critical level of SO_2 exposure in the form of an annual average concentration of about 4 ppb (10 $\mu g/m^3$) to protect sensitive lichens and bryophytes has been established (e.g. WHO 2000; European Union 2008; CCME 2016 [https://www.ccme.ca/en/resources/air/air/sulphur-dioxide.html]).

There have been significant advances in understanding thresholds of S exposure for lichens, particularly with regard to establishing relationships between SO_4^{2-} deposition and lichen presence, absence, and condition (Cleavitt et al. 2015; Geiser et al. 2019; Glavich and Geiser 2008; Pardo 2010; Will-Wolf et al. 2006, 2015).

The most recent and comprehensive study of SO_4^{2-} deposition, lichens, critical loads, and risk assessment is the work of Geiser et al. (2019). They used species detection data from 8,855 sites in the U.S. coupled with deposition estimates from the CMAQ (Schwede and Lear 2014), to calculate

critical loads for individual lichen species (Geiser et al. *in preparation*). Since they were seeking estimates for regional to national scale critical loads, they averaged deposition estimates over 3 years and used 90% Quantile Regression (Cade and Noon 2003) to limit the influence of environmental factors and factors such as habitat suitability over the thousands of sites they examined.

They found that cyanolichen diversity and abundance dropped rapidly with a decline of 80% at a deposition of 11 kg S/ha/yr (33 kg SO_4^{2-}/ha/yr). They estimate the critical load for the most sensitive cyanolichens to be 2.3 kg S/ha/yr (6.9 kg SO_4^{2-}/ha/yr), the lowest of all the lichen functional groups. They propose national critical loads of 6.0, 2.5, 2.6, and 2.3 kg S/ha/yr (18, 7.5, 7.8, and 6.9 kg SO_4^{2-}/ha/yr) for total species richness, sensitive species richness and diversity, and abundance of forage lichens, and cyanolichen functional groups respectively. They point out that using their method of risk estimation for functional groups is more robust than for individual species. Based on their analysis, they estimate that a low risk (<20%) of extirpation of rare species due to SO_4^{2-} deposition ranges from 4.8 to 48 kg SO_4^{2-} kg/ha/yr and a moderate risk (20-50%) ranges from 12 to 56 kg SO_4^{2-} kg/ha/yr, depending on the species under consideration.

They point out that there are uncertainties associated with the CMAQ model and that other models may well give different deposition estimates. Modelling accuracy and precision may also vary depending on methodology and local influences. Current CALPUFF modelling is subject to uncertainty as the comparison to active and passive air monitoring shows (see Sections 3.1.3.1 and 3.1.3.2 of this report). Also, as scale moves from continental to regional to local, the importance of factors removed by the 90% Quantile Regression, such as the availability of suitable habitat, topography, aspect, weather, and land use, become more important.

Geiser et al. (2019) state that recovery of lichen communities with decreasing deposition does occur and ranges in time from a few years to decades. They note that cyanolichens are not only sensitive to deposition, but also to habitat and they require forest continuity for decades to centuries. Given the decrease in F emissions from the modernized smelter and the previous reports relating F and lichen abundance and richness (Reid Collins and Associates 1978; 1986) some recovery of suitable habitat and lichen populations may occur depending on the relative importance of F versus S emissions.

Recently ENV established plots to document the presence or absence of cyanolichens in the Kitimat Valley (Patrick Williston, personal communication) and to try to relate those observations to modelled SO_2 deposition conducted as part of the STAR.

5.1.4.2 *Evidence to support or alter the present sampling array*

The present sampling array has a number of redundancies and plots that do not contribute to understanding the path of the plume or the flux of SO_2 to vegetation, as reported in Section 5.2.1.2. Concentration of S in hemlock is generally poorly correlated with measures of either smelter emissions or atmospheric concentrations of SO_2 modelled by CALPUFF. The highest correlation between %S in hemlock and measures of SO_2 concentration is 0.535 in 2018 between the 35 tpd emissions scenario 1-hour growing season daylight maximum and %S. A full evaluation of results from the vegetation sampling array can be found in Section 5.2.2.1.

5.1.4.3 *Evidence to support or alter the present sampling array with respect to ecosystems and plant species at risk*

We used the B.C. Conservation Data Centre (CDC) database to identify the spatial distribution of ecosystems and plant species deemed at risk in the study area. An analysis of the sampling array with respect to known occurrences of listed ecosystems and species can be found in Section 5.2.2.2.

5.1.4.4 *Methods from the scientific literature to evaluate vegetation health in the areas of predicted critical load (CL) exceedance*

Evaluating vegetation health in areas of predicted critical load exceedance depends on classical methods used in plant pathology, entomology, and ecology. While plants may express specific symptoms and signs related to pathogens and pests that will be useful, evaluating the health of plant communities subjected to long-term stress from atmospheric deposition and exceedance of critical loads is likely to be best expressed by changes in biodiversity. Recent studies (Aherne and Posch 2013; Baker and King 2010; Clark et al. 2019; Dirnböck et al. 2014; Mitchell et al. 2018; Simkin et al. 2016; Wilkins et al. 2016) have used changes in plant biodiversity to detect or measure the impacts of atmospheric deposition.

Many of the studies that assess changes in plant biodiversity due to deposition focus on measuring change across gradients in N deposition. Simkin et al. (2016) demonstrated a negative relationship between N deposition and species richness using over 15,000 sites across the US. They found the relationship to be common, but not universal due to fine-scale processes that can affect vegetation on a local scale. Wilkins et al. (2016) found significant changes in community composition along an N gradient, even where soil critical load for N was not exceeded, thus changes in biodiversity could contribute to understanding if effects on vegetation communities are occurring at or below the soil critical load. Clark et al. (2019) found a negative association between deposition of S and the occurrence of 51% of the 348 herbaceous species they examined. They do point out that species may respond differently based on local environmental and edaphic conditions. Mitchell et al. (2018) are using changes in plant biodiversity to study possible recovery of grasslands in Scotland where S deposition has decreased; they find some evidence for recovery. Based on these recent studies, plant biodiversity might be an appropriate indicator of soil acidification, perhaps at levels below the soil critical load.

Tree ring chronologies may be a useful tool to detect subtle, long-term effects of pollutant deposition. The chronology provides a look at tree growth over long periods of time and may be correlated with climate as well as other factors that affect tree growth (Cook et al. 1987; Dobbertin 2005; McLaughlin et al. 2002). Recording dendrometers may be used to measure changes in tree diameter, and over time, tree growth, however they would not provide a pre-KMP baseline that could be determined from tree ring studies.

Bunce (1979, 1984, 1985, 1989) measured the growth of western hemlock at many locations in and out of the plume path of the VSS smelter in the Kitimat Valley. He used tree ring measurements to estimate the growth loss (and associated economic loss) due to F emissions from the smelter. Similar techniques were used to assess the potential effects of acidic precipitation and O_3 on tree growth and decline in eastern North America (Cook et al. 1987; McLaughlin et al. 2002).

Recently, tree ring measurements and wood chemistry have been used to document the effects of climate change, pollutant deposition, and forest management on the growth of beech in Europe (Hafner et al. 2015).

In order to use tree ring chronologies to detect changes in growth due to factors such as deposition of pollutants, the effects of climate must be removed, so it will take some time—perhaps a decade or two—post-KMP to establish a growth pattern to assess any potential change in growth associated with increased SO_2 emissions from the modernized smelter.

5.2 What Methods Did We Use?

5.2.1 Data we collected

5.2.1.1 *Ambient Air Monitoring*

Ambient air was monitored at four sites and sampled with passive samplers at many more locations. Results are given in Section 3 of this report. Monitored concentrations did not exceed thresholds established in the scientific literature (Section 5.1.4.1).

5.2.1.2 *CALPUFF simulations (see Section 3.1 and Section 3.2)*

CALPUFF modelling methods are found in Section 3 of this report. In this section, we present methods for vegetation-related output from the modelling. CALPUFF modelling does carry uncertainties with it that may be estimated by comparison with active and passive monitoring of air concentrations and deposition as discussed in Sections 3.1 and 3.2.

CALPUFF modelling results didn't include background concentrations of SO_2 or deposition of SO_4^{2-}. In this section, background concentrations and deposition are detailed in table and figure captions. There are two exceptions: SO_2 concentration isopleths include background and are given in $\mu g/m^3$ as we made direct comparisons to critical levels used in Europe. To convert $\mu g/m^3$ to ppb, divide by 2.614; and in the discussion of the area of the valley that exceeds certain SO_4^{2-} deposition rates of interest, rates are given both with and without background of 3.6 kg SO_4^{2-}/ha/yr.

Figure 5-2 shows the location and identification of vegetation sampling and inspection sites used in the STAR and the SO_2 EEM. Site locations are shown on other maps in this section, but the site identifiers are not included in order to increase the legibility of the maps.

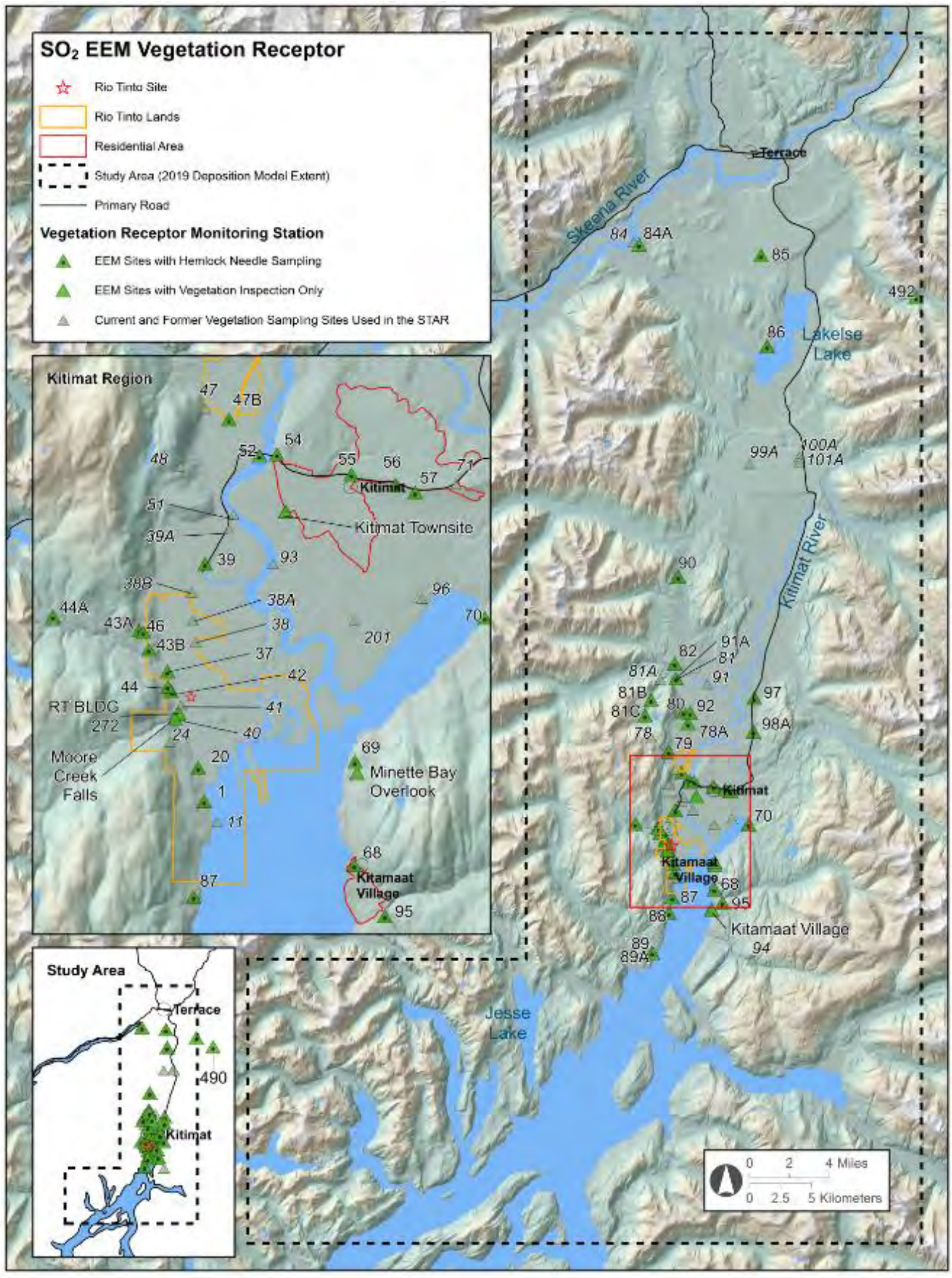


Figure 5-1. The location and identification of vegetation sampling and inspection sites used in the STAR and the SO_2 EEM Program.

Air Concentrations

Vegetation sampling locations were designated receptors in CALPUFF model runs so that SO_2 concentrations of interest, such as 1-hour, 3-hour, and 24-hour maxima; annual and growing season (April 15-October 1) means; and SO_4^{2-} deposition could be output for specific locations where observations and determinations of S in western hemlock needles were made. All three modelling cases—actual emissions, 35 tpd, and 42 tpd—were used. While we did not expect strong relationships with the 35 tpd and 42 tpd scenarios, we examined them as a method to compensate for uncertainty in modelling, particularly to detect under-prediction by CALPUFF. Separate calculations for daylight hours (7 AM to 9 PM) were made as well. Daylight hours were selected based on estimated times of significant photosynthetic activity and gas exchange and are only appropriate for use with growing season time frames.

CALPUFF results for selected measures under the actual emission scenario are shown in Table 5-1. The complete array of concentration measures for each scenario can be found in Vegetation Appendix 5.1. Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual average (and growing season), respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

Table 5-1. CALPUFF-modelled air concentrations of SO_2 in ppb at vegetation sampling and inspection sites under the Actual Emissions scenario. Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table.

	2016					2017					2018			
Plot	1-hour Maximum	3-hour Maximum	Annual Average	Growing Season Average		1-hour Maximum	3-hour Maximum	Annual Average	Growing Season Average		1-hour Maximum	3-hour Maximum	Annual Average	Growing Season Average
	(ppb)													
1	168.0	95.1	7.1	2.9		200.9	160.5	5.9	3.6		148.7	98.5	7.4	3.9
20	151.8	134.4	8.6	5.5		329.5	199.0	8.1	6.9		398.9	262.2	9.6	10.0
37	298.9	104.3	2.1	2.7		452.1	181.1	2.6	4.1		275.6	140.2	2.7	4.4
39	115.1	68.0	4.4	7.1		81.2	54.0	4.4	7.0		60.5	40.2	4.2	6.8
42	216.1	85.3	5.4	4.2		290.4	191.7	4.8	5.1		256.9	132.9	5.3	6.9
43A	68.6	52.5	1.4	1.8		90.8	46.1	1.7	2.5		127.8	75.3	1.9	3.1
43B	111.6	85.9	1.7	2.1		148.6	65.7	1.9	2.9		168.3	80.5	2.3	3.6
44	178.9	158.6	3.4	3.9		269.7	174.0	3.0	4.4		254.4	127.0	3.7	5.8
44A	123.0	41.7	0.7	0.8		100.0	55.0	0.7	1.0		106.7	76.4	0.8	1.2
46	86.9	55.1	1.6	2.1		113.3	49.4	1.9	3.0		124.1	75.3	2.2	3.5
47B	49.8	34.2	2.8	4.3		42.4	34.4	2.9	4.3		45.8	35.6	2.8	4.3
52(A)	52.3	32.7	1.8	2.6		57.3	32.6	1.9	2.7		42.7	28.4	2.0	2.7
54	47.8	26.0	1.5	1.9		60.5	32.7	1.5	2.1		41.0	26.0	1.7	2.1
55	85.9	55.8	0.6	0.7		74.0	50.4	0.6	0.6		35.2	25.4	0.7	0.7
56(A)	70.1	40.6	0.5	0.5		63.2	54.5	0.6	0.5		38.3	26.9	0.6	0.5
57	90.5	70.8	0.5	0.4		65.0	51.5	0.5	0.4		64.3	39.8	0.5	0.5
68	33.3	18.6	0.3	0.3		43.3	25.0	0.3	0.3		20.3	12.0	0.3	0.3
69	78.3	45.4	0.4	0.3		74.0	30.6	0.3	0.3		28.0	18.3	0.3	0.4
70	21.5	14.5	0.2	0.2		15.1	8.9	0.2	0.2		19.2	11.5	0.2	0.3
78 (A)	39.4	28.1	2.3	3.2		45.8	25.3	2.5	3.5		51.5	28.8	2.4	3.5
79	72.9	39.6	3.0	4.7		105.5	41.9	3.3	5.1		71.4	45.9	3.3	5.5
80	50.1	38.5	2.5	3.8		42.5	27.3	2.7	3.8		67.6	30.7	2.6	4.0
81B	103.9	62.4	1.3	1.8		76.7	46.8	1.4	2.1		150.0	108.5	1.6	2.6
81C	40.9	31.0	1.0	1.3		59.4	37.1	1.1	1.7		151.4	98.4	1.4	2.1
82	65.9	50.6	2.3	3.7		84.6	56.6	2.4	3.6		172.1	90.2	2.4	4.0
84 (A) (B)	6.5	5.0	0.1	0.1		5.6	3.8	0.1	0.2		6.8	5.3	0.1	0.1

	2016					2017					2018			
Plot	1-hour Maximum	3-hour Maximum	Annual Average	Growing Season Average		1-hour Maximum	3-hour Maximum	Annual Average	Growing Season Average		1-hour Maximum	3-hour Maximum	Annual Average	Growing Season Average
	(ppb)													
85	11.9	8.3	0.5	0.8		10.4	6.7	0.5	0.8		11.3	8.9	0.5	0.7
86	10.4	7.4	0.7	1.1		8.9	7.8	0.8	1.1		15.2	12.8	0.8	1.1
87	163.8	59.2	4.3	1.7		78.1	56.7	3.3	1.9		83.6	59.5	3.4	2.1
88	52.4	39.7	3.2	1.3		59.2	47.4	2.7	1.5		61.2	50.5	2.6	1.7
89	52.1	40.3	2.8	1.2		40.0	29.7	2.5	1.3		51.1	29.7	2.7	1.5
89A	52.5	40.6	2.9	1.2		39.9	29.5	2.5	1.3		51.4	29.9	2.7	1.5
90	56.4	43.0	1.2	2.0		45.7	34.2	1.2	1.8		55.9	27.0	1.2	2.1
91(A)	68.3	55.2	2.3	3.7		49.3	33.8	2.4	3.5		106.2	58.6	2.3	3.8
92	48.6	28.6	2.2	3.2		60.4	31.9	2.4	3.4		53.8	30.8	2.4	3.5
95	59.2	32.6	0.3	0.2		25.1	15.8	0.3	0.2		14.6	10.0	0.2	0.2
97	25.0	19.8	0.4	0.4		17.0	13.5	0.4	0.5		32.5	28.3	0.5	0.6
98A	25.5	21.0	0.3	0.3		14.5	11.1	0.3	0.4		32.7	23.2	0.4	0.4
490	6.1	3.9	0.1	0.2		5.3	2.5	0.1	0.2		7.3	4.7	0.2	0.2
492	9.2	7.7	0.3	0.4		6.9	5.3	0.3	0.4		10.8	6.6	0.4	0.5

Table 5-2 shows sites that are projected to have an annual average exceeding 4 ppb (including background) based on CALPUFF modelling. An annual average SO_2 concentration of 4 ppb corresponds to the critical annual average concentration to protect sensitive lichens (WHO 2000) and to the CAAQS set to go into effect in 2025. Sites 1, 20, 39, 42, and 44 are close to the smelter and on Rio Tinto property. Sites 47B, 79, and 87 are located off Rio Tinto property. Sites 47B, 79, and 87 are not projected to exceed an annual average of 5 ppb, the current CAAQS, under any scenario.

Table 5-2. Sites where CALPUFF modelling indicates an annual air concentration >4 ppb SO_2.

Emissions Scenario	2016	2017	2018
Actual	1, 20, 39, 42, 87	1, 20, 39, 42	1, 20, 39, 42, 44
35 tpd	1, 20, 39, 42, 87	1, 20, 39, 42	1, 20, 39, 42, 44
42 tpd	1, 20, 39, 42, 44, 46, 87	1, 20, 39, 42, 44, 47B, 79, 87	1, 20, 39, 42, 44,47B, 79, 87

Figure 5-2 shows the location of the sampling and inspection sites in relation to CALPUFF-modelled annual average air concentration isopleths of 10 and 20 µg/m^3 (3.8 and 7.6 ppb), the threshold values used in Europe to protect sensitive lichens and natural ecosystems. The 10 µg/m^3 isopleth corresponds approximately to the 2025 CAAQS. Background SO_2 is included in the isopleth values.

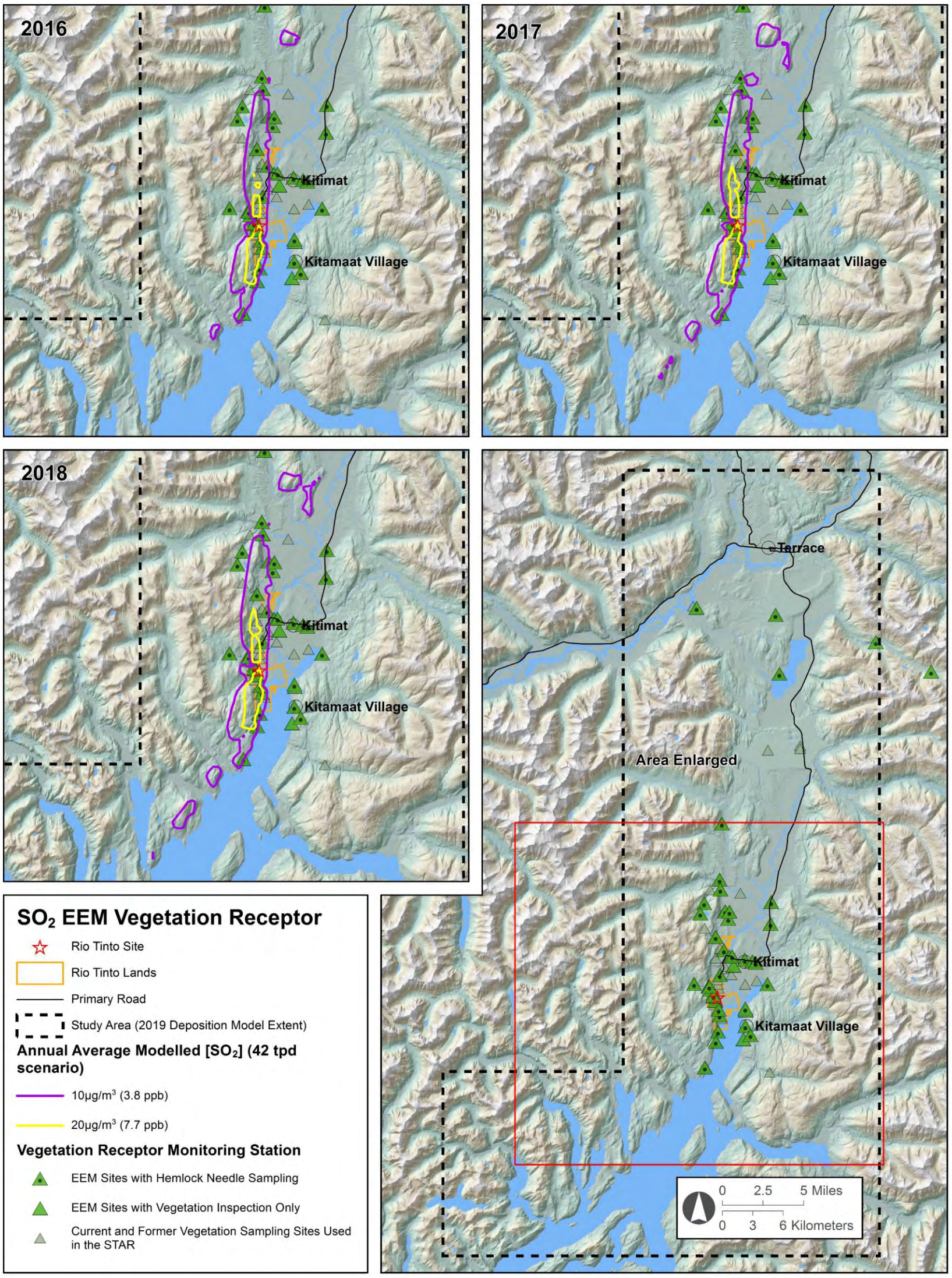


Figure 5-2. Location of sampling and inspection sites with respect to the CALPUFF-modelled annual average air concentration isopleths of 10 and 20 µg/m³ (3.8 and 7.6 ppb), the threshold values used in Europe to protect sensitive lichens and natural ecosystems. The 10 µg/m³ isopleth corresponds approximately to the 2025 CAAQS. The modelling scenario is 42 tpd (the maximum permitted level). The isopleths include background SO_2 concentrations of 0.47 ppb.

Table 5-3 presents correlation coefficients between measures of CALPUFF-modelled SO_2 concentration at sampling sites and %S in western hemlock needles collected at those sites. Correlations were calculated for all three scenarios, providing an estimate of the effect of an under-prediction of actual concentrations under the actual emission scenario. An analysis of the relationship between modelled air concentrations and %S in western hemlock needles can be found in Section 5.2.2.1.

Table 5-3. Correlation between measures of CALPUFF-modelled SO_2 concentration in ppb and %S in western hemlock needles using all vegetation sampling sites.

Air Concentration Statistic	Actual			35 tpd			42 tpd		
	2016	2017	2018	2016	2017	2018	2016	2017	2018
	Correlation Coefficient								
1-hour Maximum	0.448	0.223	0.421	0.407	0.174	0.306	0.399	0.174	0.296
1-hour Maximum Day[1]	0.339	0.272	0.386	0.507	0.215	0.321	0.514	0.170	0.311
1-hour Maximum Growing Season[1]	0.453	0.288	0.455	0.507	0.285	0.439	0.501	0.281	0.428
1-hour Maximum Growing Season Day	0.434	0.249	0.470	0.535	0.372	0.440	0.528	0.372	0.428
3-hour Maximum	0.385	0.195	0.386	0.345	0.136	0.248	0.334	0.136	0.239
3-hour Daylight	0.378	0.314	0.388	0.430	0.205	0.287	0.431	0.175	0.279
3-hour Growing Season	0.483	0.350	0.418	0.453	0.366	0.352	0.443	0.359	0.341
3-hour Growing Season Daylight	0.505	0.301	0.353	0.499	0.373	0.295	0.494	0.369	0.286
24-hour Maximum	0.263	0.362	0.283	0.174	0.153	0.204	0.161	0.149	0.195
24-hour Daylight	0.301	0.253	0.356	0.278	0.125	0.357	0.214	0.141	0.348
24-hour Growing Season	0.437	0.331	0.460	0.355	0.332	0.390	0.342	0.322	0.379
24-hour Growing Season Daylight	0.415	0.262	0.352	0.353	0.312	0.408	0.339	0.303	0.398
Annual Average	0.311	0.401	0.291	0.264	0.334	0.250	0.257	0.327	0.243
Annual Average Daylight	0.286	0.321	0.274	0.252	0.249	0.241	0.250	0.312	0.235
Growing Season Average	0.442	0.467	0.424	0.355	0.436	0.384	0.389	0.432	0.379
Growing Season Daylight	0.415	0.432	0.371	0.364	0.410	0.345	0.358	0.406	0.340

[1]Growing Season is April 15-October 1. Daylight hours are 7AM to 9PM.

In order to select a measure of SO_2 concentration for analysis with %S in western hemlock needles, we examined the relationship among the measures. A comparison of the growing season average to the annual average is shown in Figure 5-3. The effect of the seasonal dispersion pattern is clearly shown: sampling sites 42, 20, 1, 87, 88, 89, and 89A are arrayed aside or south of the smelter and the northerly flow of winds in the spring and summer results in a lower growing season average when compared to the annual average.

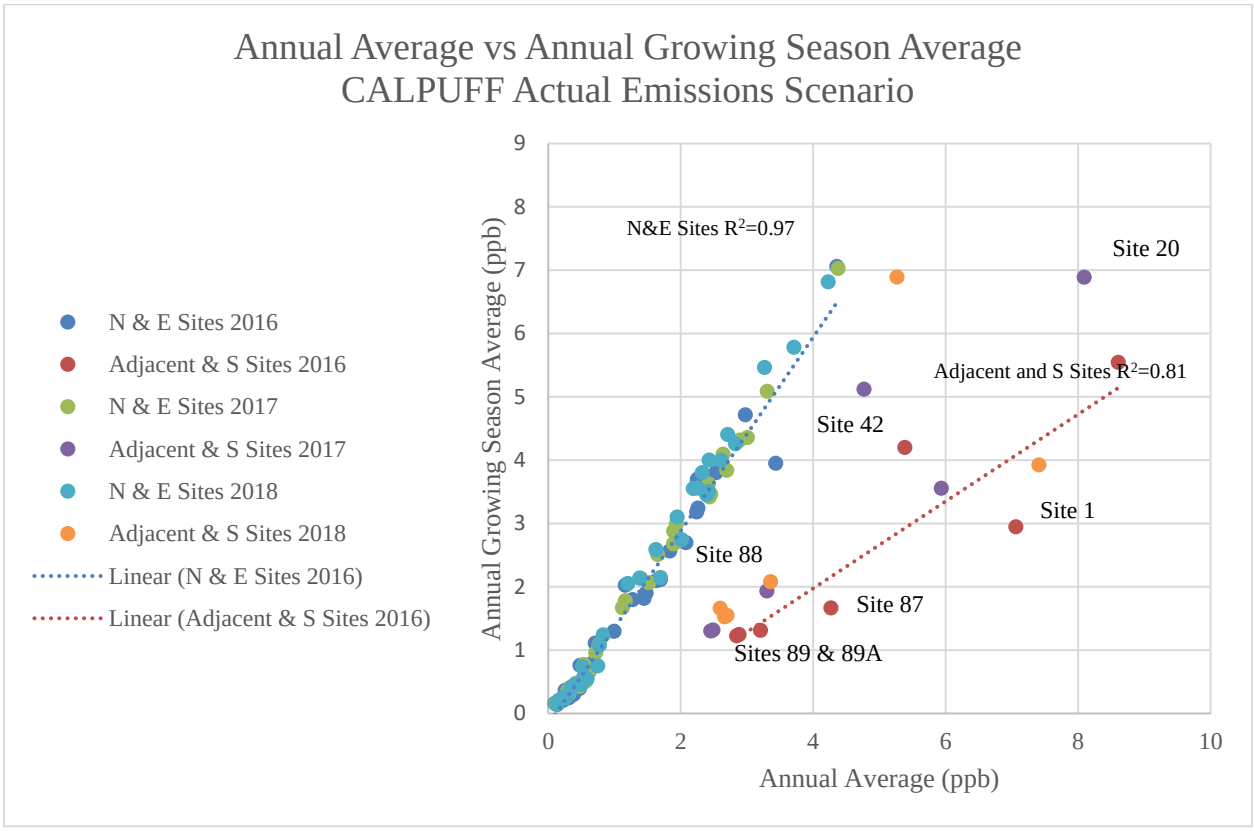


Figure 5-3. The relationship of CALPUFF-modelled annual average and growing season average SO_2 concentrations at vegetation sampling and inspection sites under the actual emissions scenario. Trend lines are fit for 2016 to illustrate the strength of the relationship. The annual and growing season averages do not include background SO_2 concentration of 0.47 ppb.

The growing season average provided a consistent, and on average, the highest correlation for the 3 years in the actual scenario, so we selected it for use in subsequent analyses of the relationship between CALPUFF-modelled SO_2 concentration and %S in needles. No measure explained more than 35% of the variation in the needle S dataset.

Average daily emissions, as reported by Rio Tinto, show a closer relationship with %S in western hemlock needles, with correlation coefficients ranging from about 0.2 to 0.9 (analysis can be found in Vegetation Appendix 5.2). Average daily emissions are also used to compare pre- and post-KMP needle S, as modelled SO_2 concentrations are not available for all pre-KMP years.

No modelled SO_2 concentration at vegetation sites exceeded the thresholds reported in the scientific literature and used in the STAR of 334, 500, and 126 ppb for 1, 3, and 24-hour maxima respectively. In two cases, 2017 and 2018 under the 42 tpd scenario, modelled concentrations at site 20 exceeded the 188 ppb 1-hour concentration that was previously used in B.C. Pollution Control Objectives as the maximum desirable level. All other sites under all scenarios and all years were well below the thresholds of concern.

The number of hours that certain key thresholds (as identified in the STAR) were exceeded at all receptors (including on-site and fence line receptors) are shown for the post-KMP period in Table

5-4. Given the number of receptor hours modelled—over 50,000,000— and the fact that on-site receptors are included, the number of exceedances of the thresholds are extremely low. In addition, given the finding that, in general, CALPUFF over-predicts SO_2 concentrations, it is highly unlikely that there will be any direct impact of SO_2 on even the most sensitive vegetation.

Table 5-4. Receptor-hours under the actual emissions scenario exceeding thresholds used in the STAR to evaluate the likelihood of visible injury to vegetation. All receptors, including on-site and fence line receptors, are included. Background SO_2 concentrations of 5.53, 2.80, and 1.74 for 1-hour, 3-hour, and 24-hour, respectively, are not included in the SO_2 concentrations listed in the table.

Averaging Period	1-Hour		3-Hour		24-Hour	
Concentration	188 ppb 491 µg/m³	334 ppb 873 µg/m³	250 ppb 653 µg/m³	500 ppb 1307 µg/m³	62 ppb 162 µg/m³	126 ppb 329 µg/m³
Model Year						
2016	317	49	19	0	3	0
2017	556	88	22	0	6	0
2018	823	108	20	0	19	0

Receptor hours = total number of hours exceeding each threshold at any receptor, including repeated occurrences at the same receptor. 12,570 receptors are modelled over 4,079 hours in the growing period, resulting in over 50,000,000 receptor-hours. Values in µg/m³ are provided for comparison to the STAR.

Locations with the highest CALPUFF-modelled SO_2 concentrations were determined for comparison with the current sampling array and are shown in Figure 5-4. Many of the highest growing season concentrations are along the ridge to the west and south of the smelter, an area of overlap with predicted soil critical load exceedance (Figure 6-5) of approximately 190 ha, of which about 87 ha are outside the Rio Tinto property line. Concentrations and coordinates for the 42 tpd growing season daylight scenario (maximum permitted level case) are found in Table 5-5. Coordinates and concentrations for other scenarios are in Vegetation Appendix 5.3. In addition, we mapped areas exceeding 10 (3.8 ppb) and 20 (7.6 ppb) µg/m³ annual average SO_2 concentrations, to determine the extent of the concentrations that exceed established thresholds for sensitive lichens and natural ecosystems used in Europe (Figure 5-5).

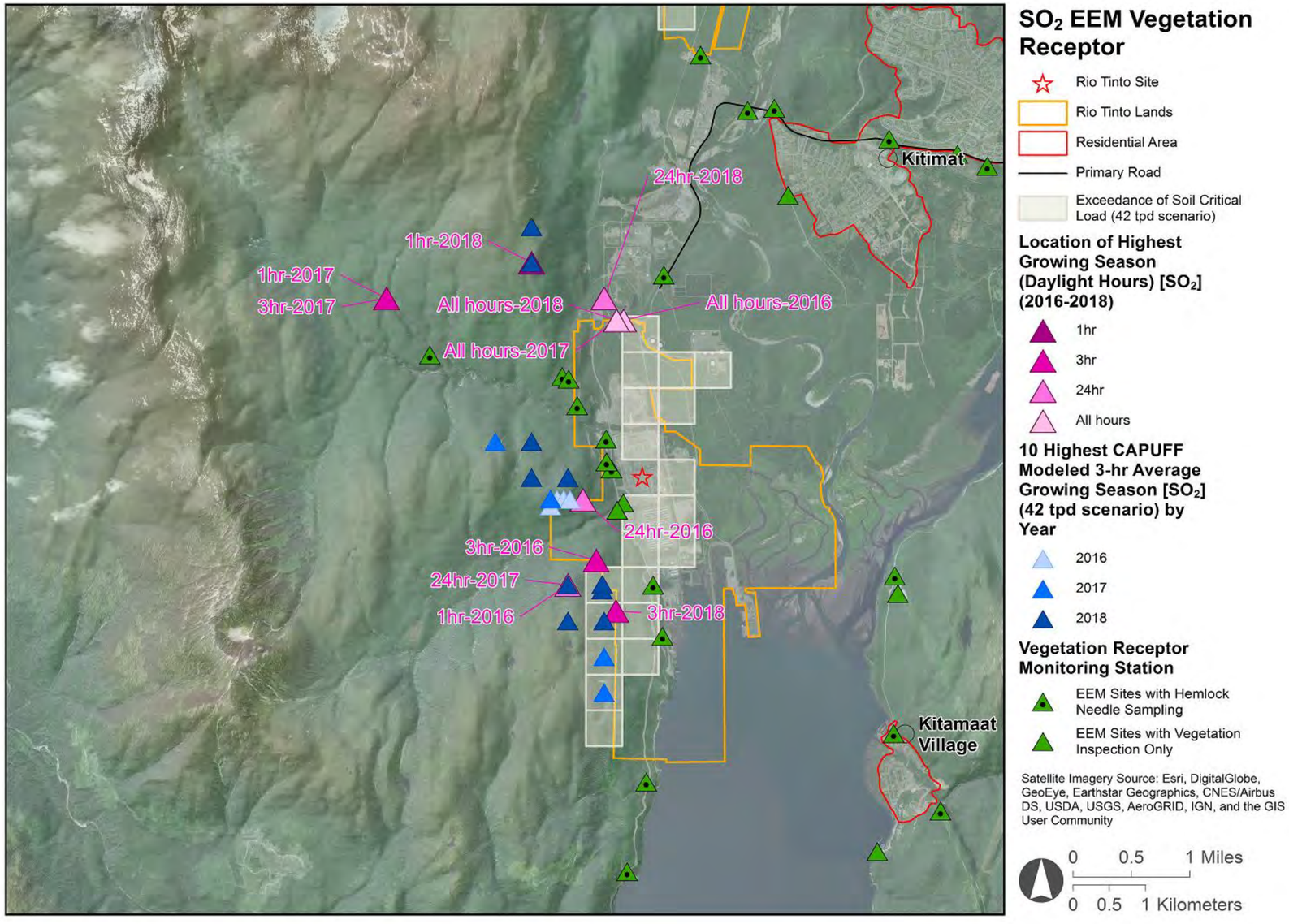


Figure 5-4. Location of the 10 highest CAPUFF modelled 3-hour average Growing Season SO_2 concentrations under the 42 tpd scenario (maximum permitted level case) for 2016-2018 (blue symbols) and the highest locations for growing season daylight hours 1-hour, 3-hour, 24-hour, and annual averages for each year (pink symbols). Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included but do not affect the locations.

Table 5-5. Coordinates and SO_2 concentrations (42 tpd scenario [maximum permitted level case]) at the 10 highest locations during the growing season outside the Rio Tinto fence line. Some locations appear more than once. Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. The addition of background does not affect the location.

		SO_2 Concentration	UTM X	UTM Y
Avg. Period	Year	(ppb)	(km)	(km)
	2016	495	518.500	5983.500
1hr	2017	611	516.000	5987.500
	2018	351	518.000	5988.000
	2016	234	518.891	5983.842
3hr	2017	284	516.000	5987.500
	2018	228	519.163	5983.139
	2016	67	518.709	5984.689
24hr	2017	63	518.500	5983.500
	2018	62	519.000	5987.500
	2016	20	519.267	5987.193
All hours	2017	21	519.173	5987.193
	2018	21	519.173	5987.193

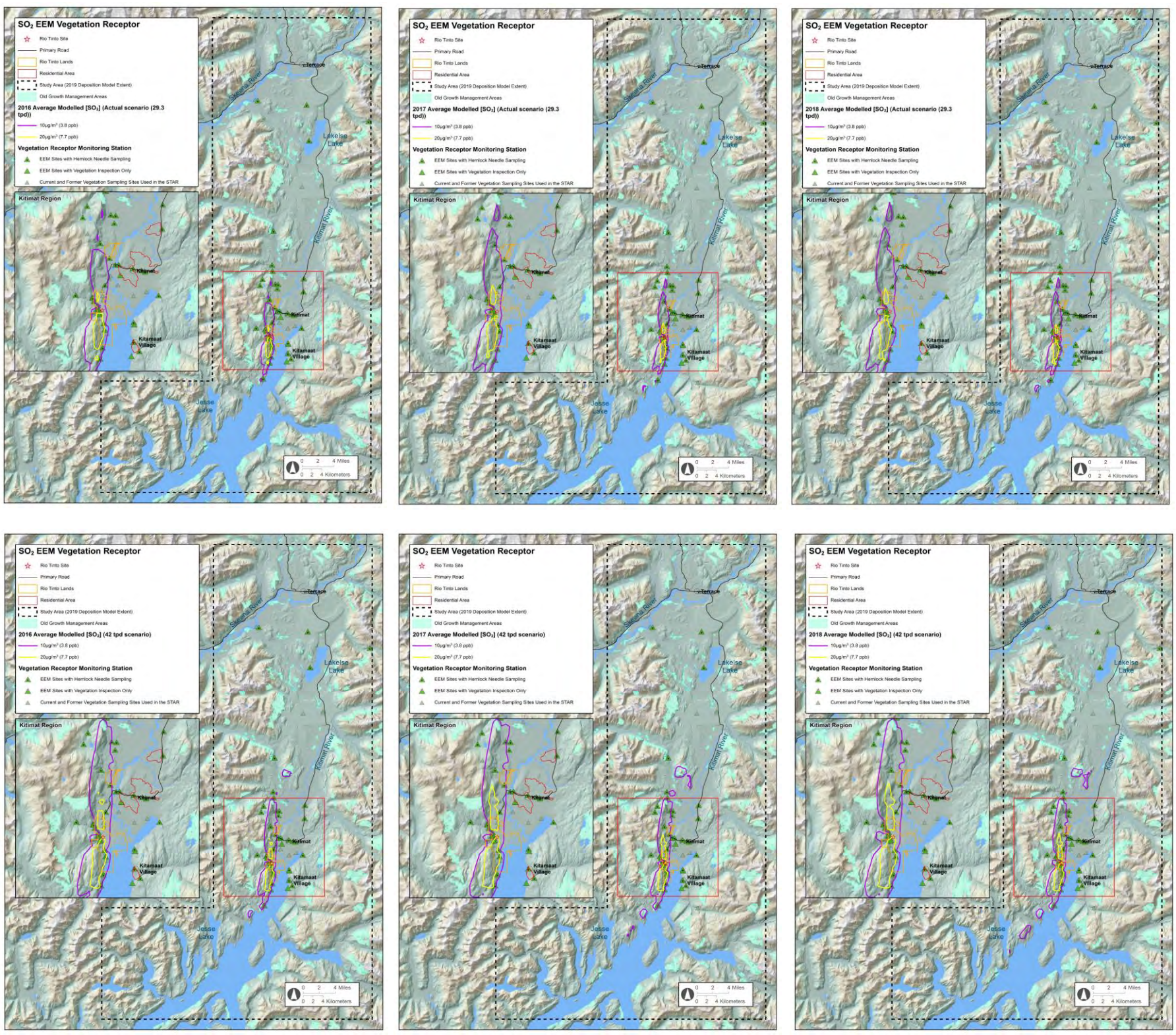


Figure 5-5. CALPUFF-modelled annual average SO_2 concentration isopleths (yellow=20 µg/m³ (7.6 ppb) and purple=10µg/m³ (3.8 ppb) for 2016-2018 under the actual emission scenario (top) and the 42 tpd scenario (bottom). Teal-coloured areas are Old Growth Management Areas. Background SO_2 concentrations are included to allow comparison to European thresholds of 10 and 20 µg/m³.

Deposition

CALPUFF was also used to model SO_4^{2-} deposition at vegetation sampling and inspection sites. The results are shown in Table 5-6. Deposition decreased rapidly with distance from the smelter. The relationship between deposition and distance from the smelter with respect to vegetation sampling sites is shown in Figure 5-6. CALPUFF-modelled deposition of SO_4^{2-} was moderately correlated with modelled SO_2 concentration, with linear regressions explaining between 56 and 73% of the variation. The spatial distribution of SO_4^{2-} deposition for the actual emissions and 42 tpd scenarios are shown in Figure 5-7. An analysis of the implications of modelled SO_4^{2-} deposition is found in Section 5.2.2.1.

Table 5-6. CALPUFF-modelled SO_4^{2-} deposition for vegetation sampling and inspection sites. Values do not include background of 3.6 kg SO_4^{2-}/ha/yr.

	CALPUFF-Modelled S Deposition kg SO_4^{2-}/ha/yr												
	Actual Emissions				35 tpd				42 tpd			
Site	2016	2017	2018	Mean	2016	2017	2018	Mean	2016	2017	2018	Mean
1	127.4	95.2	103.0	108.5	147.2	141.9	117.5	135.6	181.1	174.9	145.0	167.0
20	164.7	142.9	114.8	140.8	205.4	191.6	136.5	177.8	251.3	234.8	166.8	217.6
37	52.0	39.7	35.4	42.4	64.9	46.9	39.8	50.5	77.7	56.4	47.8	60.6
39	66.5	81.5	53.9	67.3	80.8	92.1	61.0	78.0	96.7	110.2	72.9	93.3
42	100.7	79.8	55.8	78.8	105.5	88.9	60.4	84.9	126.2	106.5	72.5	101.7
43A	19.5	16.7	15.6	17.3	23.6	18.3	17.0	19.7	28.4	22.1	20.5	23.6
43B	25.9	20.5	19.4	21.9	32.0	22.6	21.1	25.2	38.4	27.2	25.4	30.3
44	69.4	53.6	39.1	54.0	76.1	61.3	42.9	60.1	91.0	73.5	51.5	72.0
44A	6.7	6.5	6.0	6.4	8.0	7.4	6.5	7.3	9.6	8.9	7.8	8.7
46	21.8	18.8	17.4	19.3	26.6	20.6	18.7	22.0	32.0	24.9	22.5	26.5
47B	38.2	45.9	29.9	38.0	46.1	52.4	32.9	43.8	55.2	62.8	39.5	52.5
52(A)	32.8	49.6	35.4	39.3	40.6	58.3	41.9	46.9	48.7	69.8	50.1	56.2
54	31.9	50.3	33.5	38.6	39.6	60.4	38.2	46.1	47.6	72.3	45.7	55.2
55	15.4	26.8	17.1	19.8	18.9	30.6	19.7	23.1	22.8	36.9	23.8	27.8
56(A)	10.5	14.5	10.5	11.8	12.4	17.0	12.0	13.8	15.0	20.6	14.6	16.7
57	9.2	11.5	8.6	9.8	10.3	13.2	9.8	11.1	12.4	16.0	11.8	13.4
68	3.7	3.5	3.8	3.7	4.2	4.3	4.4	4.3	5.1	5.2	5.3	5.2
69	5.3	5.4	5.3	5.3	6.2	6.8	5.9	6.3	7.4	8.2	7.1	7.6
70	3.2	3.8	3.6	3.5	3.9	4.9	4.1	4.3	4.7	5.9	5.0	5.2
78 (A)	26.9	32.1	22.9	27.3	31.7	36.8	25.2	31.2	38.1	44.3	30.3	37.5
79	26.9	28.8	23.4	26.4	32.2	31.5	25.7	29.8	38.6	37.9	30.9	35.8
80	26.1	30.1	21.2	25.8	30.8	33.5	23.2	29.2	37.0	40.3	27.9	35.1
81B	9.8	10.1	9.2	9.7	11.8	10.9	10.0	10.9	14.1	13.2	12.0	13.1

	CALPUFF-Modelled S Deposition kg SO_4^{2-}/ha/yr												
	Actual Emissions					35 tpd					42 tpd		
Site	2016	2017	2018	Mean		2016	2017	2018	Mean		2016	2017	2018	Mean
81C	8.2	8.3	7.8	8.1		9.9	9.0	8.5	9.2		11.9	10.9	10.3	11.0
82	15.6	17.4	14.4	15.8		18.8	19.4	15.9	18.1		22.6	23.4	19.1	21.7
84 (A) (B)	1.7	1.3	1.1	1.4		2.2	1.5	1.2	1.6		2.6	1.8	1.5	2.0
85	3.4	3.5	3.0	3.3		4.1	4.0	3.4	3.8		4.9	4.8	4.1	4.6
86	5.1	5.4	4.7	5.1		6.2	6.2	5.2	5.9		7.4	7.4	6.3	7.1
87	48.4	40.4	38.9	42.6		54.6	49.4	42.9	49.0		66.3	59.9	52.2	59.5
88	33.3	28.6	27.5	29.8		37.2	34.4	30.4	34.0		45.1	41.7	36.9	41.3
89	22.4	19.4	20.0	20.6		25.4	23.0	21.8	23.4		30.9	27.9	26.5	28.4
89A	22.5	19.6	20.1	20.7		25.6	23.2	22.0	23.6		31.1	28.1	26.7	28.6
90	7.4	7.6	6.7	7.2		9.1	8.4	7.4	8.3		10.9	10.2	8.8	10.0
91(A)	18.4	20.1	15.9	18.1		22.0	22.5	17.5	20.7		26.5	27.1	21.1	24.9
92	25.5	30.2	21.8	25.8		30.0	34.8	23.9	29.6		36.0	41.8	28.8	35.6
95	3.0	2.9	2.9	2.9		3.4	3.4	3.4	3.4		4.2	4.1	4.1	4.1
97	7.1	10.7	8.4	8.7		8.7	12.9	9.6	10.4		10.5	15.5	11.6	12.5
98A	5.1	6.0	5.0	5.4		6.0	7.1	5.7	6.3		7.2	8.6	6.9	7.6
490	0.6	0.6	0.8	0.7		0.8	0.7	0.9	0.8		0.9	0.9	1.1	1.0
492	1.4	1.8	2.1	1.8		1.8	2.2	2.5	2.2		2.2	2.7	2.9	2.6

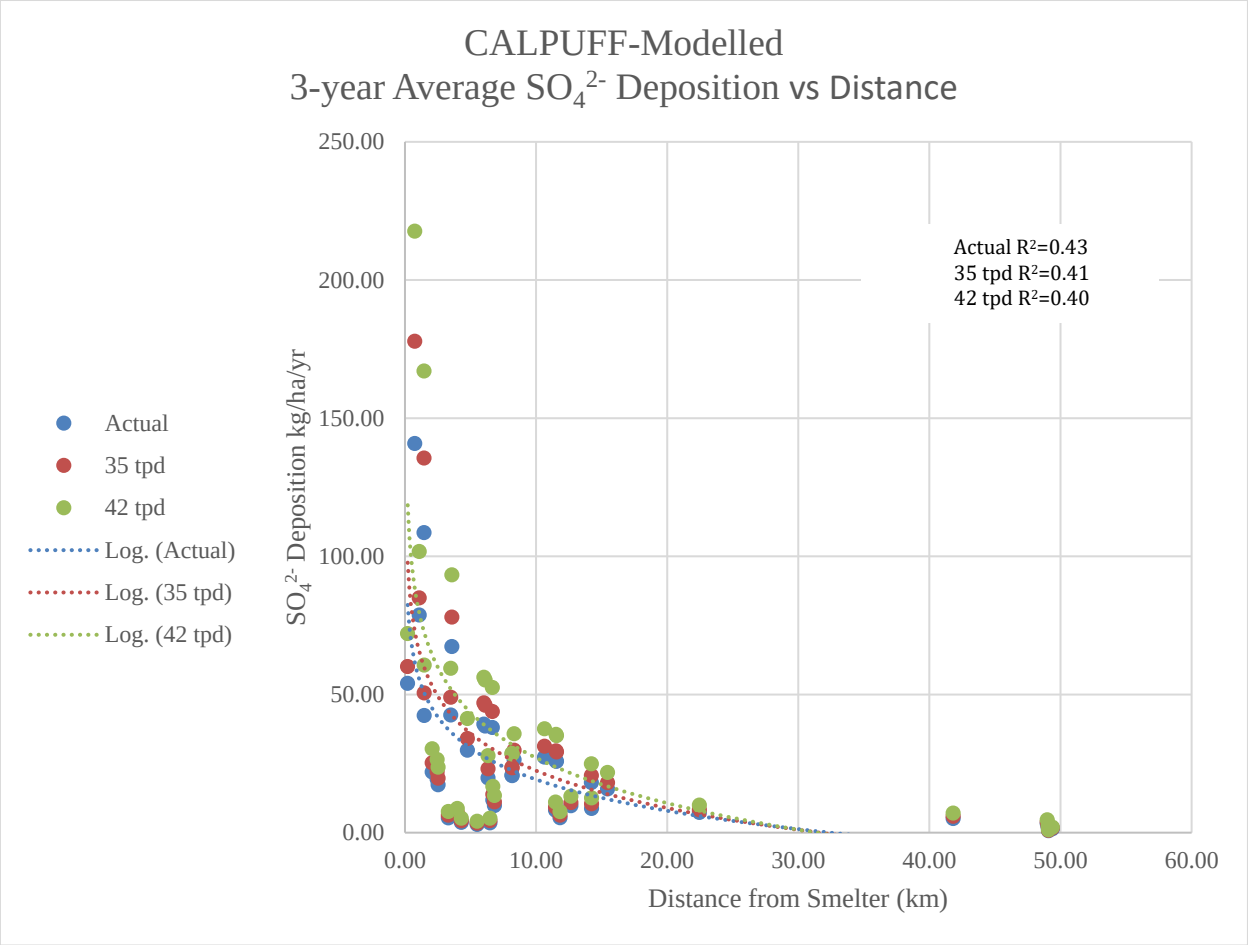


Figure 5-6. The relationship between CALPUFF-modelled 3-year average SO_4^{2-} deposition and distance of vegetation sites from the smelter. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included.

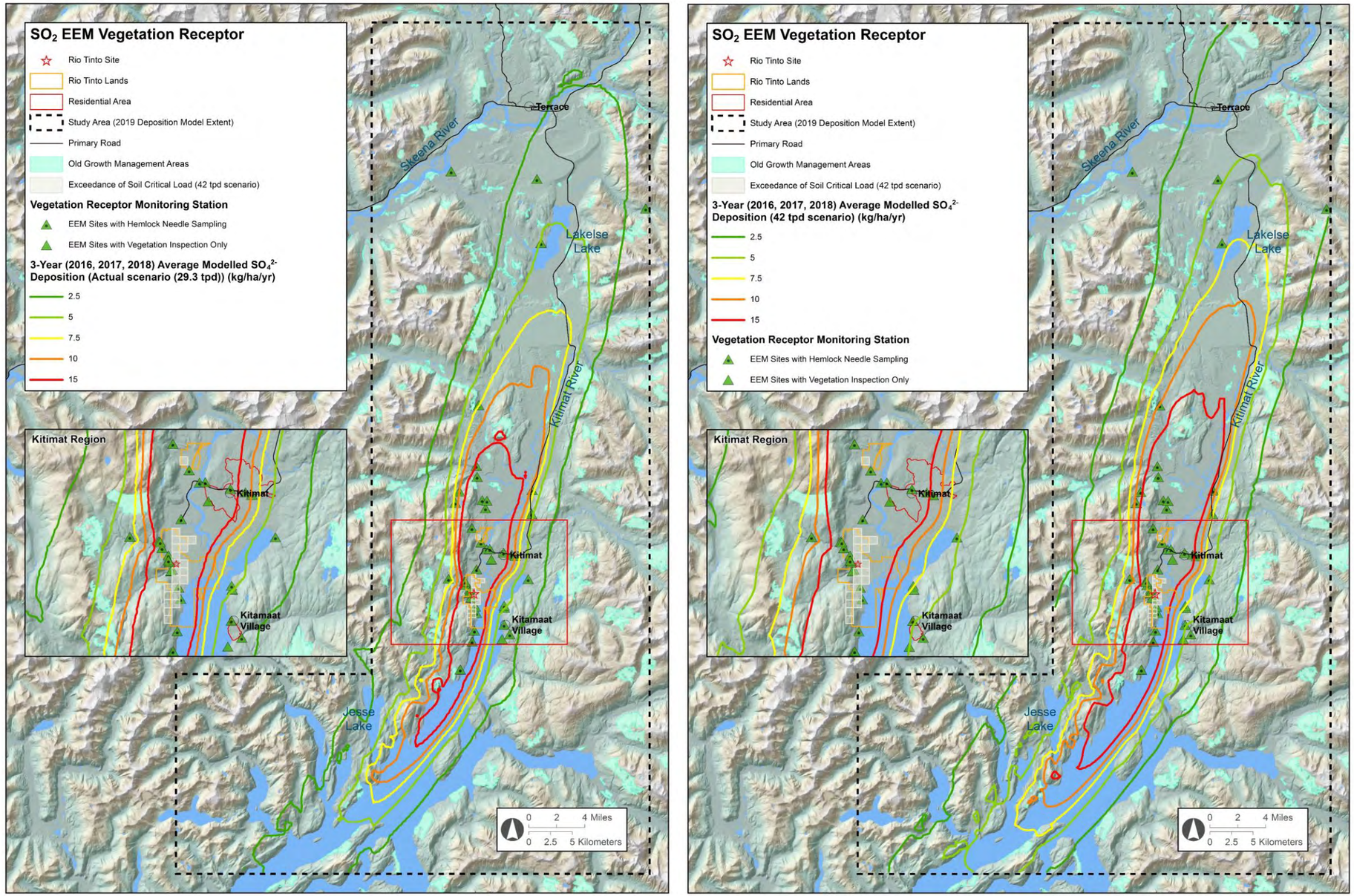


Figure 5-7. Three-year average deposition of SO_4^{2-} as modelled by CALPUFF under the actual deposition scenario (left) and 42 tpd (right). Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleths.

5.2.1.3 *Updated scientific literature on the response of vegetation and ecotypes to SO_2*

See Section 5.1.4.1.

5.2.1.4 *Field methods to document vegetation condition, health, and visible injury*

Biennially, or more frequently, a QP plant scientist (currently a plant pathologist) inspects vegetation in the Kitimat Valley. The inspection takes place at each sampling site, as well as at a few additional sites (e.g., the Rio Tinto Administration Building, Moore Creek Falls, Minette Bay overlook, Kitamaat Village, and Kitimat neighborhoods). The QP notes the general condition of vegetation and takes photos to illustrate the condition of vegetation at the time of the inspection. Symptoms and signs of plant diseases, insect infestation, and environmental stress (including drought, physical damage, and injury due to air pollution) are documented. The QP's report is prepared and submitted with the annual report of the vegetation program (see Stantec Consulting Ltd. and Laurence 2019). Full details of the methods are provided in Vegetation Appendix 5.4.

5.2.1.5 *Concentrations of S in western hemlock foliage*

Sampling and Collection Methods

Sampling and collection methods were the same as used in the annual vegetation program (Stantec Consulting and Laurence 2019) and were subject to Stantec's quality assurance program. Complete details of the sampling, collection, and sample processing methods can be found in Vegetation Appendix 5.4. Sample collection and inspection sites are shown in Figure 5-8.

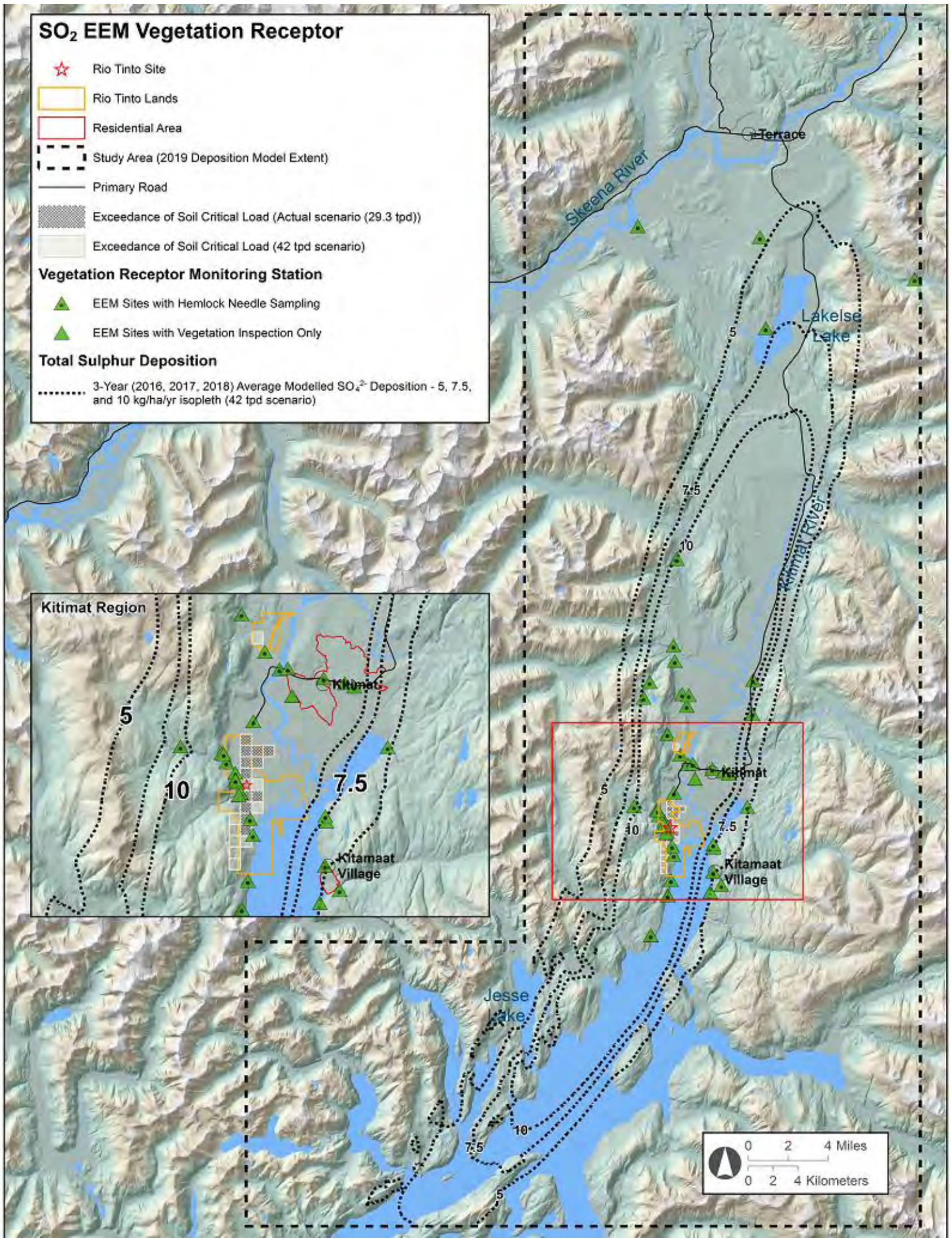


Figure 5-8. Location of vegetation sampling and inspection sites, as well as isopleths of SO_4^{2-} deposition. Background deposition of 3.6 kg SO_4^{2-}/yr is not included in the isopleths.

Chemical analysis methods

Chemical analysis of western hemlock needles to determine the S and F content is conducted by the Rio Tinto laboratory in Jonquière, Québec. Sulphur is determined using combustion, collection of gases in sodium hydroxide (NaOH), and analysis using ion chromatography column. F is determined using combustion, collection of gases in $H_2SO_4^{2-}$ or NaOH, and analysis with an ion-specific electrode. Complete details are reported in Stantec Consulting and Laurence (2019) and Laurence (2018).

5.2.2 Analyses we conducted with these data

5.2.2.1 *Spatial Evaluation of post-KMP CALPUFF simulation results versus post-KMP sulphur in western hemlock*

Air Concentration

CALPUFF-modelled measures of air concentrations were not highly correlated with %S in western hemlock needles. An example of the relationship, %S in needles and modelled growing season average SO_2 concentration is shown in Figure 5-9. No SO_2 concentration statistic explained more than 35% of the variation in S content of needles. Table 5-3 shows the correlation coefficients between all modelled air concentration statistics and %S in western hemlock.

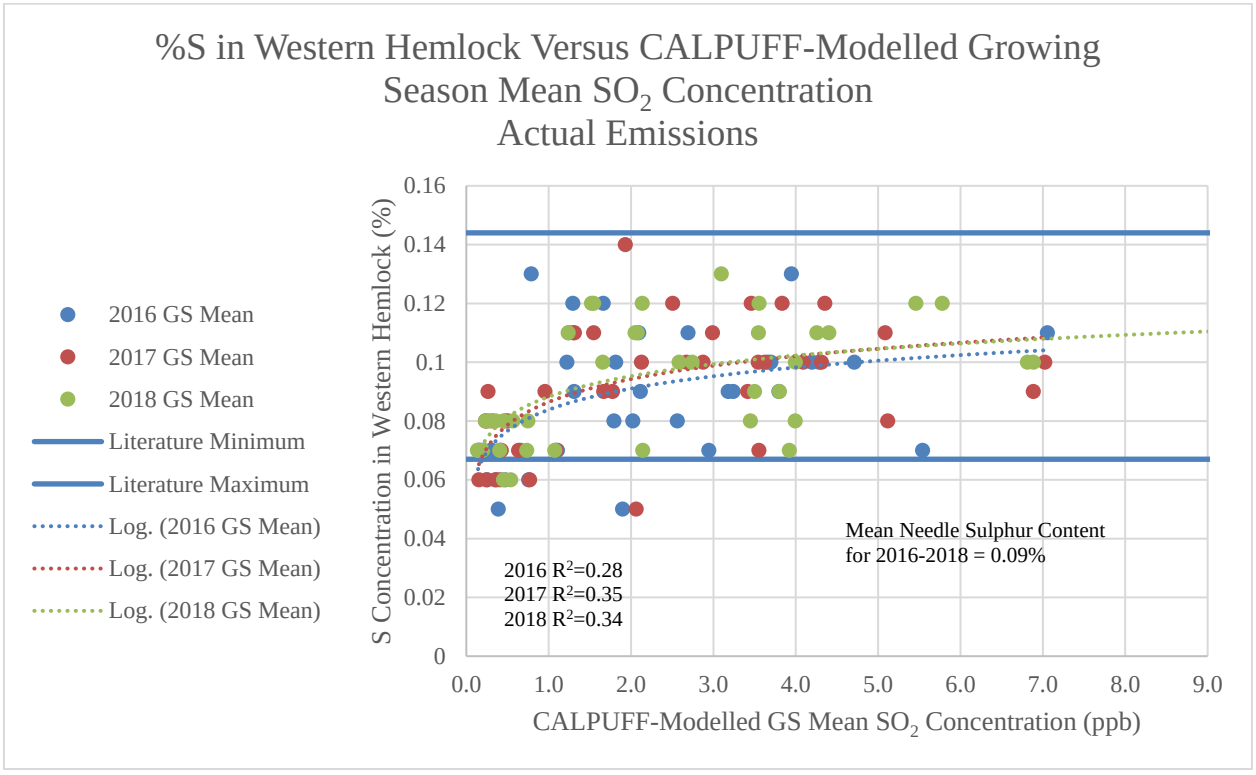


Figure 5-9. Relationship between annual growing season mean CALPUFF-modelled SO_2 concentrations and %S in western hemlock needles. Correlations for individual years are provided in Table 5-3. Background SO_2 concentration of 0.47 ppb is not included.

Figure 5-10 shows the spatial distribution of vegetation sampling sites with post-KMP average needle S concentrations and isopleths of modelled (actual scenario) annual growing season average SO_2 concentrations of 10 and 20 µg/m^3 (3.8 and 7.6 ppb), thresholds established in Europe to protect sensitive lichens and natural forest ecosystems, respectively (WHO 2000; European Union 2008). Thirty of 40 vegetation sampling sites are located outside of the 10 µg/m^3 SO_2 isopleth and represent the full range of %S found in western hemlock needles. Similarly, sites with the full range of %S occur inside the 10 µg/m^3 SO_2 isopleth as well. No vegetation sites were located inside the 20 µg/m^3 SO_2 isopleth.

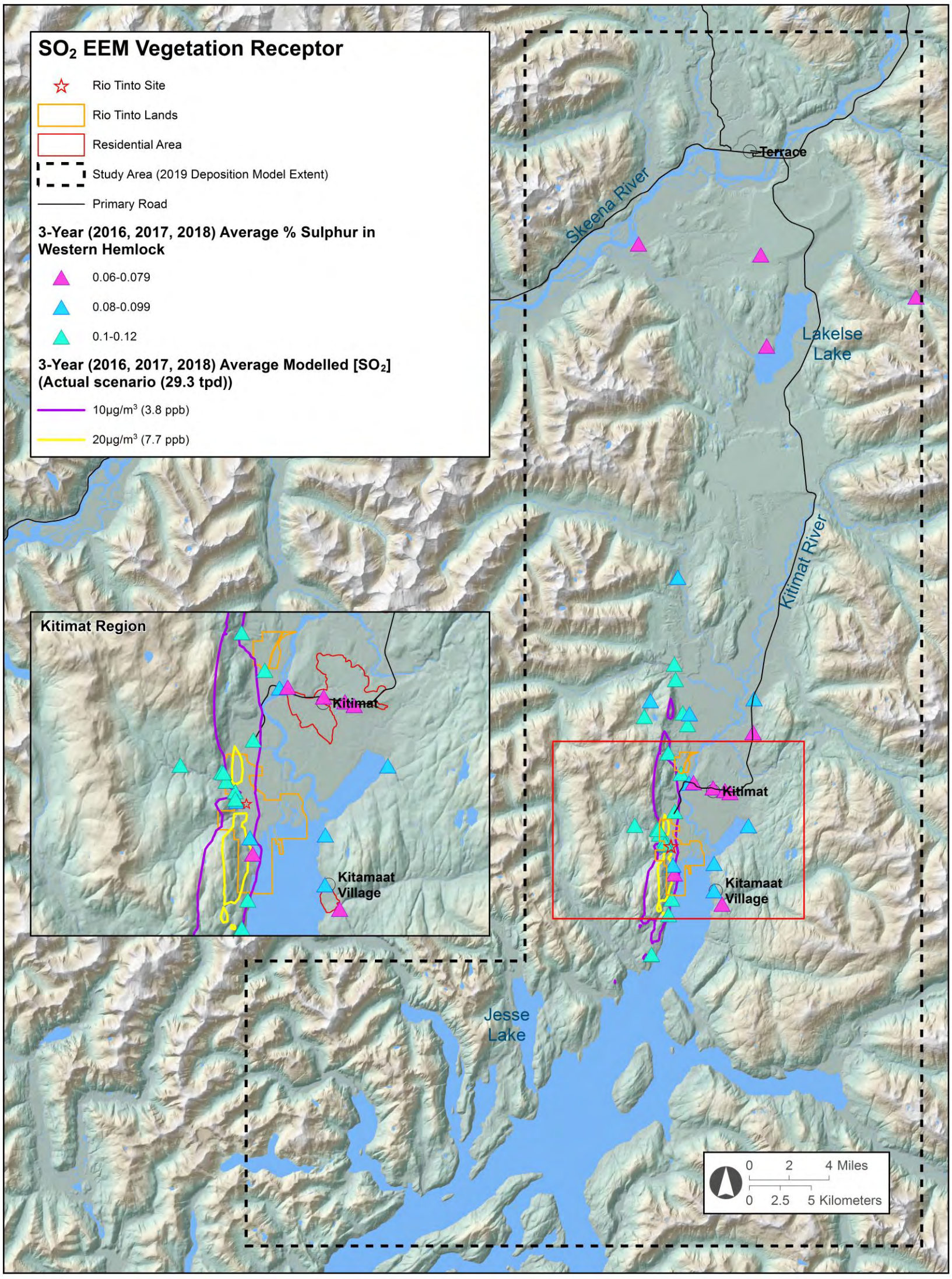


Figure 5-10. The spatial distribution of %S in western hemlock needles in relation to SO_2 concentrations as modelled by CALPUFF. Purple symbols are at sites that have a post-KMP average %S between 0.06 and 0.08; blue symbols %S between 0.08 and 0.10; cyan symbols %S between 0.10 and 0.12. Isopleths represent growing season means of 10 and 20 µg/m^3, threshold concentrations established in Europe for the protection of sensitive lichens and natural forest ecosystems respectively. Background air concentrations of SO_2 have been added.

All needle S data are provided in Vegetation Appendix 5.5. Modelled air concentrations for all post-KMP years and all scenarios at individual vegetation sampling sites are provided in Vegetation Appendix 5.1.

Deposition

Modelled SO_4^{2-} deposition was not a good predictor of %S in western hemlock. As with modelled SO_2 concentrations, we examined the relationship between SO_4^{2-} deposition and %S in western hemlock needles under all emission scenarios to guard against CALPUFF under-prediction. For example, the relationship with the post-KMP average annual deposition is shown in Figure 5-11. In no case—individual year or post-KMP average—did modelled deposition in any scenario explain more than 25% of the variation in the needle S dataset.

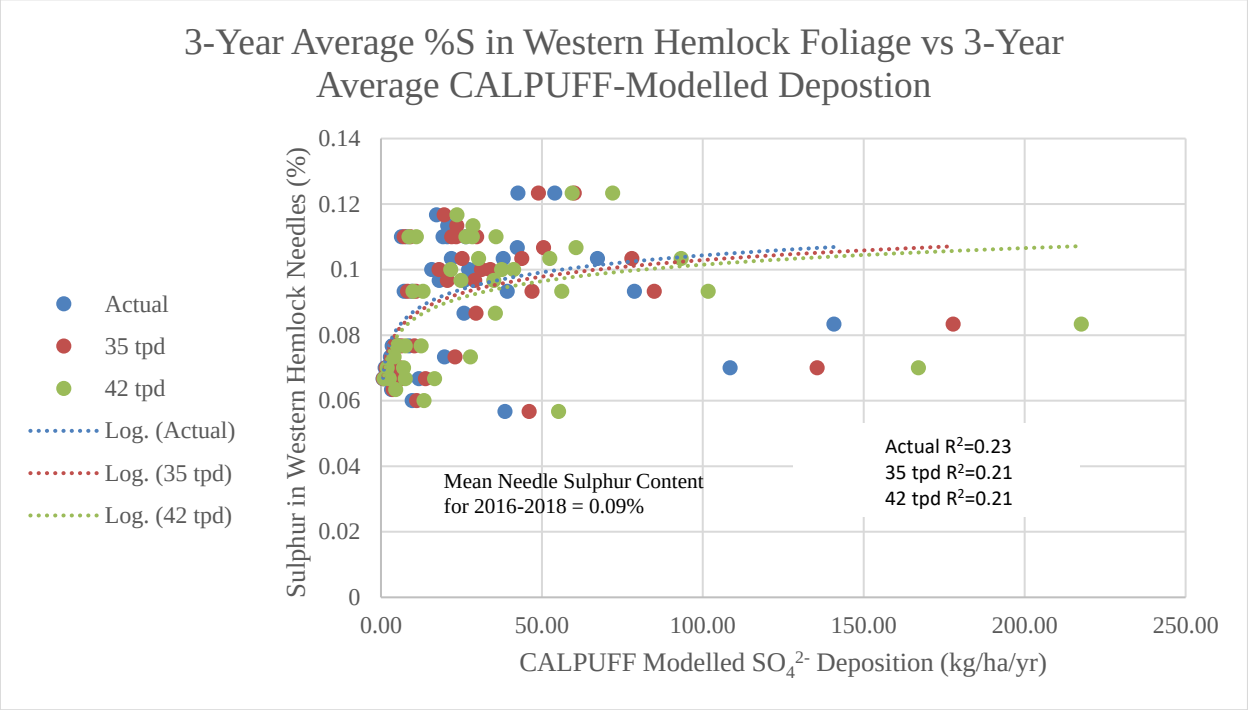


Figure 5-11. Average sulphur content (2016-2018) in western hemlock needles as related to 3-year average CALPUFF-modelled SO_4^{2-} deposition at vegetation sampling sites. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included.

The spatial association of needle sulphur and SO_4^{2-} deposition is shown in Figure 5-12. No clear pattern is apparent other than sites with concentrations above the overall mean (0.09% S in needles – represented by cyan-coloured symbols) occur mostly within the 10 kg SO_4^{2-}/ha/yr/ha/year isopleth. However, three of the sites in the lowest class (0-06-0.07 %S) also occur inside the 10 kg SO_4^{2-}/ha/yr isopleth.

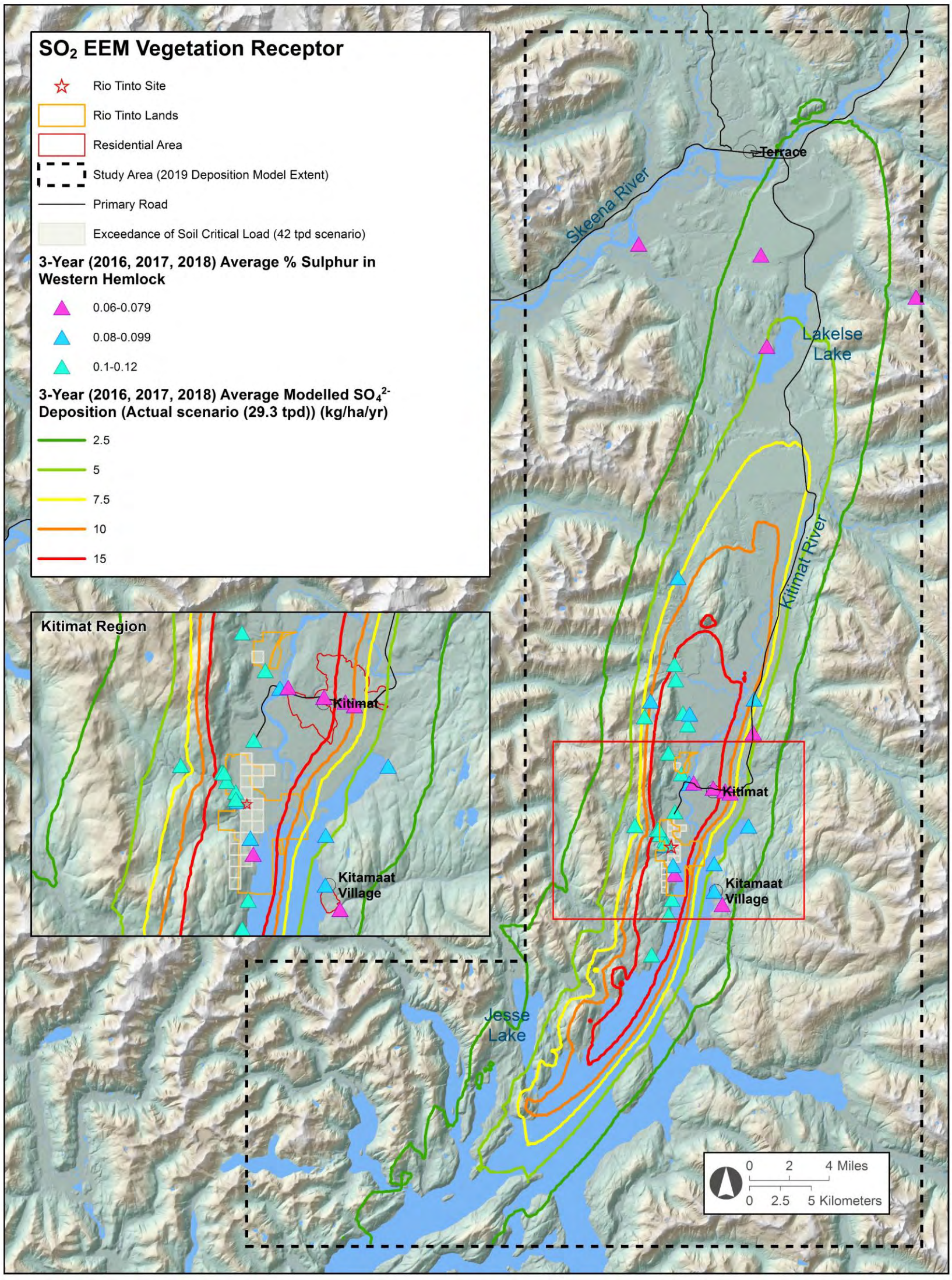


Figure 5-12. The spatial distribution of %S in western hemlock needles in relation to SO_4^{2-} deposition as modelled by CALPUFF. Purple symbols are at sites that have a post-KMP average % S between 0.06 and 0.08; blue symbols % S between 0.08 and 0.10; cyan symbols % S between 0.10 and 0.12. Isopleths represent 2.5, 5, 7.5, and 10 kg SO_4^{2-}/ha/yr. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included.

Pre-KMP, SO_2 emissions from the smelter were a better predictor of %S in western hemlock needles than any of the current model estimates of SO_2 concentration or SO_4^{2-} deposition. However, the relationship between emissions and %S in needles was not strong with the exception of a few sites (Vegetation Appendix 5.2). The relationship between F emissions and F in needles was generally much stronger (Vegetation Appendix 5.2). Post-KMP, it appears that the relationship between SO_2 emissions and needle sulphur has changed, with needle S generally not responding to increased emissions (see Section 5.2.2.2).

Comparison of %S in needles with passive samplers

Nine western hemlock sampling sites are within 2 km of passive samplers (Table 5-7). The relationship between %S in western hemlock and growing season means from the passive samplers explained between 0 and 17% of the variation in the needle %S data (Figure 5-12). Inspecting the two closest pairs where vegetation samples were taken less than 200 m from a passive sampler, the passive sampler growing season mean varied by about 2.1 to 2.25-fold in 3 years of collection while the %S in needles was within the margin of error for the analytical method (0.01%) and apparently did not respond to changes in air concentration or deposition.

The passive samplers have been shown to have a very close relationship with distance from the smelter, illustrating a decrease in air concentration and deposition with distance (see Figure 3-9). Figure 5-14 shows results from regressing %S on distance along a transect to the north of the smelter and indicates a relatively strong relationship—stronger than when regressed on estimates of SO_2 concentration, SO_4^{2-} deposition, or actual estimates of measurements of emissions. However, the relationship is not nearly as strong as that between passive samplers and distance (see Section 3.1.3.2). The same relationship did not hold for sites south of the smelter where %S in needles increased with distance from the smelter, or on the east side of Minette Bay where there was no relationship with distance. Passive sampler results from south of the smelter show a decrease in air concentration with distance.

Given the comparisons to modelled air concentration and deposition, and the measurements with passive samplers, %S in western hemlock needles is not a consistent and effective method to monitor the path of the plume.

Table 5-7. Comparison of passive sampler results and %S in western hemlock needles at vegetation sites within 2 km of passive monitors. Passive sampler sites V01-V04 are more than 2 km from the nearest vegetation sampling site.

Passive Sampler	Vegetation Site	Distance & Direction (P to V)	%S in Western Hemlock Needles			Growing Season Mean SO_2 Concentration					
						CALPUFF			PASSIVE		
			2016	2017	2018	2016	2017	2018	2016	2017	2018
V05	91A	920m @219.1°	0.1	0.1	0.09	3.7	3.5	3.8	0.4	1.5	1.8
V06	80	608m @220°	0.09	0.12	0.08	3.8	3.8	4.0	1.2	0.8	1.6
V07	78A	997m @332.3°	0.09	0.12	0.09	3.2	3.5	3.5	0.9	2.4	0.3
V08	79	676m @290.0°	0.1	0.11	0.12	4.7	5.1	5.5	0.5	3.0	2.6
V09	39	1,625m @148.7°	0.11	0.1	0.1	7.1	7.0	6.8	1.5	4.0	3.6
V10	37	96m @1.5°	0.1	0.11	0.1	2.7	4.1	4.4	1.8	3.0	4.1
V11	88	183.5m @218.5°	0.09	0.11	0.1	1.3	1.5	1.7	2.7	2.0	4.5
V12	89	1034.5m @201.5°	0.1	0.11	0.12	1.2	1.3	1.5	2.9	2.1	3.0
V13	89	1622.7m @224.8°	0.1	0.11	0.12	1.2	1.3	1.5	1.9	1.3	2.8

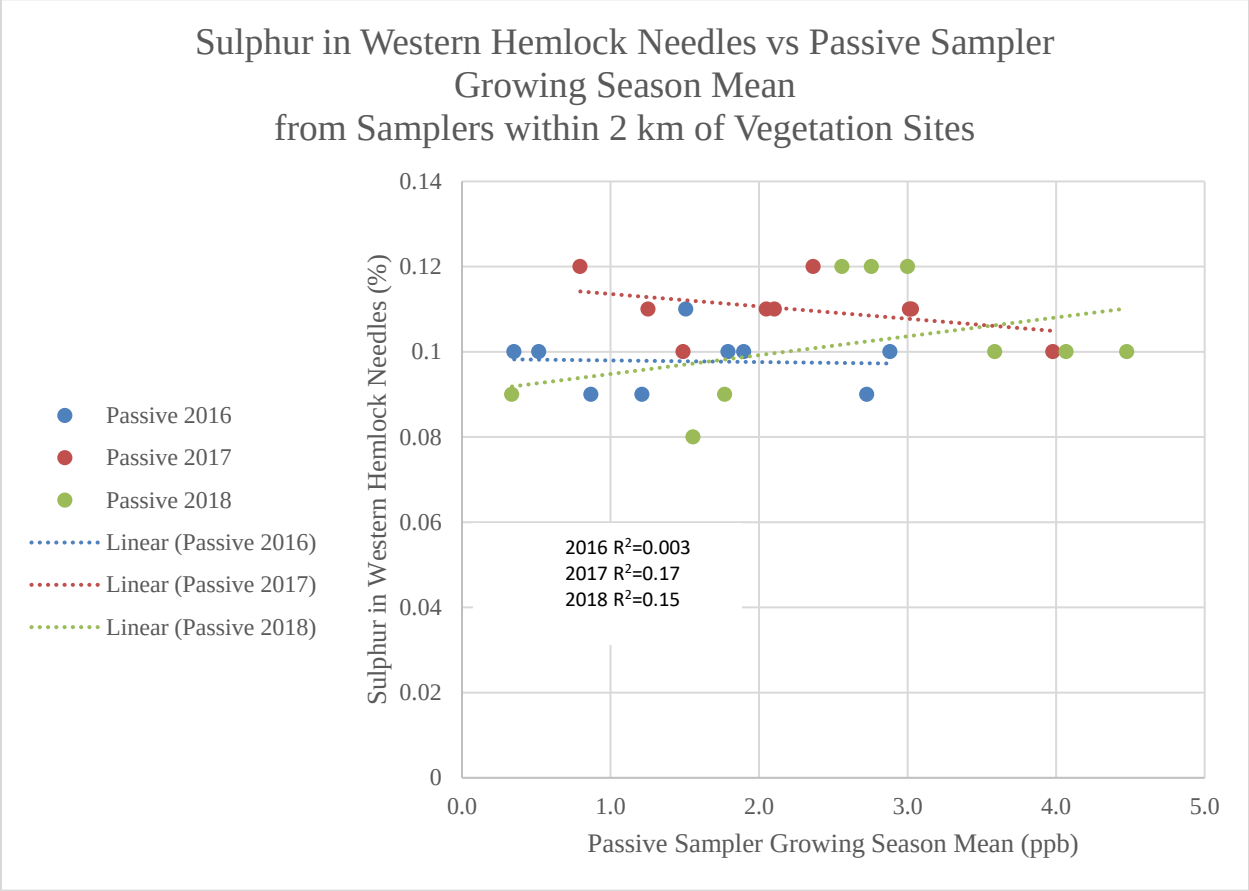


Figure 5-13. Relationship between needle S and growing season mean as measured with passive samplers at 9 sites within 2 km of vegetation sampling sites.

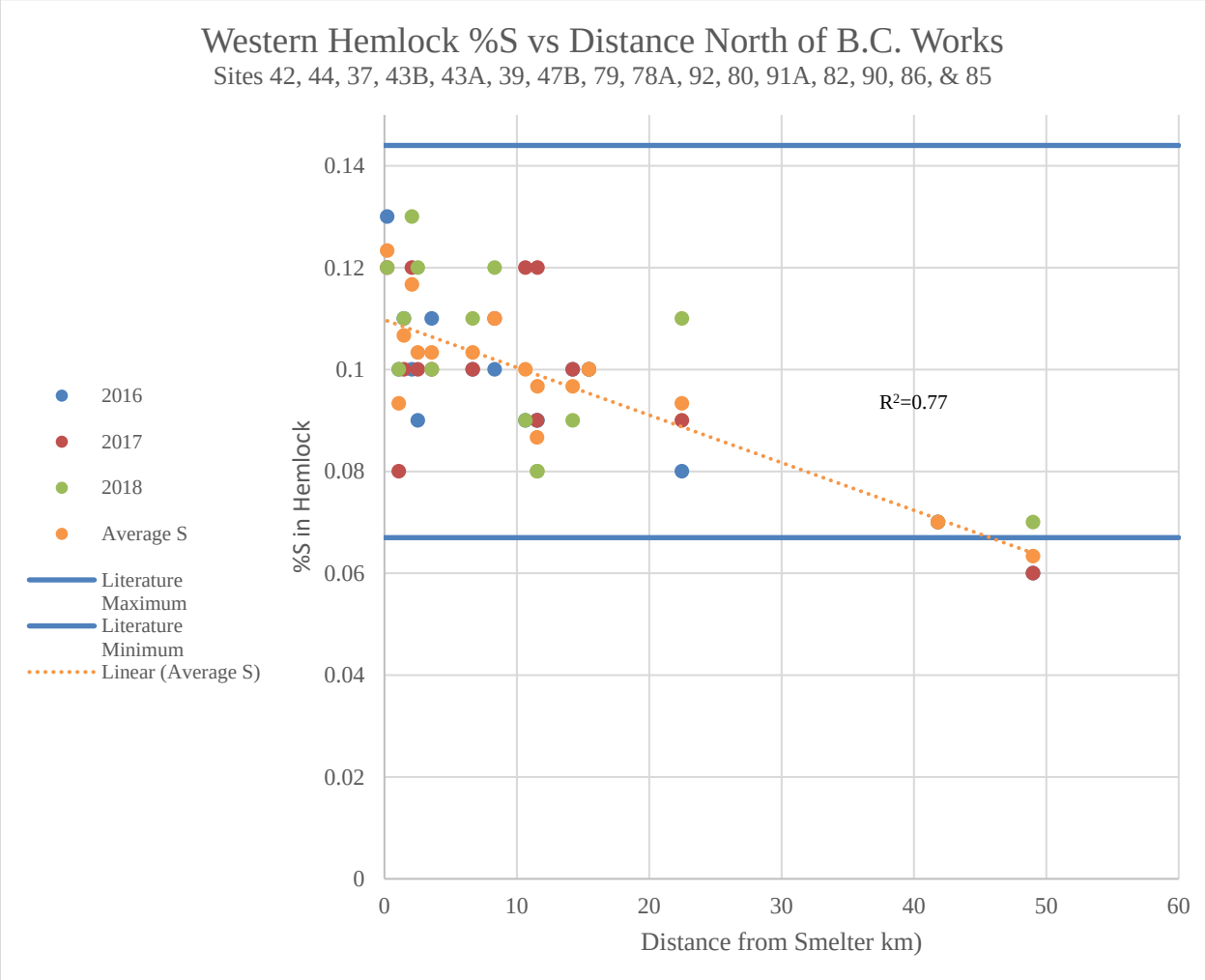


Figure 5-14. The relationship between %S in western hemlock and distance north of the smelter.

5.2.2.2 *Identification of areas of deposition of concern to vegetation, including lichens and ecosystems and species at risk*

We used the B.C. CDC search function to map the approximate locations of listed ecological communities, plants, and lichens at risk in the study domain (Figure 5-15). Exact locations of reported occurrences are not available to non-governmental users. The database does not contain an exhaustive survey but rather a catalogue of reported occurrences and the date of the report. Occurrences of listed species are not necessarily updated, so it is possible that the species or community no longer occurs at the location or that species and communities may occur at additional locations. Species and ecological communities that potentially occur in the study area and have a Provincial designation of Red or Blue may be found in Vegetation Appendix Tables 5.6.1 and 5.6.2.

The study domain has reported or historical occurrences of three listed lichens (*Nephroma occultum* [at two locations], *Pseudocyphellaria rainierensis*, and *Lobaria retigera*) and one listed plant (*Arctopoa eminens*). One listed ecological community, black cottonwood-red alder-salmonberry, occurs on the Skeena River near the northern extent of the study area. The array of sampling sites includes locations near the listed community and species, with the exception of *Arctopoa eminens*, which occurs near the southeast extent of the study domain and out of the modelled path of the plume. Reported locations for listed species and ecological communities are not in the area of predicted soil critical load exceedance. The estimated depositions at the modelling receptors closest to the sites are shown in Table 5-8. The reports from the B.C. CDC search may be found in Vegetation Appendix 5.6.

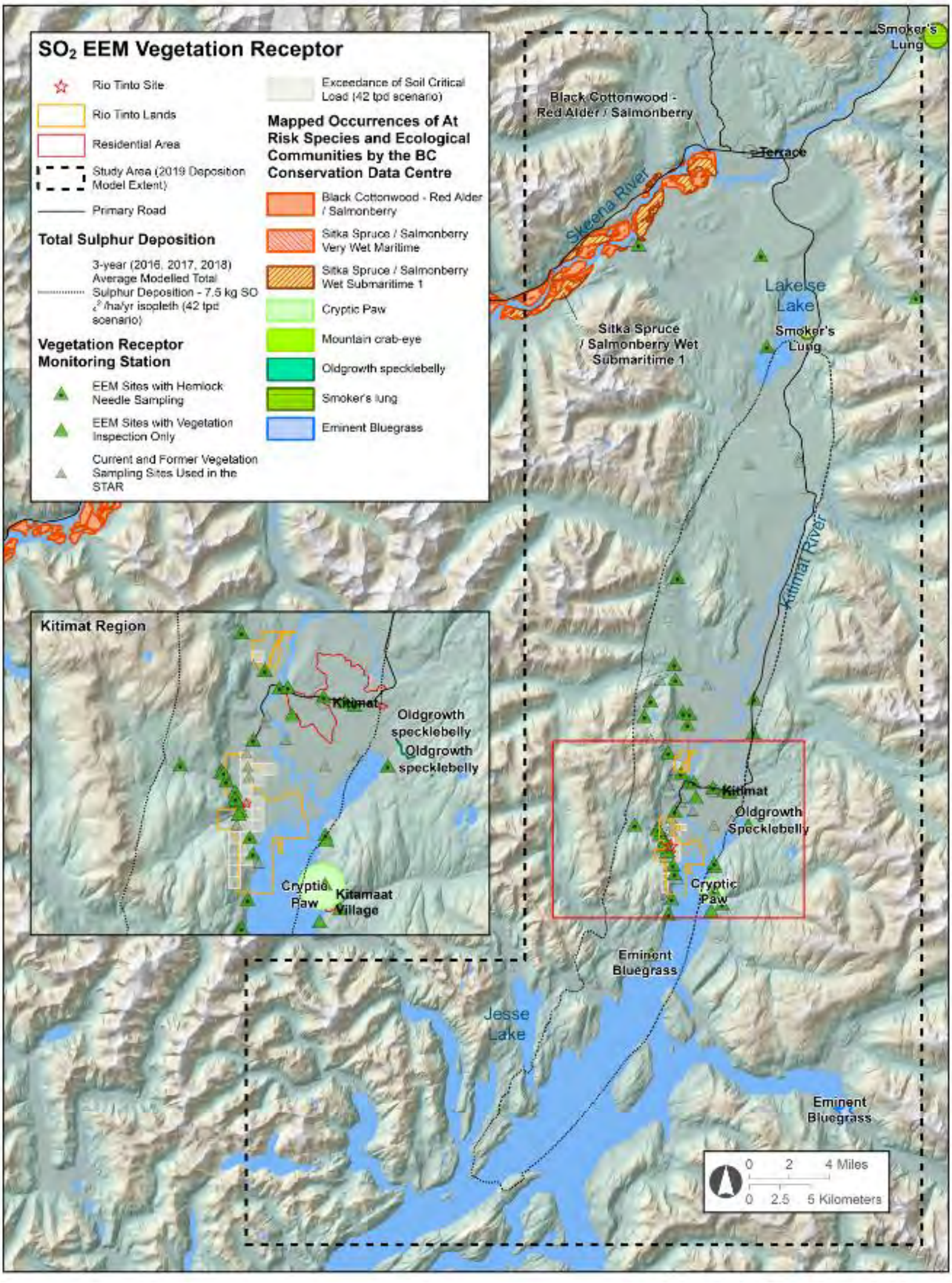


Figure 5-15. Approximate locations of listed ecological communities, plants, and lichens at risk in the study domain. The data are from the British Columbia Conservation Data Centre, accessed on February 14th, 2020.

Table 5-8. Estimated 3-year average SO_4^{2-} deposition from CALPUFF near reported sites with listed species or ecological communities. Deposition rates do not include a background of 3.6 kg SO_4^{2-}/ha/yr.

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	7.65
Nephroma occultum (Bish Cove vicinity)	Cryptic paw	Blue List Threatened/Special Concern	20.5	27.0
Pseudocyphellaria rainierensis	Old growth specklebelly	Blue List Special Concern	3.84	5.53
Lobaria retigera	Smoker's lung	Blue List Threatened	4.37	6.68
Arctopoa eminens	Eminent bluegrass	Red List Not listed	0.26	0.38
Populus trichocarpa-Alnus rubra-Rubus spectabilis	Black cottonwood-red alder-salmonberry	Blue List None	1.16	1.72

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

All four sites with listed lichen species have a modelled SO_4^{2-} deposition under the actual emissions scenario that exceeds the suggested critical load for cyanolichens of 6.9 kg SO_4^{2-}/ha/yr (Geiser et al. 2019) when background deposition is added in. The caveats discussed previously such as modelling uncertainty and the importance of local factors that may influence suitable habitat apply here as well.

Table 5-9 shows the estimated area within the study domain that exceeds certain deposition thresholds. We estimate that under the actual emissions scenario (including background deposition), approximately 79,850 ha (22% of the comprehensive review study domain) exceed deposition of 7.5 kg SO_4^{2-} /ha/yr, the critical level proposed by Geiser et al. (*in preparation*) for the United States. A substantial part of that area (based on land cover mapping) does not support habitat needed for the most sensitive lichens, cyanolichens growing on conifers. That includes land use such as industrial lands or town sites, water bodies such as Minette Bay and lakes, and industrial forest land or land that has been logged and consists presently of second growth stands of western hemlock and Sitka spruce that are in the stem exclusion stage of development. Most current old growth habitat is off the valley floor at elevations above 500 m (J. Laurence, personal observation) and may be in areas of lower deposition. About 50% of the land area in the study domain is classified as conifer, with 8% of the study domain classified as dense conifer, greater than 60% crown closure, and 75% of the basal area made up of conifers (see Figure 6-3 for land cover in the Kitimat Valley). With forestry activities such as commercial thinning and variable density management, the large blocks of land harvested 30-50 years ago will move towards more suitable lichen habitat if they are not subject to future regeneration harvest or other intensive forestry practices. The rate at which lichens will re-establish depends on dispersion from old

growth refugia and could take decades, even with suitable habitat (Geiser et al. 2019; Richardson and Cameron 2004).

Table 5-9. 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.

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	180,800	49.5	0	0
2.5-3.7	45,250	12.4	875	0.2	57,075	15.6	0	0
3.7-5	24,050	6.6	156,150	42.7	35,000	9.6	108,775	29.8
5-7.5	21,650	5.9	128,475	35.2	34,650	9.5	135,350	37.0
7.5-10	12,375	3.4	33,550	9.2	16,025	4.4	51,625	14.1
>10	27,100	7.4	46,300	12.7	57,825	11.4	69,600	19.1

Old growth forest is an important component of a diverse ecosystem. Species, such as cyanolichens, that are sensitive to SO_2 often depend on old growth forest habitat. In addition, old growth forest serves as a refuge for many species that are otherwise affected by management activities such as right-of-way clearing, construction, and logging. The locations of non-legal Old Growth Management Areas in the study area were obtained from the B.C. Data Catalogue (https://catalogue.data.gov.bc.ca/dataset/old-growth-management-areas-non-legal-current accessed August 30, 2019). Only the non-legal (forest licensees may choose to manage for diversity in a variety of ways versus prescribed methods in legal old growth management areas) layer is available to non-government users.

Table 5-10 shows the land areas by vegetation type that fall within the 10 and 20 µg/m^3 annual average SO_2 isopleths. Under the actual emissions scenario, 9 to 20 ha (depending on year) of old growth management areas fall inside the 10 µg/m^3 (3.8 ppb) annual average SO_2 isopleth modelled by CALPUFF (Figure 5-5). Under the 42 tpd scenario, 177 to 304 ha of old growth management areas fall into the 10 µg/m^3 annual average SO_2 isopleth, depending on the year. No old growth management areas fall within the 20 µg/m^3 annual average SO_2 isopleth. We chose those levels for examination because the European Union has established 20 µg/m^3 annual average SO_2 (7.6 ppb) as a critical level to protect natural ecosystems and 10 µg/m^3 annual average SO_2 (3.8 ppb) as a critical level to protect sensitive lichens.

Table 5-10. 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	1110.7	508.7	42.5	102.9	1455.9	556.4	44.0	149.1	1593.5	549.8	47.0	151.1
	20	206.1	94.5	5.2	13.67	244.5	80.7	17.0	18.8	278.8	78.9	13.2	20.0
42 tpd	10	2642.8	757.6	92.1	332.7	3302.2	791.1	98.0	465.2	3688.4	803.7	90.8	456.4
	20	388.6	147.4	21.6	35.3	476.1	227.1	23.9	48.7	528.2	224.1	22.5	50.8

All or parts of 17 old growth management areas fall within the >5 kg SO_4^{2-}/ha/yr isopleth (>8.6 kg SO_4^{2-}/ha/yr including background) as shown in Figure 5-16. These areas are spatially defined areas of old growth forest and likely contain habitat that support the growth of cyanolichens. Accessibility of the sites could make them difficult to monitor directly

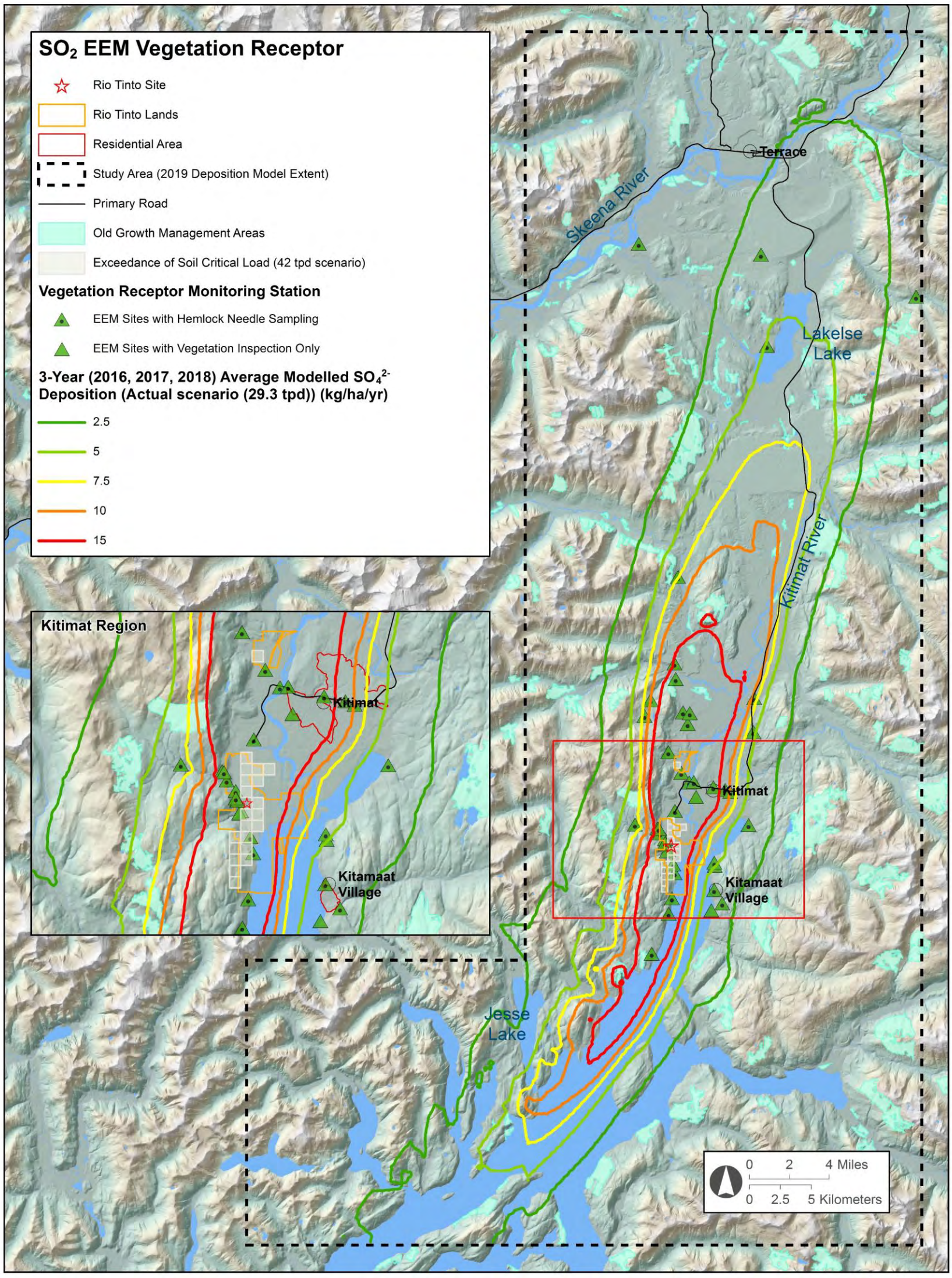


Figure 5-16. Location of old growth management areas in relation to modelled SO_4^{2-} deposition under the actual emission scenario. Isopleths shown are 2.5, 5, 7.5, 10, and 15 kg SO_4^{2-}/ha/yr. Deposition rate isopleths do not include background deposition of 3.6 kg SO_4^{2-}/ha/yr.

5.2.2.3 *Evaluation of post-KMP sulphur in western hemlock foliage to pre-KMP periods of interest*

Concentrations of F and S in current year needles of western hemlock in the Kitimat Valley have been a mainstay of the vegetation monitoring program for decades. Western hemlock was chosen as the bioaccumulator species for the program because it is not particularly sensitive to either HF or SO_2, thus the needles continue to accumulate pollutants throughout the growing season as opposed to plants that might be injured, as necrotic tissues do not continue to conduct gas exchange with the atmosphere.

During the STAR and subsequent design of the SO_2 EEM, the period of 1998-2011 was chosen and agreed upon as a baseline timeframe for pre-KMP S in western hemlock. That period represented a time of more-or-less consistent and continuous operation of the VSS smelter. In 2012 decommissioning of the VSS smelter began during construction and transition to the modernized smelter. Emissions of both HF and SO_2 declined as VSS reduction pots were removed from production.

In this review, we identified four periods of time for analysis: the pre-KMP baseline of 1998-2011, all years pre-KMP starting in 1998 (included at the request of ENV), 2015 which was during the transition to the new smelter and had very low SO_2 emissions compared to full operation, and post-KMP, 2016-2018.

All %S in western hemlock data used in the analyses reported below, graphs of the S concentrations versus smelter SO_2 emissions for each site, and box and whisker plots of %S in western hemlock needles for pre-KMP baseline (1998-2011), all years (1998-2018), and post-KMP (2016-2018) are found in Vegetation Appendix 5.5. Emissions data are used in place of deposition or air concentration, as comparable model estimates are not available pre-KMP. A total of 38 sites were sampled pre-KMP; two sites were added post-KMP as reference sites at the request of ENV. Figure 5-1 shows the location of the 40 sites that are currently sampled.

Analyses are based on data from 38 sites that existed pre-KMP. Reference sites are included post-KMP for comparison to other sites. Table 5-11 and Table 5-12 summarize those data for the purposes of this report. Figure 5-17 shows S data for all sites plotted against emissions which varied during the time period; thus, the graph is not chronological. The 2015 emission level is the lowest emission level on the graph. The line identifying the pre-KMP maximum emission level marks the transition to KMP; emissions greater than that are for the period 2016-2018. The graph shows that pre-KMP, some sites regularly exceeded 0.144%, the highest level reported for western hemlock in B.C. (Kayahara et al. 1995), however, no site has exceeded 0.14% since 2009 and so no sites have exceeded 0.144% post-KMP.

Comparison and assessment of post-KMP to pre-KMP baseline (1998-2011)

Table 5-11 and Table 5-12 identify one site out of 38 – site 89A – that had a post-KMP mean (2016-2018) that exceeded the SO_2 EEM baseline (1998-2011) but did so by less than 1 pre-KMP standard deviation. Site 89A is essentially co-located with site 89 (they are approximately 30 m apart) and had only two measurements pre-KMP. For the purposes of the vegetation inspection, sites 89 and 89A have always been considered one site. Site 89 did not exceed the EEM pre-KMP baseline mean.

Comparison and assessment of pre-KMP and post-KMP to 2015

We compared both pre-KMP and post-KMP to 2015, the year of low emissions of SO_2. When comparing pre-KMP to 2015, 33 sites decreased, but only 19 sites decreased by more than 1 standard deviation (data can be found in Vegetation Appendix 5.5). Twenty-five sites had a post-KMP mean S concentration greater than 2015 with increases ranging from 0.01% to 0.05% (the standard deviation of the analytical technique is ±0.01%). Five sites had post-KMP means that decreased (0.01 to -0.05%) and 8 sites showed no change from 2015. Only 5 of the 25 sites (69, 70, 78A, 80, and 82) that increased had an increase of more than 1 pre-KMP standard deviation (Table 5-12). Sites 69 (3.7 km ESE, 64 m elevation) and 70 (6.7 km ENE, 12 m elevation) are located on the east side of Minette Bay along the Kitamaat Village Road. They have not been disturbed recently and are representative of second-growth western hemlock forest with essentially the same vegetation as most other sites. Sites 78A (9.9 km, 32 m elevation), 80 (10.7 km, 53 m elevation), and 82 (14.8 km, 170 m elevation) north of Rio Tinto B.C. Works' aluminium smelter (referred to as "B.C. Works" in the remainder of this report) along the Wedeene Road. They, too, are undisturbed second growth western hemlock with an understory similar to almost all forested sites we sampled. Even with increased concentrations from 2015, they were well within the range of S in western hemlock needles reported in Kayahara et al. (1995) (Figure 5-18). Figure 5-18 shows foliar S concentration related to emissions which varied during the time period; thus, the graph is not chronological. The 2015 emission level is the lowest emission level on the graph. The line identifying the pre-KMP maximum emission level marks the transition to KMP; emissions greater than that are for the period 2016-2018.

Comparison and assessment of post-KMP to all pre-KMP 1998-2014

One site (89A) had a post-KMP mean (2016-2018) that exceeded the mean of all pre-KMP years (1998-2015) but by less than 1 standard deviation (Table 5-11 and Table 5-12). That result is expected as 2012 to 2014 was a period in which average monthly emissions decreased as production was reduced.

Table 5-11. Mean and standard deviation sulphur concentrations in western hemlock for the EEM baseline period (1998-2011), all years pre-KMP (1998-2014), 2015 (a historically low emission year), and post-KMP (2016-2018). The complete S in western hemlock data set is in Vegetation Appendix 5.4. Precision of the analytical technique is ±0.01%.

Site	EEM Mean (1998-2011)	EEM SD (1998-2011)	All Years Pre-KMP Mean (1998-2015)	All Years Pre-KMP SD (1998-2015)	2015	Post KMP (2016-2018)	Post-KMP SD
%S in current year needles							
1	0.10	0.02	0.09	0.03	0.07	0.07	0
20	0.12	0.02	0.12	0.03	0.07	0.08	0.01
37	0.16	0.03	0.15	0.03	0.11	0.11	0.01
39	0.13	0.02	0.12	0.03	0.09	0.10	0.01
42	0.16	0.03	0.15	0.04	0.12	0.09	0.01
43A	0.15	0.02	0.14	0.02	0.11	0.12	0.02
43B	0.16	0.04	0.15	0.04	0.07	0.10	0.02
44	0.16	0.04	0.15	0.04	0.09	0.12	0.01
44A	0.17	0.04	0.16	0.04	0.11	0.11	0.02
46	0.16	0.03	0.15	0.04	0.13	0.11	0.00
47B	0.12	0.02	0.12	0.02	0.09	0.10	0.01
52A	0.10	0.02	0.10	0.03	0.08	0.09	0.01
54	0.10	0.01	0.10	0.02	0.06	0.06	0.01
55	0.10	0.01	0.09	0.02	0.07	0.07	0.01
56	0.09	0.02	0.08	0.02	0.06	0.07	0.01
57	0.09	0.03	0.08	0.03	0.05	0.06	0.01
68	0.09	0.01	0.08	0.02	0.07	0.08	0.02
69	0.09	0.01	0.08	0.02	0.06	0.08	0.01
70	0.09	0.01	0.09	0.01	0.06	0.08	0.01
78A	0.14	0.03	0.12	0.04	0.06	0.10	0.02
79	0.12	0.03	0.12	0.03	0.1	0.11	0.01
80	0.11	0.01	0.11	0.01	0.07	0.10	0.02
81B	0.14	0.04	0.13	0.04	0.06	0.09	0.01
81C	0.11	0.03	0.11	0.03	0.09	0.11	0.02
82	0.11	0.02	0.10	0.02	0.07	0.10	0.00
84AB	0.08	0.01	0.08	0.01	0.07	0.07	0.00
85	0.08	0.02	0.08	0.02	0.05	0.06	0.01
86	0.08	0.02	0.08	0.02	0.08	0.07	0.00
87	0.14	0.04	0.13	0.04	0.12	0.12	0.02

Site	EEM Mean (1998-2011)	EEM SD (1998-2011)	All Years Pre-KMP Mean (1998-2015)	All Years Pre-KMP SD (1998-2015)	2015	Post KMP (2016-2018)	Post-KMP SD
%S in current year needles							
88	0.13	0.02	0.13	0.02	0.09	0.10	0.01
89	0.14	0.03	0.14	0.03	0.1	0.11	0.01
89A	0.11	0.02	0.10	0.01	0.1	0.11	0.01
90	0.10	0.02	0.10	0.03	0.08	0.09	0.02
91A	0.10	0.02	0.10	0.02	0.14	0.10	0.01
92	0.10	0.02	0.10	0.02	0.09	0.09	0.01
95	0.08	0.02	0.08	0.02	0.07	0.07	0.01
97	0.09	0.02	0.09	0.02	0.09	0.08	0.01
98A	0.08	0.02	0.08	0.01	0.08	0.07	0.01
490						0.07	0.01
492						0.07	0.01

Table 5-12. Difference in S concentration between post-KMP and pre-KMP for the EEM baseline (1998-2011) and for all pre-KMP years (1998-2014), and for post KMP and 2015. Precision of the analytical technique is ±0.01%.

	% S Post-KMP – Pre-KMP EEM baseline (1998-2011) (Positive=Increase)	Greater than 1 SD?	Post-KMP – Pre-KMP (All Years) Positive is Increase	Greater than 1 SD?	% S Post-KMP – 2015 (Positive=Increase)	Greater than 1 SD?
1	-0.03	NO	-0.02	NO	0.00	NO
20	-0.04	NO	-0.03	NO	0.01	NO
37	-0.05	NO	-0.04	NO	0.00	NO
39	-0.03	NO	-0.02	NO	0.01	NO
42	-0.07	NO	-0.06	NO	-0.03	NO
43A	-0.03	NO	-0.02	NO	0.01	NO
43B	-0.05	NO	-0.04	NO	0.03	NO
44	-0.03	NO	-0.03	NO	0.03	NO
44A	-0.06	NO	-0.05	NO	0.00	NO
46	-0.05	NO	-0.04	NO	-0.02	NO
47B	-0.02	NO	-0.01	NO	0.01	NO
52A	-0.01	NO	0.00	NO	0.01	NO
54	-0.05	NO	-0.04	NO	0.00	NO
55	-0.02	NO	-0.02	NO	0.00	NO
56	-0.02	NO	-0.02	NO	0.01	NO
57	-0.03	NO	-0.02	NO	0.01	NO
68	-0.01	NO	-0.01	NO	0.01	NO
69	-0.01	NO	-0.01	NO	0.02	YES
70	-0.01	NO	-0.01	NO	0.02	YES
78A	-0.04	NO	-0.02	NO	0.04	YES
79	-0.01	NO	-0.01	NO	0.01	NO
80	-0.02	NO	-0.01	NO	0.03	YES
81B	-0.05	NO	-0.03	NO	0.03	NO

	% S Post-KMP – Pre-KMP EEM baseline (1998-2011) (Positive=Increase)	Greater than 1 SD?	Post-KMP – Pre-KMP (All Years) Positive is Increase	Greater than 1 SD?	% S Post-KMP – 2015 (Positive=Increase)	Greater than 1 SD?
81C	0.00	NO	0.00	NO	0.02	NO
82	-0.01	NO	0.00	NO	0.03	YES
84AB	-0.01	NO	-0.01	NO	0.00	NO
85	-0.02	NO	-0.01	NO	0.01	NO
86	-0.01	NO	-0.01	NO	-0.01	NO
87	-0.02	NO	-0.01	NO	0.00	NO
88	-0.03	NO	-0.03	NO	0.01	NO
89	-0.03	NO	-0.03	NO	0.01	NO
89A	0.01	NO	0.01	NO	0.01	NO
90	-0.01	NO	0.00	NO	0.01	NO
91A	0.00	NO	0.00	NO	-0.04	NO
92	-0.01	NO	-0.01	NO	0.00	NO
95	-0.01	NO	-0.01	NO	0.00	NO
97	-0.01	NO	-0.01	NO	-0.01	NO
98A	-0.01	NO	-0.01	NO	-0.01	NO

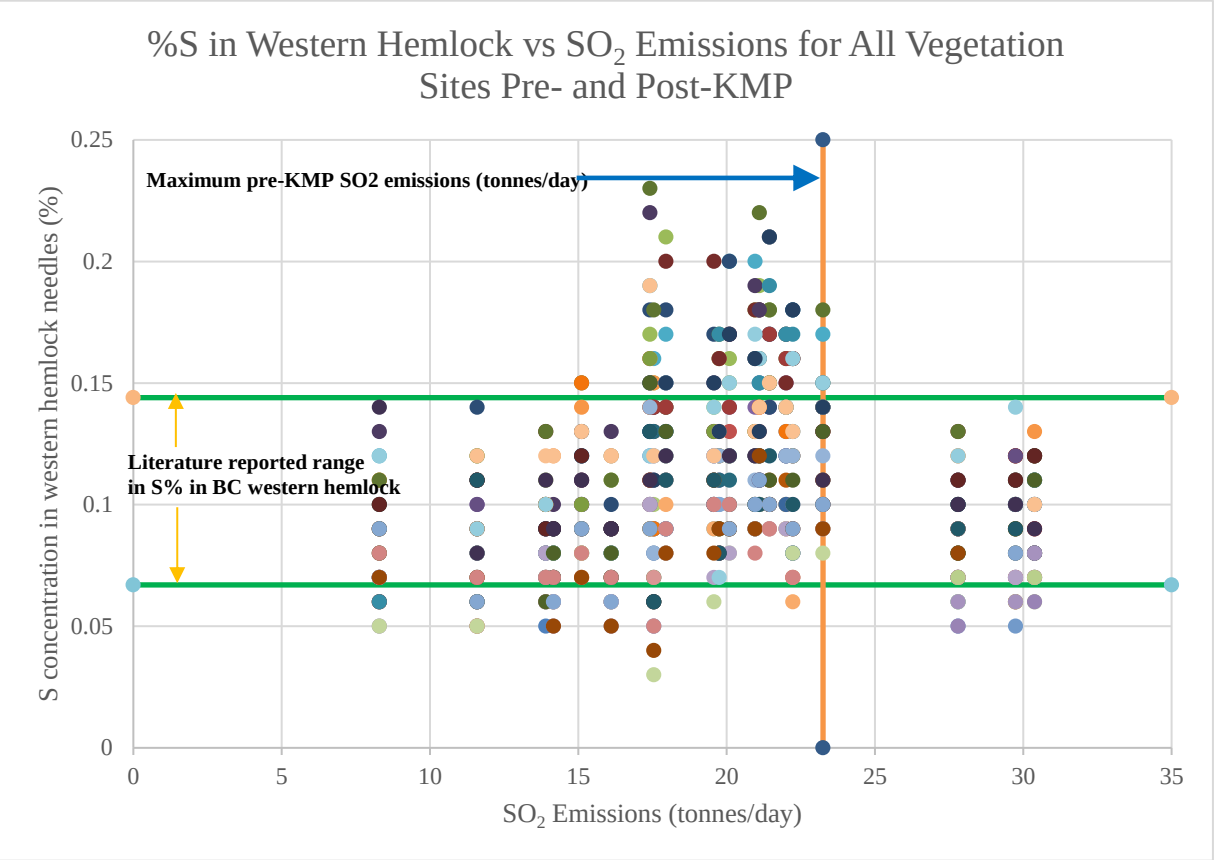


Figure 5-17. Sulphur concentration in current year needles of western hemlock at all sampling sites, for all years. Literature maximum and minimum are reported in Kayahara et al. (1995) for western hemlock in British Columbia. Individual site graphs can be found in Vegetation Appendix 5.5.

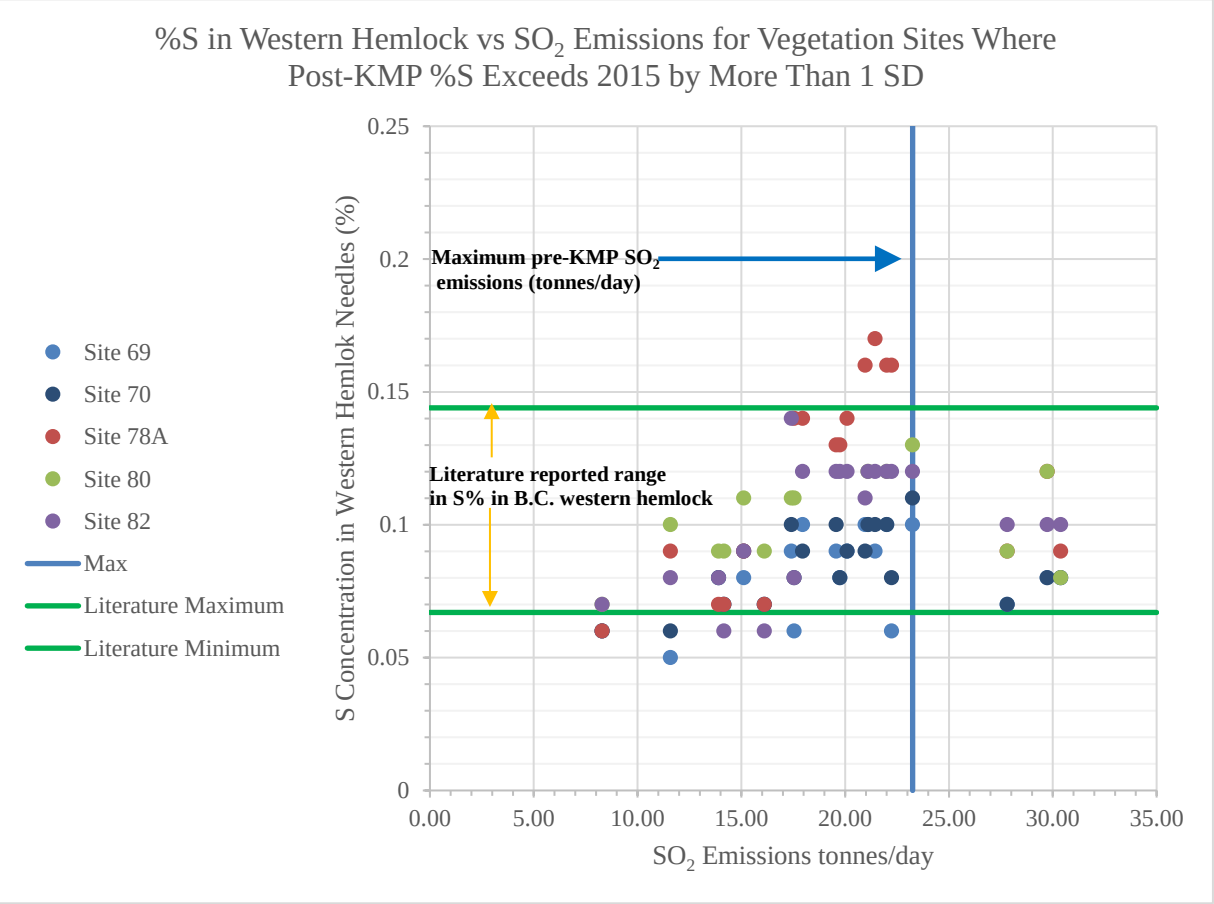


Figure 5-18. Sulphur concentration in western hemlock needles where the difference between post-KMP and 2015 exceeded one pre-KMP standard deviation (Sites 69, 70 ,78A, 80, and 82). Literature maximum and minimum are reported in Kayahara et al. (1995) for western hemlock in British Columbia. Individual site graphs can be found in Vegetation Appendix 5.5.

5.2.2.4 *Evaluation of the value and coverage of vegetation sampling sites using S and F in western hemlock foliage and soils information*

Based on 3 years of post-KMP sampling and analysis of S and F in western hemlock needles, the results do not significantly contribute to the understanding of the dispersion of the plume from the smelter that is gained from active and passive sampling of SO_2 concentrations and dry and wet deposition estimates from NADP collectors. The variability in S concentration in needles throughout the Kitimat Valley could not be extrapolated spatially; attempts using regression kriging were unsuccessful in creating isopleths of S concentration in hemlock (J. Aherne, personal communication). Only one site exceeded the pre-KMP baseline and there is generally a poor correlation with estimates of air concentration of SO_2 or deposition of SO_4^{2-}. In an evaluation of sites conducted in 2019, only 4 sites were found to have a relationship between S in needles and SO_2 emissions that accounted for more than 50% of the variation in the dataset (Vegetation Appendix 5.2). Correlations with needle S content and estimates of SO_2 air concentration or SO_4^{2-} deposition were even lower.

Post-KMP, S content of needles has increased since 2015, however, all sites remain below the maximum S content in western hemlock in B.C. reported by Kayahara et al. (1995).

The reduction in F emissions has resulted in a measured reduction of F in western hemlock needles. Post-KMP, only 12 sites have an average needle concentration greater than 15 ppm and 9 of those sites are on Rio Tinto property. Only 8 sites have an average concentration greater than 20 ppm with a maximum of 31 ppm. For all intents and purposes, post-KMP F concentrations in needles off-site are at or near background levels. Background F concentrations in most vegetation is considered to be from about 2 to 20 ppm (Weinstein and Davison 2004). Based on almost 50 years of measurement of F in western hemlock in the vicinity of B.C. Works, we estimate background concentrations to be 10 ppm or less.

Soils information does not supplement what is learned from sampling and analyzing foliage as S is not measured at soil plots because it is generally very low. It is regarded as a mobile ion and the largest pool may be associated with organic matter rather than deposition (J. Aherne, personal communication). Soils do contain substantial amounts of F but it is not generally taken up by plants nor is it an essential element as is S (Weinstein and Davison 2004).

Two vegetation sampling and inspection sites (1 and 20) are located in the area of predicted soil critical load exceedance (under the 42 tpd emissions scenario) and eight additional sites (87, 42, 44, 43B, 46, 37, 39, and 47B) are within 700 m of an area of predicted soil critical load exceedance. One additional inspection location, Moore Creek Falls, is in the area of predicted soil critical load exceedance. No signs or symptoms associated with soil acidification were observed at any site; vegetation at the sites post-KMP was typical of vegetation in the rest of the valley.

5.2.2.5 *Evaluation of the results of vegetation inspections pre- and post-KMP for visible injury and plant health*

Results of visible injury inspections

No visible injury due to SO_2 was observed at any location post-KMP. Visible injury due to SO_2 has not been reported in the results of the vegetation monitoring program since before 1999. Injury to sensitive vegetation due to HF has decreased substantially since the early 2000s. By 2014, injury was only observed in the immediate vicinity of Rio Tinto at locations such as the administration building and visitor center. No injury due to HF has been observed at any site post-KMP.

Results of plant health assessment

Plants in the Kitimat Valley show a normal range of conditions driven primarily by the growing conditions at the site and weather of the year. Growing conditions vary dramatically from site to site. For instance, some sites are relatively undisturbed by industrial activity or forest management practices. Other sites have been affected by construction of powerlines, work camps, new industrial facilities, and by forest harvest. Some sites close to the smelter have been cleared of natural vegetation in the past and continue to show signs of the legacy of more than 60 years of industrial activity. Many sites have disturbed soils that are more subject to drought due to increased drainage though gravelly and sandy soils.

In general, plants in the Kitimat area suffer from the same pathogens, pests, and environmental stressors (with the exception of industrial emissions) as may be observed at locations distant from the smelter such as Terrace or the reference vegetation sites in the Williams Creek drainage. Generally, on a year to year basis, rainfall and temperature are the most important drivers of plant health. In some years, such as 2018, low summer rainfall causes early senescence of leaves and needles, particularly on drier sites. Early or late frosts also cause growing season effects. To this point these normal stresses have not resulted in permanent effects that can be observed. If projections play out, future climate could alter ecosystem health, particularly for forests on thin soils subject to increased evapotranspiration, due to increased temperatures that will deplete soil moisture.

Vegetation in the areas of soil critical load exceedance under actual emissions and predicted under the 42 tpd maximum permitted level were inspected. No unusual signs or symptoms were observed at sites 1 and 20 or along Smeltersite Road (in the area of critical load exceedance under actual emissions). Areas of soil critical load exceedance under the actual emissions that are to the south of LNG Canada were not accessible. Visual inspection when flying over the area did not reveal any unusual observations.

We conclude that no change in the general condition of vegetation has been observed post-KMP.

Comparison of visible injury pre- and post-KMP

There was no SO_2 injury pre-KMP and none has been observed post-KMP. No visible injury due to HF has been observed post-KMP.

Extent of insect infestations and disease epidemics with regard to plant health

A slight infestation of hemlock woolly adelgid began about 2014. It was at a very low level and was found primarily at sites near the smelter and not at other sites inspected in the valley. The intensity varies from year to year but has improved since 2014. Stantec Consulting Ltd. and Laurence (2019) reported detecting adelgids at 13 of 40 sites, down from 18 sites in 2017. They report extent of the infestation as % of sample branch and sample tree affected. In only one case did the percent of a branch affected exceed 5% and no more than 2% of a single tree was affected. Their estimates indicate that the woolly adelgid is not occurring at a significant level nor is it affecting the general health of trees in the area. No adelgid infestations were observed during a survey completed in September 2019 (J. Laurence, personal communication).

There are no current plant disease epidemics occurring in the Kitimat area. Normal levels of diseases such as poplar rust, dwarf mistletoe, tar spot, and various fungal leaf spot diseases occur throughout the Kitimat Valley.

We conclude that there has been no increase in the incidence or severity of insects and plant disease post-KMP.

Presence of species selected by ENV pre- and post-KMP

In 2014, at the request of ENV, we added a checklist of plants to the vegetation inspection protocol. The list is a subset taken from Tables 3-2 and 3-3 in Legge et al. (1998). In those tables, the species are reported to be "relatively sensitive to SO_2", however, "relatively sensitive" is not defined, nor are references provided for the species in the list. The agreed-upon protocol for the program was for the QP conducting the inspection to note the presence of the species on the list. Since the inspection does not utilize a defined area at each site, the resulting checklist is not a quantitative assessment of biodiversity—it only indicates that the species was observed during the visit.

Presence or absence of many species will be determined by the growing conditions at the specific site, thus the "absence" of species close to the smelter may be driven more by physical disturbance than by any other condition, for instance the presence of higher concentrations of SO_2 or greater deposition of SO_4^{2-}.

The results do not show any clear pattern (other than some taxonomical confusion in the genera of *Alnus* and *Sorbus*), just three years post-KMP. However, we recommend a change in protocol be considered that would define an area of observation and catalog the species within that area in order to detect change.

The complete dataset is provided in Vegetation Appendix 5.7.

5.2.2.6 *Suitability of KPI and informative indicator based on 2016-2018 results*

KPI

At the time of the STAR, modelled air concentrations were such that visible injury to sensitive vegetation, although unlikely, was possible. In addition, since the sensitivity of most vegetation in the Kitimat area to SO_2 is not documented in the scientific literature, a cautious approach was taken and the KPI was established based on visible injury. Given the results of air monitoring post-KMP, it now appears extremely unlikely that the threshold concentration for visible injury will be exceeded for any species. Furthermore, the maximum off-site concentrations modelled are substantially below the thresholds to protect sensitive vegetation identified in the STAR and recently confirmed in the scientific literature (European Union 2008; U.S. EPA 2018).

Given results to date, the KPI is not suitable to be used to trigger increased monitoring or facility mitigation.

Informative indicator

The informative indicator is currently based on S concentration in current year needles of western hemlock. It is of limited value due to natural range of variability of %S in western hemlock needles plus the variability in the analytical technique (±0.01%).

Pre-KMP, the correlation between emissions and %S in foliage was greater than 0.6 in fewer than half the sites. Post-KMP, the sulphur concentration in foliage has decreased from the pre-KMP mean and has not exceeded the reported range for S in western hemlock foliage in British Columbia. The relationship between %S in western hemlock needles and CALPUFF-modelled

SO_2 concentrations and SO_4^{2-} deposition is not strong: no air concentration averaging period or deposition estimate explained more than 35% of the variation in the %S in western hemlock.

The informative indicator was poorly correlated with nearby passive samplers. Passive samplers provide a clear advantage over measuring S in needles as they can be calibrated and provide estimates of both air concentration of SO_2 and deposition of SO_4^{2-}.

Alternative KPIs and informative indicators based on the scientific literature

The question of whether emissions from the modernized smelter will directly injure sensitive vegetation in the Kitimat Valley has been answered. Monitored concentrations of SO_2 are far below the thresholds established in the scientific literature and in use by regulatory agencies in North America and Europe. The results to date and knowledge from the scientific literature point to creating a Terrestrial Ecosystems Line of Evidence that has KPI(s) focused on detecting mid- to long-term effects of S deposition. Given the SO_2 concentrations and deposition at most off-site locations, it is likely that if effects on vegetation occur, they will be long-term and mediated through soil acidification. Therefore, the Soil Critical Load KPI is an appropriate KPI for vegetation effects as well.

An informative indicator could be focused on biodiversity plots where both the overstory and understory are mapped and re-visited periodically. Changes in the biodiversity over time that are not related to natural causes or climate change could be used to imply long-term response to deposition and inform the Soil Critical Load KPI. A study to identify appropriate locations and establish necessary sample sizes and frequencies would need to be conducted to establish plant biodiversity as an informative indicator.

An informative indicator related to tree growth could be considered. A tree-ring study could be undertaken—most likely delayed until at least 10 years post-KMP to allow time for response separate from climate—to determine pre- and post-KMP growth rates of appropriate tree species. We investigated the use of the Canadian National Forest Inventory plots however the coverage in the study domain is too sparse to provide a useful tool for assessing tree growth. Only two ground plots are located in the area and both are out of the plume path. Given the importance of changing climate, it will be necessary to detect and remove that signal from the growth record. We believe plots established by the then Ministry of Forestry in the 1970s to assess regeneration potential in the Kitimat Valley are also too few, and without suitable controls, to be used in the future other than to provide anecdotal information or to be used in a tree-ring study.

Periodic inspections to document plant health and to detect potential changes related to insects, diseases, climate change, and other environmental stress should be used as an informative indicator in the Terrestrial Ecosystems Line of Evidence. Changes in plant health associated with B.C. Works and in areas of critical load exceedance would inform both the Terrestrial and Aquatic Lines of Evidence.

ENV has established lichen plots in the Kitimat Valley and those plots should be revisited 5 years after initiation to document changes in lichen communities that might indicate effects of increased deposition of SO_4^{2-} or community recovery due to reductions in F emissions.

5.3 What Did We Learn, and Did We Make Any Adjustments to the EEM Program?

5.3.1 Knowledge gained

5.3.1.1 *Summary and interpretation of updated scientific literature on the effects of SO_2 and soil/air acidification on vegetation including lichens*

Higher vegetation

Little new information on the direct effects of SO_2 has been reported since the STAR. The controlled fumigation studies that have been conducted have used plant species that are not relevant to the SO_2 EEM. Exposures (concentration x time) used in the studies also far exceed those that occur in the Kitimat Valley.

Since the STAR, Canada has adopted new ambient air quality standards and the European Union and U.S. EPA have retained their SO_2 concentration recommendations and standards. The CAAQS are in line with the European recommendation of an annual average of 10 µg/m^3 to protect sensitive lichens and natural ecosystems. The U.S. secondary NAAQS continues to be based on a short term, high concentration rather than an annual or growing season average.

New methods for detecting long-term effects of SO_4^{2-} deposition have been reported (see Section 5.1.4.1) and point to the use of measures of biodiversity (species richness and abundance) in relation to deposition in order to detect effects on trees, understory shrubs, and herbaceous plants (Clark et al. 2019; Horn et al. 2018). These new large-scale studies have, in some cases, proposed critical loads to protect plant biodiversity. Working at large scale, however, essentially removes local topographic, habitat, and climate variability so implementing a program at a local scale will require careful selection of measurement sites.

Lichens and mosses

Research since the STAR has focused on calculating critical loads to protect lichens and the use of mosses as bioaccumulators of metals. In the US, a national critical load of S of 2.5 kg/ha/yr (7.5 kg SO_4^{2-} has been proposed with a slightly lower critical load of 2.3 kg S/ha/yr (6.9 kg SO_4^{2-} /ha/yr) identified for cyanolichens. As with higher vegetation, implementation of the methodology at a local scale requires careful attention to topography, climate, and habitat disturbance.

5.3.1.2 *Summary and interpretation of post-KMP CALPUFF air concentration and deposition modelling with regard to vegetation thresholds*

Post-KMP SO_2 concentration modelling results are well below the thresholds of concern for visible injury to vegetation. Monitoring (both active and passive) and modelling results delineate an area where the growing season average SO_2 concentrations exceed the levels established in Canada and Europe to protect sensitive lichens and natural ecosystems. The area exceeding 20 µg/m^3 (7.6 ppb) is mostly restricted to the industrialized part of the valley near the smelter. Under the 42 tpd maximum permitted level scenario, the area exceeding 10 µg/m^3 (3.8 ppb) extends about 25 km to the north and 7 km to the south of the smelter. A considerable portion of the area is managed for commercial timber harvest and would not, in our opinion,

be classified as a sensitive natural system. It is likely that these areas have been exposed to elevated concentrations of both SO_2 and HF for decades.

Post-KMP CALPUFF modelling and passive monitoring delineates areas of the valley where SO_4^{2-} deposition rates exceed those thought to represent critical loads to protect sensitive lichen species. While much of the area is not currently suitable habitat for cyanolichens, there are old growth forest patches present where modelled deposition exceeds published estimates of regional to national critical loads. Caution must be used when down-scaling those estimates, however, as they don't take into account climate, topography, and other factors that may affect the suitability of habitat regardless of SO_4^{2-} deposition. In addition, some old growth habitat is in an area affected by the industrial legacy.

5.3.1.3 *Summary and interpretation of pre- and post-KMP sulphur concentrations in western hemlock foliage*

Sulphur concentrations in western hemlock needles post-KMP (with one exception, site 89A) do not exceed the pre-KMP baseline (1998-2011). Using all pre-KMP years (1998-2014), the results are the same. In neither case did site 89A exceed the mean by more than 1 standard deviation. No site since 2009 has exceeded the maximum measured S concentration of 0.144% reported for western hemlock needles province-wide in B.C., including post-KMP. Based on post-KMP measurement, all sites are within the range reported in the scientific literature. Sulphur concentration in western hemlock is weakly related to measures of air concentration or deposition modelled with CALPUFF and only slightly more related to emissions from the smelter. Estimates of air concentration and deposition did not account for more than 35% of the variation in needle S; measures of emissions appear to have a different relationship to needle S concentrations post-KMP as, although emissions have increased, S in needles has declined from the pre-KMP baseline.

5.3.1.4 *Summary and interpretation of pre-and post-KMP vegetation inspections*

No symptoms of injury due to SO_2 or F have been observed post-KMP. Injury due to SO_2 was not observed pre-KMP. No insect outbreaks or plant disease epidemics have been noted beyond what would be considered normal incidence and severity levels. Hemlock woolly adelgid did occur on some trees near the smelter, but at levels that are of no concern to the health of the trees. Environmental stresses such as drought have the greatest impact at this time.

5.3.1.5 *Summary and interpretation of the value of vegetation sampling and inspection locations*

The sampling array was well-aligned with the plume path as determined by CALPUFF modelling given the constraints of accessibility due to terrain. Sites accessed by helicopter did provide an opportunity to sample vegetation at higher elevation but did not reveal any unique responses to changes in emissions. Sulphur concentrations in hemlock needles at reference sites (490 and 492), at sites near Terrace (84A, 85, and 86), and sites on the east side of the bay (68, 69, 70 and 95) were similar, ranging from 0.07% to 0.08%.

Given the post-KMP results, neither S nor F in needle tissue provided information that is predictive or explanatory vis-à-vis emissions from the smelter. The sites do provide an adequate array for periodic visual inspection to document plant and ecosystem health. In many

cases, the inspection sites are near both ENV lichen plots and the few approximate locations – exact locations are not available – of listed plant species in the Kitimat Valley.

Ten existing vegetation sampling sites and one supplementary inspection site (Moore Creek Falls) are either in (2 sites plus Moore Creek Falls) or within 700 m of areas of predicted soil critical load exceedance (42 tpd scenario) and provide adequate coverage of the area at or near the valley floor. Vegetation inspections are currently made from the air over the inaccessible parts of the predicted soil critical load exceedance extent.

5.3.2 Modifications to the EEM Program

Going forward, the EEM Program will face added challenges due to changes in climate that are forecasted and will affect ecosystem health in the Kitimat Valley. Warmer, drier summers and wetter winters with reduced snowpack will introduce stresses that are likely to exceed the effects of SO_2 emissions on vegetation. Any modifications to the EEM need to recognize changes that will occur over the lifetime of the modernized smelter.

5.3.2.1 *Potential changes to the KPI and informative indicator*

KPI

The question of whether vegetation would be injured by short-term, high concentration exposures to SO_2 has been answered: no direct injury of vegetation has been observed and results from both the passive and active monitoring programs show concentrations far below those that would cause such injury. The KPI was not exceeded post-KMP and based on modelling and monitoring completed as part of this review, we believe it is highly unlikely that visible injury due to direct effects of SO_2 will occur in the future. For that reason, we recommend that the KPI based on visible injury to vegetation be discontinued. Results to date lead us to believe that any effects on vegetation are likely to be mediated through effects of SO_4^{2-} deposition and the resulting acidification of soils and substrates for organisms such as lichens and mosses. The soil critical load KPI supported with an informative indicator based on plant biodiversity should be sufficient to protect vegetation and sensitive ecosystems.

Informative indicator

The informative indicator has not proven effective either as an indicator of potential stress on vegetation (e.g. the concentrations of sulphur in western hemlock needles have not exceeded those reported as within the natural range for the species in B.C.) or as a surrogate for monitoring as it is poorly correlated with other monitoring and modelling methods. To a large extent, the array of vegetation sampling sites in the plume path now corresponds with the passive monitor network that provides estimates of both air concentration and deposition. The latter is particularly important with regard to potential acidification of the ecosystem. We recommend the collection of western hemlock needles for chemical analysis be discontinued.

Alternative KPIs and informative indicators

We recommend that a Terrestrial Ecosystem Line of Evidence be developed that utilizes the Soil Critical Load KPI and informative indicators of plant biodiversity, assessment of plant health, and perhaps tree growth determined by tree ring analysis at a future date. In order to

implement the Terrestrial Ecosystem Line of Evidence, we recommend that a pilot study to determine the extent and intensity of a series of plant biodiversity measurement plots be undertaken with the aim of developing a new informative indicator.

5.3.2.2 Potential adjuncts to the present vegetation sampling and inspection program

The present vegetation sampling and inspection program should be aligned to support a Terrestrial Ecosystem Line of Evidence. Periodic inspections of a subset of the current sampling and inspection sites should be continued to document plant and ecosystem health and the incidence and severity of any insect outbreaks or disease epidemics, and potential changes due to climate change (e. g. drought, early or late frost, and root/soil freezing).

5.3.3 Comprehensive synthesis ('pulling the pieces together')

5.3.3.1 *Relation of vegetation results to soil and aquatic critical load results*

We found no signs or symptoms related to plant health associated with the predicted areas of exceedance (under the 42 tpd scenario) of soil or aquatic critical loads. Eleven sampling and/or inspection sites are located in or near the area of predicted soil critical load exceedance and provide adequate coverage to detect effects of acidification, had any been apparent. No symptoms were observed from a recent aerial survey of the predicted area of soil critical load exceedance. In the case of the aquatic line of evidence, no vegetation sampling and/or inspection sites are located adjacent to EEM lakes. An aerial survey conducted as part of the vegetation program included flying over some of the EEM lakes and we did not observe anything out of the ordinary.

While the areas of predicted soil critical load exceedance have been exposed to considerable deposition in the past, it is possible that it will take some time soil critical loads to manifest with regard to vegetation in the areas of predicted exceedance. If and when it does, it will most likely be through changes in plant communities or a decline in the health of acid-sensitive species.

5.3.3.2 Potential changes to vegetation sampling array

Based on results post-KMP, we conclude that vegetation sampling and analysis should be discontinued.

5.3.4 Conclusions

5.3.4.1 *Effectiveness of the KPI and informative indicator*

The KPI was not exceeded during the first 3 years post-KMP. Given the results of air monitoring and dispersion modelling, the KPI will not be an effective tool as visible injury due to SO_2 seems highly unlikely to occur.

5.3.4.2 *Changes to the risk to vegetation associated with the modernized smelter*

Given the results of measurements and observations to date, the risk to vegetation remains unlikely to very unlikely and of minor consequence. Based on deposition modelling and recent

findings in the scientific literature, it is possible that some lichens will be affected. However, there is a strong legacy of more than 60 years of industrial and forestry activities in the area of greatest deposition. Studies in the 1970s and 1980s documented an area of impact on lichens that corresponds to the areas of greatest deposition modelled as part of this review. In those areas, the risk of further impact is small and likely of minor consequence as the area supports little suitable habitat. Based on our analysis, we conclude that outside the legacy area, the risk to cyanolichens growing on conifers is unlikely and of minor consequence in areas where deposition is less than <15 kg SO_4^{2-} /ha/yr (including background) and are of suitable habitat (e.g. undisturbed old growth for cyanolichens).

5.3.4.3 *Relation of the vegetation sampling and inspection program to other components of the SO_2 EEM Program*

The vegetation sampling and inspection program should be re-formulated to support a Terrestrial Ecosystems Line of Evidence that focuses on detecting mid to long-term effects of SO_2 and SO_4^{2-} deposition. Results of periodic inspections of vegetation could be an informative indicator to supplement the Soil Critical Load KPI and a potential plant biodiversity informative indicator.

5.3.4.4 *Conclusions regarding Questions V1-V4 from the STAR*

V1: Validation of the dispersion model – are we looking in the right place?

For the most part, the locations of vegetation sampling and inspection sites aligned well with the predicted path of the plume. Additional sites were well outside the areas of projected deposition and provided reference information. The areas off the B.C. Works site where the highest concentrations are projected to occur are not safely accessible from the ground or the air. Aerial survey of the area does not reveal any indication of change in forest condition. The vegetation informative indicator of S concentration in western hemlock needles did not help verify model predictions as there was a poor correlation between %S in needles and measures of air concentration of SO_2 or deposition of SO_4^{2-}.

V2: How healthy is vegetation in sites with predicted exceedance of critical loads of soil and/or lakes and streams south of Lakelse Lake?

Significant differences in plant heath throughout the Kitimat Valley were not observed post-KMP. There were no significant insect outbreaks or plant disease epidemics during the period under review. The greatest stress to vegetation during the period was associated with drought in 2018. No differences were observed in vegetation in the areas of soil critical load exceedance under actual emissions. On-the-ground or aerial inspection of vegetation in the area of predicted soil critical load exceedance under the maximum permitted emission level (42 tpd) did not reveal differences in the health of vegetation compared to sites located at distance, including reference sites. With respect to aquatic critical loads, only LAK044 at the northern boundary of the study area exceeded its critical load; its critical load is 0. Vegetation sampling and inspection was not conducted in the vicinity of that lake, however, inspection south of LAK044 (e.g. Lakelse Lake) did not reveal any symptoms of acidification.

V3: Are plants of public importance showing symptoms in areas with the highest exceedances of soil critical loads?

Hypothesis H_1 of no or negligible effects on plants of public importance is supported by the observations and measurements made. No symptoms associated with emissions from the modernized smelter were observed.

V4: Do plants at Kitimat that have unknown sensitivity to SO_2 and associated pollutants (acidic deposition) fall within the range of variation in the literature?

It appears that plants in the Kitimat Valley are within the range of sensitivities reported in the scientific literature. Given the low ambient concentrations of SO_2, injury would not be expected to occur, and it did not.

5.4 What Do We Recommend for the EEM Program Going Forward?

5.4.1 Recommendations for the Key Performance Indicator

We recommend that a Terrestrial Ecosystem line of evidence be established to integrate the vegetation and soils lines of evidence. The current KPI for vegetation should be discontinued and measures of plant health and plant biodiversity should be developed to replace the current KPI/informative indicators. A plant biodiversity pilot project needs to be conducted to develop appropriate thresholds and related measures of variability to assure success.

5.4.2 Recommendations for the informative indicator

Informative indicators of changes in plant biodiversity and changes in plant health due to emissions from B.C. Works based on established plant biodiversity field plots and a triennial inspection to assess and document plant and ecosystem health should be established to support the Soil Critical Load KPI. Documented changes in plant and ecosystem health would trigger increased measurement and inspection frequency.

5.4.3 Recommendations for the vegetation sampling and inspection program

The vegetation sampling and inspection program should be changed to focus on detecting mid to long-term effects on terrestrial ecosystems by:

- implementing a set of biodiversity plots to detect changes in plant communities related to Rio Tinto's B.C. Works;
- revisiting lichen plots at appropriate intervals (e.g. every 5 years) to document changes in lichen communities;
- conducting a triennial inspection to document changes in plant and ecosystem health; and
- discontinuing sampling and chemical analysis of western hemlock foliage in favor of maintaining a valley passive sampler network and measuring more informative endpoints of vegetation health.

6 Review Results for Terrestrial Ecosystems (Soils)

6.1 What Did We Set Out to Learn?

The soils component of the SO_2 EEM Program set out to address critical uncertainties and data gaps identified in the STAR (ESSA et al. 2013), i.e., gaps in the regional coverage of soils data, the use of bedrock type to regionalise soil weathering rates, and the lack of empirical observations of soil base cations.

The SO_2 EEM Program expanded the regional coverage of soils data and applied state-of-the-art mapping techniques to assess the spatial sensitivity of soils to acidic deposition. In addition, long-term soil plots were established and sampled over time to monitor changes in soil chemistry, quantify the minimum detectable change in soil base cations, and provide an estimate of time-to-depletion in base cation pools.

Ultimately the program set out to assess if the thresholds of the KPIs for soils were exceeded.

The three critical uncertainties identified under the STAR are now not relevant as soil weathering rates are now mapped using regression kriging rather than 'averaged by bedrock type' (STAR question S1), the current buffering capacity of soils in exceeded areas is only addressed if the KPI for critical loads is exceeded (STAR question S2), and long-term soil plots were established to assess changes in soil base cation pools (STAR question S3).

6.1.1 EEM Key Performance Indicators and informative indicators

There are two KPI for soils: (a) atmospheric sulphur deposition and critical load exceedance risk, and (b) long-term soil acidification (rate of change of base cation pool) attributable to sulphur deposition. The first KPI is prediction-based and uses measured soil physicochemical data from regional surveys to model and map the spatial distribution, magnitude (i.e., how large an area might be affected) and the level of exceedance of critical loads of acidity for soils (i.e., the magnitude of deposition greater than critical load). The second KPI is observation-based and uses measured soil chemistry data at long-term monitoring plots to track changes in soil base cations over time.

The soils component included three informative indicators, two of which (magnitude of exchangeable base cation pools and time to depletion of exchangeable base cation pools) will only be evaluated if the KPI thresholds are exceeded. The third is soil base cation weathering rates, which is required for the determination of critical loads.

6.2 What Methods Did We Use?

The methods were focused on two principal tasks: a regional survey of soil physicochemical properties to support the modelling and mapping of critical loads across the study domain, and the establishment of long-term soil monitoring plots to track changes in exchange base cations. For a detailed description on the methodology for the determination of critical loads of acidity, please see ESSA et al. (2013, 2014b), UNECE (2004), and de Vries et al. (2015).

6.2.1 Data we collected: regional soil survey for critical loads

Critical loads of acidity (S) for soils were revised to support the prediction-based KPI of 'critical load exceedance risk'. Digital soil maps were not available for the study region area (Figure 6-1); accordingly, a regional survey of forest soils was used to generate coverages (e.g., organic matter, sand, coarse fragment and base cation weathering) required to estimate critical loads.

Under the STAR, 51 soil pits were sampled and analysed for bulk density, organic matter content, particle size distribution and total element content. These data were used to estimate soil base cation weathering rates, which were subsequently regionalised across the study domain. Since 2013, soil sampling has been carried out in the Kitimat Valley (see Figure 6-1) under several projects (i.e., the Kitimat Airshed Emissions Effects Assessment (KAEEA) (ESSA et al. 2014b) [n = 11] and the LNG Canada Project [URL: lngcanada.ca/; n = 22]). Further, as recommended in the STAR, additional soil sampling was carried out during 2015–2017 (n = 31; see Table 6.1 in Terrestrial Ecosystems (Soils) Appendix 6.1) to address critical uncertainties and data gaps (Technical Memo S02, 2015). Soil data for the determination and mapping of soil base cation weathering rates (a key determinant of critical loads) are now available from 115 sites within the Kitimat Valley (Figure 6-1), including soil samples collected from 93 sites during 2012–2017 following a consistent sampling and analysis protocols, as described under the STAR, and data for 22 sites obtained from LNG Canada.

Soil data (at 93 locations; Figure 6-1) were obtained from field surveys conducted during June 2012 (n = 51), October 2013 (n = 11), July 2015 (n = 15) and July 2016 (n = 16); all surveys used consistent field protocols (described in ESSA et al. 2013). Under the STAR, site selection was primarily stratified by bedrock geology to ensure sample replication within the principal bedrock types (scale 1:250 000; Massey et al. 2005) and surficial geologies (scale 1:5000 000; Fulton 1996) for forest soils in the study region. In general, soil sampling locations were randomly selected from mapped geology units; however, sites were weighted towards road accessible areas (ESSA et al. 2013). Under the SO_2 EEM program, additional sites were sampled to fill gaps highlighted in the STAR, e.g., high elevation sites. At each sampling location, soil samples were collected from the four corners and centre point of a 10 m × 10 m quadrate using a soil auger and composited to obtain a representative sample for chemical analysis (ESSA et al. 2013). Mineral soils (i.e., excluding forest floor) were sampled at three fixed depths (0–10 cm; 15–25 cm and 40–50 cm) approximately representing the A and upper and lower B soil horizons. In addition to the composite soil samples, a fixed-volume bulk density core sample was taken at each mineral soil depth from the centre point.

All composite soil samples (three depths per site) were analysed for pH, loss-on-ignition (LOI: estimate of soil organic matter) and particle size (sand, silt and clay). Bulk density was determined on the fixed-volume core samples from the centre pit for each site (Terrestrial Ecosystems (Soils) Appendix 6.1). A weighted-average mineral soil sample for each site (i.e., composite of all depths weighted by bulk density and depth) was analysed for total oxide content (n = 93; Terrestrial Ecosystems (Soils) Appendix 6.1). All composite samples from several sites were analysed for qualitative mineralogy (Table 6-1 in Terrestrial Ecosystems (Soils) Appendix 6.1). All laboratory analysis is described in Terrestrial Ecosystems (Soils) Appendix 6.2.

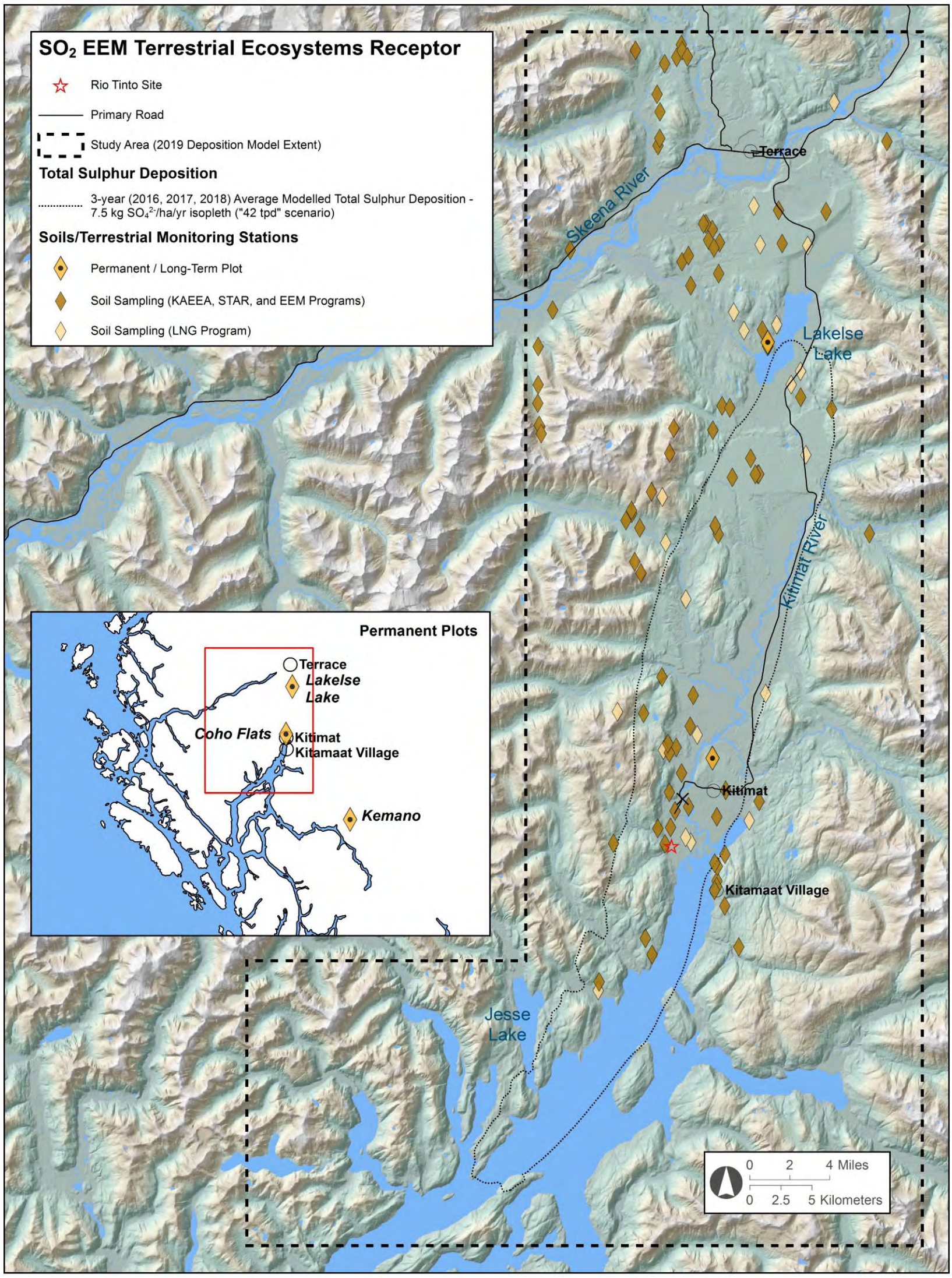


Figure 6-1. Location of the regional soil pits (n = 115) and long-term monitoring plots (n = 3). The inset depicts the location of the three long-term soil plots at Coho Flats (latitude: 54.07660, longitude: –128.65117), Lakelse Lake (latitude: 54.37827, longitude: –128.57990) and Kemano (latitude: 53.53032, longitude: –127.97384). Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleth.

6.2.2 Data we collected: long-term soil plots for exchangeable base cations

Under the SO_2 EEM Program, long-term soil monitoring plots were established to address the KPI 'observed change in base cation pool over time' (ESSA et al. 2014a). The objective of the long-term soil plots is to monitor changes in soil chemistry (base cation pools) over time through repeated sampling and analysis (every five years). The monitoring plots provide a framework for systematic replicate random sampling of soils, allowing for the statistical assessment of changes between sampling campaigns. The plot design follows the same conceptual basis as the Long-Term Soil Acidification Monitoring (LTSAM) program in Alberta (Cho et al. 2019), i.e., to provide an early warning of adverse effects of SO_2 emissions on soils, and to detect subtle changes in soil chemical parameters that would have the potential to affect plant growth, while factoring out natural variations. The soil plots were established on Rio Tinto property in near-field and far-field locations with respect to smelter emissions to ensure a gradient in potential exposure to SO_2 and to ensure long-term stability in the monitoring program. In addition, a background or reference plot was established (remote from emissions sources outside the Kitimat Valley) to assess whether a change soils (if observed) is causally related to KMP. Plot establishment and initial soil sampling (systematic random sampling) was carried out during 2015 (see Terrestrial Ecosystems (Soils) Appendix 6.11); the first soil resampling was carried out during June 2018.

During October–December 2015, near-field and far-field plots were established at Coho Flats and Lakelse Lake, respectively, and during 2016, the control plot was established at Kemano. At each location, primary and secondary (backup) plots were established within forest stands dominated by western Hemlock (see Terrestrial Ecosystems (Soils) Appendix 6.11 Table 6.5); soil was sampled from all plots (including primary and secondary) during establishment. All soil samples were analysed for basic physicochemical properties (organic matter, pH and bulk density); the soils from the secondary plots and control plot were archived without additional analysis. The secondary plots (located within 500 m of the primary plot) provide a backup or replacement to the primary plot if disturbed or destroyed within the lifetime of the monitoring program. The primary plots at Coho Flats and Lakelse Lake were resampled during June 2018 to assess changes in soil chemistry (e.g., exchangeable base cations) since the initial sampling during 2015. The control plot is only resampled and analysed if changes in soil chemistry exceeding the KPI threshold are detected at the Coho Flats and Lakelse Lake plots. All trees on the plots with a diameter at breast height (DBH) > 10 cm were recorded to assess the potential base cation uptake (Bcu) attributed to tree growth if a KPI is exceeded (see Terrestrial Ecosystems (Soils) Appendix 6.11 Table 6.10 and Figure 6.11). The secondary plots are only resampled and analysed if the primary plots are disturbed.

Each long-term soil plot is 32 m by 30 m in size and composed of twenty 8 m by 6 m sub-plots lettered A to T; the A sub-plot is oriented to the north-west corner of each plot (see Figure 6-2; and Figure 6.10 in Terrestrial Ecosystems (Soils) Appendix 6.11). Each sub-plot is further divided into twelve 2 m by 2 m sampling grids (numbered 1 to 12); one numbered grid was randomly sampled (without replacement) from each lettered sub-plot (see Table 6.6 in Terrestrial Ecosystems (Soils) Appendix 6.11 for a list of sample grids) at three depths in the mineral soil: 0–5 cm, 5–15 cm, and 15–30 cm depths (yielding a total of 60 soil samples for each plot, i.e., three soil samples by depth within each of the 20 lettered sub-plots). Soils were analysed for bulk density, coarse fragment, organic matter content, pH, exchangeable cations

and exchangeable acidity (see Terrestrial Ecosystems (Soils) Appendix 6.2 for details on the laboratory analysis).

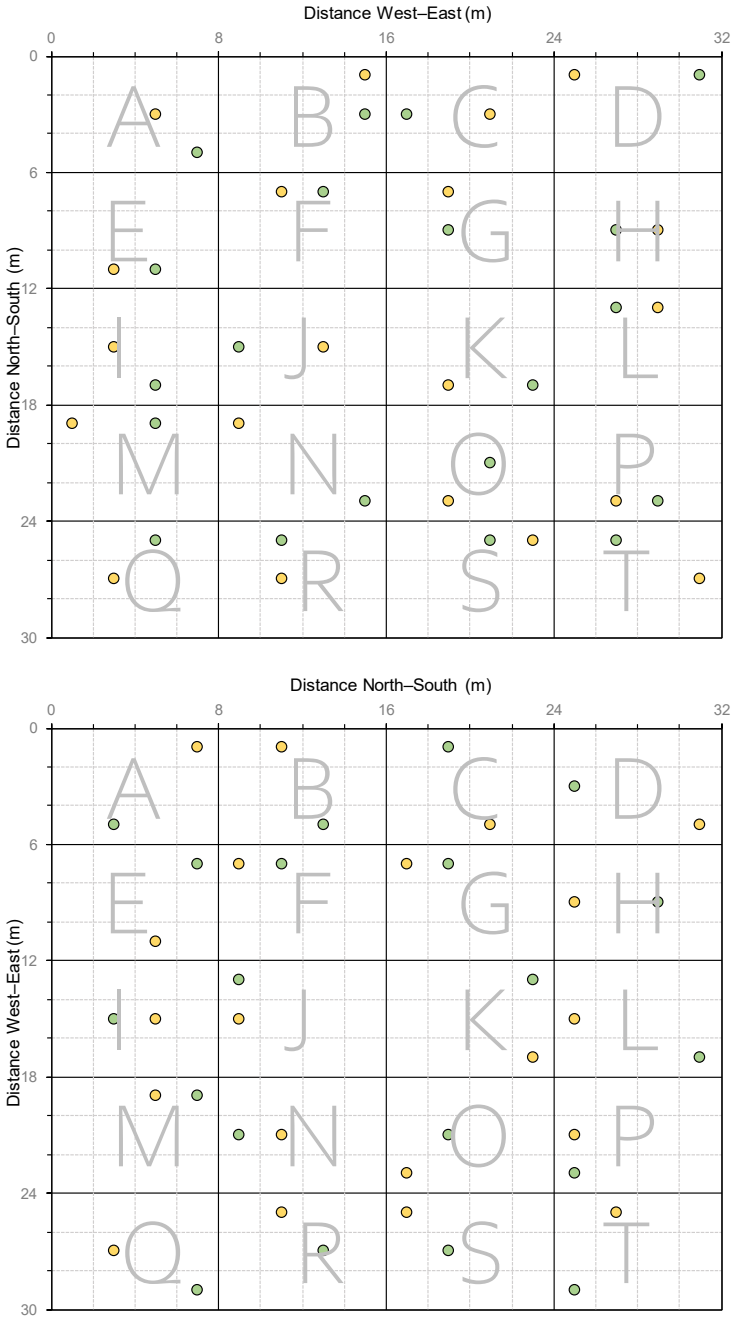


Figure 6-2. Layout of the long-term soil monitoring plots at Coho Flats (upper) and Lakelse Lake (lower) showing the lettered grids (n = 20) containing 12 sub-grids, which are randomly sampled without replacement; the green-filled circles indicate the sub-grids sampled for soil during 2015, and the orange-filled indicate the sub-grids sampled for soil during 2018. See Table 6.6 and Figure 6.10 in Terrestrial Ecosystems (Soils) Appendix 6.11 for further details.

6.2.3 Analyses we conducted: critical loads

The determination of critical loads of acidity (S) for terrestrial ecosystems (Figure 6-3) in the study region incorporated updated model parameters as recommended under the STAR and outlined under the EEM program (Technical Memo S05, 2017; Terrestrial Ecosystems (Soils) Appendix 6.5). The revised mapping incorporated new site-specific observations of soil data (see Terrestrial Ecosystems (Soils) Appendix 6.1), improved regionalisation methods (see Terrestrial Ecosystems (Soils) Appendix 6.5) and continuous digital (mapped) coverages for a range of environmental data (Table 6-1).

Critical loads of acidity (sulphur) were estimated using the Steady-State Mass Balance model (Table 6-2 and Table 6-3) following methods described in UNECE (2004) and de Vries et al. (2015). Receptor ecosystem area was delineated into 0.5 km × 0.5 km grids aligned with the modelled S deposition grid, and the areal proportion of coniferous forests (including mixed forests and shrub), deciduous forests and wetlands were recorded for each grid. The total number of receptor grids was 12,505; not all grids had 100% coverage; the average receptor cover within each 0.5 km × 0.5 km grid was 76%. Critical loads of acidity (sulphur) were estimated for each receptor ecosystem in each grid across the study area (see Figure 6-3) by combining input parameters (Table 6-3) obtained from existing environmental data sets (Table 6-1) and literature values (e.g., UNECE 2004) with derived mapped variables, e.g., soil base cation weathering rate, modelled from point observations of soil oxides that were regionalised using a geostatistical regression-kriging approach (see Appendices 6.3 and 6.4 for a detailed description of methods used to model weathering rates and map soil properties).

The level of protection for forest soils was specified via a critical ANC leaching and for wetlands via an acid neutralizing capacity limit (ANC_{limit}) similar to surface waters (see Table 6-2). The most widely used acidification threshold linking soil chemical status and plant response is a critical molar base cation (Bc) to Al ratio; sodium is excluded as it does not protect plant roots against Al toxicity. A soil solution critical molar Bc:Al ratio = 1.0 within the top 50 cm (the principal rooting zone) was chosen to be protective (95% of root growth) of the dominant tree species (*Tsuga heterophylla*, western hemlock) in the region (Sverdrup and Warfvinge 1993). In areas dominated by deciduous forests, a critical Bc:Al ratio = 8.0 within the top 50 cm (Sverdrup and Warfvinge 1993) was chosen to ensure protection of the more sensitive deciduous tree species, such as *Populus tremula* (trembling aspen)[28]. The ANC_{limit} is generally based on regional-scale assessments of the selected biological indicator; a 'default' limit of ANC_{limit} = 20 µeq/L, derived from an empirical relationship between lake water chemistry and fish status in Norway, is widely applied to protect fish, aquatic invertebrates, and benthic organisms (Lien et al. 1996; Posch et al. 2015)[29]. Non-marine base cation wet deposition (BC_{dep})[30] was derived from a constant precipitation concentration across the study area combined with mapped rainfall volume (Table 6-1; and Figure 6.7 in Terrestrial Ecosystems (Soils) Appendix 6.6). Base cation concentration in precipitation was set to 0.71 µeq/L based

[28] The critical molar Bc:Al ratios for western hemlock and trembling aspen were both directly taken from Sverdrup and Warfvinge (1993); they are set to protect 95% of tree biomass or root growth

[29] The ANC_{limit} = 20 µeq/L was selected for wetlands to protect aquatic biota rather than plant roots via the Bc:Al ratio; an ANC_{limit} = 20 µeq/L has been shown to be widely protective of fish, aquatic invertebrates, and benthic organisms (Lien et al. 1996)

[30] BC = Ca^{2+} (calcium) + Mg^{2+} (magnesium) + K^{+} (potassium) + Na^{+} (sodium)

on annual average observations during 2014–2018 at two NADP precipitation chemistry monitoring stations (Port Edward [BC24] and Lakelse Lake [BC23]). The determination of Bcu[31] and runoff (or soil percolation; Q) followed ESSA et al. (2013; 2014b). The final mapped resolution was consistent with the modelled deposition scenarios, i.e., critical load variables were estimated as the area-weighted average of all receptor ecosystems in each 0.5 km × 0.5 km grid square across the study domain.

Exceedance of critical loads of acidity was estimated under three SO_2 emissions scenarios: actual 2016–2018, 35 tpd and 42 tpd (see Section 3). Estimated exceedance also included a background total non-seasalt sulphur deposition owing to transboundary sources outside of the study domain. Background S deposition was set to a constant value of 7.5 meq/m^2/yr across the study area (for further details are given in Terrestrial Ecosystems (Soils) Appendix 6.7).

Table 6-1. Environmental data sets (site-specific observations and digital [mapped] coverages) used for the determination of critical loads of acidity (sulphur) for terrestrial ecosystems in the Kitimat Valley.

Data	Description and Source
Soil chemistry and geochemistry	Site-specific data in the study area (115 locations; see Figure 6-1), with observations of location (co-ordinates), bulk density, coarse fragment, organic matter content, particle size, major oxide content, qualitative mineralogy and site descriptions (Terrestrial Ecosystems (Soils) Appendix 6.1). Source: Terrestrial Ecosystems (Soils) Appendix 6.1
Soil maps	Soil properties (Version: v0.2, 2018) Sand content, clay content, pH, bulk density, organic carbon content and coarse fragment at 6 standard depths (1, 10, 30, 60, 100 and 200 cm) at 250 m resolution. Source: LandGIS — Open Land Data service [openlandmap.org] [github.com/Envirometrix/LandGISmaps#soil-properties-and-classes]
Geology	Bedrock Geology (Version: 2018-04-05). Source: British Columbia Geological Survey [www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology]
Elevation	Digital Elevation Model (scale: 1:20 000). Source: B.C. Ministry of Environment and Climate Change Strategy
Meteorology	Climate normals (1960–1990) for annual rainfall and annual average temperature estimated by PRISM at a 4 km by 4 km grid resolution (Daly et al. 1994). Source: ClimateWNA (Wang et al. 2006; 2012) [http://www.climatewna.com]
Precipitation chemistry	Wet-only precipitation chemistry at Haul Road, Lakelse Lake and Port Edward. Source: National Atmospheric Deposition Program [nadp.slh.wisc.edu]
Hydrology	Long-term modelled annual runoff (based on 1960 to 1990 climate normals) at a 400 m by 400 m grid resolution (Moore et al. 2012).
Land cover	Canadian Land Cover, circa 2000. GeoBase Series, 1996-2005. Grids 103H and 103I (scale: 1:250 000). Source: Natural Resources Canada. GeoPortal Canada [open.canada.ca/data/en/dataset/97126362-5a85-4fe0-9dc2-915464cfdbb7] Forest properties (Version: v0 (beta), September 2003) at 250 m resolution. Source: National Forest Inventory [https://nfi.nfis.org/en/]

[31] Bc = Ca^{2+} + Mg^{2+} + K^{+} (no Na^{+})

Data	Description and Source
Nutrient harvest	Mapped biomass removals based on allowable annual cut for TSAs, TFLs, and community forests combined with nutrient concentrations as described by ESSA et al. (2013).

Table 6-2. Critical load mass balance model for the assessment of acidification for forest soils and wetlands; see Table 6-3 for a description of model parameters and data sources.

Critical Load and Exceedance Equation	Number
Critical load: $CL(A) = BC_{dep} - Cl_{dep} + BC_w - Bc_u - ANC_{le(crit)}$	Eqn (6-1)
Where [for mineral soils] $$ANC_{le(crit)} = -Q^{\frac{2}{3}} \cdot \left(1.5 \cdot \left(\frac{Bc_w + Bc_{dep} - Bc_u}{(Bc:Al)_{crit} \cdot K_{gibb}}\right)\right)^{\frac{1}{3}} - 1.5 \cdot \left(\frac{Bc_w + Bc_{dep} - Bc_u}{(Bc:Al)_{crit}}\right)$$	Eqn (6-2a)
Or [for wetlands] $$ANC_{le(crit)} = ANC_{limit} \times Q$$	Eqn (6-2b)
Exceedance: $Exc = S_{calpuff} + S_{background} - CL(A)$	Eqn (6-3)

Critical load of acidity (CL(A)) was determined for forest (coniferous, deciduous, mixed and shrub) and wetland ecosystems (area = 2,378 km²). Exceedance was determined as the proportion (%) of the effects' domain, which is defined as the receptor ecosystem area enclosed by the 7.5 kg SO_4^{2-}/ha/yr modelled S deposition isopleth under each emission scenario.

Table 6-3. Description of input parameters and their data sources required to determine critical loads of acidity for terrestrial ecosystems in the study.

Parameter	Description	Data source
BC_{dep}	Non-marine non-anthropogenic base cations (BC = Bc (base cations) + Na^+ (sodium), Bc = Ca^{2+} (calcium) + Mg^{2+} (magnesium) + K^+ (potassium)) deposition.	Derived from observations of precipitation concentrations and long-term rainfall volume (NADP [two regional stations]). See Terrestrial Ecosystems (Soils) Appendix 6.6
Cl_{dep}	Non-marine chloride (Cl^-) deposition; it is assumed that non-marine (Cl^-) is negligible in the study area.	–
BC_w	Estimated using the A2M-PROFILE model chain (Warfvinge and Sverdrup 1992 (PROFILE); Posch and Kurz 2007 (A2M)) from site-specific soil and soil geochemical observations at 115 locations (Figure 6-1); regionalised using a regression-kriging approach (Hengl et al. 2004).	Table 6-1 (soil chemistry); Terrestrial Ecosystems (Soils) Appendix 6.3
Bc_u	Base cation removal in harvested biomass based on Annual Allowable Cut and literature values for tree species (Western Hemlock) base cation (Ca^{2+}, Mg^{2+} and K^+) concentrations.	ESSA Technologies (ESSA et al. 2013, 2014b)

Parameter	Description	Data source
$Bc:Al_{(crit)}$	For mineral soils, the critical molar base cation to Al ratio is the chemical criterion associated with ecosystem damage. Following the ESSA et al. (2014), Bc:Al = 1.0 for coniferous and mixed forests and Bc:Al = 8.0 for deciduous (updated from 6.0 to 8.0).	ESSA et al. (2014b), Sverdrup and Warfinge (1993)
ANC_{limit}	For wetland soils, the acid neutralising capacity limit was selected as the chemical criterion to protect aquatic biota. A widely used default value for broad ecosystem protection is 20 µeq/L.	UNECE (2004), de Vries et al. (2015)
Q	Long-term annual soil percolation or runoff.	Table 6-1 (hydrology)
K_{gibb}	Gibbsite equilibrium constant: Based on soil organic matter content following UNECE (2004) – pKgibb = 9.0 (LOI <5%), 8.5 (LOI >5 % and <15%) and 7.6 (LOI > 15%). Site observations of LOI (Terrestrial Ecosystems (Soils) Appendix 6) were regionalised using a regression-kriging approach.	UNECE (2004), de Vries et al. (2015)
$S_{calpuff}$	Anthropogenic sulphur deposition estimated from the CALPUFF model under three SO_2 emissions scenarios (actual 2006–2018, 35 tpd and 42 tpd). Simulated deposition is based on Rio Tinto emissions only	Section 3
$S_{background}$	Background total deposition of non-seasalt sulphur owing to transboundary sources outside of the study domain	Terrestrial Ecosystems (Soils) Appendix 6

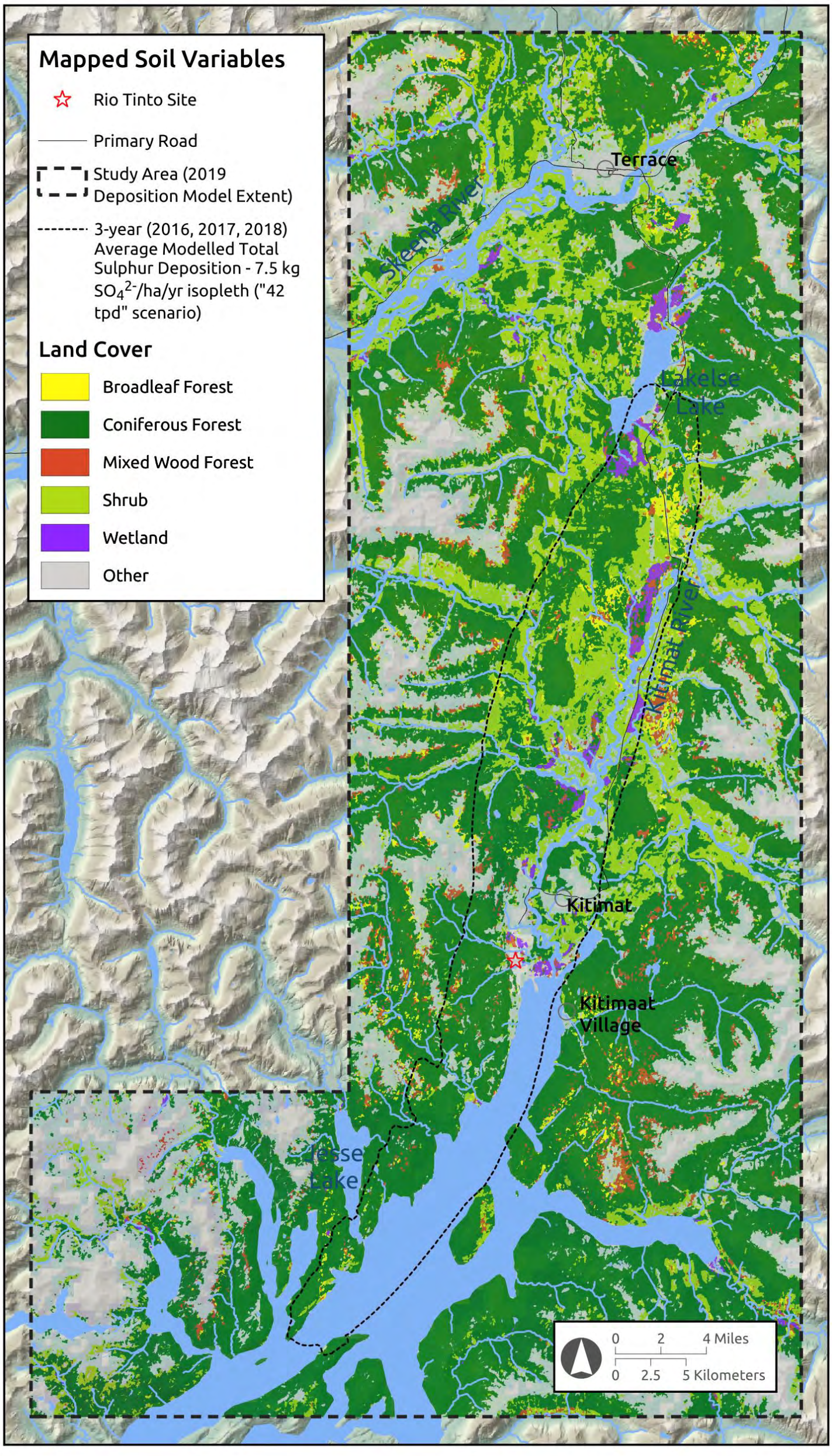


Figure 6-3. Map of the study area depicting the coverage of the receptor ecosystems used for the determination of critical loads of acidity (sulphur). Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleth.

6.2.4 Analyses we conducted: long-term soil plots

Soil chemistry data from the primary long-term plots at Coho Flat and Lakelse lake were summarised by plot (mean or geomean based on the distribution of the data) and over cumulative soil depths, i.e., 0–5 cm, and weighted-averages (weighted by depth and bulk density) for 0–15 cm and 0–30 cm. Each plot has 20 observations (for each depth), i.e., for the top 0–30 cm of soil, summary data are expressed as the average of the 20 observations, each of which represents the weighted-average soil chemistry over three depths. Exchangeable base cations (BC) were estimated as the sum of exchangeable Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}. Cation Exchange Capacity (CEC) was estimated as the sum of base cations and exchangeable acidity, this is technically termed effective CEC (CECe) as CEC was not directly measured (Tamminen and Starr 1990). Base saturation (%) was estimated as the percentage of effective CEC made up of base cations (BSe). Exchangeable base cations pools in soil were estimated by multiplying the concentrations of base cations in each layer by the corresponding soil bulk density and depth; pools were estimated for the cumulative depths of 0–5 cm, 0–15 cm and the 0–30 cm for the mineral soil. Organic soil horizons (e.g., LF and H) were not measured because they are highly influenced by internal base cation cycling through uptake and litterfall. See Terrestrial Ecosystems (Soils) Appendix 6.11 Tables 6.7 to 6.9 and Tables 6.11 to 6.13 for soil observations by plot and depth.

The measure of central tendency (MCT, i.e., average) in soil chemistry for each primary plot was calculated as a mean or geometric mean with untransformed or log10 transformed data, respectively. Variability in soil chemistry was described by the coefficient of variation (or relative standard deviation), which was estimated as the standard deviation/average × 100 (units of %). Statistical differences in soil chemistry between plots or depths was evaluated using an unpaired t-test. Further, comparison of soil properties between 2015 and 2018 was carried out using a one-sided t-test assuming equal or unequal variances according to a Levene's test for equal variances ($\alpha = 0.05$) and testing for a decrease in values for 2018. Statistical comparisons were conducted using untransformed or log10 transformed data depending on the normality of the residuals determined from a Shapiro-Wilk's test ($\alpha = 0.05$). The magnitude of difference in the MCT was calculated as (2018–2015)/2015 × 100 (units of %).

The multiple observations per depth (n = 20) define the variation in soil properties, which influence our ability to detect statistical changes in the soil properties following repeat sampling. The Minimum Detectable Difference (MDD) is the minimum change in a soil property over a given period of time required to be considered statistically significant, i.e., soil data collected during plot establishment can be used to determine how much change must occur to be considered statistically significant and not an artifact of system variability. The MDD was conducted using a t-test power analysis (α=0.05, $\beta = 0.1$) using the standard deviation in 2015 and the pooled standard deviation (2015 and 2018) and accounting for unequal variances where appropriate. MDD was expressed as a percent decrease from 2015 (–MDD/MCT2015). For transformed data, power analysis was conducted with log transformed data, but back-transformed to raw scale for % MDD relative to 2015.

The time to base cation depletion (in years) is the buffering period of base cations under continued sulphuric acid deposition, i.e., the period of time (years) that exchangeable base cations in soil can buffer incoming acidity assuming no other sources of base cations (such as

weathering or deposition) or acidity, and linear exchange on the soil exchange complex. The time to depletion for the top 30 cm of mineral soil was calculated as the base cation pool (meq/m^2) measured in 2015 divided by observation-based estimates of wet and dry sulphur deposition ($meq/m^2/yr$). Estimates of current sulphur deposition are based on wet deposition observations from the closest (or most representative) NADP precipitation chemistry monitoring station, and air concentrations from passive samplers or the nearest ambient continuous monitoring station (e.g., Whitesail was used for dry deposition at Coho Flats; see Section 3.1 for further details).

6.2.5 Assessment of acceptable or unacceptable impacts to terrestrial receptor

The assessment of impacts to terrestrial receptors is directly linked to the two KPIs, exceedance of critical loads of acidity and depletion of exchangeable base cation pools. Impacts are causally related to smelter emissions, as exceedance of critical loads is determined using CALPUFF modelled sulphur deposition, which is parameterised on smelter emissions only. In addition, if changes in exchangeable base cations above the KPI threshold are observed at the long-term soil plots, they are assessed with respect to changes in the control plot (at Kemano). There are three thresholds associated with each KPI leading to increased monitoring/modelling, receptor-based mitigation and facility-based mitigation, depending on the level of impact. The first two thresholds are associated with acceptable impacts.

If sulphur deposition, causally related to KMP emissions, exceeds critical loads in > 1% of semi-natural upland forest soils in the study area, this will trigger the threshold for increased modelling, i.e., uncertainties in the regional critical load mapping will be re-evaluated and the critical load model will be re-run with new data where required. During the EEM program, the critical loads modelling approach was expanded to be consistent with the Kitimat and Prince Rupert assessments (ESSA et al. 2014b, 2015). These revisions include the addition of non-forest ecosystems (wetlands) and the determination of proportional exceedance with reference to the modelled 7.5 kg SO_4^{2-}/ha/yr deposition isoline (see Terrestrial Ecosystems (Soils) Appendix 6.5 for model revisions; Technical Memo S05, 2017). The revisions directly influence the determination of acceptable / unacceptable impacts.

If a 40% decrease[32] in exchangeable cation pools for at least one element for one plot is observed between five-year[33] sampling events, and the decrease is causally related to emissions from the modernized smelter, the data from the regional soil survey will be used to assess (model) the spatial significance of observed base cation loss (i.e., are there wider issues over >1% of the study area?).

[32] Soil chemistry is highly variable in forests; chemical properties, such as exchangeable cations, typically vary by at least 40% (coefficient of variation) on local scale. To detect a statistically significant change in soil chemistry, the shift (increase or decrease) must be greater than the natural variation in the soil. A 40% decrease in exchange cation pools was selected as an indicator that could be reliably detected with statistical significance.
[33] To accommodate the comprehensive review reporting schedule, there was only three years between the initial (2015) and first resampling (2018).

6.3 What Did We Learn, and Did We Make Any Adjustments to the EEM Program?

The SO_2 EEM Program resulted in improved regional estimates of critical loads of acidity for the study domain. The EEM also provided information regarding the spatial variability on soil chemical properties and exchangeable base cation pools to identify the amount of change that could be significantly detected.

The results of the EEM Program directly support the two KPIs for soils: (a) atmospheric sulphur deposition and critical load exceedance risk, and (b) long-term soil acidification (rate of change of base cation pool) attributable to sulphur deposition. The improved estimates of regional critical loads provide for a direct assessment of the potential impacts of KMP emissions of SO_2 on soils within the study domain. Similarly, the repeated observations of soil chemistry at the long-term monitoring plots provide a direct measure of the rate of change in exchangeable base cations.

6.3.1 Knowledge gained: critical loads

The study domain was 3653.5 km^2, with receptor ecosystems covering 2377.8 km^2 (~65%). Soil properties (organic matter content, bulk density, coarse fragment, clay and sand) were mapped across the entire terrestrial study area (Appendices 6.3 and 6.4). Organic matter content in mineral forest soils (top 50 cm) was estimated to range from <1.0 % to 35% (average: 10.5%) across the study area (Terrestrial Ecosystems (Soils) Appendix 6.4 Figure 6.5). In general, the lowest values (< 5% LOI) were observed north of Lakelse Lake associated with fluvial, glaciofluvial and marine surficial deposits (covering ~14% of the mapped receptor ecosystems). In contrast, the highest values (> 15% LOI) were predicted to occur in mountainous regions in the west and south of the Kitimat Valley (covering 20% of the receptor area). Soil organic matter was used to predict and spatially define the gibbsite equilibrium constant (see Table 6-3 for further details).

Base cation weathering rate for mineral forest soils was estimated to range from 18.3 $meq/m^2/yr^1$ to 177.5 $meq/m^2/yr^1$ (average: 78.6 $meq/m^2/yr^1$) in the top 50 cm (Figure 6-4). The highest base cation weathering rates were predicted in southern parts of the Kitimat valley (surrounding Kitimat town) and further south-west (16% of the receptor ecosystems have weathering rates >100 $meq/m^2/yr^1$). In contrast, the lowest weathering rates (3.5% of the receptor ecosystems have weathering rates <50 $meq/m^2/yr^1$) were generally observed north, east and west of the Kitimat Valley corresponding with coarse texture mountain soils with low bulk density (Figure 6-4 and Terrestrial Ecosystems (Soils) Appendix 6.1). On average, sodium weathering (19.1 $meq/m^2/yr^1$) made up approximately 25% of estimated base cation weathering rate. Base cation weathering is a key parameter used to derive chemical criteria or indicators and determine critical loads of acidity (see Table 6-3). In general, estimated weathering rates were similar to the STAR (average: 88.6 $meq/m^2/yr^1$).

The spatial pattern of CL(A) (Figure 6-5) was similar to base cation weathering (Figure 6-4), although significantly greater in magnitude across the region (× ~2.85) owing to the dominance of the $ANC_{le(crit)}$ term, which was approximately twice the average weathering rate (see Table 6-2: Equation 1). The average critical load of acidity was 223.6 $meq/m^2/yr^1$ (range: 52.6–650 $meq/m^2/yr^1$). As such, much of the study region is considered to have moderate to

high critical loads of acidity, and consequently have moderate to low sensitivity to acidic deposition.

Exceedance of critical loads of acidity (S) was estimated under three emissions scenarios: 2016–2018 actual, 35 tpd and 42 tpd, presenting a range between current and maximum permitted emissions. The area of the receptor ecosystems (forests and wetlands) under the 7.5 kg SO_4^{2-}/ha/yr ranged from 271.1–398.4 km^2; the exceeded area under the three emissions scenarios was low, ranging from 0.97 km^2 (actual) to 2.33 km^2 (42 tpd). The greatest areal exceedance (under the 42 tpd scenario) represented 0.58% of the mapped receptor ecosystem within the effects' domain. Even though a relatively small area was predicted to be exceeded, the average exceedance was high; 149 meq/m2/yr under the 42 tpd scenario, indicating that a small area of receptor ecosystems will receive acidic deposition greatly in excess of their critical load (Table 6-4; see Terrestrial Ecosystems (Soils) Appendix 6.9 Figure 6.9 and Terrestrial Ecosystems (Soils) Appendix 6.10 Table 6.4). The exceeded area was located primarily south and north of the principal sulphur emissions sources in the Kitimat Valley, i.e., the Rio Tinto smelter (Figure 6-5). The area of exceedance outside the fence line ranges from 0.20 km^2 (actual) to 1.26 km^2 (or 0.32% under 42 tpd; see Terrestrial Ecosystems (Soils) Appendix 6.8).

The improved regional estimates of critical loads provide for a direct assessment of the potential impacts of KMP emissions on soil acidification within the Kitimat valley. The updated critical loads incorporated new site-specific observations of soil data, improved regionalisation methods, and updated model parameters. However, there is limited data or knowledge on the acid-base status of wetlands in the Kitimat valley, as such there is uncertainty in the chosen critical limit for wetlands (Table 6-3). Similarly, the gibbsite equilibrium constant (K_{gibb}), which plays a crucial role in the determination of ANC leaching (Table 6-2) is based on literature ranges, which may not be appropriate for the region. Observations of wetland geochemistry, wetland S storage capacity and aluminium solubility in mineral soils would reduce uncertainties in the regional assessment of impacts to terrestrial receptors.

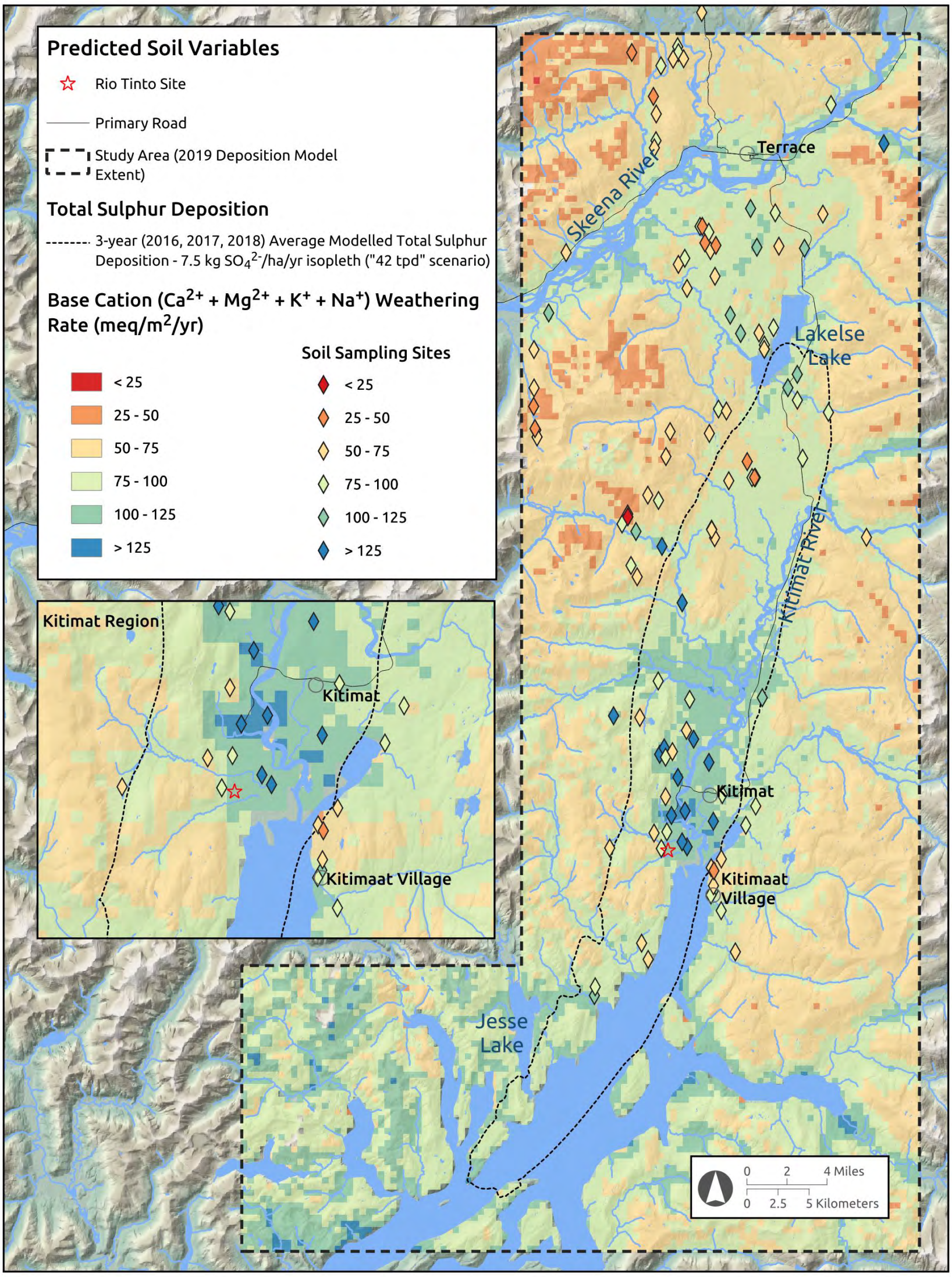


Figure 6-4. Predicted soil base cation (Ca^{2+} + Mg^{2+} + K^+ + Na^+) weathering rates (meq/m^2/yr) in the top 0–50 cm of mineral soil. Diamonds represent site-specific estimates of weathering rates used to develop the predictive map (through regression kriging). The dotted line indicates the isoline for total sulphur deposition > 7.5 kg SO_4^{2-}/ha/yr. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleth. See Terrestrial Ecosystems (Soils) Appendix 6.4 Figure 6.6 for base cation (Ca^{2+} + Mg^{2+} + K^+) weathering rates (meq/m^2/yr).

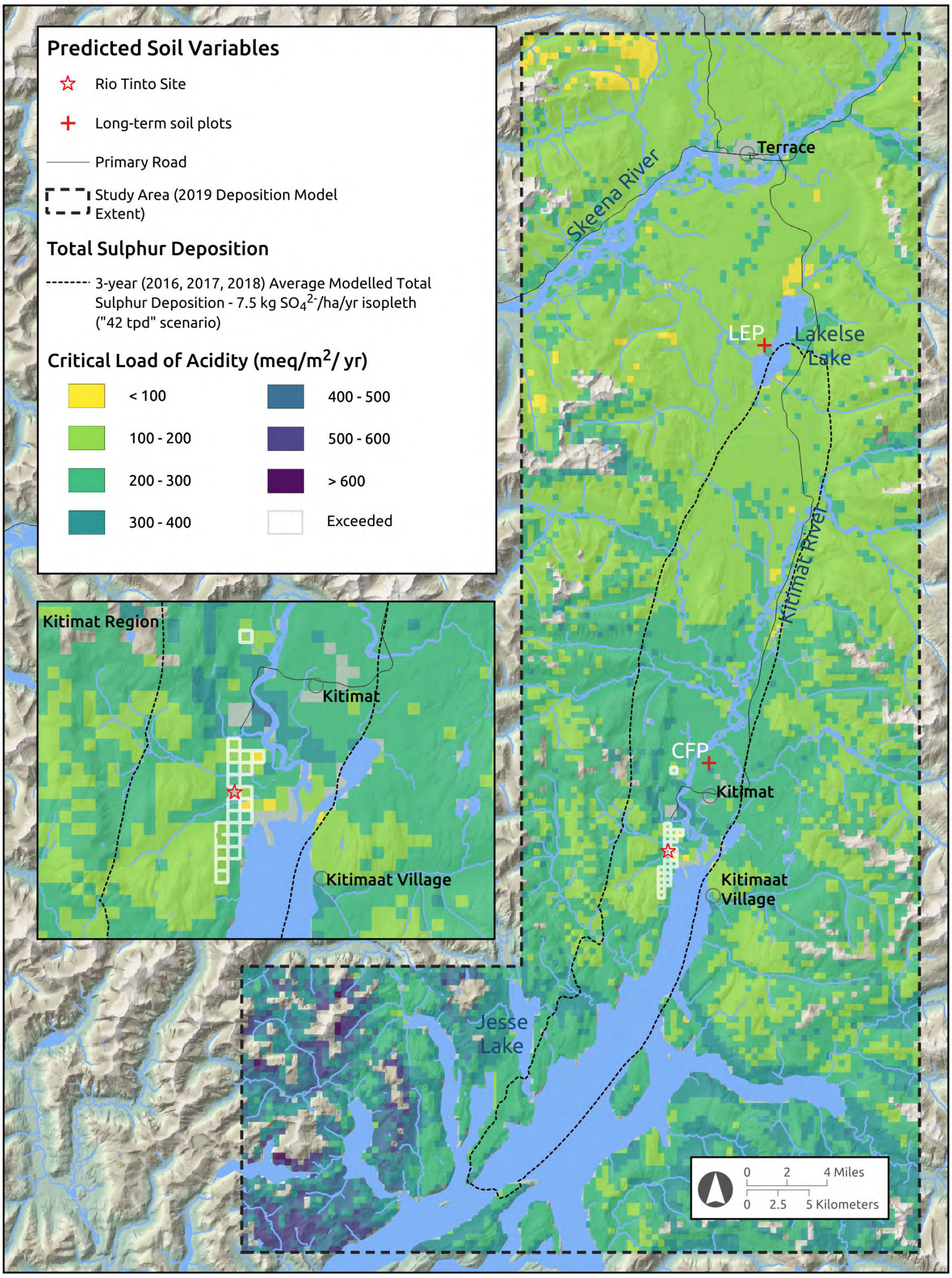


Figure 6-5. Predicted critical loads of acidity for forest and wetland soils (meq/m^2/yr) and exceedance (grids cells with white outline; n = 21) under modelled total sulphur deposition, based on maximum permitted emissions of 42 tonnes of sulphur dioxide per day. The dotted line indicates the isoline for total sulphur deposition > 7.5 kg SO_4^{2-}/ha/yr. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleth. The location of the long-term soil plots, Coho Flats Primary (CFP) and Lakelse Lake Primary (LEP), are also shown (+).

Table 6-4. Exceedance of critical loads of acidity for forest soils and wetlands under three sulphur emissions scenarios. The values within brackets refer to areas outside of the Rio Tinto fence line.

Exceedance	Deposition		
	Actual	35 tpd	42 tpd
Average exceedance (meq/m^2/yr)	119.9 (97.9)	140.0 (116.13)	149.6 (97.9)
Exceeded area (km^2)	0.97 (0.20)	1.26 (0.40)	2.33 (1.26)
Exceeded area wetland (km^2)	0.40 (0.16)	0.44 (0.16)	0.58 (0.30)
Exceeded area (%) *	0.36 (0.07)	0.39 (0.13)	0.58 (0.32)
Exceeded grids (n)	12 (5)	15 (6)	23 (11)
Mapped receptor area (km^2)	271.1	321.4	398.4

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

6.3.2 Knowledge gained: long-term soils plots

The average concentration of exchangeable base cations (Ca^{2+} + Mg^{2+} + K^+ + Na^+) in the top 0–30 cm of mineral soil at the primary plots was 1.2 meq/100g at Coho Flats and 1.5 meq/100g at Lakelse Lake during 2015. Exchangeable Ca^{2+} was the dominant cation at both plots (0.7 meq/100g at Coho Flats and 1.0 meq/100g at Lakelse Lake; Table 6-5, compare Figure 6-7 with Terrestrial Ecosystems (Soils) Appendix 6.11 Figure 6.12) followed by Mg^{2+} (0.26 meq/100g at Coho Flats and 0.30 meq/100g at Lakelse Lake). Base saturation in the top 0–30 cm of mineral soil was 15% at Coho Flats compared with 47% at Lakelse Lake, which was primarily driven by the higher CECe at Coho Flats. The higher CECe at Coho Flats is a result of the higher exchangeable acidity, which is driven by the higher organic matter content (estimated as LOI, 17.7% at Coho Flats compared with 5.5% at Lakelse Lake).

There was no statistical difference in the concentration of exchangeable base cations in the top 0–30 cm of mineral soil at both primary plots (Coho Flats and Lakelse Lake; Table 6-5). In contrast, the exchangeable base cation pools are statistically different between plots (see Terrestrial Ecosystems (Soils) Appendix 6.11 Table 6.11; 1,708 meq/m^2 Coho Flats versus 4,041 meq/m^2 Lakelse Lake) owing to the difference in soil bulk density (0.466 g/cm^3 Coho Flats versus 0.890 g/cm^3 Lakelse Lake). The lower bulk density at Coho Flats is related to the higher organic matter content. It should be noted that, the deep organic soil layer (LFH) at Coho Flats makes it difficult to accurately sample mineral soils.

Soil chemistry was highly variable among the 20 observation points (weighted average of three depths) at both sites. The coefficient of variation for average soil chemistry in the top 0–30 cm of mineral soil ranged from 21.6% (exchangeable acidity) to 74.5% (exchangeable Ca^{2+}) at Coho Flats and from 26.8% (exchangeable acidity) to 50.6% (exchangeable Mg^{2+}) at Lakelse Lake during 2015. Variation in the concentration of exchangeable base cations ranged from 42–56% (Lakelse Lake to Coho Flats); soil base cation pools showed a similar variation of ~52% for both primary plots (Figure 6-5).

The variability in soil chemistry influences our ability to detect statistical differences (decreases) in exchangeable base cations between sampling periods (see Table 6-5). The

minimum detectable difference[34] (decrease) based on the variability in soil chemistry during 2015 ranged from 20% (exchangeable acidity) to 50% (exchangeable Ca^{2+}) at Coho Flats, and from 23% (base saturation) to 44% (exchangeable Ca^{2+}) at Lakelse Lake in the top 0–30 cm of mineral soil. The minimum detectable decrease in exchangeable base cations is 40% at Coho Flats and 37% at Lakelse Lake, i.e., to detect a statistical decrease between sampling periods at Lakelse Lake, exchangeable base cations would have to decrease by 37%. However, the minimum detectable difference (decrease) is also influenced by the variability in soil chemistry during the second sampling period, i.e., detectable difference is influenced by the pooled variability of sampling events[35]. The minimum detectable difference (decrease) based on the variability in soil chemistry during 2015 and 2018 ranged from 29% (effective cation exchange capacity) to 68% (exchangeable Mg^{2+}) at Coho Flats, and from 29% (base saturation) to 46% (exchangeable Ca^{2+}) at Lakelse Lake in the top 0–30 cm of mineral soil (Table 6-5). The minimum detectable decrease in exchangeable base cations increased to 45% at Coho Flats and 42% at Lakelse Lake based on pooled variability during 2015 and 2018 compared with 2015 only. At Coho Flats, the minimum significant decrease in base saturation that can be statistically detected based on the variability in the soils during 2015 is 34%. Considering the variability in soil during the second sampling period (2018), the minimum significant decrease that can be statistically detected is 38% (Table 6-5). These levels of change are both below the KPI threshold of 40%, suggesting that base saturation is a better (more reliable) indicator of long-term soil acidification under the EEM.

There was no statistical decrease in exchangeable soil chemistry between 2015 and 2018 in the top 0–30 cm of mineral soil at both plots. For example, there was no statistical decrease in exchangeable Ca^{2+} between 2015 and 2018 in the top 0–30 cm of mineral soil at both plots; at Coho Flats a slight increase (13%) was observed in exchangeable Ca^{2+} between 2015 and 2018 (Table 6-5). There was a statistical decrease in pH at Coho Flats between 2015 (mean = 4.34) and 2018 (mean = 4.02) in the 0–30 cm of mineral soil but not at Lakelse Lake (mean pH 2015 = 5.11 and 2018 = 5.07). However, this decrease was driven by the higher organic matter content of the soil samples during 2018 at Coho Flats (Figure 6.12 in Terrestrial Ecosystems (Soils) Appendix 6.11); the average content was 17.7% in 2015 compared with 21.1% in 2018. As noted above, the LFH at Coho Flats made it difficult to accurately sample mineral soils; the observed difference in organic matter content reflects a change in sampling depths between years. The only soil variable that consistently showed a statistical decrease at lower cumulative depths (i.e., 0–15 cm and 0–5 cm) was exchangeable acidity, suggesting that there was a decrease in acidity between 2015 and 2018, despite the increase in acidic deposition (see Section 3). This was likely driven by differences in organic matter content between sampling periods (Figure 6.12 in Terrestrial Ecosystems (Soils) Appendix 6.11).

[34] Minimum Detectable Difference was conducted using a t-test power analysis (α=0.05, β = 0.1), i.e., the level of significance is 0.05 and the power is 0.9 (=1 – β). A power of 0.9 means that there is a 90% probability that a test of significance will pick up on an effect that is present.

[35] It is important to note that the KPI, *long-term soil acidification (rate of change of base cation pool) attributable to sulphur deposition*, is defined with respect to changes since the establishment of the soil monitoring plots during 2015. Therefore, MDD (2015) should be used to set the threshold for statistical detection. Nonetheless, it is important to recognise that soil variability during the repeat sampling periods may influence (positively and negatively) the statistically significant level of detection.

The time to base cation depletion (in years), i.e., the buffering period of soil exchangeable base cations under current sulphuric acid deposition in the top 0–30 cm ranged from 115 years (Coho Flats) to 373 years (Lakelse Lake) during 2015. The current observation-based estimates of acidic deposition for both sites ranged from 12.2 meq/m^2 at Lakelse Lake to 16.8 meq/m^2 at Coho Flats; observation-based estimates were derived from annual average wet deposition during 2016–2018 (from the nearest, or most appropriate, NADP station) and dry deposition estimated from air concentrations (from passive samplers or the nearest ambient continuous station) and modelled deposition velocity. However, the critical load of acidity was not exceeded at either plot (see Figure 6-5) indicating that base cation weathering rate buffers incoming acidity and that depletion of base cation pools is unlikely.

We have primarily focused our analysis of soil chemistry at the long-term soil on the top 0–30 cm of mineral soil at both primary plots. However, the results are consistent for the other cumulative depths (0–5 cm and 0–15 cm). The chemistry for individual layers displays the expected relationships with depth, i.e., organic matter (estimated as LOI) and exchangeable cations decrease with depth, whereas bulk density and pH increase with depth (see Figure 6.12 in Terrestrial Ecosystems (Soils) Appendix 6.11). Base saturation (%) was the most sensitive parameter for detecting change in exchangeable base cations, i.e., it consistently had the lowest minimum detectable difference based on the variability in the soils during 2015 and the pooled variability for 2015 and 2018. This was generally consistent when considering cation concentrations (Table 6-5) or pools (Table 6.11 in Terrestrial Ecosystems (Soils) Appendix 6.11), and also between different cumulative depths (0–5, 0–15 and 0–30 cm). Average soil chemistry (concentrations) for the 0–30 cm had a slightly lower minimum detectable difference compared with other depths and compared with base cation pools. A disadvantage of using base cation pools is they also require measurements of soil bulk density.

The long-term monitoring plots provide systematic replicate random samples of soil chemistry to address the KPI of 'observed change in base cation pool over time'. The original KPI was based on a 40% decrease in exchangeable base cation pools; however, the study results indicate that base saturation is a more reliable indicator of long-term soil acidification as it was the only soil property (related to base cations) that had a minimum detectable difference less than 40%. While exchangeable acidity and cation exchange capacity also had minimum detectable differences less that 40% (Table 6-5 and Terrestrial Ecosystems (Soils) Appendix 6.11 Table 6.11), they do not provide any information on changes in base cations, which are essential nutrients for sustainable tree growth. The use of exchangeable base cation pools under the EEM adds uncertainty to the KPI, as their minimum detectable difference was generally above 40% (see Terrestrial Ecosystems (Soils) Appendix 6.11 Table 6.11).

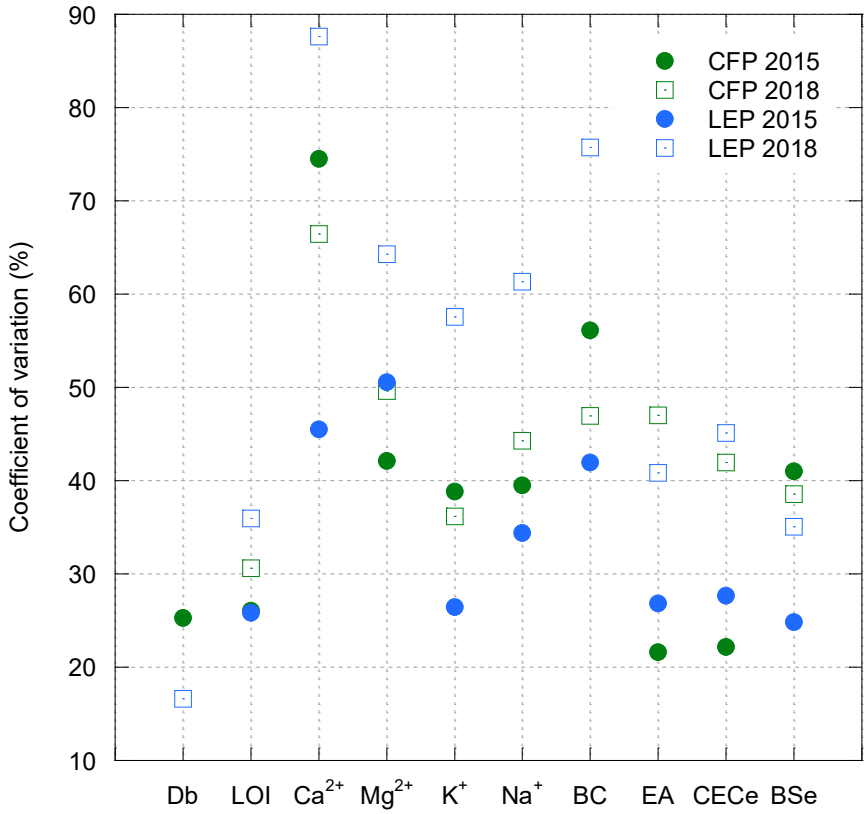


Figure 6-6. Coefficient of variation (%) in soil physico-chemical properties (20 observations for each variable) at Coho Flat Primary (CFP) and Lakelse Lake Primary (LEP) during 2015 and 2018. Soil properties: bulk density (Db), loss-on-ignition (LOI), exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), base cations (BC), exchangeable acidity (EA), effective cation exchange capacity (CECe) and effective base saturation (BSe).

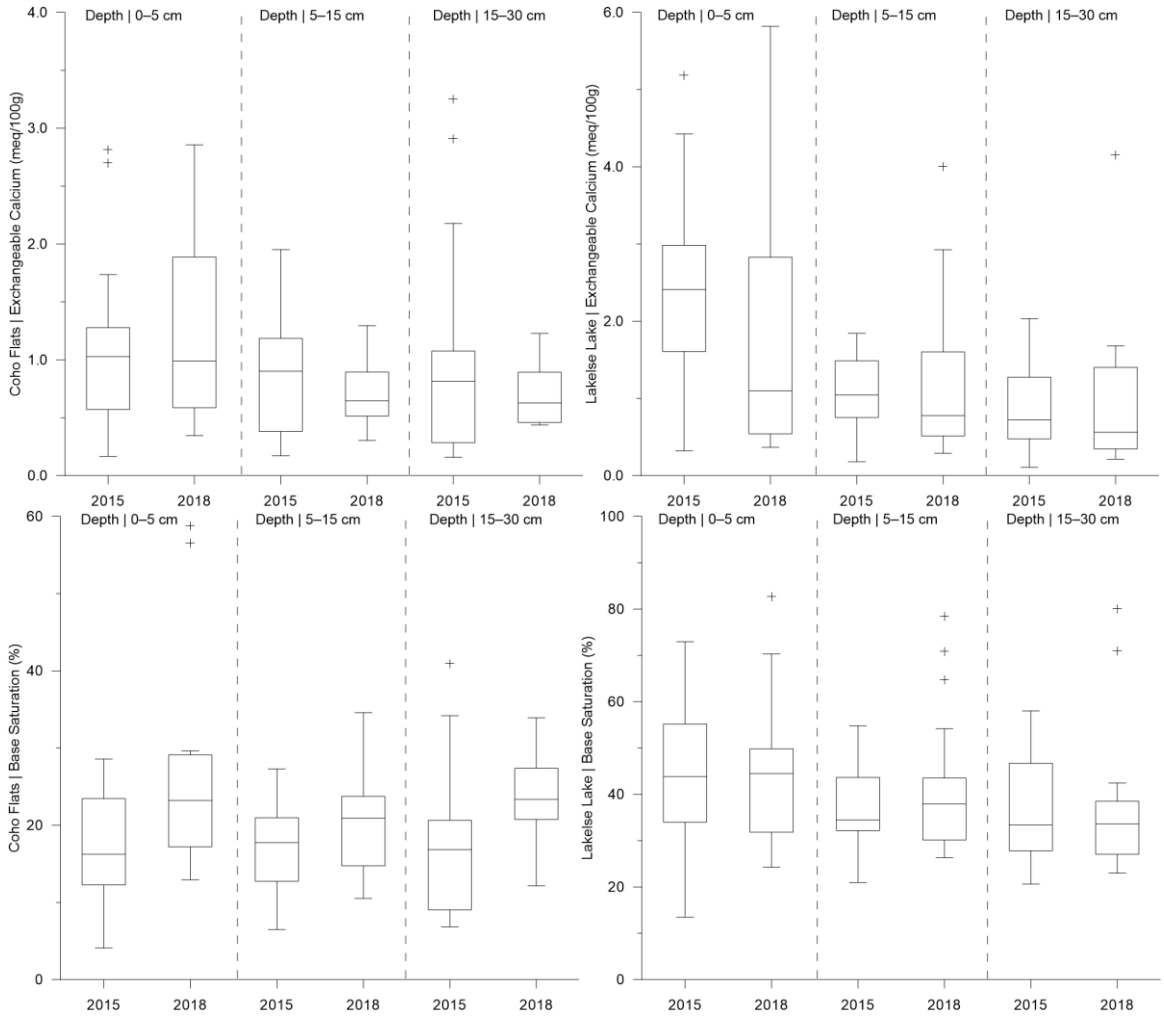


Figure 6-7. Boxplots showing exchangeable calcium (meq/100g) and base saturation (%) by depth during 2015 and 2018 at Coho Flats and Lakelse Lake long-term soil plots. There are 20 observations per depth. For the boxplot, the horizontal centre line represents the median concentration, the box represents the 75th (top, upper quartile) and 25th (bottom, lower quartile) percentiles and the whiskers represent 1.5 × the interquartile range, with any point that falls outside as an outlier (+).

Table 6-5. Average soil chemistry by depth during 2015 and 2018, probability of decrease between 2015 and 2018, magnitude of difference (MOD) and minimum detectable difference (MDD) based on the variability (pSD) during 2015 and pooled variability during 2015 and 2018 at Coho Flats Primary (CFP) and Lakelse Lake Primary (LEP) plots.

Plot	Depth	Param †	Unit	Test[a]	n 2015	Trans[b]	MCT[c] 2015	MCT[c] 2018	p-value	MOD[d] %	MDD[e] 2015	MDD[e] pSD
CFP	0–5	Ca^{2+}	meq/100g	tequal	19	Log10	0.87	1.0	0.737	15	-50	-52
		Mg^{2+}	meq/100g	tunequal	19	None	0.32	0.63	1.000	93	-37	-62
		BC	meq/100g	tequal	19	Log10	1.4	1.9	0.955	34	-43	-48
		EA	meq/100g	tunequal	18	None	7.8	6.2	0.006	-21	-16	-23
		CEC_e	meq/100g	tequal	18	None	9.4	8.3	0.074	-12	-18	-23
		BS_e	%	tequal	18	Log10	15	24	0.999	62	-38	-43
LEP	0–5	Ca^{2+}	meq/100g	tequal	20	Log10	2.2	1.2	0.007	-46	-45	-51
		Mg^{2+}	meq/100g	tequal	20	Log10	0.62	0.36	0.010	-42	-38	-48
		BC	meq/100g	tequal	20	Log10	3.0	1.7	0.006	-43	-39	-48
		EA	meq/100g	tequal	20	None	3.7	2.9	0.012	-24	-27	-30
		CEC_e	meq/100g	tequal	20	None	7.1	5.2	0.003	-27	-23	-28
		BS_e	%	tequal	20	None	47	41	0.150	-11	-31	-32
CFP	0–15	Ca^{2+}	meq/100g	tequal	19	Log10	0.80	0.84	0.597	5	-44	-46
		Mg^{2+}	meq/100g	tunequal	19	None	0.30	0.53	1.000	76	-36	-57
		BC	meq/100g	tequal	19	Log10	1.3	1.6	0.873	18	-36	-38
		EA	meq/100g	tunequal	18	None	7.1	5.9	0.030	-17	-18	-25
		CEC_e	meq/100g	tequal	18	None	8.6	7.7	0.101	-11	-18	-24
		BS_e	%	tequal	18	Log10	16	22	0.995	40	-32	-34
LEP	0–15	Ca^{2+}	meq/100g	tequal	20	Log10	1.3	1.0	0.071	-27	-42	-46
		Mg^{2+}	meq/100g	tequal	20	Log10	0.40	0.29	0.053	-27	-35	-44
		BC	meq/100g	tequal	20	Log10	1.9	1.4	0.076	-24	-37	-43
		EA	meq/100g	tequal	20	None	3.0	2.5	0.042	-18	-31	-31
		CEC_e	meq/100g	tequal	20	None	5.1	4.3	0.067	-16	-26	-30
		BS_e	%	tequal	20	None	41	39	0.389	-3.0	-28	-31
CFP	0–30	Ca^{2+}	meq/100g	tequal	19	Log10	0.70	0.79	0.726	13	−50	−57
		Mg^{2+}	meq/100g	tunequal	19	None	0.26	0.49	1.000	87	−40	−68
		BC	meq/100g	tequal	19	Log10	1.2	1.5	0.909	23	−40	−45
		EA	meq/100g	tunequal	19	None	6.5	5.6	0.078	−15	−20	−30
		CEC_e	meq/100g	tunequal	19	None	7.9	7.2	0.176	−9.3	−21	−29
		BS_e	%	tequal	19	Log10	16	23	0.997	44	−34	−38
LEP	0–30	Ca^{2+}	meq/100g	tequal	20	Log10	1.0	0.84	0.166	−19	−44	−46
		Mg^{2+}	meq/100g	tequal	20	Log10	0.30	0.25	0.170	−17	−40	−44
		BC	meq/100g	tequal	20	Log10	1.5	1.2	0.132	−19	−37	−42
		EA	meq/100g	tequal	20	None	2.6	2.2	0.095	−13	−25	−30
		CEC_e	meq/100g	tequal	20	None	4.3	3.8	0.148	−12	−26	−32
		BS_e	%	tequal	20	None	39	39	0.479	−0.51	−23	−29

† Soil parameters (Param) included exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), base cations (BC), exchangeable acidity (EA), effective cation exchange capacity (CEC_e) and effective base saturation (BS_e). [a] One-sided t-test assuming equal variances (tequal) or not (tunequal) according to a Levene's test for equal variances ($\alpha = 0.05$) and testing for a decrease in values for 2018. [b] Statistical comparisons were conducted using untransformed (None) or log10 transformed (Log10) data depending on the normality of the residuals determined from a Shapiro-Wilk's test ($\alpha = 0.05$). [c] The measure of central tendency (MCT) was calculated as a mean or geometric mean with untransformed or log10 transformed data, respectively. [d] The magnitude of difference was calculated as 2018 – 2015/ 2015 × 100% using the MCT. [e] The Minimum Detectable Difference (MDD) was conducted using a t-test power

analysis (α=0.05, β = 0.1) using the standard deviation in 2015 and the pooled standard deviation (2015 and 2018) and accounting for unequal variances where appropriate. MDD was expressed as a percent decrease from 2015 (–MDD/MCT2015). For transformed data, power analysis was conducted with log transformed data, but back-transformed to raw scale for % MDD relative to 2015.

6.3.3 Comprehensive synthesis and conclusions ('pulling all the pieces together')

The thresholds for the two terrestrial KPIs were not reached, i.e., the area of critical load exceedance was < 1% and there was no statistical change (decrease) in soil base cations at the long-term soil plots between 2015 and 2018.

In general, the areal extent of exceedance was similar to the STAR, i.e., areas with exceedance under the 42 tpd deposition scenario were close to the smelter. If exceedance is limited to areas outside the fence line, then areal exceedance drops by 55%. It is important to note that exceedance is not driven by sensitive soils, rather it is driven by high modelled sulphur deposition close to the smelter. As such, the limitations and uncertainties in the modelling and mapping of critical loads are unlikely to greatly influence the overall results of this KPI.

The long-term soil plots at Coho Flats and Lakelse Lake show no statistically significant decrease in exchangeable base cations or base saturation between 2015 and 2018 in the 0–30 cm depth. In general, the minimum detectable difference is lower for soil base cation compared with pools (note: base cation pools are specified in the KPI *long-term soil acidification attributable to sulphur deposition*). In addition, pools have the added requirement that soil bulk density be measured. Our results indicate that soil base saturation (a soil property related to base cations) provides the most reliable detectable difference of 40% in the top 0–30 cm of mineral soil. In contrast, it is highly uncertain that a statistically significant decrease of 40% in exchangeable base cations can be detected.

Exchangeable base cations in soil at Coho Flats and Lakelse Lake showed a range of changes between 2015 and 2018 in the 0–30 cm depth, e.g., there was an increase in exchangeable Ca^{2+} and Mg^{2+} at Coho Flats in the 0–30 cm depth but decrease at Lakelse Lake (Table 6-5). However, there were no statistically significant changes in soil chemistry between 2015 and 2018 in the 0–30 cm depth. The only consistent statistically significant change (decrease) at lower soil depths was observed for exchangeable acidity suggesting soils became less acidic between 2015 and 2018. In general, the size of the base cation pools and the level of base saturation at Coho Flats and Lakelse Lake are consistent with forest soils elsewhere in North America. The results for the long-term soil plots suggest that there were no impacts to sensitive receptors. In contrast, exceedance of critical load was predicted for a small area, indicating that growth of tree roots or stem biomass will likely be impacted (reduced by > 5%). However, the areal exceedance was < 1% and did not exceed the KPI threshold.

6.4 What Do We Recommend for the EEM Program Going Forward?

We recommend that both of the KPIs for soils under the EEM Program (atmospheric S deposition and critical load exceedance risk, and long-term soil acidification attributable to S deposition) be maintained going forward as they are both well-established and widely used indicators of the impacts from S deposition. Further, we recommend no changes to the critical loads KPI and suggest that critical loads of acidity for terrestrial ecosystems only need to be revised if new data or revised critical limits become available. We recommend that exceedance

continues to be routinely estimated for any updated S (and N) deposition scenarios, primarily to allow for the early detection of potential impacts from the smelter.

1. Nonetheless, there were several uncertainties in the regional assessment of impacts to terrestrial receptors. To address these uncertainties, we recommend that:
   a. A survey of wetland geochemistry and sulphur storage capacity be carried out; wetlands make up almost 25% of the exceeded area, yet there is no chemical information on wetlands in the Kitimat valley. This information will provide support for the critical limit for wetlands.
   b. An assessment of aluminium solubility in mineral soils be carried out; aluminium solubility is a key parameter in the determination of critical loads, associated with the critical limit and $ANC_{leaching}$[36] (see Terrestrial Ecosystems (Soils) Appendix 6.10). This information will help to confirm the current estimates on ANC leaching.
   c. If feasible, at least one of the (newly) proposed plant biodiversity plots (see Section 5: Review Results for Vegetation) be established within the exceeded areas south of the smelter. Further, as noted in Section 5.4.1, a Terrestrial Ecosystem line of evidence should be established to integrate the vegetation and soil lines of evidence.

2. We recommend that the assessment of changes in exchangeable base cation at the long-term soil plots be revised to:
   a. Use a change (decrease) in base saturation (%) to calculate the KPI rather than a change in exchangeable base cation pools; base saturation was the most sensitive parameter in detecting a change of 40% in exchangeable cations between two sampling periods (accommodating the variability in soil chemistry during both sampling events).
   b. Use soil concentrations in the top 0–30 cm (rather than 0–5cm or 0–15 cm) of mineral soil rather than pools to assess changes in soil chemistry.
   c. The minimum detectable difference should be further analysed to evaluate the potential of an early warning change in soil base saturation using a lower level of significance and / or lower power. While this decreases the probability of detecting a true statistical change, it may identify a potential influence at a lower level of change, e.g., a reduction in power may allow for the detection of a significant decrease in base saturation of 20% rather than 40%.
   d. Carry out the next sampling of long-term plots during 2025 (to move back to a five-year period) and measure trees (DBH) at time of soil sampling. Further, if the KPI is triggered, then tree chemistry should be measured to assess base cation update by trees.

[36] $ANC_{leaching}$ is a major component of the critical load (~70%) in this region owing to the high runoff.

7 Review Results for Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)

7.1 What Did We Set Out to Learn?

The STAR predicted that under the maximum post-KMP deposition (i.e., associated with emissions of 42 tpd), the pH would decrease by greater than 0.1 pH in 7 of the 41 lakes sampled. Five of these lakes with potential significant declines in pH were also predicted to exceed their critical loads under such deposition conditions. The rest of the 34 sampled lakes (including Lakelse Lake, which is the largest lake in the area and important to local communities and First Nations because of the fisheries it supports) and all 20 of the sampled stream sites were predicted to decline by less than 0.1 pH units in response to KMP. The STAR concluded that the impact on the aquatic ecosystems receptor under maximum permitted post-KMP emissions was **moderate**, as per the defined assessment framework. The approval of the permit acknowledged that this level of impact was acceptable but would require monitoring through the EEM program to assess any early warnings, potential impacts, and additional monitoring or mitigation actions as appropriate. The STAR assessment also concluded that the change in pH due to KMP would not be enough to have regional impacts on lakes or streams of importance to the public, or on fish production or on wildlife dependent on aquatic biota.

For this receptor, the STAR identified four critical uncertainties (ESSA et al. 2013), framed as questions to be addressed through the EEM program (Table 7-1).

Table 7-1. Critical questions for the aquatic ecosystems component of the EEM Program.

#	Question
W1	How do uncertainties in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post- KMP?
W2	How many of the 7 to 10 potentially vulnerable lakes actually acidify, and to what extent? a. Have any of the sensitive lakes exceeded their KPI thresholds? b. Does the weight of evidence suggest that any of the lakes have actually acidified and that such acidification is due to KMP (examining changes in all relevant water chemistry parameters)? c. What is the water chemistry of the four less sensitive lakes? Do any of them show any evidence of acidification and/or impact from KMP? d. How many lakes have actually acidified due to KMP and exceeded their KPI thresholds? e. Are additional sites suggested by ENV (i.e., lakes MOE-3 and MOE-6, Cecil Creek, and Goose Creek) at risk of acidification under KMP?
W3	What is the current status of the fish community in the potentially vulnerable lakes that can be safely accessed for fish sampling?
W4	If some of the potentially vulnerable lakes that can be safely sampled for fish show an acidifying trend, then do these lakes also show changes in their fish communities?

For each critical uncertainty, we developed at least two hypotheses (Table 7-2) representing alternative outcomes and identified the information that would be required (measured or modelled) to provide the evidence required to test these hypotheses.

Table 7-2. Critical uncertainties, hypotheses and modelling or monitoring needs for the aquatic receptor, as initially identified in the STAR (Table 10.3-1 in ESSA et al. 2013).

Critical uncertainties	Hypotheses	Modelling and monitoring needs
W1. How do uncertainties in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post-KMP?	**H1.** Predicted extent and magnitude of exceedances are reasonable or are overestimates. **H2.** Predicted extent and/or magnitude of exceedances are underestimates.	Assess uncertainties in SSWC and modified ESSA/Fisheries and Oceans Canada (DFO) models (estimates of deposition, F-factor) and analyses.
W2. How many of the 7 to 10 potentially vulnerable lakes actually acidify, and to what extent?	**H1**. Changes in water chemistry post-KMP (acidification) are similar to the Steady State Water Chemistry (SSWC) model and modified ESSA/DFO predictions. **H2.** Changes in water chemistry post-KMP are less than predicted. **H3.** Changes in water chemistry post-KMP are greater than predicted.	Slightly smaller set of parameters than sampled in 2012; survey 7-10 potentially vulnerable lakes. Seven high priority lakes are Lakes LAK006 (End Lake), LAK012, LAK022, LAK023 (West Lake), LAK028, LAK042, LAK044. For 2 of the lakes with good road access (West Lake – LAK023 and End Lake – LAK006), could also examine water chemistry after snowmelt and storm events to assess if acidic episodes are occurring. Focus on seven lakes with predicted pH change >0.10 pH units, sampling annually during KMP ramp-up until lake chemistry stabilized (probably within 2-3 years), then once every 3 years for 2 more cycles.
W3. What is the current status of the fish community in the potentially vulnerable lakes that can be safely accessed for fish sampling?	Establish baseline conditions of fish communities prior to implementation of KMP.	Establish baseline biological conditions prior to KMP start-up in safely accessible lakes (which could include Lakes LAK023 (West Lake), LAK006 (End Lake), LAK012, LAK042 and LAK044, to be confirmed by reconnaissance). Resample if pH declines by 0.30 pH units or more relative to 2012 pH. Of the other five lakes, one is an alpine lake inaccessible to fish (LAK047), and the other four lakes have no safe means of access for fish sampling (LAK022, LAK028, LAK054 and LAK056).
W4. If some of the potentially vulnerable lakes that can be safely accessed for fish sampling show an acidifying trend, then do these lakes also show changes in their fish communities?	**H1.** No effects. **H2.** Some loss of diversity but community is still functional. **H3.** Major loss of diversity and function.	Repeat monitoring of fish contingent upon detecting chemical change >0.30 pH units relative to 2012 sample[37]. If pH change is <0.30 pH units, then there would be no resampling of lake fish communities.

[37] Gill netting was used to define the baseline. However, additional gill netting could itself lead to depletion of small fish populations in fish lakes, therefore it will be important to apply discretion and/or alternative monitoring methods if individual lakes require resampling.

7.1.1 EEM Key Performance Indicators

For each receptor, the EEM Plan identifies KPIs that comprise an important metric of potential change, quantitative thresholds associated with that metric, and decision rules that trigger increased monitoring and/or mitigation actions. The 2014 SO_2 EEM Plan (ESSA et al. 2014a) includes two types of KPIs: prediction- and observation-based indicators. The aquatic ecosystems receptor has one observation-based KPI that tracks water chemistry data to determine the pH changes in sensitive lakes (as defined in Table 7-3). The results were designed to reveal the magnitude of impact (i.e., how large the pH change is in lakes expected to be affected). The three critical indicators monitored in the program are SO_4^{2-}, pH and Gran ANC (the capacity of a solution to neutralize strong acids, determined by titration to the inflection point of the pH-alkalinity titration curve). Increases in SO_4^{2-} due to smelter emissions were predicted in the STAR and are not a problem for lake biota provided that pH and Gran ANC do not decrease below threshold levels (e.g., pH 6.0) and by amounts (e.g., decrease ≥ 0.30 pH units) which would be expected to cause biological effects.

The EEM Plan establishes receptor- and facility-based mitigation actions when certain thresholds in the KPIs are reached. For aquatic receptors, the threshold for increased monitoring was defined as an observed pH decrease ≥ 0.30 pH units below the pre-KMP baseline pH level that is causally linked to KMP. If further water chemistry evidence confirms a pH decrease greater than 0.3 pH units linked to KMP, the identified receptor-based mitigation measure involves liming the lake (subject to feasibility and necessary approvals). Studies of acidification impacts on biota in Sweden (Fölster et al. 2007) provided an operational rule for the protection of surface waters, namely that lakes should be maintained within 0.4 pH units of their original, pre-industrial pH. For the Kitimat Airshed Emissions Effects Assessment (ESSA et al. 2014b; page 152), ENV used two criteria for the protection of aquatic ecosystems: 1) avoiding exceedance of critical loads; and 2) if critical loads are exceeded, limiting pH declines to less than 0.30 pH units, adapted from the work of Fölster et al. 2007. As the Kitimat Airshed Assessment was underway at the same time as finalization of the EEM Plan, ENV adopted similar criteria (KPIs) for the EEM Plan.

If the KPI threshold for receptor-based mitigation is reached and receptor-based mitigation is applied but proves ineffective or unfeasible, then facility-based mitigation would be implemented to reduce SO_2 emissions.

Table 7-3. KPI and thresholds for the aquatic receptor (ESSA et al. 2014a).

Key performance indicator	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Water chemistry – acidification	Observed pH decrease ≥ 0.30 pH units below mean baseline pH level measured pre-KMP and is causally related to KMP. Action: additional monitoring to determine seasonal variation in pH and SO_4^{2-}	Lake is rated Medium or High (based on relative lake rating) and shows a decrease causally related to KMP of > 0.30 pH units below measured baseline pre-KMP and liming is feasible given access. Action: liming to bring the lake back up to pre-KMP pH, subject to approval by B.C. ENV/DFO prior to implementation.	More than 2 lakes rated Medium or High (based on relative lake rating) with decrease causally related to KMP of > 0.30 pH units below measured baseline pre-KMP (prior to liming). Action: reduction in SO_2 emissions	Aquatic biota: fish presence / absence per species on sensitive lakes ratings Evidence that pH decrease is causally related to KMP SO_2 emissions.

7.1.2 EEM informative indicators

The EEM Plan also identified "informative indicators", which may have decision rules for increased monitoring or modelling, but they do not have decision mitigation actions on their own. The purpose of the informative indicators is to provide additional evidence in support of the KPIs.

The SO_2 EEM Plan (ESSA et al. 2014a) identified seven informative indicators (Table 7-4) that provide evidence in support of the lake acidification KPI. The first informative indicator for this receptor is prediction-based: measured water chemistry data and measured S deposition data are used as inputs for updated modelling of critical loads and expected exceedance of those critical loads. Results will reveal the extent of expected impact (i.e. how many lakes might be affected) and will guide where sampling should occur. The informative indicator "*evidence that pH is causally related to KMP SO_2 emissions*" involves the analysis of changes in Gran ANC, SO_4^{2-}, dissolved organic carbon (DOC), base cations, Cl, in combination with the application of the evidentiary framework. These topics are covered in greater detail in later sections. The methods used for collecting data pertaining to these indicators are briefly described in Table 7-4 and discussed in more detail in Section 7.2.1.

Table 7-4. Informative indicators and thresholds for the aquatic receptor (ESSA et al. 2014a).

Informative indicators	Threshold for increased monitoring	Indicators to be jointly considered
Atmospheric S deposition and CL exceedance risk	CL exceeded in more than the 10 acid-sensitive lakes identified in the STAR as having either CL exceedance or predicted to acidify by more than 0.1 pH units. Action: expand the monitoring to include newly identified lakes with predicted exceedance.	• Predicted steady state pH versus current pH (if predicted change > 0.1 pH units then level of concern is higher than if predicted change < 0.1 pH units) • Water chemistry – acidification
Predicted steady state pH versus current pH	Seven lakes with predicted pH change >-0.10 units are included in the set of lakes that are monitored annually each October.	• Surface water model inputs, as described in Section 8.6.3.4 of ESSA et al. (2013)
Estimates of natural variability in pH and other indicators	If the fall index sample is below the pH threshold for any lake, the EEM Program will then obtain four chemistry samples during the fall index period of the following year to better estimate the mean index value and natural variability of pH and other parameters.	• Baseline estimates of natural variability in pH and other indicators from End Lake (LAK006), Little End Lake (LAK012) and West Lake (LAK023) • These estimates will be used to assess whether observed pH values (and other indicators) are within or outside the range of natural variability
Evidence that pH decrease is causally related to KMP SO_2 emissions	Used in application of all three KPI thresholds	• Trends and levels of SO_2 emissions, SO_4^{2-} deposition, N deposition • Trends and levels of lake ANC, SO_4, • NO_3^-, Cl^- and DOC in both individual lakes and across all seven acid-sensitive lakes
Aquatic biota: fish presence / absence per species on sensitive lakes	Decrease in pH ≥0.30 units confirmed by more intensive sampling in the fall index period. Action: resample the fish community in lakes that can be safely accessed for fish sampling	• None
Episodic pH change	NA	• None
Amphibians	NA	• Atmospheric S deposition

7.1.3 Other questions that have emerged

Other questions that arose during the STAR and/or the development of the EEM Program

- **How do the observed changes in SO_4, Gran ANC and pH compare to the steady-state predictions from the STAR?**
  The STAR included predictions of future lake chemistry properties based on the current lake chemistry and maximum increases in deposition that could occur under the prospective permit. One of the most basic questions to address with the water chemistry data collected after the smelter increased emissions is how the observed changes compare to the initial predictions (after accounting for the fact that post-KMP emissions have been significantly below the permit levels assessed in the STAR – i.e., approximately 30 vs 42 tpd SO_2).

- **Can we estimate F-factors[38] from the empirical sampling results?**
  As more years of data are collected on the water chemistry of each of the lakes, and if there is sufficient change within the data, it may be possible estimate the F-factor for individual lakes based on the actual observed changes in total base cations and SO_4^{2-}.

- **Do we see any evidence of regional acidification if we analyze the lakes as a group rather than individuals?**
  In contrast to many or most freshwater acidification monitoring and assessment programs, the EEM Program is explicitly designed to assess the potential impacts on individual lakes. Usually regional acidification monitoring programs focus on regional trends and patterns. This gives the program greater power to detect regional patterns in water chemistry. However, in the development of the EEM Program, concerns were raised that a regional assessment could mask changes of concern at individual lakes of interest, which is why the program is focused on patterns of change for individual lakes.

Other questions that have emerged since the development of the EEM Program

During the implementation of the EEM Program (2013-2018), new questions that were not originally identified in the EEM Program emerged as data were collected and analyzed.

- **Is there a benefit to adding appropriate control lakes to the EEM?**
  The EEM Program did not originally include control lakes. Four less sensitive lakes in the Kitimat Valley were included in the EEM Program, to provide contrasts in responsiveness to acidic deposition (i.e., these lakes would be expected to show changes in lake [SO_4] if exposed to increased S deposition, but would not show biologically significant changes in pH or Gran ANC). However, early monitoring results suggested that the variability in the lake chemistry was greater than anticipated, which raised the question of whether appropriate control lakes

[38] The F-factor is equal to the ratio of the change in base cations to the change in sulphate in a lake (i.e., F-factor = $\Delta BC / \Delta SO_4^{2-}$). It is a simple way to represent cation exchange processes, specifically the proportion of incoming acidity accompanying sulphate that is exchanged in the soil for base cations. The F-factor is an important parameter for both the Steady-state Water Chemistry model (critical loads and exceedances) and the ESSA-DFO model (future steady-state pH).

could be identified in areas of very low S deposition, and whether adding them to the EEM could improve the program's ability to detect and interpret changes in the EEM lakes.

- **Is there a benefit to more intensive water sampling?**
  The sampling frequency was increased for multiple EEM lakes in response to initial indications that the variability in the lake chemistry properties might be much greater than anticipated during the STAR and the design of the EEM Plan. It is important to understand the benefit of more frequent sampling in order to determine the value of continuing such monitoring.

- **Is there a benefit to collecting other data on the EEM lakes?**
  Bathymetric data would allow a more accurate estimation of lake volume, and thus water residence time. Water residence time is a factor that influences water chemistry variability in lakes. Lake level information could provide information on changes in inflows prior to sampling events. Increased runoff can influence the concentration of different ions in the lake and lead to short-term decreases in pH.

- **Will increased emissions result in immediate (i.e., same year) changes to lake chemistry or will there be a lag?**
  Much of the modelling done in the STAR was based on analyses of future, steady-state conditions. However, it was not known whether the changes predicted under steady-state conditions would occur quickly or slowly after emissions increased.

- **How important will it be to consider multiple metrics in our evaluations of the data?**
  From the beginning of the EEM Program, we have been considering multiple metrics in our quality assurance, modelling, and statistical analyses of water chemistry data. The EEM Plan included a multi-metric evidentiary framework for determining if changes in lake chemistry were caused by the smelter, considering the various processes that can affect lake chemistry; we apply that framework in this report in Table 7-12. In completing this report, we have simplified the EEM evidentiary framework, presented as a decision flowchart with three key questions, focused on SO_4^{2-}, pH and Gran ANC (see Section 7.2.4). This decision flowchart examines the evidence for chemical change in each lake, beginning with changes in SO_4^{2-} (the link to the smelter), and then assessing the evidence for changes to pH and Gran ANC (indicators of acidification). Other ions are used to help explain observed patterns of change in lake chemistry.

7.1.4 Complexity and causality of changes in lake chemistry

7.1.4.1 *Complexity of lake chemistry; separating anthropogenic and natural changes*

The complexity of watershed-lake ecosystems makes it difficult to clearly identify what caused all observed changes in lake chemistry. Fortunately, that isn't required. The EEM Program is not intended to be a comprehensive research program to evaluate the causes and effect of all observed changes in lake chemistry. However, it is important to be able to confidently separate natural and anthropogenic changes. The focus of the aquatic component of the EEM Program is to identify and understand whether increases in emissions from the smelter are contributing to acidification of any lakes through increased SO_4^{2-} deposition. However, even in the absence of the smelter emissions (either at stable or increased levels), lake chemistry properties are not static. Changes in ANC, pH, organic acids, Cl, SO_4, base cations, and other ions are subject to a suite of

natural drivers that lead to daily, monthly, seasonal, and annual variability in lake chemistry. For example, concentrations of ions tend to decrease during wet periods due to dilution effects, and increase during droughts due to concentration effects. While these factors make it more difficult to understand trends in lake chemistry, the focus of the analysis is on a simpler question – have smelter emissions and associated S deposition caused acidification of the sensitive lakes?

7.1.4.2 *Evidentiary Framework*

The EEM Evidentiary Framework was developed to provide a structured approach for evaluating the causes of any acidification observed in the lakes. The EEM Plan provided the following description of the context and purpose of the Evidentiary Framework (EEM Plan, p. 42-44):

> Proving causality (i.e., acidification of lakes related to KMP) requires following the cause-effect chain in the source-pathway-receptor diagram (Figure 7), and evaluating multiple lines of evidence for alternative causal pathways. Weight of evidence analyses (Burkhardt-Holm and Scheurer 2007, Marmorek et al. 2011) rely on four types of evidence: 1) a plausible mechanism; 2) exposure to the pollutant; 3) correlation of pollutant exposure and chemical / biological response in space and time; and 4) experimental evidence from the region or other published studies. The pathways and plausible mechanisms of acidification of surface waters are well understood (Marmorek et al. 1989; Baker et al. 1991), so the focus of the proposed weight of evidence analysis is on exposure, correlation and experimental evidence.
>
> The evidentiary framework (Table 17) provides a series of questions and tests for various different lines of evidence that then need to be jointly evaluated to draw a conclusion regarding the likelihood that KMP has caused acidification.

The Evidentiary Framework is further discussed in Section 7.2.4 and applied in Section 7.3.4.5. We developed a simpler Evidentiary Framework for this report, and have applied both the simpler and more complex frameworks in Section 7.3.4.5.

7.1.4.3 *Multiple metrics, types of lakes and lines of evidence*

Separating smelter effects from natural changes requires multiple metrics (deposition, full lake chemistry, precipitation), control lakes that are outside of the plume (and therefore reflect only natural changes), and multiple lines of evidence (presented in this report and its appendices). In addition to the Evidentiary Framework, Appendix H of the EEM Plan provides further guidance on interpreting patterns of change across multiple lake chemistry metrics.

7.1.4.4 *Limitations of pH as a KPI*

Although pH is the primary metric upon which the aquatic KPI is based, it would not be appropriate to rely solely upon observed changes in pH. First, there are many natural processes which can change pH, such as increases in precipitation (decreases pH) and increases in primary production (increases pH). The EEM Plan recognized this explicitly by defining the KPI based on changes in pH that are *causally related* to the increased smelter emissions. Assessing that causal linkage implicitly requires evaluation of other changes in lake chemistry, especially ANC and SO_4, as outlined in the Evidentiary Framework and Appendix H of the EEM Plan. However, there are

still some additional limitations and concerns with the pH-based KPI that were not well understood at the time the EEM Plan was developed. First, the natural variability in the pH of the EEM lakes is much greater on average than for other North American lakes for which lake chemistry data sets were available in the literature. Even within the EEM lakes, the variability in pH is much greater than the variability in ANC, which will be an important consideration if new KPIs are developed for the next phase of the EEM. Second, over the course of the EEM sampling program, we have learned that measuring pH in lakes with low ionic strength is difficult and not all laboratories and instruments can achieve consistent, stable measurements. Third, even for instruments and laboratory processes able to achieve stable measurements of pH, the measurement uncertainty is still relatively large compared to the effect size of interest.

7.2 What Methods Did We Use?

This section provides a high-level summary of the major methods applied for the collection, processing, and analysis of data for implantation of the aquatic ecosystems component of the EEM Program. The methods applied are briefly introduced in terms of identifying the method (or suite of methods) and the purpose. The detailed specifications of how each method was implemented are reported in the appendices (e.g., primarily Aquatic Appendices A, F, and G).

7.2.1 Data we collected

7.2.1.1 *Water chemistry data*

We focused on biologically-relevant water chemistry as the primary indicator (i.e., pH, ANC, SO_4, DOC, and other major ions), because it provides the earliest possible indication of potential impacts to aquatic biota. Water chemistry data are needed to assess the form, rate and magnitude of changes that may be occurring in lake chemistry. Water chemistry data also provide the inputs necessary for predictive modelling of changes that may occur in the future under different emissions scenarios. Limnotek implemented the water sampling program, including collecting samples, conducting some field measurements, sending samples for laboratory analyses and performing Quality Assurance/Quality Control (QA/QC) analyses on the results (see Limnotek's annual technical reports). We performed additional QA/QC checks on the data and then converted the data into equivalent concentration values. As described in the STAR, we applied an adjustment factor to the measured concentration of SO_4^{2-} and base cations to correct for the influence of marine sea salts (i.e., marine-adjusted concentration), as is conventional practice in acidification analyses. Throughout the comprehensive review we always use and/or present the marine-adjusted values unless explicitly noted.

7.2.1.2 *Sampling locations*

The EEM Program includes sampling of the following sets of lakes:

- **EEM Sensitive Lakes[39]:** Seven lakes that were predicted in the STAR to decrease in pH >0.1 units under maximum future emissions levels.
- **EEM Less Sensitive Lakes[40]**: Two moderately sensitive lakes, one highly insensitive lake, and one lake of high public value (also highly insensitive). These lakes were expected to show changes in lake SO_4^{2-} if exposed to increased deposition of S, but no biologically significant changes in pH or Gran ANC due to their greater ability to neutralize acidic deposition.
- **EEM Control Lakes:** Three control lakes, which are sensitive lakes located well outside of the deposition plume. These were added to the program in 2015 but already had sampling data from 2013 from the KAEEA program

The STAR sampled 41 lakes (all lakes greater than 1 ha in the study area which fulfilled the selection criteria), and 20 stream sites. The selection of the seven sensitive and four less sensitive lakes was based on the analyses of the full set of lakes and streams in the STAR. As part of the updated analyses of critical loads and exceedances in the comprehensive review, we also included any lakes from the KAEEA program that are located within the CALPUFF modelling domain. Figure 7-1 shows the location of all the lake and stream sites within the study area, as sampled during the STAR, KAEEA and/or EEM programs. Figure 7-2 focuses on the locations, frequency and types of sampling implemented as part of the EEM Program specifically.

An incidental outcome of having selected the lakes based on chemical criteria (i.e., acid sensitivity properties) rather than geographic criteria is that the lakes are unevenly distributed across the study area. As shown in Figure 7-2, the EEM lakes are located in three distinct groupings. Three of the EEM lakes (two sensitive lakes and one less sensitive lake) are located in a cluster in the northernmost part of the study area. Six of the EEM lakes (four sensitive lakes and two less sensitive lakes) are located in a cluster to the south and southwest of Lakelse Lake (itself a less sensitive lake), which is roughly halfway between the smelter and the northern boundary of the study area. Only one EEM lake (LAK028, a sensitive lake) is located fairly close to the smelter and is in fact the only lake in the southern half of the study area. From the perspective of minimizing potential environmental effects, it is fortuitous that there is only one sensitive lake relatively close to the smelter.

This uneven distribution of lakes evokes a couple of obvious questions: 1) are there any other lakes close to the smelter that should have been included in the EEM?, and 2) why does the EEM

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[39] The methodology and criteria by which the sensitive lakes were selected is explained in detail in the STAR (refer to Sections 9.4.1.4, 9.4.2.5) and the EEM Plan (refer to Section 6.2.1, Appendix D, and Appendix H).

[40] The rationale for the inclusion of less sensitive lakes and the methodology and criteria by which they were selected is explained in detail in Appendix H of the EEM Plan. Note that these lakes were initially included in the design as "control lakes" that were located within the deposition plume but not predicted to exhibit any changes in chemistry associated with increased deposition. However, this characterization was revised early in the EEM Program. Further consideration concluded that equally sensitive lakes located well outside the plume would provide better controls. Such control lakes were added to the EEM Program in 2015 but the initial control lakes were retained as "less sensitive" lakes for potential comparisons to the sensitive lakes.

not include any lakes south of the smelter? The answer to both of these questions is that, as described above, the STAR assessed the acid sensitivity of all of the candidate lakes within the study area and did not find any other lakes that should be included in the EEM program. The details of these conclusions are expanded upon below.

Other STAR lakes close to the smelter
In the STAR, there were only two other lakes south of the Little Wedeene River and in relative proximity to the smelter, which were LAK027 and LAK030. LAK027 (Bowbyes Lake) had a pH of 6.6, Gran ANC of 70 µeq/L, an estimated critical load of 248 meq/m^2/yr, and a predicted future pH change of 0.0 pH units. LAK030 was even more insensitive, with a pH of 7.4, Gran ANC of 390 µeq/L, an estimated critical load of 802 meq/m^2/yr, and a predicted future pH change of 0.0 pH units. These two lakes are not acid sensitive and did not need to be included in the EEM Program.

Other STAR lakes south of the smelter
There were five STAR lakes to the southwest of the smelter in the 2019 modelled deposition area (LAK053, LAK054, LAK055, LAK056, and LAK057) and 9 KAEEA lakes (see Aquatic Appendix G, Table 2-2). The STAR and KAEEA concluded that these lakes were all at a low risk of acidification (i.e., predicted pH decreases of less than 0.1 pH units in the STAR and 0.3 pH units in the KAEEA). Three of the five STAR lakes (LAK053, LAK055, LAK057) show no critical load exceedances and a predicted pH change of 0.0 (Aquatic Appendix G, Tables 2-2 and 3-2). Two of the five STAR lakes (LAK054 and LAK056) are naturally acidified with high DOC and very low critical loads (0 and 1.2 meq/m^2/yr respectively), therefore showing exceedances under all deposition scenarios (Aquatic Appendix G, Table 2-2), but with predicted pH decreases of less than 0.1 pH units under the STAR's 42 tpd scenario (Aquatic Appendix G, Table 3-2).

Seven of the nine KAEEA lakes to the southwest of the smelter showed no critical load exceedances under any of the new deposition estimates (Aquatic Appendix G, Table 2-2). Two of the KAEEA lakes (DCAS07A and DCAS07B) have a CL of 0.0 so they show CL exceedance under all emissions scenarios, but the predicted change in pH under the highest KAEEA emissions (Scenario H_82.6, with 55.8 tpd of SO_2; 26.8 tpd of NO_x) was only -0.03 pH units for both lakes (KAEEA unpublished analyses).

7.2.1.3 *Aquatic biota*

In the discussions leading up to the development of the EEM Plan, we discussed the pros and cons of monitoring aquatic biota directly (e.g., zooplankton, benthic organisms, fish). While biotic indicators do provide direct evidence of aquatic impacts, changes in such indicators (e.g., community structure or species diversity) lag behind changes in aquatic chemistry. Due to their public importance, we did take baseline estimates of fish density in 5 sensitive lakes (those that were safely accessible – End Lake (LAK006), Little End Lake (LAK012), West Lake (LAK023), Finlay Lake (LAK042) and LAK028, and three of the less-sensitive lakes – Clearwater Lake (LAK007), LAK016, and LAK034.

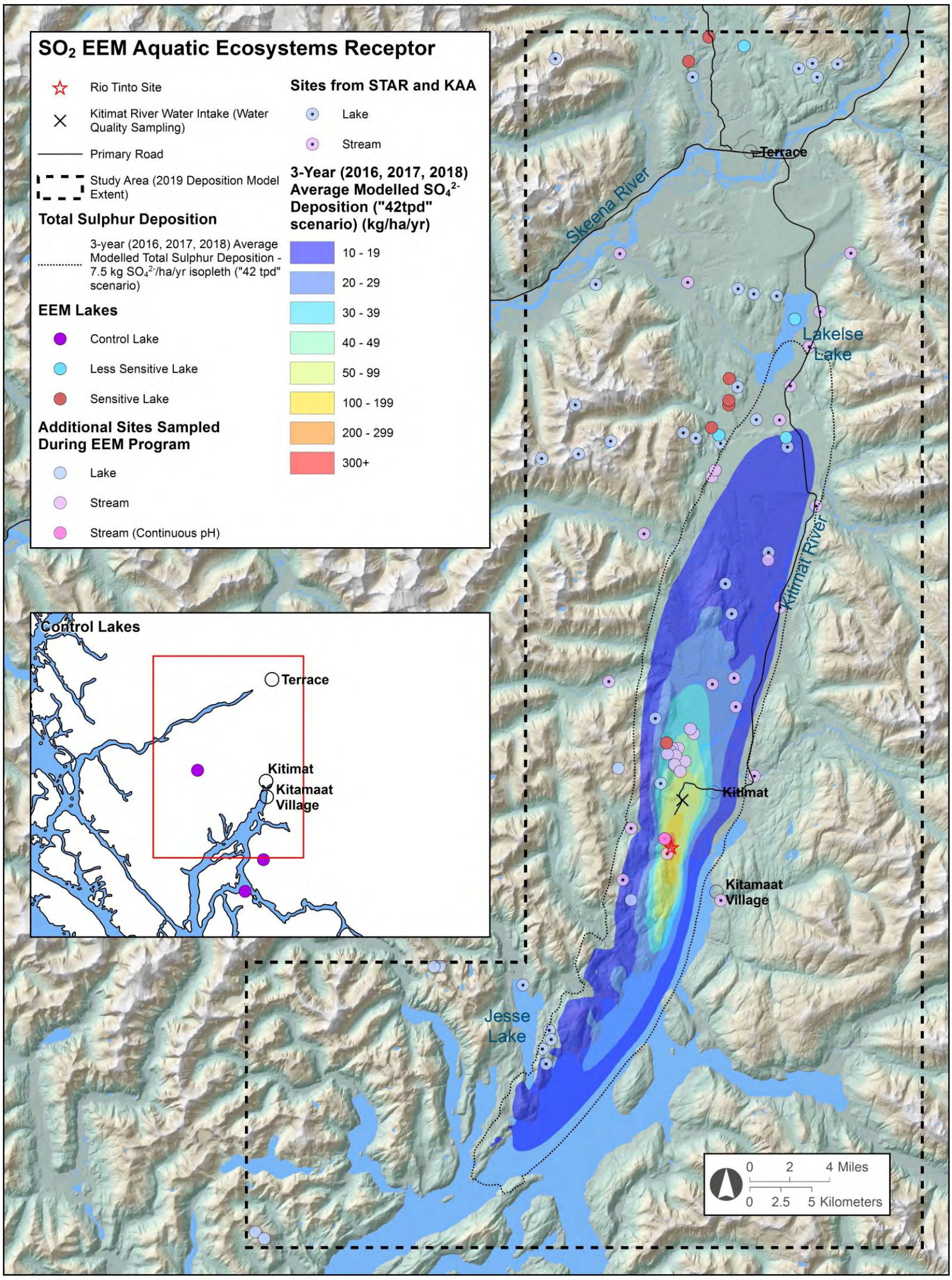


Figure 7-1. Locations of ongoing and existing monitoring and sampling for the aquatic receptor of the EEM Program. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleths.

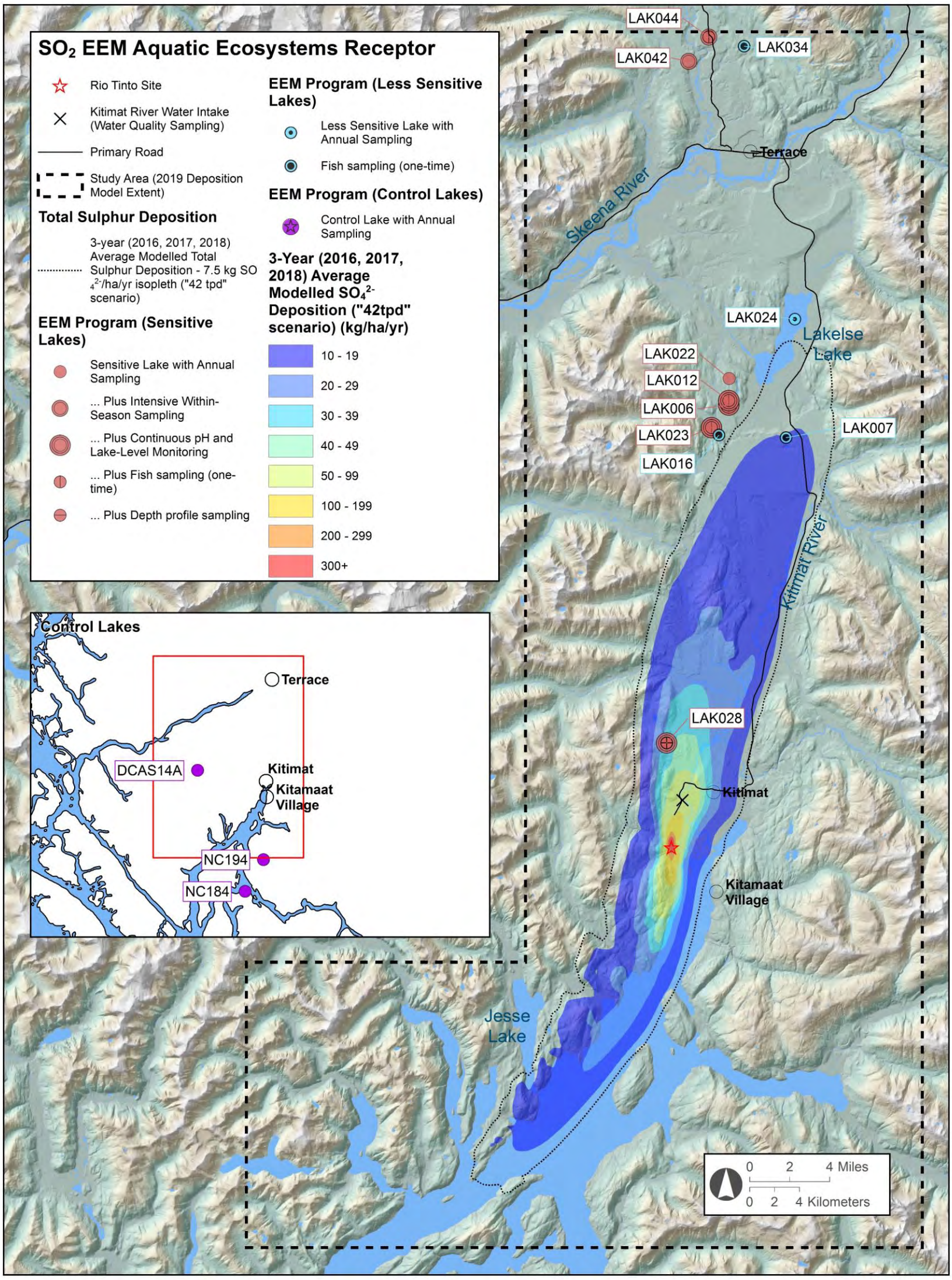


Figure 7-2. Locations of the study lakes of the EEM Program. Lakes are grouped by their classification as sensitive lakes, less sensitive lakes and control lakes. The map also shows the frequency and type of monitoring conducted at each of the lakes. The plume shows the estimated deposition under the maximum emissions rate. The estimated deposition values for each watershed under current emissions are documented in Table 2-2 of Aquatic Appendix G. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleths.

7.2.2 Quality of water chemistry data

The methods utilized in the collection of water samples, field measurements, storage and transport of samples, and laboratory analyses of water chemistry properties are subject to rigorous quality control and quality assurance procedures, as described in the annual technical reports prepared by Limnotek, who are responsible for the implementation of the EEM aquatic ecosystems monitoring program.

Once the water chemistry data are received, we conduct additional checks to ensure the data do not appear to have any data quality deficiencies that would raise any concerns regarding their use in our analyses. A reasonable balance between cations and anions and relatively small differences between the measured and estimated conductivity provides assurance that there are no concerns with the laboratory analyses (or data management procedures) and that all of the major constituents of the water chemistry are accurately represented within reasonable bounds of uncertainty expected in these types of data. Aquatic Appendix A provides addition information.

7.2.3 Analyses we conducted with these data

This section provides a high-level summary of the major types of analyses we conducted. Specific details of the implementation of these analyses are described in Aquatic Appendices A and F.

7.2.3.1 *Variable organic charge density*

The contribution of organic anions to the charge balance is estimated as a function of the measured DOC and an assumed charge density. In the STAR and EEM, we have applied the Oliver et al. (1983) function. In the STAR we used a uniform organic charge density with an assumed value based on the literature. In the comprehensive review we explored whether using alternative values for the organic charge density would improve the charge balance – i.e., thus indicating a more accurate characterization of the contribution of organic anions. We used two different approaches. First, we continued to use a uniform value across all sites and found the organic charge density value that resulted in the best charge balance across the entire data set. Second, we allowed organic charge density to vary by site (but with a single value for each lake across years) and found the value that resulted in the best charge balance for each individual lake.

7.2.3.2 *Exploration of ANC values and metrics*

There are multiple ways of measuring and/or estimating the ANC of a particular water sample. In the STAR and EEM we have primarily used Gran ANC in our analyses of both the observed and predicted changes in lake chemistry. Gran ANC is the capacity of a solution to neutralize strong acids, including the buffering effect of organic anions. However, measuring Gran ANC requires specialized laboratory equipment that is not widely accessible.

Charge balance ANC (CBANC) is an alternative estimation of the capacity of a solution to neutralize acidity. It is generally calculated as the equivalent difference between the total base cations and strong acid anions. CBANC is widely used in acidification studies because it is estimated from easily measured ions, but it does not account for the buffering effect of organic anions. Additional alternatives are based on modifying the estimate CBANC to explicitly account for the effect of organic anions. The two we compared are the Lydersen et al. (2004) method for

estimating an organic anion adjusted ANC (ANC_{oaa}) and the Lawrence et al. (2007, 2013) method for making a conceptually similar adjustment to ANC, but termed Base Cation Surplus (BCS).

7.2.3.3 *Temporal patterns in water chemistry*

Table 7-5 outlines the key questions of interest, the rationale for these questions, and the methods used to address these questions. These analyses are presented in detail in the Aquatic Appendix F and summarized below in Section 7.3.2.3.

Table 7-5 Analyses of temporal patterns in water chemistry: questions, rationale and methods.

Questions of Interest / Rationale	Methods Used
How long does it take to reliably assess whether or not key water chemistry parameters (SO_4, pH, ANC) have changed relative to pre-KMP conditions, and (for pH and ANC) whether those changes exceed the 0.3 unit threshold established in the EEM Plan for pH, and the lake-specific thresholds established subsequently for Gran ANC? Water chemistry varies naturally, both within and between years, due to changes in weather and lake productivity. We are interested in detecting the signal of long-term chemical change against the noise created by natural variability. We would like to avoid two types of errors: false positives (concluding that changes in lake chemistry exceed a threshold, when in fact they don't) and false negatives (not detecting a true exceedance of a threshold). Appendix H of the EEM Plan describes the general types of responses that could be observed in different lakes, depending on the degree of sensitivity and level of exposure. Aquatic Appendix C of the report shows the time series of empirical observations, which show that the changes have generally been gradual.	• In 2015 we conducted a power analysis of the data collected to date (i.e., 2012-2014), to assess our ability to detect changes in water chemistry for SO_4, pH and ANC. Having now collected data for seven years (2012-2018) we have better estimates of year-to-year and within-year variability.
What are the general patterns of variability and change over time in key water chemistry parameters? These graphs are meant to simply examine general patterns, independent of any assignment of causality, quantitative statistical analysis or application of the evidentiary framework. The patterns of interest include variability across and within years within each lake, differences in the magnitude of variability across different lakes, and differences in water chemistry between different groups of lakes (e.g., sensitive, less sensitive, control).	• Simple graphs of changes over time of each variable of interest for each lake (as included in previous EEM reports).
Do the values of key water chemistry parameters vary with the magnitude of recent precipitation? The EEM is designed to detect long term trends, not episodic changes in water chemistry. Eight lakes are sampled annually during the fall index period, while six lakes are sampled four times during this period. We are, however, interested in understanding the extent to which late summer and fall storms may affect lake chemistry, and the apparent trends over multiple	• Scatter plots to look at relationships among water chemistry variables of interest (i.e., SO_4, ANC, pH, DOC, BC, Cl, Al) and recent precipitation (during the last 3 days, and last 14 days) at the Haul Rd monitoring site. • Inclusion of precipitation covariates in statistical analyses (Sections 7.6.4.2.6,

Questions of Interest / Rationale	Methods Used
years. Snowmelt and rainstorms may affect water chemistry through a number of natural and anthropogenic mechanisms, including dilution, nitrification, organic acid production and the sea salt effect (Wigington et al. 1996). Snowmelt and rainstorms could create a spurious long-term trend. For example, if big storms occurred prior to the annual sampling later in the 7-year time series (i.e., 2017 or 2018), and increased SO_4, due to washout of atmospheric or watershed SO_4, this might generate a false long-term pattern of increasing SO_4^{2-} over multiple years. Conversely, if major storms occurred prior to annual sampling early in the time series (i.e., 2012 or 2013), and increased SO_4, this might generate a false long-term pattern of decreasing SO_4^{2-} over multiple years.	7.6.4.3.6 and 7.6.4.4.6 of Aquatic Appendix F).
Do the values of key water chemistry parameters vary with emissions? The absence of any positive correlation between lake SO_4^{2-} concentrations and recent increases in SO_2 emissions (or the lack of any trend of increasing SO_4^{2-}) is evidence against the new smelter being a cause of changes in a lake's $[SO_4^{2-}]$. However, the lack of a correlation could also reflect the fact that emissions are only a proxy indicator of the actual deposition at each lake. Estimates of lake-specific deposition are only available with the revised CALPUFF model for the period from 2016 to 2018, and therefore cannot provide contrast between the pre-KMP and post-KMP period. While the presence of a positive correlation between lake $[SO_4^{2-}]$ and SO_2 emissions is consistent with the hypothesis of the new smelter causing changes in lake SO_4, such a correlation is not by itself incontrovertible evidence that smelter emissions caused the increase in lake SO_4. For example, drought conditions can cause SO_4^{2-} that was historically stored in a reduced form in wetlands to be re-oxidized and then (once the drought is over) washed into the lake, causing an increase in SO_4^{2-} and decreased pH (Yan et al. 1996).	• Scatter plots to look at relationships among water chemistry variables of interest (i.e., SO_4^{2-}, ANC, pH, DOC, BC, Cl, Al) and average emissions of SO_2 from the smelter (in tpd). • Inclusion of smelter emissions as a covariate in statistical analyses (Sections 7.6.4.2.6, 7.6.4.3.6 and 7.6.4.4.6 of Aquatic Appendix F).
How much change has occurred in key water chemistry parameters (SO_4, pH, ANC) between the pre-KMP period (2012) and the post-KMP period (2016-2018)[41], within each lake? For pH and ANC, how likely is it that the changes exceed the EEM thresholds? Figures 11 and 12 in Volume 1 of the STAR demonstrate the expectation in 2012 that the new smelter would result in both a higher level of sulphur deposition, and a different spatial pattern of deposition. We are therefore interested to learn which lakes experienced an increase in SO_4^{2-} concentrations, and which lakes experienced a decrease. Critical to the EEM Plan is the evaluation	We applied seven frequentist methods: 1. Two-sample Before-After t-test using mean values for 2012 and 2016-2018 (all lakes) 2. Two-sample Before-After t-test using individual samples (for the six sensitive lakes with four fall samples during each year) 3. Before-After Control-Impact (BACI), using mean values (all lakes)

[41] Data from 2013 to 2015 is not included in these temporal analyses because it represents a period in which emissions were decreasing as production was ramped down prior to the transition to the new smelter. The pre-KMP baseline year for the aquatic analyses is 2012. The new smelter was ramped up in late 2015, therefore 2016 onwards represents "post-KMP".

Questions of Interest / Rationale	Methods Used
of whether lake pH changed by more than 0.3 pH units, and whether ANC decreased by more than the lake-specific thresholds for ΔANC.	4. BACI, using individual samples (six sensitive lakes) 5. BACI, assuming no change in mean of the control lakes between the before and after period. 6. BACI, using covariates for emissions and precipitation to explain inter-annual variation 7. Temporal Trend Analyses – Mann-Kendall non-parametric test for monotonic trend detection. We also applied two Bayesian approaches: 1. Bayesian Estimation Supersedes the T-Test (BEST; using a range of informative priors) 2. Bayesian analysis with uninformative priors The Bayesian approaches provide a "percent belief" in chemical changes of interest (e.g., SO_4^{2-} increases, Gran ANC or pH decreases beyond thresholds).
Based on the three intensively monitored lakes (End Lake, Little End Lake, West Lake), are there are seasonal and long-term trends in pH?	We applied a Seasonal Mann-Kendall test, using average values for each season per year to reduce auto-correlation. Spring = [April, May, June]; Summer = [July, Aug], Fall = [Sept, Oct., Nov]).

7.2.3.4 *Assessing observed changes in water chemistry relative to STAR predictions*

The STAR included predictive analyses of future changes in water chemistry under increased deposition at maximum emissions levels (i.e., the permitted level of 42 tpd SO_2). We compared the changes that have been observed thus far to those predicted changes, after accounting for the fact that average post-KMP emissions (i.e., 29.3 tpd SO_2) have been much lower than the maximum permitted level of 42 tpd. We therefore adjusted the STAR predictions based on current emissions to facilitate an equivalent comparison.

7.2.4 Weight-of-Evidence approach for assessing causality

Table 17 of the 2014 SO_2 EEM Plan (ESSA et al. 2014a) laid out nine questions which would jointly be helpful in determining if lakes were acidifying due to emissions from KMP, or whether other factors might be responsible for observed changes in lake chemistry. We called this table an "evidentiary framework", since it laid out multiple lines of evidence. In Section 7.3.4.2, we address these nine questions as written in the EEM Program Plan, and have also developed a simpler evidentiary framework (Figure 7-3), which provides a clearer categorization of lakes into different types. The primary advance in Figure 7-3 is that it first filters out types of lakes which are not a concern (i.e., lakes which have shown no change in $[SO_4^{2-}]$ or strong evidence of a

decrease in in [SO_4^{2-}]), which aligns with the focus of the EEM in determining whether or not the lakes have experienced any smelter-driven acidification. The next filter is for lakes which have shown an increase in [SO_4^{2-}] but no evidence for decreases in either pH or ANC. The focus then turns to lakes which are the greatest concern (i.e., lakes with an increase in [SO_4^{2-}] and some support for a decline in either ANC or pH), to determine if the magnitude of decline exceeds the defined thresholds. The simplified evidentiary framework assumes that any lake with strong support for a post-KMP increase in lake SO_4^{2-} reflects contributions of S to that lake from SO_2 emitted from the new smelter. This assumption reflects the fact that there are not any other major sources of regional S emissions which changed over the period of interest[42] and that the smelter emissions do not include enough N to have a meaningful impact on aquatic acidification. The KAEEA included N in its acidification analyses because it included other types of facilities with significantly different emissions profiles (e.g., higher N oxides from LNG facilities); however, the smelter emits only a small amount of N oxides (~1 tpd). This is corroborated by the fact that the observed changes in nitrate (NO_3^-) concentrations in the EEM lakes have been roughly an order of magnitude less than the observed changes in SO_4^{2-} concentrations (see Figures 7.23 and 7.24 in Aquatic Appendix A), Lakes could acidify naturally by increases in organic acids, but that would not be related to the smelter. That is, sulphur is the only potential driver of acidification that is causally associated with smelter activity and that is present in sufficient quantity to influence lake chemistry. Furthermore, the smelter is the only major source of sulphur emissions in the region. Therefore, the first question of the simplified evidentiary framework is an appropriate screen to eliminate lakes from further consideration if they do not have evidence of an increase in lake [SO_4]. Explaining changes in lake chemistry that are unrelated to the smelter is not within the scope of the EEM Program.

The simplified evidentiary framework also more easily incorporates the results of the statistical analyses and permits conclusions to be drawn with respect to which lakes are or are not of current concern. However, for sake of completeness and alignment with the original EEM Plan, we have still worked through the full nine questions of the detailed evidentiary framework (Section 7.3.4.2, Table 7-13).

[42] This assumption could cause an over-estimate of smelter impacts, as increases in lake sulphate could be due to climatic fluctuations that release S stored in wetlands (i.e., droughts followed by storms; see discussion in fourth row of Table 7-5). However, the most notable drought occurred in the summer of 2018, and there is not any evidence of a broad increase in sulphate concentrations in the samples taken in the fall of 2018, as shown in Section 7.6.2.1.1 of Aquatic Appendix G.

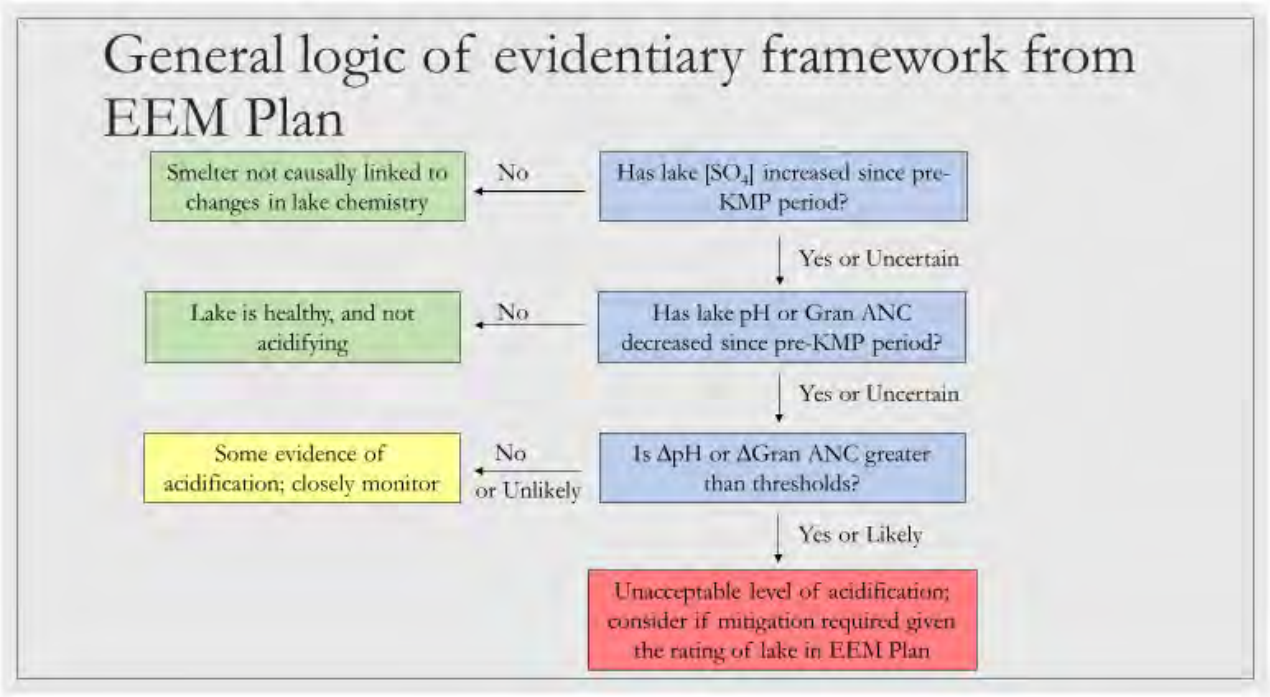


Figure 7-3. Simplified evidentiary framework, building on Table 17 in the EEM Plan. Note that within the Evidentiary Framework, "some evidence of acidification" (i.e., the yellow box) represents lakes that show some evidence of any level of acidifying change but have not exceeded their EEM thresholds, whereas "unacceptable level of acidification" (i.e., the red box) represents lakes that show strong evidence of having acidified beyond their EEM thresholds.

7.2.5 Episodic acidification studies

As discussed in EEM Annual Reports, the two sources of information intended to provide the inputs for exploring this topic were the continuous pH data from LAK006, LAK012 and LAK023 as well as the results of an independent, parallel research project being conducted by Dr. Paul Weidman to determine (among other research objectives) the extent of episodic acidification within the Kitimat watershed. However, as described more fully in Aquatic Appendix A, Limnotek (2019) concluded that due to concerns with the ability of the continuous pH monitors to accurately and consistently measure pH in lakes with low ionic strength, the data have not been of sufficient quality for conducting such studies. Although not ideal, the inability to use these data for their original purpose is not a significant detriment to the program because the pH and ANC thresholds for chronic chemistry were designed to be sufficiently conservative to protect aquatic biota. Additionally, the results of Dr. Weidman's work are not yet available for review. Therefore, we are unable to report on any studies of episodic acidification.

However, Aquatic Appendix F includes analyses of the temporal trends of the pH sampling associated with the bi-weekly field visits required to calibrate the continuous monitors over the years they were installed. Furthermore, new instruments better suited to measuring pH in waters of low ionic strength have been piloted in 2018.

7.2.6 Critical loads, exceedances and predicted changes in pH

We applied the same methodologies as used in the STAR for estimating critical loads and predicting exceedances of those critical loads and future steady-state pH under different deposition levels. Critical loads and exceedances were assessed using the Steady State Water Chemistry Model and future pH was assessed using the ESSA-DFO model. These methods are described in detail in the STAR and KAEEA. Details on the updated and/or revised data inputs available for the comprehensive review, the model scenarios and sensitivity analyses, and all the results from all the different model runs are documented in Aquatic Appendix G.

7.2.6.1 *Critical Loads and Exceedances*

We performed analyses of critical loads and exceedances at two different spatial-temporal scopes. Firstly, we conducted analyses on the entire set of all the lakes within the study area for which we have lake chemistry data – i.e., all of the STAR lakes, any KAEEA lakes within the study, plus additional non-EEM lakes sampled during the course of the EEM program. For this data set we used the original estimates of their critical loads, calculated the predicted exceedances under *current* deposition, and compared these results to the STAR. We also conducted some sensitivity analyses on the original estimates of critical loads with model inputs for which we now have additional or improved data *across all of the lakes*, as well as higher levels of deposition. Secondly, we conducted analyses on the EEM lakes, for which we have much more extensive data. For this data set we developed new estimates of their critical loads based on the best, most defensible data inputs currently available, calculated the predicted exceedances under *maximum future* deposition, and compare the results to the STAR. We also conducted extensive sensitivity analyses on the critical loads and exceedances for the EEM lakes across multiple data inputs, different emissions scenarios, and potential uncertainty in the CALPUFF model estimates of deposition.

7.2.6.2 *Future steady-state pH*

For the modelling of future steady-state pH and changes from 2012 levels, there is not an analogous analysis that can be applied across the first data set (all lakes) using the updated deposition estimates – the ESSA-DFO model requires before/after estimates of deposition levels and the updated modelling did not include a pre-KMP scenario within the same CALPUFF modelling framework (e.g., meteorological years and models used) as the actual emissions (29.3 tpd), 35 tpd and 42 tpd scenarios. However, there were a couple sensitivity analyses performed with the STAR modelling (which applies the pre-KMP and post-KMP modelled deposition estimates) on a couple of model inputs for which we now have additional or improved data *across all of the STAR lakes.* However, for the EEM lakes, we developed new predictions of their future steady-state pH based on the best, most defensible data inputs to characterize current, post-KMP (2016-2018) lake chemistry and the change in deposition from *current* (i.e., actual emissions scenario, based on 29.3 tpd) to *maximum future* (i.e., 42 tpd scenario). We then compared these results to the baseline pH values in 2012 and conducted a series of sensitivity analyses across multiple data inputs, different emissions scenarios, and potential uncertainty in the CALPUFF model estimates of deposition.

7.2.7 Kitimat River water quality

Rio Tinto voluntarily conducts water sampling at their intake on the Kitimat River. This voluntary sampling was initiated following a request from a concerned citizen over perceived impacts of the

smelter's SO_2 emissions on the District of Kitimat's potable water supply. As these water supplies have a high capacity to neutralize acidity (Gran ANC), have shown no changes over time, and remain well within all B.C. objectives for drinking water, Rio Tinto will discontinue sampling water quality in the Kitimat River at the end of 2019.

7.2.8 Other data and/or analyses previously reported

As reported through the Annual Reports, other monitoring activities and analyses outside the core water chemistry sampling program for EEM lakes have been conducted during the course of the EEM program in support of the aquatic ecosystems component. These activities have included fish sampling in EEM lakes, a literature review of the potential effects of acidification on amphibians, lake level monitoring, bathymetric analyses and estimation of water residence time for lakes, and sampling of non-EEM sites. These activities are summarized in Aquatic Appendix A and have been described in detail in previous Annual Reports, technical appendices, and/or technical memos.

7.2.9 Assessment of acceptable or unacceptable impacts to aquatic receptor

The assessment of the impacts to the aquatic receptor as "acceptable" or "unacceptable"[43] is directly linked to the KPI, as currently defined in the EEM Plan (ESSA 2014a). If the KPI threshold associated with facility-based mitigation in the EEM is exceeded, this is identified as an "unacceptable" impact for the aquatic receptor. Impacts to the aquatic receptor that do not exceed the KPI threshold associated with facility-mitigation in the EEM are identified as "acceptable".

7.3 What did we learn, and did we make any adjustments to the EEM Program?

7.3.1 Empirical data from lake chemistry monitoring program

It is worth emphasizing that the goal of the analyses of changes in lake chemistry is to determine whether the smelter has caused lake acidification, and if so, whether the magnitude of acidification exceeds thresholds for biological effects. While it may be of scientific interest to understand the causes of all chemical changes in each lake, that is beyond the scope of the EEM Program, the comprehensive review, and this analysis.

The measured changes in major water chemistry properties between the baseline period (2012) and the post-KMP period (average of 2016-2018) are summarized in Table 7-6 and Table 7-7. The three-year average is used because the mean of the post-KMP period is a better indication of longer-term changes than individual years that are subject to multiple sources of variability that do not reflect longer-term changes. Long term changes are the focus of the EEM. Increasing the statistical power to detect an effect requires multiple years of data whereas using post-KMP years individually reduces statistical power. Although the results presented in this section are simply comparisons of the empirical observations rather than statistical analyses (see Section 7.3.2.3 and Aquatic Appendix F), the principles of statistical power still apply. The empirical observations

[43] Section 4.2.6 of the P2-00001 permit, dated March 15, 2016, states "If any unacceptable impacts are determined through the use of the impact threshold criteria pertaining to emission reduction, then the maximum SO_2 daily discharge limit shall revert back to 27 Mg/d, unless the Director amends the discharge limit."

show that sulphate has increased in four of the seven sensitive EEM lakes and in two of the four less sensitive lakes, but none of these lakes show decreases in Gran ANC or pH. Detailed statistical analyses of the changes in water chemistry are in Aquatic Appendix F, and summarized below in Section 7.3.2.3. The only lake with a decrease in Gran ANC is LAK007, which is highly insensitive and has Gran ANC levels that are two orders of magnitude higher than the sensitive lakes (LAK007 also has shown a small decrease in SO_4^{2-} concentrations). The only lake with a decrease in pH is LAK034 but this change cannot be driven by sulphur emissions from the smelter because its sulphate concentration has decreased to essentially zero. These results are also mapped in Figure 7-4.

However, given the known variability in these data, measurement error, low power, and the limited number of years of post-KMP observations, any interpretation of these results must take into consideration the results of the rigorous statistical analyses of the data (see Section 7.2.3.3 for the statistical methods and Section 7.3.2.3 for a summary of results, with full details in Aquatic Appendix F). However, statistical power will increase with more years of observations (see Section 7.3.2.2).

Additional visualization of these results is included in Aquatic Appendix A. Time series of the inter-annual changes in these lake chemistry properties (and intra-annual variation for lakes with additional sampling during the fall index period) across the period of record from 2012 to 2018 are presented for all of the EEM lakes in Aquatic Appendix C. The underlying data (in microequivalents and raw, unconverted values) are reported in Aquatic Appendix D.

Table 7-6. Changes in pH, Gran ANC and SO_4^{2-} from baseline conditions (2012) to the post-KMP period (2016-2018). Green cells indicate increases and red cells indicate decreases. * = corrected for marine influence. Statistical analyses of changes in these parameters are in Aquatic Appendix F, and are summarized in Table 7-9.

	pH			Gran ANC (µeq/L)			SO_4^{2-*}(µeq/L)		
EEM sensitive lakes	2012	Post-KMP	ΔpH	2012	Post-KMP	ΔANC	2012	Post-KMP	ΔSO_4^{2-*}
LAK006	5.8	6.0	0.24	25.7	27.7	2.0	11.4	14.0	2.5
LAK012	5.6	6.2	0.52	57.0	58.3	1.3	6.1	12.9	6.8
LAK022	5.9	6.1	0.15	27.8	33.0	5.1	30.2	38.8	8.6
LAK023	5.7	5.9	0.22	19.8	26.4	6.7	19.0	12.3	-6.7
LAK028	5.0	5.0	0.02	-4.0	-3.5	0.5	56.9	128.4	71.5
LAK042	4.7	5.2	0.54	-20.4	5.6	26.1	6.2	5.4	-0.8
LAK044	5.4	5.6	0.15	1.3	5.0	3.7	6.2	4.4	-1.9
Total lakes with increase			**7**			**7**			**4**
Total lakes with decrease			**0**			**0**			**3**

EEM less sensitive lakes	2012	Post-KMP	ΔpH	2012	Post-KMP	ΔANC	2012	Post-KMP	ΔSO_4^{2-*}
LAK007	8.0	8.0	0.03	1437.6	1385.9	-51.6	51.4	47.0	-4.4
LAK016	6.3	6.7	0.34	68.7	89.8	21.1	39.0	44.5	5.4
LAK024	7.1	7.5	0.36	299.5	463.2	163.7	24.8	38.9	14.1
LAK034	6.7	6.4	-0.29	99.4	139.6	40.2	24.1	0.1	-24.0
Total lakes with increase			**3**			**3**			**2**
Total lakes with decrease			**1**			**1**			**2**

Control lakes	2013	Post-KMP	ΔpH	2013	Post-KMP	ΔANC	2013	Post-KMP	ΔSO_4^{2-*}
DCAS14A	6.5	6.6	0.2	50.6	55.9	5.4	33.4	36.4	3.0
NC184	5.7	5.8	0.1	16.2	27.0	10.8	5.7	6.2	0.5
NC194	6.6	6.4	-0.2	28.0	22.4	-5.6	3.6	2.5	-1.1
Total lakes with increase			**2**			**2**			**2**
Total lakes with decrease			**1**			**1**			**1**

Table 7-7. Changes in dissolved organic carbon (DOC), total base cations (∑BC), and chloride (Cl^-) from baseline conditions (2012) to the post-KMP period (2016-2018). * = corrected for marine influence. Green cells indicate increases and red cells indicate decreases.

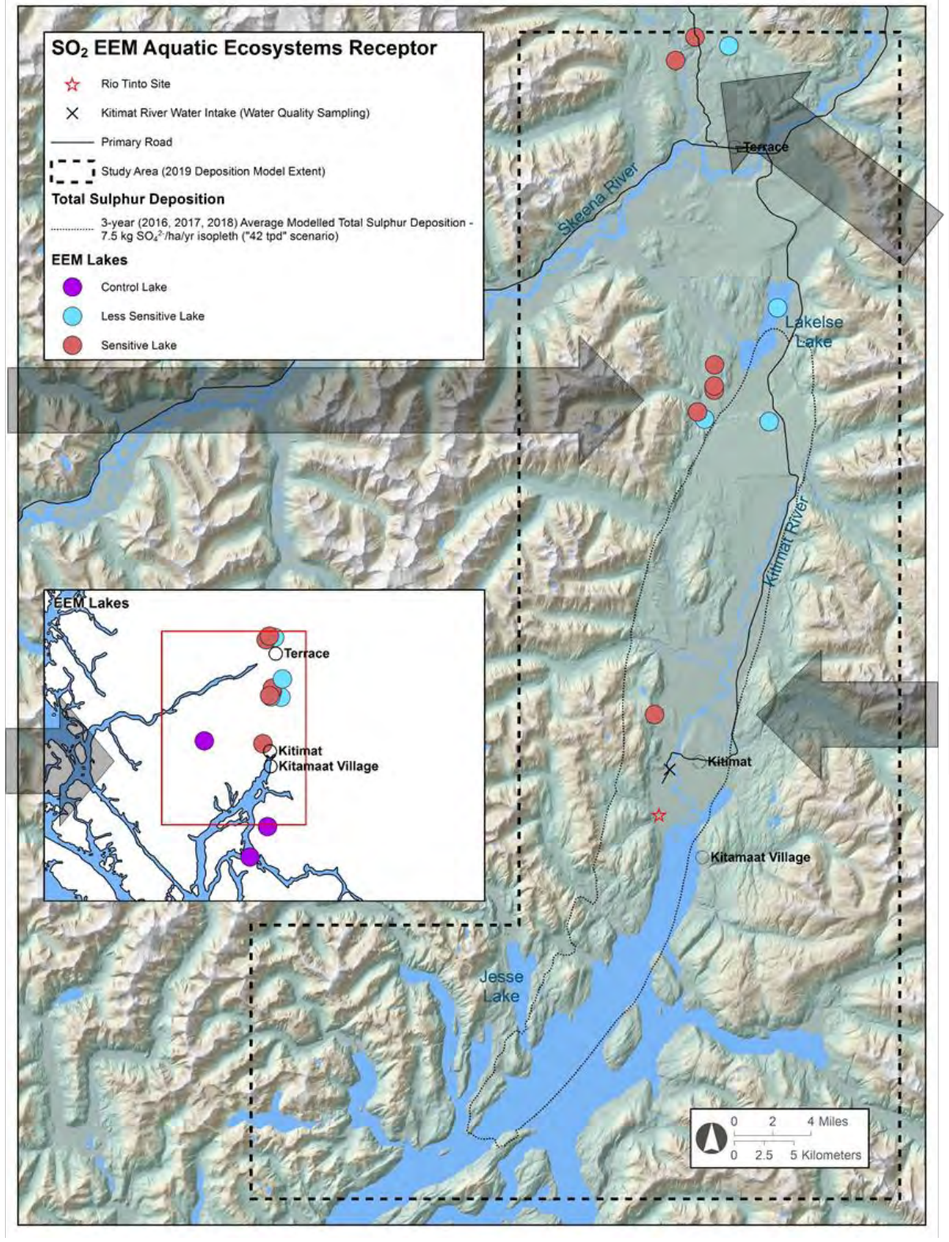
	DOC (mg/L)			∑ BC (µeq/L)			Cl (µeq/L)		
EEM sensitive lakes	2012	Post-KMP	ΔDOC	2012	Post-KMP	ΔBC*	2012	Post-KMP	ΔCl
LAK006	3.6	3.9	0.4	60.6	72.1	11.5	5.8	5.7	-0.1
LAK012	4.6	5.0	0.3	120.6	111.5	-9.1	4.2	6.3	2.1
LAK022	5.3	6.1	0.7	98.1	114.7	16.5	6.9	7.4	0.5
LAK023	4.2	5.6	1.5	65.9	72.8	6.9	4.5	4.7	0.2
LAK028	4.9	6.6	1.7	72.9	136.7	63.8	6.1	8.4	2.4
LAK042	13.2	10.7	-2.5	53.4	64.8	11.4	6.1	6.7	0.5
LAK044	1.7	1.8	0.1	14.2	18.1	3.9	5.6	6.2	0.6
Total Lakes with Increase			**6**			**6**			**6**
Total Lakes with Decrease			**1**			**1**			**1**

EEM less sensitive lakes	2012	Post-KMP	ΔDOC	2012	Post-KMP	ΔBC*	2012	Post-KMP	ΔCl
LAK007	0.6	0.4	-0.2	1503.9	1494.3	-9.6	24.6	26.4	1.8
LAK016	3.7	4.6	0.9	166.3	179.5	13.2	6.3	7.7	1.4
LAK024	1.4	2.1	0.7	340.0	558.5	218.4	27.3	68.3	41.0
LAK034	4.5	6.2	1.7	201.7	191.2	-10.5	5.8	4.5	-1.3
Total Lakes with Increase			**3**			**2**			**3**
Total Lakes with Decrease			**1**			**2**			**1**

Control lakes	2013	Post-KMP	ΔDOC	2013	Post-KMP	ΔBC*	2013	Post-KMP	ΔCl
DCAS14A	1.4	1.3	-0.0	90.6	109.7	19.1	9.2	7.1	-2.0
NC184	11.6	10.3	-1.3	86.2	94.8	8.6	24.0	17.5	-6.5
NC194	0.7	1.0	0.3	39.2	45.8	6.6	7.6	5.9	-1.7
Total Lakes with Increase			**1**			**3**			**0**
Total Lakes with Decrease			**2**			**0**			**3**

	2012 to 2016-18		
LAKE	ΔSO_4^{2-}	ΔANC	ΔpH
Lak006	2.5	2.0	0.2
LAK012	6.8	1.3	0.5
LAK022	8.6	5.1	0.1
LAK023	-6.7	6.7	0.2
LAK007	-4.4	-51.6	0.0
LAK016	5.4	21.1	0.3
LAK024	14.1	163.7	0.4

	2013 to 2016-18		
LAKE	ΔSO_4^{2-}	Δ ANC	Δ pH
DCAS14A	3.0	5.4	0.2
NC184	0.5	10.8	0.1
NC194	-1.1	-5.6	-0.2



	2012 to 2016-18		
LAKE	ΔSO_4^{2-}	Δ ANC	Δ pH
LAK042	-0.8	26.1	0.5
LAK044	-1.9	3.7	0.2
LAK034	-24.0	40.2	-0.3

	2012 to 2016-18		
LAKE	ΔSO_4^{2-}	Δ ANC	Δ pH
LAK028	71.5	0.5	0.0

Figure 7-4. Observed changes in SO_4^{2-}, Gran ANC and pH from the baseline period (2012) to the post-KMP period (2016-2018). Green cells indicate increases and red cells indicate decreases. Background deposition of 3.6 kg SO_4^{2-} /ha/yr is not included in the isopleth.

7.3.1.1 *Observed increases versus predicted decreases in pH*

As shown above, pH increased from 2012 to the post-KMP period for all of the EEM sensitive and less sensitive lakes except one less sensitive lakes, which may at first seem to contradict the predictions in the STAR of future decreases in pH. However, there are multiple factors that may collectively contribute to this perceived contradiction:

1. **Maximum vs. Actual Emissions:** The STAR predictions of future pH were based on estimated deposition levels under the maximum permitted emissions (42 tpd) whereas actual emissions have been much lower (29.3 tpd).
2. **Deposition**: Deposition has been less than expected in 6 of the 7 sensitive lakes (LAK028 being the exception). Therefore, the changes in lake SO_4^{2-} have been less than predicted in the sensitive lakes, even after accounting for emissions at ~30 tpd rather than 42 tpd. See Aquatic Appendix A (Section 7.1.2.3.4, Assessing observed changes in water chemistry relative to STAR predictions). Some lakes have shown a decrease in SO_4^{2-} rather than an increase, which likely reflects changes in the spatial distribution of deposition since pre-KMP conditions.
3. **Long-term vs. Short-term Changes**: The STAR analyses of changes in pH were based on predictions of future, *steady-state* pH – i.e., predictions of long-term change rather than short-term. It may take a number of years to reach steady-state under the new deposition levels.
4. **Lake Sensitivity:** For sensitive lakes which have shown an increase in SO_4^{2-} (i.e., LAK006, LAK012, LAK022, LAK028), but no decrease in ANC or pH, it appears that their F-factor is higher (less sensitive to acidification) than what we had assumed in the STAR. The only lake for which we can compare assumed vs observed F-factors is LAK028, where the observed F-factor (0.65 to 0.89) was higher than what was estimated in the STAR (0.44) (see Aquatic Appendix G, Section 2.3.3).
5. **Precipitation:** It is possible that environmental conditions (e.g., drier summers than historically) could have led to a concentration effect, increasing base cations, ANC and pH. As shown in Aquatic Appendix G (Section 2.3.2), average annual precipitation was 9% lower during 2016-2018 compared to the climate reference period of 1960-1990. Furthermore, when compared to the 3-year period prior to the STAR sampling (i.e., 2010-2012) the relative difference is even greater because those years were on average slightly wetter than the climate reference period – i.e., relative to that period, the average annual precipitation for 2016-2018 was 13%, 9% and 25% less for the three stations with data (though the 25% decline applies only to 2018). However, statistical analyses of the correlations between lake chemistry and precipitation (on both short term and seasonal time scales) have not revealed any statistically significant relationships (Aquatic Appendices F and I).
6. **Natural Variability and Measurement Error**: In addition to precipitation, there are variations from year to year in watershed processes (e.g., wetland releases of organic acids and stored sulphate), and in-lake processes (e.g., photosynthesis, sulphate reduction), which add noise to observed patterns and trends in lake chemistry. While the quality of data has been very high (see Section 7.2.2), there are measurement errors, which add additional noise to the observed patterns and trends. As the EEM program gathers more years of data, these sources of variation become less important, and it becomes easier to see if there is in fact a long-term trend.

7.3.2 Knowledge gained

7.3.2.1 *Measuring pH*

During the EEM Program we have learned that pH is more highly variable than expected. Those expectations were based on literature and data from other regions. We have also learned that it is difficult to measure pH well in lakes with low ionic strength. The low ionic strength means that a long time is needed to get stable readings – longer than factory settings for some instruments or laboratory protocols at some facilities. Not allowing sufficient time for readings to stabilize results in less reliable pH data. Furthermore, even when allowing sufficient time for stabilization, the measurement error for the different instruments (± 0.2 pH units) is high relative to the effect size of interest (0.3 pH units).

7.3.2.2 *Ability to detect changes in water chemistry*

In 2015 we conducted a power analysis of the data collected to date (i.e., 2012-2014), to assess our ability to detect changes in water chemistry for SO_4, pH and ANC. Our analyses revealed that lakes in the EEM program had a higher level of year-to-year variability in SO_4^{2-} and ANC over 2012-2014 than did lakes in the Georgia Basin sampled by Environment Canada from 2005 to 2014 (Figure 3 in EEM Technical Memo W05, 2016). The data from 2012-2014 likely overestimates the year-to-year variability in lake chemistry, because there were significant changes in smelter emissions of SO_2 during this period (from an average of 16.1 tpd in 2012 to 11.6 tpd in 2014). Other key findings from the power analyses completed in 2015 included the following:

- On average, the statistical power to detect changes in pH that exceed the KPI threshold is quite low (<0.1 for LAK012 and LAK042), due to high within-year and between-year variability, as well as measurement error.
- The power to detect changes in ANC and SO_4^{2-} is however quite high (>0.8 after a 5-year period) for four of the seven sensitive EEM lakes (LAK006, LAK012, LAK022, LAK023), indicating the benefit of using multiple metrics.
- The ability to detect changes in all three variables increases over time, and with multiple samples per year.
- Gran ANC provided the most reliable indication of long-term changes in acid-base chemistry (i.e., highest statistical power to detect changes of biological significance), but required ≥ 3 years of annual measurements to obtain acceptable statistical power in five of the sensitive lakes.
- Two of the seven sensitive lakes (LAK028 and LAK042) showed low statistical power (<0.1) to detect biologically significant changes in Gran ANC even after 10 years of annual measurements, due to high natural variability.

Since 2014, the intensively monitored lakes (End Lake – LAK006, Little End Lake – LAK012, West Lake LAK023) have included Rio Tinto's voluntary continuous monitoring of pH (including biweekly measurements of field pH during calibration of the continuous monitors) and four samples of full chemistry during the month of October. Our observations from the power analysis (i.e., high year-to-year variability and low statistical power in several EEM lakes) led us to increase the number of lakes with four fall samples, adding 3 of the remaining 4 sensitive lakes (LAK028, LAK042, LAK044) in 2016. It is not feasible to access LAK022 for multiple samples in the fall index period.

In general, at least five years of post-KMP data are required to reach adequate statistical power for Gran ANC, with significantly more years required for three of the lakes. For this report, we have only three years of post-KMP data. Therefore, at least two more years of post-KMP data are required to attain adequate statistical power for Gran ANC, preferably three more years of data (see Recommendations, Section 7.4). The inter-annual and intra-annual variability in pH is much higher than the variability in Gran ANC, and therefore it is more difficult to detect changes in pH than changes in Gran ANC. More information on the power analyses is provided in Aquatic Appendix F, Section 7.6.3. The statistical analyses included in Aquatic Appendix F and Aquatic Appendix I (sensitivity analysis of alternative baselines) have the benefit of more years of data than were available for the 2015 power analysis, allowing for better estimates of variability in lake chemistry both within and between years.

A weakness of the EEM Program is that for pH and ANC, we have only one measurement in August 2012 as a baseline. In the statistical analyses for pH and ANC using 2012 as the baseline, we have assumed that the year-to-year variability observed in 2016-2018 is representative of the year-to-year variability during the baseline year of 2012 (see Aquatic Appendix F). In the EEM plan, we had assumed that we could include 2012-2014 as an expanded baseline period. Over time, we realized that the period from 2012-2014 was better described as a *transition period* with the decommissioning of the old smelter, and not as a pre-KMP baseline. We did not apply an expanded baseline period (2012-2014) to pH and Gran ANC, because doing so would increase two risks: 1) the risk confounding baseline water chemistry conditions with the effects of smelter decommissioning; and 2) the risk of a Type I error (a false positive) in testing for exceedances of pH and ANC thresholds. Including pH and ANC observations from 2013 and 2014 in the estimates of mean pre-KMP pH and mean pre-KMP Gran ANC would increase those metrics to a level that is not representative of the pre-KMP period prior to and including 2012, and increase the risk of a false exceedance of the thresholds for changes in pH and Gran ANC. Changes in lake [SO_4] are an important part of the simplified and full evidentiary frameworks (Section 7.3.4.5). Using 2012-2014 as a baseline also could increase the risk of a false positive for detecting an increase in lake [SO_4], if a lake's [SO_4] decreased during 2013-3014 due to the decommissioning of the old smelter and reduced emissions of SO_2. Therefore, both the draft comprehensive review report and the 2018 EEM Report used 2012 as a baseline for comparison.

In response to requests from reviewers of the draft comprehensive report, we have completed a sensitivity analysis to assess the effects of using 2012-2014 as an alternative baseline to 2012 (Aquatic Appendix I). While use of a 2012-2014 baseline does change some of the results of the statistical analyses, it does not change any of the overall conclusions regarding effects of the smelter on EEM lakes (see Table 7.82 and Figure 7.147 in Aquatic Appendix I).

7.3.2.3 *Spatial and temporal patterns in water chemistry*

There are multiple ways in which the spatial and temporal patterns in water chemistry have been explored, assessed and analyzed.

Comparison of August vs. October sampling

Sampling during the STAR (providing data for the baseline year of 2012) was conducted in August and sampling during the EEM program has been during October (see EEM Plan and EEM Annual Reports for addition discussion – in particular the 2013/2014 EEM Annual Report explored the

potential implications and sensitivities of the seasonal transition in the sampling period). As part of the comprehensive review, we further explored this issue with new data.

Based on analyses of the field pH, lab pH and Gran ANC data from samples collected during the calibration visits to the lakes with continuous pH monitors, it was not possible to detect a difference in the mean values for August and October. This provides some further support to work done in previous years to evaluate the potential effects of having sampled the baseline year of 2012 in August rather than during the fall index period used throughout the EEM Program. However, although this analysis could not detect a difference, the analysis is limited by the duration and sample size of the data available. For LAK006, LAK012 and LAK023, there were two or three field pH samples in August and an average of four for October during 2015-2018. For 2017 and 2018, these samples also include measurements of lab pH and Gran ANC. For LAK028, these analyses could only be done for 2018, when the lake was sampled once in August and four times in October. Aquatic Appendix A (Sections 7.1.2.3.3 and 7.1.3.2.3) provides further details on these analyses and results.

Observed Changes in Water Chemistry

This topic is predominantly addressed within Section 7.3.1. However, Aquatic Appendix A includes additional exploration of a) the relative changes in base cations and SO_4^{2-} and b) changes in the ion composition over time.

Magnitude of Changes in Nitrate

In the STAR, nitrate was excluded from analyses of potential acidification as it was assumed to represent a negligible contribution. Examination of the magnitudes of the changes in NO_3^- relative to changes in SO_4^{2-} over the observation period confirmed that the changes in NO_3^- have been negligible.

Statistical Analyses

The key results of the extensive statistical analyses of changes in lake chemistry across all the lakes in the EEM Program are summarized in Table 7-8 and Table 7-9. Table 7-9 uses results from Bayesian statistical analyses (Sections 7.6.4.2.9, 7.6.4.3.9 and 7.6.4.4.9 of Aquatic Appendix F) since this approach provides the greatest ability to assess the level of support for different hypotheses of chemical change. The logic of Table 7-9 reflects the logic of the simple evidentiary framework (Figure 7-3 and Figure 7-10). The control lakes are far outside of the plume of the smelter, and so changes which have occurred there are unrelated to the smelter. For the other lakes, the following logic applies:

- Lakes with a low percent belief in a sulphate increase (< 20%, or a strong belief in a sulphate decrease) can be eliminated from further consideration (as indicated by cells coloured green in the sulphate column of Table 7-9; this includes sensitive lakes LAK023, LAK044, and less sensitive lakes LAK007 and LAK034.
- Lakes with cells coloured red in the sulphate column (sensitive lakes LAK006, LAK012, LAK022, LAK028; less sensitive lakes LAK016 and LAK024) show strong evidence for a sulphate increase (>80% belief), and proceed on to evaluations of the next two columns (Gran ANC and pH). If there is a low percent belief (< 20%) that the ΔGran ANC and ΔpH for these lakes exceeded the identified thresholds, then the cells in those columns are

coloured green, indicating that these lakes show no evidence of smelter-induced acidification.

- Lakes coloured yellow in the sulphate column (sensitive lake LAK042) show an intermediate level of support for a sulphate increase (20% to 80% belief), and are also evaluated for their changes in Gran ANC and pH.
- The conclusions in the rightmost column of Table 7-9 reflect a consideration of both the statistical analyses and the magnitudes of changes in lake chemistry. Two lakes (LAK028 and LAK012) are shaded yellow because they show some evidence of acidification[44], but neither lake has exceeded its thresholds for ΔGran ANC and ΔpH.

Power or Minimum Effect Size

The power analyses completed in 2015 represent a comprehensive analysis of the power to detect differences based on the available data and statistical model applied at the time.

The Aquatic Appendix F quantifies the minimum detectable difference (MDD) values for the frequentist analyses performed (7.6.4.2 for SO_4^{2-}; 7.6.4.3 for pH; 7.6.4.4 for ANC). These sections of Aquatic Appendix F include sensitivity analyses of the MDD based on assumptions about variability in the pre-KMP period. The Bayesian analysis, which involves running 1,000 simulations to test each hypothesis, provides a more comprehensive assessment of the level of support (percent belief) for an increase or decrease in a chemical parameter, and for a decrease beyond the thresholds of concern. The Bayesian analysis provides useful insights for situations where the frequentist analysis was unable to determine whether or not the observed change exceeded the threshold.

Potential Lag Effects

There could be a lag between increased SO_2 emissions and increased SO_4^{2-} concentrations in lakes due to variability in winds and the plume, and due to temporary watershed storage of deposited SO_4^{2-} in wetlands. However, both of these potential lag effects are expected to be temporary (e.g., no longer than two years). Once additional SO_4^{2-} enters a lake, lake chemistry should adjust quickly (based on lake residence time), but the magnitude of change in lake pH depends on the sensitivity of the watershed and the lake to acidification. If a lake has higher ANC (lower sensitivity), there is not expected to be any decline in lake pH associated with higher SO_4^{2-}. If a lake is sensitive to acidification, then the magnitude of change will depend on concurrent changes in base cations and ANC (e.g., there might no decrease in pH if base cations went up concurrently). These different types of potential responses are also described in Appendix H of the EEM Plan.

Section 7.6.4.6 of Aquatic Appendix F summarizes the results of other statistical analyses of chemical change (e.g., frequentist methods) which are consistent with the results presented in Table 7-9. The full results of the statistical analyses are reported in Aquatic Appendix F. In response to requests from reviewers of the draft comprehensive review report, we have completed a sensitivity analysis to assess the effects of using 2012-2014 as an alternative baseline to 2012 (Aquatic Appendix I). While use of a 2012-2014 baseline does change some of the results

[44] LAK028 shows moderate support for *any level* of ANC and pH (34% belief and 46% belief, respectively) and LAK012 shows moderate support for a decline in ANC only (46% belief), but as shown in Table 7-9 there is no to low support for declines exceeding the EEM thresholds (i.e., no support in LAK012 for exceeding either the ANC or pH threshold; no support in LAK028 for exceeding the ANC threshold and low support for exceeding the pH threshold). The analyses of the level of support for *any level* of decline in ANC or pH, are shown in Section 7.6.4.6 of Aquatic Appendix F (see Tables 7.72 and 7.73).

of the statistical analyses, it does not change any of the overall conclusions regarding effects of the smelter on EEM lakes (see Table 7.82 in Aquatic Appendix I).

Figure 7-5 summarizes the patterns of change in water chemistry on a map of the study area, so as to elucidate any effects of lake location, specifically distance from the smelter. Six of the eight lakes to the south of Lakelse Lake showed strong evidence of increases in sulphate. It isn't clear why LAK023 and LAK007 were exceptions to this pattern – perhaps they are topographically more isolated from the path of the plume. None of the six lakes with strong evidence for increases in sulphate showed statistical support for changes in pH or Gran ANC beyond the thresholds, as evidenced by the low levels of % belief for such changes. Lakes to the north of Terrace (LAK034, LAK044, LAK042) are outside of the deposition isopleth for 7.5 kg SO_4^{2-} / ha / year, consistent with low to intermediate support for sulphate change (0%, 36% and 1% belief, respectively). The control lakes were selected to be well outside of the plume. Two of the control lakes showed intermediate levels of support for increases in sulphate between 2013 and 2016-2018, but the amount of change in sulphate concentrations was very small (Table 7-6).

Table 7-8. Key findings for each of the questions posed in Table 7-5.

Questions of Interest	Key Findings
How long does it take to reliably assess whether or not key water chemistry parameters (SO_4, pH, ANC) have changed relative to pre-KMP conditions, and (for pH and ANC) whether those changes exceed the 0.3 unit threshold established in the EEM Plan for pH, and the lake-specific thresholds established subsequently for Gran ANC?	This question was addressed by the power analysis, described above in Section 7.3.2.2, and in Section 7.6.3 of Aquatic Appendix F. We found that it takes less time to reliably detect changes in Gran ANC than to reliably detect changes in lake pH, as Gran ANC is less variable. We found that it would take at least 5 years of post-KMP monitoring to reliably detect changes of interest in Gran ANC within 4 of the 7 sensitive lakes, 10 years of monitoring for one other lake, and an uncertain amount of time in the other 2 lakes. These may be over-estimates of the time required as the variability of water chemistry was likely over-estimated from 2012-2014 data, due to declines in emissions during this time period. Nevertheless, we have only 3 years of post-KMP data so far, and more years of data will improve our ability to detect how much change has occurred.
What are the general patterns of variability and change over time in key water chemistry parameters?	See graphs in Section 7.6.2.1 of Aquatic Appendix F. The quantitative analyses of changes in water chemistry (summarized below, with details in Section 4 of Aquatic Appendix F) provide an assessment of what patterns of change are statistically significant.
Do the values of key water chemistry parameters vary with the magnitude of recent precipitation?	Sulphate, pH and Gran ANC show a negative correlation with the amount of precipitation over the past 3 and past 14 days, but these correlations are not statistically significant (Sections 7.6.4.2.6, 7.6.4.3.6 and 7.6.4.4.6 of Aquatic Appendix F).
Do the values of key water chemistry parameters vary with emissions?	Neither SO_4, pH or Gran ANC varied significantly with emissions over the time period of measurements. This could be because deposition varies considerably over space and time, and a single measure of emissions does not explain variability in observed water chemistry.
Based on the annual fall sampling, how much change has occurred in key water chemistry parameters (SO_4, pH, ANC) between the pre-KMP period (2012) and the post-KMP period (2016-2018), within each lake? For pH and ANC, how likely is it that the changes exceed the EEM thresholds?	The only lakes of concern (i.e., those with both an increase in SO_4^{2-} and decreases in either pH or Gran ANC) are sensitive lakes LAK012 and LAK028. Changes in pH and Gran ANC in these two lakes are less than thresholds. See Table 7-9 and Figure 7-5. LAK028, situated about 9 km north of the smelter, is the only lake with values of BCS[45] that are consistently less than 0 (true in 5 of the 7 years of the EEM program, including 2012 and 2013, during the pre-KMP period). Values of BCS < 0 µeq/L are indicative of water chemistry conditions potentially damaging to aquatic biota. The fact that LAK028 has consistently shown BCS values < 0 µeq/L is evidence of water chemistry likely to damage aquatic biota. EEM sampling in 2017 to establish a biological baseline found that LAK028 does not have any fish.

[45] Base cation surplus (BCS) is a measure of acid-neutralizing capacity that adjusts CBANC to account for the influence of strong organic acid anions. BCS also acts as a strong predictor for aluminium toxicity for aquatic organisms - a distinct threshold for inorganic aluminium (Al) mobilization occurs at a BCS value that closely approximates 0, therefore BCS values < 0 would indicate that acid-neutralization within the watershed is not sufficient to buffer acidic deposition without mobilization of toxic inorganic Al. Further details are provided in the literature review on ANC metrics and thresholds (Aquatic Appendix B). BCS is calculated and explored for the EEM lakes in Aquatic Appendix A.

Questions of Interest	Key Findings
Based on the three intensively monitored lakes (End Lake, Little End Lake, West Lake), are there are seasonal and long-term trends in pH?	As expected, field pH measurements were more variable than lab pH measurements (in the lab, samples are allowed to equilibrate with the atmosphere, which reduces a key source of variability, the degree of supersaturation of CO_2). Trends in field pH over 2015-2019 were negative in all three lakes, but this trend was only statistically significant in LAK023 (West Lake), with an estimated change in field pH of -0.12 over 2015-2019. West Lake showed strong evidence of a decrease in sulphate, so the decline in field pH within West Lake was unrelated to the smelter. Field pH values were generally lowest in the fall (in 9 out the 12 lake-years of data with spring, summer and fall measurements), and highest in the spring or summer. A key caveat on these trends is that as SO_2 emissions declined from 2012 to 2014, lab pH values increased in all three lakes, so the field pH values in late 2014 and early 2015 are not representative of pre-KMP conditions, and should not be used for calculations of ΔpH and comparisons to the 0.3 threshold. Season and time of day can have important effects on lake pH. During the summer, low ANC lakes can show substantial diurnal fluctuations in pH (e.g., one pH unit or more) due to photosynthetic activity, which does not cause negative biological effects as long as the pH remains within a tolerable range (Morgan 1985; Robertson-Bryan Inc. 2004).

Table 7-9. Summary of findings across all lakes monitored in the EEM Program. The % belief values are derived from the Bayesian version of Method 1, as described in Aquatic Appendix F. Values of % belief < 20% are coloured green, 20-80% yellow, and >80% red.

LAKE	Changes in SO_4^{2-} (% belief in SO_4^{2-} increase / decrease from Bayesian analysis - Method 1 violin plot)	Changes in Gran ANC (% belief that ANC threshold exceeded, from Bayesian analysis - Method 1 violin plot)	Changes in pH (% belief that pH threshold exceeded, from Bayesian analysis - Method 1 violin plot)	OVERALL INTERPRETATION[5]
Sensitive Lakes				
LAK006	83% belief in increase	0%	1%	SO_4^{2-} increase; no evidence of S-induced acidification
LAK012	91% belief in increase	1%	1%	SO_4^{2-} increase; some-evidence of S-induced acidification but no evidence of exceeding the ANC or pH thresholds established in the EEM Plan to protect aquatic biota
LAK022	88% belief in increase	0%	0%	SO_4^{2-} increase; no evidence of S-induced acidification
LAK023	5% belief in increase	0%	1%	SO_4^{2-} decrease; no evidence of S-induced acidification
LAK028	96% belief in increase	2%	18%	SO_4^{2-} increase; some evidence of S-induced acidification; low belief in exceeding the pH threshold and no evidence of exceeding its ANC threshold; conditions were potentially damaging to biota pre-KMP and remained so (see Section 7.3.4.2).
LAK042	36% belief in increase	0%	2%	No clear change in SO_4^{2-}; no evidence of S-induced acidification
LAK044	1% belief in increase	0%	0%	SO_4^{2-} decrease; no evidence of S-induced acidification
Less Sensitive Lakes				
LAK007	0% belief in increase	58%	2%	SO_4^{2-} decrease; no evidence of S-induced acidification
LAK016	97% belief in increase	0%	1%	SO_4^{2-} increase; no evidence of S-induced acidification
LAK024	96% belief in increase	1%	1%	SO_4^{2-} increase; no evidence of S-induced acidification
LAK034	0% belief in increase	0%	43% [2]	SO_4^{2-} decrease; no evidence of S-induced acidification
Control Lakes				
DCAS14A	68% belief in increase[3]	0%	6%	No clear change in SO_4^{2-}; no evidence of S-induced acidification
NC184	58% belief in negligible increase [3]	5%	28%[1]	No clear change in SO_4^{2-}; no evidence of S-induced acidification
NC194	1% belief in increase	TBD[4]	12% [1]	SO_4^{2-} decrease; no evidence of S-induced acidification

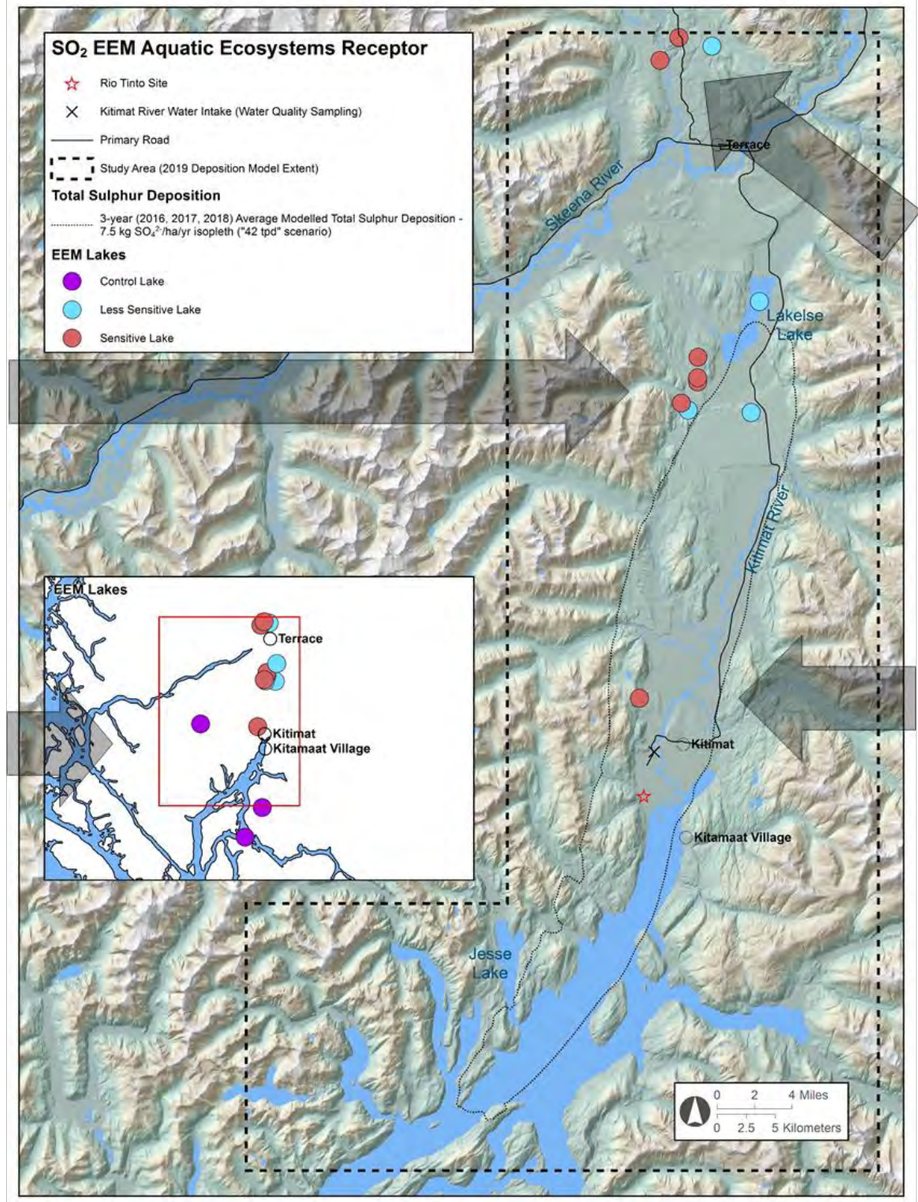
[1] Mean pH in NC184 changed from ~5.7 (2013) to ~5.8 (2016-18); Mean pH in NC194 changed from ~6.6 (2013) to ~6.4 (2016-18).

[2] Not related to S deposition as lake SO_4^{2-} has declined in LAK034.

[3] Magnitude of increase in [SO_4] between 2013 and 2016-2018 is very small in NC184 (0.5 µeq/L), and only 4 samples were available for statistical analysis.
[4] Lake NC194 did not have a lab titration from which we could determine an ANC threshold. It had a 55% belief in an ANC decline (about 6 µeq/L between 2013 and 2016-2018), though very low belief (1%) in a SO_4^{2-} increase, so the ANC decline was not related to SO_4^{2-}.
[5] The overall interpretation is also based in part on the level of support for *any level* of decline in ANC or pH, as are shown in Section 7.6.4.6 of Aquatic Appendix F (see Tables 7.72 and 7.73). Only two lakes show evidence of any level of decline in ANC or pH. LAK028 shows moderate support for declines in ANC and pH (34% belief and 46% belief, respectively) and LAK012 shows moderate support for a decline in ANC only (46% belief), but both of these lakes show no to low support for exceedance of the ANC and pH thresholds (as shown in the table). The coding of these two lakes in this table thus aligns with the results of the Evidentiary Framework.

LAKE	% belief in change		
	↑ SO_4^{2-}	↓ ANC	↓ pH
LAK006	83%	0%	1%
LAK012	91%	1%	1%
LAK022	88%	0%	0%
LAK023	5%	0%	1%
LAK007	0%	58%	2%
LAK016	97%	0%	1%
LAK024	96%	1%	1%

LAKE	% belief in change		
	↑ SO_4^{2-}	↓ ANC	↓ pH
DCAS14A	68%**	0%	6%
NC184	58%	5%	28%
NC194	1%	TBD	12%



LAKE	% belief in change		
	↑ SO_4^{2-}	↓ ANC	↓ pH
LAK042	36%	0%	2%
LAK044	1%	0%	0%
LAK034	0%	0%	43%

LAKE	% belief in change		
	↑ SO_4^{2-}	↓ ANC	↓ pH
LAK028	96%	2%	18%

Figure 7-5. Spatial distribution of percent belief in chemical change. Numbers show % belief in: a) SO_4^{2-} increase (no threshold), b) pH decrease below 0.3 threshold, and c) ANC decrease below lake-specific ANC threshold. The % belief values are derived from the Bayesian version of Method 1, as described in Aquatic Appendix F. NC194 does not have an estimated ANC threshold because it did not have appropriate titration data available. **The increase in SO_4^{2-} in control lake DCAS014A was only ~3 µeq/L, and only 0.5 µeq/L in NC184. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleth.

7.3.2.4 *Observed changes in water chemistry relative to STAR predictions*

The changes in SO_4, ANC and pH that were predicted in the STAR were initially modelled under the *maximum future* emissions of 42 tpd SO_2, as per the permit. In order to assess whether the observed changes have been more or less than the models predicted, we adjusted the STAR estimates based on the actual average emissions during 2016-2018 (i.e., 29.3 tpd[46], as compared to the maximum 42 tpd permitted levels under which the STAR predictions were made). The quantitative details of these analyses are presented in Aquatic Appendix A (Section 7.1.3.2.4).

The STAR modelling predicted that **sulphate** would increase in all lakes (even when adjusted for lower current emissions). For six of the seven EEM sensitive lakes and two of the three EEM less sensitive lakes, the observed changes in SO_4^{2-} have been lower than the predicted changes (five of the lakes have actually shown decreases). LAK024 had an observed increase in SO_4^{2-} that was greater than predicted. LAK028 had an observed increase in SO_4^{2-} that was many times greater than predicted.

The STAR predicted that **Gran ANC** would decrease for all of the sensitive lakes and decrease or remain unchanged for all of the less sensitive lakes. The observed changes have been less than the predicted changes insofar as Gran ANC has actually increased for all of the lakes except LAK007, which is highly insensitive and has a Gran ANC that is two orders of magnitude larger than the sensitive lakes.

The STAR modelling predicted that **pH** would decrease in all of the sensitive lakes (even when adjusted for lower current emissions) and remain unchanged for all of the less sensitive lakes. The observed changes in pH have been less than the predicted changes insofar as pH has actually increased for all of the lakes except LAK034. LAK034 was predicted to have no change in pH under increased emissions and although the observed change has been a decrease of 0.3 pH units, this cannot be associated with increased sulphur deposition from smelter emissions because SO_4^{2-} has decreased to essentially zero over the same period.

These results suggest that the STAR modelling predictions were cautious, since they have almost exclusively predicted changes of greater magnitude than have been observed. The one notable exception is the result for SO_4^{2-} at LAK028, that suggests that deposition levels close to the smelter have been much higher than the model estimates of deposition from the STAR. LAK028 is by far the closest lake to the smelter; all of the other sensitive lakes are much further north. The details of these comparisons (including the values of the initial STAR predictions, the STAR predictions adjusted for observed emissions, and the empirical observations) are reported in Section 7.1.3.2.4 of Aquatic Appendix A.

Deposition levels close to the smelter have been higher than the model estimates of deposition in the STAR. This raises the question of whether there could be some sensitive lakes that were not identified in the STAR, and were not included in the EEM but either would have been included based on these higher deposition levels, or could be more sensitive than their original assessment suggested. It is very unlikely that there were any lakes ≥1 ha in the study area that should have been included in the EEM

[46] Note: The underlying analyses described here were conducted based on actual emissions of 29.4 tpd rather than the correct 29.3 tpd. The difference was due to minor differences in 2016 data resulting from use of preliminary data that was later revised. However, the analyses have been retained as is because this difference would have a negligible impact on the results and therefore not affect the conclusions of these comparisons.

but were not. In the STAR, we did a sensitivity analysis on variation in sulphate deposition (from 50% to 200%; see Section 9.4.1.3.4, page 330 of the STAR) and found little change in the number of lakes with critical load exceedances. Doubling deposition only increased the number of lakes with exceedances from 8 to 10. The two additional lakes with exceedance under a doubling of deposition are LAK022 and LAK012, which were already included in the EEM due to predicted declines in future pH of greater than 0.1 pH units. Figure 7-9 shows which lakes had critical load exceedances, predicted changes in future pH > 0.1, or both, based on both the analyses of the STAR and in the present review. Other lakes in the vicinity of the smelter (e.g., Bowbyes Lake LAK027 (ANC = 70), and LAK030 (ANC=391)) do not show exceedance even with a doubling of STAR deposition (i.e., essentially equivalent to emissions of 84 tpd). Both of these lakes were predicted in the STAR to have a pH change of 0.0 pH units under 42 tpd of emissions. Furthermore, when we re-estimated critical load exceedances based on the updated deposition modelling as well as doubling the amount of deposition (i.e., equivalent to emissions of 84 tpd) we did not identify additional lakes which should have been included in the EEM program (Aquatic Appendix G, Sections 2.5.1 and 2.5.3). Based on the sensitivity analyses done in the STAR there were no other lakes ≥ 1 ha in size near the smelter which could potentially acidify. If we had found such lakes, they would have been included in the EEM Program.

7.3.2.5 *Critical loads, exceedances and predicted changes in pH*

The results of the primary scenarios – i.e., the base case (the original estimates of critical loads from the STAR and/or KAEEA under *current* deposition and the "best case" (new estimates with updated data inputs for the EEM lakes under *maximum future* deposition) – are shown below. Aquatic Appendix G contains the detailed results from all the sensitivity analyses conducted across multiple data inputs, different emissions scenarios, and potential uncertainty in the CALPUFF model estimates of deposition.

The control lakes are not included in the modelling of critical loads or future pH because we do not have deposition estimates for their watersheds. The three control lakes were chosen explicitly because they are located well outside the deposition plume (and thus the CALPUFF modelling domain).

Critical loads and exceedances

<u>All Lakes within Study Area</u>
We re-assessed the original critical loads for all the lakes within the study area against *current* deposition estimates from the updated CALPUFF modelling (i.e., current emissions are represented by the actual emissions scenario).

Of the 51 lakes in the entire data set, seven lakes show exceedances of those original critical loads. Of these seven lakes, five lakes have critical loads of zero (LAK044, LAK047, LAK054, DCAS09A, DCAS09B) and one lake has a critical load very near to zero (1.2 meq/m^2/yr; LAK056) (see Aquatic Appendix G for tabular, graphic and spatial summaries of these results).

The number of exceedances does not change when the higher emissions scenarios are applied. Under the STAR's "post-KMP" deposition estimates (based on the 42 tpd SO_2 emissions permit limit), there were three additional lakes with predicted exceedances that are no longer predicted to have exceedances. Even with the inclusion of background deposition (which was not accounted for in the STAR), these three lakes are not predicted to have exceedances under any of the new emissions scenarios.

The number of exceedances under current emissions did not change with any of the sensitivity analyses applied to the original critical loads. The sensitivity analyses on the CALPUFF modelled deposition estimates showed that the number of exceedances decreased by one lake when deposition under the actual (i.e., 29.3 tpd) emissions scenario was reduced by 50%, but remained unchanged when the deposition was doubled.

EEM lakes – new estimates of critical loads

We estimated new critical loads for the EEM lakes based on new or revised data and assessed them against *maximum future* deposition estimates from the updated CALPUFF modelling (i.e., the 42 tpd emissions scenario).

The new "best case" estimates for critical loads for the EEM lakes and exceedances under different emissions scenarios are summarized in Table 7-10 and mapped in Figure 7-6.

Only one lake (LAK044) shows an exceedance under the 42 tpd emissions scenario, and because it has a critical load of zero, it has an exceedance under all emissions scenarios. In the STAR, five of the EEM lakes were predicted to have exceedances under the "post-KMP" emissions scenario (i.e., also based on 42 tons SO_2 per day).

For eight of the 11 EEM lakes, the revised estimates of critical loads are quite similar to the original estimates in the STAR (see Aquatic Appendix G). The revised critical load estimates are higher than the STAR for LAK024 and LAK028 and lower for LAK012.

The exceedances of the revised critical loads under the 42 tpd emissions scenario are consistently smaller in magnitude than those predicted in the STAR (Figure 7-7). Since the revised estimates of critical loads are mostly similar to those in the STAR, the reduction in the magnitude of exceedances relative to the STAR primarily reflects lower estimates of deposition. Across the three new modelled emissions scenarios, the magnitude of exceedance increases as deposition increases but there are no additional exceedances – that is, the number of exceedances is not sensitive to the emissions scenario.

The number of exceedances under maximum future emissions increased by one lake (LAK028) when an alternate estimate of the F-factor was applied. Otherwise, the number of exceedances did not change with any of the other sensitivity analyses applied to the new estimates of the critical loads for the EEM lakes. The sensitivity analyses on the CALPUFF modelled deposition estimates showed that the number of exceedances remained the same (1 lake; LAK044) when deposition under the 42 tpd emission scenario was reduced by 50% but increased by two lakes (LAK006 and LAK028) when the deposition was doubled.

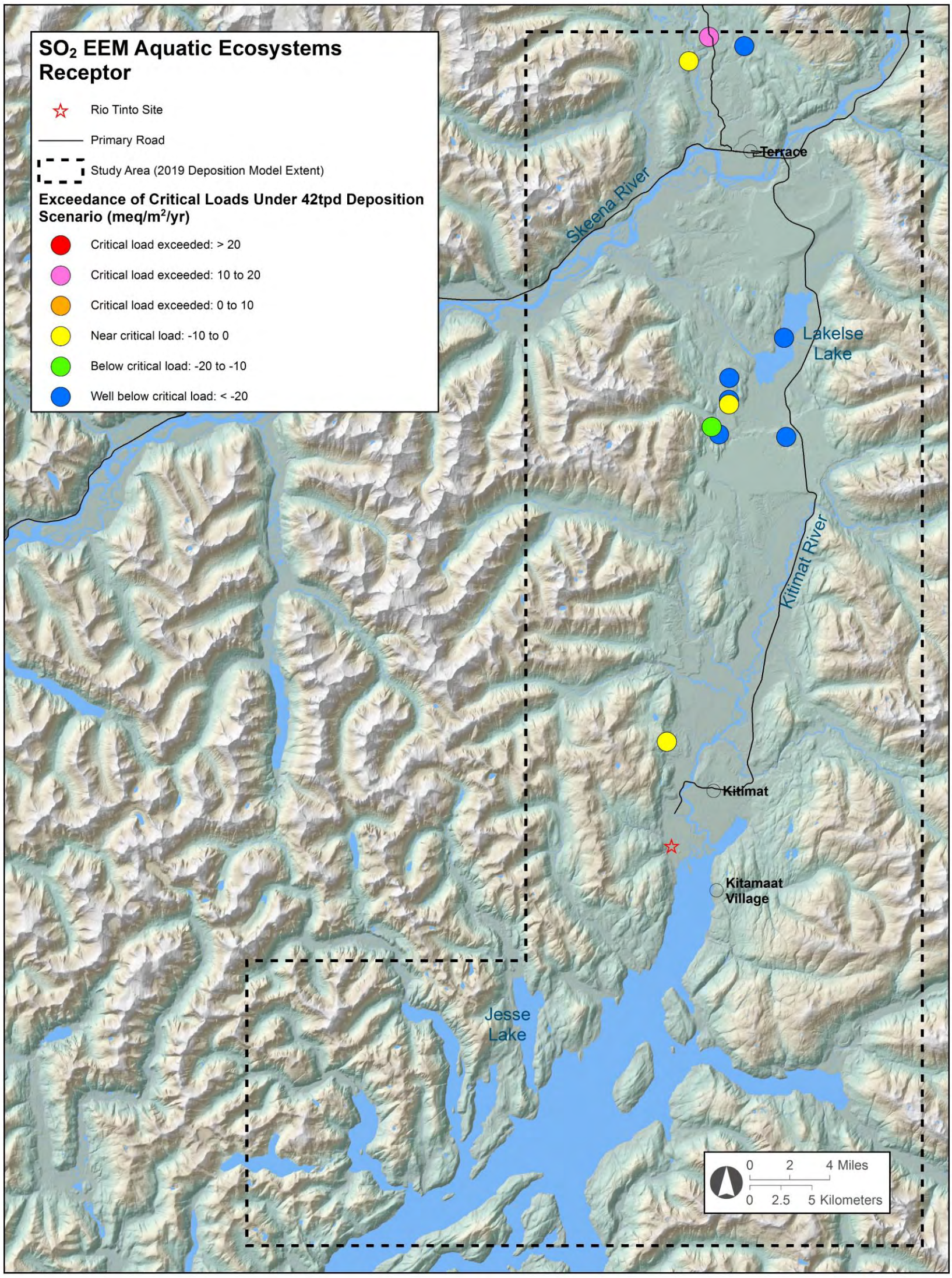


Figure 7-6. Exceedances of new critical loads for EEM lakes with modelled deposition under the 42 tpd emissions scenario.

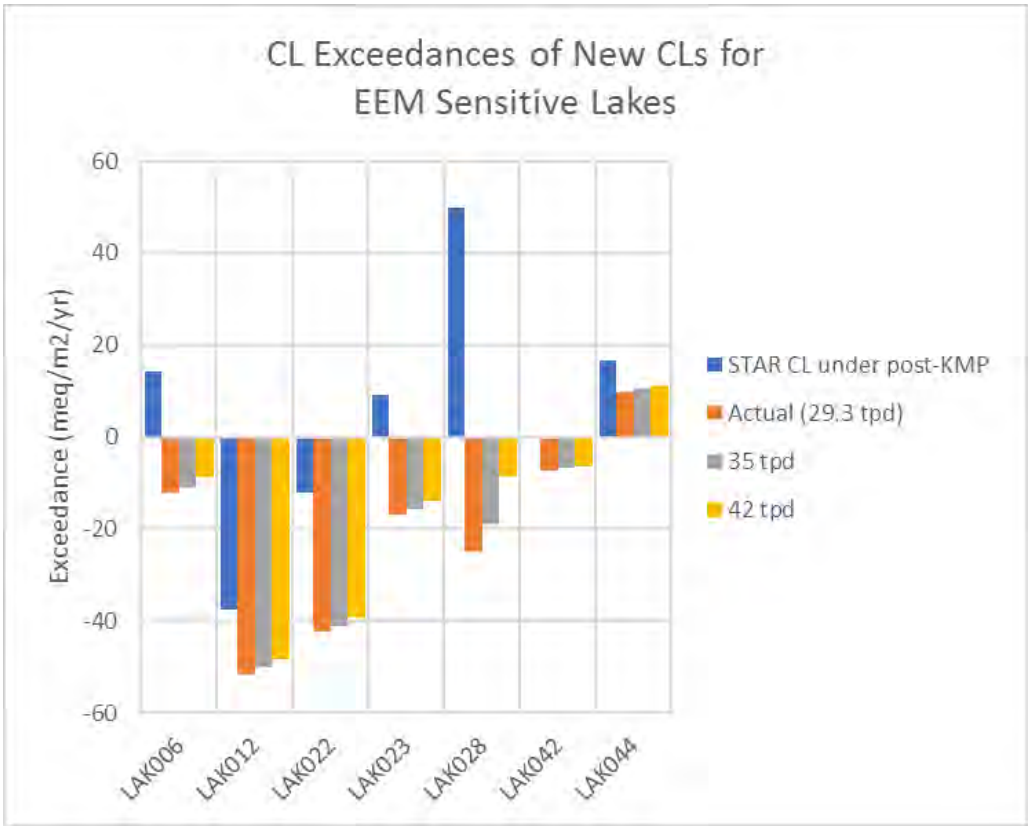


Figure 7-7. Critical load exceedances for the EEM lakes under different levels of deposition. Results from the STAR under the "post-KMP" emissions scenario are included for comparison. Results from the STAR "post-KMP" scenario did not include background deposition, whereas the exceedances estimated under the three new deposition scenarios do include background deposition of 7.5 meq/m2/yr. The exceedance for LAK042 from the STAR was smaller than perceptible on this graph (+0.2 meq/m²/yr).

Future steady-state pH

<u>EEM lakes – new predictions of future pH based on maximum future emissions vs. current</u>
We developed new predictions of future steady-state pH for the EEM lakes, using average lake chemistry conditions for the post-KMP period (2016-2018) and the change in deposition from the modelled current deposition (29.3 tpd) to the modelled maximum future deposition (42 tpd) (Table 7-10).

The new predictions for steady-state pH (i.e., based on post-KMP data, 2016-2018) show a decrease or no change for all EEM lakes relative to current condition; however, for the majority of the EEM lakes, these changes are substantially smaller than the observed *increases* in pH from 2012 to the post-KMP period. Given that the predicted decreases are predominantly much smaller than the observed increase thus far, this means that when expressed as a change relative to 2012 (relevant for comparing results

to the STAR and the baseline period defined in the EEM), the calculated changes show predicted increases in pH for many of the lakes from 2012 to steady-state conditions. However, this is an indirect effect of the changes observed so far and should not be interpreted as a prediction that increased deposition will drive increases in pH in these particular lakes.

Figure 7-8 shows the STAR and current predictions for steady-state pH relative to observed pH values for 2012 and the post-KMP period (2016-2018) for all the EEM lakes. This provides a visualization of the common patterns – i.e., that pH is predicted to decrease or remain unchanged for all of the EEM lakes relative to current pH, but because current pH is predominantly above 2012 pH levels, these steady-state predictions appear to show an increase in pH when compared to 2012.

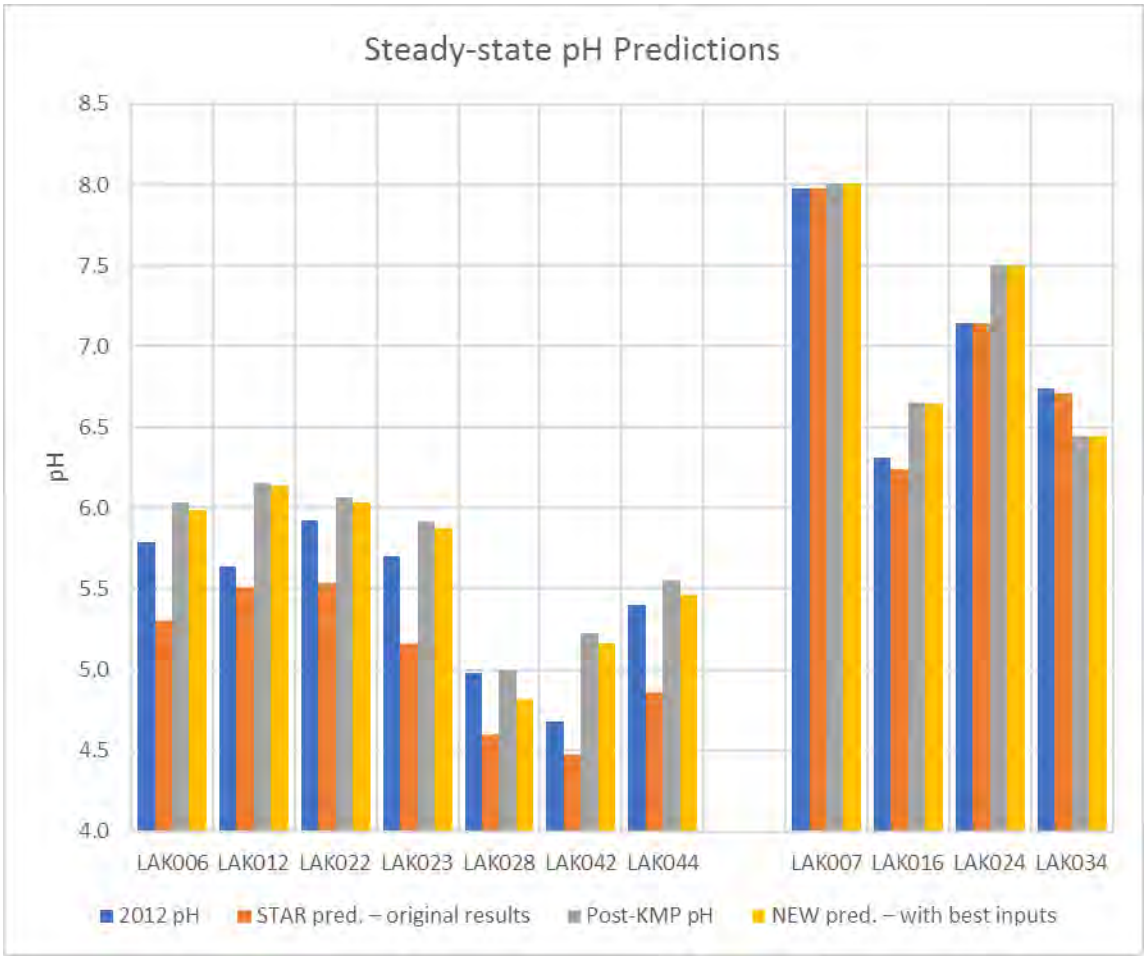


Figure 7-8. Observed pH and predicted steady-state pH for all of the EEM lakes. The STAR predictions were based on the change in deposition from the "pre-KMP" to the "post-KMP" modelled deposition. The new predictions are based on the increase in modelled deposition from current emissions (29.3 tpd) to the maximum future emissions level (42 tpd).

The applied sensitivity analyses did not change the number of lakes with predicted decreases in pH (relative to 2012) of greater than 0.1 pH unit (under maximum future emissions of 42 tpd). The sensitivity analyses on the CALPUFF modelled deposition estimates showed that for LAK028 the predicted pH change relative to 2012 was smaller than a 0.1 unit decrease when the 42 tpd emissions

scenario was reduced by 50% and increased to greater than a 0.3 pH unit decrease when the deposition was doubled – but none of the other lakes changed with respect to either of those thresholds.

Summary of critical loads, exceedances and future steady-state pH

The results from the "best case" analyses of the critical loads and steady-state pH for the EEM lakes are shown in Table 7-10. To be most conservative, these forward-looking analyses have been performed assuming the maximum level of emissions allowed under the permit (i.e., 42 tpd scenario). For each of the key metrics of interest (i.e., exceedances of critical loads, predicted changes in pH relative to the 2012 baseline, and predicted changes in Gran ANC thresholds relative to the 2012 baseline), there is only one lake that exceeds the reference threshold (as defined in the table caption):

Exceedance of critical loads
LAK044 has a critical load of zero and therefore shows a positive exceedance under all deposition scenarios. None of the other EEM lakes are predicted to show an exceedance of their critical loads (i.e., revised estimates based on the best data inputs) under the maximum predicted deposition levels (i.e., 42 tpd emissions scenario). Sensitivity analyses indicate that it is possible that the critical load for LAK028 could be exceeded under the 42 tpd scenario, but steady state predictions of future pH show that the expected future decline in pH under such a scenario is only 0.2 pH units.

Future changes in pH from baseline conditions
LAK034 is shown to have a predicted future pH that is 0.3 pH units below its 2012 level; however, this decline is unrelated to the smelter because sulphate has also decreased during the same period (as explained by the evidentiary framework). In fact, LAK034 is predicted to have zero change in pH from current (2016-18) levels, but these levels are already below 2012.

Future changes in Gran ANC from baseline conditions
LAK007 is shown to have a predicted change in Gran ANC that is greater than its lake-specific threshold; however, this result is an artifact of a change that has already occurred and is unrelated to the smelter. Gran ANC has declined since 2012 but because sulphate is also lower than 2012, the decline must not be driven by smelter emission (as per the evidentiary framework). LAK007 is highly insensitive to acidic deposition – it has very high Gran ANC and is predicted to have zero change in Gran ANC from current levels with higher deposition (even under the sensitivity analyses of 200% deposition). Furthermore, its pH has not changed since 2012 and is not predicted to change under any deposition scenario or sensitivity analysis.

The estimates of exceedances of critical loads and future changes in pH and Gran ANC are all based on steady-state modeling. Steady state models predict the eventual condition of lake chemistry under a sustained level of acidic deposition, but do not estimate the time frame over which the predicted changes will occur. We have used these models to assess the longer-term effects of the smelter. Dynamic models, which can provide predictions of changes over time, are not required for making decisions about the potential longer-term impacts of the smelter, and require much more intensive monitoring of hydrology, soils and lake chemistry.

Table 7-10. Summary of the estimated critical loads and the predicted exceedances, pH and Gran ANC under the 42 tpd emissions scenarios. Red cells indicate critical loads of zero, positive exceedances, predicted declines in pH of greater than 0.3 pH units, or predicted declines in Gran ANC that exceed the lake-specific threshold. Yellow cells indicate predicted declines in pH of greater than 0.1 pH units (but less than 0.3 pH units). The changes in LAK007 and LAK034 are unrelated to the smelter, as per the evidentiary framework and further explained in the text. Total sulphur deposition includes the CALPUFF estimate plus background deposition of 7.5 meq/m². NO_3^- leaching is a minor contribution to exceedance but included for clarity on how the exceedance is calculated.

	CALPUFF results		SSWC Model Results			ESSA-DFO Model Results								
	S Deposition (42tpd)		Total S Dep. + NO_3^- leaching	Critical load	Ex(A)	pH				Gran ANC (µeq/L)				
LAKE	meq/ m^2/yr	kg/ha / yr	meq/ m^2/yr	meq/ m^2/yr	meq/ m^2/yr	Baseline (2012)	Post-KMP (2016-18)	Future (steady-state)	ΔpH (from 2012)	Baseline (2012)	Post-KMP (2016-18)	Future (steady-state)	ΔANC (from 2012)	ANC threshold
EEM Sensitive Lakes														
LAK006	12.2	5.9	20.5	29.4	-8.9	5.8	6.0	6.0	0.2	25.7	27.7	24.7	-1.0	-10.8
LAK012	11.8	5.7	19.9	68.1	-48.3	5.6	6.2	6.1	0.5	57.0	58.3	56.0	-1.0	-16.3
LAK022	11.2	5.4	19.0	58.3	-39.3	5.9	6.1	6.0	0.1	27.8	33.0	30.4	2.6	-11.5
LAK023	11.1	5.3	19.4	33.3	-13.9	5.7	5.9	5.9	0.2	19.8	26.4	23.8	4.0	-10.5
LAK028	63.6	30.5	72.6	81.1	-8.5	5.0	5.0	4.8	-0.2	-4.0	-3.5	-9.3	-5.3	-13.4
LAK042	3.4	1.6	11.2	17.4	-6.3	4.7	5.2	5.2	0.5	-20.4	5.6	4.2	24.6	-24.4
LAK044	3.6	1.7	11.4	0.0	11.4	5.4	5.6	5.5	0.1	1.3	5.0	2.8	1.5	-6.2
EEM Less Sensitive Lakes														
LAK007	22.1	10.6	30.0	1383.4	-1353.5	8.0	8.0	8.0	0.0	1437.6	1385.9	1385.9	-51.6	-50.6
LAK016	13.2	6.4	21.5	118.1	-96.7	6.3	6.7	6.6	0.3	68.7	89.8	88.0	19.4	-25.6
LAK024	11.8	5.7	20.2	551.6	-531.4	7.1	7.5	7.5	0.4	299.5	463.2	463.2	163.7	-60.4
LAK034	4.7	2.2	12.5	138.4	-126.0	6.7	6.4	6.4	-0.3	99.4	139.6	138.7	39.3	-22.0

Reapplying the STAR Criteria for Inclusion in EEM

The STAR identified lakes with low pH (<6.0 pH units) and/or predicted exceedances of their critical loads and/or predicted declines in pH of greater than 0.1 pH units. The seven lakes identified for inclusion in the EEM program were those with a predicted pH decline of greater than 0.1 pH units. Lakes with existing pH<6.0 that did not have a predicted pH decline greater than 0.1 pH units were not included. Lakes with a positive exceedance and pH>6.0 would have been considered for inclusion but none of the STAR lakes met those criteria.

We used the same criteria from the STAR to position the lakes within the study area (Figure 7-9). The updated classification shows that of the seven lakes previously predicted to have a future pH decline greater than 0.1 pH units relative to 2012, only one of the lakes (LAK028) remains in that classification. Furthermore, of the eight lakes previously predicted to have an exceedance under the maximum level of emissions, only four of those lakes remain in that classification and all those lakes have critical loads of zero. It should be noted that two KAEEA lakes added to the present study (but outside the boundaries of the STAR study area) also have exceedances predicted, but similarly they also both have critical loads of zero, pre-KMP pH (i.e., 2013) less than 6.0 and also original pre-industrial pH less than 6.0. Therefore, had these two KAEEA lakes been included in the original STAR, they would have been identified as naturally acidic lakes with a negligible predicted change in pH and thus excluded for consideration as EEM lakes.

The results of the updated analyses of critical loads, exceedances and future pH suggest that the STAR did not omit any lakes that should have been considered for inclusion in the EEM. Additionally, it suggests that many of the lakes included in the EEM no longer match the inclusion criteria initially applied.

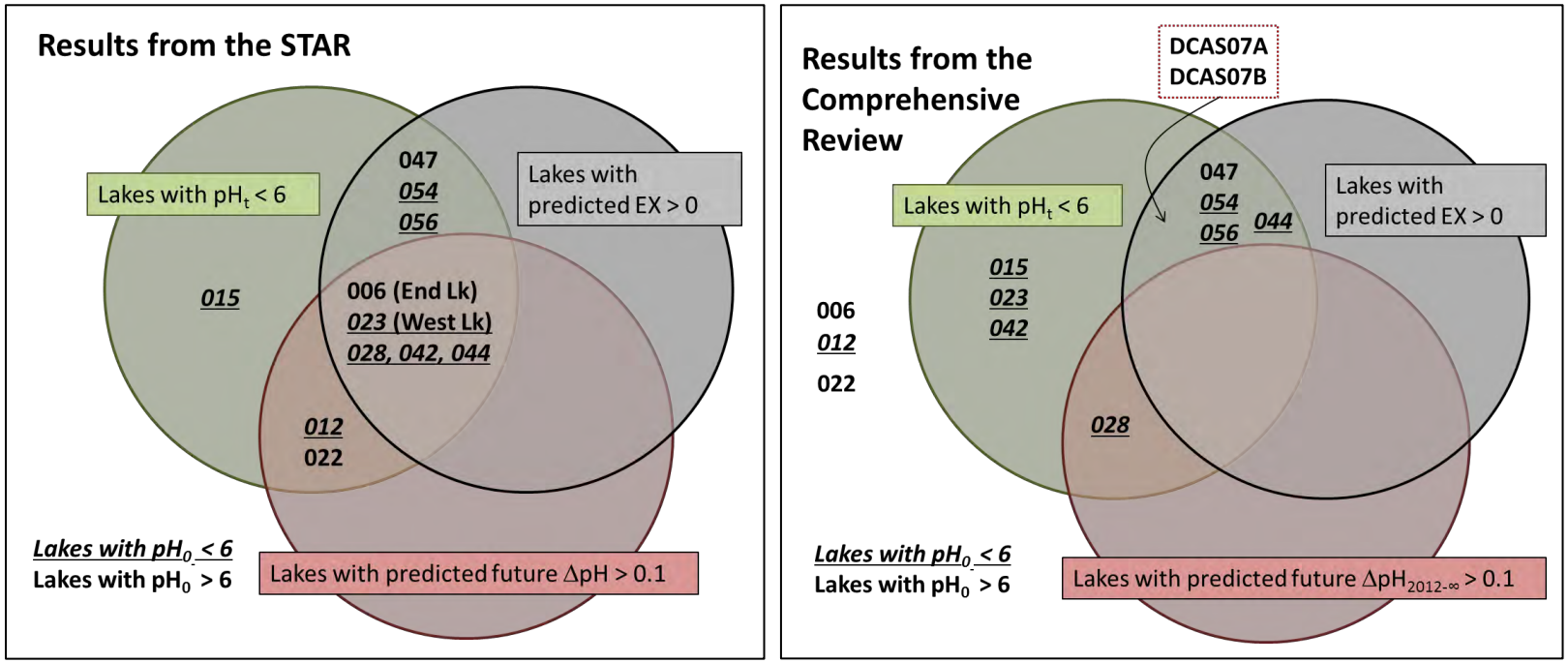


Figure 7-9. Application of the STAR criteria for identifying potential lakes for further monitoring using the new results available. The left panel shows the STAR results and the right panel shows the current results. Current pH (pH_t) and predicted change in pH are relative to 2012. DCAS07A and DCAS07B were from the KAEEA, therefore a) they were not included in the STAR classification, b) pH_t refers to 2013, and c) they do not have estimates of ΔpH (due to lacking deposition data for comparable emissions scenarios to the STAR). The results for LAK015, LAK047, LAK054, and LAK056 are based on their critical loads from the STAR (and do not have updated predictions of steady-state pH, as discussed elsewhere), whereas the results of LAK006, LAK012, LAK022, LAK023, LAK028, LAK042 and LAK044 (i.e., the EEM lakes) are based on the analyses using the most recent data.7

7.3.2.6 *Kitimat River water quality*

The results of the water quality sampling at the Rio Tinto intake on the Kitimat River are shown in Aquatic Appendix H. None of the results showed exceedances of the B.C. water quality objectives. The maximum measured sulphate concentration was less than 1% of the B.C. Drinking Water Guideline.

7.3.2.7 *Results from previously reported analyses*

Results from other, supporting analyses that have been previously reported during the EEM Program are summarized in Aquatic Appendix A. These assessments and/or analyses include: fish sampling in EEM lakes, a literature review of the potential effects of acidification on amphibians, lake level monitoring, estimation of water residence time for lakes, and sampling of non-EEM sites.

7.3.3 Modifications to the EEM Program

Modifications to the aquatic ecosystem component of the EEM Program during this phase (i.e., 2013-2018) have included: adding LAK024; adding three control lakes; increasing the frequency of water chemistry sampling to four times each fall for six of the seven sensitive lakes; and several Rio Tinto initiatives: adding continuous pH monitors to LAK006, LAK012 and LAK023 (End Lake, Little End Lake and West Lake) and LAK028 more recently, adding water level monitoring, conducting bathymetric surveys, improving the method for defining watershed area, adding a commercial laboratory, and, for LAK028, developing a depth profile and conducting depth sampling. These modifications and other improvements are further described in Aquatic Appendix A.

7.3.4 Comprehensive synthesis ('pulling all the pieces together')

7.3.4.1 *Synthesis across four lines of evidence*

We have synthesized four lines of evidence in Table 7-11: statistical analyses of changes over time in SO_4, pH and ANC; observed changes in pH, modelling of CL exceedance; and modelling of future changes in pH. Statistical analyses of data from the EEM Program have revealed patterns of change in lake chemistry, and allowed hypothesis testing for key questions despite natural variability in water chemistry. As the EEM program continues, we will have more years of post-KMP data, which will increase the statistical power to detect changes in lake chemistry. The overall conclusions are as follows:

- Of the 14 lakes in the EEM program (seven acid-sensitive lakes, four less sensitive lakes, three control lakes), 12 lakes show no evidence of sulphur-induced acidification causally related to the Kitimat smelter.

- LAK028, a 1 ha fishless lake[47] close to the Kitimat smelter, shows some evidence of sulphur-induced acidification causally related to the smelter, but the data indicate a low percentage belief that thresholds for ΔpH and ΔANC have been exceeded (18% and 2% respectively). Chemical conditions in LAK028 were potentially damaging to aquatic biota pre-KMP (i.e., in 2012 and 2013) and have remained so post-KMP (2016-2018); see Section 7.1.2.3 of Aquatic Appendix A. LAK028 is the only sensitive lake with a predicted future pH below 2012 levels under a 42 tpd emission scenario (0.2 units below 2012 levels, still less than the KPI threshold of 0.3 units).
- LAK012 (Little End Lake), a 2.3 ha lake to the southwest of Lakelse Lake, has shown increased concentrations of sulphate and some evidence of a decline in ANC, but no evidence of sulphur-induced acidification causally related to the smelter that exceeds the ANC or pH thresholds established in the EEM Plan to protect aquatic biota.

The design of the EEM program, and the set of analytical methods outlined in the TOR, provide valuable insights for assessing trends in lake chemistry.

[47] LAK028 is the headwater to Goose Creek, where fish have been found. However, all the samples taken from the many tributaries collectively known as Goose Creek (15 samples, over 2014, 2015 and 2018, across 11 sites) were found to be insensitive to acidification (see Aquatic Appendix A Sections 7.1.2.8 and 7.1.4.2).

Table 7-11. Synthesis of evidence from water chemistry analyses, critical loads (CL) models and ESSA-DFO model. Shading in the table: green – evidence against past or future acidification; yellow – situation worth close monitoring; red – exceedance of CL or decrease in observed / predicted pH (see Section 7.3.4.2). With respect to the rightmost column, average emissions over 2016-2018 have been 29.3 tpd. The 0.3 pH decline in LAK034 is not related to SO_4, which declined from 2012 to 2016-2018. The control lakes do not have results from the CL modelling or the ESSA-DFO model because they are located outside the CALPUFF model area and therefore do not have estimates of deposition. Note: Future pH is predicted to be similar or less than current pH for all lakes, but this is still higher than 2012 due to increases observed since 2012 (see Section 7.3.2.5).

Lake	Insights from Water Chemistry Analyses[48]	Observed ΔpH from 2012 to mean of 2016-2018	Insights from CL Modelling (exceedance under 42 tpd, in meq/m²/yr)	Insights from ESSA-DFO Modelling under 42 tpd
Sensitive Lakes				
LAK006	**SO_4^{2-} increase**; no evidence of S-induced acidification	0.2 unit pH increase	No exceedance predicted (-9)	Predicted future pH > 2012
LAK012	**SO_4^{2-} increase**; some evidence of S-induced acidification; no evidence of exceeding pH and ANC thresholds	0.5 unit pH increase	No exceedance predicted (-48)	Predicted future pH > 2012
LAK022	**SO_4^{2-} increase**; no evidence of S-induced acidification	0.1 unit pH increase	No exceedance predicted (-39)	Predicted future pH > 2012
LAK023	*SO_4^{2-} decrease*; no evidence of S-induced acidification	0.2 unit pH increase	No exceedance predicted (-14)	Predicted future pH > 2012
LAK028	**SO_4^{2-} increase**; some evidence of S-induced acidification; no evidence of exceeding ANC threshold; low belief in exceeding pH threshold[49]	0.0 unit pH change	No exceedance predicted (-9)	Predicted future pH is 0.2 pH units below 2012
LAK042	No clear change in SO_4^{2-}; no evidence of S-induced acidification	0.5 unit pH increase	No exceedance predicted (-6)	Predicted future pH > 2012
LAK044	*SO_4^{2-} decrease*; no evidence of S-induced acidification	0.2 unit pH increase	Zero CL; Exceedance predicted (11)	Predicted future pH > 2012
Less Sensitive Lakes				
LAK007	*SO_4^{2-} decrease*; no evidence of S-induced acidification	0.0 unit pH change	No exceedance predicted (-1354)	Predicted future pH > 2012
LAK016	**SO_4^{2-} increase**; no evidence of S-induced acidification	0.3 unit pH increase	No exceedance predicted (-97)	Predicted future pH > 2012

[48] See Table 7-9 for additional information on this line of evidence.
[49] Conditions in LAK028 were potentially damaging to biota pre-KMP and have generally remained so (Section 7.1.2.3 of Aquatic Appendix A)

Lake	Insights from Water Chemistry Analyses[48]	Observed ΔpH from 2012 to mean of 2016-2018	Insights from CL Modelling (exceedance under 42 tpd, in meq/m²/yr)	Insights from ESSA-DFO Modelling under 42 tpd
LAK024	**SO_4^{2-} increase**; no evidence of S-induced acidification	0.4 unit pH increase	No exceedance predicted (-531)	Predicted future pH > 2012
LAK034	*SO_4^{2-} decrease*; no evidence of S-induced acidification	-0.3 unit pH decrease (not related to smelter)	No exceedance predicted (-126)	Predicted future pH is 0.3 pH units below 2012 *(zero additional change predicted)*
Control Lakes		*Change from 2013*		
DCAS14A	No clear change in SO_4; no evidence of S-induced acidification	0.2 unit pH increase	Outside CALPUFF model area	Outside CALPUFF model area
NC184	No clear change in SO_4; no evidence of S-induced acidification	0.1 unit pH increase	Outside CALPUFF model area	Outside CALPUFF model area
NC194	SO_4^{2-} decrease; no evidence of S-induced acidification	-0.2 unit pH decrease	Outside CALPUFF model area	Outside CALPUFF model area

7.3.4.2 *Changes to and/or confirmation of the STAR results and assumptions*

Emissions / deposition**:** Post-KMP emissions have been well below the maximum permit emissions that were applied in the STAR (42 tpd). The steady-state analyses of critical loads, exceedances and future pH are still based on deposition levels under the maximum future emissions (i.e., 42 tpd) but the estimated deposition at each of the EEM lakes under that maximum scenario (as based on the updated CALPUFF modelling framework) is less than was previously estimated in the STAR. Therefore, deposition values under both current and future maximum emissions are less than predicted in the STAR. See Chapter 3 for further details on the changes in the atmospheric modelling framework.

F-factor: LAK028 was the only lake with a sufficient change in lake sulphate to permit an empirical estimate of the F-factor to compare against the model-based estimates used in the STAR (see Section 2.3.3 of Aquatic Appendix G). The revised empirically-based estimates of the F-factor for LAK028 are in the range from 0.65 to 0.85, compared to an initial estimate of 0.44 in the STAR. This indicates that over the period of the EEM program approximately 65% to 85% of the deposited acidity associated with sulphur deposition was neutralized by exchanges for base cations in the watershed of LAK028. Thus, LAK028 was able to neutralize a larger fraction of the deposited acidity than had been assumed in the STAR.

Critical Loads and Exceedances: Fewer lakes are predicted to have exceedances under the maximum future emissions of 42 tpd than were predicted in the STAR. Only one lake (LAK044) shows an exceedance under the 42 tpd emissions scenario. Because LAK044 has a critical load of zero, it has an exceedance under all emissions scenarios. In the STAR, five of the EEM lakes were predicted to have exceedances under the "post-KMP" emissions scenario (i.e., also based on emissions of 42 tons SO_2 per day). For eight of the 11 EEM lakes, the revised estimates of critical loads are quite similar to the original estimates in the STAR. The revised critical load estimates are higher than the STAR for LAK024 and LAK028 and lower for LAK012. The exceedances of the revised critical loads under the 42 tpd emissions scenario are consistently smaller in magnitude than those predicted in the STAR (Figure 7-7). Since the revised estimates of critical loads are mostly similar to those in the STAR, the reduction in the magnitude of exceedances relative to the STAR primarily reflects lower estimates of deposition. See Section 7.3.2.5 and Aquatic Appendix G.

Predicted Future Steady-state pH: The updated predictions of future pH are higher than the predictions from the STAR for all of lakes except LAK034, which has already decreased below its STAR prediction and is not predicted to change further. We developed new predictions of future steady-state pH for the EEM lakes, using average lake chemistry conditions for the post-KMP period (2016-18) and the change in deposition from the modelled current deposition (29.3 tpd) to the modelled maximum future deposition (42 tpd). The pH is predicted to decrease or remain unchanged for all of the EEM lakes relative to current pH, but because current pH is predominantly above 2012 pH levels, these steady-state predictions appear to show an increase in pH when compared to 2012. By comparison, the STAR predicted that future pH would be lower than 2012 values for all of the sensitive EEM lakes and one of the less sensitive EEM lakes, and would remain unchanged for the other three less sensitive EEM lakes. See Section 7.3.2.5 and Aquatic Appendix G.

7.3.4.3 *Summary of observed changes in lake chemistry, 2012-2018*

The statistical analyses of empirical observations of the changes in lake chemistry between 2012 and the average of the post-KMP years (2016-2018), summarized in Table 7-9 show the following patterns for the seven sensitive EEM lakes, four less sensitive EEM lakes and the three control lakes:

- There was a high percent belief in increases in $[SO_4]$ in four of the sensitive lakes (LAK006, LAK012, LAK022, LAK028) and two of the less sensitive lakes (LAK016 and LAK024). There was an intermediate percent belief in SO_4^{2-} increases within two of the control lakes (DCAS14A and NC184) and one of the sensitive lakes (LAK042). The other 5 lakes had no support for increases in $[SO_4]$.
- All but one of the 14 lakes (LAK007) showed a low percent belief in Gran ANC declines below the lake specific threshold; (LAK007) showed an intermediate level of support for such a decline, but is a very insensitive lake with very high Gran ANC.
- All but two of the 14 lakes (less sensitive lake LAK034 and control lake NC184) showed a low percent belief in pH declines of 0.3. LAK034 had an intermediate percent belief in a pH decline of 0.3, but since $[SO_4]$ in this lake declined to essentially zero, this change was unrelated to the smelter. Control lake NC184 also showed an intermediate percent belief in a pH decline of 0.3, but this reflects a small data set (just 4 samples); the mean pH changed from 5.7 in 2012 to 5.8 over 2016-18.

See Sections 7.3.1 and 7.3.2.3 and Aquatic Appendices A, C, D and F for full details.

7.3.4.4 *Exceedances of EEM indicators*

Based on the KPIs and thresholds in the EEM Plan (for pH), as well as those added for Gran ANC, there have been no exceedances of these thresholds. This is also the case when using the alternate baseline of 2012-14, as described in Aquatic Appendix I.

7.3.4.5 *Application of the Evidentiary Framework*

Applying the simplified evidentiary framework from Figure 7-3 to the 14 lakes, we obtain Figure 7-10. The results of applying this decision tree are as follows:

- At the first blue decision box (*Has lake $[SO_4]$ increased since pre-KMP period?*), six lakes are eliminated from further consideration of smelter effects, as there is strong evidence of decreases in their sulphate concentrations: Sensitive lakes LAK023 and LAK044; Less Sensitive lakes LAK007 and LAK034; Control lakes NC194 and NC184. Control lake DCAS14A is also eliminated from further consideration, as all of the control lakes are well outside of the smelter's plume (see Figure 7-1), and therefore any changes in lake sulphate were not associated with the smelter. In addition, observed increases over time in sulphate were negligible in both NC184 (0.5 µeq/L), and DCAS14A (i.e., 3 µeq/L); Table 7-6. Control lake NC194 showed an observed decrease in sulphate concentrations of 1.1 µeq/L (Table 7-6).
- At the second blue decision box (*Has lake pH or Gran ANC decreased since pre-KMP period?*), five more lakes are eliminated from further consideration of smelter effects, as there is strong evidence that their pH and Gran ANC concentrations have not declined: Sensitive lakes LAK006, LAK022, LAK042; and Less Sensitive lakes LAK016, LAK024. The evidence is insufficient to reject the hypothesis of declines in Gran ANC for sensitive lakes LAK012 and LAK028 (46% and 34% belief in an ANC decline, Table 7.73 in Aquatic Appendix F), so they move on to the next part of the decision tree.

- At the third blue decision box, we find that lakes LAK012 and LAK028 have not exceeded the thresholds for either pH or Gran ANC (low % belief, see Table 7-9). These lakes should be closely monitored over time. In the ranking of lakes within the EEM Plan (Appendix D in ESSA et al. 2014), both these lakes were considered to be of low importance.
- In response to requests from reviewers of the draft comprehensive review report, we have completed a sensitivity analysis to assess the effects of using 2012-2014 as an alternative baseline to 2012 (Aquatic Appendix I). While use of a 2012-2014 baseline does change some of the results of the statistical analyses, it does not change any of the overall conclusions regarding effects of the smelter on EEM lakes (see Table 3-4 and Figure 6 in Aquatic Appendix I).

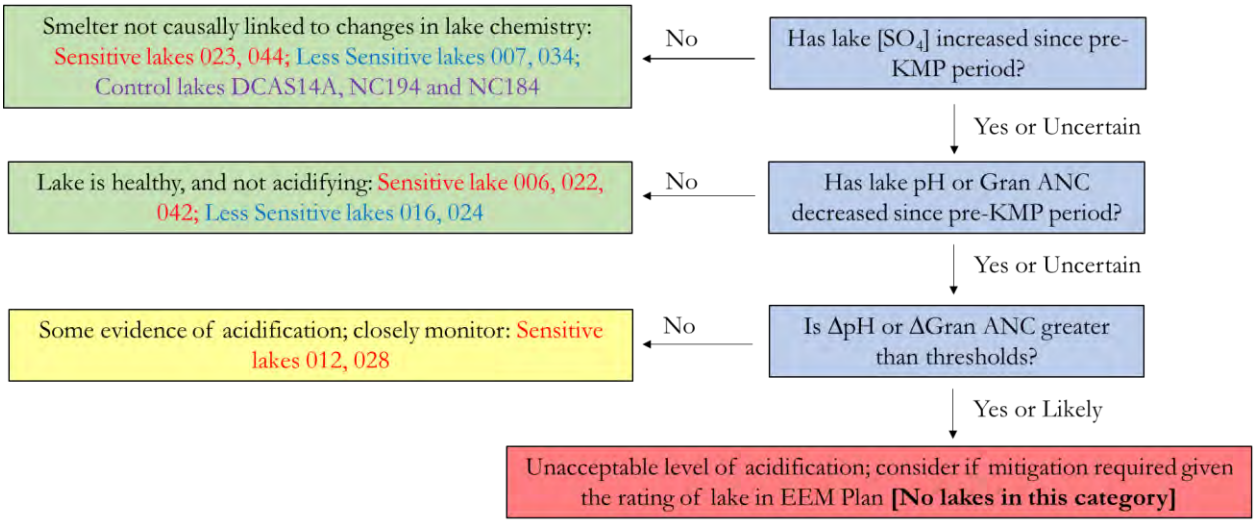


Figure 7-10. Classification of EEM lakes according to the simplified evidentiary framework in Figure 7-3.

Table 7-12. Application of EEM Evidentiary Framework (Table 17 in the 2014 SO_2 EEM Plan, ESSA et al. 2014a) for evaluating if acidification has occurred and whether it is or is not related to KMP. SPR = Source-Pathway-Receptor conceptual model for the EEM Program (see Section 1.1). The last three columns show answers to the question in column 2. Highlighted cells are the answer to the question (pink for evidence consistent with smelter effects, orange for evidence inconsistent with smelter effects, purple for uncertain outcomes).

Links in SPR model	Question	Methods Used to Answer Question *Answers to question* [References with examples of these analyses]	Implications of Answers		
			Evidence consistent with KMP as primary cause of observed change	Evidence against KMP as primary cause of observed change	Can't answer question with available data
3	Have SO_2 emissions from KMP increased significantly beyond levels in the pre-KMP period, potentially causing increased acidic deposition?	Compare mean daily emissions in pre-KMP period vs. KMP ramp-up period vs. post-KMP steady state period; assess trends. *Emissions of SO_2 increased from an average of 12.5 tpd in 2012-2015 (pre-KMP plus transition period) up to an average of 29.3 tpd over 2016-2018 (post-KMP period); see Section 1.* ***Therefore, emissions increased by about 135% between the 2012-2015 period and the 2016-2018 period.***[50]	**Yes**	No	Uncertain
3	Has SO_4^{2-} deposition at Kitimat and Lakelse monitoring stations increased since pre-KMP period in a manner proportional to SO_2 emissions? Has N deposition shown negligible changes? Is deposition of base cations too low to neutralize SO_4^{2-} deposition?	Compare monthly and annual SO_4^{2-} deposition in pre-KMP period vs. KMP ramp-up period vs. post-KMP steady state, and assess trends, for each deposition site. *Wet deposition increased by 37% at Haul Road (2016-2018 vs. 2012-2015) and by 62% at Lakelse Lake (2016-2018 vs. 2013-2015); Section 3.2. Dry deposition increased by 73% at Haul Road between 2015 and 2016-2018 (Section 3.2).* ***Therefore, wet and dry deposition have increased, but by a smaller percentage than the increase in SO_2 emissions.*** *The most likely explanation for this pattern is that only a small fraction of the emitted SO_2 is deposited within the study area (8.1%, see Section 3.2).*	**Yes**, but not proportional to change in emissions	No	Uncertain

[50] We are using the periods 2012-2015 and 2016-2018 to allow comparisons with the record of deposition monitoring. We used only 2012 as a pre-KMP period for pH and Gran ANC, as discussed in Section 7.3.2.2.

Links in SPR model	Question	Methods Used to Answer Question *Answers to question* [References with examples of these analyses]	Implications of Answers		
			Evidence consistent with KMP as primary cause of observed change	Evidence against KMP as primary cause of observed change	Can't answer question with available data
2, 3	Has background SO_4^{2-} deposition (long range sources outside the study area) increased much less than the estimated increase in KMP-related SO_4^{2-} deposition, since the pre-KMP period?	Examine trends in SO_4^{2-} deposition and [SO_4] in wet deposition from Alaska and other monitoring stations, as reported in the literature. Compare observed change to modelled effect of KMP deposition. *Whereas wet deposition of SO_4^{2-} increased by 37% and 62% at Haul Road and Lakelse Lake (respectively) between pre-KMP and post-KMP periods, wet deposition at three NADP monitoring sites outside of the study area (Port Edward, B.C.; Marblemount, WA; Juneau, AK) showed decreases of 23%, 26%, and 25% between the pre and post-KMP periods (see Section 3.2).* ***Therefore, background wet deposition has decreased during the period that wet deposition increased within the study area.***	**Yes**	No	Uncertain
3, 8, 9	Has lake [SO_4] increased post-KMP in a manner consistent with predicted increases in deposition of SO_4, and deposition levels inferred from monitoring observations?	Examine distribution of changes in lake [SO_4] across multiple lakes and time trends within individual lakes. Compare trends in [SO_4] to predicted changes in SO_4^{2-} deposition with KMP in the STAR, as well as observed SO_4^{2-} deposition from Kitimat and Lakelse monitoring stations. *There is strong support for SO_4^{2-} increases in six of the 14 EEM lakes (LAK006, LAK012, LAK022, LAK016, LAK024 and LAK028), intermediate support in three lakes (LAK042, DCAS14A, NC184), and very low support in five lakes (LAK044, LAK034, LAK023, LAK007, NC194). In LAK028 and LAK024 (Lakelse Lake) the change in lake SO_4^{2-} was greater than expected (Section 7.1.3.1.2 of Aquatic Appendix A), but it was less than expected in the other 9 EEM lakes included in the analysis (all but the control lakes). The trends in lake [SO_4^{2-}] are not correlated with changes in emissions of SO_2 (Aquatic Appendix F).* ***Despite evidence of increased wet deposition of SO_4, there is strong support for increased lake [SO_4^{2-}] in only 6 of 14 lakes.***	**Yes *for 6 lakes***	**No *for 5 lakes***	**Uncertain *for 3 lakes***

Links in SPR model	Question	Methods Used to Answer Question *Answers to question* [References with examples of these analyses]	Implications of Answers		
			Evidence consistent with KMP as primary cause of observed change	Evidence against KMP as primary cause of observed change	Can't answer question with available data
7,9	Do the observed spatial and temporal changes in climate, pH, ANC, DOC and sulphate suggest drought-caused oxidation of sulphate stored in wetlands, related to KMP rather than due to climate fluctuations affecting wetland storage of historical S deposition?	Examine trends in annual precipitation from meteorological stations, and assess if periods of drought followed by wetter years were correlated with increases in [SO_4] and decreases in ANC. *This question is most relevant for two lakes (LAK012, LAK028) where there have been increases in SO_4, and decreases in pH or ANC (though less than the thresholds). However, there is no wetland upstream of LAK028, and there is no evidence of changes in DOC, which would be expected if there were releases of SO_4^{2-} from wetlands. There was a drought in the summer of 2018, so 2019 data will be important to determine if the drought and subsequent wash-out of watershed ions had any temporary effects on water chemistry in the following year. It may not be possible to confidently answer this question, as wash-out of watershed ions could occur at times of the year outside of the sampling window.* ***Uncertain.***	Yes	No	**Uncertain**
8	Has lake ANC decreased post-KMP in a manner consistent with increases in lake [SO_4] and watershed neutralizing abilities (F-factor)?	Examine distribution of changes in lake ANC across multiple lakes and ANC time trends within individual lakes. Compare ANC and SO_4^{2-} time trends. *Changes in mean ANC between 2012 and 2016-2018 have been positive in all 7 sensitive lakes, opposite from what was predicted given the estimated change in SO_4^{2-} deposition (Section 7.1.3.1.2 of Aquatic Appendix A). This question is most relevant for just two of the seven sensitive lakes (LAK012, LAK028) where there is strong support for increases in SO_4^{2-}, moderate support for decreases in ANC (46% and 34%, respectively), but very low support for ANC changes beyond the KPI thresholds (1% and 2% respectively). Changes in mean ANC have been opposite to what was expected given the increase in SO_4^{2-} concentrations, and the F-factors for these lakes (i.e., mean ANC increased rather than decreased).* ***Therefore, ANC has not decreased post-KMP in a manner consistent with increases in lake [SO_4^{2-}] and watershed neutralizing abilities.***	Yes	**No**	

Links in SPR model	Question	Methods Used to Answer Question *Answers to question* [References with examples of these analyses]	Implications of Answers		
			Evidence consistent with KMP as primary cause of observed change	Evidence against KMP as primary cause of observed change	Can't answer question with available data
8	Has lake pH decreased post-KMP in a manner consistent with SO_4^{2-} increases, ANC decreases, and lake-specific titration curves?	Examine distribution of changes in lake pH across multiple lakes and time trends within individual lakes. Use lake-specific titration curves to assess if SO_4, ANC and pH changes are all consistent with hypothesis of SO_4-driven acidification. *Changes in mean pH between 2012 and 2016-2018 have been positive in all 7 sensitive lakes, opposite from what was predicted given the estimated change in SO_4^{2-} deposition (Aquatic Appendix G). This question is only relevant for just two of the seven sensitive lakes (LAK012, LAK028) where there is strong support for increases in SO_4. Based on the fall sampling (four samples/year), there is 0% support for decreases in mean lab pH in LAK012, and 1% support for decreases greater than the KPI threshold. LAK028 shows intermediate support for decreases in pH (46% belief; Aquatic Appendix F), but low support that these decreases exceeded the KPI threshold of 0.3 pH units (18%; Aquatic Appendix F).* ***Therefore, lake pH has not decreased post-KMP in a manner consistent with SO_4^{2-} increases.***	Yes	**No**	
8	Have lake pH and ANC values decreased beyond identified thresholds?	Assess pH changes across all 7 EEM lakes, and the percent of comparisons showing decreases of more than 0.3 pH units. Examine time trends in pH and ANC using regression analyses for lakes with more intensive monitoring that provide better estimates of natural variation in pH and ANC. *This question is only relevant for two of the seven sensitive lakes (LAK012, LAK028) where there is strong support for increases in SO_4, and low to intermediate support for changes in either pH or ANC. There are only very low levels of support for changes in pH and ANC beyond the thresholds (pH: 1%, 18%; ANC: 1%, 2% respectively for LAK012, LAK028). Two of the three intensively monitored lakes (LAK006, LAK012) showed both increased SO_4^{2-} and declining trends in pH since late 2014, but these trends reflect changes from an elevated baseline after emissions declined, were not statistically*	Yes	**No**	

Links in SPR model	Question	Methods Used to Answer Question *Answers to question* [References with examples of these analyses]	Implications of Answers		
			Evidence consistent with KMP as primary cause of observed change	Evidence against KMP as primary cause of observed change	Can't answer question with available data
		significant and did not exceed the 0.3 threshold. ***None of the lake pH and ANC values have decreased beyond identified thresholds.***			
2, 3, 7, 8, 9	Are observed changes in Cl^-, NO_3^- and DOC consistent with causes of acidification other than KMP (i.e., sea salt driven episodes, N emissions, organic acidification)?	Examine the percent anion composition of each lake and how it has changed over time. *This question is only relevant for just two of the seven sensitive lakes (LAK012, LAK028) where there is strong support for increases in SO_4, and low to intermediate support for changes in either pH or ANC. Based on visual inspection of graphed data, there are no apparent changes in nitrate, Cl^- or DOC, though we have not conducted statistical analyses of these parameters.* ***There is no apparent evidence for acidification driven by sea salt, N emissions or organic acidification.***	No	Yes	

7.3.5 Conclusions

7.3.5.1 *Does the Weight of Evidence indicate that KMP has contributed to the acidification of aquatic ecosystems?*

Of the 14 lakes in the EEM program (seven acid-sensitive lakes, four less sensitive lakes, three control lakes), 12 lakes show no evidence of sulphur-induced acidification causally related to the Kitimat smelter. The sensitive lakes have shown considerably less response to increased emissions than was predicted in the STAR. LAK028, a 1 ha fishless lake close to the Kitimat smelter, shows some evidence of sulphur-induced acidification causally related to the smelter, a continuation of pre-KMP conditions, but the EEM thresholds for ΔpH and ΔANC have not been exceeded. LAK012 (Little End Lake), a 2.3 ha lake to the southwest of Lakelse Lake, has shown increased concentrations of sulphate and some evidence of a decline in ANC, but no evidence of sulphur-induced acidification causally related to the smelter that exceeds the ANC or pH thresholds established in the EEM Plan to protect aquatic biota.

7.3.5.2 *Summary of answers to questions in the STAR and EEM*

Table 7-13 summarizes the answers to the key questions identified in the STAR, as described in Section 7.1. Table 7-14 summarizes the answers to the other questions that emerged during or since the development of the EEM Plan, as described in Section 7.1.3.

Table 7-13. Summary of answers to questions in the STAR.

Questions from the STAR	Answers
W1. How do assumptions in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post- KMP?	The main report describes the expected level of exceedance of critical loads, and future changes in pH and Gran ANC under the most likely assumptions. Aquatic Appendix G contains sensitivity analyses for many model inputs and parameters. In general, the model results are robust to wide variation in assumptions.
W2. How many of the seven to ten potentially vulnerable lakes actually acidify under KMP, and to what extent?	Of the 14 lakes in the EEM program (seven acid-sensitive lakes, four less sensitive lakes, three control lakes), 12 lakes show no evidence of sulphur-induced acidification causally related to the Kitimat smelter. LAK028, a 1 ha fishless lake close to the Kitimat smelter, shows some evidence of sulphur-induced acidification causally related to the smelter. LAK012 (Little End Lake), a 2.3 ha lake to the SW of Lakelse Lake, has shown increased concentrations of sulphate, but no consistent evidence of sulphur-induced acidification causally related to the smelter.
[**W2a**.] Have any of the sensitive lakes exceeded their KPI thresholds?	As illustrated in the simplified evidentiary framework, this question is only relevant for lakes which have shown an increase in sulphate concentrations, and a potential decline in either pH or ANC (i.e., any level of decline, irrespective of the thresholds). Only two lakes meet these criteria: LAK028 and LAK012. However, LAK028 shows a low % belief that thresholds for either ΔpH and ΔANC have been exceeded (18% belief and 2% belief respectively) and LAK012 shows no support for exceedance of the thresholds for either ΔpH or ΔANC (1% belief for both thresholds).
[**W2b**.] Does the weight of evidence suggest that any of the lakes have actually acidified and that such acidification is due to KMP (examining changes in all relevant water chemistry parameters)?	LAK028 showed evidence of smelter influence prior to KMP (described in the STAR), and still shows evidence of smelter influence. Its pH and Gran ANC levels have not decreased beyond the EEM thresholds.
[**W2c**.] What is the water chemistry of the four less sensitive lakes? Do any of them show any evidence of acidification and/or impact from KMP?	The data from two of the less sensitive lakes (LAK016 and LAK024 – Lakelse Lake) show strong evidence of increases in SO_4^{2-} (97% belief and 96% belief, respectively), but no support for decreases in pH or ANC beyond the EEM thresholds (0% belief and 1% belief respectively for pH; 1% belief and 1% belief for ANC). The other two less sensitive lakes (LAK007 and LAK034) show strong support for a decline in lake SO_4.
[**W2d**.] How many lakes have actually acidified due to KMP and exceeded their KPI thresholds?	None.
[**W2e.**] Are additional sites suggested by ENV (i.e., lakes MOE-3 and MOE-6, Cecil Creek, and Goose Creek) at risk of acidification under KMP?	No. All of these sites were found to have high critical loads and to be insensitive to acidification (see Section 7.4.1 and Aquatic Appendix A).

Questions from the STAR	Answers
W3. What is the current status of the fish community in the potentially vulnerable lakes that can be safely accessed for fish sampling?	Four of the seven sensitive lakes were sampled for fish using gill nets in 2013 (West Lake (LAK023), End Lake (LAK006), Little End Lake (LAK012), Finlay Lake (LAK044)), and a fifth sensitive lake was sampled in 2017 (LAK028). No fish were caught in Finlay Lake (which has no inlets or outlets) or in LAK028 (which has no inlet and a blocked outlet). Threespine stickleback and coho salmon were present in West Lake, End Lake and Little End Lake, though in West Lake the coho were confirmed to remain in freshwater for their entire life cycle, rather than going to sea. End Lake and Little End Lake also had coastal cutthroat trout and dolly varden char. Three of the less sensitive lakes were sampled in 2015: Clearwater Lake (LAK007), LAK016 and LAK034. They generally had similar fish assemblages and numbers of fish species to the sensitive lakes with fish. Coastal cutthroat trout was common in all three lakes. Other species found included coho salmon and dolly varden char (in LAK007 and LAK016), threespine stickleback (in LAK007 and LAK034), and (in LAK007 only) rainbow trout and Chinook salmon. Altogether, six species were found in LAK007, three in LAK016, and two in LAK034. Further details on age classes and size of fish are available in the Limnotek annual technical reports from each of the years of sampling.
W4. If some of the potentially vulnerable lakes that can be safely accessed for fish sampling show an acidifying trend, then do these lakes also show changes in their fish communities?	None of the lakes have shown an acidifying trend beyond the EEM thresholds requiring them to be resampled.

Table 7-14. Summary of answers to questions that emerged after the STAR, especially during the development and implementation of the EEM Program.

Questions that emerged after the STAR	Answers
How do the observed changes in SO_4, Gran ANC and pH compare to the steady-state predictions from the STAR?	The observed changes in SO_4, Gran ANC and pH have generally been much less than the steady-state predictions from the STAR (as adjusted to reflect actual emissions rather than maximum emissions). The only exceptions have been: 1) LAK024 increased in sulphate more than predicted (but showed very low support for a ΔGran ANC and ΔpH beyond the thresholds – 1% belief and 1% belief respectively, consistent with the STAR predictions of no change in either parameter) ; 2) LAK028 increased in sulphate much more than predicted; 3) LAK007 decreased in Gran ANC despite a prediction of no change (but LAK007 has an extremely high Gran ANC, and shows strong evidence (100% belief) of a small *decrease* in sulphate, indicating that the change in Gran ANC was unrelated to emissions from the smelter); and 4) LAK034 decreased in pH despite a prediction of

Questions that emerged after the STAR	Answers
	no change (but this is not associated with smelter emissions because sulphate decreased to essentially zero).
Can we estimate F-factors from the empirical sampling results?	Only for LAK028, where there was a sufficient change in lake sulphate to permit an estimate of the F-factor. The revised estimates of the F-factor are in the range from 0.65 to 0.85, compared to an initial estimate of 0.44 in the STAR, indicating that over the period of the EEM program approximately 65% to 85% of the deposited acidity associated with sulphur deposition was neutralized by exchanges for base cations in the watershed of LAK028. Some additional neutralization of acidity occurs through bacterial reduction of sulphate in the deeper waters (anoxic hypolimnion) of LAK028. The only way to determine the long-term ability of LAK028's watershed and in-lake processes to neutralize acidity is through continued monitoring of its lake chemistry.
Do we see any evidence of regional acidification if we analyze the lakes as a group rather than individuals?	No. There is a spatial pattern to changes in lake sulphate, with lakes closer to the smelter being more likely to show an increase in sulphate, but none of the lakes have acidified beyond the established thresholds for pH and Gran ANC (Figure 7-5).
Is there a benefit to adding appropriate control lakes to the EEM?	Yes. The control lakes provide insights and statistical inferences on natural variability in water chemistry unrelated to the smelter (e.g., year-to-year variation in regional weather patterns and longer term changes in climate), and can be used in statistical analyses to detect changes in the sensitive lakes that differ from the control lakes. The power analysis completed in 2016 demonstrated that inclusion of control lakes increases statistical power.
Is there a benefit to more intensive water sampling?	Yes. Intensive water sampling provides a better estimate of within-year variability in water chemistry, allows for a more precise estimate of lake chemistry for the fall period, and provides an additional data set for examining long-term trends in pH. As discussed below (Section 7.4), it is sufficient to have data from just one intensively monitored lake rather than three.
Is there a benefit to collecting other data on the EEM lakes?	Yes – the bathymetric analyses have provided a much more accurate estimate of lake volume and therefore improved our initial estimates of water residence time so we can better understand the temporal lag (or lack thereof) in lake chemistry responses to changes in deposition levels. Yes – the lake level data have provided information by which to examine the extent to which intra-annual changes in lake chemistry may be associated with hydrologic events. The lake level data provide information specific to the watershed rather than general regional patterns that are represented by weather stations or flow data from major rivers.
Will increased emissions result in immediate (i.e., same year) changes to lake chemistry or will there be a lag?	Changes in lake chemistry have not shown a consistent response to the increase in sulphur emissions after 2015. Additionally, estimates of water residence time shown in Appendix A (including revised estimates from those in the EEM Plan and more precise estimates for four lakes with bathymetry data) suggest that all seven sensitive lakes should respond within a year or two to changes in watershed inputs.

Questions that emerged after the STAR	Answers
How important will it be to consider multiple metrics in our evaluations of the data?	As discussed above in Section 7.1.3, the approach that we've used in this report, and will continue to use in future comprehensive review reports, uses multiple metrics, in a logical evidentiary framework. The simplified evidentiary framework (Figure 7-3) organizes multiple metrics into a logical decision tree.

7.3.5.3 *Assessment of acceptable or unacceptable impacts on aquatic receptor*

Based on the KPIs and thresholds in the EEM Plan (for pH), as well as those added for Gran ANC, there have been no exceedances of these thresholds, and therefore no unacceptable impacts on aquatic receptors

7.3.5.4 *What outstanding questions still require further or ongoing investigation?*

We only have three years of post-KMP data so far, and more years of data will improve our ability to detect how much change in water chemistry has occurred.

7.3.5.5 *What new questions have emerged?*

By the 2050s, global warming is likely to result in warmer summers (possibly drier or wetter) and warmer, wetter winters, with less snowpack[51]. Continued monitoring of both the sensitive lakes and control lakes will help to elucidate the independent and combined effects of the smelter and climate change.

LNG Canada will be developing a liquified natural gas facility in the Kitimat area, which will add emissions of both SO_2 and N oxides. Modelling will be required to disentangle the relative impacts of the Rio Tinto smelter and the LNG Canada facility.

7.4 What Do We Recommend for the EEM Program Going Forward?

7.4.1 Monitoring program for aquatic ecosystems

Going forward, we have the following recommendations for the monitoring program for aquatic ecosystems:

Recommendation 1 – Monitoring of sensitive lakes: The seven sensitive lakes should continue to be the core of the EEM Program. Continue with four samples of full chemistry each October from the six sensitive lakes that are accessible (LAK006, LAK012, LAK023, LAK028, LAK042, LAK044) to provide reliable measures of year-to-year changes in lake chemistry. Continue annual sampling (once per year) of sensitive LAK022, which is only accessible by helicopter.

Recommendation 2 – Monitoring of less sensitive lakes: Continue annual sampling of the full chemistry of less sensitive LAK016, which has an intermediate level of sensitivity (Gran ANC of 70 to 90 µeq/l). Discontinue the annual sampling of LAK007 (Clearwater Lake), LAK024 (Lakelse Lake) and LAK034, as the EEM program has shown these lakes to be insensitive under both *current* and *maximum future* levels of sulphur emissions. Under the initial EEM design, the less sensitive lakes were added to the sampling program to serve as reference points against which the changes in the sensitive lakes (i.e., the lakes of concern) could be compared. However, these

[51] Climate projections are available for the Kitimat-Stikine region from the Pacific Climate Impacts Consortium (PCIC) here: https://www.pacificclimate.org/analysis-tools/plan2adapt

lakes were not appropriate as controls since they are subject to the same exposure as the sensitive lakes (i.e., located within the plume) but not expected to change in response to increased emissions. Within the first couple years of the EEM Program, we decided that it would be most beneficial to add some true control lakes that would add information that would be more directly valuable to the program than the less sensitive lakes – i.e., lakes of comparable sensitivity to the EEM sensitive lakes that are located outside of the smelter plume and thus able to provide information about regional patterns independent of smelter emissions. Three such control lakes were added in 2015 (with baseline data from 2013), which provide a superior reference point for the lake chemistry patterns observed in the EEM sensitive lakes, and therefore the EEM less sensitive lakes no longer serve an essential purpose within the program. The box below provides some additional technical context on the relative sensitivity of the less sensitive lakes, especially the three being recommended to discontinue.

How sensitive are the "less sensitive" lakes

- **LAK024** (Lakelse Lake) was added to the EEM due its public importance. Analyses show that it has a high critical load (CL) (370 meq/m^2/yr based on the STAR 2012 data; 552 meq/m2/yr based on 2012-2018 data) but would receive only 11.8 meq/m2/yr of sulphur deposition under a 42 tpd emission scenario (Table 2-3 in Aquatic Appendix H). Therefore, S deposition would need to increase 31x to 47x above the permitted emission level of 42 tpd before LAK024 would exceed its CL (ratio of CL to deposition level under 42 tpd).
- For **LAK007** (Clearwater Lake, chosen due to its ease of access), S deposition would need to increase 63 X above the permitted level before its CL would be exceeded.
- For **LAK034**, in the north of the study area with a projected S deposition of only 4.7 meq/m2/yr under emissions of 42 tpd, deposition would need to increase 27x to 29x above the permitted level before its CL would be exceeded.

None of these three lakes showed any evidence of S-driven acidification (Table 7-12). With such a huge safety margin between maximum potential deposition and CLs, and no evidence of S-driven acidification, there is no need to continue to monitor these lakes within the EEM Program.

By comparison, the CL safety margin for **LAK016** (recommended for continued inclusion in the next phase of the EEM) is 9x. Although this is considerably smaller than for the other three EEM less sensitive lakes described above; however, it still means that S deposition would need to be almost an order of magnitude greater than the deposition modeled under the maximum permitted emissions level in order to exceed its estimated critical load.

Recommendation 3 – Monitoring control lakes: Continue annual sampling of the full chemistry of the three control lakes (NC184, NC194, DCAS14A) to provide reliable measures of year-to-year changes in lake chemistry, an assessment of regional factors such as changing weather patterns, and critical data for statistical analyses of changes in sensitive lakes relative to control lakes. Include one year with multiple sampling visits of the three control lakes during October, so as to estimate the within-year variability in lake chemistry, and thereby improve statistical inferences (added to the 2019 October lake sampling).

Recommendation 4 – Re-evaluation of EEM lakes monitoring program: We recommend that the EEM lakes be re-evaluated in the 2021 Annual Report with respect to their inclusion in the EEM Program going forward. Some of the EEM lakes (which were all identified in the STAR as being potentially sensitive to increased acidic deposition) are now not predicted to acidify under updated modelling based on additional years of data. There are multiple lakes that are not predicted to exceed their critical loads, not predicted to decrease in pH below their 2012 baseline

values, and do not show any evidence in their empirical observations of lake chemistry of patterns that are consistent with smelter-driven acidification. However, the power analyses conducted in 2014-2015 recommended that the EEM Program should not make any strong conclusions about the changes in lake chemistry that have occurred until there have been at least five years of post-KMP data collected. Therefore, we are recommending collecting an additional three years of post-KMP data for all of the originally identified sensitive lakes, for a total of six years of post-KMP data, before making any conclusions about the need for the continued inclusion of each of the lakes.

Recommendation 5 – Additional lakes: We do not recommend adding any additional lakes to the EEM Program. We examined the critical loads and exceedances in the context of the updated CALPUFF deposition modeling for all the original STAR lakes, KAEEA lakes located within the study area, and additional lakes sampled early in the EEM Program. These analyses did not provide evidence that any of the lakes excluded from EEM Program should be re-considered for inclusion in the program.

Recommendation 6 – Intensively monitored lakes: Continue intensive sampling (Rio Tinto voluntary initiative) of LAK006 (End Lake) with the new Onset pH monitor – install the monitor for the ice-free period of the year, measure pH every half hour, with calibration visits every two weeks (including a chemistry sample analyzed for pH and ANC), and changes in the pH sensor every 3 months, so as to provide long term measures of variability in pH and ANC. Continue measurements of lake levels so as to assess pH changes associated with storm events. Discontinue continuous monitoring of LAK012 (Little End Lake) and LAK023 (West Lake), as these lakes have shown very similar patterns to End Lake, and provide no incremental value beyond the intensive monitoring of End Lake. Furthermore, West Lake has not shown any increase in lake SO_4^{2-} since the pre-KMP period. In both the intensively monitored lakes and the other EEM lakes, it is essential to allow sufficient time for pH measurements to stabilize (see Limnotek's recommendations in Section 7.1.3.2.7 of Appendix A).

Recommendation 7 – Intensively monitored streams: Thoroughly review the report prepared by Paul Weidman (once it is released) to determine potential next steps in stream monitoring. Discontinue the monitoring of Anderson Creek, which has not provided useful information to the EEM Program.

Recommendation 8 – Fish sampling: If additional fish sampling is required (i.e., additional sampling is triggered by specific conditions in the EEM design), then explore the use of eDNA sampling to estimate any changes in the presence of fish species, and avoid the potential population impacts of gill-net sampling.

Recommendation 9 – Other "non-EEM" sites sampled during EEM Program: In addition to the lakes sampled annually within the EEM Program, multiple other "non-EEM" lake and stream sites (i.e., outside the core program) were identified for exploratory water chemistry sampling in particular years over the course of the EEM Program. None of these sites were found to be sensitive to the predicted increases in acidic deposition and therefore none of them were recommended to be added to the EEM Program for further monitoring. See Aquatic Appendix A for more details.

7.4.2 Changes to the KPIs or informative indicators and thresholds

KPIs should fulfill the following criteria:

1. be responsive to changes in deposition;
2. provide an early warning of potential impacts to biota;
3. have scientifically defensible thresholds of change that can act as triggers for more intensive monitoring or mitigation;
4. are capable of being monitored, analyzed and modelled with an acceptable level of reliability; and
5. have an appropriate balance of Type I and Type II errors.

There are some strengths and weaknesses to the existing KPI that focuses on pH. We have used a pH of 6.0 as the threshold for determining critical loads. This threshold is well supported by existing literature on biological effects, as described in the STAR, and deposition scenarios can be evaluated against this threshold through well-established models. There is abundant literature showing how aquatic biota respond to pH levels, as reviewed in the STAR and EEM Plan. The existing KPI threshold of a 0.3 unit change in pH fulfills most of the above criteria well, but scores only a fair grade on criterion 4 due to the high levels of variability in pH on various time scales (year-to-year, seasonal, daily). This weakness was evident in the power analysis completed in 2016 and described in Section 7.3.2.2 – ΔpH had lower statistical power than ΔGran ANC. In addition, the logarithmic nature of pH means that the actual pH level needs to be considered jointly with the ΔpH (e.g., a change from pH 5.0 to 4.7 is biologically significant, whereas a change from pH 7.0 to 6.7 is not). ANC scores well on all of the five criteria for a KPI, and in particular does better than pH on criterion 4.

Recommendation 10 – ANC KPI: We recommend that ANC become the primary KPI for the EEM Program, with pH as an informative indicator, since ANC better fulfills the criteria for a KPI.

Recommendation 11 – Alternative ANC metrics: We recommend that further analyses be completed to determine which of three possible metrics should be utilized as the KPI for the EEM Program: Gran ANC, BCS or ANC_{OAA}. Each of these metrics have various advantages and disadvantages: Gran ANC has been used throughout the EEM Program to date, but is difficult to analyze in commercial labs; BCS has been used in the northeastern U.S. and is easily computed from data analyzed in commercial labs; ANC_{OAA} is used in Europe and is also easily computed from data analyzed in commercial labs. A criterion level to protect aquatic biota of 25 µeq/L would be consistent for both BCS (Baldigo et al. 2009) and ANC_{OAA} (Hesthagen et al. 2016), as described in the literature review of ANC (Aquatic Appendix B). These analyses can be conducted with existing data in support of the development of the next phase of the EEM Program. There will then be an additional year of data available (i.e., 2019) but that is not a critical pre-requisite.

Recommendation 12 – Two threshold KPI structure: We recommend that the KPI(s) include two components: a *level of protection* to prevent acidification of lakes that are currently not at risk of aquatic impacts (i.e., an absolute threshold); and a *change limit* which prevents further acidification (for lakes already below the level of protection due to natural organic acids or past acidic deposition) (i.e., a relative threshold). A *level of protection* of 25 µeq/L would be consistent for both BCS (Baldigo et al. 2009) and ANC_{OAA} (Hesthagen et al. 2016), as described in the literature review of ANC (Aquatic Appendix B). Re-analysis of the functional relationship between pH and Gran ANC, using all the EEM data, has determined that a pH of 6.0 corresponds to a Gran ANC of 31 µeq/L, which would form the *level of protection* for Gran ANC. The other component of

the threshold would be the allowable ΔANC, which was derived from the lab titrations for each lake – the Δ Gran ANC equivalent to a 0.3 unit change in pH. Determining lake-specific *change limits* (ΔANC) for alternative ANC metrics equivalent to those developed for Gran ANC will require further evaluation.

Recommendation 13 – Implementation of KPI: We recommend that KPI should be defined such that a lake must exceed ***both*** the *level of protection* and *change limit* in order to be considered as an exceedance of the indicator. This concept is summarized in Table 7-15, using potential values for each of the thresholds.

Table 7-15. Proposed structure for ANC and pH indicators.

	Indicators	
Water chemistry component	**ANC**	**pH**
Level of Protection *(i.e., absolute threshold)*	Decrease† below BCS or ANC_{oaa} of 25 ueq/L , or Gran ANC of 31 µeq/L	Decrease† below pH=6.0
Change Limit *(i.e., relative threshold)*	Decrease† of greater than lake-specific thresholds (from titration analyses)	Decrease† of > 0.3 pH units
KPI Exceedance	**BOTH** thresholds exceeded in more than two lakes of medium to high importance*	**BOTH** thresholds exceeded in more than two lakes of medium to high importance*

† To be considered as a contribution toward exceedance of the indicator, exceedance of either threshold must be causally related to the smelter (i.e., increase in SO_4^{2-} sufficient to explain ANC or pH decrease).
*Lake importance evaluated in Table 22 of Aquatic Appendix D of the 2014 SO_2 EEM Plan (ESSA et al. 2014a).

This two-threshold structure will provide protection of aquatic ecosystems (by using thresholds supported from the literature) while avoiding the following types of false positives:

- A lake demonstrates a decrease in the indicator that is greater than the *change limit* but remains sufficiently above the *level of protection* that a change of that magnitude is not a concern for aquatic biota (e.g., decreasing in pH from 7.1 to 6.7 or in BCS from 60 to 45 µeq/L).
- A lake is already below the *level of protection* but always has been (e.g., a naturally acidic lake that is not expected to change much).
- A lake just above the *level of protection* demonstrates a minor decrease that drops it below that level.

In practice this approach essentially means that: 1) lakes that are currently above the *level of protection* must be kept above that level, and 2) lakes that were historically below or close to the *level of protection* must be kept to small changes.

Recommendation 14 – Potential use of biological indicators (e.g., zooplankton): Continue to use indicators of biologically relevant water chemistry, which provides the best early warnings of changes in lake chemistry that could be damaging to aquatic biota *in advance* of potential damage to aquatic biota and is therefore a *proactive* indicator. Do not use indicators of biological change which provide an indication that damage to aquatic ecosystems *has already occurred* and is therefore a *reactive* indicator. Biologically relevant water chemistry provides the best early warnings of changes in lake chemistry that could be damaging to aquatic biota, *in advance* of potential damage to aquatic biota, and is therefore a *proactive* indicator. Biological change provides an indication that damage to aquatic ecosystems *has already occurred* and is therefore a *reactive* indicator. Changes in ANC and pH are detectable prior to changes in lake biota such as zooplankton or benthic species richness, or fish densities. Early detection of biological change requires extensive knowledge of the relative sensitivity of different species to pH change (e.g., Marmorek and Korman 1993), information which is not available for the lakes in the Kitimat Valley and would be very difficult to acquire. Without such detailed information on each species' sensitivity to acidification, one must rely on such measures as total species richness, which only declines with major changes in lake pH, due to species replacements at the early stages of the acidification process (Marmorek and Korman 1993). Changes in sulphate, Gran ANC and pH are the most reliable early warning indicators of changes that could cause an impact on aquatic biota.

7.4.3 Critical loads and exceedances modelling

Recommendation 15 – Critical loads modelling: The critical loads modelling does not need to be done again in the future, except in a case where a lake has shown strong evidence of acidification (not the case for any of the EEM lakes). The critical load of a particular lake is an inherent property of the lake based on the geochemical characteristics of its watershed and is not expected to change over time. With seven years of water chemistry data, we now have greatly improved estimates of the critical loads of the EEM lakes. We have also greatly improved upon the modelling of critical loads that was done in the STAR by conducting extensive sensitivity analyses.

Recommendation 16 – Prediction of critical load exceedances: The prediction of exceedances does not need to be updated again in the future unless actual or predicted cumulative emissions from all sources are in excess of 42 tpd SO_2 or if the emissions modelling framework is significantly modified. Predicted exceedances of the estimated critical loads was based on deposition under the *maximum* future emissions allowable under the permit (i.e., 42 tpd SO_2), whereas actual future emissions are anticipated and/or planned to remain well under that ceiling (e.g., 35 tpd SO_2).

Recommendation 17 – Critical loads and/or exceedances as indicators: As described in the previous two recommendations, the critical loads of the EEM lakes do not need to be modelled again in the future and there is no need to estimate exceedances again until there are significant changes in emissions of sulphur or N in the Kitimat Valley beyond the currently permitted level. For these reasons, neither critical loads nor predicted exceedances would be appropriate metrics upon which to build an indicator for the EEM Program. These two metrics will not be responsive to potential changes in deposition due to smelter operations over the next phase of monitoring and therefore do not satisfy a critical criterion for a good indicator (see list of five criteria for indicators at start of Section 7.4.2).

7.4.4 Analyses and annual reporting

Recommendation 18 – Statistical methods for detection of change in water chemistry: The statistical methods provided in Aquatic Appendix F provide a sound basis for evaluating future changes in water chemistry in the seven sensitive lakes, less sensitive lake LAK016, and the three control lakes, as well as examining changes on a finer scale in the intensively monitored LAK006 (End Lake). These statistical methods will be re-run on an annual basis to assess status and detect any anomalous patterns.

Recommendation 19 – Annual Report: We recommend that the Annual Report be significantly streamlined where possible. The Annual Report should focus on reporting the new data from the monitoring program and updating critical analyses. The Annual Report should not attempt to make interpretations or inferences with respect to year-to-year changes in water chemistry, but should update statistical evaluations of long term changes between pre-KMP and post-KMP periods (see Recommendation 17). However, the scope of the future annual reports will be determined as part of the discussion and development of the next phase of the EEM Program.

7.4.5 Additional Topics

Effects of acidic deposition on wetlands. This is discussed in Section 6 on terrestrial ecosystems.

Potential inclusion of inorganic monomeric Al**.** Inorganic monomeric aluminium has been added to the lake sampling program for 2019 and could be included going forward. Additional years of data (beyond only 2013) would provide better understanding of patterns and relationships with other water chemistry properties. However, it can be very difficult to find commercial laboratories that can measure inorganic monomeric Al. The lakes of concern (e.g., LAK028) are already flagged by other analyses and accurately identified by values of BCS < 0. Therefore, we propose continuing to calculate BCS and use it as an indicator of Al toxicity concerns.

Hypolimnion of LAK028. SO_4^{2-} concentrations in LAK028 may be affected by episodic mixing of hypolimnetic waters (i.e., hypolimnetic SO_4^{2-} that is converted to hydrogen sulfide by sulphate-reducing bacteria, and could be re-oxidized back to SO_4^{2-} as it rises through shallower waters). Sulphate-reducing bacteria have been identified in the deeper waters of LAK028 below the thermocline. A temperature mooring placed in LAK028 in 2019 will help to describe the mixing characteristics in LAK028 that may help in either ruling out a contribution of hypolimnetic sulphur to surface chemistry or show that it is occasionally a confounding factor.

8 Holistic Understanding of KMP Effects on the Environment and Human Health across all Lines of Evidence

The SO_2 EEM Program was designed to monitor effects of the modernized smelter along the lines of evidence assessed in the STAR. Results of the SO_2 EEM Program for 2013 to 2018 along these lines of evidence are discussed in Sections 3, 4, 5, 6 and 7. In this holistic section, we describe what we have learned about the links between SO_2, human health and ecosystems when we examine results from the SO_2 EEM Program *across* those lines of evidence.

It is helpful to understand the linkages between the lines of evidence, as this informed how we approached the holistic analysis. One of the linkages is through shared exposure pathways among some receptors. Human health and vegetation share the atmospheric SO_2 exposure pathway, and vegetation, terrestrial ecosystems and aquatic ecosystems share the atmospheric S deposition exposure pathway. There are also ecological linkages among vegetation, terrestrial ecosystems and aquatic ecosystems; and both terrestrial and aquatic ecosystems use critical loads as an indicator. This is illustrated in Figure 8-1 which shows the SPR conceptual model first presented in Section 1, with symbols added to show where SO_2 EEM monitoring and modelling fits in. Another linkage is co-location. Some of the pathway and receptor monitoring occurs in the same geographic locations, or very near to each other. This is illustrated in Figure 8-2 which shows a map of all SO_2 EEM monitoring sites in the Kitimat Valley. Some of these linkages also result in the informational linkages among the pathways and receptors shown in the looking-outward matrix in Table 8-1.

This synthesis examines evidence through several lenses: (1) KPI results compared to thresholds for all receptors, (2) results for receptors sharing the SO_2 exposure pathway, (3) results for receptors sharing the S deposition exposure pathway, (4) knowledge we have gained over the past six years about pathways and effects in the SPR model, and (5) the ability of KPIs and informative indicators to detect trends towards unacceptable impacts. This section concludes with a summary of what we have learned from the first six years of the SO_2 EEM Program about the links between SO_2, human health and ecosystems, and what the results mean overall for the health of the valley.

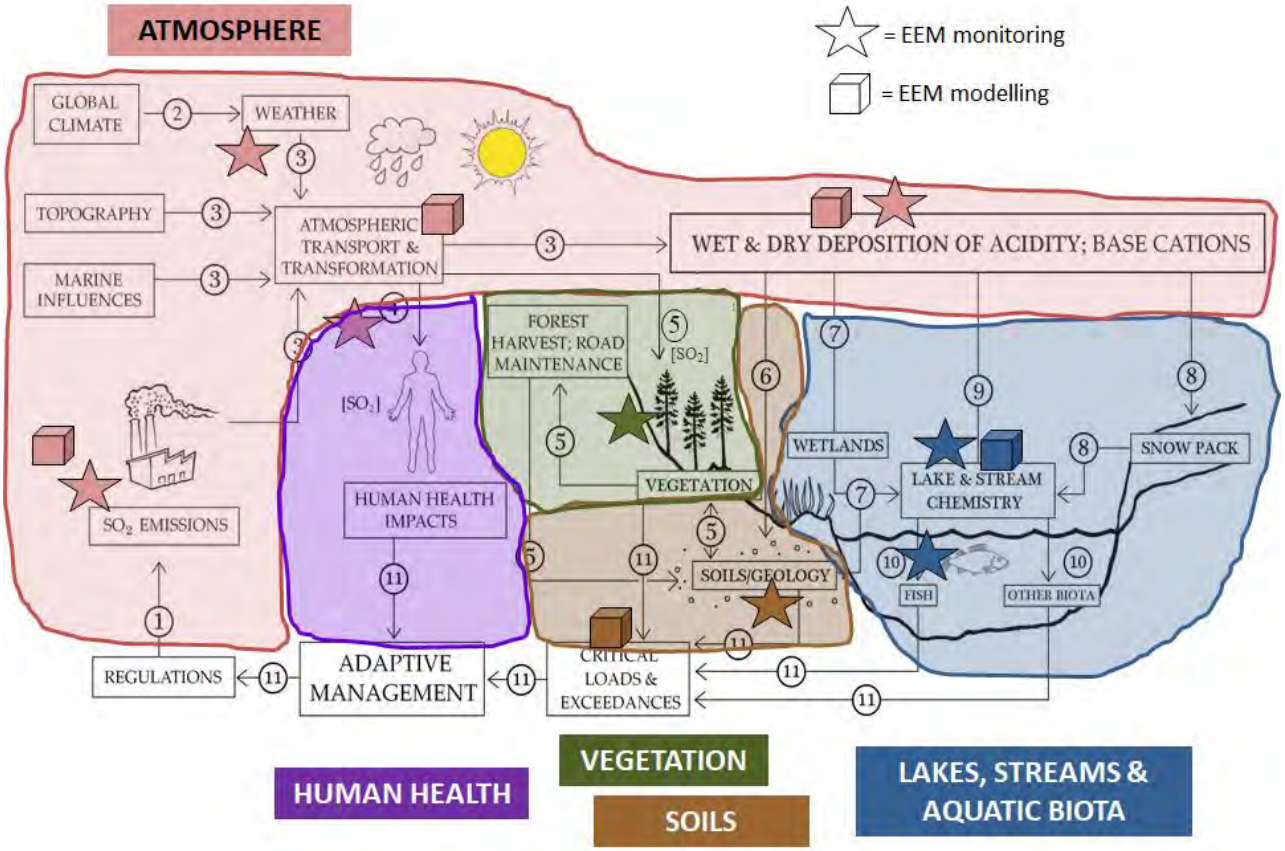


Figure 8-1. SO_2 Source-Pathway-Receptor (SPR) conceptual model for the SO_2 EEM Program, showing where SO_2 EEM monitoring and modelling occurs.

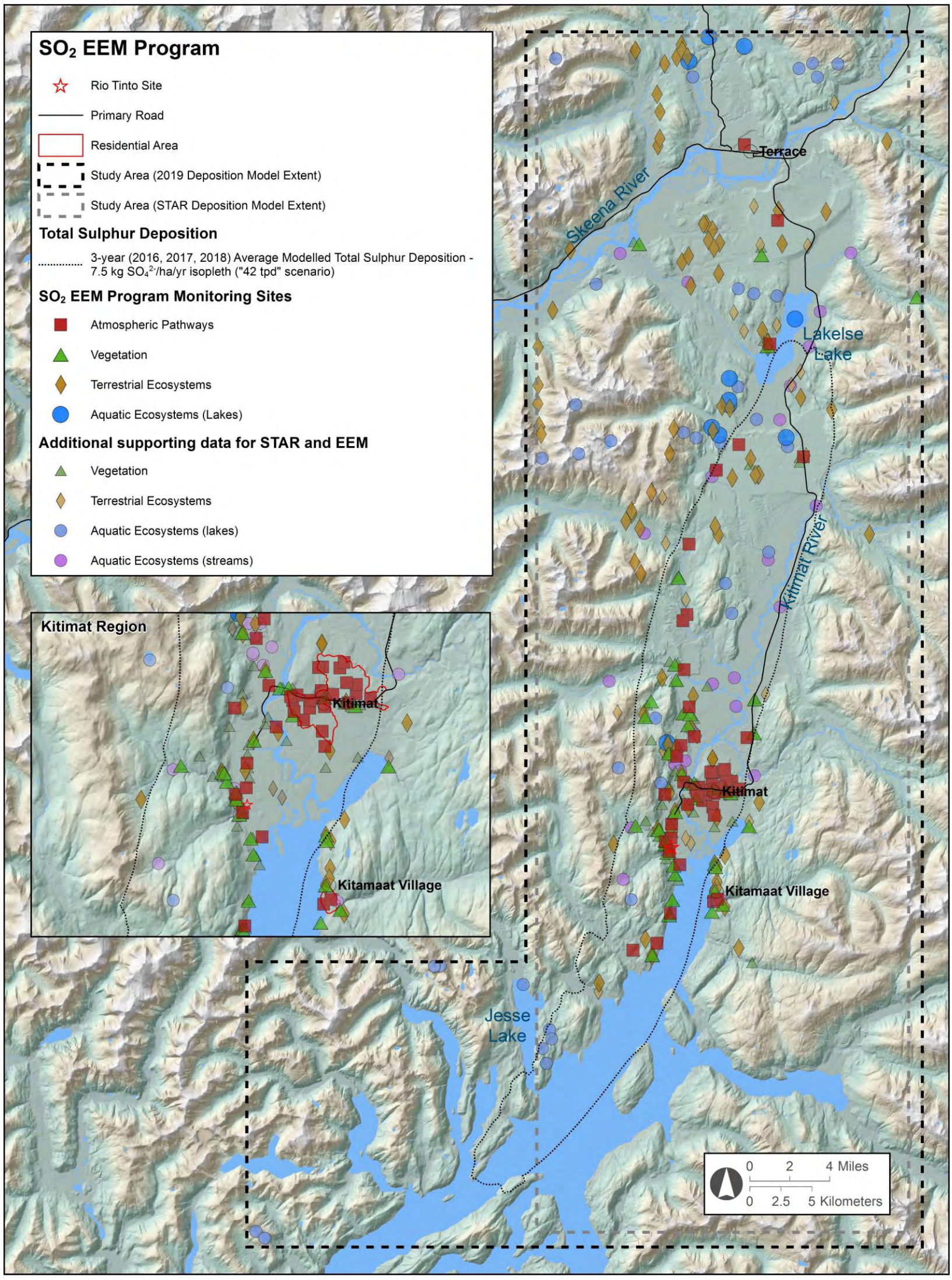


Figure 8-2. Map of monitoring locations across all lines of evidence. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleth.

Table 8-1. Looking Outward Matrix showing information linkages among SO_2 EEM pathways and receptors. Each cell describes information that is provided *from* the line of evidence for that row *to* the line of evidence for that column.

To → **From ↓**	Atmosphere	Human Health	Vegetation	Terrestrial Ecosystems (Soils)	Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)
Atmosphere		SO_2 concentrations vs. the KPI threshold	SO_2 concentrations and SO_4^{2-} deposition versus vegetation thresholds, including passive monitoring sites	Deposition vs CL, and versus soil base saturation	Deposition vs CL, and versus acidic episodes Use SO_4^{2-} deposition predictions for 2016-18 to estimate lake $[SO_4^{2-}]$, under varying assumptions of runoff
Human Health	NA		NA	NA	NA
Vegetation	SO_2 concentrations in needles versus observed / predicted SO_2 concentrations in air	NA		Observations of acidification effects on vegetation	Observations of vegetation effects in a given watershed
Terrestrial Ecosystems (Soils)	NA	NA	Soil CL exceedance versus vegetation observations		Soil CL exceedance versus lake CL exceedance; compare soil weathering rates with SSWC estimates
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)	NA	Water quality in Kitimat River near water treatment plant	Locations where there is some evidence of lake acidification	BC weathering rate from [BC] and runoff versus soil estimates	

8.1 Synthesis Lens 1: KPI Results Compared to Thresholds – Early Warning of Adverse Effects

All receptors in the SO_2 EEM program have KPIs, and KPI thresholds that provide early warning of harm. The KPI for human health is based on the CAAQS which are based on the response of the most susceptible population. The KPI for vegetation is based on ambient SO_2 exposures that are known to cause visible injury to plant species, and inspections that document and assess plant health and provide early warning of impacts on vegetation. One of the two KPIs for terrestrial ecosystems is a precautionary and early-warning prediction-based indicator, with a second observation-based indicator for further precaution. The KPI for aquatic ecosystems is based on water chemistry which is a broad indicator of aquatic ecosystem health. Using biologically-relevant water chemistry as a KPI provides earlier warning of aquatic ecosystem effects than using biota as a KPI.

Thus far in the SO_2 EEM Program, none of the KPI thresholds have been reached for any of the receptors. Table 8-2 summarizes the KPIs, their thresholds, and results from 2012 to 2018.

Table 8-2. Summary of KPIs, thresholds and performance 2012-2018.

	KPI	Threshold for **increased monitoring**	Threshold for **receptor-based mitigation**	Threshold for **facility-based mitigation**	Summary of Results
Human Health	B.C. Air Quality Objective measured at residential air monitoring stations	NA – there is no threshold for increased monitoring for this KPI	NA – there is no threshold for receptor-based mitigation for this KPI	3-yr average of 97th percentile of the D1HM for 2015-2017; 97.5th percentile for 2016-18; 98th percentile for 2017-2019. There is an allowance of a one-time exceedance of the 75 ppb threshold to a maximum concentration of 85 ppb over 2017-2019.	The KPI threshold was not exceeded
Vegetation	Visible vegetation injury caused by SO_2	More than occasional symptoms of SO_2 injury outside of Rio Tinto Alcan Kitimat properties, causally related to KMP	NA – there are no reasonable receptor-based mitigations	Severe & repeated symptoms of SO_2 injury outside Rio Tinto properties causally related to KMP, including species of economic or social/ traditional importance, or symptoms of SO_2 injury causally related to KMP at long-distance (>15km) monitoring locations	Neither of the two thresholds were exceeded
Terrestrial Ecosystems (Soils)	Atmospheric S deposition and critical load exceedance risk	S deposition causally related to KMP emissions exceeding CL in > 1% (~20 km^2) of semi-natural upland forest soils in the study area	S deposition causally related to KMP exceeding CL in >5% (~100 km^2) of semi-natural upland forest soils in the study area within 200 yrs	S deposition causally related to KMP emissions exceeding CL in >5% (~100 km^2) of semi-natural upland forest soils in the study area within 100 years (based on projected change in base cations)	None of the thresholds were exceeded

	KPI	Threshold for **increased monitoring**	Threshold for **receptor-based mitigation**	Threshold for **facility-based mitigation**	Summary of Results
	Long term soil acidification attributable to S deposition	For one plot: a 40% decrease in 5 yrs or a 20% decrease in 10 yrs in exchangeable cation pools for at least one element, and decrease is causally related to KMP emissions	For one or more plots: a 40% decrease in 5 yrs or a 20% decrease in 10 yrs in exchangeable cation pools for at least 1 element and in >1% (~20 km^2) of the area of semi-natural upland forest soils	Decrease in the magnitude of exchangeable cation pool of >20% in 10 years, and in > 5% (~100 km^2) of the area of semi-natural upland forest soils, based on modelling, and decrease is causally related to KMP	None of the thresholds were exceeded
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)	Water chemistry - acidification	Observed decrease in pH ≥0.30 pH units below mean baseline pH level measured pre-KMP in one or more of the 7 acid-sensitive lakes, and other evidence	More intensive sampling confirms a decrease causally related to KMP of> 0.30 pH units below mean baseline pH level pre-KMP and liming is feasible	More than 2 lakes rated Medium or High (based on relative lake rating; Appendix D of the 2012-2018 SO_2 EEM Plan) with decrease causally related to KMP of > 0.30 pH units below measured baseline pre-KMP (prior to liming)	None of the thresholds were exceeded

Why have no KPI thresholds been reached?

The KPIs in the SO_2 EEM Program were chosen to provide early warning of potential impacts on the receptors. The KPI thresholds were also set at levels that the receptors can tolerate, so that if needed, action could be taken to avoid impacts. Air concentrations of SO_2 at residential monitoring stations are well below the B.C. IAQO. The concentrations are also below the CAAQS which will become the B.C. Air Quality Objectives starting in 2020. Air concentrations of SO_2 in the valley are well below concentrations that would cause visible injury to vegetation. The only areas of predicted exceedance of soil critical loads under the 42 tpd scenario were close to the smelter, and less than 1% of semi-natural upland forest soils in the study area. There was no statistical decrease in soil chemistry between 2015 and 2018 in the top 0–30 cm of mineral soil, and the only soil variable that consistently showed a statistical decrease at lower cumulative depths was exchangeable acidity, suggesting that there was a decrease in acidity between 2015 and 2018, despite the increase in acidic deposition. Even after adjusting for the fact that deposition of SO_4^{2-} has been less than predicted in the STAR, most lakes (12 out of 14) have shown a smaller increase in SO_4^{2-} than expected (after adjusting for the fact that emissions have been lower than the modelled 42 tpd), and all sensitive lakes have shown a smaller change in pH and ANC than expected. These results reflect the conservative assumptions built into both atmospheric and aquatic models, which tend to over-predict effects of the smelter.

Atmospheric dispersion of emissions led to actual SO_2 air concentrations and S deposition that were different from what was predicted in the STAR. We took a conservative approach to the CALPUFF modelling in the STAR by making assumptions that would over-predict SO_2 concentration and S deposition. We therefore expected that actual SO_2 concentrations and S deposition would be lower than modelled. Indeed, the STAR predictions were generally conservative, particularly in residential areas. Actual measured SO_2 concentrations were substantially lower than model predictions of post-KMP SO_2 concentrations from the STAR at most locations and were near model predictions at Haul Road.

Even though smelter emissions have not reached the 42 tpd maximum allowed under the permit, we based predictive modeling of critical loads for soils and lakes on the permit limit of 42 tpd. Observational KPIs were calculated using actual emissions.

8.2 Synthesis Lens 2: Results for Receptors along the SO_2 Concentration Exposure Pathway

Both plants and humans have metabolic pathways that require sulphur because it is an essential element necessary for certain amino acids (Laurence 2012; Nimni et al. 2007). Plants can use sulphur that is taken up through soil or air, while humans use sulphur taken up through ingestion.

Both humans and plants are also affected by the concentration of SO_2 in the air. Some humans and plants are more sensitive to concentration of SO_2 in the air, and some are less sensitive. A great majority of plants and a great majority of humans do not respond to SO_2 until exposed to concentrations at a much higher level than the levels occurring in and around Kitimat.

For plants and lichens, there are specific species that are known to be more sensitive to SO_2 such as cyanolichens; however, given the SO_2 concentrations monitored, cyanolichens would respond to changes in deposition rather than air concentrations and would not provide effective early (within a single growing season) warning. Plants in the genus *Rubus*, such as salmonberry and thimbleberry, may be among the more sensitive higher plants, and would respond more quickly and in a more identifiable manner (e.g. visible injury to leaves) than lichens if SO_2 concentrations reached a threshold. Visible symptoms of SO_2 injury have not been observed on either salmonberry or thimbleberry. For humans, specific properties of the upper airways of asthmatics cause this population to have a much higher level of sensitivity to short-term peaks of SO_2 concentration. For these reasons, the design of the 2014 SO_2 EEM Plan and the KPIs for vegetation and human health have focused on thresholds or phenomena *acutely* affecting the most sensitive species or sub-populations.

SO_2 thresholds set for the most sensitive populations of humans and plants are in a similar range. Acute effects of SO_2 on plants may occur at 500 ppb in three hours and causes leaf damage but is not typically fatal to plants. There are also one-hour thresholds that are higher, reaching 1,000

ppb or more. Effects of acute exposure of SO_2 on humans have been observed in asthmatic humans at levels of 200 to 400 ppb. The CAAQS is set at 70 ppb to protect the most susceptible asthmatics.

The KPI for neither vegetation nor human health were exceeded. Air concentrations of SO_2 are well below the B.C. Air Quality Objective at residential monitoring stations, and well below concentrations that would cause visible injury to vegetation.

What do these results tell us?

Two of the four SO_2 EEM receptors – people and plants – respond directly to atmospheric SO_2 concentrations. To date, monitored and modelled SO_2 concentrations have not exceeded the levels established as protective and accepted by regulatory agencies. The concentrations are low enough with respect to the known sensitivity of plants that we can refocus our program to monitor long-term, more subtle effects thus integrating vegetation more strongly with terrestrial ecosystems.

8.3 Synthesis Lens 3: Results for Receptors along the S Deposition Exposure Pathway

The soils and aquatic analyses have used observational data: long term soil plots and long-term monitoring of lake chemistry. Neither of these two data sets have shown evidence of sulphur-induced acidification that exceeds the protective thresholds established in the EEM Plan, with the exception of one small lake (LAK028) near the smelter that has low support for a decline below the pH threshold and no support for a decline beyond its ANC threshold.

The map of soil critical loads (left panel in Figure 8-3) shows exceedance near the smelter and one grid cell very close to LAK028. Deposition at LAK028 was close to exceeding its aquatic critical load (0 to -10 meq/m^2/yr).

Average weathering rates estimated for soils (78 meq/m^2/yr) are less than average weathering rates estimated for all the STAR lakes (352.8 meq/m^2/yr). This is to be expected because the soils analysis only computes weathering rates for the top soil layers, whereas the lake analysis considers all the parts of the watershed contributing base cations to the lake.

Weathering rates from the soil analysis are generally homogenous in the area to the SW of Lakelse Lake, and lakes in this zone also show a similar level of non-exceedance (right panel in Figure 8-3). In the north central part of the study area, there are three very small lakes with divergent CL levels (top of right panel in Figure 8-3), whereas the soils analysis shows similar weathering rates; this reflects the small scale heterogeneity in watershed soil and hydrologic attributes that can influence lake chemistry. In the northwestern part of the study area, there is an area with relatively low soil CLs. The only sampled lake in this area (LAK041) had a CL in the STAR of 54 meq/m^2/yr, but no exceedance in either the STAR or CL, as CALPUFF deposition was 5 meq/m^2/yr in the STAR, and 1.2 meq/m^2/yr in this report (with a background deposition of 7.5 meq/m^2/yr).

We compared the soil weathering rates by watershed with weathering rates for each of these watersheds computed in the aquatic analysis (estimated from the SSWC model for each of the

STAR lakes, plus additional lakes within the study area that were sampled in the Kitimat Airshed Assessment). As expected from the average weathering rates noted above, the weathering rates from the SSWC model were consistently higher than the soil weathering rates (in 42 of the 51 watersheds analyzed), and there was no consistent relationship between these two metrics. This is not surprising given that the soil weathering rates are estimated at a coarse grid scale (0.5 km x 0.5 km = 0.25 km^2), whereas the weathering rates from the SSWC model are based on the water chemistry of lakes which often have very small watershed areas (32 of the 51 watersheds are less than 1 km^2 in area). Though the soil mapping cannot capture the fine-scale heterogeneity that appears in the lake chemistry, the two measures together provide complimentary and valuable lines of evidence.

Wetlands are least well-known due to a lack of information on sensitivity as well as distribution of wetlands. (We considered using data from the KAEEA, but that landcover map did not cover the full study area.) Only 5 of the 51 lakes have more than 0.5% of their catchments characterized as wetland land classes from landcover data. This implies that effects of wetlands on lake chemistry are likely to be minor.

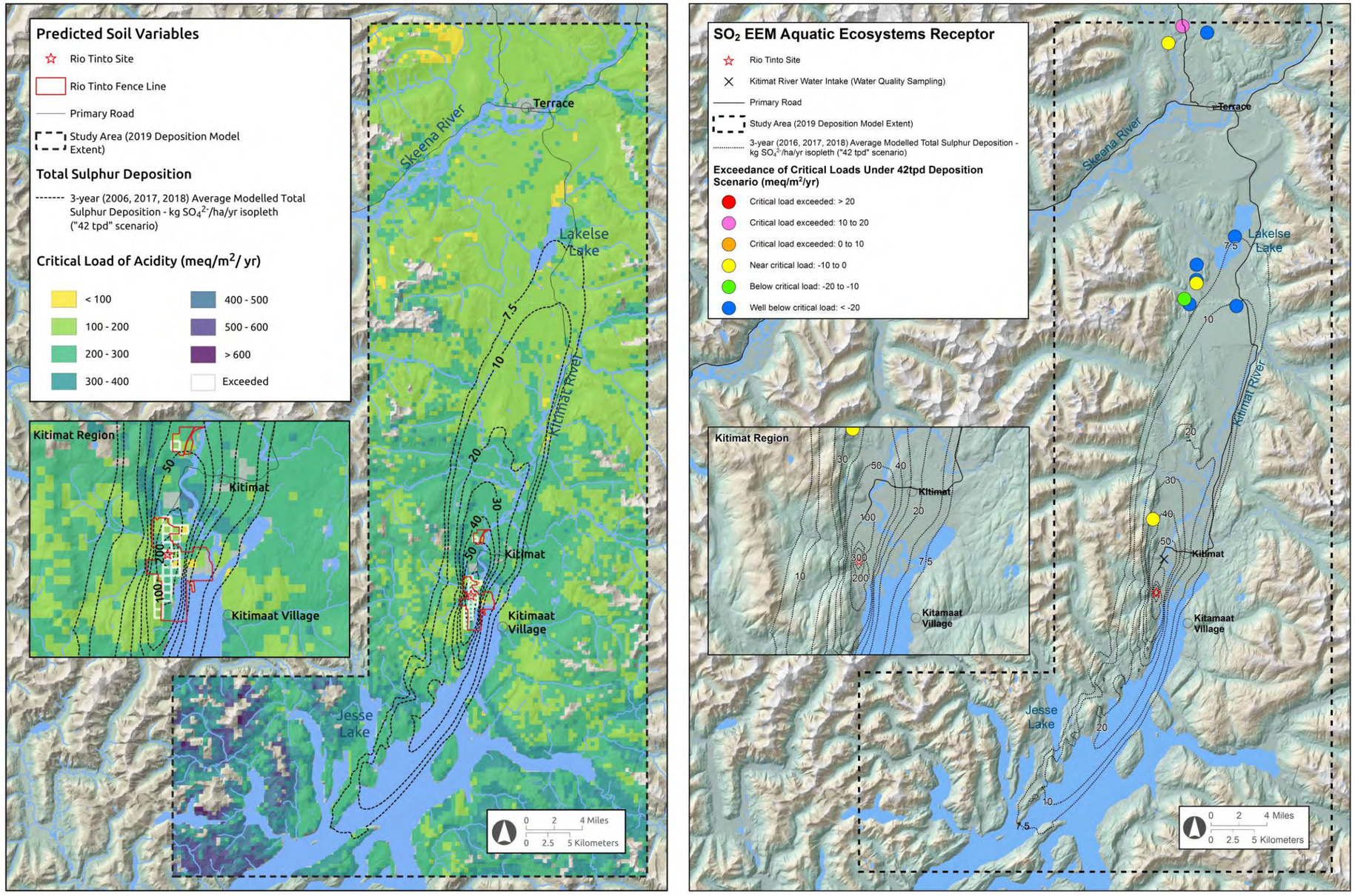


Figure 8-3. Maps showing areas of predicted critical loads and predicted critical load exceedances in soils (left) and predicted critical load exceedances in aquatic ecosystems (right), both under the 42 tpd scenario. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleths.

Do vegetation results appear to relate to soil and aquatic critical load results?

We did not observe signs or symptoms related to plant health, including symptoms of SO_2 exposure or soil acidification associated with the predicted areas of exceedance (under the 42 tpd scenario) of soil or aquatic critical loads. Eleven sampling and/or inspection sites are located in or near the area of predicted soil critical load exceedance and provide coverage to detect effects of acidification, had any been apparent. No symptoms were observed from a recent aerial survey of the predicted area of soil critical load exceedance. In the case of the aquatic line of evidence, no vegetation sampling and/or inspection sites are located adjacent to EEM lakes. An aerial survey conducted as part of the vegetation program included flying over some of the EEM lakes and we did not observe anything out of the ordinary.

While the areas of predicted soil critical load exceedance have been exposed to considerable deposition in the past, it is possible that it will take some time for soil critical loads to manifest with regard to vegetation in the areas of predicted exceedance. If and when it does, it will most likely be through changes in plant communities or a decline in the health of acid-sensitive species.

What do these results tell us?

The exceedance of the soil critical loads very close to LAK028 shows a consistency between the soil and aquatic critical load analyses in that part of the study area. This contrasts with the very northern part of the study area where there is a lot of variability in the aquatic critical load results for three lakes, whereas there is strong consistency in the soil critical load results (all mapped as having critical loads in the range of 100-200 meq/m^2). This is probably because there is fine-scale variability in the geology, soils and hydrology which is not reflected in the coarser-scale interpolations from geology and soils data.

8.4 Synthesis Lens 4: What We have Learned under the SPR Conceptual Model

What have we learned about the SPR conceptual model, and what new questions have arisen?

Table 8-3 summarizes what we have learned, uncertainties we have reduced in our understanding of the SPR model for SO_2 effects in the Kitimat Valley, and remaining knowledge gaps to include in the SO_2 EEM Program going forward. Table 8-3 demonstrates linkages across the different components of the EEM Program, from emissions through atmospheric SO_2 concentrations and deposition, to responses of the human health, vegetation, soils and aquatic receptors.

Table 8-3. Summary of what we have learned under the SPR conceptual model, and remaining knowledge gaps.

Link #	Link Name	What We Have Learned Since 2013	Remaining Knowledge Gaps
1	Regulation of SO_2 emissions	• Emissions have increased by 135% between the 2012-2015 period (12.5 tpd) to the 2016-2018 period (29.4 tpd) although they are still well below the maximum permitted level of 42 tpd. • Emissions may be over-estimated, since it is assumed that all S in raw materials is emitted.	• None
2	Global Climate	• Projected trends in climate for the region include wetter, warmer winters and drier, warmer summers which could be either drier or wetter[52]. • Drought in 2018 (approximately a 30% decrease in precipitation) affected both patterns of deposition (more dry deposition, less wet deposition), water chemistry (increased pH in many lakes), and vegetation health (leaves aged and dropped prematurely in dry areas). • We need more years of monitoring to determine the longer-term effects of the 2018 drought on lake chemistry.	• We don't know the interactive effects of climate change and SO_2 emissions on vegetation or lake ecology • If runoff and temperature changes, then soil weathering rates could change • Changes in snowpack could make roots more vulnerable to freezing
3	Atmospheric transport and transformation/ sea salt episodes and acidic deposition	• Due to a large amount of dispersion of emissions, only a small fraction of the emitted SO_2 (~8.1%, see Section 3.2) is deposited within the study area, a similar result to what was found in the STAR. • Deposition patterns are sensitive to variations in weather, with lower levels of deposition in dry years such as 2018 (Section 3.1)	• Understanding east-west extent and position of the plume (e.g., location of 7.5 kg SO_4^{2-}/ha/yr isopleth) to north and the extent and position of the plume to the south
4	Human Health impacts	• The highest SO_2 concentrations are well below the health KPI. • Average annual SO_2 concentrations during 2016-2018 were very low (<1 ppb in all three monitoring areas), and compare well with other communities.	• No knowledge gaps need to be included in the SO_2 EEM Plan moving forward
5	Vegetation impacts/forest interactions	• Direct effects of SO_2 on vegetation, including visible injury, have not been observed despite surveys, and under emissions of 42 tpd, are only expected rarely in a few locations. • Work during the 1970s and 1980s, as well as recent surveys by ENV, show a similar area of reduced lichen species richness that corresponds to the plume path for at least the last 50 years. • S concentrations in hemlock does not correlate well with modelled SO_2 emissions or concentrations, or S deposition.	• Deposition modelling and new science tells us that we have areas where there are likely effects on sensitive lichen species. Impacts on lichens have been documented since the 1970s and were likely the result of exposure to both SO_2 and HF. HF

[52] Projections are available for the Kitimat-Stikine region from the Pacific Climate Impacts Consortium (PCIC) at: https://www.pacificclimate.org/analysis-tools/plan2adapt.

Link #	Link Name	What We Have Learned Since 2013	Remaining Knowledge Gaps
		• Under current emissions (~29.4 tpd) and potential emissions (42 tpd), only 0.36% and 0.58% (respectively) of the valley's forest soils are projected to receive deposition at levels that could indirectly affect vegetation through changes to soils. • Soil acidification has not been observed in long term monitoring plots.	emissions have dropped substantially. Will improvement in lichens be observed in the future? • No vegetation observations exactly in the area of soil CL exceedance off of the Rio Tinto property • Developing vegetation informational indicators to support the terrestrial ecosystem line of evidence
6	Watershed acid neutralization/ geology	• Virtually all of the area's forest soils have a very high ability to neutralize acidic deposition and would not be affected under an emissions scenario of 42 tpd. • In general, the region's soils and lakes are not sensitive to acidic deposition, based on high neutralizing capacity of the regions' soils, and the weathering of minerals.	• Understanding sensitivity of wetlands to acidification • Understanding Al solubility in upland soils
7	Wetlands and organic acids	• Many of the lakes in the Kitimat Valley are brown water lakes with organic acids, and have been naturally acidified (STAR, Figure 9.4-9). • Organic acids have been considered in the analyses of changes in water chemistry. • Over 2012-2018, there have been only minor changes in the concentrations of DOC (Aquatic Appendix E), which appear to be insufficient to markedly shift the ANC or pH of lakes. • Only 5 of the 51 sampled lakes have more than 0.5% of their watershed area as wetlands, so changes to wetlands from acidic deposition are unlikely to affect lake chemistry.	• Statistical analyses of changes over time in DOC and organic anion concentrations
8	Acidic episodes, snowmelt and fall rains	• The SO_2 EEM program has focused on lakes, which have more stable water chemistry than streams. • Lake pH levels tend to decrease after heavy storm events, but these changes are not statistically significant (Section 7.6.4.3.6 of Aquatic Appendix F on Statistical Analysis of Water Chemistry)	• Awaiting report from Paul Weidman
9	Lake and stream chemistry	• Of the 14 lakes in the SO_2 EEM program (7 acid-sensitive lakes, 4 less sensitive lakes, 3 control lakes), 12 lakes show no evidence of sulphur-induced acidification causally related to the Kitimat smelter. LAK028, a 1 ha fishless lake	• Need more years of data to obtain higher statistical power • Need better understanding of within-

Link #	Link Name	What We Have Learned Since 2013	Remaining Knowledge Gaps
		close to the Kitimat smelter, shows some evidence of sulphur-induced acidification causally related to the smelter. LAK012 (Little End Lake), a 2.3 ha lake to the SW of Lakelse Lake, has shown increased concentrations of sulphate, but no consistent evidence of sulphur-induced acidification causally related to the smelter. • Going forward, only LAK028 is expected to show declines in pH greater than 0.1 pH units (0.2).	year variability of control lakes' chemistry
10	Acidification effects on biota	• Modelling of critical loads has used pH 6.0 to ensure protection of the region's lakes. • Water chemistry monitoring indicates that the conditions for aquatic biota have not changed since 2012. • Fish sampling revealed a total of six species across 6 lakes (sensitive lakes LAK006, 012 and 023; less sensitive lakes LAK007, 016, 034). No fish were caught in LAK042 (which has no inlets or outlets) or in LAK028 (which has no inlet and a blocked outlet). • Since no lakes have shown evidence of declines in pH and ANC below the thresholds, there has been no need to resample fish in these lakes.	• None at this time
11	Adaptive management/ critical loads	• The SO_2 EEM Plan provides for adaptive changes to emissions if required. • As none of the KPI thresholds have been exceeded, no adaptive changes to emissions are required at this time.	• None at this time

8.5 Synthesis Lens 5: How the EEM Program Will Detect Trends Towards Unacceptable Impacts

The EEM Program has been designed both to detect the exceedance of KPI thresholds, as well as trends towards unacceptable impacts, as described in Table 8-4.

Table 8-4. Ability of KPIs and informative indicators to detect trends towards unacceptable impacts.

	KPI	Ability to Detect Trends Towards Unacceptable Impacts
Human Health	B.C. Air Quality Objective measured at residential air monitoring stations	Hourly air quality monitoring of SO_2 at three residential sites provides the inputs used to calculate the KPI. Short term declines in air quality lead to advisories based on the Air Quality Health Index. Trends in both the inputs to the KPI, as well as trends in the KPI itself provide an early warning of trajectories towards unacceptable impacts. Since rare meteorological events can have a strong impact on the KPI, it is important to determine if observed trajectories in the KPI are driven primarily by trends in emissions or by rare meteorological events. Going forward, the health KPI will shift toward alignment with the CAAQS for SO_2.
Vegetation	Visible vegetation injury caused by SO_2	Future KPI and informative indicators are under development. Triennial monitoring of plant biodiversity along deposition gradients in areas potentially susceptible to changes in soil chemistry or critical load could provide a long-term trend in vegetation response (Section 5.4). Any future KPI and associated thresholds will be determined through collaborative work by Rio Tinto, ENV and QPs in 2020 and 2021.
Terrestrial Ecosystems (Soils)	Atmospheric S deposition and critical load exceedance risk	Modelling of the exceedance of terrestrial critical loads of acidity has indicated areas where there is a risk to plant health, which together with the KPI for long term soil acidification (described below) provide an early warning of trajectories towards unacceptable impacts in soils. In addition, exceedance of critical loads has helped to define sensitive areas for monitoring of plant biodiversity (described above). Critical loads and exceedances may be re-estimated if new data become available or there are significant increases in S or N deposition beyond the scenarios that have been modelled (Section 6.4).
	Long term soil acidification attributable to S deposition	The objective of the three long-term soil plots is to monitor changes in soil chemistry (exchangeable base cations) attributable to S deposition over time, through repeated sampling and analysis (every five years). The monitoring plots provide a framework for replicate random sampling of soils, allowing for the statistical assessment of changes between sampling campaigns, which can provide an indication of trajectories towards unacceptable impacts at these sites. Monitoring at the soil plots can detect a change of 40% in exchangeable cations over a 5-year period with high statistical power (Section 6.4). Smaller changes in exchangeable cations may be observed, but will have lower statistical power for drawing conclusions

	KPI	Ability to Detect Trends Towards Unacceptable Impacts
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)	Water chemistry - acidification	Lake chemistry has been sampled annually for eight years, gradually increasing the sampling intensity. The future EEM program will continue annual sampling in seven sensitive lakes, one less sensitive lake, and three control lakes, as well as intensive monitoring of pH in one sensitive lake (End Lake). The rigorous statistical methods described in Aquatic Appendix F provide the means of detecting trajectories in SO_4, ANC and pH, and will be applied annually. Trends in the percent belief of KPI exceedance and trends in pH in End Lake can provide an indication of possible trajectories towards unacceptable impacts, though the EEM Program has been designed to detect exceedances of the EEM thresholds, not smaller changes. Going forward, ANC will be the KPI, and pH will be an informative indicator (Section 7.4). Power analyses showed that ANC is less variable than pH, and therefore provides for earlier detection of biologically significant thresholds with higher statistical power.

8.6 Holistic Summary

What have we learned about the links between SO_2, human health and ecosystems?

Humans and plants are both affected by the concentration of SO_2 in the air, and they both have populations that are more sensitive to SO_2 and populations that are less sensitive to SO_2. In plants this includes variation in sensitivity both within and between species. Thresholds for SO_2 in the air are set for the most sensitive populations of humans and plants are in a similar range. Acute effects of SO_2 on plants occurs at 500 ppb in three hours and causes leaf damage but are not typically fatal to plants. Effects of acute exposure of SO_2 on humans have been observed in asthmatic humans at levels of 200 to 400 ppb. To date, monitored and modelled SO_2 concentrations have not exceeded the levels for either humans or direct effects on plants established as protective and accepted by regulatory agencies.

The soils and aquatic analyses both used observational data: long-term soil plots and long-term monitoring of lake chemistry. These data have shown no evidence of sulphur-induced acidification that exceeds the protective thresholds established in the EEM Plan, except for one small lake (LAK028) near the smelter that has low support for a decline below the pH threshold and no support for a decline beyond its ANC threshold. The soils and aquatic analyses also both used predictive critical load modelling under the 42 tpd scenario. Critical loads of acidity for forest soils and wetlands are predicted to be exceeded near to the smelter, and near LAK28 which is close to exceeding its aquatic critical load. Though two other lakes further north are also predicted to be close exceeding their critical loads, and the northern-most lake in the study area is predicted to exceed its critical load, none of these three lakes is predicted to show a decrease in pH of more than 0.1 pH units under an emissions scenario of 42 tpd. Continued sampling of the water chemistry of sensitive lakes will be valuable to provide at least five years of post-KMP data, which will improve the statistical power to detect changes.

There is a lack of information on the distribution and sensitivity of wetlands. Effects of wetlands on lake chemistry are likely to be minor, as only 5 of the 51 lakes have more than 0.5% of their catchments characterized as wetland land classes from landcover data.

Overall, what do the results mean for the health of the valley?

The KPIs in the SO_2 EEM Program were chosen to provide early warning of potential impacts on the receptors, and thus far we see no early warnings. None of the KPI thresholds have been reached, not even the thresholds for increased monitoring. No prediction-based KPI threshold exceedances are projected even under the 42 tpd scenario. Air concentrations of SO_2 at residential monitoring stations are well below the B.C. Air Quality Objective. Air concentrations of SO_2 in the valley are well below concentrations that would cause visible injury to vegetation. No soil plots show evidence of acidification. Only one small lake near the smelter shows some evidence of sulphur-induced acidification that exceeds the protective thresholds established in the EEM Plan (low support for a decline below the pH threshold and no support for a decline beyond its ANC threshold); the other lakes do not show any evidence of such a change. Prediction-based KPIs for soils and lakes are not expected to reach mitigation thresholds even under SO_2 emissions at 42 tpd. Looking across these lines of evidence we do not see signs of harm in the valley, under present or predicted future conditions. Through all of the analyses, discussions, and results of the comprehensive review we are confident in these conclusions and recommend going forward with a more consolidated, efficient program.

9 Overall Recommendations

This section provides a summary compilation of all of the recommendations conveyed in the previous sections for all pathways and receptors. Further details on these recommendations are provided in the pathway and receptor sections. The section ends with a recommendation for the next review.

Recommendations for Atmospheric Pathways

1) Continue SO_2 continuous monitoring at all or most of the current sites.
2) Consider establishing a temporary or fixed continuous SO_2 monitoring station within the Service Centre commercial area to provide information on model performance in this area.
3) Continue the passive sampling network in the Kitimat Valley and review the number of sites and frequency of monitoring.
   a) Add passive sampling sites to the east and west of current sites located to the north of the smelter, where possible.
4) Consider reducing the current north to south network if needed to accommodate the proposed east to west expansion.
   a) Evaluate whether additional passive sampling sites can be established in locations south of the smelter.
   b) Assess the passive sampling site locations for whether some sites could be moved to align with the proposed biodiversity plots (or vice versa).
5) For the deposition monitoring program, we recommend continuing the Lakelse Lake monitor and considering discontinuing the Haul Road wet deposition monitor. The monitoring of wet deposition at Haul Road provides no ecological value (i.e., for the assessment of impacts) owing to its fence line location, and it provides limited value for model (CALPUFF) evaluation.

Recommendations for Human Health

The KPI for the EEM Program going forward will shift toward alignment with the CAAQS for SO_2. As such, there is no basis for a recommendation for changes to the quantitative basis for the existing KPI since it is in the process of changing according to the adoption and further adjustment of the CAAQS.

Recommendations for Vegetation

Acute effects on plants are unlikely and we recommend shifting SO_2 EEM monitoring to long-term, more subtle effects that integrate vegetation more strongly with terrestrial ecosystems.

1) Establish a terrestrial ecosystem line of evidence with the soil KPI of critical loads and informative indicators of plant biodiversity and plant health.
   a) Discontinue the current KPI for vegetation.
   b) Conduct a plant biodiversity pilot project to develop appropriate thresholds and related measures of variability to assure success.
2) Establish informative indicators of changes in plant biodiversity and changes in plant health due to emissions from B.C. Works to support the Soil Critical Load KPI.

3) Change the focus of the vegetation sampling and inspection program to detecting mid to long-term effects on terrestrial ecosystems by:
   a) Implementing a set of biodiversity plots to detect changes in plant communities related to B.C. Works,
   b) Revisiting ENV-established lichen plots at appropriate intervals (e.g. every 5 years) to document changes in lichen communities,
   c) Conducting a triennial inspection to document changes in plant and ecosystem health, and
   d) Discontinuing sampling and chemical analysis of western hemlock foliage in favor of maintaining a valley passive sampler network and monitoring vegetation health.

Recommendations for Terrestrial Ecosystems (Soils)

1) Revise critical loads of acidity for terrestrial ecosystems only if new data become available; however, estimate exceedances for any updated S (and N) deposition scenarios.
2) To address several uncertainties in the regional assessment of impacts to terrestrial receptors:
   a) Survey wetland geochemistry and sulphur storage capacity; wetlands make up almost 25% of the exceeded area, yet there is no chemical information on wetlands in the Kitimat valley. This information will provide support for the critical limit for wetlands.
   b) Assess Al solubility in mineral soils; Al solubility is a key parameter in the determination of critical loads, associated with the critical limit and $ANC_{leaching}$. This information will help to confirm the current estimates on ANC leaching.
   c) If feasible, establish at least one of the (newly) proposed plant biodiversity plots within the critical load exceeded areas south of the smelter. Further, as noted in the vegetation section, a terrestrial ecosystem line of evidence should be established to integrate the vegetation and soil line of evidence.
3) Revise the assessment of changes in exchangeable base cation at the long-term soil plots to:
   a) Use a change (decrease) in base saturation (%) to calculate KPI (rather than a change in exchangeable base cation pools),
   b) Use soil concentrations in the top 0–30 cm (rather than 0–5cm or 0–15 cm) of mineral soil rather than pools to assess changes in soil chemistry,
   c) Further analyse the minimum detectable difference to evaluate the potential of an early warning change in soil base saturation using a lower level of significance and / or lower power, and
   d) Carry out the next sampling of long-term plots during 2025 (to return to a five-year period) and measure trees (DBH) at time of soil sampling. If the KPI is triggered, measure tree chemistry to assess Bcu by trees.

Recommendations for Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)

Recommendations for the aquatic monitoring program:

1) The seven sensitive lakes should continue to be the core of the EEM Program. Continue with four samples of full chemistry each October from the six sensitive lakes that are accessible, to provide reliable measures of year-to-year changes in lake chemistry. Continue annual sampling (once per year) of sensitive LAK022, which is only accessible by helicopter.

2) Continue annual sampling of the full chemistry of less sensitive LAK016, which has an intermediate level of sensitivity. Discontinue the annual sampling of LAK007 (Clearwater Lake), LAK024 (Lakelse Lake) and LAK034, as the SO_2 EEM Program has shown these lakes to be insensitive under both *current* and *maximum future* levels of sulphur emissions.

3) Continue annual sampling of the full chemistry of the three control lakes to provide reliable measures of year-to-year changes in lake chemistry, an assessment of regional factors such as changing weather patterns, and critical data for statistical analyses of changes in sensitive lakes relative to control lakes. Include one year with multiple sampling visits of the three control lakes during October, to estimate the within-year variability in lake chemistry, and improve statistical inferences.

4) Re-evaluate the EEM lakes in the 2021 Annual Report with respect to their inclusion in the SO_2 EEM Program going forward. This will allow us to collect an additional three years of post-KMP data for all of the originally-identified sensitive lakes, for a total of six years of post-KMP data, before deciding on the need for the continued inclusion of each of the lakes.

5) We do not recommend adding any additional lakes to the EEM Program. We examined the critical loads and exceedances in the context of the updated CALPUFF deposition modeling for all the original STAR lakes, KAEEA lakes located within the study area, and additional lakes sampled early in the EEM Program. These analyses did not provide evidence that any of the lakes excluded from EEM Program should be re-considered for inclusion in the program.

6) Continue intensive sampling of LAK006 (End Lake) with the new Onset pH monitor. Continue measurements of lake levels to assess pH changes associated with storm events. Cease continuous monitoring of LAK012 (Little End Lake) and LAK023 (West Lake), as these lakes have shown very similar patterns to End Lake, and provide no incremental value beyond the intensive monitoring of End Lake. Furthermore, West Lake has not shown any increase in lake SO_4^{2-} since the pre-KMP period.

7) Conduct a thorough review of the report prepared by Paul Weidman (once released) to determine potential next steps in stream monitoring. Discontinue the monitoring of Anderson Creek, which has not provided useful information to the SO_2 EEM Program.

8) If additional fish sampling is required, explore the use of eDNA sampling to estimate any changes in the presence of fish species, and avoid the potential population impacts of gill-net sampling.

9) In addition to the lakes sampled annually within the SO_2 EEM Program, multiple other "non-EEM" lake and stream sites were identified for exploratory water chemistry sampling in particular years over the course of the EEM Program. None of these sites were found to be sensitive to the predicted increases in acidic deposition and therefore none of them were recommended to be added to the EEM Program for further monitoring.

Recommendations for aquatic KPIs, thresholds, and informative indicators:

10) Use ANC as the primary KPI for the program, with pH as an informative indicator.

11) Undertake further analyses to determine which of three possible metrics should be utilized as the KPI for the EEM Program: Gran ANC, BCS or ANC_{OAA}.

12) Include two components in the KPI(s): a *level of protection* to prevent acidification of lakes that are currently not at risk of aquatic impacts (i.e., an absolute threshold); and a *change limit*

which prevents further acidification (for lakes already below the level of protection due to natural organic acids or past acidic deposition) (i.e., a relative threshold).

13) Define the KPI such that a lake must exceed *both* the *level of protection* and *change limit* in order to be considered as an exceedance of the indicator.

14) Continue to use indicators of biologically relevant water chemistry, which provides the best early warnings of changes in lake chemistry that could be damaging to aquatic biota *in advance* of potential damage to aquatic biota and is therefore a *proactive* indicator. Do not use indicators of biological change which provide an indication that damage to aquatic ecosystems *has already occurred* and is therefore a *reactive* indicator.

Recommendations for aquatic critical loads and exceedance modelling:

15) Do not conduct critical loads modelling again in the future, except in a case where a lake has shown strong evidence of acidification (not the case for any of the EEM lakes).

16) Do not update the prediction of exceedances again in the future unless actual or predicted cumulative emissions from all sources are in excess of 42 tpd SO_2 or if the emissions modelling framework is significantly modified.

17) As described in the previous two recommendations, the critical loads of the EEM lakes do not need to be modelled again in the future and there is no need to estimate exceedances again until there are significant changes in emissions of sulphur or nitrogen in the Kitimat Valley beyond the currently permitted level. For these reasons, neither critical loads nor predicted exceedances would be appropriate metrics upon which to build an indicator for the EEM Program.

Recommendations for aquatic analyses and annual reporting:

18) Use the statistical methods provided in Aquatic Appendix F for evaluating future changes in water chemistry in the seven sensitive lakes, less sensitive lake LAK016, and the three control lakes, as well as examining changes on a finer scale in the intensively monitored LAK006 (End Lake). These statistical methods can be re-run on an annual basis to assess status and detect any anomalous patterns.

19) We recommend that the Annual Report be significantly streamlined where possible. The Annual Report should focus on reporting the new data from the monitoring program and updating critical analyses. The Annual Report should not attempt to make interpretations or inferences with respect to year-to-year changes in water chemistry, but should update statistical evaluations of long term changes between pre-KMP and post-KMP periods (see aquatic recommendation #17). However, the scope of the future annual reports will be determined as part of the discussion and development of the next phase of the EEM Program.

<u>Recommendations for the next Review</u>

As the 2019 comprehensive review will conclude in 2020, we recommend that the next review be done in 2026. We recommend that it be more focused than this 2019 review, because of the considerable learning that has occurred in the first six years of the SO_2 EEM Program.

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Technical Memo P04. Atmospheric Sulphur Dioxide – Passive Diffusive Sampler Network: 2016 (March 2017, Trent University)

Technical Memo P05. Atmospheric Sulphur Dioxide – Passive Diffusive Sampler Network: 2017 Results (June 2018, Trent University)

Technical Memo F01. Atmospheric Sulphur – Filter Pack Measurements of Particulate Sulphate (June 2018, Trent University)

Technical Memo D01. Atmospheric Sulphur Dioxide – Method for Estimating Dry Deposition (September 2016, Trent University)

Technical Memo D02. Atmospheric Sulphur Dioxide – Method for Estimating Dry Deposition: 2017 Update (June 2018, Trent University)

Technical Memo S02. Steady-State Soil Modelling - Supplemental Soil Sampling (March 2015, Trent University)

Technical Memo S05. Steady-State Soil Modelling – Supplemental Soil Sampling (March 2017, Trent University)

Technical Memo W05. Power Analyses Technical Appendix (March 2016, ESSA Technologies Ltd.)

Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project

Volume 2: 2019 Comprehensive Review Report Technical Appendices, V.3 Final

[Appendix 1: Introduction]

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No.	Date	Summary of content /changes
V.1	October 31, 2019	Draft appendix for review by the B.C. Ministry of Environment and Climate Change Strategy
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V.3	October 15, 2020	Final appendix

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1 Appendix to Section 1 of the Comprehensive Review Report: Introduction

1.1 2014 SO_2 EEM Plan

This report has been inserted in its original format as a PDF file on the subsequent pages, and as such has different headers and footers from this main appendix file.

Rio Tinto Alcan

Kitimat Modernization Project Sulphur Dioxide Environmental Effects Monitoring Program

Program Plan for 2013 to 2018

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Executive Summary

This document describes the modeling and monitoring that is planned for the next six years (2013 to 2018) under the sulphur dioxide (SO_2) Environmental Effects Monitoring Program for the Kitimat Modernization Project, and thresholds for increased monitoring or mitigation if warranted based on the monitoring results. Rio Tinto Alcan will implement SO_2 mitigation strategies if the outcomes of monitoring and modeling described in this plan show adverse impacts causally related to SO_2 that are considered to be unacceptable.

The EEM Program is specific to SO_2 emissions from KMP. Non-SO_2 KMP emissions, emissions and impacts from other facilities, and research and development of new indicators or monitoring methods are all outside of the scope of the EEM Program.

The plan distinguishes two types of indicators: key performance indicators (KPIs) which will have quantitative thresholds for increased monitoring or for mitigation, and informative indicators which will provide evidence in support of key performance indicators. The following table presents a synthesis of the indicators described in the plan:

Pathway / Receptor	**Key Performance Indicators (KPIs)**	Informative Indicators
Atmospheric Pathways		Atmospheric SO_2 concentrations Atmospheric S deposition Base cation deposition
Human Health	The health section of the EEM program and KPI will be updated when provincially applied SO_2 ambient air quality guidelines come in effect.	Predicted annual restricted airway responses
Vegetation	**Visible vegetation injury caused by SO_2**	S content in hemlock needles
Soils	**Atmospheric S deposition and critical load exceedance risk** **Long-term soil acidification (rate of change of base cation pool) attributable to S deposition**	Magnitude of exchangeable cation pools (Ca, Mg, K, Na) Time to depletion of exchangeable cation pools (Ca, Mg, K, Na) Base cation weathering rates
Lakes and Streams, and Aquatic Biota	**Water chemistry – acidification**	Atmospheric S deposition and critical load exceedance risk Predicted steady state pH versus current pH Evidence that pH decrease is causally related to KMP SO_2 emissions (ANC, SO_4, DOC) Aquatic biota: fish presence / absence per species on sensitive lakes Lake ratings Episodic pH change Amphibians

Glossary

acid deposition	Transfer of acids and acidifying compounds from the atmosphere to terrestrial and aquatic environments via rain, snow, sleet, hail, cloud droplets, particles, and gas exchange
acidification	The decrease of acid neutralizing capacity in water, or base saturation in soil, by natural or anthropogenic processes
acid neutralizing capacity	The equivalent capacity of a solution to neutralize strong acids; ANC and alkalinity are often used interchangeably; ANC includes alkalinity plus additional buffering from dissociated organic acids and other compounds
anion	An ion with more electrons than protons, giving it a negative charge, e.g., SO_4^{2-}
base cations	An alkali or alkaline earth metal (Ca^{2+}, Mg^{2+}, K^+, Na^+)
base cation exchange	The replacement of hydrogen ions in the soil water by base cations from soil particles
critical load	A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur, according to present knowledge
dissolved organic carbon	Organic carbon that is dissolved or unfilterable in a water sample (0.45 µm pore size in the National Surface Water Survey)
dry deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via gravitational settling of large particles and turbulent transfer of trace gases and small particles
environmental effects	Impacts on receptors from KMP SO_2 emissions
facility-based mitigation	Sulphur dioxide (SO_2) emission reduction at the KMP facility
F-factor	A simple way to represent cation exchange processes, specifically the proportion of incoming acidity accompanying sulphate that is exchanged in the soil for base cations
informative indicator	Indicators that will provide supporting information for key performance indicators, and may have quantitative thresholds triggering additional monitoring or modelling, but on their own will not trigger mitigation

key performance indicator	Indicators that will have quantitative thresholds triggering additional monitoring or modelling, receptor-based mitigation, and/or facility-based mitigation
liming	The addition of any base materials to neutralize surface water or sediment or to increase acid neutralizing capacity
pH	A measure of how acidic or basic a solution is, on a scale of 0-14; the lower the pH value, the more acidic the solution; pH 7 is neutral; a difference of 1 pH unit indicates a tenfold change in hydrogen ion activity
receptors	Components of the environment assessed for potential impacts from SO_2 emissions from KMP: human health; vegetation; soils; and lakes, streams and aquatic biota
receptor-based mitigation	Receptor-specific actions to reduce exposure or effects, such as air quality advisories in local communities or liming of selected lakes
RIO TINTO ALCAN properties	Core set of contiguous lands owned by Rio Tinto Alcan around the Kitimat Smelter between Haisla Boulevard and District Lot 5469
wet deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via precipitation (e.g., rain, snow, sleet, hail, and cloud droplets)

Abbreviations

Δ	delta, meaning quantitative change (e.g. ΔANC or ΔSO_2)
<	is less than what follows
≤	is less than or equal to what follows
>	is greater than what follows
≥	is greater than or equal to what follows
[ ]	The concentration, e.g., $[SO_2]$ means the concentration of sulphur dioxide
Al	Aluminum
ANC	Acid neutralizing capacity
Bc	Base cations
BC MOE	British Columbia Ministry of Environment
Ca^{2+}	Calcium
CL	Critical load
Cl^-	Chloride
DOC	Dissolved organic carbon
EEM	Environmental effects monitoring
H^+	Hydrogen
K^+	Potassium
KMP	Kitimat Modernization Project
KPI	Key performance indicator
Mg^{2+}	Magnesium
Na^+	Sodium
NH_4^+	Ammonium
NO_3^-	Nitrate
RTA	Rio Tinto Alcan
SO_4^{2-}	Sulphate
SO_2	Sulphur dioxide
STAR	SO_2 Technical Assessment Report (for KMP)

1.0 Introduction

1.1 PURPOSE AND SCOPE

In 2013 a technical assessment (ESSA et al. 2013) was completed for the Kitimat Modernization Project (KMP), to determine the potential impacts of sulphur dioxide (SO_2) emissions along four lines of evidence: effects on human health, vegetation, terrestrial ecosystems (soils), and aquatic ecosystems (lakes and streams, and aquatic biota).

The purpose of the SO_2 Environmental Effects Monitoring (EEM) Program is to answer questions that arose during the technical assessment, and to monitor effects of SO_2 along these lines of evidence. Results from the EEM Program will inform decisions regarding the need for changes to the scale or intensity of monitoring, as well as decisions regarding the need for mitigation.

The scope of the EEM Program encompasses KMP SO_2 emissions at full production capacity, and this plan focuses on the EEM Program for first 6 years (2013-2018). What is learned during this period will be applied to improve the Program in 2019. Other KMP emissions, research and development related to SO_2 impact measurement and mitigation, monitoring for non-KMP acid deposition and monitoring not specific to KMP SO_2 impacts are all outside of the scope of the SO_2 EEM Program.

This document describes the modeling and monitoring that is planned for the next six years, and decision rules based on quantitative indicator thresholds for increased monitoring or mitigation if warranted based on these results. Two broad categories for mitigations are identified:

Receptor-based – mitigations that would be receptor-specific in design and application, for example air quality advisories in local communities or adding lime to selected lakes

Facility-based – sulphur dioxide (SO_2) emission reduction at the KMP facility

The SO_2 EEM Program focuses on indicators which can be causally related to SO_2 emissions. Two types of indicator are recognized:

Key performance indicator (KPI) – which will have decisions rules (quantitative thresholds) for increased monitoring and for mitigation

Informative indicator – which may have decision rules for increased monitoring, but will have no decision rules for mitigation on their own; instead they will provide evidence in support of key performance indicators

Sections 2 through 6 present indicators and methods for the pathways and receptors depicted in Figure 1. Section 7 describes how a "causal relationship to KMP" will be determined for indicators exceeding their thresholds. Section 8 summarizes the actions that Rio Tinto Alcan will take if unacceptable impacts occur, and Section 9 describes the schedule and content for SO_2 EEM reporting and review.

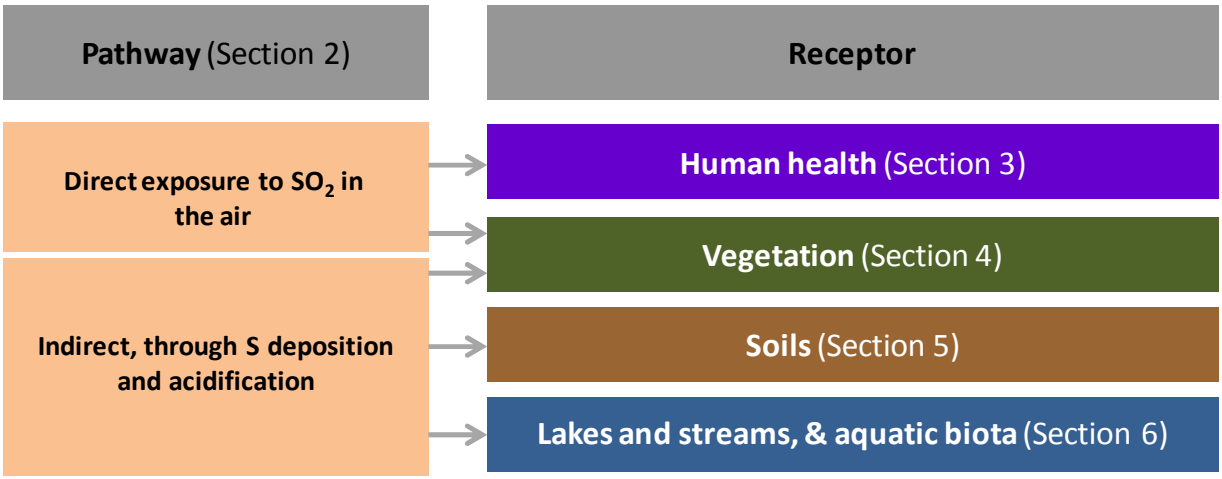


Figure 1. Organization of information in this SO_2 EEM Plan.

1.2 SO_2 EEM FRAMEWORK

Figure 2 illustrates the decision framework for the SO_2 EEM Program. It is divided into three overall phases: pre-KMP, ramp-up and initial KMP operation (2013-2018), and 2019 onward.

The first phase began pre-KMP with the SO_2 technical assessment to determine the potential impacts of SO_2 emissions from KMP. Four potential impact categories were identified, and remain relevant for interpreting monitoring results from the SO_2 EEM Program (Table 1):

Table 1. Impact categories used in the SO_2 Technical Assessment Report

Impact Category	Interpretation
Low	No impact or acceptable impact
Moderate	Acceptable impact but in need of closer scrutiny
High	Unacceptable impact; mitigation action needed
Critical	Extremely unacceptable impact; mitigation action needed

The SO_2 technical assessment predicted that impacts on vegetation would fall into the green (low) impact category, and that impacts on human health, soil, and water and aquatic biota would fall into the yellow (moderate) impact category. The SO_2 EEM Program will determine whether these predictions were correct, and if EEM results indicate that actual outcomes under KMP for any of the receptors will fall into higher impact categories than predicted, describe the decisions rules for action.

In addition, the SO_2 EEM Program will answer questions that arose during the technical assessment (presented in Appendix A). The answers will result in one of three possible outcomes for the receptors:

- The pre-KMP assessment *over*estimated or accurately estimated the impact category. In other words, the impact category predicted in the assessment was either too high, or correct. In the framework, this situation is represented by a "thumbs up".



- The pre-KMP assessment *under*estimated the impact category. In other words, the assessment was overly optimistic – represented in the framework as one or two "thumbs down", depending on the implications of the underestimation of impacts.



- It is unclear whether the assessment underestimated or overestimated the impact risk – represented in the framework as "thumbs down" with a question mark.



The second phase occurs in 2013 to 2018, from KMP ramp-up through to the first years of full operation. It is focused on learning, through regular evaluation of results designed to provide:

- Evidence that the technical assessment *under*estimated the impact category () **and/or** that the impacts are (or are expected to be) high ( ) or critical ( ).
  This will require mitigation and an escalation in either the frequency or extent of monitoring, or both.
- Evidence that the assessment correctly or *over*estimated the impact category (), or *under*estimated the impact category () **but** the impacts are (or are still expected to be) low ( ) or moderate ( ).
  This will require no mitigation, but may require modifications to monitoring.
- Unclear evidence either way due to lack of time for effects to be manifested (e.g., to observe that a lake is acidifying) (), and the impact category is still estimated to be no higher than moderate ( ).
  This will require no mitigation, but may require modifications to monitoring, either to increase the frequency or number of monitoring locations, or both.

Annual SO_2 EEM Program reports will be produced during the first 6 years to convey results as well as any mitigation that has been undertaken during the preceding year. Annual monitoring plans for the next year will also be developed based on these results.

The third phase begins in 2019, when a report will be produced that synthesizes what has been learned during the first 6 years and assesses which questions have been sufficiently answered and which have not. Based on this report a decision will made about what monitoring should continue, and the frequency of reporting. The SO_2 EEM Program is expected to evolve over time according to what is learned.

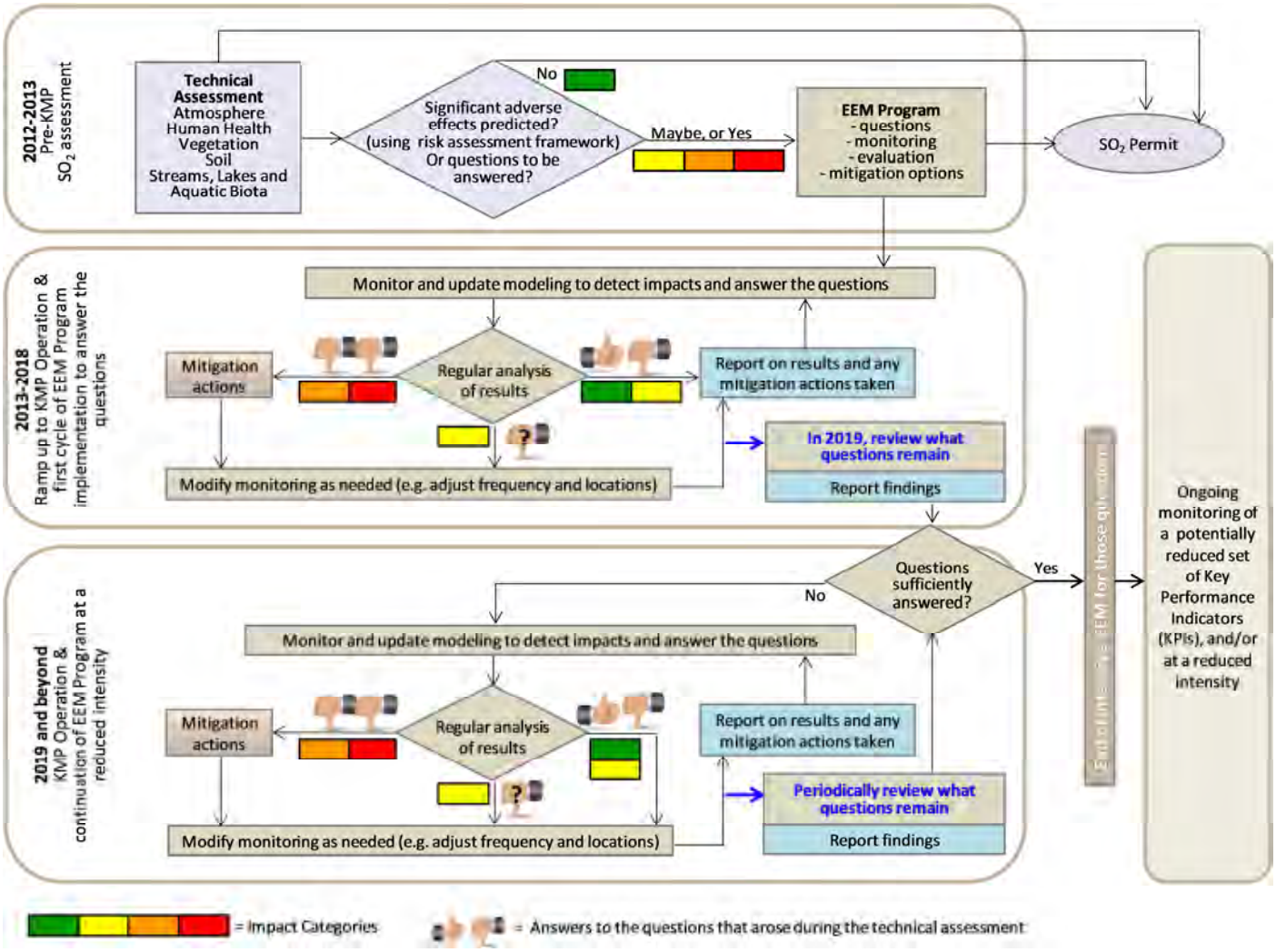


Figure 2. SO_2 EEM framework for KMP.

1.3 DECISION RULES

The cycle within the second phase (2013-2018) of the framework in Figure 2 involves a set of quantitative, threshold-based "decision rules" as illustrated in Figure 3. Thresholds for increased monitoring are lower than thresholds for mitigation, and thresholds for receptor-based mitigation are lower than thresholds for facility-based mitigation. If receptor-based mitigations are not feasible, or are implemented but found to be ineffective, facility-based mitigations will be implemented.

Results of the synthesis and comprehensive review in 2019 will inform decisions about:

- which KPIs and informative indicators should be monitored in 2019 and beyond and at what level of intensity,
- modifications to monitoring methods,
- refinement to KPI thresholds (decision rules), and
- the timeline for the next comprehensive review.

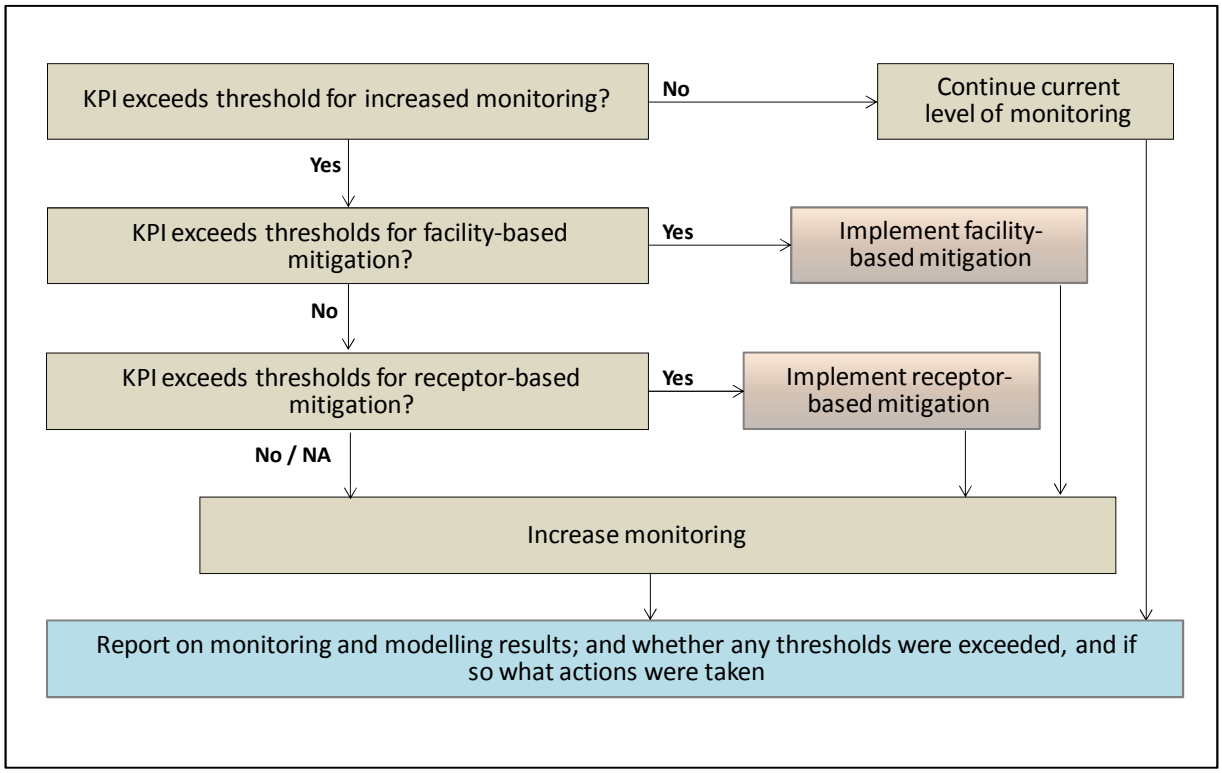


Figure 3. Decision tree for quantitative thresholds of key performance indicators.

2.0 Atmospheric Pathways

2.1 INDICATORS

Table 2. Informative indicators for atmospheric pathways.

Informative indicators	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Atmospheric SO_2 concentration	- Not applicable; will support KPIs and informative indicators for the receptors	- Predicted annual restricted airway responses (3-year rolling average) - Visible vegetation injury caused by SO_2 - Atmospheric S deposition and critical load (CL) exceedance risk
Atmospheric S deposition	- Not applicable; will support KPIs and informative indicators for the receptors	- Atmospheric S deposition and critical load (CL) exceedance risk - Long-term soil acidification attributable to S deposition - Water chemistry - acidification
Base cation deposition	- Not applicable; will support critical load (CL) modelling	- Atmospheric S deposition and critical load (CL) exceedance risk

2.2 METHODS

Table 3. Overview of methods for calculating informative indicators for atmospheric pathways.

Informative indicators	Method overview
Atmospheric SO_2 concentration	Continuous analyser measurements of SO_2 air concentrations from Haul Road, Whitesail, Riverlodge, Kitamaat Village and possibly also Lakelse Lake, as well as the MOE-operated station at Terrace
Atmospheric S deposition	Wet deposition monitoring stations at Haul Road and Lakelse Lake Estimation of dry deposition of S (gaseous S using continuous analysers and pilot testing of passive samplers; particulate S using a filter pack; requires ancillary meteorological monitoring)
Base cation deposition	Wet deposition monitoring and modelling based on data from Haul Road and Lakelse Lake

2.2.1 Atmospheric SO_2 concentration

Sampling locations:

- Essential locations for continuous samplers: Haul Road (fenceline), Whitesail (upper Kitimat), Riverlodge (lower Kitimat), Kitamaat Village (Haisla)).[1] Monitoring at the KMP Camp should also be continued until the analyser is relocated to Lakelse Lake; and then continuous SO_2 monitoring will occur at the new Lakelse Lake site. In addition, MOE will establish a continuous sampler station at Terrace.[2]

Sampling timing, frequency and duration:

- Maintain operation of continuous analysers through 2018 (this assumes that KMP will be fully implemented and at steady-state operations by the end of 2017).

Monitoring protocols and sampling methods:

- Continue to follow the monitoring protocol for continuous analysers including maintenance, calibration, and data collection and quality review.

How and when monitoring data will be evaluated:

- Using continuous analyser data from 2014 to 2018, compare measured concentrations to post-KMP concentrations modelled for the STAR (completed in the first quarter of each year from 2015 to 2019). This timeline assumes that KMP will be fully implemented and at steady-state operations by the end of 2017.
    A. Post-KMP Monitoring Data Study:
        1. Collect and Quality-Assure 12 months of post-KMP emissions data
        2. Collect and Quality-Assure 12 months of SO_2 continuous monitoring data and meteorological data for corresponding time period.
        3. Model actual emissions from 12-month period using the CALPUFF modeling system (including CALMET for new period) using STAR methods
        4. Compare modelled results to monitoring data
    B. Refine CALPUFF Modelling Methods (if the Monitoring Data Study does not show desirable agreement between model results and monitoring data):
        1. Identify model refinement options
        2. Test each option individually to determine effect on model performance.
        3. Define refined CALPUFF model methods based on Step 2 tests
        4. Run refined CALPUFF model for 12 months post-KMP actual emissions
        5. Compare refined CALPUFF model results to monitoring data to confirm overall improvement in model-monitor agreement

[1] The number and location of continuous monitoring stations is subject to finalization in 2018.

[2] Four lines of evidence will provide insights on spatial distribution of SO_2: 5-6 continuous samplers measuring actual SO_2 concentrations, CALPUFF modeling of SO_2 concentrations, S content in hemlock needles, and passive samplers.

2.2.2 Atmospheric S, base cation and chloride deposition

Deposition monitoring will include S, base cations and chloride. The SO_2 technical assessment analyses for predicting critical load exceedance in soils and surface water assumed that deposition of base cations was zero. This was a conservative assumption, as non-marine base cation deposition would increase critical loads and reduce estimates of exceedance.

Sampling locations:

- The NADP site at Haul Road and the proposed site at Lakelse Lake, noting that Lakelse Lake provides the most relevant data to define background base cation precipitation chemistry.
- Regional observations may be supplemented with existing observations from western North American networks, and regional maps of precipitation volume.

Sampling timing, frequency and duration:

- Establishment and continued monitoring at two NADP stations providing data for 3+ years to evaluate background S, base cation and chloride deposition. In this respect, Lakelse Lake will provide the most valuable data.

Monitoring protocols and sampling methods:

- Wet deposition monitoring will be carried out by the NADP following standard NADP network protocols for sample collection, handling and analysis (http://nadp.sws.uiuc.edu). The analysis of wet deposition samples will include sulphur (S), nitrogen (N), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}); as well as chloride (Cl^{-}).

How and when monitoring data will be evaluated:

- S deposition maps will be generated, as was done for the KMP SO_2 Technical Assessment Report (Figure 7.6-5 in ESSA et al. 2013)
- Base cation precipitation chemistry maps will be used to revise regional critical load and exceedance maps to incorporate base cation deposition.

2.2.3 Additional studies

2.2.3.1 Passive Samplers

Consideration is also being given to the use of passive samplers to monitor atmospheric SO_2 concentrations at a broader suite of locations, to increase the spatial coverage of data collection for this indicator.

Sampling locations:

- It is essential that the passive samplers in the pilot program be co-located with continuous monitoring stations to ensure they correlate well ($r \geq 0.8$) with continuous SO_2 monitors (as such the pilot program is dependent upon reliable operation of continuous monitors).

Sampling timing, frequency and duration:

- Examine the results of the passive monitoring conducted in 2011-2012, to inform development of protocols for 2015 trials and future expanded monitoring in the humid environment of the study area. Conduct a pilot program for passive sampling in 2015. If the pilot program is successful, implement at a larger scale in summer of 2016, 2017 and 2018, expanding to include near- and far-field locations to capture a spatial gradient of air concentrations.

Monitoring protocols and sampling methods:

- Follow the protocol for the passive sampling pilot program in 2014. If the passive samplers are proven effective, develop a revised passive diffusive SO_2 monitoring program by the first quarter of 2015 to augment continuous SO_2 analysers.

How and when monitoring data will be evaluated:

- Passive sampling data from 2015 will be compared with continuous analyser data to assess the accuracy of passive samplers.
- If a full-scale passive sampling program is implemented, data from 2016 to 2018 will be used to evaluate the relative distribution of CALPUFF modelled concentrations compared to the distribution of measured concentrations at the passive samplers.

2.2.3.2 Dry Deposition Estimation

The method for estimating dry deposition will be developed in 2015.

2.2.3.3 Ambient Air Network Rationalization

A rationalization process for ambient air monitoring stations (number and location) will begin in 2015.

2.2.4 Summary of Atmospheric Pathway actions, 2013-2018

Table 4. Schedule of work on the atmospheric component of EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Atmospheric SO_2 Concentrations – Continuous Analysers	Maintain existing 4 continuous SO_2 analysers. Assess and compare [SO_2] at Haul Road vs KMP Campsite.	Maintain existing 4 continuous SO_2 analysers.	Maintain 4 continuous SO_2 analysers. Compare to model output. Develop a protocol approved by BC MOE to assess the location of continuous analysers and agree on a strategy and timeline for potentially relocating station(s) to more representative locations.	Maintain 4 continuous SO_2 analysers. Compare to model output. Implement the strategy for station locations approved by BC MOE in 2015.	Maintain 4 continuous SO_2 analysers. Compare to model output. Implement the strategy for station locations approved by BC MOE in 2015.	Maintain 4 continuous SO_2 analysers. Compare to model output.
Atmospheric SO_2 Concentrations – Passive Diffusive SO_2 Monitoring	–	Write up 2011-2012 passive monitoring results; use to inform design low cost pilot program with non-TEA based samplers at least 3 sites to see if they correlate well with continuous SO_2 monitors.	Implement pilot program.	If (and only if) pilot program shows good correlations with continuous monitors, then develop revised passive diffusive SO_2 monitoring program to augment SO_2 analysers.	If methodology proven to be effective in 2015 pilot, conduct passive monitoring	If method proven to be effective in 2015 pilot, conduct passive monitoring program.
Wet Deposition – S , Base Cations, Chloride	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake).	Maintain 2 rain chemistry stations (Haul Road and Lakelse Lake). [In 2019, compare 2013-2018 data to model output, and assess number of rain chemistry stations.]
Dry Deposition	–	Determine entity to develop method for estimating dry deposition using existing data.	Develop and apply the method, to see if this is a significant data gap. Relocate Campsite KMP ambient air and meteorological station to allow for estimating dry deposition at Lakelse Lake (or in 2016, as per the row for [SO_2]).	Continue to estimate dry deposition at both Haul Road and Lakelse Lake stations.	Continue to estimate dry deposition at both Haul Road and Lakelse Lake stations.	Continue to estimate dry deposition at both Haul Road and Lakelse Lake stations [In 2019, compare 2013-2018 data to model output.]
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

3.0 Human Health

3.1 INDICATORS AND THRESHOLDS

The period between 2014 and 2019 is an interim period for baseline air quality data collection to support the establishment of a health indicator for SO2 emissions. As an interim metric, a dose – response health risk metric is used to inform the EEM program of the health risks associated with KMP derived SO2 emissions. Following 2019 or when a provincially approved SO2 ambient air quality guideline is established, both section 3 and table 5 of the EEM program will be updated to include the new air quality guidelines and associated SO2 management actions.

In support of the development of a health based key performance indicator, the Kitimat ambient air station monitoring network will undergo a review and rationalization process in 2015 to ensure that the monitoring stations are representative of KMP SO2 emissions (please see table 4).

Rio Tinto Alcan Kitimat will also participate in an air quality advisory system for SO2 when it is developed by the BC Ministry of Environment.

Table 5. Interim Informative indicator for human health and Key Performance Indicator that will based on a Provincially approved air quality guideline

Informative indicator	Threshold for increased monitoring	Indicators to be jointly considered
Predicted annual number of SO2-associated respiratory responses (3-year rolling average)	Not applicable	Atmospheric SO2 concentrations

Future Key performance indicator	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
The health section of the EEM program and KPI will be updated when provincially applied SO_2 ambient air quality guidelines come in effect.[3]			Should there be non-attainment of the guidelines once in effect and following 3 years of applicable data collection, emission reduction will be managed in accordance with section 8 of the EEM plan.[4]	Atmospheric SO_2 concentrations

The health section of the EEM program and KPI will be updated when provincially applied SO_2 ambient air quality guidelines come in effect. The Ambient air data collection to support the future KPI will commence when the Smelter reaches full metal production capacity. Should there be non-attainment of the guidelines once in effect and following 3 years of applicable data collection, emission reduction will be managed in accordance with section 8 of the EEM plan. The choice for attainment of the air quality guideline will be based on a scientific process using tools such as dispersion modeling.

[3] Ambient air data collection to support the KPI will commence when the Smelter reaches full metal production capacity (anticipated in 2016).

[4] The choice for attainment of the air quality guideline will be based on a scientific process using tools such as dispersion modeling.

3.2 METHODS

Table 6. Overview of method for calculating the informative indicator for human health.

Informative indicator	Method overview
Predicted annual number of SO_2-associated respiratory responses	Repeat on an annual basis the calculations conducted in the STAR, under the same baseline assumptions, but using air dispersion modelling refined based on the SO_2 monitoring network and updated estimates of the Peak-to-Mean ratio under Post-KMP conditions.

3.2.1 Predicted annual number of SO_2-associated respiratory responses

The analysis will be conducted according to the following process:

1) Air dispersion modelling will be repeated annually for the same near-field locations as were studied in the STAR (Upper and Lower Kitimat, Kitamaat Village, Service Centre).
2) One or more monitoring stations will be chosen to generate estimates of the Peak-to-Mean ratio in the Post-KMP context. The peaks will be calculated as the highest 5-minute average within each hour. A distribution for the peak-to-mean ratio in the form of a binned histogram will be used in later calculations.
3) The refined air dispersion model output and the updated Peak-to-Mean ratio will be used to generate health risk estimates (annual respiratory airway events) exactly as they were previously in the STAR. The baselines assumptions from the STAR will be applied (e.g., exercise frequency and location, indoor versus outdoor exercise).
4) Each year starting with the third year, the rolling three-year annual average will be compared to the results from the STAR.

3.2.2 Summary of Human Health actions, 2013-2018

Table 7. Schedule of work on the human health component of the EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Atmospheric SO_2 concentration	–	–	Increase accessibility of ambient air quality data to the community. Report on SO_2-associated predicted airway responses.	Report on SO_2-associated predicted airway responses.	Report on SO_2-associated predicted airway responses.	Report on SO_2-associated predicted airway responses.

4.0 Vegetation

4.1 INDICATORS AND THRESHOLDS

Table 8. KPI and informative indicator for vegetation.

Key performance indicator	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Visible vegetation injury caused by SO_2	More than occasional symptoms of SO_2 injury outside of Rio Tinto Alcan Kitimat properties, causally related to KMP Action: assess ambient air data, meteorological data and KMP SO_2 production data to find the potential causes; and increase visual inspection frequency to annual	Not applicable – there are no reasonable receptor-based mitigations	Severe & repeated[5] symptoms of SO_2 injury outside of Rio Tinto Alcan properties causally related to KMP, including species of economic or social/traditional importance, or symptoms of SO_2 injury causally related to KMP at long-distance (>15km) monitoring locations Action: reduction in SO_2 emissions	- Atmospheric SO_2 concentration - S content in hemlock needles - Atmospheric S deposition (specifically, wet deposition)

Informative indicator	Threshold for increased monitoring[6]	Indicators to be jointly considered
S content in hemlock needles	An increase of more than 1 standard deviation (from pre-KMP baseline data)[7] in 20% of the sites for 3 consecutive years, causally related to KMP Action: assess ambient air data, meteorological data and KMP SO_2 production data to find the potential causes; and increase visual inspection frequency to annual	- Atmospheric SO_2 concentration - Water chemistry - Soil chemistry - Atmospheric S (wet) deposition

S content in hemlock needles will be used to validate the air modelling, and could be replaced by passive monitors if the pilot described in Section 2 is undertaken and proves effective.

[5] "Severe" means more than 50% of the leaf area is necrotic due to SO_2 exposure on more than 50% of the plants of a single species at an inspection location outside the RTA boundary at the inspection time in late summer (the last 2 weeks of August to the first 10 days of September). It would take at least 2 years (2 late-summer inspections) to determine if the damage seen the first year is "repeated".

[6] Thresholds for increased monitoring are not applicable. This indicator will assist with interpretation of results for the visible injury KPI.

[7] Based on historical monitoring of S in vegetation (1989-2011) (Table 9.2-1 in the STAR (ESSA et al. 2013)).

4.2 METHODS

Table 9. Overview of methods for calculating the KPI and informative indicator for vegetation.

Key performance indicator	Method overview
Visible vegetation injury caused by SO_2	Visual inspection for SO_2 injury every 2 years

Informative indicator	Method overview
S content in hemlock needles	Yearly chemical analysis of S content in needles

4.2.1 Visible vegetation injury caused by SO_2

Sampling locations:

- Areas with existing vegetation surveys (Figure 8.4-1 in the KMP SO_2 Technical Assessment Report (ESSA et al. 2013)).
- Additional locations where critical loads in soils are predicted to be exceeded (from the KMP SO_2 Technical Assessment Report).

Sampling timing, frequency and duration:

- Visual inspection and evaluation will occur every other year[8], near the end of the growing season (late August to early September). The inspection frequency will be increased to annual if the threshold for increase monitoring is reached.
- Frequency and duration after 2018 to be determined in 2019 based on results to 2018.

Monitoring protocols and sampling methods:

- According to visual inspection protocols documented in Laurence (2010).
- A list of vegetation species in the study area that have been reported to be sensitive to SO_2 will be incorporated into a checklist on the field survey forms for visual inspection. During the annual inspections, the checklist will also be used to determine the presence of species that may be sensitive to SO_2 (see Appendix B).

How and when monitoring data will be evaluated:

- Data from 2014 to 2018 will be used to determine whether the health of vegetation is significantly affected compared to the condition at locations remote to KMP.
- Diagnosing injury to vegetation due to air pollutants is aided by two factors: specific symptoms and pattern of injury, and the species injured.

[8] Visual surveys could potentially also be done during 'in-between' years if coincident with sampling hemlock needles for S content.

- Hydrogen fluoride (HF) (gaseous F) causes symptoms at the margins of broadleaf plants or the tips of needles or blade-leaf plants (such as gladiolus). SO_2 generally causes symptoms of interveinal chlorosis or necrosis on broadleaf plants. It can cause tip necrosis similar to HF on conifers. It may also cause some marginal chlorosis, but that is generally accompanied by interveinal symptoms as well. The pattern of injury is generally marginal for HF and interveinal for SO_2. Injury due to SO_2 often has a more bleached appearance than that due to HF.
- Plants differ in sensitivity to the pollutants as well. Plants such as gladiolus, Hypericum, mugo pine, cherry, and scouler willow are sensitive and diagnostic for HF. Plants such as Rubus, Acer, and Phaseolus are sensitive and diagnostic for SO_2.

How to determine the magnitude of emissions reductions needed if the threshold for facility-based mitigation is reached for this KPI:

There are two possibilities:

i. The actual concentrations and associated exposures (concentration x time) are in excess of the concentrations and exposures predicted in the STAR
ii. The vegetation at the site is more sensitive than the literature indicated

The following steps would determine the quantitative reduction necessary in exposure:

1. Co-locate an atmospheric monitor (or a passive monitor, if the passive monitoring pilot is successful) with the vegetation inspection/sampling site(s) where the injury has been observed to determine the actual exposures that are occurring at that location. If the exposures are greater than predicted in the STAR, we will use CALPUFF to determine necessary emission reductions to reduce the exposure to the acceptable levels.
2. If the exposures are within the range predicted in the STAR to occur without causing injury, then the vegetation apparently is more sensitive than reported in the literature. In that case, new thresholds would be calculated based on monitored exposures at locations where effects were within the acceptable range, and modeling studies would be used to determine the reductions in emissions necessary to reach those new thresholds.

4.2.2 S content in hemlock needles

Sampling locations:

- In locations where continuous and passive samplers are operating and at vegetation sampling and inspection sites (Laurence 2010).

Sampling duration and frequency, and essential years and times:

- Samples will be collected near the end of the growing season from mid-August to mid-September (Laurence 2010), for at least the first three years, and longer if warranted based on these results.

Monitoring protocols and sampling methods:

- Monitoring and sampling will be done according to current procedures in use for annual and biennial vegetation sampling protocols (Laurence 2010).

How and when monitoring data will be evaluated:

- Chemical analysis will be conducted by Rio Tinto Alcan and analysed and interpreted in the winter.
- The results will be reported to MOE in March, in time to adjust sampling and inspection for the next growing season if needed.

4.2.3 Summary of Vegetation actions, 2013-2018

Table 10. Schedule of work on the vegetation component of the EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Vegetation Survey	–	Add checklist for presence / absence of sensitive species on field survey form; conduct visible injury survey. Continued vegetation sampling as per Laurence (2010).	–	Visible injury survey. Continued vegetation sampling as per Laurence (2010).	–	Visible injury survey. Continued vegetation sampling as per Laurence (2010).
S Content in Hemlock Needles	–	Samples collected near the end of the growing season from mid-August to mid-September.	Sampling from mid-August to mid-September.	Sampling from mid-August to mid-September.	Sampling from mid-August to mid-September, if warranted from results in 2014 – 2016.	Sampling from mid-August to mid-September, if warranted from results in 2014 - 2016.
Sensitive Ecosystem Mapping (applies to vegetation, soils, and water receptors; listed just once here to avoid repetition)	–	Review Predictive and Thematic mapping to see if there are sensitive ecosystems within the plume not covered by the existing network of vegetation, soil and surface water sampling sites.	–	–	–	–
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

5.0 Soils

5.1 INDICATORS AND THRESHOLDS

The first KPI for this receptor is prediction-based: measured soil chemistry data and measured S deposition data will be used as inputs for updated modeling of critical loads, to determine the spatial distribution and magnitude of exceedance of critical loads of acidity for forest soils. Results will reveal the *extent* of expected impact (i.e. how large an area might be affected) and the *level* of exceedance (i.e. the magnitude of deposition greater than critical load). The second KPI is observation-based: soil chemistry data in selected plots will be tracked to determine actual change in soil base cations over time. For both KPIs, if the thresholds for receptor-based mitigation are reached, and receptor-based mitigations are applied but prove ineffective, facility-based mitigations will be implemented.

Table 11. KPIs and informative indicators for soils.

Key performance indicator	Threshold for increased monitoring / modelling	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Atmospheric S deposition and critical load (CL) exceedance risk[9]	S deposition causally related to KMP emissions exceeding CL in > 1% (~20 km^2) of semi-natural upland forest soils in the study area (Figure 4)[10] Action: re-evaluate uncertainties in the regional critical load mapping and re-run the CL model with new data where required	S deposition causally related to KMP emissions exceeding CL in >5% (~100 km^2) of semi-natural upland forest soils in the study area within 200 years (based on projected change in base cations) Action: Pilot application of lime/wood ash, to reduce soil acidity and increase base cation pools to pre-KMP levels, subject to BC MOE[11] approval	S deposition causally related to KMP emissions exceeding CL in >5% (~100 km^2) of semi-natural upland forest soils in the study area within 100 years (based on projected change in base cations) Action: reduction in SO_2 emissions	- Atmospheric S deposition - Magnitude of exchangeable cation pools (Ca, Mg, K, Na) - Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)
Long-term soil	For one plot: a	For one or more	Decrease in the	- Atmospheric S

[9] Even though KMP will become operational during the 6-year period of this plan, risk of CL exceedance remains a *prediction* based on a combination of monitoring data and modeling. Confidence in these predictions will increase through monitoring of atmospheric S deposition and long-term soil acidification.

[10] As described in Section 8.5-2 of the KMP SO_2 Technical Assessment Report (ESSA et al. 2013), undisturbed forest sites on mineral soils comprise 69% of the study area (1991 km^2 of 2,895 km^2).

[11] Information on the feasibility of this mitigation is provided in Appendix G.

Key performance indicator	Threshold for increased monitoring / modelling	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
acidification (rate of change of base cation pool) attributable to S deposition	40% decrease in 5 yrs or a 20% decrease in 10 yrs in exchangeable cation pools for at least one element, and decrease is causally related to KMP emissions Action: extended soil survey and modelling to assess spatial significance of observed base cation loss (i.e., are there wider issues over >1% of the study area?)	plots: a 40% decrease in 5 yrs[12] or a 20% decrease in 10 yrs in exchangeable cation pools for at least one element and in > 1% (~20 km^2) of the area of semi-natural upland forest soils, based on dynamic modelling, and decrease is causally related to KMP emissions Action: pilot application of lime/wood ash to reduce soil acidity and increase base cation pools to pre-KMP levels, subject to MOE approval	magnitude of exchangeable cation pool of ≥ 20% in 10 years, and in > 5% (~100 km^2) of the area of semi-natural upland forest soils, based on modelling, and decrease is causally related to KMP Action: reduction in SO_2 emissions	deposition - Magnitude of exchangeable cation pools (Ca, Mg, K, Na)

Informative indicators[13]	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Magnitude of exchangeable cation pools (Ca, Mg, K, Na)	- Not applicable; supports critical load modeling and calculation of time to depletion of exchangeable cation pools in locations where CL is exceeded	- Atmospheric S deposition and critical load (CL) exceedance risk - Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)
Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)	- Not applicable; supports critical load modeling for locations where CL is exceeded	- Atmospheric S deposition and critical load (CL) exceedance risk - Magnitude of exchangeable cation pools (Ca, Mg, K, Na) relative to the level of exceedance

[12] The first resampling would occur over a 3-year interval (i.e. sampling in 2015 and then 2018) in order to have two data points for the first synthesis. Observed changes during that period would therefore be pro-rated to a 5-year and 10-year rate of change. Sampling will be at 5 year intervals thereafter.

[13] Thresholds for increased monitoring/modelling, or mitigation, are not applicable. These indicators support critical load modeling.

Informative indicators[13]	Thresholds for increased monitoring or mitigation	Indicators to be jointly considered
Base cation weathering rates	- Not applicable; supports critical load modeling	- Atmospheric S deposition and critical load (CL) exceedance risk

The thresholds for both of the KPIs for soils are related to a proportional areal exceedance of the receptor study domain. In the absence of provincially-established air zone boundaries, the STAR used a study area along the Kitimat valley encompassing the modelled post-KMP 10 kg SO_4^{2-}/ha/yr plume and potentially sensitive terrestrial and aquatic receptor ecosystems. The study domain was defined in agreement with BC MOE, and encompassed 1991 km^2 of forested ecosystems on mineral soil (69% of the study area). The proportional exceedance reported in the STAR was referenced to this domain area. More recently under the Kitimat Airshed Emissions Effects Assessment (ESSA et al. 2014), BC MOE favoured an effects domain based on the area under the modelled 7.5 kg SO_4^{2-}/ha/yr plume. In 2017 the proportional areal exceedance will be evaluated using the original domain area and an effects domain defined by the area under the 7.5 kg SO_4^{2-}/ha/yr plume. Both domains capture near field emission impacts and far field impacts owing to long-range transport of sulphur dioxide emissions.



Figure 4. Semi-natural upland forest soils in the study area. Source: Figure 9.3-2 from ESSA et al. (2013).

5.2 METHODS

Table 12. Overview of methods for calculating the KPI and informative indicator for soils.

Key performance indicators	Method overview
Atmospheric S deposition and critical load (CL) exceedance risk	Re-running the critical load model in 2017
Long-term soil acidification attributable to S deposition	Soil sampling and modelling studies to assess the rate of change in magnitude of exchangeable cation pools (Ca, Mg, K, Na), using all available data sources

Informative indicators	Method overview
Magnitude of exchangeable cation pools (Ca, Mg, K, Na)	Measured from soil samples (if >5% exceedance in study area)
Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)	Deposition monitoring as described in Section 2 and soil samples (if >5% exceedance in study area)
Base cation weathering rates	Soil sampling, laboratory analysis

5.2.1 Atmospheric S deposition and critical load (CL) exceedance risk

The monitoring method for this indicator is described in Section 2. Critical load exceedance (and % of area with CL exceedance) will be re-calculated in 2017, adding weathering rate data from new soil sampling sites, base cation deposition and revised critical limits.

Steps for determining the magnitude of emissions reductions needed if the threshold for facility-based mitigation is reached for this KPI:

1. Critical load exceedance is expressed in the same unit as sulphur deposition; as such, the magnitude of exceedance is equivalent to the required deposition reduction;
2. Use CALPUFF to explore different emission scenarios for reducing deposition to meet targets (reduced magnitude / areal exceedance);
3. Run the SSMB model to determine the expected magnitude and areal extent of exceedance under revised deposition from Step 2;
4. Iterate Steps 2 and 3 as necessary to achieve the required level of exceedance reduction (see example in Figure 5);
5. Use finalised CALPUFF scenario to inform decisions on facility-based SO_2 emission reduction (options, amounts and timelines presented in Section 8).

6. Implement the chosen methods of facility-based mitigation as per process described in Section 8.
7. Develop revised monitoring and modelling plan for post-mitigation period to determine if the revised emissions and deposition result in the anticipated recovery of soil conditions.

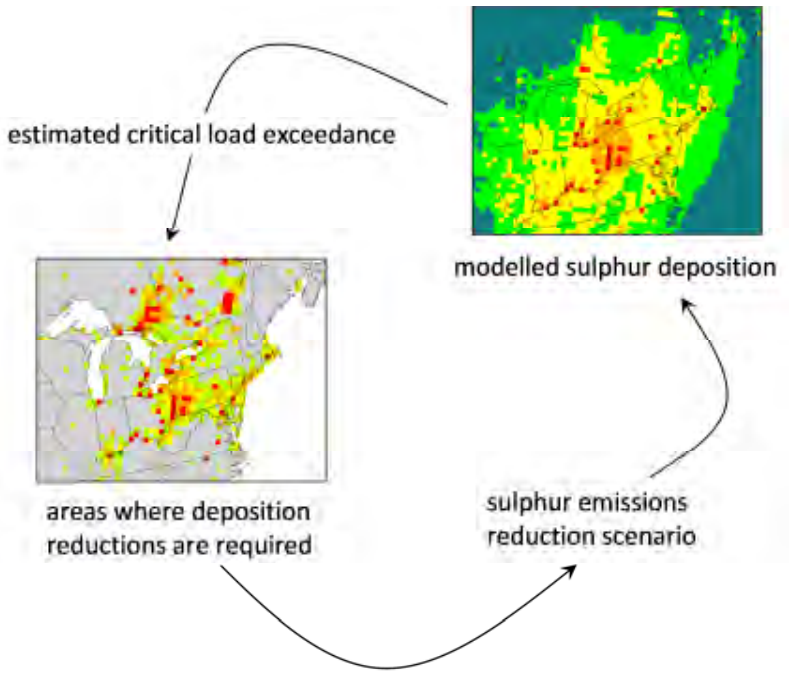


Figure 5. Example showing iterative cycle of critical load exceedance, sulphur emissions reduction scenario, revised modelled deposition based on emissions scenario, and revised (reduced) critical load exceedance

5.2.2 Long-term soil acidification attributable to S deposition

Sampling locations:

- Sites to be determined in consultation with MOE, in long term forest productivity sites; variability of soils will determine the number of samples.
- The Haisla First Nation will be invited to participate in the selection of soil sampling sites.

Sampling duration and frequency, and essential years and times:

- Sampling at 3 plots, every 5 years (with the exception of the first re-sampling interval at 3 years, i.e. 2015, 2018, 2023, 2028, 2033, 2038, etc.).

Sampling methods:

- To be determined in consultation with BC MOE.

How and when monitoring data will be evaluated:

- To be determined in consultation with BC MOE.

Steps for determining the magnitude of emissions reductions needed if the threshold for facility-based mitigation is reached for this KPI:

1. Use a dynamic model to define a target deposition load, i.e., the deposition required to reach a desired soil chemistry within a specified timeframe;
2. Use CALPUFF to explore different scenarios for reducing deposition to meet the target load;
3. Run the dynamic model to predict timeline of recovery in exchangeable cation pools under revised deposition from Step 2;
4. Iterate Steps 2 and 3 as necessary to stay below the magnitude and timeline thresholds for loss in exchangeable cation pools;
5. Use CALPUFF scenario that emerges from Step 4 to inform facility-based mitigation (options, amounts and timelines presented in Section 8);
6. Implement the chosen methods of facility-based mitigation as per process described in Section 8.
7. Continue monitoring soil plots (5 year internals) to determine if the reduced deposition results in the expected chemical change.

5.2.3 Magnitude of exchangeable cation pools (Ca, Mg, K, Na) compared to S deposition, and time to depletion of these pools

Sampling location, and timing, frequency and duration:

- No additional sampling; we will use the samples obtained for the SO_2 technical assessment, and the supplemental soil collected for determining the base cation weathering rate (as described below).

How and when the analyses will be conducted:

- If exceedance is predicted for >5% of the study area in the analyses to be completed in 2017 (i.e., the receptor-based mitigation threshold is reached for the "atmospheric S deposition and CL exceedance risk" KPI), then archived soil samples (all three layers from the relevant site composite samples) will be analysed for exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium and (Na^{+}) using an unbuffered ammonium chloride extraction (soil samples and extraction solution are shaken for 2 hours and filtered), using flame atomic adsorption spectrometry or inductively coupled plasma optical emission spectrometry.

- The magnitude of exchangeable cation pools will be compared to S deposition to estimate the time to deplete the base cation pool. (I.e., [[TOTAL POOL OF BASE CATIONS] / [ANNUAL EXCEEDANCE]]. For example, a soil with a base cation pool of 1,000 meq/m^2 and an exceedance of 10 meq/m^2/yr would be exhausted in 100 years.)

5.2.4 Base cation weathering rates

Spatial variability in weathering rates of base cations is a source of uncertainty for all critical load calculations. Sites within the study area were identified in the STAR either as: (1) potentially vulnerable (i.e. critical loads may be exceeded); (2) soils not sampled during the SO_2 technical assessment survey that were in areas with low base cation concentration lakes; or (3) regions that were not considered during the initial site selection including glaciofluvial soils. As a result, there are data gaps with respect to the base cation weathering rates for these regions.

Sampling locations:

- Locations associated with: (1) quartz diorite bedrock south of Lakelse Lake, spatially co-located with lakes that had very low base cation concentrations (highest priority); (2) calc-alkaline bedrock near the smelter to support current weathering estimates that were based on extrapolation from other sites (lower priority as this is unlikely to change conclusion of high exceedance; however this is the only region showing exceedance as such site estimates are warranted); (3) orthogneiss metamorphic bedrock in the unsampled southern portion of the study domain consistent with the region receiving high modelled S deposition (southwestern portion of the study area); and (4) surficial geologies not represented in the initial soil sampling.
- Specific sites to be determined in consultation with MOE and Rio Tinto Alcan.

Sampling timing, frequency and duration:

- Sampling will be conducted during the summer of 2015 in a single field campaign. Sampling may also be carried out to take advantage of synergies with water sampling (described in Section 6).

Sampling methods:

- Soil sampling; maximum of 12–18 sites divided equally between the three bedrock categories.
- All field measurements will follow the 2012 protocol described the STAR (with maximum of five soil pits per supplemental study region sampled from three fixed depths: 0 to 10 cm; 15 to 25 cm, and 40 to 50 cm). Samples from each pit will be combined into one composite sample for each depth.
- Laboratory analyses for pH, loss-on-ignition (LOI), particle size (sand, silt and clay), moisture content, bulk density.
- Composite soil samples for each site to be analysed for major oxides, and subset analysed for qualitative mineralogy.

How and when monitoring data will be evaluated:

- Data collected in 2015 will be used to estimate weathering rates for the new sample sites and revise the regional critical load and exceedance maps in 2017. The new weathering rate may be revised to incorporate information on surficial geology if digitally available and if deemed appropriate (e.g., could post-stratify weathering rates based on surficial geology categories).

5.2.5 Summary of Soils actions, 2013-2018

Table 13. Schedule of work on the soils component of the EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Steady state soil modelling	–	Rio Tinto Alcan/MOE/QP collaboration on details of study design for this component. Obtain digitized surficial geology map from BC MOE; overlay with 2012 sampled soil sites. Undertake a sensitivity analysis of STAR predictions under multiple chemical criterion (Bc:Al, Ca:Al, pH, Al).	Develop weight-of-evidence approach for assessing whether change in CL exceedance (if predicted) is causally related to KMP. Conduct additional soil sampling to fill data gaps (QD bedrock type in sensitive lake areas S of Lakelse Lake accessible by road; CA bedrock type near smelter; OG bedrock type in SW part of region; and filling any important gaps for glaciofluvial landforms).	–	Re-do analysis for risk of CL exceedance (and % of area with CL exceedance), adding data from the new sites. Incorporate Bc deposition values from Lakelse monitoring and revised critical limits. Include a sensitivity analysis of multiple chemical criterion. Also calculate for an effects domain defined by the 7.5 kg/ha/yr S deposition isopleth, to compare with using the original study domain area.	Re-analyse archived soils if required based on results of analysis in 2017
Time to depletion of base cation pools (only if triggered by CL exceedance > 5% of study area)	–	–	–	–	Analyze 2012 and new soil to determine base cation exchangeable pools (as an input to the 2017 analysis in the first Soils row).	–
Review critical limit selection: Bc:Al ratio	Obtain digitized vegetation map from VRI	Collaboration with MOE on appropriate critical limit for soils, Bc:Al ratio, by vegetation type (consider use of BEC zones to derive reasonable dominant species boundaries).[14]	–	–	Incorporate any changes in Bc:Al ratio into revised modelling (the 2017 analysis in the first Soils row).	–

[14] A higher Bc:Al ratio results in a lower CL, and a greater chance of exceedance. A sensitivity study could be done on CLs given various ratios.

Topic	2013	2014	2015	2016	2017	2018
Permanent soil plots	–		Establishment of plots in collaboration with BC MOE, initial soil sampling and analysis. Develop weight-of-evidence approach for assessing whether a change in base cation pools in soil samples (if this occurs) is causally related to KMP.–	–	–	Re-sample plots (sampling interval of 5 years thereafter)
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

6.0 Lakes, Streams and Aquatic Biota

6.1 INDICATORS AND THRESHOLDS

The KPI for this receptor is observation-based: water chemistry data will be tracked to determine actual pH change in lakes. Results will reveal the *magnitude* of impact (i.e. how large the pH change is in lakes expected to be affected). The intent and rationale of the sampling and data analysis strategy is described in detail in Appendix H. The first informative indicator for this receptor is prediction-based: measured water chemistry data and measured S deposition data will be used as inputs for updated modeling of critical loads, and expected exceedance of those critical loads. Results will reveal the *extent* of expected impact (i.e. how many lakes might be affected), and will guide where sampling should occur. If the KPI threshold for receptor-based mitigation is reached and receptor-based mitigation is applied but proves ineffective or unfeasible, facility-based mitigation will be implemented.

Table 14. KPI and informative indicators for surface water.

Key performance indicator	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Indicators to be jointly considered
Water chemistry – acidification	Observed decrease in pH ≥ 0.30 pH units below mean baseline pH level measured pre-KMP in one or more of the 7 acid-sensitive lakes, and other evidence (see informative indicators and methods) Action: increase frequency of fall sampling in subsequent year, to more accurately estimate mean and variability of pH and other informative indicators during the fall index period. Appropriate sampling frequency to be determined by statistical power analysis.	More intensive sampling confirms a decrease causally related to KMP of ≥ 0.30 pH units below mean baseline pH level pre-KMP and liming is feasible (see Appendices G and I). Action: pilot liming to bring the lake back up to pre-KMP pH, subject to approval by BC MOE/DFO prior to implementation (see Appendix I describing a systematic approach to a pilot liming effort)	More than 2 lakes rated Medium or High (based on relative lake rating; Appendix D) with decrease causally related to KMP of ≥ 0.30 pH units below measured baseline pre-KMP (prior to liming) Action: reduction in SO_2 emissions	- Atmospheric S deposition and CL exceedance risk - Aquatic biota: fish presence / absence per species on sensitive lakes Lake ratings (Appendix D) - Evidence that pH decrease is causally related to KMP SO_2 emissions: ANC, SO_4, DOC (see Section 7)

Informative indicators	Threshold for increased monitoring[15]	Indicators to be jointly considered
Atmospheric S deposition and CL exceedance risk	CL exceeded in more than the 10 acid-sensitive lakes identified in the STAR as having either CL exceedance or predicted to acidify by more than 0.1 pH units (Figure 6)[16]. Action: expand the monitoring to include newly identified lakes with predicted exceedance	- Predicted steady state pH versus current pH (if predicted change > 0.1 pH units then level of concern is higher than if predicted change < 0.1 pH units) - Water chemistry – acidification
Predicted steady state pH versus current pH	Seven lakes with predicted pH change > -0.10 units are included in the set of lakes that are monitored annually each October. Lakes recommended by MOE (MOE-3 and MOE-6, the former sampled in Oct 2013) could be added to this set of annually monitored lakes depending on the outcome of analyses based on sampling in 2013 (MOE-3) and 2014 (MOE-6).	- Surface water model inputs, as described in Section 8.6.3.4 of ESSA et al. (2013)
Estimates of natural variability in pH and other indicators	If the fall index sample is below the pH threshold for any lake, the EEM Program will then obtain four chemistry samples during the fall index period of the following year to better estimate the mean index value and natural variability of pH and other parameters.	- Baseline estimates of natural variability in pH and other indicators during from End Lake (006), Little End Lake (012) and West Lake (023) – see Section 6.2 - These estimates will be used to assess whether observed pH values (and other indicators) are within or outside the range of natural variability
Evidence that pH decrease is causally related to KMP SO_2 emissions	Used in application of all three KPI thresholds	- Trends and levels of SO_2 emissions, SO_4 deposition, N deposition; - Trends and levels of lake ANC, SO_4, NO_3, Cl and DOC in both individual lakes and across all 7 acid-sensitive lakes - See Section 7, also Section 6.2 and Appendix H

[15] Thresholds for mitigation are not applicable. These indicators will provide weight of evidence for assessing the magnitude, extent and causes of lake acidification (Appendix H and Section 7).

[16] The 10 sampled lakes in Figure 6 with either CL exceedance or predicted ΔpH > -0.1 units were the same 10 lakes showing critical exceedance during a sensitivity analysis in which KMP deposition was doubled (STAR, pg. 330). As shown in Table 16, the critical load analysis will be repeated in 2019 using better information. It is unlikely that other sampled lakes will show exceedance under KMP alone, but the 2019 modelling analysis will be completed to confirm or reject this expectation.

Informative indicators	Threshold for increased monitoring[15]	Indicators to be jointly considered
Aquatic biota: fish presence / absence per species on sensitive lakes	Decrease in pH ≥0.30 units confirmed by more intensive sampling in the fall index period Action: resample the fish community in lakes that can be safely accessed for fish sampling	- none
Lake ratings (Appendix D)	Not applicable. Used in thresholds for receptor-based mitigation and source-based mitigation	- none
Episodic pH change	Not applicable	- none
Amphibians	Not applicable	- Atmospheric S deposition

6.2 METHODS

Table 15. Overview of methods for calculating the KPI and informative indicators for surface water.

Key performance indicator	Method overview
Water chemistry - acidification	Water quality sampling to assess trends in ANC, pH, SO_4, base cations. Various analyses to detect water quality trends and whether thresholds have been exceeded (see Section 6.2, Section 7, and Appendix H, especially Table 27).

Informative indicators	Method overview
Atmospheric S deposition and CL exceedance risk	In 2014 re-run the Steady State Water Chemistry (SSWC) and ESSA-DFO models for the 10 lakes sampled in both 2012 and 2013 (to assess fall vs. summer sampling). In 2019 re-run the SSWC and ESSA-DFO models based on water chemistry data for all sampled lakes (those sampled from 2012 to 2018), and then re-run the CL model with the new atmospheric S deposition data
Fish presence / absence per species on sensitive lakes	Fish sampling from standard overnight gill net sets using RIC (1997) nets and small mesh nets
Episodic pH change	Continuous pH measurement in Anderson Creek
Amphibians	Support of community based groups conducting amphibian monitoring

6.2.1 Water chemistry – acidification, and episodic pH change

Ten lakes are sensitive to acidification (Figure 6). This KPI will include water sampling in 7 of these lakes (described below) and laboratory analyses of major anions ($[Cl^-]$, $[F^-]$, $[NO_3^-]$, $[HC0_3^-]$*, $[CO_3^{2-}]$*, $[SO_4^{2-}]$, $[OH^-]$*, DOC, Total Alkalinity, Gran ANC), major cations ($[Ca^{2+}]$, $[Mg^{2+}]$, $[Na^+]$, $[K^+]$, $[NH_4^+]$, $[H^+]$, dissolved Al).[17,18] These ions are needed to assess the form, rate and magnitude of changes in lake chemistry, estimate a key parameter (F-factor = Δ base cations / Δ SO_4) for the Steady-State Water Chemistry and ESSA/DFO models, compare deposition-predicted change in SO_4, ANC and pH vs observed change, and confirm QA/QC of water samples by examining charge balance. Ion exchange processes in the watershed can exchange H+ for other cations such as Ca, Mg, Na, K, Al. Dissolved Al is also an indicator of toxicity of water to fish. Lake-specific titration curves will be obtained from the Gran ANC titrations, which will provide the information base for developing lake-specific thresholds for ANC and SO_4.

Sampling will also include field measurements of temperature, dissolved oxygen (e.g., very low oxygen might explain pH shifts), and total dissolved solids.

We will also perform intensive monitoring of Anderson Creek to assess frequency, magnitude and duration of acidic episodes in this stream.

[17] Ions with * are calculated from other measurements.

[18] All of these measurements are important for understanding why pH is changing, which is important for determining if the changes are causally related to KMP (as described in Section 7).

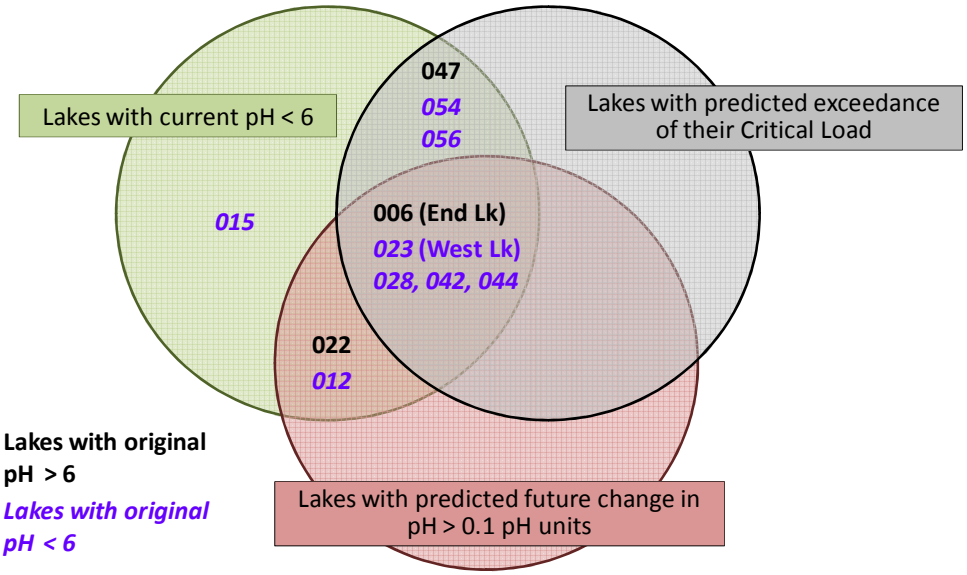


Figure 6. Conceptual diagram of criteria for lake vulnerability. Lake 15 is the only one in the diagram not considered vulnerable, because its original pH was below 6.0 and it is not expected to experience a pH decrease or a critical load exceedance.

Intent and rationale of the sampling strategy: Please see Appendix H for a detailed description.

Sampling locations:

- Essential locations: 7 vulnerable lakes with predicted pH Δ > 0.10. These include: LAK006 (End Lake), LAK023 (West Lake), LAK028, LAK042, LAK044, LAK012, LAK022. Five of these 7 lakes also show critical load exceedance (map provided in Appendix E).[19]
- Two lakes recommended by MOE (MOE-3 and MOE-6[20]).
- Three insensitive lakes to be sampled for chemistry and fish (LAK007, LAK016, LAK034). The insensitive lakes have higher Gran ANC values (1438, 69, 99 µeq/l respectively), do not have exceedance of their CLs, and are not predicted to acidify significantly (predicted ΔpH=0.0, -0.07, 0.03 respectively). In addition to serving as a reference for biological changes, the insensitive lakes will provide a check on model predictions for less acid-sensitive lakes. Fish sampling from the insensitive lakes will occur in 2014.

[19] Three other lakes with CL exceedance are predicted to have a pH change < 0.1 pH units (LAK047, LAK054, LAK056), are low priority for sampling, and are not included in the current field program. LAK047 is a high alpine lake not accessible by fish; LAK054 and LAK056 are naturally acidic, low pH lakes dominated by organic acids (Appendix E).

[20] Site MOE-3 was sampled in October 2013. Site MOE-6 could not be safely sampled in October 2013 due to continuous fog at that high elevation, which prevented helicopter access. . MOE-6 will be sampled in October 2014.

- Lakelse Lake, given its importance and profile in the Valley, even though it is predicted to be insensitive to SO_2 emissions from KMP.
- Cecil Creek (outlet of West Lake) was sampled in 2013, to check if its chemistry mirrors that of West Lake.
- Hydrologic, fish habitat and chemical reconnaissance sampling of Goose Creek, to assess its connectivity to Lake 028, and its sensitivity to acidification.
- Kitimat River (to assure that water supply is not affected by low pH or elevated metals); either upstream of the intake for the Kitimat water treatment plant, or at the intake.
- Anderson Creek (pH measurements to assess frequency and magnitude of acidic episodes).

Sampling timing, frequency and duration:

- The water chemistry of all of these lakes was sampled in October 2013. Chemical data from the sites that were sampled in 2012 (all except the stream sites, MOE-3, and MOE-6) will be used to show the combined effects of inter-year and inter-month variability of CL (August 2012 versus October 2013). Future sampling will occur during the fall when lakes are well mixed, less productive and have greater stability in their chemistry (preferably in October).
- To understand chronic or long term acidification, the 7 acid-sensitive lakes and 3 insensitive lakes will be sampled annually during 2014 to 2018 during the same seasonal timeframe as in 2013 (i.e., fall index period) to track any increase in sulphate and changes in other ions as KMP ramps up (particularly decreases in pH and ANC), and to be able to demonstrate leveling-off to steady state. Minimum emissions are likely to occur in the early part of 2014. Each lake will be considered both independently and also as part of the complete set of 7 acid-sensitive lakes (greater statistical power) with respect to its trends in water chemistry over time.
- In 2014, we will determine if the 2 MOE lakes have CL exceedance or are vulnerable to acidification. If “no”, sampling will be discontinued. If “yes”, they will be added to the set of vulnerable lakes sampled annually. While the CL has not yet been calculated for MOE-3, the Gran ANC and charge balance alkalinity measurements in the fall of 2013 (168 and 138 µeq/l, respectively) strongly suggest that MOE-3 will not have CL exceedance. See footnote on previous page.
- Anderson Creek: continuous pH sampling, beginning in fall 2014 to get a pre-KMP-ramp up baseline.
- Kitimat River: monthly water quality sampling, beginning after KMP commissioning in 2015 to evaluate any changes in the quality of drinking water

Monitoring protocols and sampling methods:

- The same as for the sampling done in 2012 for these parameters during the SO_2 technical assessment (ESSA et al. 2013).

How and when monitoring data will be evaluated:

- For water quality parameters which show statistically or biologically significant differences between summer 2012 and fall 2013/2014 values, the mean baseline pre-KMP values will be defined as the mean of the fall index samples in 2013 and 2014. For parameters which showed no statistically or biologically significant differences between summer 2012 and fall 2013 samples, the mean baseline pre-KMP values will be defined as the mean of summer 2012, fall 2013 and fall 2014 values.
- During 2014 and 2015 (to be summarized in 2015 EEM report), the program will estimate pre-KMP natural variability in pH and other indicators from End Lake (006), Little End Lake (012) and West Lake (023) through the following steps:
    - A pilot test of continuous pH monitors (calibrated and cross-checked against a field pH meter every two weeks) will record pH every 30 minutes beginning in September 2014 for a period long enough to provide a reliable baseline of variability in pH during the pre-KMP period (except during winter when ice cover prevents access); and
    - Full chemistry samples will be obtained four times during the fall sampling in 2014 to assess baseline natural variability during the index period, and periodically until August 2015, except during winter when ice cover prevents access.
- Estimates of natural variability from 2013-2014 intensive sampling of 3 EEM lakes, plus analyses of Ontario and U.S. lakes (Yan pers. comm; Stoddard et al. 1996) will be used to:
    - Provide estimates of natural variability for all lakes; and
    - Assess statistical power to detect thresholds of interest for both individual lakes and the complete set of 7 acid-sensitive lakes (to be summarized in 2014 EEM report)
- If the fall index sample falls below the pH threshold for any lake, the EEM Program will then obtain more frequent chemistry samples during the same period of the following year to better estimate the mean and variability of pH and other parameters.[21]
- During the period from December to March of each year, monitoring data will be analyzed to assess trends in both individual lakes and in the overall population of 7 acid-sensitive lakes, and in the 3 insensitive lakes, as explained in the following two bullets

[21] It is not feasible to resample a lake more intensively in the fall index period of the same year for two reasons: 1) helicopter time needs to be reserved well in advance; and 2) measurements of pH from the lab (the least variable and best metric for assessing lake pH) will not be immediately available.

- Analyses of trends in individual lakes:
  - Compare fall index sample to pH, ANC and SO_4 thresholds developed from lake-specific titration curves Table 27);
  - Determine if pH thresholds exceeded (KPI), and if reductions in pH are consistent with declines in ANC and increases in SO_4 (informative indicators)
  - Assess whether annual observations are within the range of natural variability, as estimated from 2014-2015 sampling
  - Examine the trend in fall observations for each lake relative to the pre-KMP baseline
  - Determine how individual lakes compare to patterns observed in full set of seven acid-sensitive lakes
- Analyses of trends in the full set of seven acid-sensitive lakes and the set of three insensitive lakes:
  - Examine distribution of estimated changes in pH, ANC and SO_4 (see Figure 17in Appendix H)
  - Conduct paired t-test on pH, ANC and SO_4 to assess mean change in each parameter in each year compared to baseline period, versus thresholds of change for each parameter
  - Conduct trend analyses on the complete set of acid-sensitive lakes to determine overall trends in pH, ANC and SO_4 (see Section 7 and Appendix H)
- The data collected from 2014 to 2018 will be analyzed in early 2019 to:
  - Estimate expected time to steady state for SO_4 based on observed trends in [SO_4] and approximate estimates of water residence time (Table 25).
  - Examine actual Δ SO_4, ANC and pH for all lakes over time relative to steady state predictions of exceedance from SSWC, predicted ANC and pH change at steady state from the ESSA/DFO model, and expected lake [SO_4] from CALPUFF post-KMP predictions of SO_4 deposition / model-based runoff estimates. Apply the approaches described in Section 7 to deduce the most likely causes of acidification at each site.
  - Estimate the F- factor from Δ base cations / Δ SO_4 and compare to the assumed F-factor. The F-factor is an estimate of watershed acid neutralization through cation exchange, where F=0 means that no acidity is neutralized and F=1 means that all acidity is neutralized.

Resampling of STAR lakes:

- Re-sampling of a subset of STAR study lakes may occur if a greater than predicted change in water chemistry of the 10 lakes occurs.

Assess frequency, magnitude and duration of acidic episodes in Anderson Creek, how these change with ramp-up of KMP emissions, how they relate to climatic factors (e.g., snowmelt, storms, first flush after a long dry period in which sulphate gases might have built up in the atmosphere), and how they relate to toxicity thresholds for biota. Anderson Creek provides an indication of acidic episodes in a single stream close to the smelter, but does not provide an assessment of the extent and frequency of acidic episodes across the study area. If acidic episodes are detected in Anderson Creek, then sample other ions in Anderson Creek to determine if these episodes are related to KMP (i.e., SO4-driven) or factors unrelated to KMP (i.e., organic acids, base cation dilution; Bishop et al. 2000). If the episodes in Anderson Creek are shown to be related to KMP, then complete intensive sampling of lake outlets during snowmelt and/or fall storms in Lakes 012, 006 and 023 to compare to baseline intensive sampling in 2014-2015, and determine if the frequency and magnitude of acidic episodes has changed. These 3 EEM lakes will have baseline chemistry information that provide a more thorough - basis for change detection than Anderson Creek.

Steps for determining the magnitude of emissions reductions needed if the threshold for facility-based mitigation is reached for this KPI:

1. Determine the level of pH and ANC recovery required in each acid-sensitive lake.
2. Look at actual chemical change versus the predicted chemical change in the STAR.
3. Adapt models if required based on observations (e.g., change the F factor).
4. Use the ESSA-DFO model and SSWC sensitivity analyses to determine the target reduction in S deposition necessary to achieve the required pH recovery.
5. Use CALPUFF to explore different scenarios of facility-based mitigation for reducing deposition to meet target (options described in Section 8).
6. Run CALPUFF output through the ESSA-DFO and SSWC models to determine the expected exceedance and pH change with the revised deposition from Step 5.
7. Iterate steps 5 and 6 until a satisfactory reduction in deposition is determined which meets required recovery of pH and ANC identified in Step 1.
8. Implement the chosen methods of facility-based mitigation.
9. Continue monitoring to determine if the revised emissions and deposition result in the anticipated recovery of pH and ANC.

6.2.2 Atmospheric S deposition and critical load (CL) exceedance risk

The monitoring method for this informative indicator is described in Section 2. Critical load exceedance (and % of study area lakes with CL exceedance) will be re-calculated in 2019.

The assumptions in deposition and surface water models affect predictions of magnitude and extent of CL exceedance. Testing these assumptions will require the following inputs:

- Atmospheric S deposition (described in Section 2)
- Base cation deposition (described in Section 5)
- Water chemistry – acidification (described below), specifically major cations ($[Ca^{2+}]$, $[Mg^{2+}]$, $[Na^{+}]$, $[K^{+}]$, $[NH_4^{+}]$, $[H^{+}]$, dissolved Al) and acidic anions ($[SO_4^{2-}]$, $[NO_3^{-}]$, organic anions (commonly represented as$[A^{-}]$), ANC, DOC)
- ANC is estimated by three different measures to provide redundancy in trend detection total alkalinity, Gran ANC and charge balance alkalinity (Hemond 1990)

Sampling locations:

- As described below, for Water chemistry – acidification

Sampling timing, frequency and duration

- As described in Section 2, for Atmospheric S deposition
- As described in Section 5, for Base cation (Bc) deposition
- As described below, for Water chemistry – acidification
- Kitimat River: monthly water sampling, for two years after KMP startup; then revisit sampling frequency based on observed changes (i.e., does it appear to have reached a steady state?)

Monitoring protocols and sampling methods:

- As described in Section 2, for Atmospheric S deposition
- As described in Section 5, for Base cation deposition
- As described below, for Water chemistry – acidification

How and when monitoring data will be evaluated:

- The acidification models will be re-run in 2019 with the latest input parameters from the sampling described above.
- CLs will be recalculated in 2014 to assess the effects of sampling on different dates (August 2012 compared with October 2013). Lakes are better mixed and less productive in the fall index period, leading to less spatial and temporal variability in lake chemistry (Landers et al. 1987).

6.2.3 Aquatic biota: fish presence / absence per species on sensitive lakes

Sampling locations:

- In safely accessible lakes, which will include 4 vulnerable: LAK023 (West Lake), LAK006 (End Lake), LAK012[22] and LAK044 (Finlay Lake); and the 3 reference lakes: LAK007, LAK016 and LAK034 (map provided in Appendix E).

Sampling timing, frequency and duration:

- The four vulnerable lakes were sampled in the fall of 2013, prior to KMP start-up, coincident with water sampling. In 2013 we also obtained access information for the 3 reference lakes, in preparation for sampling these the following year.
- The 3 reference lakes will be sampled in 2015, to provide a baseline for future measurement.

Monitoring protocols and sampling methods:

- Gill net sampling for fish using RIC (RIC 1997) and small mesh nets (method described in Appendix E). These methods are sufficient to provide reliable information on fish presence / absence and fish age / length distributions. Accurate estimates of fish density are not feasible, as they would require much more gill net time, causing unacceptable levels of fish mortality.

How and when monitoring data will be evaluated:

- Data will be used to clarify for the public the fish communities present in each of the vulnerable lakes that could be safely accessed for fish sampling. Analyses will include:
  - Presence/absence by species, and by age
  - Mean and variance of length and weight for each species by age class
  - Frequency distributions of lengths for each species if sufficient numbers of fish are caught
  - Weight-length plots and equations for each species where sample sizes allow
  - Length at age plots for each species of salmonids where sample sizes permit
  - Simple index of species richness (e.g., number of species caught) and a more complex diversity index (effective species richness as in Jost 2006) if sample sizes permit

6.2.4 Amphibians

Support will be provided to existing local community groups who conduct annual monitoring of amphibians in the Terrace–Kitimat valley. Information generated from amphibian monitoring will be used to help inform the understanding of the health of the environment within the airshed.

[22] LAK006 and LAK012 are connected, and fish can easily move back and forth between them.

6.2.5 Summary of Lakes, Streams and Aquatic Biota actions, 2013-2018

Table 16. Schedule of work on the surface water component of the EEM Program.

Topic	2013	2014	2015	2016	2017	2018
Steady state water modelling	–	Re-run acidification models to calculate CLs, to assess the effects of sampling in Aug (2012) versus Oct (2013).	–	–	–	Organize all data so that acidification models can be re-run in 2019 to calculate CLs and exceedance.
Chemistry: water body sampling	Annual water sampling and laboratory analysis; sample Cecil Creek.	Annual water sampling and laboratory analysis. More intensive sampling of 3 lakes to determine natural variability. Develop weight-of-evidence approach for assessing whether chemical change is causally related to KMP (Section 7 of this document).	Annual water sampling, laboratory analysis, and data evaluation.	Annual water sampling and laboratory analysis, and data evaluation.	Annual water sampling and laboratory analysis, and data evaluation.	Annual water sampling and laboratory analysis, and data evaluation. Review sampling requirements based on outcomes of the data evaluation.
$[SO_4]_0$; F-factor	–	–	–	–	–	Reduce the uncertainties of these factors based on lake chemistry (F) and review of deposition estimates ([SO4]o.
Fish presence / absence sampling	Sampling of 4 vulnerable lakes.	Reconnaissance of habitat and water chemistry in Goose Creek – future sampling TBD based on results.	Sampling of the 3 reference lakes. Resample if lake pH change reaches threshold.	Resample if lake pH change reaches threshold.	Resample if lake pH change reaches threshold.	Resample if lake pH change reaches threshold.
Episodic acidification	–	Initiate study design for snow melt and fall storm episodic acidification in Anderson Creek near KMP (gauged stream). Examine 1997 pH data for Anderson Creek as possible baseline.	Finalize study design.	Implement study.	–	Implement study.
Amphibians	–	Initiate discussion with interested party.	Provide support to existing local community groups who conduct annual amphibian monitoring.	Provide support to existing local community groups who conduct annual amphibian monitoring.	Provide support to existing local community groups who conduct annual amphibian monitoring.	Provide support to existing local community groups who conduct annual amphibian monitoring.
Reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting	Annual reporting

7.0 Determination of Causal Relationship to KMP

The KPI thresholds presented in Sections 2 through 6 include the condition that threshold exceedances are causally related to KMP. The process for determining KMP causality is summarized below, by KPI. These steps would be undertaken for a given KPI if the thresholds for increased monitoring or modelling are reached.

Atmospheric SO_2 Concentrations

- Investigate each 1-hour exceedance event by assessing meteorological conditions, and estimates of KMP SO_2 emissions.

Visible Vegetation Injury

- Assess ambient SO_2 concentration data, meteorological conditions, the nature of the injury to foliage (i.e., assess consistency with the known form of impacts to foliage of SO_2) and estimates of KMP SO_2 emissions versus all emissions sources

Atmospheric S Deposition and Critical Load Exceedance Risk for Soils

- Assess the relative likelihood of alternative explanations for critical load exceedances: 1) KMP alone; 2) cumulative effect of non-KMP emission sources including LNG plants and other sources; or 3) cumulative effect of all emission sources including KMP.
- Re-evaluate uncertainties in the mapping and modelling of deposition, critical loads and exceedances

Long-term Soil Acidification Attributable to S deposition

- Conduct an extended soil survey and modelling to assess the spatial significance of observed base cation loss; for example, whether there are there wider issues over >1% of the study area.
- Assess the relative likelihood of alternative explanations for soil acidification: 1) KMP alone; 2) cumulative effect of non-KMP emission sources including LNG plants and other sources; or 3) cumulative effect of all emission sources including KMP.

Atmospheric S Deposition and Critical Load Exceedance Risk for Water

- Assess the relative likelihood of alternative explanations for critical load exceedances: 1) KMP alone; 2) cumulative effect of non-KMP emission sources including LNG plants and other sources; or 3) cumulative effect of all emission sources including KMP.
- Re-evaluate uncertainties in the mapping and modelling of deposition, critical loads and exceedances.

Water Chemistry – Evidentiary Framework for Evaluating the Cause of acidification

Proving causality (i.e., acidification of lakes related to KMP) requires following the cause-effect chain in the source-pathway-receptor diagram (Figure 7), and evaluating multiple lines of evidence for alternative causal pathways. Weight of evidence analyses (Burkhardt-Holm and Scheurer 2007), Marmorek et al. 2011) rely on four types of evidence: 1) a plausible mechanism; 2) exposure to the pollutant; 3) correlation of pollutant exposure and chemical / biological response in space and time; and 4) experimental evidence from the region or other published studies. The pathways and plausible mechanisms of acidification of surface waters are well understood (Marmorek et al. 1989, Baker et al. 1991a), so the focus of the proposed weight of evidence analysis is on exposure, correlation and experimental evidence.

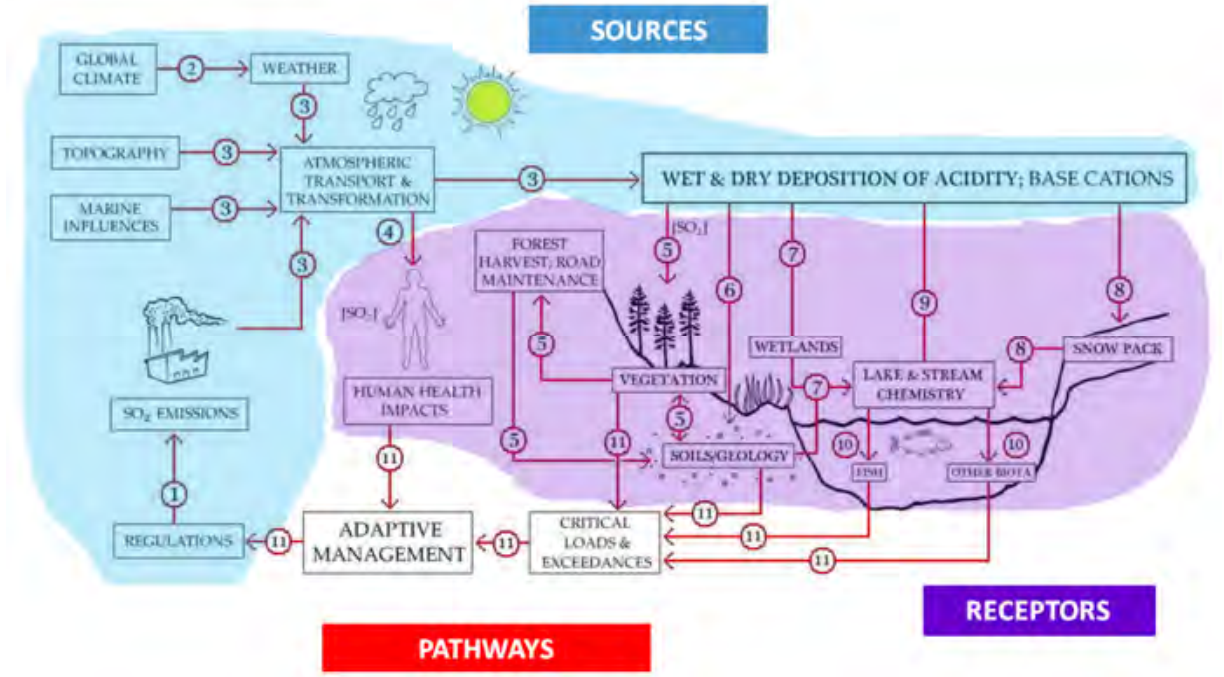


Figure 7. Conceptual (Source-Pathway-Receptor) model of SO_2 emissions in the environment, showing linkages between sources and receptors. Source: Figure 3.1-1 from ESSA et al. 2013.

The evidentiary framework (Table 17) provides a series of questions and tests for various different lines of evidence that then need to be jointly evaluated to draw a conclusion regarding the likelihood that KMP has caused acidification. This conclusion and the associated evidence could be peer reviewed if there are concerns about the data, methods or conclusions. All questions will be reviewed each year, and answered to the degree possible. As the program continues, the statistical power to detect small changes in lake chemistry will increase due to larger sample sizes (Figure 16 in Appendix H). Some questions may not be clearly answerable in the early years of the program due to insufficient sample sizes and limited statistical power. The statistical power analyses discussed in Appendix H will be helpful for defining how many years of data are required to detect changes of interest (e.g., Table 27) with high statistical power.

Table 17. Evidentiary framework for evaluating if acidification has occurred and whether it is or is not related to KMP. SPR = Source-Pathway-Receptor Diagram (Figure 7). The last three columns show answers to the question in column 2.

Links in SPR model	Question	Methods Used to Answer Question [References with examples of these analyses]	Implications of Answers	
			Evidence consistent with KMP as primary cause of acidification	Evidence against KMP as primary cause of acidification
3	Have SO_2 emissions from KMP increased significantly beyond levels in the pre-KMP period, potentially causing increased acidic deposition?	Compare mean daily emissions in pre-KMP period[23] vs. KMP ramp-up period vs. post-KMP steady state period; assess trends. [STAR, Figure 7.4-2, pg. 139; Stoddard et al. 2003]	Yes	No
3	Has SO_4 deposition at Kitimat and Lakelse monitoring stations increased since pre-KMP period in a manner proportional to SO_2 emissions? Has N deposition shown negligible changes? Is deposition of base cations too low to neutralize SO_4 deposition?	Compare monthly and annual SO_4 and N deposition in pre-KMP period vs. KMP ramp-up period vs. post-KMP steady state, and assess trends, for each deposition site. Regress deposition at each site vs. KMP emissions. Also assess trends in [SO_4] in wet deposition (µeq/l/yr) since 2011. [STAR, Figure 7.4-6, pg. 142-143; Stoddard et al. 2003, pg. 21-29]	Yes	No
2, 3	Has background SO_4 deposition (long range sources outside the study area) increased much less than the estimated increase in KMP-related SO_4 deposition, since the pre-KMP period?	Examine trends in SO_4 deposition and [SO_4] in wet deposition from Alaska and other monitoring stations, as reported in the literature. Compare observed change to modelled effect of KMP deposition [ESSA et al. 2014, pg. 259]	Yes	No
3, 8, 9	Has lake [SO_4] increased post-KMP in a manner consistent with predicted increases in deposition of SO_4, and deposition levels inferred from monitoring observations?	Examine distribution of changes in lake [SO_4] across multiple lakes and time trends within individual lakes. Compare trends in [SO_4] to predicted changes in SO_4 deposition with KMP in the STAR, as well as observed SO_4 deposition from Kitimat and Lakelse monitoring stations [Stoddard et al. 1996 [eq 1]; Stoddard et al. 2003, pg. 32-56, Sullivan et al. 1998].	Yes	No
7,9	Do the observed spatial and temporal changes in climate, pH, ANC, dissolved organic carbon (DOC) and sulphate	Examine trends in annual precipitation from meteorological stations, and assess if periods of drought followed by wetter years were correlated with increases in [SO_4] and decreases in ANC [Yan et al.	Yes	No

[23] Further discussion is required to define the pre-KMP period, considering changes in both smelter emissions and other sources (e.g., 2010-2012).

Links in SPR model	Question	Methods Used to Answer Question [References with examples of these analyses]	Implications of Answers	
			Evidence consistent with KMP as primary cause of acidification	Evidence against KMP as primary cause of acidification
	suggest drought-caused oxidation of sulphate stored in wetlands, related to KMP rather than due to climate fluctuations affecting wetland storage of historical S deposition?	1996, Dillon et al. 1996, Stoddard et al. 2003 (pg. 29-30); Laudon et al. 2004]		
8	Has lake ANC decreased post-KMP in a manner consistent with increases in lake [SO_4] and watershed neutralizing abilities (F-factor)?	Examine distribution of changes in lake ANC across multiple lakes and ANC time trends within individual lakes. Compare ANC and SO_4 time trends (e.g., Figure 11, Figure 12 and Figure 13). Examine Δ(Ca + Mg) versus ΔSO_4 to estimate F-factor for each lake, and to understand why ANC has or has not changed. [Section 6.2; Figure 17; Stoddard et al. 1996 [eq 1]; Stoddard et al. 2003 pg. 32-56]	Yes	No
8	Has lake pH decreased post-KMP in a manner consistent with SO_4 increases, ANC decreases, and lake-specific titration curves?	Examine distribution of changes in lake pH across multiple lakes and time trends within individual lakes. Use lake-specific titration curves to assess if SO_4, ANC and pH changes are all consistent with hypothesis of SO_4-driven acidification [Section 6.2; Figure 11, Figure 12 and Figure 13; Figure 17; Stoddard et al. 2003 pg. 32-56]	Yes	No
8	Have lake pH and ANC values decreased beyond identified thresholds (Table 27)?	Use graphs like Figure 17 to assess pH changes across all 7 EEM lakes, and the % of comparisons showing decreases of more than 0.3 pH units, a trigger for more monitoring in Table 14. Examine time trends in pH and ANC using regression analyses for lakes with more intensive monitoring that provide better estimates of natural variation in pH and ANC. [Section 6.2, Appendix H]	Yes	No
2, 3, 7, 8, 9	Are observed changes in Cl, NO_3 and DOC consistent with causes of acidification other than KMP (i.e., sea salt driven episodes, N emissions, organic acidification)?	Examine the percent anion composition of each lake and how it has changed over time [e.g., STAR pages 310 to 314, Marmorek et al. 1988, Marmorek et al. 1989, Baker et al. 1991a, Monteith et al. 2007]	No	Yes

8.0 RIO TINTO ALCAN Mitigation Response for Unacceptable Impacts

Rio Tinto Alcan will implement SO_2 mitigation strategies if the outcomes of monitoring and modeling under the SO_2 EEM Program show adverse impacts related to Rio Tinto Alcan emissions of SO_2 that are considered to be unacceptable. The EEM Program distinguishes two types of mitigations: receptor-based mitigations and facility-based mitigations. The following paragraphs describe examples of each type.

8.1 RECEPTOR-BASED MITIGATION

- If soil critical loads are predicted to be exceeded in >5% of the study area within 200 years, or if exchangeable cation pools will decrease by amounts and within timeframes detailed in Section 5.1, the application of lime and wood ash are options for reducing soil acidity in very localized applications, increasing calcium concentrations in trees, and potentially improving tree growth. Given the wide range of effectiveness of these treatments (summarized in Appendix F), small scale pilot applications would be required as a proof of concept prior to large scale application. The 200 year horizon allows ample of time for a liming/wood ash pilot, and consideration of a shift to facility-based mitigation if the pilot is unsuccessful. Most studies show a response in the soil within 5-10 years.

- If pH in a valued[24] lake declines by more than 0.30 pH units, and the most likely explanation of this pH decline is increased SO_2 emissions from KMP, then if liming is logistically feasible, Rio Tinto Alcan could develop and implement a process to restore the lake pH back to its level in 2012, and reverse the acidification caused by KMP SO_2 emissions. One of the options used to mitigate acidic conditions in surface water is the addition of alkaline materials like limestone (calcium carbonate). Depending on lake access, safety and other environmental considerations, liming could be done on the whole lake, its running water or on its watershed using a boat, truck or helicopter (Olem 1990). A summary of the state of knowledge regarding liming of lakes is provided in Appendix G. Liming would only be applied for up to two lakes; if more than 2 lakes show pH declines greater than 0.30 units and related to KMP, Rio Tinto Alcan would implement facility-based mitigation[25].

[24] Refer to Appendix D for information on the method and results for rating the vulnerable lakes.
[25] Refer to Section 6.1 for the thresholds for receptor-based mitigation.

8.2 FACILITY-BASED MITIGATION

Sections 3.1, 4.1, 5.1 and 6.1 describe (respectively) the health, vegetation, soil and surface water thresholds for facility-based mitigation. Facility-based mitigation will be a response to demonstrated unacceptable impacts caused by SO_2 emissions resulting from KMP future operations. Facility-based mitigation will reduce SO_2 emissions from the smelting operation by a sufficient level to address the demonstrated unacceptable impact, and may be episodic or permanent depending on the persistence of the threshold exceedance. The methodology for reducing SO_2 emissions will be an Rio Tinto Alcan business based decision that will factor in consideration of the nature of the impacts, feasibility and sustainability of alternative mitigation methods, and market place conditions. Some of the options that Rio Tinto Alcan will consider for reducing SO_2 emissions are briefly described below, followed by Table 18 which presents the range of SO2 reduction in t/day that could be achieved, and the implementation timeline.

a) Procuring lower sulphur content coke

   The coke blend used for anode manufacturing can be adjusted to lower the overall sulphur content in the anode. The magnitude of the sulphur content reductions will be determined based on market place conditions and accessibility to anode grade cokes with lower sulphur content.

b) Reducing the amount of calcined coke produced on site

   Increased quantities of calcined coke can be procured to reduce the amount of coke calcining onsite. The feasibility of this option will be based on market place conditions for anode grade calcined coke.

c) Importing anodes

   Baked anodes can be imported to Kitimat to either reduce or stop coke calcining or anode baking operations. This option would be reviewed for feasibility based on market place access to baked anodes and transportation costs.

d) Scrubber on Coke Calciner

   Implementing a scrubber on the coke calciner is possible. A decision to implement scrubbing on the coke calciner will be based on a business review of a scrubbing option compared to costs, and the accessibility of either lower sulphur content cokes or increased quantities of calcined coke. The assessment will also consider the environmental impact assessment of this mitigation measure, including waste generation, energy consumption, GHG emissions, the operating risks of the scrubber and the acceptability to stakeholders of the selected type of feasible scrubbing.

e) Scrubbing on one or both gas treatment centres

The option of implementing scrubbing on one or both gas treatment centres will be based on a business case review of the options to reduce SO_2 emissions from the Kiitmat smelter. The review will consider the construction and operating costs of the scrubber in comparison to the feasibility assessment of the other options to reduce SO_2 loadings from smelting operations. The assessment will also consider the environmental impact assessment of this mitigation measure, including waste generation, water release, energy consumption, GHG emissions, the operating risks of the scrubber and the acceptability to stakeholders of the selected type of feasible scrubbing.

Table 18. SO_2 reduction options and associated timeline for reduction[26].

Reduction option	potential range of reduction		Implementation timeline
	minimum t/day	maximum t/day	
Procuring lower sulphur content coke	1	15	3 to 6 months
Reducing the amount of calcined coke produced on site	1	8	Short-term curtailment: 1 day to 2 weeks Long-term curtailment: 6 months
Importing anodes with lower sulfur content	1	20	6 to 18 months
Scrubber on Coke Calciner	7	NA	5 - 6 years : a) Feasibility study: 1 year b) Permitting: 1 years c) Engineering, Procurement, Construction: 2 - 3 Years d) Commissioning: 1 years
Scrubber on 1 GTC	14	NA	7-8 years : a) Feasibility study: 1 years b) Permitting: 2-3 years c) Engineering, Procurement, Construction: 3 years d) Commissioning: 1 years
Scrubbers on 2 GTC	29	NA	

[26] One or more of these reduction options would only be implemented if there is:

- a confirmed environmental impact related to KMP SO_2 emissions,
- an EEM KPI source-based mitigation trigger is reached, and
- the needed amount of SO_2 reduction has been determined through the methods described in sections 3-6 of this document.

These options are not binding, as the efficacy and availability of some options may vary with time and other options may become available in the future

9.0 Annual Reporting, and Comprehensive Review in 2019

9.1 ANNUAL REPORTING AND CONSULTATION

SO_2 EEM reporting will occur on an annual basis. These annual reports will contain a concise summary of activities and results from the year, and plans for the subsequent field program based on the results from the previous field season. Information on aluminum production and SO_2 for the past year will also be included, to provide context for results interpretation. The annual reports will be written for a non-technical audience and intended for public distribution. Annual report preparation will begin early in the next calendar year, with the intention of publication by March 31st. Details of the results from each year will be documented in technical memoranda, allowing access to the technical details for the ECC, KPAC, and anyone else who is interested. The Haisla First Nation will be invited to participate in detailed annual program reviews, study designs and evolutions of the EEM program.

Each year of the EEM program, a meeting will be called to review the annual EEM program report and during the course of the meeting develop an interpretation of the EEM data integrated across the four lines of evidence (surface waters, vegetation, soils, and human health).

Annual Kitimat Public Advisory Committee (KPAC) meetings will be held in each spring to review EEM results and report out on the findings from the previous year, and discuss actions planned for that year.

9.2 COMPREHENSIVE REVIEW IN 2019

A comprehensive review will be conducted in 2019, examining what has occurred under the SO_2 EEM Plan from 2013 to 2018. A report synthesizing the results of this review will be prepared by October 31, 2019, which will:

- Summarize what has been learned, and what question have been answered,
- Describe which if any of the KPI thresholds have been reached, and if so, what actions were taken,
- Describe any modifications to KPIs, methods or thresholds that have been made based on annual results to date, and why,
- Look across the data sets of the four lines of evidence to develop an holistic understanding of KMP SO2 effects on the environment and human health,
- Recommend changes if/as needed to: the suite of KPIs to be continued post-2018, their measurement methods, and/or their thresholds – along with the rationale for these recommended changes, and
- Recommend a date for the next comprehensive review.

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Appendix A: Questions the SO_2 EEM Program Will Answer

Questions that arose during the SO_2 technical assessment – and which are important to answer in the SO_2 EEM Program (as explained in Section 1.2) – are summarized in Figure 8. While most of the questions pertain directly to the receptors, three of the questions pertain to impact pathways – and as such, the answers may affect the predicted impact categories for one or more of the receptors. The questions are listed in greater detail in Table 19. At least two hypotheses representing alternative outcomes are provided for each question (where applicable). In addition to answering these assessment questions, the SO_2 EEM Program will also answer the question, *will SO_2 emissions from KMP have unacceptable impacts on any these four receptors?* Table 20 matches the EEM indicators to these questions.

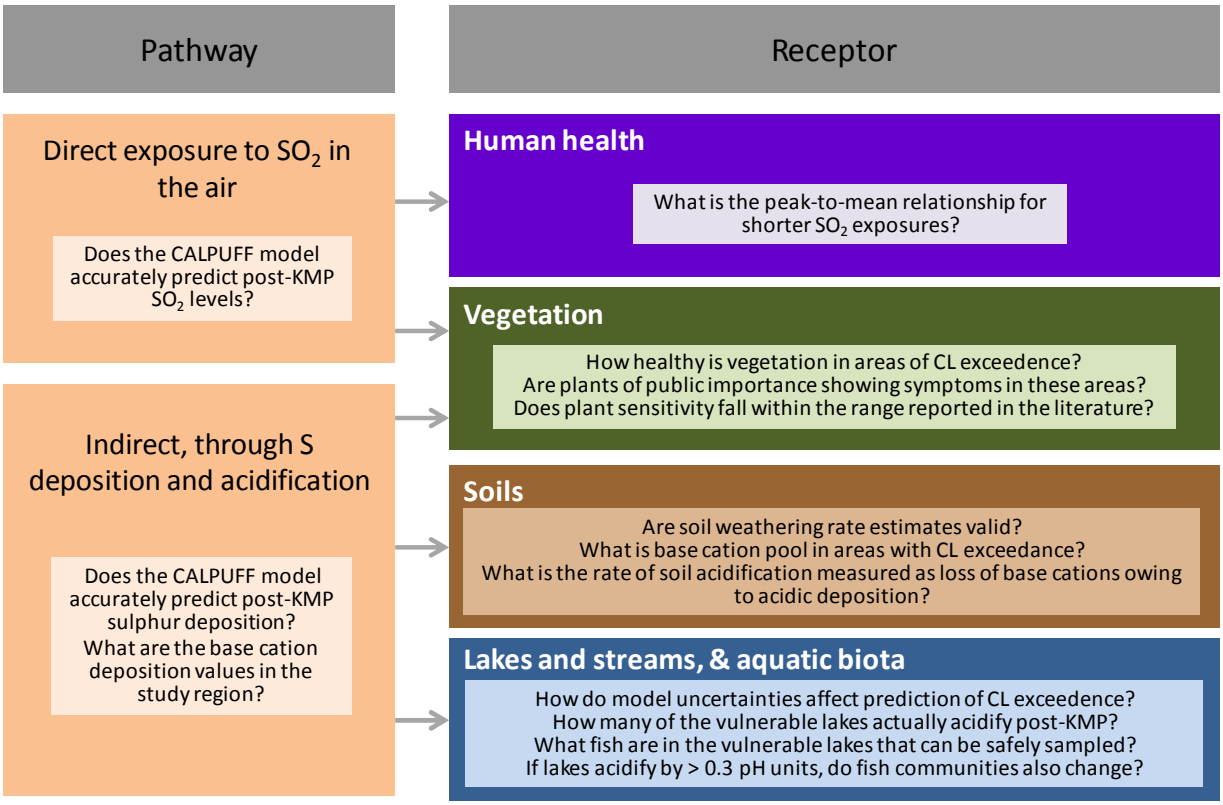


Figure 8. Summary of the questions that the KPIs and informative indicators in the SO_2 EEM Program will answer, by pathway and receptor.

Table 19. Questions and hypotheses that will be addressed in the SO_2 EEM Program.

Pathway or Receptor	Question	Hypotheses
Atmospheric Concentrations	**A1.** Does CALPUFF accurately represent post-KMP SO_2 air concentrations? *Affects predictions for all receptors, either directly (i.e., sulphur exposure impacts) or indirectly (i.e., acidification impacts).*	H_1. CALPUFF model predictions fall within an acceptable range when compared to actual SO_2 concentration data.  H_2. CALPUFF model predictions fall outside an acceptable range when compared to actual SO_2 concentration data. 
Atmospheric Deposition	**D1.** Does the CALPUFF model accurately predict post-KMP total sulphur deposition? *Affects predictions of acidification for soil, lakes and streams.*	H_1. Total sulphur deposition measurements show an acceptable level of agreement with CALPUFF predictions.  H_2. Total sulphur deposition measurements are lower than CALPUFF predictions (i.e., CALPUFF was conservative).  H_3. Total sulphur deposition measurements are higher than CALPUFF predictions. 
	D2. What are the base cation deposition values in the study region?	H_1. Measurements of base cation deposition result in reduced estimates of magnitude or extent of exceedance of soil and water critical loads (or no change in predictions).  H_2. Measurements of base cation deposition do not result in reduced estimates of exceedance of soil or water critical loads. 
Human Health	**HH1.** How conservative is the CALPUFF model in predictions of SO_2 levels?	H_1. Model predictions are conservative or similar to actual post-KMP conditions in residential areas.  H_2. Pre-KMP model predictions underestimate SO_2 levels in residential areas (i.e., greater SO_2 concentrations post-KMP). 
	HH2. What is the peak-to-mean relationship for shorter duration exposures?	H_1. The peak-to-mean ratios observed post-KMP are equal to or less than that produced by the model.  H_2. The observed peak-to-mean ratios post-KMP are greater than what is modelled. 
Vegetation	**V1.** Validation of the dispersion model – are we looking in the right place?	H_1. Post-KMP passive and continuous monitoring measurements show a similar SO_2 concentration distribution to that predicted by the model.  H_2. Post-KMP passive and continuous monitoring measurements show a different SO_2 concentration distribution to that predicted by the model. 

Pathway or Receptor	Question	Hypotheses
	V2. How healthy is vegetation in sites with predicted exceedance of critical loads of soil and/or lakes and streams south of Lakelse Lake?	No hypotheses to test; answering the question requires monitoring for damage in areas of highest predicted critical load exceedance.
	V3. Are plants of public importance showing symptoms in areas with highest exceedances of soil critical loads?	H_1. Negligible or no effects. H_2. Indirect effects on plants via changes in soil base cations and Al are moderate. H_3. Indirect effects on plants via changes in soil base cations and Al are significant. 
	V4. Do plants at Kitimat that have unknown sensitivity to SO_2 and associated pollutants (acidic deposition) fall within the range of variation in the literature?	H_1. Yes, the scientific literature accounts for the responses of the most sensitive plants. H_2. No, symptoms indicate that plants at Kitimat may be more sensitive than those reported in the literature. 
Soils	**S1.** Are estimates of average weathering rates by bedrock type valid for vulnerable areas (e.g., where lakes have low base cations)?	H_1. Estimates of soil weathering rates used in this assessment are applicable to vulnerable areas such as lakes with low base cations. H_2. Estimates of soil weathering rates used in this assessment are too high for the most vulnerable areas, resulting in underestimates of exceedance of soil critical loads. 
	S2. What is the current buffering capacity (base cation pool) of the soils in exceeded areas?	H_1. The current buffering capacity of soils is large and under post-KMP deposition it will take many decades to be depleted. H_2. The current buffering capacity of soils is small and under post KMP deposition it will take only a few years to be depleted. 
	S3. What is the rate of soil acidification measured as loss of base cations (or increase in protons) owing to acidic deposition?	H_1. Measurements of actual base cation loss indicate the magnitude and extent of soil acidification will be as predicted, and will take many decades or more. . H_2. Measurements of actual base cation loss indicate the magnitude or extent of soil acidification will occur within only a few years or a few decades. 

Pathway or Receptor	Question	Hypotheses
Lakes and Streams and Aquatic Biota	**W1.** How do assumptions in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post- KMP?	H_1. Predicted extent and magnitude of exceedances are reasonable, or are overestimates.  H_2. Predicted extent and/or magnitude of exceedances are underestimates. 
	W2. How many of the 7 lakes with predicted pH change >0.1 actually acidify under KMP, and to what extent? Are additional lakes suggested by MOE (MOE-3 and MOE-6) likely to receive deposition in excess of critical load? What is the water chemistry of the insensitive lakes?	H_1. Changes in water chemistry post-KMP (acidification) are similar to SSWC and modified ESSA/DFO predictions.  H_2. Changes in water chemistry post-KMP are less than predicted.  H_3. Changes in water chemistry post-KMP are greater than predicted. 
	W3. What species, age classes, and size of fish are present in the potentially vulnerable lakes that can be safely accessed for fish sampling?	Establish baseline conditions of fish communities prior to implementation of KMP.
	W4. If some of the potentially vulnerable lakes that can be safely accessed for fish sampling show an acidifying trend, then do these lakes also show changes in their fish communities?	H_1. No loss of any fish species.  H_2. Loss of some fish species. 

The following paragraphs summarize why each of these questions is important to answer in the SO_2 EEM Program.

A1. *Does the CALPUFF model accurately predict post-KMP SO_2 air concentrations?*

Modelled estimates of post-KMP concentrations of SO_2 are used to assess effects of sulphur on human health and vegetation, and also drive deposition estimates (explained under **D1**). The accuracy of the SO_2 concentrations predicted in the CALPUFF model therefore affects the accuracy of the assessment for all of the receptors. If CALPUFF underestimated post-KMP SO_2 concentrations, impacts on receptors may be greater than predicted; alternatively if CALPUFF overestimated SO_2 concentrations, impacts may be less than predicted. Conducting updated CALPUFF modelling using post-KMP estimates of SO_2 concentration will answer questions regarding SO_2 exposure impacts, and provide a reliable, empirically-calibrated tool which can be used to explore mitigation options.

D1. *Does the CALPUFF model accurately predict post-KMP total sulphur deposition?*

Modelled estimates of post-KMP sulphur deposition are used to predict critical load exceedances for soils and lakes and streams. If CALPUFF underestimated post-KMP SO_2 concentrations, impacts on receptors may be greater than predicted; and if CALPUFF overestimated these concentrations then impacts may be less than predicted. Conducting updated CALPUFF modelling using post-KMP estimates of sulphur deposition will answer questions regarding exceedance of critical loads and acidification impacts, and provide a reliable, empirically-calibrated tool which can be used to explore mitigation options.

D2. *What are the base cation deposition values in the study region?*

Base cation deposition in the study region is not known. This is important for the critical load analyses (and more so for soil than water analysis, described further under **W1**). In the absence of any reliable estimates, the soil critical load analyses for the technical assessment conservatively assumed that base cation deposition was zero, meaning that any base cation deposition will increase soil critical loads and may potentially reduce estimates of exceedance.

HH1. *How conservative is the CALPUFF model in predictions of SO_2 levels?*

Explained under **A1.**

HH2. *What is the peak-to-mean relationship for shorter duration exposures?*

Respiratory responses in individuals with restrictive airway diseases are most closely linked to short-term peaks of SO_2 exposure. The shortest time period over which monitoring data are available is a 1-hour average. Therefore the relationship between 1-hour averages and these shorter-term peaks must be determined in order to accurately predict the risk. (This will be used to evaluate how close SO_2 measurements fit with air modelling used to predict air restriction events, but will not itself be an indicator.)

V1. *Validation of the dispersion model – are we looking in the right place?*

Relates to **A1.** Conclusions about impacts (predicted to be low (green)) on vegetation from direct exposure to SO_2 based on evidence of vegetation damage may be underestimated if damage surveys are not done in the areas where highest concentrations of SO_2 are expected.

V2. *How healthy is vegetation in sites with predicted exceedance of critical loads of soil and/or lakes and streams south of Lakelse Lake?*

Indirect impacts on vegetation from soil acidification are predicted to be low (green). Sensitivity analyses of soil critical loads based on *minimum* estimates of mineral weathering rates (as opposed to *average* weathering rates) suggest that a few areas in quartz diorite bedrock south of Lakelse Lake could exceed the soil critical load post-KMP (further

explained under **S1**). Extension of existing vegetation surveys to these areas would help to detect any indirect soil-mediated effects on vegetation (i.e., symptoms of base cation depletion or aluminum toxicity in the rooting zone of plants).

V3. *Are plants of public importance showing symptoms in areas with highest exceedances of soil critical loads?*

As for **V2**, but applicable to exceedances elsewhere than just south of Lakelse Lake, and explicitly focusing on plants of particular value to stakeholders.

V4. *Do plants at Kitimat that have unknown sensitivity to SO_2 and associated pollutants (acidic deposition) fall within the range of variation in the literature?*

If the only plants showing symptoms of direct impacts are found in locations with SO_2 concentrations *greater than* literature thresholds for damage (i.e., one would expect plants to show damage based on literature thresholds), then all plants fall within the range of variation in the literature. If however plants show symptoms of direct impacts in locations with SO_2 concentrations *lower than* literature thresholds, then it suggests that some plants may have a greater sensitivity than those plants used in dose-response experiments and other studies to derive damage thresholds in the literature.

S1. *Are estimates of average weathering rates by bedrock type valid for vulnerable areas (e.g., where lakes have low base cations)?*

This question about weathering rates for base cations arises for all critical load studies. Critical loads for soils were estimated during the technical assessment using a limited number (four to six) soil pits within each bedrock category, therefore there are areas in the study region where weathering rates are underestimated. Answering this question is most important for two bedrock types in an area south of Lakelse Lake where exceedance is not predicted using estimates of average weathering rates, but is predicted using estimates of minimum weathering rates. This work would likely not change the predictions of high exceedance for a very small area near the smelter, or the overall impact category predicted to be moderate (yellow), as the potentially affected area is a very small percentage of the study region. It would however increase confidence in the assessment, and provide more informative estimates of exceedance risks, including how long it would take for soils to reach various thresholds (described under **S2**).

S2. *What is the current buffering capacity (base cation pool) of the soils in exceeded areas, and when would this base cation reservoir be used up?*

The mass balance models used to determine whether critical loads will be exceeded do not provide information on *when* exceedance will occur. Estimating how long it will take to use up the base cation reservoir will provide a temporal element to the interpretation of the impacts of exceedances.

S3. *What is the rate of soil acidification measured as loss of base cations owing to acidic deposition?*

There are assumptions in the deposition and soil models used to derive impact predictions (questions **S1** and **S2**). Monitoring soils that are potentially susceptible to acidification will help to understand the time to depletion of base cation pools in regions of exceedance under potential future acidification.

W1. *How do assumptions in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post-KMP?*

Predictions of sulphur deposition affect estimates of both critical loads and exceedances, so the answer to **D1** is important. Similar to the soil critical loads analyses, the water critical loads analyses in the technical assessment also assumed that deposition of base cations was zero, *but* implicitly capture any base cation deposition as part of the measured base cation concentration in the lake, and ascribe all of this to mineral weathering in the calculation of original pre-industrial base cation concentrations ($[BC^*]_0$). Changes in base cation deposition (question **D2**) could affect the estimates of critical loads and exceedance for acid-sensitive lakes, but are unlikely to affect the extent of exceedance because such a high proportion of lakes and lake area in the study area is insensitive to acidification. After several years of monitoring water chemistry, if $[SO_4^*]$ has changed, it will be easy to empirically estimate an F-factor for each lake ($\Delta[BC^*] / \Delta[SO_4^*]$).

W2. *How many of the seven potentially vulnerable lakes with predicted pH change > 0.1 actually acidify under KMP, and to what extent? Are additional lakes suggested by MOE (MOE-3 and MOE-6) likely to receive deposition in excess of critical load? What is the chemical status of insensitive lakes?*

There are various assumptions in the deposition and surface water models used to derive impact predictions. Existing information and sensitivity analyses (described under **W1**) provides a high level of confidence in the potential extent of acidification (low to moderate), but less confidence in the magnitude of acidification (i.e., observed versus predicted exceedance and pH change). Monitoring lakes that are potentially susceptible to acidification will help to increase confidence in model predictions. Monitoring results could reduce the impact category from moderate (yellow) to low (green), but are unlikely to increase the impact category beyond moderate (yellow).

W3. *What is the current status of the fish communities in the subset of potentially vulnerable lakes that can be safely accessed for fish sampling?*

This is important because the acceptability of impacts of possible acidification in the acid-sensitive lakes will depend on the fish communities present in those lakes, and how important these fish communities are to stakeholders. Prior to the EEM Program there was only limited empirical information on fish composition for two of the 10 lakes being considered in the EEM plan (West Lake and End Lake). Having a baseline is essential for

evaluating potential future changes (**W4**), where such a baseline can be safely established given access issues. Sampling in the fall of 2013 provided information on fish communities in four of the seven EEM lakes that could be safely accessed for fish sampling. The results of these field surveys (and other available information on fish populations) are summarized in row 4 of Table 22 in Appendix D of this document.

W4. *If some of the potentially vulnerable lakes that can be safely accessed for fish sampling show an acidifying trend, then do these lakes also show changes in their fish communities?*

This follows from **W2** and **W3**. If some of the lakes which can be safely sampled for fish show pH declines sufficient to potentially affect fish (i.e., a pH decline >0.30 units, evaluated under **W2**), then it is appropriate to resurvey the fish composition of the sensitive and insensitive lakes in the future (to determine whether changes were related to acidification or other factors). This would provide greater confidence in the actual *magnitude* of impacts in susceptible surface waters, but is unlikely to affect estimates of the *extent* of impacts, as explained under **W1**. Therefore the impact category is not expected to change.

Table 20. Alignment of key performance and informative indicators with the questions that the SO_2 EEM Program will answer.

		Key performance indicators and informative indicators															
Pathway or Receptor	Question (those with bold numbers were identified in the STAR)	SO_2 concentration	S deposition	Base cation deposition	Predicted annual # of SO2-associated respiratory responses	**Visible vegetation injury caused by SO_2**	S content in Hemlock needles	**Atmospheric S deposition & CL exceedance in soil**	**Long-term soil acidification attributable to S deposition**	Magnitude of base cation pools	Time to depletion of exchangeable cation pools	Base cation weathering rate	Atmospheric S deposition & CL exceedance in water	**Water chemistry - acidification**	Fish presence / absence per specie on sensitive lakes	Episodic pH change on Anderson creek	Amphibians
Atmosphere	**A1.** Does CALPUFF accurately represent post-KMP SO_2 air concentrations?	■					■										
	D1. Does the CALPUFF model accurately predict post-KMP total sulphur deposition?	■	■														
	D2. What are the base cation deposition values in the study region?		■	■													
Human Health	**HH1.** How conservative is the CALPUFF model in predictions of SO_2 levels?	■															
	HH2. What is the peak-to-mean relationship for shorter duration exposures?	■															
	Is the increased SO_2 having an impact on population health?				■												
Vegetation	**V1.** Validation of the dispersion model – are we looking in the right place?	■				■	■										
	V2. How healthy is vegetation in sites with predicted exceedance of CLs of soil and/or lakes south of Lakelse Lake?					■											
	V3. Are plants of public importance showing symptoms in areas with highest exceedances of soil critical loads?					■											
	V4. Do plants at Kitimat with unknown sensitivity to acidic deposition fall within the range of variation in the literature?					■											
	Is the increased SO_2 having an impact on vegetation?					■											
Soils	**S1.** Are estimates of weathering rates by bedrock type valid for vulnerable areas (e.g. where lakes have low base cations)?											■					

		Key performance indicators and informative indicators																
Pathway or Receptor	Question (those with bold numbers were identified in the STAR)	SO_2 concentration	S deposition	Base cation deposition	Predicted annual # of SO2-associated respiratory responses	**Visible vegetation injury caused by SO_2**	S content in Hemlock needles	**Atmospheric S deposition & CL exceedance in soil**	**Long-term soil acidification attributable to S deposition**	Magnitude of base cation pools	Time to depletion of exchangeable cation pools	Base cation weathering rate	Atmospheric S deposition & CL exceedance in water	**Water chemistry - acidification**	Fish presence / absence per specie on sensitive lakes	Episodic pH change on Anderson creek	Amphibians
	S2. What is the current buffering capacity (base cation pool) of the soils in exceeded areas?									■	■						
	S3. What is the rate of soil acidification, measured as loss of base cations owing to acidic deposition?			■					■	■	■						
	Is the increased SO_2 having an impact on soils?							■	■	■	■						
Lakes and Streams and Aquatic Biota	**W1.** How do assumptions in deposition and surface water models affect predicted CL exceedance?		■	■									■	■			
	W2. a) How many of the 7 lakes with predicted pH change >0. 1 *actually* acidify under KMP, and to what extent?													■			
	b) Are additional lakes suggested by MOE (MOE-3 and MOE-6) likely to receive deposition in excess of critical load?		■										■	■			
	c) What is the chemical status of insensitive lakes used in the biological program?													■			
	W3. What is the status of fish communities in the potentially vulnerable lakes that can be safely accessed for fish sampling?														■		
	W4. If some potentially vulnerable lakes show an acidifying trend, do they also show changes in their fish communities?														■		
	Is the increased SO_2 having an impact on lakes and streams, and on aquatic biota?													■	■		■
	What is the frequency and magnitude of episodic events?															■	

Appendix B. Checklist of Plants Potentially Sensitive to SO_2

Presence/absence of the following species will be noted during regular visual inspections for vegetation injury from SO_2:

- ☐ *Amelanchier alnifolia* (Saskatoon berry)
- ☐ *Aralia nudicaulis (*wild sarsaparilla,)
- ☐ *Cornus stolonifera* (red-osier dogwood)
- ☐ *Disporum hookeri* (Hooker's fairybells)
- ☐ *Dryopteris expansa* (spiny wood fern; spreading wood fern)
- ☐ *Epilobium angustifolium* (fireweed)
- ☐ *Lycopodium clavatum* (running club-moss)
- ☐ *Menziesia ferruginea* (fool's huckleberry, false azalea)
- ☐ *Pteridium aquilinum* (bracken fern)
- ☐ *Rosa acicularis* (prickly wild rose)
- ☐ *Rubus parviflorus* (thimbleberry)
- ☐ *Rubus spectabilis* (salmonberry)
- ☐ *Senecio triangularis* (arrowleaf ragwort; arrow-leaved groundsel)
- ☐ *Symphoricarpos albus* (common snowberry)
- ☐ *Vaccinium alaskaense* (Alaska blueberry)
- ☐ *Vaccinium membranaceum* (black blueberry; black huckleberry; thinleaf huckleberry)
- ☐ *Vaccinium ovalifolium* (oval-leaf blueberry)
- ☐ *Vicia Americana Vicia Americana* (American vetch)
- ☐ *Abies amabilis* (amabilis fir; Pacific silver fir)
- ☐ *Abies lasiocarpa* (subalpine fir)
- ☐ *Acer glabrum* (Douglas maple)
- ☐ *Alnus crispa* (green alder)
- ☐ *Alnus tenuifolia* (mountain alder)
- ☐ *Betula papyrifera* (paper birch)
- ☐ *Crataegus douglasii* (black hawthorne)
- ☐ *Pinus contorta* (lodgepole pine; shore pine)
- ☐ *Populus tremuloides* (quaking aspen; trembling aspen)
- ☐ *Populus trichocarpa* (black cottonwood)
- ☐ *Prunus pensylvanica* (pin cherry)
- ☐ *Prunus virginiana* (choke cherry)
- ☐ *Sorbus scopulina* (western mountain-ash)
- ☐ *Sorbus sitchensis* (Sitka mountain-ash)
- ☐ *Tsuga heterophylla* (western hemlock)

Note that some species may locally be known by different common names than those listed above (which were obtained from BC eFlora).

Sources:

BC eFlora (http://www.geog.ubc.ca/biodiversity/eflora/) accessed September 9, 2013.

Flagler, R.B. 1998. Recognition of Air Pollution Injury to Vegetation: A Pictorial Atlas. Pittsburgh, PA: Air & Waste Management Association.

Pojar, J. and A. MacKinnon (eds.) 1994. Plants of Coastal British Columbia: Including Washington, Oregon and Alaska. Lone Pine Publishing, 527 pp.

Appendix C. Quantitative Thresholds for Lakes and Streams and Aquatic Biota

The quantitative thresholds for lakes and streams and aquatic biota were specified in Tables 8.6-5 to 8.6-7 of the STAR (ESSA et al. 2013), and are reproduced below. Examples of lake specific thresholds for pH, ANC and SO4 are provided in Table 27 of Appendix H.

Likelihood (as per definition below)	**Consequence** (as per definitions below)				
	1 – Minor	2 – Medium	3 – Serious	4 – Major	5 – Catastrophic
A – Almost Certain	**Moderate**	**High**	**Critical**	**Critical**	**Critical**
B – Likely	**Moderate**	**High**	**High**	**Critical**	**Critical**
C – Possible	**Low**	**Moderate**	**Moderate**	**High**	**Critical**
D – Unlikely	**Low**	**Low**	**Moderate**	**Moderate**	**Moderate**
E – Very Unlikely	**Low**	**Low**	**Moderate**	**Moderate**	**Moderate**

Quantitative definitions of the five Likelihood levels:

A – Almost Certain	B – Likely	C – Possible	D – Unlikely	E – Very Unlikely
Predicted deposition ≥10 meq/m^2/yr **above CL**	Predicted deposition 0 to 10 meq/m^2/yr **above CL**	Predicted deposition 0 to 10 meq/m^2/yr **below CL**	Predicted deposition 10 to20 meq/m^2/yr **below CL**	Predicted deposition more than 20 meq/m^2/yr **below CL**

Quantitative definitions of the five Consequence levels:

1 - Minor	2 - Medium	3 - Serious	4 - Major	5 - Catastrophic
<5 % of study area lakes exceed CL AND **0** sampled streams exceed CL AND Lakelse Lake does not exceed CL	**5-10 %** of study area lakes exceed CL AND **0** sampled streams exceed CL AND Lakelse Lake does not exceed CL	**>10-15 %** of study area lakes exceed CL OR **1-2** sampled streams exceed CL AND Lakelse Lake does not exceed CL	**>15-25 %** of study area lakes exceed CL OR **3-4** sampled streams exceed CL AND Lakelse Lake does not exceed CL	**>25 %** of study area lakes exceed CL OR **5+** sampled streams exceed CL OR Lakelse Lake exceeds CL

Figure 9 shows pH levels at which biologically significant change is expected in aquatic biota.

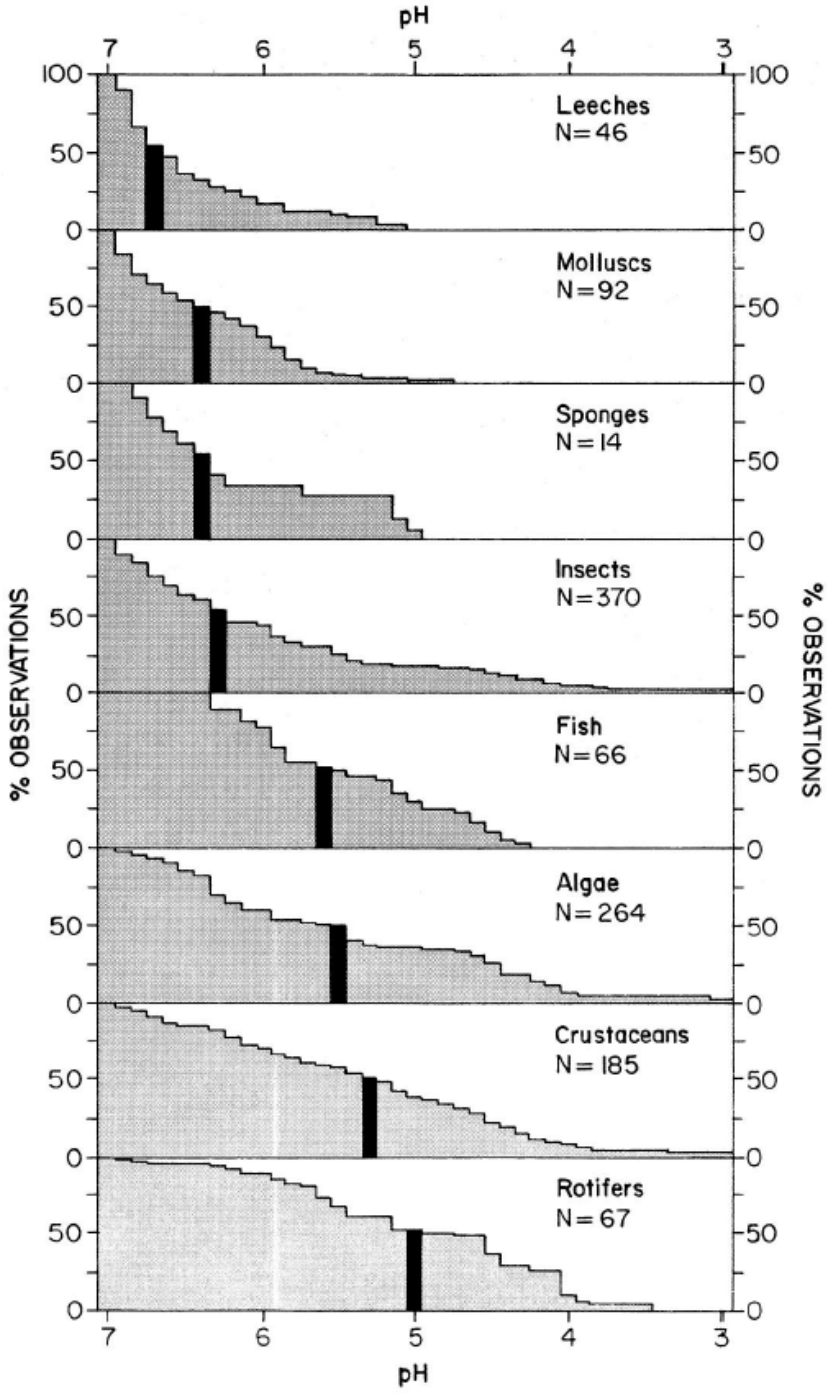


Figure 9. Cumulative frequency distribution of minimum pH values for field observations of aquatic taxa, showing percent reduction in species along a pH continuum. (The medial minimum pH value is indicated by the solid bar.) From: Eilers et al. 1984.

Appendix D. Lake Rating – Method and Results

Rating of the 10 vulnerable lakes (Figure 6) is needed for determining mitigation thresholds for the Water chemistry KPI (described in Section 6). This appendix describes the method used to determine the relative rating of these lakes, and presents the results.

The following method was used in rating the lakes:

1. Determine the rating criteria (Table 21).
2. Document the criteria for each lake (Table 22).
3. For each criterion, assign each lake a rating of Low, Medium, or High (Table 22).
4. Assign an overall rating Low, Medium, or High for each lake within the set of 10 acid-sensitive lakes, across all criteria (Table 23 and Table 24).

The relative rating of each lake within the 134 lakes > 1 ha in size within the study area was considered, recognizing that a lake could have a High relative rating within the set of acid-sensitive lakes, but a low relative rating within the overall study area. For the few criteria where this information was available, however, the ratings within this larger context did not differ appreciably from the ratings already assigned when looking just at the 10 vulnerable lakes.

The results of this rating exercise will help inform decisions regarding lake liming if the receptor-based mitigation threshold (described in Section 6) is reached, with the intention of protecting lakes of particular public interest.

Table 21. Criteria for rating of 10 lakes with either CL exceedance or predicted ΔpH > 0.1.

Criteria	Sources Sought for the Information
1. Accessibility and non-recreational use by people (presence/absence of road and trails for access; residences on shoreline; water licences; drinking water, industrial, irrigation or livestock use)	▪ Google Earth and BC Watershed Atlas maps ▪ Local MOE / FLNRO fish biologists[27] and angling / recreational groups; traditional knowledge ▪ Spreadsheet completed by Shauna Bennett of Limnotek in consultation with Fred Seiler ▪ Observations of existing trail, road, and ATV access from actual sampling of lakes ▪ Provincial water license database
2. Recreational value (e.g. angling, hiking, cross country skiing, snowmobiling, canoeing)	▪ Local MOE / FLNRO fish biologists ▪ Angling / recreational groups ▪ Recreational map for Northern BC
3. Lake surface area, which is a general indicator of fish biomass, diversity, habitat connectivity and	▪ STAR ▪ BC Watershed Atlas, 2012

[27] Joe De Gisi and Jeff Lough, FLNRO.

Criteria	Sources Sought for the Information
food supply for downstream areas[28]	
4. Sustainable fish species present; history of stocking; stocking suitability; unique fish species or life histories (including genetically significant populations, i.e. kokanee); other unique biota besides fish (including rare species)	▪ STAR ▪ Fisheries Information Summary System (FISS)[29] ▪ DFO information on salmon distribution ▪ Local MOE / FLNRO fish biologists ▪ 2013 fish sampling on presence/absence for LAK006 (End Lake), LAK012, LAK023 (West Lake) and LAK044 ▪ Presence of lake inflows and outflows, for lakes where fish presence is unknown
5. Lake is habitat used by anadromous salmon for accessing spawning areas upstream or for rearing by juveniles; supports culturally important food fishery	▪ DFO information on salmon distribution ▪ FISS ▪ Local MOE / FLNRO fish biologists; First Nations ▪ Presence/absence of inflow streams observed during actual lake sampling in 2013
6. Influence of DOC and organic acids[30]	▪ From STAR Section 9.4.1.2.3 – based on anion content and retrospective predictions of original pre-industrial pH ▪ Inferred % of potential fish species that were present in pre-industrial times, and currently (based on literature curves)
7. Estimated mid-range lake volume and max residence time	▪ From Table 25

[28] Compared to small lakes of similar productivity which contain fish, large lakes with fish are generally rated more highly, since they will have more total fish biomass (i.e., total biomass = biomass / area * area), are likely to have more diverse fish habitats and species composition, are more likely to have inlets and outlets, and are more likely to contribute forage fish for downstream piscivorous fish.

[29] Presence of species in FISS indicates that species was present at one time, but species may or may not be present now; absence of species in FISS does not mean that it is not present now.

[30] If lake naturally has a low pH due to organic acids (especially a pH less than 5 – see Figure 9), this would result in lower fish species diversity and likely lower fish production.

Table 22. Criteria results for the 10 lakes vulnerable lakes, as well as their relative ratings. Sources are listed below the table. (Note: LAK012 is hydrologically connected to End Lake (LAK006).)

Criteria	LAK012	LAK022	End Lake (LAK006)	West Lake (LAK023)	LAK028	LAK042	LAK044	LAK047	LAK054	LAK056
1. ACCESSIBILITY AND NON-RECREATIONAL USE BY PEOPLE	ATV access and existing trail into lake[13] good access from ski trails[1] No residences using it for drinking water[16] No irrigation or livestock use; possible silvicultural activities[15]	No road access[10] Accessibility is poor[1]; not accessible[2]	ATV access and existing trail into lake[13] Can get boat into lake on ATV trailer[13]; no official boat access[15] Good access from ski trails[1] No shoreline residences present[16] No irrigation or livestock use[15] Possible silvicultural activities[15]	Road access[3,11] No shoreline residences[16] Forestry campsite on east side of lake (where the road meets the lake), definite use of this area[15] No residences, no water licenses, no irrigation or livestock[15] West side of lake and creek has been logged –have since had a hard time getting conifers to grow[15]	No road access[10]; not accessible[2,15] Claque Mountain Trail (hiking & snowmobiling) in the vicinity, but isn't clear if it runs near this lake[5,6,7] Likely no water users[15]	No road access[10]; Poor to fair access[1,2]; nearest road is ~200 m away, allowing an inflatable boat to be packed in[3]; may be some trails along old logging roads[15] No shoreline residences visible[3] Lake has very large wood waste dump site located south of it; leachate coming from this site may affect water quality[15]	Road access[10]; large pull out on highway with 50m walk on a well worn and wide trail to lake shore[13] Residence to the north of the lake may have a septic field[1] Water licence in lake for residence to the north[7]	Inaccessible mountain lake[3] Possible hiking trails[15]	No road access[10]; not accessible[2]	No road access[10]; not accessible[2]
Relative rating:	Medium	Low	Medium	High	Low	Low	High	Low	Low	Low
Notes on Rating:	Road access lakes are rated High; good ATV access lakes are rated Medium; and the rest are rated Low. Liming is most feasible in lakes with boat access.									
2. RECREATIONAL VALUE	Ski trails[1]; roads present to lakes north & south of this lake, both of which appear to be connected to LAK012 by	Possibly fishing, hiking, snowshoeing, cross country skiing, snow-mobiling[15]	Ski trails[1] Definite ATV, snowmobile use; fishing, boating, photography, hiking, snowshoeing, hunting; and	Campsite beside lake[1]; forest rec-reation site[7] Trails around lake; ATVs use old forestry roads around it; used for	Possibly hiking, snowshoeing, cross country skiing and snowmobiling[1,5]	Hiking[15]	Swimming, skiing, skating[15]	Hiking[15]	No information, but isolation and lack of access (criterion #1) suggests low recreational value	No information, but isolation and lack of access (criterion #1) suggests low recreational value

Criteria	LAK012	LAK022	End Lake (LAK006)	West Lake (LAK023)	LAK028	LAK042	LAK044	LAK047	LAK054	LAK056
	creeks[2] ATV, snow-mobile use; fishing, boating, photography, hiking, snowshoeing, hunting; likely has a trapline around it[15]		probably is a trapline around it[15]	snowmobiling, hiking, angling, canoeing, hunting, and trapping; road to lake is not plowed in the winter so would be far for CC skiing[15]						
Relative rating:	High	Medium	High	High	Medium	Medium	High	Medium	Low	Low
Notes on rating:	Lakes with multiple known recreational uses are rated High, lakes with a few possible recreational uses are rated Medium, and lakes with no known recreational uses are Low.									
3. LAKE SURFACE AREA	2.3 ha [2,9] Ranks 57 among 134 lakes >1 ha (in the top 60%)	5.7ha [2,9] Ranks 28 among 134 lakes >1 ha (just below the top 20%)	10.2 ha [2,9] Ranks 14 among 134 lakes >1 ha (in the top 20%)	6.8 ha [2,9] Ranks 24 among 134 lakes >1 ha (in the top 20%)	1.0 ha [2,9] Ranks 127 among 134 lakes >1 ha (in the bottom 30%)	1.5 ha [2,9] Ranks 92 among 134 lakes >1 ha (in the bottom 30%)	2.0 ha [2,9] Ranks 66 among 134 lakes >1 ha (in the top 60%)	1.6 ha [2,9] Ranks 83 among 134 lakes >1 ha (just under the top 60%)	1.5 ha [2,9] Ranks 89 among 134 lakes >1 ha (just under the top 60%)	1.8 ha [2,9] Ranks 72 among 134 lakes >1 ha (in the top 60%)
Relative rating:	Low	Medium	High	Medium	Low	Low	Low	Low	Low	Low
Notes on Rating:	Of the 134 lakes in the study area >1 ha, Lakelse Lake (1,374.4 ha) and Jesse Lake (1,166.6 ha) are exceptionally large in surface area, two orders of magnitude larger than the third largest lake (Kitelse Lake, at 30.8 ha). Vulnerable lakes within the top 15 largest lakes in the study area were rated High (only West Lake, which at 10.2 ha is the 14th largest lake). Lakes within the top 30 largest lakes were rated Medium (LAK022 and LAK023 (West Lake)), which were also larger than 5 ha, and ranked 28th and 24th in area , respectively). Other lakes were rated Low. Since 51% of the 134 lakes in the study area were less than 2 ha, areas significantly larger than 5 ha (at least double that size) seemed a reasonable distinction between Medium and Low.									
4. SUSTAINABLE FISH PRESENCE	EEM sampling in Oct 2013 using RIC and small mesh gill nets confirmed presence of cutthroat trout, dolly varden, coho, three-spine stickleback	Previously stocked (DFO)[1] Fish habitat inferred[14] Connection to Coldwater Creek[1] Should be accessible to freshwater fish based on stream gradients, although there	EEM sampling in Oct 2013 using RIC and small mesh gill nets confirmed presence of cutthroat trout, dolly varden, coho, three-spine stickleback	Kokanee, cut-throat caught 1990[1]; coho 1989[4]; Chinook and cutthroat (no date)[4]; coho, Chinook, stickleback, cutthroat[2] EEM sampling using RIC and small mesh gill nets in Oct 2013 showed residualized	Accessibility to fish unknown, anadromous fish unlikely [2,15]	BC Watershed Atlas infers accessibility to freshwater fish based on stream gradients[14] Current production may be relatively low given the high concentration of organic acids and low pH value[2]	Was stocked ~ 25 years ago (anecdotal) but fish have all died off[15] EEM sampling in Oct 2013 using RIC and small mesh gill nets showed no fish present and no inflow or outflow stream	Not accessible to fish[14] Most likely none; feeds Coldwater Creek – an important fish stream in the Lakelse Watershed[15]	BC Watershed Atlas infers accessibility to freshwater fish based on stream gradients[14] Current production may be relatively low given the high concentration of organic acids and naturally low	BC Watershed Atlas infers accessibility to freshwater fish based on stream gradients[14] Current production may be relatively low given the high concentration of organic acids and naturally low

Criteria	LAK012	LAK022	End Lake (LAK006)	West Lake (LAK023)	LAK028	LAK042	LAK044	LAK047	LAK054	LAK056
		are no empirical observations of fish recorded in the Atlas for this lake[14] Unknown, but there could be cutthroat present [15]		coho (to be confirmed with DNA analysis) plus three-spine stickleback					pH [2]	pH [2]
Relative rating:	High	Medium	High	Medium	Medium	Medium	Low	Low	Medium	Medium
Notes on Rating:	LAK012, End Lake (LAK006), West Lake (LAK023) and LAK044 were sampled for fish in 2013 as part of the EEM Program, and these lakes have the highest level of certainty regarding fish composition. Confirmed fish presence in the presence of outflow streams rates High. Confirmed fish presence with ephemeral presence of outflows (West Lake) rates Medium. For the other lakes, important information includes fish observations in the Watershed Atlas for *observed fish habitat*[12], and estimates of *inferred fish habitat* and *non-fish habitat* based on stream gradients[14]. Of the 134 lakes >1 ha in the study area, 11 lakes have *observed fish habitat* (including the lakes rated here as High, with fish presence confirmed by the Oct 2013 EEM fish sampling), 76 have *inferred fish habitat* (including the lakes rated here as Medium), 33 have *non-fish habitat* (including the lakes rated here as Low), and 14 were rated *unknown* (including LAK044, which was subsequently confirmed by fish sampling in 2013 to have no fish and therefore rated Low).									
5. HAB ITAT USE BY ANADROMOUS SALMON	Presence of coho confirmed by EEM sampling in 2013	Inferred[14]	Observed[12] Presence of coho confirmed by EEM sampling in 2013	Observed[12] Presence of residualized coho (to be confirmed with DNA) in EEM sampling in 2013	Anadromous fish unlikely [15]	Inferred[14]	No fish present in EEM 2013 sampling (see criterion #4)	Non-habitat[2] No [15]	Inferred[14]	Inferred[14]
Relative rating:	High	Medium	High	Medium	Low	Medium	Low	Low	Medium	Medium
Notes on rating:	Confirmation of the presence of anadromous salmon (coho) by sampling in 2013 results in a High rating. Residualized / resident coho were detected in West Lake, but appear not to be anadromous because outflows are only ephemeral. Lakes with inferred fish accessibility are rated Medium. Lakes with confirmation of no fish under criterion #4 are rated Low.									
6.-INFLUENCE OF DOC AND ORGANIC ACIDS	26% organic ions; est. pre-industrial pH 5.74[2] (53% of potential fish species present[8]); current pH 5.64[2] (51% of potential fish species	35% organic ions; est. pre-industrial pH 6.11[2] (77% of potential fish species present[8]); current pH 5.92[2] (60% of potential fish species	34% organic ions; est. pre-industrial pH 6.02[2] (71% of potential fish species present[8]); current pH 5.79[2] (54% of potential fish species	36% organic ions; est. pre-industrial pH 5.96[2] (64% of potential fish species present[8]); current pH 5.70[2] (52% of potential fish species	25% organic ions; est. pre-industrial pH 5.77[2] (54% of potential fish species present[8]); current pH 4.98[2] (26% of potential fish species	81% organic ions; est. pre-industrial pH 4.92[2] (25% of potential fish species present[8]); current pH 4.68[2] (18% of potential fish species	38% organic ions; est. pre-industrial pH 5.80[2] (54% of potential fish species present[8]); current pH 5.40[2] (47% of potential fish species	10% organic anions; est. original pH 6.0[2]	61% organic ions; est. pre-industrial pH 4.67[2] (18% of potential fish species present[8]); current pH 4.59[2] (12% of potential fish species	56% organic ions; est. pre-industrial pH 4.56[2] (10% of potential fish species present[8]); current pH 4.5[2] (9% of potential fish species

Criteria	LAK012	LAK022	End Lake (LAK006)	West Lake (LAK023)	LAK028	LAK042	LAK044	LAK047	LAK054	LAK056
	present[8], for a loss of 2% relative to pre-industrial conditions); predicted future pH 5.51[2] (48% of potential fish species present[8] for a loss of 5% relative to pre-industrial conditions)	present[8] for a loss of 17% relative to pre-industrial conditions); predicted future pH 5.54[2] (49% of potential fish species present[8] for a loss of 28% relative to pre-industrial conditions)	present[8] for a loss of 17% relative to pre-industrial conditions); predicted future pH 5.31[2] (46% of potential fish species present[8] for a loss of 25% relative to pre-industrial conditions)	present[8] for a loss of 12% relative to pre-industrial conditions); predicted future pH 5.16[2] (38% of potential fish species present[8] for a loss of 26% relative to pre-industrial conditions)	present[8] for a loss of 28% relative to pre-industrial conditions); predicted future pH 4.60[2] (12% of potential fish species present[8] for a loss of 42% relative to pre-industrial conditions)	present[8] for a loss of 7% relative to pre-industrial conditions); predicted future pH 4.48[2] (9% of potential fish species present[8] for a loss of 16% relative to pre-industrial conditions)	present[8] for a loss of 7% relative to pre-industrial conditions); predicted future pH 4.86[2] (24% of potential fish species present[8] for a loss of 30% relative to pre-industrial conditions)		present[8] for a loss of 6% relative to pre-industrial conditions); predicted future pH 4.53[2] (10% of potential fish species present[8] for a loss of 8% relative to pre-industrial conditions)	present[8] for a loss of 1% relative to pre-industrial conditions); predicted future pH 4.44[2] (8% of potential fish species present[8] for a loss of 2% relative to pre-industrial conditions)
Relative rating:	Medium	Medium	Medium	Medium	Medium	Low	Medium	High	Low	Low
Notes on rating:	A High rating is assigned to lakes where organic anions (i.e., natural acidification) make up < 25%, of the total anions (i.e., if they have a low pH, this is more likely to be related to pollution). A Medium rating is assigned to lakes with organic acid influence (25-50% organic anions), where natural acidification is important in addition to any pollution effects. A Low rating is assigned to lakes that are dominated by organic acids (> 50% organic anions), and lakes were naturally acidified prior to any pollution sources.									
7. ESTIMATED MIDRANGE LAKE VOLUME & MAXIMUM RESIDENCE TIME	80,530 m^3 0.156 yrs	580,128 m^3 2.616 yrs	584,232 m^3 1.089 yrs	182,857 m^3 0.758 yrs	156,726 m^3 1.273 yrs	175,186 m^3 1.185 yrs	300,832 m^3 7.165 yrs	8,028 m^3 0.012 yrs	77,707 m^3 0.058 yrs	116,897 m^3 0.400 yrs
Relative rating:	Low	Medium	Medium	Medium	Medium	Medium	High	Low	Low	Low
Notes on rating:	Lakes with longer residence times have a slower rate of response to changes in acid loading, and will be more suitable sites for liming. Lakes with maximum residence time greater than 3 years are rated High. Lakes with maximum residence time between 1 and 3 years are rated Medium. Lakes with maximum residence time less than 1 year are rated Low.									

Sources:

[1] File "*Lake Recce Summary 14 June2013.xls*" prepared by Limnotek; information on access collected from maps, Google Earth, and local knowledge of field technicians who live in Terrace

[2] STAR (ESSA et al. 2013)

[3] Google Earth map

[4] BC Fisheries Information Summary System (of the 10 vulnerable lakes, only West Lake [ID 00012KITR] and End Lake [ID 00146LKEL] represented in the database)

[5] Kitimat recreation trails map (http://www.for.gov.bc.ca/dkm/recreation/kitimat/kitimat_rec.PDF)

[6] Clague Mountain Trail map (http://www.recsiteimages.tca.gov.bc.ca/REC6595/sitemaps/Mt%20Clague%20SummerTrail%20Exhibit%20%27A%27.pdf)

[7] BC iMap 2.0 (http://maps.gov.bc.ca/ess/sv/imapbc/)

[8] Eilers et al. (1984) Figure 1 showing expected biological responses to declining pH

[9] Field sampling data summarized by Limnotek in "*all 134 lakes sorted by area.xlsx*"

[10] Field sampling data summarized by Limnotek in "*Rio Tinto Alcan Field Data 2012 10Jan2013 for MOE.xlsx*"; the access information in this file was collected in an overflight and was not ground-truthed

[11] Christopher Perrin, Limnotek (email communication dated Sept. 19, 2013)

[12] BC Watershed Atlas

[13] Field notes from ground reconnaissance by Limnotek in August 2013, "*Field Notes_26AUG2013.pdf*"

[14] BC MOE, 2011. Fish Passage GIS analysis, FishHabitat [data set]. Craig Mount, MOE [distributor]

[15] Mitch Drewes, Hidden River Environmental Mgmt., Terrace BC (recommended by Markus Feldhoff, DFO)

[16] Observations during sampling of water and fish in 2013

Table 23. Method used to combine ratings on individual criteria into the overall ratings shown on the bottom row of Table 24.

Lakes must have ratings within the shaded categories to be assigned the corresponding overall rating. Criteria for which all three ratings are shaded (Low, Medium and High) had less weight on the overall rating (e.g. criterion 7) than criteria for which only a High value was required for an overall rating of High (e.g., criteria 2, 4 and 5).

Overall Rating	Criteria	Required Ratings		
		High	Medium	Low
High	1. ACCESSIBILITY AND USE BY PEOPLE	■	■	
	2. RECREATIONAL VALUE	■		
	3. LAKE SURFACE AREA	■	■	
	4. SUSTAINABLE FISH PRESENCE	■		
	5. HABITAT USE BY ANADROMOUS SALMON	■		
	6.-INFLUENCE OF DOC, ORGANIC ACIDS	■	■	
	7. EST. LK VOLUME & RESIDENCE TIME	■	■	■
Medium	1. ACCESSIBILITY AND USE BY PEOPLE	■	■	■
	2. RECREATIONAL VALUE	■	■	
	3. LAKE SURFACE AREA	■	■	
	4. SUSTAINABLE FISH PRESENCE	■	■	
	5. HABITAT USE BY ANADROMOUS SALMON	■	■	
	6. INFLUENCE OF DOC, ORGANIC ACIDS		■	
	7. EST. LK VOLUME & RESIDENCE TIME	■	■	■
Low	1. ACCESSIBILITY AND USE BY PEOPLE	■	■	■
	2. RECREATIONAL VALUE	■	■	■
	3. LAKE SURFACE AREA		■	■
	4. SUSTAINABLE FISH PRESENCE		■	■
	5. HABITAT USE BY ANADROMOUS SALMON		■	■
	6. INFLUENCE OF DOC, ORGANIC ACIDS		■	■
	7. EST. LK VOLUME & RESIDENCE TIME	■	■	■

Table 24. Rating results for the 10 lakes with either CL exceedance or predicted ΔpH > 0.1. Lakes with an asterisk (*) were sampled in 2013 and have high certainty on criteria 4 and 5.

Criteria	LAK012*	LAK022	End Lake (LAK006)*	West Lake (LAK023)*	LAK028	LAK042	LAK044*	LAK047	LAK054	LAK056
1. ACCESSIBILITY AND USE BY PEOPLE	M	L	M	H	L	L	H	L	L	L
2. RECREATIONAL VALUE	H	M	H	H	M	M	H	M	L	L
3. LAKE SURFACE AREA	L	M	H	M	L	L	L	L	L	L
4. SUSTAINABLE FISH PRESENCE	H*	M	H*	M*	M	L	L*	L	M	M
5. HABITAT USE BY ANADROMOUS SALMON	H	M	H	M	L	M	L	L	M	M
6.-INFLUENCE OF DOC, ORGANIC ACIDS	M	M	M	M	M	L	M	H	L	L
7. EST. LK VOLUME & RESIDENCE TIME	L	M	M	M	M	M	H	L	L	L
OVERALL RATING	**H**[31]	**M**	**H**	**M**	**L**	**L**	**L**	**L**	**L**	**L**

[31] LAK012 would rate "M" if it were isolated (due its small size, see Table 23), but since it is connected to End Lake (rated H) it should also be rated H.

Appendix E. Fish Sampling Locations and Method

Fish sampling will occur in seven lakes: four vulnerable lakes which can be safely accessed, and three reference lakes (Figure 10).

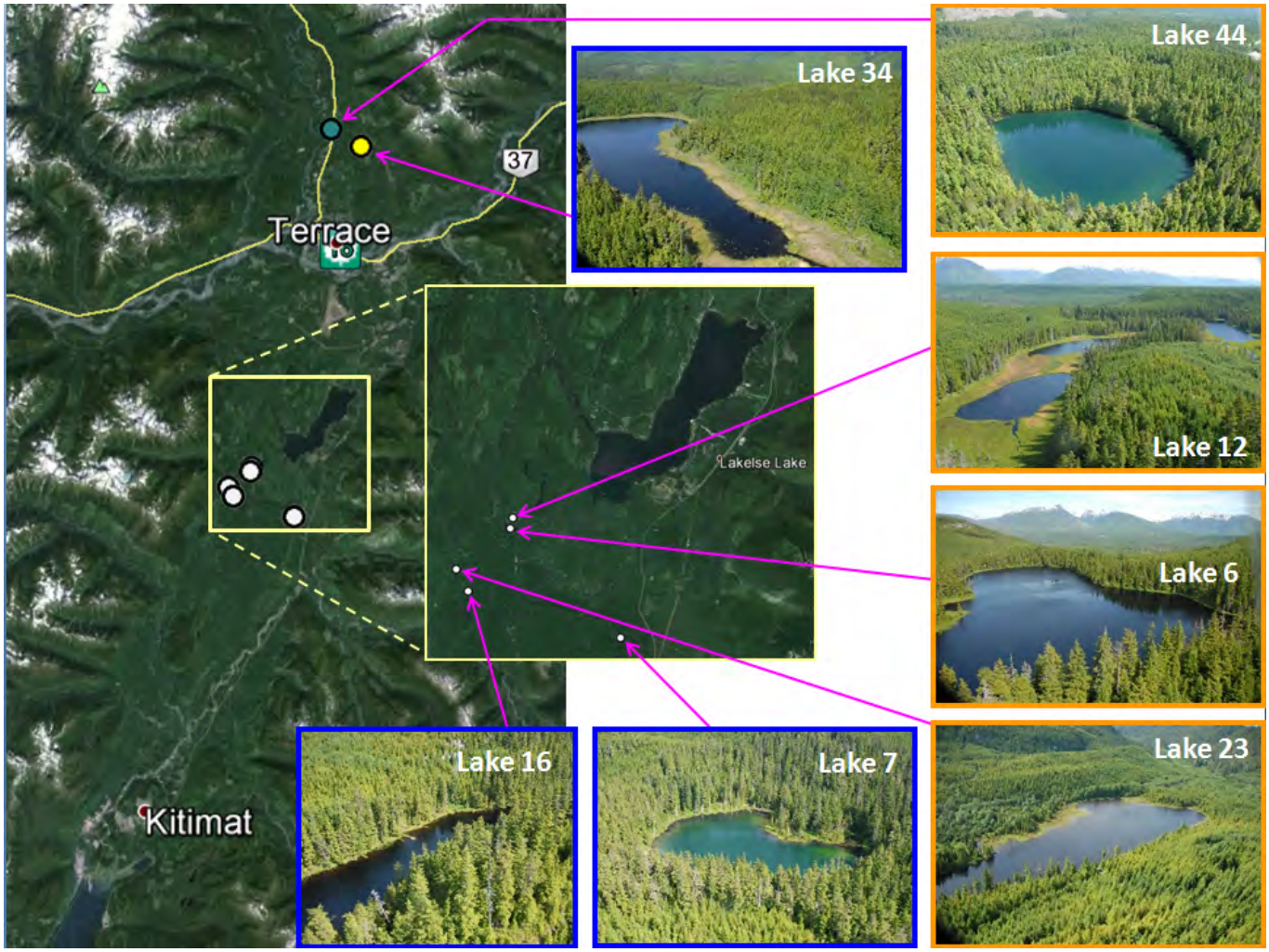


Figure 10. Map of the seven lakes that will be sampled for fish presence/absence. The four vulnerable lakes (Lakes 6, 12, 23 and 44) are indicated by orange borders around their photographs, and reference Lakes 7, 16 and 34 are indicated by blue borders.

Fish sampling will be scheduled for a time when water temperature in the epilimnion (surface mixed layer if the lake is density stratified) or the complete water column if no stratification is present is 7-13°C. Fish capture using gill nets is known to be most effective in this temperature range (Ward et al. 2012). Temperatures >13ºC may cause unacceptable fish mortality while temperatures <7ºC reduce fish activity and catch rates in passive gears such as gill nets. Based on available information for lakes in the Kitimat Valley, this temperature range is likely to occur in the latter half of September or early October.

Fish sampling will be done using gill nets. Two standard RIC nets (RIC 1997) and two small mesh nets will be fished in each lake using standard overnight methods (RIC 1997). The nets will be installed in late afternoon and recovered the following morning. One floating and one sinking RIC standard gill net (RIC 1997) will be used, each having dimensions of 91.2 x 2.4 m with six panels of different mesh sizes (25, 89, 51, 76, 38, and 64 mm stretched mesh). One floating and one sinking fine mesh gill net will be used to capture small underyearling fish. The fine mesh nets will have dimensions of 1.8 x 12.4 m with four panels of different small meshes (12.5, 19, 16, 25 mm stretched mesh). Material for the small mesh netting will be uncoloured monofilament <0.13 mm for the three smallest meshes and 0.18 mm for the largest mesh size.

The nets will be placed in habitat considered optimal for catching fish. The crew will deploy the gill nets and record coordinates using a GPS receiver. Procedures follow standard methods for gill netting by Lester et al (2009), Appelberg (2000), and Morgan and Snucins (2005). Use of sinking and floating nets will facilitate sampling of most depths in each lake. Various rigging will be used to either sink a net or float a net to a specific depth to achieve collection of samples from target depths.

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Appendix F. State-of-Knowledge Summary for Liming of Soils

One of the long-term legacies of acid rain has been identified as calcium depletion in soils (Lawrence et al. 1999; Huntington et al. 2000; Watmough and Dillon 2003a; Yanai et al. 2005). Calcium (Ca) is a macronutrient for trees (Lawrence et al. 1999) and other biota, and is important for sustaining growth (Lawrence et al. 1995). Acid deposition leaches calcium from the soil (Driscoll et al. 2001; Likens et al. 1998), making less available for uptake by roots to replenish losses in the canopy. Losses of calcium in the soil make forest ecosystems increasingly sensitive to continuing inputs of acid (Likens et al. 1998), and threaten forest health and productivity (Watmough and Dillon 2003b). Site-specific application of buffering compounds may be effective. The wide range of success of such treatments suggests a need for testing specific locations on a pilot scale.

Lime and wood ash are used for forest soil amelioration, with the objective of reducing soil acidity, increasing calcium concentrations in trees, and improving tree growth (Reid and Watmough 2013). Soil pH, calcium foliar concentration, and various tree growth metrics are typically used to measure success. Other useful performance metrics include base saturation, ectomychorrhizae (ECM) root colonization, and indices of microbial diversity, richness and abundance (Reid and Watmough 2013).

The two most common buffering compounds used in liming research are calcite (calcium carbonate, limestone, $CaCO_3$) and dolomite ($CaMg(CO_3)_2$), but wollastonite (CaSiO3), gypsum (CaSO4), calcium nitrate (Ca(NO3)2), and calcium chloride (CaCl2) can also be used (Reid and Watmough 2013). Solubility affects the response of soils to calcium treatment. Calcium in wood ash is more soluble than calcium in lime compounds (Meiwes 1995). In wood ash, calcium is typically present as $CaCO_3$, but concentrations tend to be highly variable and inferior to those in liming agents (Demeyer et al. 2001). Potentially toxic elements such as cadmium (Cd) and lead (Pb) may also be present in wood ash (Demeyer et al. 2001; Aronsson and Ekelund 2004).

On the whole, additions of calcium to soils have not been universally beneficial. In their meta-analysis of 350 independent trials from 110 peer-reviewed liming and wood ash studies, Reid and Watmouth (2013) found that treatment efficacy depends on a number of inter-related factors, including soil type (organic vs. mineral), time since treatment, material used (lime vs. wood ash), dose, forest stand age, and tree species (hardwood vs. softwood). For example, organic soils exhibited a larger increase in pH following calcium addition than did mineral soils (mean increases of 1.04 and 0.36 pH units respectively), and organic soils responded better to lime than to wood ash additions. Young forest stands (<50 yrs) on organic soils that were treated with lime showed the greatest mean increase in pH (1.68 units). In mineral soils, the greatest mean increase in pH (0.64 pH units) occurred in initially acidic soils (pH <4.5) that received higher treatment doses (>5000 kg/ha). The largest increase in base saturation (42.4%)

occurred in the organic soils of softwood stands where sampling took place ≥10 years after treatment. Foliar calcium concentration showed the highest increase in limed stands (48.5% over control) as compared to stands treated with wood ash (13.8% over control). Limed hardwood stands treated with high doses (>5000 kg/ha) exhibited the greatest mean increase in foliar calcium concentration (92.5% over control). As a performance measure, tree growth showed the highest degree of variation in the analysed trials, with time since treatment, initial soil pH, and tree species all affecting the response to treatment. The highest mean increase in growth (116% over control) occurred for softwoods on soils with initial pH >4.5 and where measurements were taken more than 10 years after treatment. For sites with initially acidic soils (pH <4.5), hardwoods showed greater growth increases than softwoods, especially at higher doses (>5000 kg/ha).

When soils are treated with calcium, the lime or wood ash is applied to the upper organic horizon and takes time to leach down into the mineral soil. Short-term trials may fail to detect effects in the mineral horizon. Recycling of calcium by forests may also serve to hold the added calcium in the organic layer (Reid and Watmough 2013). Recent research on sugar maple stands in Quebec demonstrated that lime addition on the forest soil surface can take more than a decade to reach and influence mineral soils (Moore et al. 2012). Additionally, the response of organic soils to calcium additions may be affected by forest stand age. Older stands have higher calcium demands than younger stands, resulting in fewer of the hydrogen ions in soil being replaced by calcium (Reid and Watmough 2013). Additionally, young stands are able to mobilize more calcium than they can accumulate in biomass, resulting in higher concentrations of calcium in the soil exchangeable pool (Johnson et al. 1994). More calcium in the exchangeable pool could lead to sustained positive effects on foliar calcium concentration and tree growth (Reid and Watmough 2013).

Lime treatment produces a larger response in soil pH and foliar calcium concentration than wood ash, largely because the calcium content in lime compounds is higher than in the same mass of wood ash (Reid and Watmough 2013). Other treatment attributes that may affect response include method of application and calcium solubility. Higher liming rates produce a longer-lasting effect on soils than lower rates (Moore et al. 2012).

Initial soil pH, tree species (hardwood vs. softwood), and time since treatment all influence tree growth in response to soil amelioration with calcium. In the meta-analysis of calcium trials conducted by Reid and Watmough (2013), both hardwood and softwood stands exhibited the largest increase in growth on soils that were initially only moderately acidic (pH 4.5 - 6). The authors postulated that these sites may have been less limiting in terms of other nutrients (magnesium, potassium, nitrogen, phosphorus) than more acidic sites (pH <4.5). Calcium additions from liming or wood ash treatment can induce pronounced soil changes no matter the initial soil pH, but a growth response will not occur if other nutrients are also limiting. For example, Aronsson and Ekelund (2004) found that forest growth can be increased on wood ash-

ameliorated peatlands rich in nitrogen. However, no change or even decreased growth occurred on nutrient-poor mineral soils treated with wood ash.

Growth effects from calcium treatment of soils also varied by tree species and time since treatment in the trials analysed by Reid and Watmough (2013). Within the hardwoods, sugar maple growth increased in response to calcium addition, American beech showed no change in growth, and black cherry growth declined. Such species-specific variability reflects the complexities inherent in the requirements for tree growth (Reid and Watmough 2013). Tree growth also takes time, and 50% of the trials in the analysis measured growth less than 6 years after treatment. The paucity of long-term trials may explain the substantial number of studies that reported no growth effect (Reid and Watmough 2013). Additionally, environmental conditions such as rainfall or pollutants may influence tree growth and vitality during the trial period, affecting site condition and treatment effects (Van der Perre et al. 2012).

In their review of wood ash trials in boreal forest and aquatic ecosystems, Aronsson and Ekelund (2004) concluded that the effects of calcium treatment on ground vegetation, fungi, soil microbes, and soil-decomposing animals were not very clear. The discrepancies between different studies could be largely explained by abiotic factors such as variation in fertility among sites, different degrees of stabilization, and wood ash dosage used, and different time scales among different studies. Given uncertainties about the efficacy of wood ash application, and the potential for biotoxic effects on both terrestrial and aquatic ecosystems, the authors recommended site-specific application practices, rather than broad and general wood ash application to forests.

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Appendix G. State-of-Knowledge Summary for Liming of Lakes

Other than source control of emissions, the most effective mitigation strategy for managing acidic conditions in lakes, streams, or watersheds is liming (Olem 1990, Clair and Hindar 2005 – excerpts from these documents are included at the end of this appendix). Liming commonly results in significant positive physical, chemical, and biological changes in aquatic ecosystems. The pH, ANC, dissolved inorganic carbon, and calcium of surface waters generally increase with the addition of limestone. Concentrations of nutrients do not typically change, but liming increases nutrient cycling, decomposition, and primary productivity. Aluminum, iron, lead, manganese, and zinc – metals that may be toxic to aquatic biota – are sometimes lower in limed lakes due to precipitation, oxidation, surface adsorption, and ion exchange. Liming generally has positive impacts on fish, with successful reproduction and growth of resident and re-introduced species in many cases (Olem 1990). Despite its many benefits, liming may not restore the biota believed to be present prior to acidification, particularly if certain taxa have been eliminated due to a large reduction in lake pH for a considerable length of time. Liming cannot counteract the effects of acidic episodes from influent streams or from littoral zones. Other factors that distinguish limed lakes from their unacidified counterparts include the presence of precipitated metals, undissolved base material, elevated calcium levels, and the possibility of re-acidification between treatments (Olem 1990).

Studies completed since 1990 generally support the overall conclusions of Olem (1990) regarding the physical and chemical changes that occur following the liming of an acidic lake (e.g. see Clair and Hindar 2005). However, many post-1990 studies suggest that biological recovery in limed lakes is variable, and is not always as successful as reported by Olem (1990). While in many cases restocked fish populations were re-established (e.g., Sandøy and Romundstad 1995), unintended and undesired responses can include: instability of the fish community due to both chemical and biological factors (Appelberg et al. 1995, Nilssen and Wærvågen 2002); incomplete restoration of biota to the species mix present in unacidified lakes (Hultberg and Andersson 1982; Renberg and Hultberg 1992), though species diversity may be comparable (Appelberg et al. 1995, Hörnström et al. 1993); undesirably large expansions of macrophyte populations that take advantage of the more alkaline conditions (Roelofs et al. 1994). Recovery can be severely prolonged in strongly disturbed, chronically acidified ecosystems (Nilssen and Wærvågen 2002).

Emissions reduction at source is clearly a more permanent solution than liming, but it may not be the preferred solution if only a few lakes are affected, and source control involves other environmental impacts. Extensive liming efforts in Norway and Sweden have shown that systems that are treated before all fish species are lost, and before major dominance shifts occur within the macroinvertebrate community, recover the most quickly (Nilssen and Wærvågen 2002). For localized mitigation through liming, the most prudent approach for conserving fish populations and other biota in lakes considered to be valuable (and feasible for

liming) would be to maintain their pH at close to their current level (i.e., preventative liming). Localized mitigation would involve occasional, careful additions of precisely estimated amounts of limestone to the lake surface to maintain lake pH at its current level (i.e., if the lake pH falls 0.3 units below its 2012 level, then restore it back to its 2012 level). Laboratory tests of collected lake water should be used to empirically determine the appropriate dosage, and develop a titration curve for each lake. Models could be used to check these estimates. However, it should be considered that liming will likely need to be redone on an ongoing basis (every few years) if the source of acidification remains unchanged. All of the European studies with long-term results showed that the termination of liming programs resulted in rapid reacidification and the reversal to pre-liming conditions (Clair and Hindar 2005).

The best candidates for liming (Weigmann et al. 1993) have the following characteristics:

- Softwater lakes with pH < 6.5 (true for all 10 acid-sensitive lakes in the Rio Tinto Alcan region);
- Large pH fluctuations (not known for these lakes, but could be determined by placing a pH sonde);
- Retention time > 3 months (need to know mean depth[32] to estimate this accurately, but can get a rough estimate from 2012 sampling – see Table 25);
- Evidence of historical fish populations (have anecdotal and survey data on this point for some lakes in the valuation table, and will have more detailed data from 2013 sampling); and
- Slow fish growth and low food production (can infer this from fish densities in 2013 sampling).

The New York Department of Environmental Conservation (1990) used somewhat different criteria for deciding which lakes were appropriate for liming, focusing on lakes with a pH < 5.7 and a retention time **less than** 6 months.

Clair and Hindar (2005) further emphasize the importance of proponents and regulators following a clear process to minimize ecological damage and maximize the chance of meeting their objectives. To achieve these conditions, Clair and Hindar suggest the following issues be carefully considered (2005, p. 18, emphasis added):

1. First, there needs to be a **good rationale to justify attempting to modify an ecosystem**, and the parts of the ecosystem in need of protection need to be clearly identified.
2. There must be **clear understanding of the target species life cycle**.
3. The proponents must have **reasonable expectations of what is achievable** with the methods they will be using.

[32] From the sampling conducted in 2012, we know the depth of lakes at the sampling point, but not the mean depth which requires a bathymetry survey. The depth of the lake at the sampling point is a rough estimate of the mean depth, but is driven by the safest place for the helicopter to hover, so the mean depth could be ~50% lower or higher than the sampled depth.

4. The proponents must have a **good understanding of the time to recovery** of the system.

Given the small size of the lakes of interest in the KMP study area, application of a limestone slurry from a tank onboard a boat would be the most cost-effective approach for road-accessible lakes, which ensures both rapid dissolution and accurate delivery across the lake surface (Olem 1990, pg. 15-59). Delivery of limestone by helicopter or fixed wing aircraft would be the only option for lakes which are not accessible by road, and the pros and cons would need to be carefully evaluated (e.g., safety, lake's value, degree of pH control); these methods have had mixed success (Olem 1990, pg. 15-61 to 15-63).

Table 25. Estimate of water retention[a] time (or residence time) for the ten acid-sensitive lakes. All but two lakes (LAK012 and LAK054) have more than a 3-month residence time.

SITE_ID	Lake Area (ha)	Depth at sampling point (m)	Water-shed Area (ha)	Runoff (m)	Estimated Midrange Lake Volume (m_3)	Estimated Midrange Residence Time (yr)	Min Residence Time (yr)	Max Residence Time (yr)	> 3 month residence time?
LAK006	10.25	5.7	91.2	0.88	584,232	0.726	0.363	1.089	YES
LAK012	2.30	3.5	90.1	0.86	80,538	0.104	0.052	0.156	NO
LAK022	5.74	10.1	39.9	0.83	580,128	1.744	0.872	2.616	YES
LAK023	6.77	2.7	40.3	0.90	182,857	0.505	0.253	0.758	YES
LAK028	1.02	15.5	11.9	1.58	158,726	0.849	0.424	1.273	YES
LAK042	1.46	12.0	37.2	0.60	175,186	0.790	0.395	1.185	YES
LAK044	2.01	15.0	9.9	0.64	300,832	4.777	2.388	7.165	YES
LAK047	1.61	0.5	42.9	2.41	8,028	0.008	0.004	0.012	NO
LAK054	1.52	5.1	125.3	1.61	77,707	0.038	0.019	0.058	NO
LAK056	1.77	6.6	27.3	1.60	116,897	0.267	0.133	0.400	YES

[a] Retention time (yr) = Lake Volume (m^3) / Annual Outflow (m^3/yr). This can be estimated from:
Retention time (yr) = [Lake Area (m^2) * Mean Depth (m)] / [Watershed Area (m^2) * Annual Runoff (m/yr)].

Summary from Olem 1990:

> Acidic conditions in surface waters can be mitigated by adding alkaline materials to the lake, stream, or watershed or by less common methods. The primary objective is the maintenance of water quality suitable for the support of fish populations. The mitigation strategy most effective for mitigation of acidic conditions is the addition of limestone.
>
> Conventional whole lake liming is a more established mitigation alternative than liming running waters or watersheds. Lakes have been the receptors most widely treated, primarily because

they can be treated with a single application that may last several years. Limestone applications from boats or helicopters are generally the most effective techniques. Relatively few running waters have been treated to date[33]; permanent structures are generally required to provide continuous streamwater treatment. Treatment of the watershed to protect lakes and streams has been receiving increased interest in recent years. Watershed liming has been shown to last longer than surface water liming and may provide increased protection from episodic acidic conditions and leaching of trace metals. Little experience exists for watershed liming[34]; its use in the United States is experimental. Accurate methods are available for determining limestone doses required for treating lakes, streams, and watersheds, and for estimating lake reacidification rates.

The addition of base materials to surface waters commonly results in significant positive physical, chemical, and biological changes in aquatic ecosystems. Physical changes that normally occur in low humic waters after liming are decreased transparency and increased color and temperature. The pH, ANC, dissolved inorganic carbon, and calcium of surface waters generally increase after limestone addition. Concentrations of nutrients and organic matter do not significantly change after liming, but some studies have shown a response in limed lakes. Metals that may be toxic to aquatic organisms- particularly aluminum, iron, lead, manganese, and zinc- are sometimes lower in limed waters due to precipitation, oxidation, surface absorption, and ion exchange. Limestone addition often causes changes in lake sediments due primarily to the instantaneous adsorption of calcium.

Liming generally increases nutrient cycling, decomposition, and primary productivity and results in a positive response in aquatic biota. Liming often results in increased plankton biomass and considerable alteration in community structure of benthic macroinvertebrates. The effects of liming have been clearly favorable to fish populations. Liming has permitted the stocking of fish species previously lost form the system, introduction of new species, or the recovery of existing but stressed fish populations. Successful reproduction and growth of resident and reintroduced fish species have been developed in many limed surface waters. In a few isolated instances, liming has caused mortalities in resident fish populations due to metal toxicity, but the conditions causing the toxicity were not always clearly identified.

Restoration of water quality conditions to those believed to exist before acidification has not always resulted in restoration of the original biota. It may also be possible that liming cannot restore conditions exactly as they were before acidification. For example, whole-lake liming does not eliminate acidic episodes from influent streams or from littoral zones. Other factors also separate limes waters from their unacidified counterparts, including precipitated metals, undissolved base material, elevated calcium levels, and the possibility of reacidification between treatments.

[33] Significantly more experience and research on stream liming and watershed/catchment liming has accumulated since 1990 (e.g., see Clair and Hindar 2005 for a more recent review).

[34] See previous footnote.

Excerpts from Clair and Hindar (2005):

NOTE: the studies reviewed by Clair and Hindar (2005) concern freshwater systems with much more substantial levels of acidification than represented by pH thresholds identified in the present EEM. The predominant focus of research on liming has been highly acidified lakes in Europe and eastern North America, which have been exposed to heavy levels of deposition over decades. Consequently, compared to the context of the EEM, the pre-liming conditions of the lakes and streams described by Clair and Hindar (2005) represent systems with much higher levels of acidification, thus requiring more intensive liming treatments targeting greater changes in pH, and significant ecological degradation that has occurred over time. The possible application of liming within the EEM concerns a much smaller change in pH and a much more responsive timeframe for potential mitigation.

> Based on our analysis of the literature, we must come to the conclusion that with very few exceptions, the use of lime or dolomite on either catchments or water bodies is not deleterious to aquatic ecosystems either in the short or long term. The one exception to these conclusions is the liming of wetlands. (p. 116)
>
> Most of the studies we report on have been able to modify the chemistry of receiving waters to a desired state. Generally, the biological communities in rivers and lakes that have been limed tend to accumulate more acid-sensitive species, and have not shown any obvious further degradation in community composition or structure. However, returns to what may have been pre-acidification ecological conditions have been more elusive. An important reason for this is that the chemical changes brought about to streams, lakes, and catchments are usually temporary, as reacidification is bound to return ecosystems to their previous "damaged" state upon cessation of the liming effort. The reversion is immediate when liming streams and rivers, usually within a few years when liming lakes, and between 10 and 50 years when liming catchments. So the question that must be asked is whether liming is a worthwhile exercise in the long term. As we show that liming is not generally harmful to the environment, deciding whether or not to lime will involve a number of social, policy, and even philosophical considerations. (p. 116)
>
> The main shortcoming of liming programs is that ecosystems do not completely return to preacidification conditions for several reasons. First, unstable or inadequate chemistry conditions may occur when using unsuitable liming strategies. Secondly, species interactions and a lack of sources for sensitive species reintroduction will affect community composition. Generally, the papers quoted in this review show that targetted fish species usually, but not always, can be assisted in returning to viable numbers, as long as pH and ANC (and thus lower Ali) can be maintained over long periods of time and that restocking or protection against predators is done. More often than not, however, the rest of the ecosystem is never completely returned to pre-acidification conditions and the new communities may be relatively unstable and prone to large changes in composition. (p. 117)
>
> Ecosystem liming must be viewed as a tool to keep ecosystems or targetted fish populations from being irretrievably lost until nature can restore itself under less polluted conditions. It cannot be a substitute for pollution prevention, nor should it be used to create conditions that did not exist before the acidification problem existed. (p. 118)

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Appendix H. Design Considerations for Detecting Trends in Lake Chemistry

The BC Ministry of Environment has requested a detailed description of the statistical and inferential methods to be used to evaluate the EEM triggers in Table 14, using both the key performance indicator of pH and other informative indicators such as ANC. The methods described below build on previous acidification studies, but will be further adapted based on detailed studies on lake chemistry being conducted in 2014.

The EEM triggers in Table 14 (decrease in lake pH of 0.3 pH units) are meant to result in the earliest possible detection of biologically significant acidification that is related to KMP. The following points help to provide a context for the methods described below:

1. No acidification would show patterns like those in Figure 11 (i.e., increases in SO_4 deposition and lake SO_4, but no change in lake in ANC or pH).
2. Acidification strongly related to KMP would generate the patterns shown in Figure 12 (i.e., increases in emissions of SO_2, deposition of SO_4 and lake [SO_4]; and decreases in lake ANC and pH).
3. Acidification unrelated to KMP could show patterns like those in Figure 13 (decreases in pH and ANC, no change in SO_4), but increases in other anions, such as NO_3 (other pollution sources), Cl (acidification due to deposition of seasalt in watersheds with organic acids) and/or organic anions (watershed releases due to changes in climate).
4. Combinations of natural and anthropogenic processes could result in patterns intermediate between Figure 12 and Figure 13. For example, releases of stored sulphate from wetlands or marine clays might cause episodic acidification, but would not be expected to show a long term, continued acidification trend correlated with changes in sulphate deposition.
5. Acidification trends are best detected by examining multiple indicators (deposition of SO_4, lake [SO_4], lake ANC, and lake pH) across multiple lakes with similar characteristics (Stoddard et al. 1996, 2003). Examining water quality trends jointly for the acid-sensitive lakes with similar characteristics (to be evaluated as part of the statistical power analysis) will provide much higher statistical power to evaluate trends than examining each lake's trends independently. Six of the seven acid-sensitive lakes in the EEM Program have similar pH levels (4.98 to 5.92), ANC (-4 to 57 µeq/l) and percentages of organic anions (25 to 28%), as shown in Table 26. Lake 042 has a somewhat lower pH (4.68) and ANC (-20 µeq/l) due its higher percent of organic anions (81%). Fortunately, Stoddard et al. (1996) found that lakes with low ANC and low DOC, as well as lakes with low ANC and high DOC, have relatively low year to year variability in ANC and pH, and therefore have relatively good statistical power for detecting trends compared to other types of lakes with higher ANC (Figure 16).

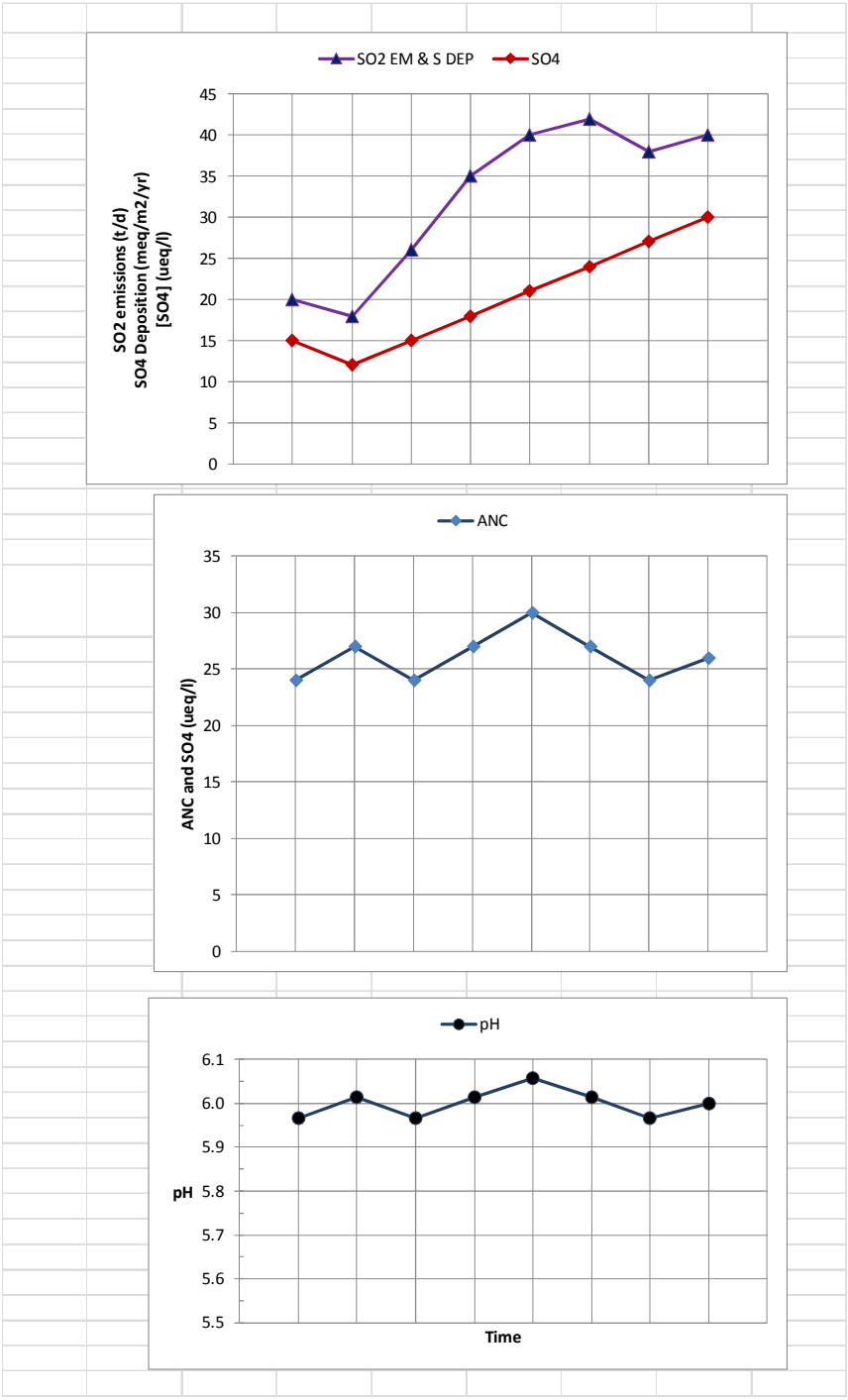


Figure 11. Patterns of changes in SO_4 deposition (top graph), lake [SO_4] and ANC (middle graph), and lake pH (bottom) indicating no acidification (i.e., lake [SO_4] increases, but sufficient weathering rates to neutralize deposited acids, so no change in ANC or pH).

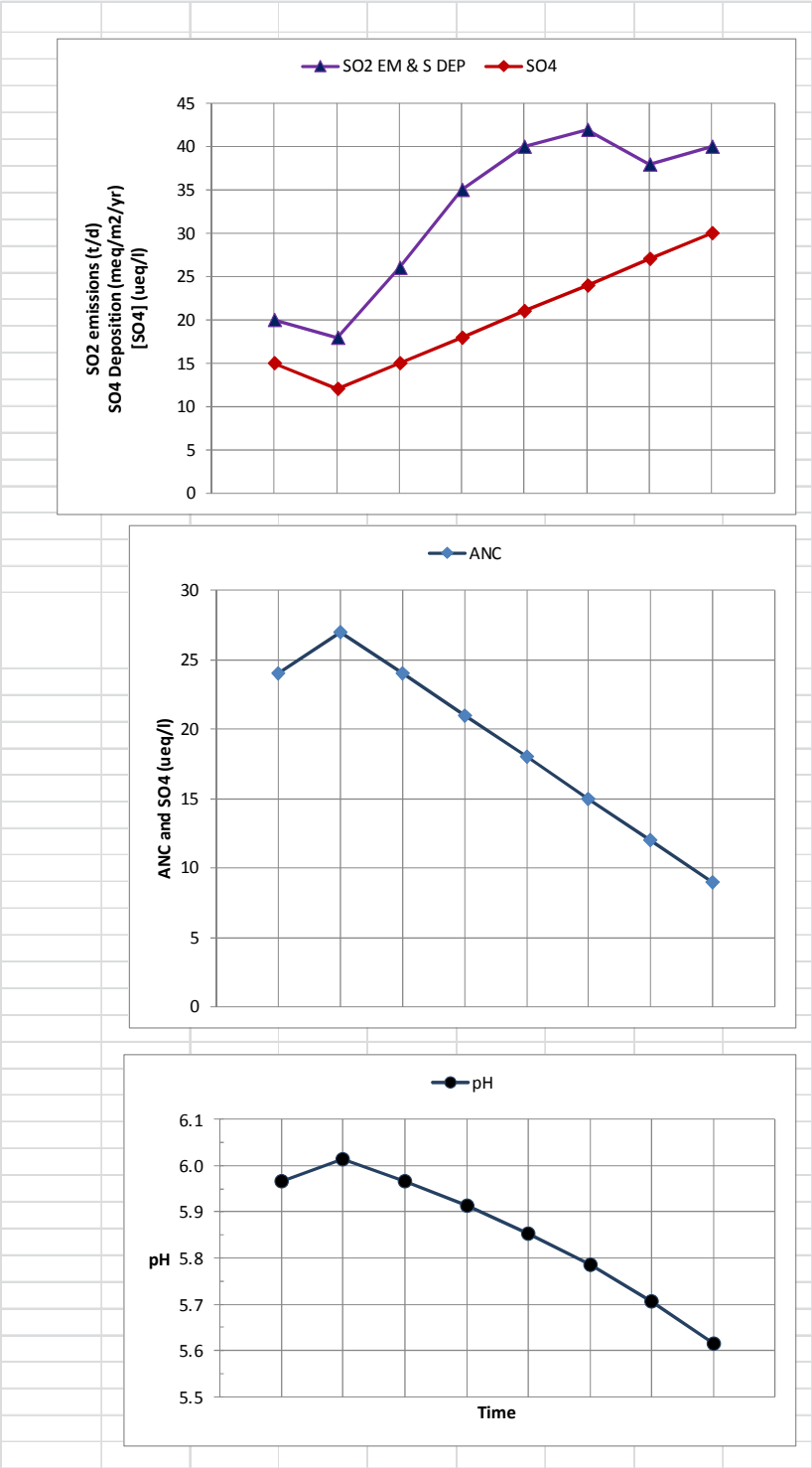


Figure 12. Patterns of changes in SO_2 emissions, SO_4 deposition and lake [SO_4] (top graph), ANC (middle graph), and lake pH (bottom graph) consistent with acidification due to KMP.

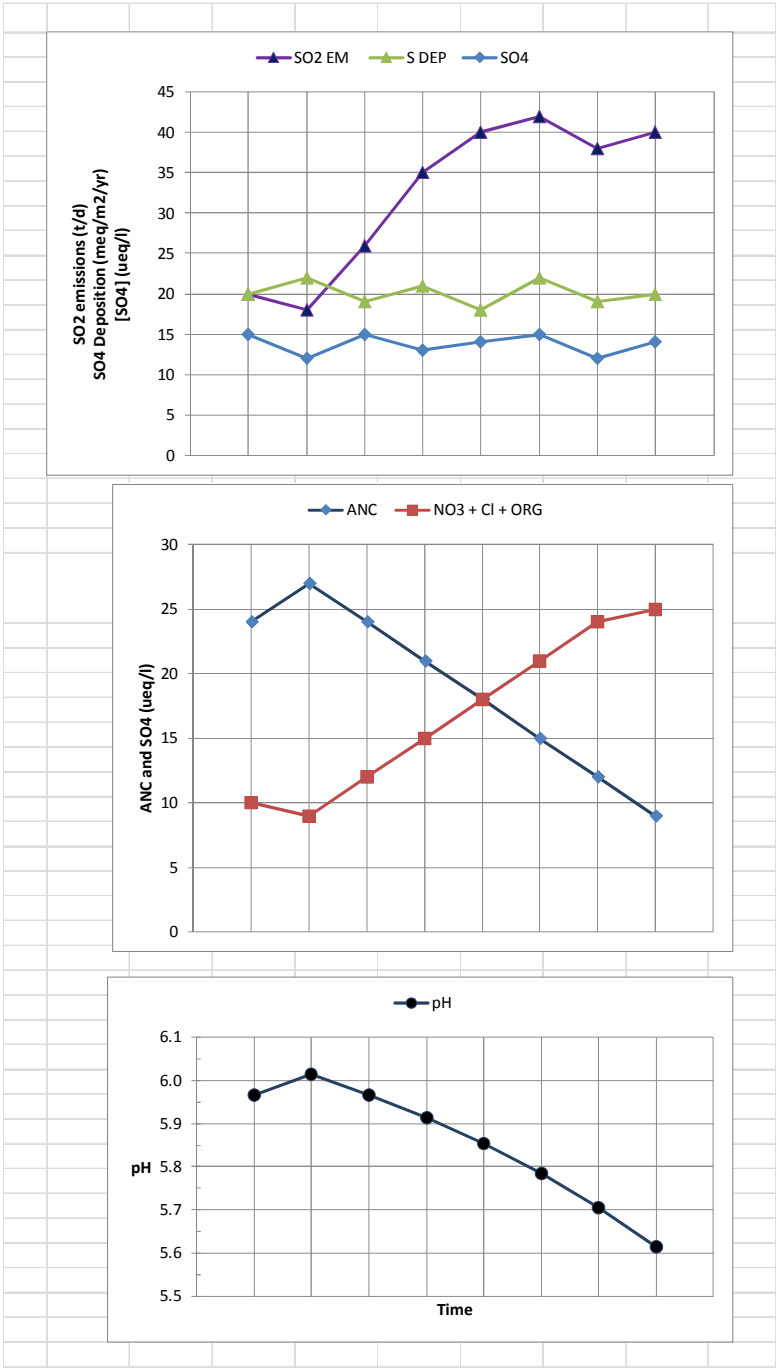


Figure 13. Patterns of changes in SO_2 emissions, SO_4 deposition and lake [SO_4] (top graph), ANC and other anions [NO3+CL+Organic], (middle graph); and lake pH (bottom graph) consistent with acidification due factors other than KMP (i.e., N emissions, sea salt acidification, and/or climate-driven releases of organic anions). This pattern might occur for high DOC lakes close to the sea but far from the smelter plume and therefore receiving low levels of S deposition.

Table 26. Characteristics of lakes included in the EEM Program. Chemical values shown are from sampling in August 2012. EEM Program will rely on fall sampling.

IDENTIFICATION		SITE ATTRIBUTES							ANION COMPOSITION					CRITICAL LOAD, DEPOSITION & EXCEEDANCE				pH (original, present, post-KMP)			
Lake/Stream ID	Name	Elevation	Lake Area	Watershed Area	Runoff	Acid Sensitivity Class (ASC) [1]	Fish Habitat [2]	Gran ANC	HCO_3	Cl	SO_4	ORG	F	Critical Load	SDEP [5] (pre-KMP)	SDEP [5] (post-KMP)	Exceedance	Estimated original pH	Measured current pH	Predicted future steady-state pH	Predicted Δ pH (2012 to future)
		m	ha	ha	m			µmeq/ L	%	%	%	%	%	meq/ m^2/yr	meq/ m^2/yr	meq/ m^2/yr	meq/ m^2/yr	pH_0	pH_t	pH_∞	
Acid Sensitive Lakes																					
LAK006	End L.	151	10.2	91	0.9	3	Yes - Obs.	25.7	34%	8%	17%	34%	6%	28.4	20.7	42.4	14.2	6.02	5.79	5.31	-0.48
LAK012	Little End L.	151	2.3	90	0.9	3	Yes - Obs.	57.0	61%	4%	6%	26%	4%	79.1	19.9	41.5	-37.4	5.74	5.64	5.51	-0.13
LAK022		162	5.7	40	0.8	3	Yes - Infer.	27.8	24%	7%	29%	35%	6%	53.9	19.5	41.5	-12.2	6.11	5.92	5.54	-0.39
LAK023	West L.	211	6.8	40	0.9	3	Yes - Obs.	19.8	25%	6%	25%	36%	7%	31.9	20.3	40.7	9.0	5.96	5.70	5.16	-0.54
LAK028		267	1.0	12	1.6	4	Unknown	-4.0	0%	5%	51%	25%	18%	46.1	63.7	96.8	51.2	5.77	4.98	4.60	-0.38
LAK042		171	1.5	37	0.6	1	Yes - Infer.	-20.4	0%	7%	8%	81%	4%	15.9	6.7	15.7	0.2	4.92	4.68	4.48	-0.20
LAK044	Finlay Lake	219	2.0	10	0.6	1	No - Obs.	1.3	9%	19%	24%	38%	10%	0.0	7.0	16.6	16.7	5.80	5.40	4.86	-0.55
Control Lakes																					
LAK007	Clearwater Ls.	152	2.6	367	1.0	3	Yes - Obs.	1437.6	95%	2%	3%	0%	0%	1390.0	16.8	35.9	-1353.7	7.98	7.98	7.98	0.00
LAK016		247	2.6	41	0.9	3	Unknown	68.7	53%	4%	23%	15%	5%	115.5	21.9	44.3	-70.9	6.37	6.31	6.24	-0.07
LAK034		292	8.6	73	0.7	3	Yes - Infer.	99.4	69%	3%	11%	15%	3%	125.1	8.0	18.8	-105.9	6.76	6.74	6.71	-0.03
Special Study Streams																					
STR002	Anderson Cr. d/s	146		3741	2.1	3	Yes - Obs.	94.2	57%	2%	37%	3%	1%	330.6	21.4	25.5	-301.9	6.91	6.91	6.91	0.00
STR009	Kitimat R. d/s	112		157136	1.6	3	Yes - Obs.	160.6	80%	4%	13%	2%	0%	299.3	13.9	23.6	-273.4	6.98	6.98	6.98	0.00

Table 27 shows examples of pH, ANC and SO_4 thresholds that will be determined for each of the 7 acid-sensitive lakes in the EEM Program, based on a lake specific titration curve derived from the Gran ANC calculations. The titration curve is the relationship between pH and ANC, and its shape is affected by the amount and character of dissolved organic acids in a lake (ESSA et al. 2013 (pgs. 238-239, 304), Hemond 1990, Marmorek et al. 1996).

Table 27. Illustration of pH, ANC and SO_4 thresholds which would be established for each of the 7 acid-sensitive lakes in the EEM Program, based on lake specific titration curves. Exceeding SO_4 thresholds is not a concern as long as the pH and ANC thresholds are not exceeded. The calculation of the Baseline value is discussed in Section 6.2.2.

Hypothetical Lake	pH			ANC			SO_4		
	Base-line	Threshold		Base-line	Threshold		Base-line	Threshold	
	value	Value	Δ	value	Value	Δ	value	Value	Δ
A	6.0	5.7	0.3	26	11.8	-14.2	30.2	44.4	14.2
B	5.5	5.2	0.3	5.8	-1.1	-6.9	6.2	13.1	6.9
C	5.0	4.7	0.3	-5.8	-15.6	-9.8	56.9	66.7	9.8
D	4.5	4.2	0.3	-26	-53.2	-27.2	9.0	36.2	27.2

Determining whether or not an individual lake's fall pH measurement has decreased by 0.3 units (Table 14 trigger for increased monitoring) involves comparing baseline estimates of the pre-KMP pH with post KMP pH measurements. Combining all of the data for the seven acid-sensitive lakes will increase the sample size 7-fold for detecting overall trends in pH, ANC and SO_4.

Comparisons of lake pH values will be affected by variability in pH both between years (due to annual variation in climate) and within the fall sampling period (due to variability in lake productivity, mixing and weather). Ultimately there are two potential types of errors:

1. *False negative:* not detecting a real pH decrease of 0.3 units that has occurred, could affect aquatic biota, and is due to KMP (an environmental risk); and
2. *False positive:* detecting a pH change of 0.3 units which is actually due to natural fluctuations and falsely attributing it to KMP, leading to unnecessary expenditures on monitoring and/or mitigation (an economic risk).

The EEM Program will use five strategies to reduce the risks of these errors:

1. examine long term data sets from other regions of North America to assess within-year and between-year variability in lake chemistry;
2. obtain estimates of the natural variability in pH, ANC, SO_4 and other ions from 3 of the acid-sensitive lakes (End Lake (lake 006), Little End Lake (lake 012), and West Lake (lake 023))[35];
3. use inferences from steps 1 and 2 to conduct statistical power analyses of the ability to detect changes in pH, ANC and SO_4 over different time frames, using either fall index samples or more frequent sampling, building on the work of Stoddard et al. (1996), excerpted in Figure 16;
4. use data from all 7 acid-sensitive EEM lakes jointly to increase statistical power;
5. examine patterns of change in lake chemistry across gradients of SO_4 deposition and sensitivity within the 11 sampled lakes (7 acid-sensitive and 4 insensitive lakes); and
6. use multiple lines of evidence to assess whether or not acidification is occurring (i.e., lake pH, ANC, SO_4, NO_3, DOC, S and N deposition), as discussed above.

Step 1 has been partially completed and provides some useful insights. Further work is planned in 2014. The 7 acid-sensitive lakes in the EEM Program all have pH values less than 6 (pH ranges from 4.7 to 5.92). Figure 14 shows that within year variability in pH in Ontario lakes was much less for lakes with a mean pH<6, than for lakes with a mean pH>6. These results reflect two factors: 1) pH is on a log scale, so a given change in hydrogen ion concentration results in a smaller pH change below pH 6 than above pH 6; and 2) lakes with pH < 6 are generally less productive than lakes with pH > 6 and therefore have less within-year variability in pH. Figure

[35] Continuous pH monitors (calibrated and cross-checked against a field pH meter every two weeks) will record pH every 30 minutes from September 2014 to August 2015 except during winter months when ice cover prevents access. Full chemistry samples will be obtained four times during October 2014 to assess natural variability during the index period, and monthly during other months except for the winter period.

14 provides encouragement that a year on year change of > 0.3 pH units will generally be greater than within year variability in pH for the EEM lakes, and therefore more feasible to detect. Furthermore, variability within the fall index period is likely to be less than variability within the entire year.

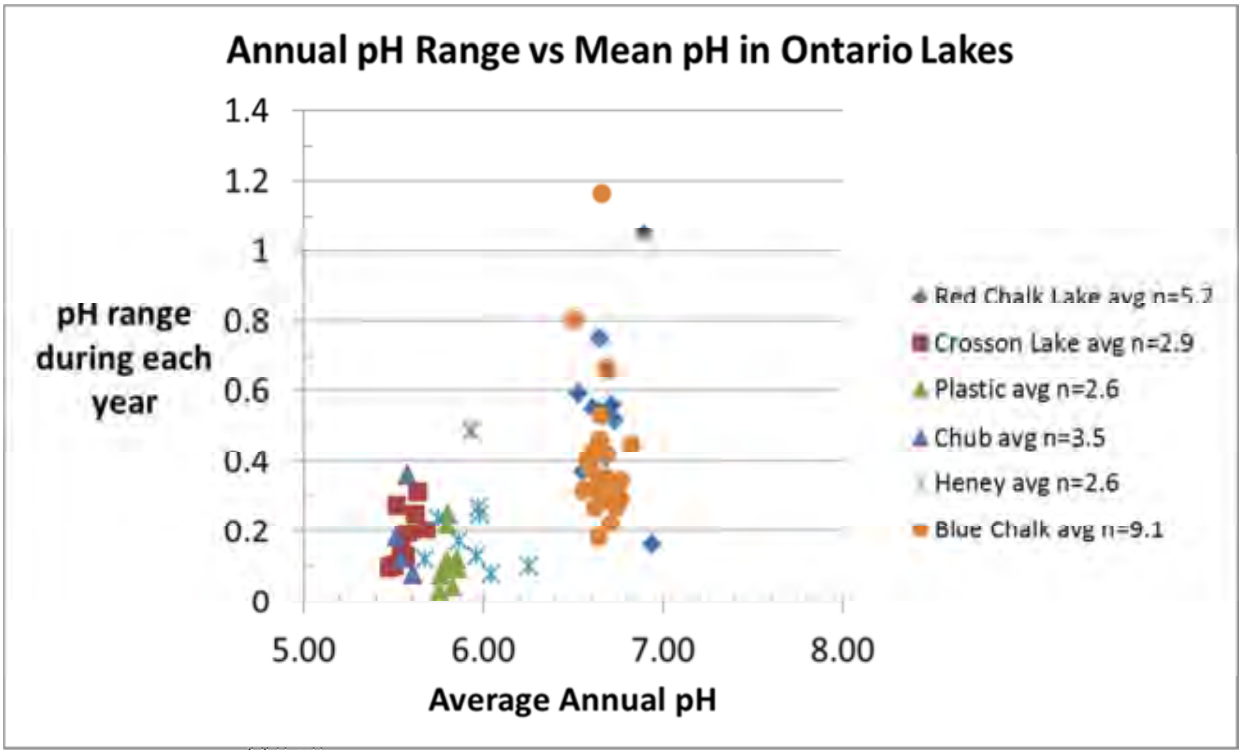


Figure 14. Within year range of pH (maximum pH – minimum pH) versus mean annual pH, for 63 lake-years of data from Ontario lakes. For lakes with an annual mean pH < 6, the pH range was less than 0.3 pH units for 27 out of the 31 lake years of data. Source of data: Dr. Norman Yan (York University) and Andrew Paterson (Ontario Ministry of Environment).

Figure 15 is from 32 years of monitoring data for Blue Chalk Lake in Ontario, which over the period from 1976 to 2007 had an average pH between 6.4 and 6.8, and a slightly increasing trend. Since the mean pH of Blue Chalk Lake was greater than 6, it had more variability in pH than Ontario lakes with a mean pH < 6 (Figure 14) and more variability than we would expect to observe in the 7 EEM lakes, which all had a pH < 6 in August 2012. Figure 15 shows that October pH samples in Blue Chalk Lake generally tracked the overall trend in pH over this period, and showed less variability than the complete data set. Similar analyses of variability in long term monitoring data led the US EPA to select the fall index period for lake sampling in the National Surface Water Survey (Landers et al. 1987), and the subsequent Environmental Monitoring and Assessment Program (Stoddard et al. 1996).

The work by Stoddard et al. (1996) on behalf of the US EPA is very relevant to the KMP EEM Program. Stoddard et al found that annual sampling of 5 low ANC-low DOC lakes (top curve of top graph in Figure 16) could detect an annual ANC trend of 0.5 µeq L^{-1} yr^{-1} at high statistical power (0.8) after 10 years, or a total change in ANC of 5 µeq L^{-1} after 10 years. Though Stoddard et al. do not present curves for other effect sizes, it should take less time to reliably detect larger ANC changes. As shown in the example of Table 27, the KMP EEM Program needs to detect ANC changes in the range from 7 to 27 µeq L^{-1}, which are larger than the decadal changes of 5 µeq L^{-1} assessed by Stoddard et al. These results suggest that it should be feasible to reliably detect the desired ANC changes in less than a decade for the complete set of EEM lakes, but this preliminary observation needs to be confirmed in the statistical power analyses to be conducted based on data gathered in 2014.

Trends in SO_4 (bottom graph in Figure 16) can be reliably detected sooner than trends in ANC (top graph in Figure 16), as SO4 is less variable than ANC. Stoddard et al. found that it would take only 5 years to detect an annual trend in SO4 of 1.2 µeq L^{-1} yr^{-1}, or 12 µeq L^{-1}per decade (at the low end of the range in Table 27); smaller changes in SO_4 would be detectable with high statistical power after a decade of monitoring.

The data for all 7 acid-sensitive lakes could also be analyzed using an approach like that in Figure 17. This would provide an estimate of the proportion of the complete sample of all acid-sensitive lakes which show pH changes beyond the specified threshold. A similar approach could be applied to ANC and SO_4. As shown in Figure 16, the 7 acid-sensitive lakes should provide a sufficient sample size for the population of interest.

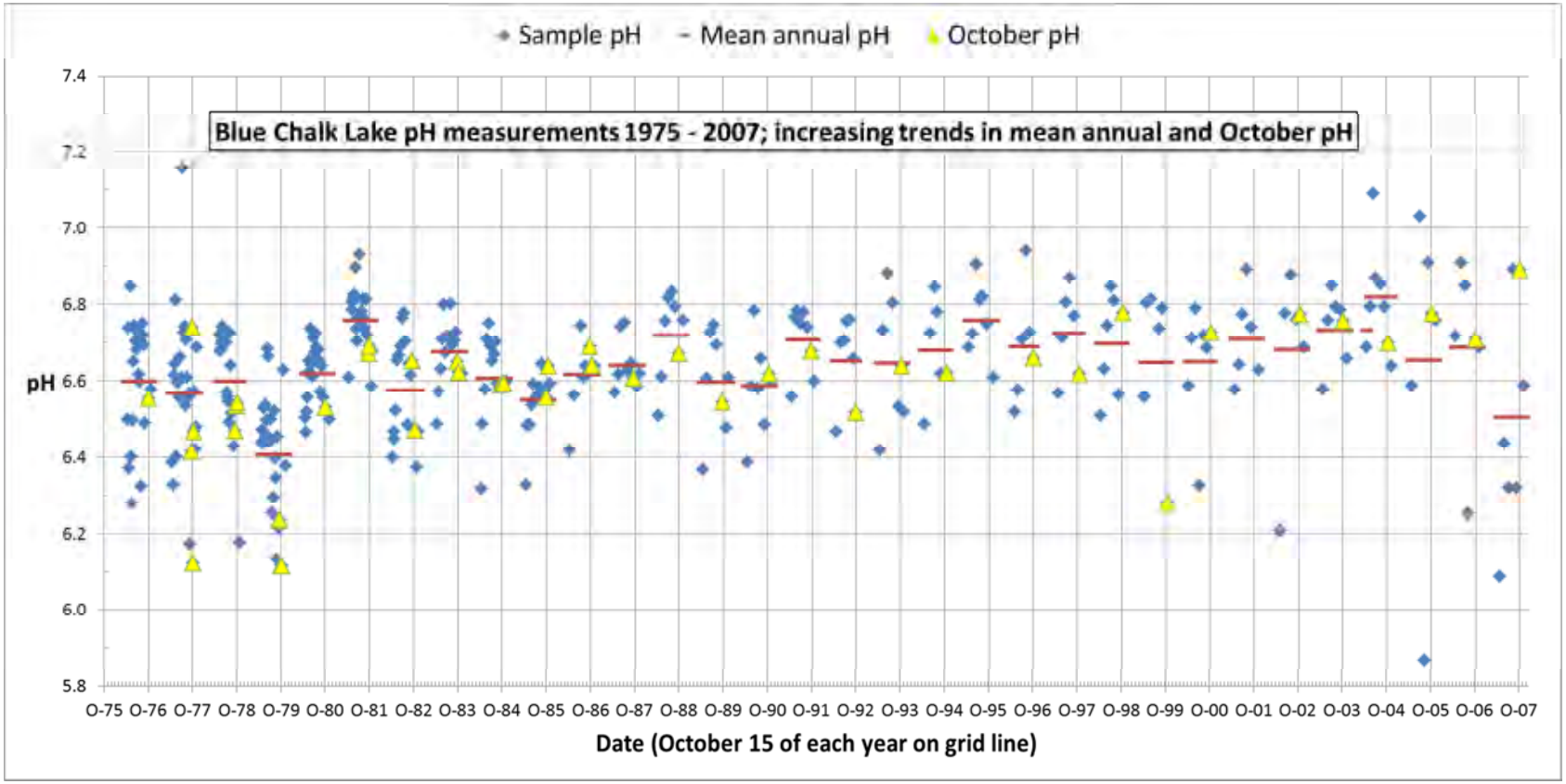


Figure 15. Long term trends in pH in Blue Chalk Lake in Ontario. All sampled pH values are shown by the blue diamonds. October pH samples (coinciding with the vertical grid lines) are shown by the yellow triangles. The mean pH for each year is shown by the red bars for each year.

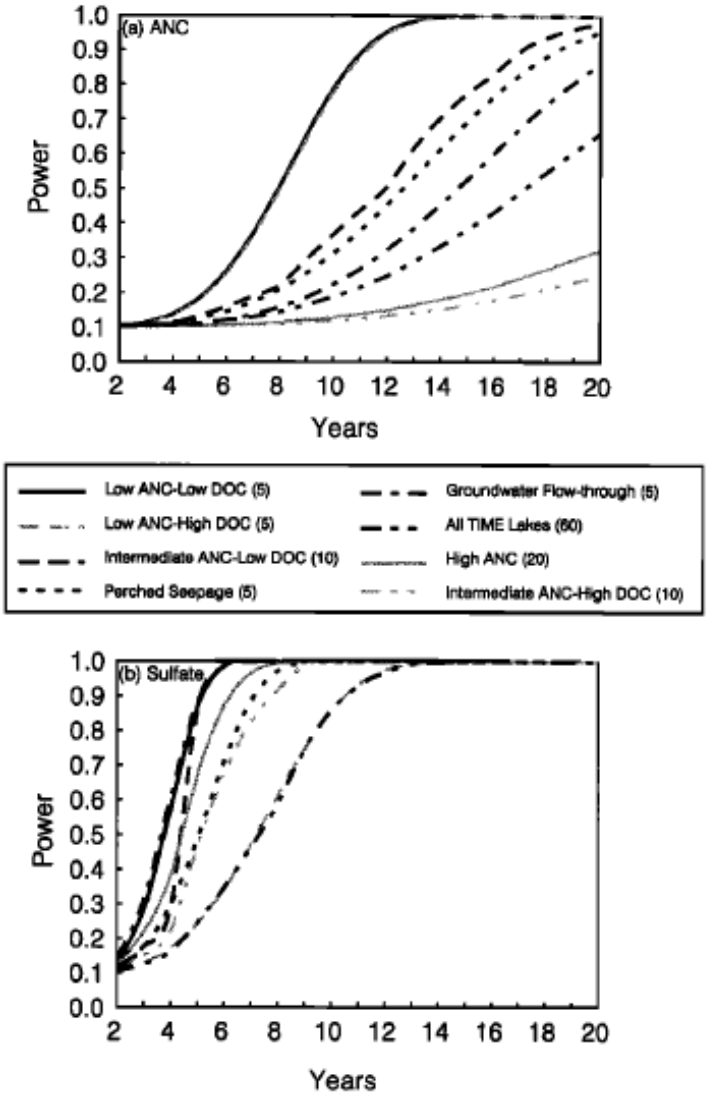


Figure 4. Results of power calculations for seven TIME subpopulations and all TIME lakes for trends in (a) ANC ($\Delta = 0.5$ μeq L^{-1} yr^{-1}) and (b) SO_4^{2-} ($\Delta = 1.2$ μeq L^{-1} yr^{-1}). In both plots, $\alpha = 0.10$. For ease of interpretation, lake subpopulations are listed in the legend in decreasing order of power for ANC trends (power curves for the low-ANC/low-DOC and low-ANC/high-DOC subpopulations are nearly coincident and plot together). Numbers in parentheses in legend are the annual sample sizes used in the calculations for each subpopulation.

Figure 16. Statistical power analyses for detecting changes in lake ANC and SO. Source: Figure 4 in Stoddard et al. (1996).

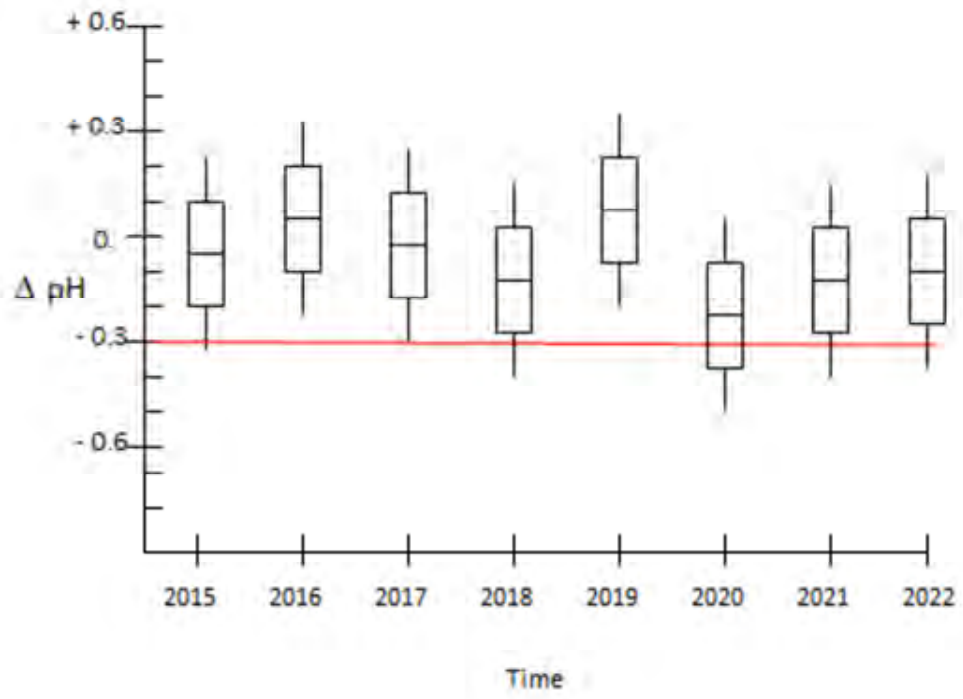


Figure 17. Illustration of hypothetical regional trends in the distribution of pH changes across the set of 7 EEM lakes.

A similar graph could be generated for other parameters (ANC, SO, base cations). From 2015 onwards, the pH measurements from each of the seven acid-sensitive lakes would be compared to the mean pH for each lake from the baseline period (discussed in Section 6.2.2). The box represents the distribution of the middle 50% of such comparisons of pH change (i.e., 25th to 75th percentiles), and the tails represent the 10th to 90th percentiles. These data could be used to determine the proportions of pH changes in any one year (across all lakes) that are less than -0.3. Water quality data from multiple lakes (pH, ANC, SO, base cations) could also be analyzed using a linear mixed-effects model having lakes and years as class variables (equation 1 in Stoddard et al. 1996).

References:

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, B.C. 450 pp.

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Stoddard, J.L., J.S. Kahl, F.A. Deviney, D.R. DeWalle, C.T. Driscoll, A.T. Herlihy, J.H. Kellogg, P.S. Murdoch, J.R. Webb, and K.E. Webster. 2003. Response of Surface Water Chemistry to the Clean Air Act Amendments of 1990. EPA 620/R-03/001. US Environmental Protection Agency, Office of Research and Development. National Health and Environmental Effects Research Laboratory, Research Triangle Park, NC 27711. 92 pp.

Appendix I. Liming Treatment to Mitigate Acidic Effects on an EEM Study Lake: Conceptual Design of Pilot Study

Context

If the KPIs for lakes, streams and aquatic biota exceed the threshold for receptor-based mitigation, the prescribed action is:

> "Pilot liming to bring the lake back up to pre-KMP pH, subject to approval by BC MOE/DFO prior to implementation"

In the case that an exceedance of the KPI has been observed, measured and concluded to be real (i.e., not a false positive), the following section provides an outline of the approach for designing a pilot study for liming.

Objectives

Objectives of the Liming Treatment

1. Restore lake pH to its pre-acidification chemical condition without causing adverse ecological impacts

Objectives of the Pilot Study

2. Determine the optimum method of liming.
3. Determine the chemical effects of the liming treatment on the target lake
4. Determine the biological effects of the liming treatment on the target lake

Hypothesis

The pilot study will be designed to be able to evaluate whether the evidence supports or fails to support the following hypothesis:

> *Liming treatment will restore lake chemistry (i.e., pH and ANC) without causing adverse effects to biological functioning of the lake ecosystem.*

Candidate Lakes for Limestone Treatment

The lake or lakes being considered as candidates for limestone treatment will be those that have exceeded the KPI thresholds for receptor-based mitigation, as per the design of the EEM. *There will be **two lakes at most** under consideration* for limestone treatment because any more than two lakes would trigger the requirement for facility-based mitigation.

Suitability Criteria

The best candidates for liming (Weigmann et al. 1993) have the following characteristics:

- Softwater lakes with pH < 6.5;
- Large pH fluctuations;
- Retention time > 3 months;
- Evidence of historical fish populations; and
- Slow fish growth and low food production.

Additionally, the candidate lake needs to be safely accessible, both for treatment and monitoring purposes. Ideally, it will be easily accessible to facilitate repeated monitoring visits before and after treatment.

Methods

Initial analyses

A number of analyses will need to be conducted before implementing a pilot liming treatment.

1. The candidate lake(s) must be assessed in terms of its suitability for treatment.
2. A benefit-cost analysis of liming treatment options will be needed to inform the design of the pilot study (e.g., accessibility will influence the treatment methods, such as surface or aerial application, and the cost of repeated monitoring).
3. The amount of limestone to be applied in the treatment in order to achieve the target increase in pH will be calculated (i.e., based on the physical properties of the lake and the lake-specific titration curve).
4. A conservative, incremental approach will be designed for the application limestone to ensure the pH target is not exceeded.
5. The full experimental design of the pilot study will be finalized, with additional review by:
    a. Limestone treatment expert – to ensure the treatment has the highest probability of being successful; and,
    b. Statistical design expert – to ensure the study has ability to correctly detect changes in lake chemistry and biology (e.g., power analyses).

Pre-liming sampling to establish chemical and biological baseline

Baseline sampling must be conducted prior to application of the limestone to be able determine the impacts of the liming treatment on lake chemistry and biology.

Water chemistry: The pre-liming baseline for water chemistry conditions will be established by the annual EEM fall index sample. This sample includes full chemistry (pH, ANC, base cations, anions, Al and other metals, as described for annual monitoring in the EEM.

Lake biology: The pre-liming baseline for lake biological conditions will be established by sampling phytoplankton, zooplankton, and fish communities to estimate biomass, density and diversity. Establishing a robust baseline for phytoplankton and zooplankton will require six monthly samples from May to October, obtained from near the middle of the lake in the pelagic zone. Additional baseline monitoring could include estimating zooplankton productivity and/or sampling macrophyte biomass, coverage and diversity; however, further evaluation is required to assess their utility for achieving the objectives of the pilot study.

Buffer compound

Calcite (agricultural limestone) is the most commonly used liming compound (Clair and Hindar 2005). It is relatively inexpensive, widely available, natural, non-toxic and easy to work with (Weigmann et al. 1992). Dolomite limestone is chemically similar, with slightly higher buffering capacity but lower solubility, but an acceptable alternative when calcite is not readily available (Weigmann et al. 1992). Numerous other liming compounds exist but most have only been used experimentally or are difficult to work with (Clair and Hindar 2005).

Application of liming treatment

Given the small size of the lakes of interest in the KMP study area, application of a limestone slurry from a tank onboard a boat would be the most cost-effective approach for road-accessible lakes, which ensures both rapid dissolution and accurate delivery across the lake surface (Olem 1990, pg. 15-59). Delivery of limestone by helicopter or fixed wing aircraft would be the only option for lakes which are not accessible by road, and the pros and cons would need to be carefully evaluated (e.g., safety, lake's value, degree of pH control); these methods have had mixed success (Olem 1990, pg. 15-61 to 15-63).

Post-liming chemical and biological monitoring

After the application of the limestone treatment, monitoring of water chemistry and lake biology would occur annually for three years, following the same approach as described above for pre-liming monitoring (i.e., fall index sampling for chemistry, six monthly samples for biology). At that point, the chemical and biological effectiveness of the program would be evaluated, and decisions made regarding future monitoring.

Analyses of pre- and post-liming monitoring data

Pre- and post-liming monitoring data would be compared and analyzed in order to determine the impacts of the limestone treatment on lake chemistry and biological conditions and assess the statistical and biological significance of those impacts.

Documentation and reporting

Documentation of the study design for the pilot limestone treatment, preliminary analyses, treatment implementation, monitoring results, and subsequent analyses would be reported within the annual EEM reporting framework.

1.2 Terms of Reference for the Comprehensive Review

This report has been inserted in its original format on the subsequent pages.

Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project

Detailed Terms of Reference for the 2019 Comprehensive Review

May 31, 2019

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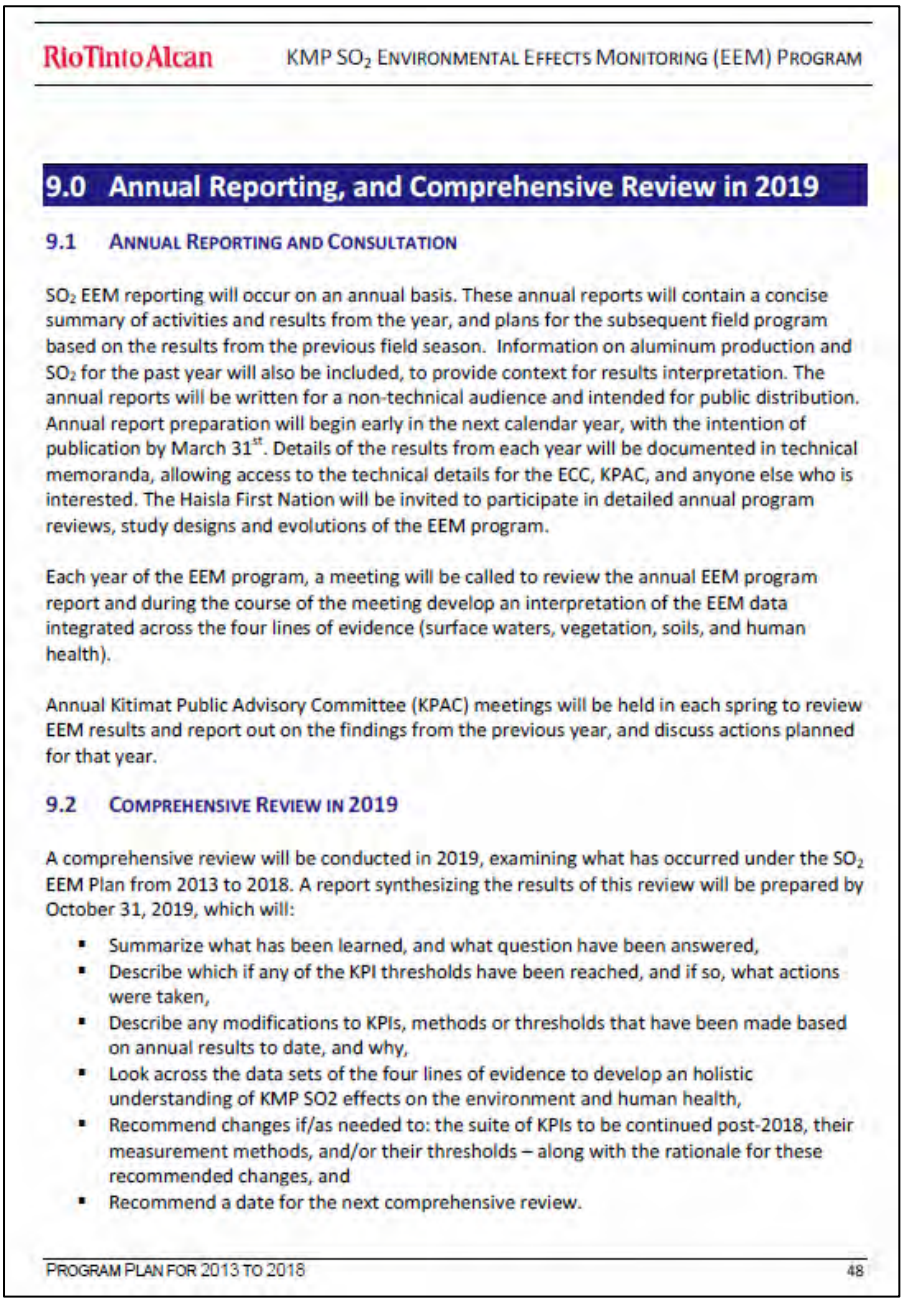
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The Terms of Reference (TOR) consist of three items:

1. **Section 9.2 of the EEM Program Plan for 2013-2018**
2. **Draft outline for the Comprehensive Review Report**
3. **Draft schedule for Comprehensive Review tasks**

TOR Item 1: EEM Program Plan for 2013-2019, Section 9.2



RioTinto Alcan KMP SO_2 Environmental Effects Monitoring (EEM) Program

9.0 Annual Reporting, and Comprehensive Review in 2019

9.1 Annual Reporting and Consultation

SO_2 EEM reporting will occur on an annual basis. These annual reports will contain a concise summary of activities and results from the year, and plans for the subsequent field program based on the results from the previous field season. Information on aluminum production and SO_2 for the past year will also be included, to provide context for results interpretation. The annual reports will be written for a non-technical audience and intended for public distribution. Annual report preparation will begin early in the next calendar year, with the intention of publication by March 31st. Details of the results from each year will be documented in technical memoranda, allowing access to the technical details for the ECC, KPAC, and anyone else who is interested. The Haisla First Nation will be invited to participate in detailed annual program reviews, study designs and evolutions of the EEM program.

Each year of the EEM program, a meeting will be called to review the annual EEM program report and during the course of the meeting develop an interpretation of the EEM data integrated across the four lines of evidence (surface waters, vegetation, soils, and human health).

Annual Kitimat Public Advisory Committee (KPAC) meetings will be held in each spring to review EEM results and report out on the findings from the previous year, and discuss actions planned for that year.

9.2 Comprehensive Review in 2019

A comprehensive review will be conducted in 2019, examining what has occurred under the SO_2 EEM Plan from 2013 to 2018. A report synthesizing the results of this review will be prepared by October 31, 2019, which will:

- Summarize what has been learned, and what question have been answered,
- Describe which if any of the KPI thresholds have been reached, and if so, what actions were taken,
- Describe any modifications to KPIs, methods or thresholds that have been made based on annual results to date, and why,
- Look across the data sets of the four lines of evidence to develop an holistic understanding of KMP SO2 effects on the environment and human health,
- Recommend changes if/as needed to: the suite of KPIs to be continued post-2018, their measurement methods, and/or their thresholds – along with the rationale for these recommended changes, and
- Recommend a date for the next comprehensive review.

PROGRAM PLAN FOR 2013 TO 2018 48

TOR Item 2: Outline for the Comprehensive Review Report

Executive Summary and KPI Report Cards

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Glossary

Abbreviations

ANC	Acid neutralizing capacity
BACI	Before-after-control-impact
BCS	Base cation surplus
CBANC	charge balance ANC
CCME	Canadian Council of the Ministers of the Environment
CL	Critical load
CR	SO_2 EEM 2019 Comprehensive Review
DFO	Canadian Department of Fisheries and Oceans
DOC	Dissolved organic carbon
ECCC	Environment and Climate Change Canada
ENV	BC Ministry of Environment and Climate Change Strategy
KAEEA	Kitimat Airshed Emissions Effects Assessment
KMP	Kitimat Modernization Project
KPI	Key performance indicator
MDD	Minimum detectable difference
NADP	National Atmospheric Deposition Program
PCA	Principle components analysis
QA/QC	Quality assurance / quality control
QPs	Qualified professionals (for the SO_2 EEM Program)
$RCOO^-_s$	Strongly acidic organic anions
SO_2 EEM	Rio Tinto BC Works' SO_2 Environmental Effects Monitoring Program
SSMB	Steady State Mass Balance (model)
STAR	SO_2 Technical Assessment Report
TOR	terms of reference for the SO_2 EEM 2019 Comprehensive Review

1 Introduction

1.1 Background

List the objectives of the report (from EEM Plan, Section 9.2):

- Summarize what has been learned, and what question have been answered.
- Describe which if any of the KPI thresholds have been reached, and if so, what actions were taken.
- Describe any modifications to KPIs, methods or thresholds that have been made based on annual results to date, and why.
- Look across the data sets of the four lines of evidence to develop an holistic understanding of KMP SO_2 effects on the environment and human health.
- Recommend changes if/as needed to: the suite of KPIs to be continued post-2018, their measurement methods, and/or their thresholds – along with the rationale for these recommended changes.
- Recommend a date for the next comprehensive review.

1.2 Facility Production and Emissions from 2013 to 2018

- Present production and emissions data from 2013-2018.
- Discuss SO_2 emission rate variability and what information is available.

1.3 Organization of this Report

2 Evaluation of KPIs against Thresholds, Informative Indicators, & Synthesis of Results

To be written after Section 3 is completed.

- Summarize results and learning across pathways and receptors:
  - Results and recommendations (example template shown in Table 1 below)
  - What has been learned and what questions have been answered (example template shown in Table 2 below)

Table 1. Summary of results pertaining to KPIs or informative indicators.

	Atmospheric Pathways	Human Health	Vegetation	Terrestrial Ecosystems (Soils)	Lakes, Streams & Aquatic Ecosystems
Were any KPI thresholds reached? If so, what was the response?					
Were any KPIs modified? Are any					

	Atmospheric Pathways	Human Health	Vegetation	Terrestrial Ecosystems (Soils)	Lakes, Streams & Aquatic Ecosystems
modifications recommended to either KPIs or informative indicators that support KPIs?					
Were there any modifications to methods used for KPIs and informative indicators? Are any modifications recommended to methods of monitoring or modelling KPIs or informative indicators?					

Table 2. Summary of what questions have been answered thus far under the EEM Program, and whether any questions remain to be answered or new questions have emerged.

	Atmospheric Pathways	Human Health	Vegetation	Terrestrial Ecosystems (Soils)	Lakes, Streams & Aquatic Ecosystems
EEM Questions that have been answered					
Questions still to be answered					
New questions that emerged					

- This will be a summary table showing which questions from Table 19 of the EEM Plan have been answered, and which are still in process. The questions will be stated here, but not the hypotheses.
- A table of questions and hypotheses will be in the back of this report. The wording of those from the original STAR/EEM Program questions/hypotheses may appear slightly modified in this report, as needed based on how things evolved during the EEM Program development, and subsequently during the first 6 years. If the wording of the questions and hypothesis in this report is not an exact match to those in the STAR we will explain why.

3 Review Results for Atmospheric Pathways

3.1 Atmospheric Concentrations

3.1.1 What did we set out to learn?

- Explain that we set out to learn if any KPI thresholds were reached.
- Briefly explain the questions and hypotheses from the STAR.
  - A1. Does CALPUFF accurately represent post-KMP SO_2 air concentrations?
  - D1. Does the CALPUFF model accurately predict post-KMP total sulphur deposition?
  - D2. What are the base cation deposition values in the study region?

3.1.1.1 EEM Informative Indicators

- Informative Indicator: Atmospheric SO_2 concentrations
- Informative Indicator: Atmospheric S deposition
- Informative Indicator: Atmospheric base cation deposition
- Contribution of particulate sulphate to dry S deposition
- Contribution of dry deposition to total deposition

3.1.2 What methods did we use?

- Describe all of the inputs and methods used in the analyses for this review.
- Provide an overview and put details in an appendix.

3.1.2.1 Data we collected: modeling

- Describe the collection of data inputs for CALPUFF.

3.1.2.2 Planned analyses: modeling

- Model actual SO_2 emissions for 2016-2018 post-KMP using CALPUFF (including CALMET data for 2016- 2018), actual emissions, and methods similar to SO_2 Technical Assessment Report (STAR) methods (as detailed in the May 2019 model plan). Compare with monitored SO_2 data for the same period. Refine CALPUFF methods if there is insufficient alignment between modeled and monitored SO_2 concentrations (method described in EEM Program Plan, page 7). This subtask includes evaluating hourly SO_2 concentrations at the Haul Road, Riverlodge, Whitesail and Kitamaat Village continuous monitoring station locations, for 2016-2018. [This subtask must be done early in the Review process as the results are required inputs for some of the receptor analyses.] We will also model 35 and 42 tpd.[1]
- Compare monitoring with modelling (quantitative and qualitative):
  a) Compare continuous analyzer monitoring results to CALPUFF model output from the STAR and to output from the 2018 CALPUFF for 2016-2018.

[1] We considered running a separate 30 tpd scenario, but 2016-2018 actuals will serve as the ~30 tpd future steady state case because the average of the 2016-2018 emissions is 29.3 tpd (27.8 tpd, 29.5 tpd, and 30.6 tpd in 2016, 2017, and 2018 respectively).

b) Compare the spatial gradient of SO_2 concentrations from the passive monitoring program to output from the CALPUFF model to 2016-2018.
c) Compare wet deposition monitoring results (S) for 2016-2018 to CALPUFF model output from the STAR and to output from CALPUFF for 2016-2018.
d) Compare dry and total deposition of S to estimates (using the Big Leaf model and observations) for 2016-2018 to CALPUFF model output from both STAR and output from CALPUFF for 2016-2018.

3.1.2.3 Data we collected: monitoring

- Describe the continuous monitoring network; site locations and sampling frequency.
- Describe the SO_2 passive sampler network; site locations and sampling frequency.
- Describe additional monitoring under the multi-seasonal study.
    - Include statistical analysis that accounts for wind direction.
- Describe the monitoring of particulates using filter packs.

3.1.2.4 Planned analyses: monitoring

- Report on progress of multi-seasonal study on seasonality aspects of Kitimat's air quality to determine the seasonal and spatial variability of SO_2 concentrations in the residential areas of Kitimat; Terms of Reference to be finalized with ENV.
- Report on the optimization of the air quality monitoring network and summarize optimization effort and associated conclusions to-date.
    - Discuss why zoning maps were used instead of census data.
    - Comment on whether commercial areas are sufficiently represented.
    - Identify what planning documents were used as information sources.
    - Summarize the 2016 Air Quality Workshop, results, and public feedback.
- Evaluate sulphur dioxide (SO_2) passive sampler results for 2015–2018.
    a) Calibrate passive samplers against active (continuous) stations (compare average monthly SO_2 concentrations estimated from passive monitors with observations from 4 continuous monitors during the period from 2015 to 2018; note: during 2015 data are only available for passive sampler trial). The calibration / evaluation will be carried out station-by-station.
    b) Assess if a peak-to-mean ratio can be established for the SO_2 passive samplers.
    c) Evaluate temporal variation in SO_2 passive samplers in the Kitimat Valley (2016 to 2018).
    d) Evaluate spatial variation in SO_2 passive samplers in the Kitimat Valley (spatio-temporal plots).
    e) Develop framework for synthesizing SO_2 results from 2016-2018; the objective will be to develop an approach for spatial and temporal scaling.
- Evaluate particulate sulphate (pSO_4^{2-}) filter pack results for 2017–2018.
    a) Evaluate performance of filter packs, i.e., comparison of filter pack SO_2 to continuous station SO_2 (for all co-exposures).
    b) Evaluate the SO_2 to pSO_4^{2-} ratio, and its relationship to SO_2 concentration.
    c) Develop a framework for synthesizing pSO_4^{2-} results; the objective will be to develop an approach for spatial and temporal scaling.

3.1.3 What did we learn, and did we make any adjustments to the EEM Program?

- Provide an overview of the results, referencing past Tech Memos, and put details in an appendix.
- Summarize what has been learned overall from these results thus far under the first 6 years of the EEM Program.
- Describe adjustments that have been made to modelling and monitoring methods based on what was learned.
- Explain whether question A1 from the EEM Plan has been answered, and whether new material questions have emerged.
- Are the spatial SO_2 dispersion patterns predicted in STAR within residential areas and the Service Centre of Kitimat in agreement with post-KMP measurements (from continuous analyzers and possibly passive samplers)?
- Are changes needed to the SO_2 monitoring network (answered through network optimization efforts, status reported in Section 3.12.4)?
- Identify incomplete actions from sections 2.2.1, 2.2.2, 2.2.3 and 2.3.3 of the EEM Plan.
- Explain what changes if any have been already made to this informative indicator.

3.1.4 What do we recommend for the EEM Program going forward?

- Recommended changes to monitoring methods, frequency or extent
  - Evaluate whether available data to the south of the smelter are sufficient for receptor impact analysis needs.
- Recommended changes to modelling methods
- Recommended changes to the informative indicators

3.2 Atmospheric Deposition

3.2.1 What did we set out to learn?

- Briefly explain the questions and hypotheses from the STAR.

3.2.2 What methods did we use?

- Describe all of the inputs and methods used in the analyses for this review.
- Provide an overview and put details in an appendix.

3.2.2.1 Data we collected: Wet deposition

- Describe the collection of rainfall chemistry by the NADP stations.

3.2.2.2 Analyses we conducted with these data: Wet deposition

- Evaluate wet deposition results for Haul Road (2012–2018) and Lakelse Lake (2013–2018).
  a) Examine ion balance (quality control) of precipitation chemistry; other QA/QC procedures will be applied to evaluate the quality of the data (in general the methods will follow accepted approaches used under the Convention on Long-Range Transboundary Air Pollution).
  b) Evaluate rainfall amount (compared with ECCC meteorological stations).
  c) Evaluate seasonality in precipitation chemistry and deposition.
  d) Evaluate temporal change in precipitation chemistry and deposition.

e) Evaluate relationship between station chemistry.
f) Compare Haul Road and Lakelse Lake to the NADP station at Prince Rupert (and potentially further afield).
g) Produce temporal maps of sulphate deposition (month by week plots) for Haul Road and Lakelse Lake.
h) Assess base cation precipitation chemistry (inputs to revision of regional critical loads).

3.2.2.3 Data we collected: Dry deposition

- Describe the collection of data for modelling of dry deposition.

3.2.2.4 Analyses we conducted with these data: Dry deposition

- Evaluate the Big Leaf dry deposition model.
  a) Describe data requirements for the Big Leaf model.
  b) Describe data sources (2015 to 2018; 4 years) for application of the model to Kitimat and Terrace Airport.
  c) Evaluate model sensitivity to cloud cover and approach for the estimation of solar irradiance.
  d) Evaluate the use of temperature and wind speed from Haul Road versus Whitesail on deposition velocity for SO_2 in Kitimat.
  e) Compare dry deposition velocity for SO_2 and pSO_4^{2-} in Kitimat and Terrace (may use temporal maps [day by hour] to visual changes in dry deposition velocity).
- Evaluate dry deposition of SO_2 (passive samplers) and pSO_4^{2-} (filter pack).
  a) Summarise hourly deposition velocity for SO_2 (and pSO_4^{2-}) into monthly exposure periods, i.e., summaries that correspond to the exposure periods for passive samplers.
  b) Estimate dry deposition for monitoring periods and assess relative importance of particulate deposition. Note: particulate concentration at each passive sampling location will be estimated from the filter pack relationship.

3.2.2.5 Analyses we conducted with these data: Total deposition

a) Evaluate total S deposition at Haul Road and Lakelse Lake for passive sampler monitoring periods, i.e., wet SO_4^{2-}, dry SO_2 and dry pSO_4^{2-}.
b) Extrapolate seasonal total deposition to annual estimates.

3.2.3 What did we learn, and did we make any adjustments to the EEM Program?

- Provide an overview of the results, referencing past EEM reports and Technical Memos, and put details in an appendix.
- Summarize what has been learned overall from these results under the first 6 years of the EEM Program.
- Identify incomplete actions from sections 2.2.1, 2.2.2 and 2.2.3 of the EEM.
- Explain whether questions D1 and D2 from the EEM Plan have been answered, and whether new questions have emerged.
- Explain what changes if any have been already made to the informative indicators.

3.2.3.1 Knowledge gained

- Reliability of passive samplers

- Spatial and temporal variation of SO_2
- Relative importance of particulate sulphate
- Spatial and temporal variation of total sulphur deposition
- Contribution of dry to total deposition
- Evaluation of modelled and observed atmospheric sulphur data

3.2.4 What do we recommend for the EEM Program going forward?

- Recommended changes to monitoring methods, frequency or extent
  - Passive sampler network: Valley and Kitimat
  - Continuous network (station locations)
- Recommended changes to modelling methods
- Recommended changes to the informative indicators

4 Review Results for Human Health

4.1 What Did We Set Out to Learn?

- Explain that we set out to learn if any KPI thresholds were reached or exceeded.
- Briefly explain the questions and hypotheses from the STAR.
- Review the rightmost column of Table 10.3-1 in Volume 2 of the STAR.

4.2 What Methods Did We Use?

- Describe all of the inputs and methods used in the analyses for this review.
- Provide an overview and put details in an appendix.

4.2.1.1 Planned analyses:

- Evaluate KPI results for 2017-2018. Describe evolution of this KPI over time (past and future, BC IAAQO and CCME values).
  - Conduct assessment of acceptable or unacceptable impacts to the receptor (was the threshold for facility-based mitigation exceeded?).

4.3 What Did We Learn, and Did We Make Any Adjustments to the EEM Program?

- Provide an overview of the results, referencing past EEM reports and Technical Memos, and put details in an appendix.
- Summarize what has been learned overall from these results re human health thus far under the first 6 years of the EEM Program.
- Explain whether questions HH1 and HH2 have been answered, and whether new questions have emerged.
- Explain whether a KPI threshold been reached, and if so, what actions were taken, or need to be taken.
- Explain what changes if any have been already made to the health KPI (the KPI itself, methods, or thresholds).
  - Convey that the threshold will become 65 ppb after 2025.
- Discuss the shift away from the informative indicator in the EEM Plan, and why.

4.4 What Do We Recommend for the EEM Program Going Forward?

- Recommended changes to monitoring methods, frequency or extent
- Recommended changes to the KPI
- Recommended responses to exceedances of thresholds

5 Review Results for Vegetation

5.1 What Did We Set Out to Learn?

- Explain that we set out to learn the answers to the vegetation questions in Table 19 of the EEM Program Plan, and their underlying hypotheses.
    - V1. Validation of the dispersion model – are we looking in the right place?
    - V2. How healthy is vegetation in sites with predicted exceedance of critical loads of soil and/or lakes and streams south of Lakelse Lake?
    - V3. Are plants of public importance showing symptoms in areas with highest exceedances of soil critical loads?
    - V4. Do plants at Kitimat that have unknown sensitivity to SO_2 and associated pollutants (acidic deposition) fall within the range of variation in the literature?

5.1.1 EEM Key Performance Indicator

- Was the Key Performance Indicator exceeded?
- Is the Key Performance Indicator appropriate? Evaluate within the context of the answers to questions V1-V4 (see Section 5.1)

5.1.2 EEM Informative Indicator

- Was the Informative Indicator exceeded?
- Is the Informative Indicator appropriate? Evaluate within the context of the answers to questions V1-V4 (see Section 5.1).

5.1.3 Other questions that have emerged since the development of the EEM

- Are there more sensitive indicators, such as growth rates of forest trees or lichen richness, of potential impacts on vegetation?
- Is the sampling array appropriate given current emissions and predictions of deposition?
- Is the sampling array representative of ecotypes in the area, including ecosystems at risk and plant species at risk in the area?
- What quantifiable metrics can be used to evaluate vegetation health in areas of predicted critical load (CL) exceedance?

5.2 What Methods Did We Use?

5.2.1 Data we collected

- CALPUFF simulations for actual deposition and emission scenarios of interest
- Updated scientific literature on the response of vegetation to SO_2
- Observations of vegetation condition, health, and visible injury
- Concentrations of sulphur in western hemlock foliage

5.2.2 Analyses we conducted with these data

- Evaluate the post-KMP CALPUFF results (for actual emissions and additional scenarios) both to answer question V1 in the STAR, but also to assess the extent of potential S deposition that might affect sensitive vegetative receptors, including ecosystems at risk and plant species at risk (as determined using Provincial conservation data and including lichens). Determine the areas of high deposition in relation to the reported occurrence of plants and ecosystems at risk. Revisit the STAR dose-response and threshold analysis to determine if it has changed based on the updated CALPUFF modeling results or recent results published in peer-reviewed scientific literature since STAR.
- Evaluate the results of visible injury inspections and S analysis in western hemlock post-KMP and compare them to those in the pre-KMP SO_2-Vegetation baseline of 1998-2011.
- Evaluate the results of post-KMP S concentrations in western hemlock and compare them to periods of low emissions, including 2015.
- Evaluate visual vegetation inspection results for 2014-2018.

5.2.2.1 Planned analyses:

- Analyze the extent of any insect infestations or disease epidemics to observation results.
- Evaluate the results of chemical analysis of western hemlock foliage post-KMP (2016-2018) and compare S (and F to provide context) to pre-KMP baseline (1998-2011) and to 2015, the year of very low emissions.
    - Conduct assessment of acceptable or unacceptable impacts to the receptor (was the threshold for facility-based mitigation exceeded?)
    - If needed, apply the weight-of-evidence approach for assessing causality (described in Section 7 of the EEM Program Plan).
- Conduct a spatial analysis to relate results to 2019 CALPUFF modeling (actual and scenarios); include a map overlaying 2019 CALPUFF model results for Vegetation.
- Using historical data and post KMP S and F concentrations in western hemlock foliage, assess the value of each vegetation sampling site with regard to understanding deposition.
- Integrate the results of vegetation monitoring—inspection and sampling—with results of soils monitoring to assure coverage of sensitive soils or critical load exceedances.
- Compare presence in 2014-2015 with presence in 2016-2018 of species reported to be sensitive to SO_2 selected by ENV.
- Evaluate the state of knowledge of plant ecotypes in the study area.
- Evaluate the suitability of the KPI and Informative Indicator to assess impacts to vegetation and ecosystems. Incorporate published peer-reviewed scientific literature since STAR in the analysis.
    - Explore alternative KPIs as suggested by peer-reviewed scientific literature, including the use of lichens as indicators.

5.3 What Did We Learn, and Did We Make Any Adjustments to the EEM Program?

5.3.1 Knowledge gained

- An updated synthesis of scientific literature on the effects of SO_2 and soil/air acidification on vegetation, including lichens
- Updated thresholds of concern for vegetation, including lichens
- Relationship of S (and F for context) concentrations in western hemlock to measured and modeled deposition of S, including measures of wet and dry deposition as appropriate based on monitoring data from near vegetation sites
- Comparison of pre- and post-KMP S (and F for context) concentrations in western hemlock needles, including measures of variability
- A synthesis of results of vegetation inspections (including any biotic stressors) pre- and post-KMP
- An analysis of whether the location of sampling and inspection sites is appropriate given changes in monitored and modeled deposition patterns post-KMP

5.3.2 Modifications to the EEM Program

- Identify potential changes to the KPI and Informative Indicator depending on the results of the analyses.
- Make recommendations for other potential KPIs or Informative Indicators that are more integrative of air monitoring, soil measures, critical loads, and vegetation results.
- Describe potential development of measures to support the inspection and sampling program-for instance, periodic measurement and assessment of permanent forest plots including Canadian Forest Service NFI plots.

5.3.3 Comprehensive synthesis ('pulling the pieces together')

- Relate vegetation results-observations of plant health and results of chemical analyses-to soils, aquatics, and critical load results.
    - Provide spatial overlays of vegetation sites with sensitive soils, and SO_2 isopleths to visually show the relationships
- Use CALPUFF results and results from soil, aquatics, and critical load analyses to adjust the location of vegetation inspection and sampling sites if necessary.

5.3.4 Conclusions

- Are the current KPI and Informative Indicator sensitive and useful for assessment of the risk to health of vegetation and ecosystems from KMP emissions? If not, are changes in the levels necessary, or are there more appropriate indicators.
    - Discuss uncertainties in the ability of the KPI and Informative Indicator to detect an early effect / worsening condition signal on vegetation.
- What changes have occurred post-KMP with regard to risk to vegetation and ecosystem health, including species and ecosystems at risk?
- How does the vegetation inspection and sampling program integrate with and support other components of the EEM?
- What are the conclusions with regard to questions V1-V4 from the EEM Plan?

5.4 What Do We Recommend for the EEM Program Going Forward?

- Recommendations regarding the Key Performance Indicator
- Recommendations regarding the Informative Indicator
- Recommendations for the inspection and sampling program

6 Review Results for Terrestrial Ecosystems (Soils)

6.1 What Did We Set Out to Learn?

- Explain that we set out to learn if any KPI thresholds were reached.
- Briefly explain the questions and hypotheses from the STAR.
- Review the rightmost column of Table 10.3-1 in Volume 2 of the STAR.
    - S1. Are estimates of average weathering rates by bedrock type valid for vulnerable areas (e.g., where lakes have low base cations)?
    - S2. What is the current buffering capacity (base cation pool) of the soils in exceeded areas?
    - S3. What is the rate of soil acidification measured as loss of base cations (or increase in protons) owing to acidic deposition?
    - What is the minimum detectable change in soil base cation pools?
    - What is the time-to-depletion for base cation pools in the long-term soil plots under current (modelled) deposition of sulphur?

6.1.1 EEM Key Performance Indicators

- KPI: Atmospheric S deposition and critical load (CL) exceedance risk
- KPI: Long-term soil acidification (rate of change of base cation pool) attributable to S deposition

6.1.2 EEM Informative Indicators

- Informative Indicator: Soil base cation weathering rates
- Informative Indicator: Magnitude of exchangeable cation pools (Ca, Mg, K, Na)
- Informative Indicator: Time to depletion of exchangeable cation pools (Ca, Mg, K, Na)

6.2 What Methods Did We Use?

- Describe all of the inputs and methods used in the analyses for this review.
- Provide an overview and put details in an appendix.

6.2.1 Data we collected

- Regional soil samples (sampling and analysis)
- Establishment of long-term soil plots
- Sampling and analysis of long-term soil plots (2015 and 2018)
    - Explain the protocol/rationale for not sampling the Kemano plot (and secondary plots).
    - Explore the idea of sampling plots more frequently at first and less frequently later and convey the conclusion/recommendation.

6.2.2 Analyses we conducted: critical loads

- Re-calculate critical loads across the study domain using the SSMB model with updated methodology and additional soil and updated deposition data. See Technical Memo S01 (March 2015) for overview:
  a) Physico-chemical properties in the Kitimat Valley: Describe results from STAR soils and EEM soil sampling (oxide content, organic matter, coarse fragment, particle size, etc.); describe data distributions, descriptive statistics, relationships between parameters, change in soil properties with depth
  b) Application of the A2M solver to estimate soil mineralogy; A2M requires soil oxide content
  c) Modelling of soil base cation weathering rate using the PROFILE model. The model requires mineralogy (estimated using A2M and soil observations from the regional soil samples)
  d) Collation of continuous data layers (maps) for the Study domain; climate, soils, geology, land cover, etc.
  e) Application of regression-kriging to map soil properties (such as organic matter, texture, bulk density, etc.) across the Kitimat Valley
  f) Spatial mapping of soil weathering rate across the Kitimat Valley using regression kriging and spatial maps of soil properties (approach removes dependency on bedrock geology)
  g) Evaluation of appropriate critical chemical indicators, i.e., selection of Bc:Al ratio by vegetation type (requires that vegetation types can be identified from existing spatial databases)
  h) Regional mapping of base cation deposition (using observations from the NADP stations)
  i) Re-calculate CL using SSMB with updated soil weathering maps, base cation deposition, background sulphur deposition (domain boundary inputs are not included in CALPUFF), and revised Bc:Al [Note: the assessment will include wetlands as applied under the Prince Rupert Airshed Study]
  j) Estimate exceedance of the study area using CALPUFF results from Atmospheric Pathways (the current deposition (2016–2018), 35 and 42[2] tonnes per day CALPUFF predictions)
  k) Sensitivity analysis: determination of exceedance of critical load under multiple chemical criteria to assess the influence of the chosen criterion on predicted exceedance (following approach used under the KAEEA)
  l) Exceedance will be evaluated for the entire study area and effects domain (the area under the 7.5 kg SO_4^{2-}-$ha^{-1}yr^{-1}$ deposition plume from 42 tonnes per day CALPUFF predictions).
  m) If exceedance is expected in some areas, analyze sampled soils for exchangeable base cations to estimate time to effects (based on estimated depletion of the base cation pool).

[2] We considered running a separate 30 tpd scenario, but 2016-2018 actuals will serve as the ~30 tpd future steady state case because the average of the 2016-2018 emissions is 29.3 tpd (27.8 tpd, 29.5 tpd, and 30.6 tpd in 2016, 2017, and 2018 respectively).

6.2.3 Analyses we conducted: long-term soil plots

- Evaluate results of the long-term plots during from 2015 and 2018.
  a) Define conceptual basis for long-term soil monitoring plot.
  b) Discuss long-term soil monitoring plot design, location and sampling (Coho Flats, Lakelse and Kemano).
  c) Describe biomass (tree species only) and evaluate spatial (horizontal and vertical) variability in soil properties at Coho Flats, Lakelse Lake and Kemano (pH, organic matter and bulk density). Evaluate the use of geostatistical approaches to describe (quantify and visualise) variability.
  d) Evaluate spatial variability of soil exchangeable cations including calcium (horizontal and vertical) at Coho Flats and Lakelse Lake. Evaluate the use of geostatistical approaches to describe variability.
  e) Evaluate relationship between soil variables.
  f) Determine exchangeable pools (including calcium) and base saturation; evaluate spatial variability at Coho Flats and Lakelse Lake. Evaluate the use of geostatistical approaches to describe variability.
  g) Determine time to effects, to depletion of base cation pools under 2016 to 2018 deposition (and scenarios based on 35 and 42 tonnes per day CALPUFF predictions).
  h) Evaluate temporal variability in soil exchangeable pools (including calcium), base saturation, pH and organic matter at Coho Flats and Lakelse Lake (2015 and 2018).
  i) Evaluate statistical power for detecting change in exchangeable base cation pools (using minimum detectable distance or power analysis).
- Evaluate results of the long-term plots during from 2015 and 2018, and the schedule of future sampling (e.g., assessment of resample period).

6.2.4 Assessment of acceptable or unacceptable impacts to terrestrial receptor

- The assessment of the impacts to the terrestrial ecosystems as “acceptable” or “unacceptable” is directly linked to the KPI (exceedance of critical loads, and change in exchangeable base cation pools). The weight of evidence approach for assessing whether the critical load exceedance is casually related to KMP will be summarised. .
  - If the KPI thresholds associated with facility-based mitigation in the EEM is exceeded, this will be identified as an “unacceptable” impact to the terrestrial receptor.
  - Impacts to terrestrial ecosystems that do not exceed the KPI threshold associated with facility-mitigation in the EEM will be identified as “acceptable”
  - NOTE: all impacts, regardless of classification will be explored, analyzed, interpreted and documented in detail.
- If needed, apply the weight-of-evidence approach for assessing causality (described in Section 7 of the EEM Program Plan).

6.3 What Did We Learn, and Did We Make Any Adjustments to the EEM Program?

- Provide rationale for the KPI's and the Informative indicators.
- Provide an overview of the results, referencing past EEM reports and Tech Memos, and put details in an appendix.
- Discuss what has been learned overall regarding KMP effects on soils thus far under the first 6 years of the EEM Program.
- Explain whether questions S1, S2 and S3 have been answered, and whether any new questions have emerged.
- Explain whether a KPI threshold been reached, and if so, what actions were taken, or need to be taken.
- Explain what changes if any have been already made to the soils KPIs (the KPI itself, methods, or thresholds) or the informative indicators.

6.3.1 Knowledge gained

- Spatial information (mapping) of soil properties
- Critical loads and exceedances for terrestrial ecosystems
- Spatial patterns in soil chemistry
- Ability to detect changes in soil chemistry
- Identification of major knowledge gaps that add uncertainty in results

6.3.2 Comprehensive synthesis ('pulling all the pieces together')

- Summary of observed changes in soil chemistry
- Exceedances of critical loads
- Link changes in base saturation, base cation pools, exceedance of critical loads in the context of potential effects to sensitive receptors, lakes, and vegetation.

6.3.3 Conclusions

- Has KMP contributed to the Acidification of terrestrial ecosystems?
- Summary of uncertainties from the STAR and EEM
- Assessment of acceptable or unacceptable impacts on Terrestrial receptor

6.4 What Do We Recommend for the EEM Program Going Forward?

- Recommended changes to monitoring methods, frequency or extent
- Recommended changes to the KPIs or informative indicators
- Recommended changes to thresholds
- Recommended responses to exceedances of thresholds

7 Review Results for Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)

7.1 What Did We Set Out to Learn?

- Briefly explain the questions and hypotheses from the STAR, noting that the questions and hypotheses are further refined later in this outline.
- Review the rightmost column of Table 10.3-1 in Volume 2 of the STAR.
- QUESTIONS from STAR & EEM:
  - W1. How do assumptions in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post- KMP?
  - W2. How many of the 7 to 10 potentially vulnerable lakes actually acidify under KMP, and to what extent?
    - [W2a.] Have any of the sensitive lakes exceeded their KPI thresholds?
    - [W2b.] Does the weight of evidence suggest that any of the lakes have actually acidified and that such acidification is due to KMP (examining changes in all relevant water chemistry parameters)?
    - [W2c.] What is the water chemistry of the 4 less sensitive lakes? Do any of them show any evidence of acidification and/or impact from KMP?
    - [W2d.] How many lakes have actually acidified due to KMP and exceeded their KPI thresholds?
    - [W2e.] Are additional sites suggested by MOE (i.e., lakes MOE-3 and MOE-6, Cecil Creek, and Goose Creek) at risk of acidification under KMP?
  - W3. What species, age classes, and size of fish are present in the potentially vulnerable lakes that can be safely accessed for fish sampling?
  - W4. If some of the potentially vulnerable lakes that can be safely accessed for fish sampling show an acidifying trend, then do these lakes also show changes in their fish communities?
- OTHER questions elsewhere within the STAR / EEM Plan
  - Do we see any evidence of regional acidification when we analyze the lakes as a group?
  - "Estimate expected time to steady state for SO_4 based on observed trends in [SO_4] and approximate estimates of water residence time".
  - Examine changes in ANC, SO_4 and pH relative to steady-state predictions.
  - Estimate F-factor from empirical sampling.

7.1.1 EEM Key Performance Indicators

- KPI: Observed pH decrease ≥0.30 pH units below mean baseline pH level measured pre-KMP, and is causally related to KMP emissions (where the mean pH during 2012 was measured in August, and the mean pH during 2013-2018 was measured during the fall index period – month of October)

7.1.2 EEM Informative Indicators

- *Informative Indicator:* Atmospheric S deposition and CL exceedance risk
- *Informative Indicator:* Predicted steady state pH versus current pH

- *Informative Indicator:* Estimates of natural variability in pH and other indicators
  - For intensively monitored lakes we're interested in all of these time scales for the ice-free period (daily, weekly, monthly, seasonally, storm effects). For other lakes, we're interested in variability within the index period (e.g., SE of the mean of 4 measurements), and also year to year variability.
  - Other important lake chemistry indicators = ANC, SO_4, DOC, base cations, Cl
- *Informative Indicator:* Evidence that pH is causally related to KMP SO_2 emissions
  - This includes analyses of the changes in ANC, SO_4, DOC, base cations, Cl, in combination with application of the evidentiary framework.
  - NOTE: Particular attention and rigor will be given to the analyses of ANC
    - The importance of ANC as a potentially stronger indicator of changes in lake chemistry and a candidate for a future KPI has received increasingly focused attention since the development of the EEM.
    - Changes in ANC will be analysed *as if* it were a KPI (i.e., "dry run" for potential future implementation), including sensitivity analyses on different formulations of ANC thresholds (both variability in ΔANC corresponding to a ΔpH of 0.3 (from lab titrations), and a scientifically defensible range for the ANC threshold in the CL analysis (e.g., 20, 26 and 40 μeq/l)).
    - The role of organic acids needs to be carefully considered throughout the analysis, both retrospectively and prospectively, as some lakes have a high organic acid component.
- *Informative Indicator:* Aquatic biota: fish presence/absence per species in sensitive lakes
- *Informative Indicator:* Lake ratings
- *Informative Indicator:* Episodic pH change
- *Informative Indicator:* Amphibians

7.1.3 Other questions that have emerged since the development of the EEM

- New questions that have emerged
  - Is there a benefit to adding appropriate control lakes to the EEM?
  - Is there a benefit to additional intra-annual data (e.g., intensive/continuous)?
  - Is there a benefit to collecting other data on the EEM lakes?
    - Water residence time analysis
    - Lake level monitoring
  - Will increased emissions result in immediate (i.e., same year) changes to lake chemistry or will there be a lag?
  - How sensitive will the analyses be to alternative assumptions about the baseline?
  - How important will it be to consider multiple metrics in our evaluations of the data?

7.1.4 Complexity and causality of changes in lake chemistry

- Contextual discussion on the complexity of lake chemistry dynamics within these lakes.

- There are various changes occurring simultaneously (e.g., changes in ANC, pH, organic acids, Cl, SO_4), which add complexity to analyses and interpretations of changes in lake chemistry.
- Importance of understanding both natural and anthropogenic change
- Brief discussion of limitations and concerns with pH KPI
- Summarize how the EEM evidentiary framework (section 7) assesses causality associated with observed changes in lake chemistry.
- Explain the rationale for developing a multi-metric framework for assessing causality (i.e., understand mechanisms driving observed changes to better understand system; understand whether or not observed changes are attributable to changes in emissions from the smelter).

7.2 What Methods Did We Use?

- Describe all of the inputs and methods used in the analyses for this review.
- Provide an overview and put details in an appendix, including improved methods based on comments from Tim Sullivan (e.g., revising charge density assumptions to improve charge balance).

7.2.1 Data we collected

- Annual Monitoring Samples (full chemistry, collected during October, the fall index period)
- Intensive Monitoring of Lakes (pH, measured every half hour during the ice-free season – generally April through to the end of October)
- Summarize (with reference to the STAR and Kitimat Airshed Assessment) how all lakes were selected, (including the control lakes, and their similarities in various attributes to the sensitive EEM lakes).

7.2.2 Analyses we conducted with these data

- NOTE ON ANC VALUES:
  - Gran ANC has been the primary measure of ANC for all the analyses in the STAR and EEM. It is the capacity of a solution to neutralize strong acids, and is determined by titration to the inflection point of the pH-alkalinity titration curve. Gran ANC includes the buffering effect of organic anions.
  - Based on recommendations from other QPs, ENV, and external experts at the workshop held December 10-11th, 2018, and a subsequent conference call on Jan 10, 2018, we will explore using charge balance ANC (CBANC), and Base Cation Surplus (BCS, Lawrence et al. 2007, 2013) as alternative measures of ANC.
  - CBANC is also the capacity of a solution to neutralize acidity, and is generally calculated as the equivalent sum of base cations (Ca, Mg, Na, K) minus the equivalent sum of strong acid anions (SO_4, NO_3, Cl).
    - CBANC has the benefits that it has been used in many studies of long-term trends (e.g., Stoddard et al. 1998, 2003), and it can be analyzed in commercial labs without specialized equipment for Gran ANC titrations. However, the usual formulation of CBANC has the detriments that it doesn't take into account buffering by organic anions (which are very

important in some of the EEM lakes) and that it's calculated from the sum of seven different measurements and therefore can potentially accumulate measurement errors (Evans et al. 2001). Estimating charge balance and charge density also involves summing up multiple measurements.

- The Gran ANC and CBANC are related by the following equation:
  - CBANC = Gran ANC + a * DOC, [1]
  - where a is an estimate of charge density, generally in the range of 4-6 μeq per mg DOC, but can be from 2-10 μeq per mg DOC (Hemond 1990, Marmorek et al. 1996).
  - Based on the recommendations ENV's external expert, we propose to calculate a lake-specific charge density (a) to achieve the best possible charge balance, and then apply that value to equation [1] to compare CBANC vs Gran ANC within each lake, for the purposes of understanding the relationship between these two indicators.
  - We will explore the feasibility of using only CBANC and BCS in future years, due to the difficulties of finding commercial labs that can reliably conduct Gran ANC titrations (which have to date been performed at Trent University).
- BCS is equal to CBANC minus strongly acidic organic anions (called $RCOO^-_s$), which (Lawrence et al. 2007, 2013) estimate from a linear regression of anion deficits vs. DOC for samples with a pH between pH 4 and 4.5 (33 stream samples in their 2007 paper, 200 lake samples in their 2013 paper). $RCOO^-_s$ is set equal to the anion deficit from this linear regression, for all water samples (i.e., both those with pH ≤ 4.5, and those with pH > 4.5), since the strong acid fraction of DOC is not likely to change with pH. The advantage of BCS as a measure of lake condition is that inorganic aluminum (which is associated with acidification and is toxic to fish and other organisms) consistently increases as BCS declines below zero (i.e., BCS < 0 is a concern).
  - In the EEM data set we do not have any samples with a pH < 4.5, so we would need to either: a) directly apply the regression lines from Lawrence et al. 2013 (derived from lakes in Adirondacks NY); b) derive similar linear regressions using EEM and other regional data for lakes within a pH range from 4.5 to 5.1; or c) fitting a triprotic model for organic acids, applied to all of the STAR and KAA lake chemistry samples as per Lydersen et al. 2004, Hruska et al. 2001, or Driscoll et al. 1994.
  - Method a) has the advantage of using data in a pH range where it can be assumed that the anion deficit is entirely due to strong organic acids (weaker organic anions will be protonated), but has the weakness that organic anions in the Adirondacks may be of different character than those found in EEM lakes.
  - Method b) has the advantage of using local data, but we would need to derive regressions from data with a higher pH range than that recommended by Lawrence et al. (2007, 2013). For method b), we have ~14 lake samples with pH values in the range from 4.5 to 5.1 based on the STAR and EEM sampling (LAK028, LAK042, LAK054, LAK056). Most of these samples (11 of 14) come from LAK028. None of the additional

40 lakes sampled in the Kitimat Airshed Study had a pH below 5.1. Two lakes sampled by Environment Canada for the Prince Rupert Airshed Study had high DOC and pH values below 5.1 (NC313 - pH 4.84; DOC 16 mg/l; NC360 - pH 4.91, DOC 12 mg/l), so we could get up to n=16, which is about half the sample size of Lawrence et al. (2007). The DOC in these 16 samples varies from 4.5 to 16 mg/L, so there might be enough contrast to get a weak regression line between anion deficit and DOC, from which we could estimate strong organic anions and apply the BCS approach.
        - Method c) involves fitting a triprotic model (3 pK values for organic anions) to all of the data, and then estimating the strong organic acid component.
        - We propose to compare methods a), b) and c). Methods a) and c) are more defensible.
        - Inorganic Al was measured in 2013; total Al and dissolved Al has been measured every year. Analyses of the 2013 data could be used to determine how inorganic Al is related to dissolved Al, pH and DOC in EEM lakes.
    - In the Comprehensive Review, we'll assess the variability, strengths and weaknesses of these three measures (i.e., Gran ANC, CBANC, and BCS) and compare them. If appropriate, analyses of ΔANC over time will be conducted with all three measures, using a weight of evidence approach.

7.2.2.1 Critical loads, exceedances and predicted changes in pH

- Re-run the SSWC model (critical loads & exceedances) and ESSA-DFO model (predicted pH at steady-state) based on water chemistry data for all lakes sampled from 2012-2018 (original 40 STAR lakes, plus any lakes from the Kitimat Airshed Assessment, sampled in 2013, that fit within the Rio Tinto CALPUFF modelling domain).
    - Re-run SSWC model with 2012 Critical Loads (CLs), 2012 water chemistry and updated CALPUFF predictions of deposition under 2016-2018 emissions, as well as 35 and 42[3] tpd; get revised estimates of exceedances.
        - Run sensitivity analyses of CLs (e.g., run model with 2016-2018 water chemistry - post-KMP conditions for EEM lakes only).
        - Examine effects of using CB-ANC rather than Gran ANC.
        - Sensitivity analysis of runoff assumptions (using WRF model)
    - Re-run ESSA-DFO model based on current 2012 water chemistry and updated CALPUFF predictions of deposition under 2016-2018 emissions, as well as 35 and 42 tpd.
        - Run sensitivity analyses (e.g., run model with 2016-2018 water chemistry; post-KMP conditions for EEM lakes only).
        - Sensitivity analysis of runoff assumptions (using WRF model)
        - Examine effects of using CBANC rather than Gran ANC.

[3] We considered running a separate 30 tpd scenario, but 2016-2018 actuals will serve as the ~30 tpd future steady state case because the average of the 2016-2018 emissions is 29.3 tpd (27.8 tpd, 29.5 tpd, and 30.6 tpd in 2016, 2017, and 2018 respectively).

        - Empirical estimate of F-factor, original SO_4 for LAK028.
    - Compare different scenarios with new inputs with original STAR results.
    - Estimate F-factor in those lakes where there has been sufficient chemical change to do so, and compare to the assumed F-factor. [Quite close for LAK028, see 2016 EEM tech report].
    - Compare soil CL results with aquatic CL results [may get moved to section on holistic synthesis].

7.2.2.2 Temporal patterns in water chemistry

- **General Patterns of Variability and Change**
    - Scatter plots to look at relationships among emissions, precipitation and water chemistry variables of interest (i.e., SO_4, ANC, pH, DOC, BC, Cl, Al)
    - Simple graphs of changes over time in mean values of each variable of interest for each lake (as included in previous EEM reports)
    - Overview of statistical power analyses from 2015 EEM tech memo and implications (with only 3 years of post-KMP observations, statistical power will generally be low for pH, but somewhat better for ANC)
- **Statistical Analyses of Trends and Temporal Patterns, and comparison to EEM thresholds**
    - **EEM Thresholds:** 0.3 units for ΔpH; lake-specific thresholds for ΔANC that correspond to 0.3 units of ΔpH in each lake; analysis will consider a range of ANC thresholds, derived from multiple ANC titrations performed at Trent University
    - **Focal Questions:** *Within each of the seven sensitive EEM lakes, use a weight of evidence approach to determine how much change has occurred in each chemical indicator of interest (Y in examples below) between the pre-KMP period and the post-KMP period? How likely is it that the change in pH and ANC exceeds the EEM thresholds?*
    - **Methods for annually sampled lakes.**
        - We plan to use the simplest methods first (in which all sources of variation are present in the data), and then explicitly account for individual sources of variation to improve our understanding of the sources of variation.
        - We propose 8 analyses, which build incrementally, and are applied using both frequentist and Bayesian approaches.
        - If the frequentist approach shows a clear result for a lake (e.g., 95% confidence intervals for ΔANC do not overlap that lake's threshold for ΔANC) then there's no need to proceed with the Bayesian analysis for that parameter in that lake.
        - To simplify the presentation in the Comprehensive Report, and minimize confusion, we'll present the most scientifically defensible approach (likely the later analyses in the sequence presented below). We'll only include additional sensitivity analyses in the appendices if they're helpful in clarifying the results and add incremental value and understanding. This is similar to the preparation of a journal paper,

where only the most scientifically defensible analytical method is included, with sensitivity analyses as required.

Frequentist approach (use alpha=0.01 to account for multiple tests):

1. Two-sample Before-After t-tests of 2012 chemistry vs. 2016-2018 for each individual lake, just using mean values for each year
    - This is the simplest analysis, providing (for each lake) an estimate of the change in the mean value of each chemical component between the pre-KMP period (2012) and the post-KMP period (2016-2018). This analysis does not account for various sources of variation (e.g., natural variability unrelated to the smelter, variability within the October sampling period).
    - It will be very difficult to show a statistically significant change given only 1 pre-KMP observation and 3 post-KMP observations. Calculate Minimum Detectable Difference (MDD) to demonstrate what level of change would be statistically significant.
    - Apply methods of Kilgour et al. 1998.
    - *Form of test:* $Y_t \sim BA$; where *Y* is the overall mean across both before and after categories of years, and BA is the effect of Pre-KMP (Before) vs Post-KMP (After)
    - *Assumptions:*
        - The chemistry of component Y in a given lake is a function only of the time period (before vs after).
        - The mean value of component Y represents the state of component Y in a given year.
        - Use process error from 2016-18 to provide estimated variability for 2012 measurement.

2. Two-sample Before-After test of 2012 chemistry vs. 2016-2018 for each individual lake, using 4 measurements from each year.
    - This method provides greater insight than method 1, as it accounts for unequal sampling in various years and lakes (e.g., 1 sample in some lakes in some years, 4 samples in most lakes and years). The estimated before-after change between the pre-KMP and post-KMP periods removes the effect of natural variability within the sampling period.
    - *Form of test:* $Y_t \sim BA + YRE$, where YRE = Year Random Effect due to multiple samples taken in the October sampling period;
    - *Assumptions:*
        - Same as analysis 1, plus:
        - The chemistry of component Y in a given lake is a function of the time period (before vs after), as well as the variability within the October sampling window

- All of measured values of component Y during the October sampling window represent the state of component Y in a given year

3. BACI (Before-After-Control-Impact) approach: Data from one sensitive lake vs. group of 3 control lakes.
    - Focal questions for this analysis are slightly different: *how much change has occurred in chemical indicator Y between the pre-KMP period and the post-KMP period, relative to the changes observed in the control lakes? Is the direction and magnitude of change in the sensitive lake different from what was observed in the control lakes?*
    - We will describe in section 7.2.1 how the control lakes were selected, and their similarities in various attributes to the sensitive EEM lakes.
    - This method explicitly accounts for natural variation in lake chemistry due to factors other than the smelter (e.g., year to year changes in precipitation and temperature) which affect both the EEM lakes and the control lakes.
    - The effect of the smelter on a given lake is expressed in terms of how the chemical changes over time (between the pre-KMP and post-KMP periods) differ from the changes observed in the control lakes (taken as a group), taking into account before-after changes that have affected all lakes.
    - *Form of test:* $Y_t \sim$ BA + ICE + BACI Interaction + LRE + YRE, where
        - ICE = Impact/Control Effect;
        - BACI Interaction = Treatment * Time Interaction (difference in how impact and control lakes changed over time; key variable in the analysis);
        - LRE = Lake Random Effect due to consistent differences between lakes (e.g., the sensitive lake always has a lower pH than two of the control lakes);
        - BA and YRE as in analysis 2
    - *Assumptions:*
        - Same as analysis 2, plus:
        - Observed value from 2013 serves as a pre-KMP value for the control lakes (control lakes were not sampled in 2012); implicitly assume that 2012 and 2013 were similar
        - Variability in the control lakes over 2013, 2015-2018 used to help estimate variability in the sensitive lake in 2012

4. BACI approach with individual measurements rather than just using mean values. Same model as analysis #3 + lake*year interaction random effect. The differences between analyses 4 and 3 are

analogous to the differences between analyses 2 and 1. The form of output is the same as in method #3, but now takes into account the variability observed during the sampling period.

5. Method 4 + assumption of no change in control lakes. If we assume that there's no B/A change in control lakes (forcing ΔY in control lakes to be zero), the B/A change in the sensitive lake becomes the absolute change in component Y. This would involve removing some of the terms in the model 4. Note that the range of fluctuation in pH in the control lakes over 2013 and 2015-2018 is generally close to the range of pH measurement error of ± 0.2 pH units. The form of output is the same as in method #4.

6. Adding other measurements (e.g., ALS pH in addition to Trent University pH), or covariates (such as emissions or precipitation) to explain year to year variation. If these covariates help to explain variability in chemistry, then we could use 2013-2015 data, in addition to 2012 and 2016-2018. In terms of the form of the test, we would add covariates into the linear model to ascribe some of the observed changes in chemical components to these covariates (e.g., increase in $[SO_4]$ with emissions of SO_2 in the year prior to October sampling; decreases in component concentrations with precipitation in the week prior to sampling). The overall form of the results would be similar to method 4, but would potentially separate out variation due to changes in emissions, or due to fluctuations in precipitation (if these covariates are shown to be correlated with the measured chemistry).

7. We could also explore using Principle Components Analysis (PCA) on each lake's measurements, and then use the PC in the BACI analysis, and compare the results. The PCA approach would describe (for each lake) the combination of chemical constituents which explains the greatest amount of variability in the 2012-2018 dataset. The overall form of the results would be similar to method 4, but would show the changes in the first principle component, over time and relative to the control lakes.

8. Building on analysis #6, conduct an analysis with 3 time periods: Before (2012); Transition (2013-2015); and After (2016-2018), using covariates established in analysis #6. Advantage is that having more years gives a better estimate of process error. The overall form of the results would be similar to method 4, but with three time periods (before, transition, after) rather than just two (before, after).

9. Examination of the temporal trends in lake chemistry within groups of lakes (e.g., those closest to the smelter, those at an intermediate distance, and those furthest away). Grouping lakes will provide higher

levels of statistical power, and is the approach used by Stoddard et al. (1996, 1998, 2003) for assessing trends in the northeastern U.S. Due to the paucity of baseline data, analyses of covariance may be helpful in elucidating trends (e.g., Wiens and Parker 1995).

Bayesian approach: As noted above, we would only apply a Bayesian approach in situations where the frequentist approach is unable to clearly reject the hypothesis of a smelter effect. For the Bayesian approach, we would use the BEST approach (Kruschke 2013), applied to methods 1-8. Results are expressed in terms of the posterior belief that a lake's change in pH or ANC has exceeded an EEM threshold. For other chemical parameters, results are expressed in terms of the credible range of changes from pre-KMP to post-KMP periods. Sensitivity analyses would include an analysis of the effects of assumed priors.

- **Methods to be used for intensively monitored lakes:**
  - Assess variability in pH on various time scales (i.e., daily, weekly, monthly, seasonally, storm effects).
  - Assess various covariates to explain variability in pH (time of day, season, lake elevation change, hourly CALPUFF predictions of S deposition during 2016-2018).
  - Could apply methods 1-6 using the mean pH values for the October index period, accounting for serial correlation in the data.
  - Use "process control plots" to identify potential anomalies in continuously monitored pH (e.g., storm events), or could do analysis to determine effects of storm events first.

7.2.2.3 Assessing changes in water chemistry with respect to STAR and EEM

- Empirical Changes in Water Chemistry Relative to Steady-state Predictions
  - Examine actual change in SO_4, ANC and pH vs. predicted ANC and pH change at steady state from the ESSA/DFO model, and expected lake [SO_4] from CALPUFF post-KMP predictions vs. observed [SO_4].
  - Redo ESSA/DFO and SSWC model predictions using specific CALPUFF runs for current emissions (2016-2018; average of 29.3 tpd emissions), 35 tpd and 42 tpd.
  - Assess changes relative to both pre-KMP and pre-industrial conditions (estimated in the STAR; ESSA-DFO model predicts pre-industrial ANC and pH; SSWC model predicts pre-industrial base cations).
  - Assess influence of runoff assumptions.

7.2.3 Weight-of-Evidence approach for assessing causality

- Evidentiary framework for identifying patterns consistent with smelter-driven acidification
- Summarize how we have applied EEM evidentiary framework to assess evidence that observed changes in chemistry are causally related to KMP (based on empirically observed changes – Table 17, pg. 43 in EEM Plan).
- What are the most likely causes of the observed chemical changes in each of the seven sensitive lakes? (e.g., STAR table 9.4-4)

7.2.4 Episodic acidification studies

- See section 7.2.2.2
- Analyze continuous pH data (3 lakes + Anderson Creek) with respect to episodic acidification.
    - Look at Lakelse wet deposition data and lake level data to assess if correlated with observed pH episodes.
    - Summarize analyses of factors causing variation in water chemistry during the October index period (only period with full chemistry analyses).
- Research Project by Dr. Paul Weidman (pending availability of results)

7.2.5 Kitimat River water quality

- Monitoring and analyses methods

7.2.6 Other data and/or analyses previously reported

- BRIEFLY mention other pieces and cite past reports for details:
    - Fish sampling – methods and extent of fish sampling under the EEM
    - Amphibians work under the EEM
    - Flow data
    - Lake level monitoring
    - Water residence time – report on estimated residence time of water for lakes with detailed bathymetry

7.2.7 Assessment of acceptable or unacceptable impacts to aquatic receptor

- The assessment of the impacts to the aquatic receptor as "acceptable" or "unacceptable"[4] is directly linked to the KPI
    - If the KPI threshold associated with facility-based mitigation in the EEM is exceeded, this will be identified as an "unacceptable" impact for the aquatic receptor.
    - Impacts to the aquatic receptor that do not exceed the KPI threshold associated with facility-mitigation in the EEM will be identified as "acceptable".
    - NOTE: all impacts, regardless of classification will be explored, analyzed, interpreted and documented in detail.

7.3 What did we learn, and did we make any adjustments to the EEM Program?

- Provide an overview of the results, referencing past EEM reports and Tech Memos, and put details in an appendix.
- Discuss what has been learned overall regarding KMP effects on aquatic ecosystems thus far under the first 6 years of the EEM Program.
- Explain whether questions W1, W2, W3 and W4 have been answered, and whether any new questions have emerged.

[4] Section 4.2.6 of the P2-00001 permit, dated March 15, 2016, states "If any unacceptable impacts are determined through the use of the impact threshold criteria pertaining to emission reduction, then the maximum SO2 daily discharge limit shall revert back to 27 Mg/d, unless the Director amends the discharge limit."

- Explain whether a KPI threshold been reached, and if so, what actions were taken, or need to be taken.
- Explain what changes if any have been already made to the KPI (the KPI itself, methods, or thresholds) or the informative indicators.

7.3.1 Knowledge gained

7.3.1.1 Ability to detect changes in water chemistry

- This IS reported elsewhere, but the results are so fundamental to much of our interpretation and modifications (especially relevant to interpretation of rest of the results).
    - What has been learned from the statistical power analysis and the analyses in this report about the ability to detect changes in water chemistry?

7.3.1.2 Spatial and temporal patterns in water chemistry

- Observed Changes and Variability
- Statistical Analyses of Trends and Temporal Patterns
- Observed Changes Relative to Steady-state Predictions
- Application of multiple lines of evidence
- Observed Changes Relative to KPI Thresholds
- Statistical Evaluation of Observed Changes Relative to KPI Thresholds
- Results of Sensitivity Analyses

7.3.1.3 Critical loads, exceedances and predicted changes in pH

- Results of scenarios with new inputs, compared to STAR results (by lake)
    - Are the results substantially different?
    - Were the original results over/underestimates?
    - What are the implications of this – lakes are more likely less/more sensitive?
    - How to results from aquatic CL models compare with soil CL models?
- F-factor – new empirically based estimates vs. STAR assumptions

7.3.1.4 Episodic acidification studies

- Results from analyses of continuous pH monitoring data
- Results from research project by Dr. Paul Weidman (pending availability of results)

7.3.1.5 Kitimat River water quality

- Summary of results of water quality monitoring

7.3.1.6 Results from previously reported analyses

- BRIEFLY mention other pieces and cite past reports for details:
    - Results of Kitimat Airshed Assessment
    - Fish sampling
    - Amphibians
    - Flow data
    - Lake level monitoring
    - Water residence time for lakes

- Non-EEM sites

7.3.2 Modifications to the EEM Program

7.3.2.1 Adjustments to sampling program

7.3.2.2 Modification of methods

7.3.2.3 Refining how we interpret the results

- Variability in pH and Issues with Low Power
- Need to Examine Other Metrics (particularly ANC)

7.3.3 Comprehensive synthesis ('pulling all the pieces together')

7.3.3.1 Changes to and/or confirmation of STAR results and assumptions

- i.e., Emissions/deposition, F-factor, Critical Loads and Exceedances, Predicted pH

7.3.3.2 Summary of observed changes in lake chemistry, 2012-2018

7.3.3.3 Exceedances of EEM indicators

- i.e., KPI and informative indicators

7.3.3.4 Application of the Evidentiary Framework

- For each lake, does the evidence suggest that acidification has occurred and is causally related to KMP (application of evidentiary framework in Table 17 of EEM Plan)?

7.3.4 Conclusions

7.3.4.1 Does the Weight of Evidence indicate that KMP has contributed to the acidification of aquatic ecosystems?

7.3.4.2 Summary of answers to questions in the STAR and EEM

7.3.4.3 Assessment of acceptable or unacceptable impacts on aquatic receptor

7.3.4.4 What outstanding questions still require further or ongoing investigation?

7.3.4.5 What new questions have emerged?

7.4 What Do We Recommend for the EEM Program Going Forward?

7.4.1 Recommendations regarding EEM lakes

NOTE: The following outlines the categories under which recommendations could potentially be made. Additional notes describe some of the topics that we currently anticipate will warrant discussion. However, the actual recommendations will be an outcome of the comprehensive review process and design work in 2020 – the notes in this section are not intended to suggest or reject any particular recommendation.

- Recommended changes to monitoring methods, frequency or extent, to be ranked in terms of their importance to the EEM program
    - Continue monitoring EEM lakes?
    - All EEM lakes?
    - Annual and/or within-season?
    - Full lake chemistry sampling?
    - Continuous pH monitoring?
    - Control lakes?
- Recommended changes to the KPIs or informative indicators and thresholds
    - Identification and discussion of criteria for choosing effective KPIs
        - e.g., timeliness of response to changes in deposition, relationship to biological change, ability to measure/model with acceptable of reliability, appropriate balance of Type I and Type II errors
    - Discussion of benefits and limitations of current KPI
    - Potential changes to KPI of ΔpH = 0.3
        - Higher variability / lower statistical power for pH than for ANC
        - Logarithmic nature of pH means that actual pH level is also important, not just ΔpH (e.g., change from pH 5.0 to 4.7 is 100 times greater change in [H+], and biologically very significant, whereas change from pH 7.0 to 6.7 is not biologically significant)
    - Discussion of other proposed alternatives for KPIs and/or thresholds, including:
        - Tim Sullivan's proposal for pH and ANC:
            1. [ΔpH of $\geq$ -0.3] AND [pH < lake-specific pH threshold to protect biota] OR
            2. [lake-specific ΔANC equivalent to ΔpH of 0.3] AND [lake-specific ANC threshold equivalent to lake specific pH threshold]
            3. Biological rationale for thresholds (e.g., Baldigo et al. (in review), Lydersen et al. 2004, Holt et al. (2003), Lien et al. 1997, Baker et al. 1990)
            4. Application of evidentiary framework (Table 17 in section 7 of EEM Plan), including analysis of patterns in marine salt loading (Cl), organics (DOC) and climate (yr-to-yr and within year variation)
            5. Review of the literature to determine lake-specific levels of pH and ANC to use as appropriate thresholds
        - Potential for adding exceedances of CL as a KPI (Frazer's proposal)
- Recommended changes to EEM analyses going forward
    - Discuss relative benefits and limitations of Gran ANC vs. CBANC vs. BCS.
    - Discussion of relative benefits and limitations of frequentist vs. Bayesian statistical approaches.
    - Effects of wetlands on lake chemistry (effects of deposition on wetlands will be discussed in section 6 on terrestrial ecosystems).
    - Potential use of biological indicators (e.g., zooplankton; fish species tolerance; eDNA)
    - Potential inclusion of inorganic monomeric Al
    - Potential use of critical loads and exceedances as indicators

7.4.2 Recommendations regarding non-EEM lakes

- Reiterate the recommendations from the relevant annual reports
- Additional recommendations as appropriate

8 Holistic Understanding of KMP Effects on the Environment and Human Health across all Lines of Evidence

- Provide a map showing all sampling/monitoring locations across pathways and receptors.
- Look across all lines of evidence and receptors, integrate information across disciplines, and provide a clear summary of what we've learned about the links between SO_2, human health and ecosystems.
    - Consider including a Looking Outward Matrix to organize this (example template shown in Table 3 below).
    - Summary of KPI, thresholds and results over 2012-2018 (example template in Table 4 below)
    - Synthesis of deposition-driven S results across vegetation, terrestrial ecosystems and aquatic ecosystems
    - Synthesis of SO_2 concentration-driven results across human health and vegetation
- Summarize what we've learned in terms of the STAR source-pathway-receptor diagram, and identify gaps in data or knowledge.

Table 3. Looking Outward Matrix showing information links among pathways and receptors (example for illustration of the matrix format).

To → / From ↓	Atmosphere	Human Health	Vegetation	Soils	Surface Waters
Atmosphere		[SO_2] vs. KPI & respiratory responses	[SO_2] vs. vegetation thresholds	Deposition vs CL, and vs. soil base saturation	Deposition vs CL, and vs. acidic episodes
Human Health					
Vegetation	[S] in needles vs. observed / predicted [SO_2] in air				
Soils			Soil CL exceedance vs. Vegetation observations		Soil CL exceedance vs. Lake CL exceedance
Surface Waters	Use Δ lake [SO_4] to inform CALPUFF	Water quality in Kitimat River near water treatment plant		BC weathering rate from [BC] and runoff vs. soil estimates	

Table 4. Summary of KPIs, thresholds and performance 2012-2018.

	KPIs	Threshold for increased monitoring	Threshold for receptor-based mitigation	Threshold for facility-based mitigation	Results over 2012-2018
Human Health					
Vegetation					
Soils					
Surface Waters					

9 Cited References and Reports

These will include the following references cited in Section 7 of this outline:

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10 Cited EEM Technical Memos

Appendices

- Appendices will be prepared for Comprehensive Review details not appropriate for the main CR Report

TOR Item 3: Schedule of Comprehensive Review Tasks

| Schedule for EEM 2019 Comprehensive Review *** | | READ ME | | Weeks in 2019 | | |

Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project

Volume 2: 2019 Comprehensive Review Report Technical Appendices, V.3 Final

[Appendix 3: Atmospheric Pathways]

October 15, 2020

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Version Tracking Table

No.	Date	Summary of content /changes
V.1	October 31, 2019	Draft appendix for review by the B.C. Ministry of Environment and Climate Change Strategy
V.2	June 30, 2020	Draft appendix for KPAC review
V.3	October 15, 2020	Final appendix

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Volume 2: Technical Appendices of the 2019 Comprehensive Review of Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project, V.3 Final is packaged in four parts: Appendix 1; Appendix 3; Appendices 4, 5 and 6; and Appendix 7. Each Technical Appendix is numbered according to the chapter in the Comprehensive Review Report (Volume 1) that it supports. There is no Appendix 2 as there is no appendix material for Section 2 in the Comprehensive Review Report.

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> ESSA Technologies, J. Laurence, Risk Sciences International, Trent University, and Trinity Consultants. 2020. 2019 Comprehensive Review of Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project – Volume 2: Technical Appendices (Appendix 3), V.3 Final. Prepared for Rio Tinto, B.C. Works, Kitimat, British Columbia.

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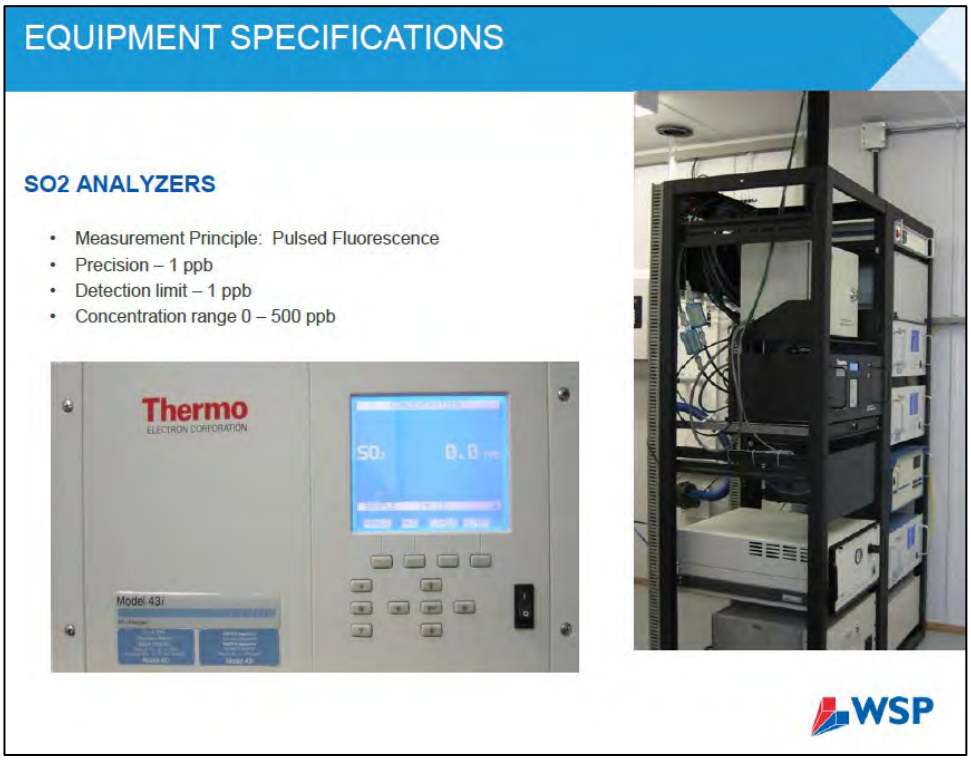
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3 Appendix to Section 3 of the Comprehensive Review Report: Atmospheric Pathways

3.1 Atmospheric Concentrations

3.1.1 Continuous SO_2 analyzer details

In order to monitor atmospheric SO_2 concentrations, Rio Tinto maintained four continuous SO_2 analyzers at Haul Road, Riverlodge, Whitesail, and Kitamaat Village. In addition, a fifth SO_2 monitoring station located at Lakelse Lake was added to the network during 2018 in order to estimate dry deposition. The excerpts from the June 2016 Air Quality Workshop below provide details on the continuous monitoring network and equipment. All continuous SO_2 monitoring stations use the Thermo Scientific Model 43i SO_2 analyzer.



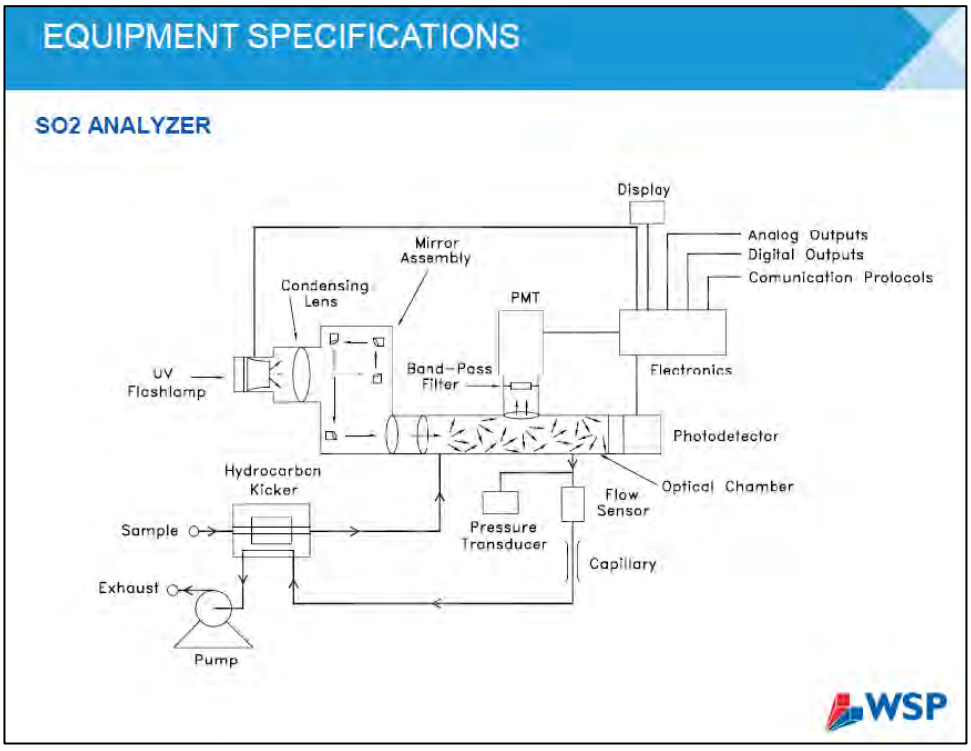


Figure A3-1. Continuous SO_2 analyzer equipment specification (Rio Tinto Kitimat Air Quality Workshop, June 2016, PDF page 95)

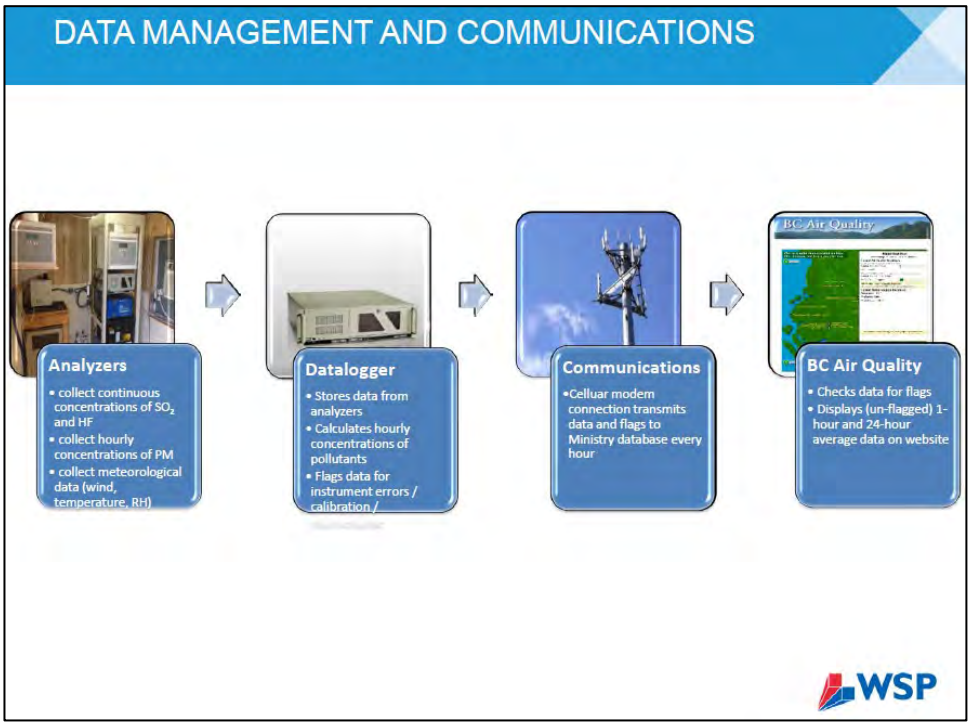


Figure A3-2. Continuous monitoring network data management (Rio Tinto Kitimat Air Quality Workshop, June 2016, PDF page 99)

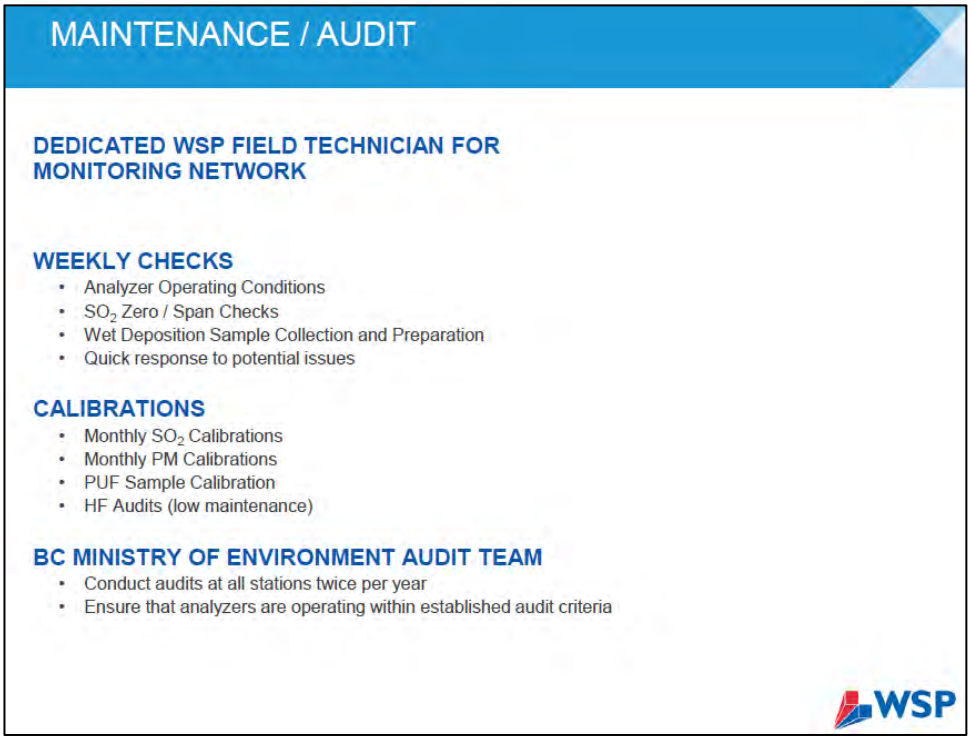


Figure A3-3. Continuous monitoring network maintenance and audit summary (Rio Tinto Kitimat Air Quality Workshop, June 2016, PDF page 100)

3.1.2 Peak-to-mean ratio analysis (1-hour peak to 30-day average)

Table A3-1 below presents a summary of the 1-hour peak to 30-day mean ratios based on SO_2 continuous monitoring data for 2016, 2017, and 2018. The ratios range from 7.1 to 112.4, with a high standard deviation for all stations. The ratios are calculated starting with the 30-day period from January 1, 2016 through January 30, 2016, and include all 36 periods through December 15, 2018 (all periods included sufficiently complete data). Figure A3-4 and Figure A3-5 present the 1-hour peak and 30-day mean values for all stations, including the best fit linear equation and the coefficient of determination (R^2). Figure A3-6 presents the 1-hour peak and 30-day mean values for the residential stations (Riverlodge, Whitesail, and Kitimat Village), so the detail of the data at the lower levels can be seen more clearly without the much higher Haul Road data. Riverlodge and Whitesail are the two stations of most interest for understanding relationships that may be applied to passive samplers in the Urban Network.

The R^2 values of 0.12, 0.13, and 0.22 (or -.09, 0.10, and 0.18 for the intercept = 0 case) for Haul Road, Kitamaat Village, and Whitesail, respectively mean that minimal or very weak correlation exists, while the R^2 value of 0.42 (0.42 also for the intercept = 0 case) for Riverlodge indicate a weak to moderate correlation.[1] Since Riverlodge has the strongest correlation (weak to moderate), Figure A3-6 also shows the bounds of the relationship between 1-hour peak and 30-day mean for Riverlodge.

Table A3-1. Peak-to-mean ratios for the four continuous SO_2 monitoring stations, 2016-2018.

	Peak-to-Mean Ratio			
	Kitamaat Village	**Haul Road**	**Riverlodge**	**Whitesail**
Min	7.1	7.3	9.8	9.3
Median	33.6	16.2	33.5	31.0
Mean	38.3	19.2	36.5	37.5
Max	112.4	51.4	85.0	97.5
Standard Deviation	25.7	10.9	17.5	21.4

[1] Moore, D. S., Notz, W. I, & Flinger, M. A. (2013). The basic practice of statistics (6th ed.). New York, NY: W. H. Freeman and Company. Page (138).

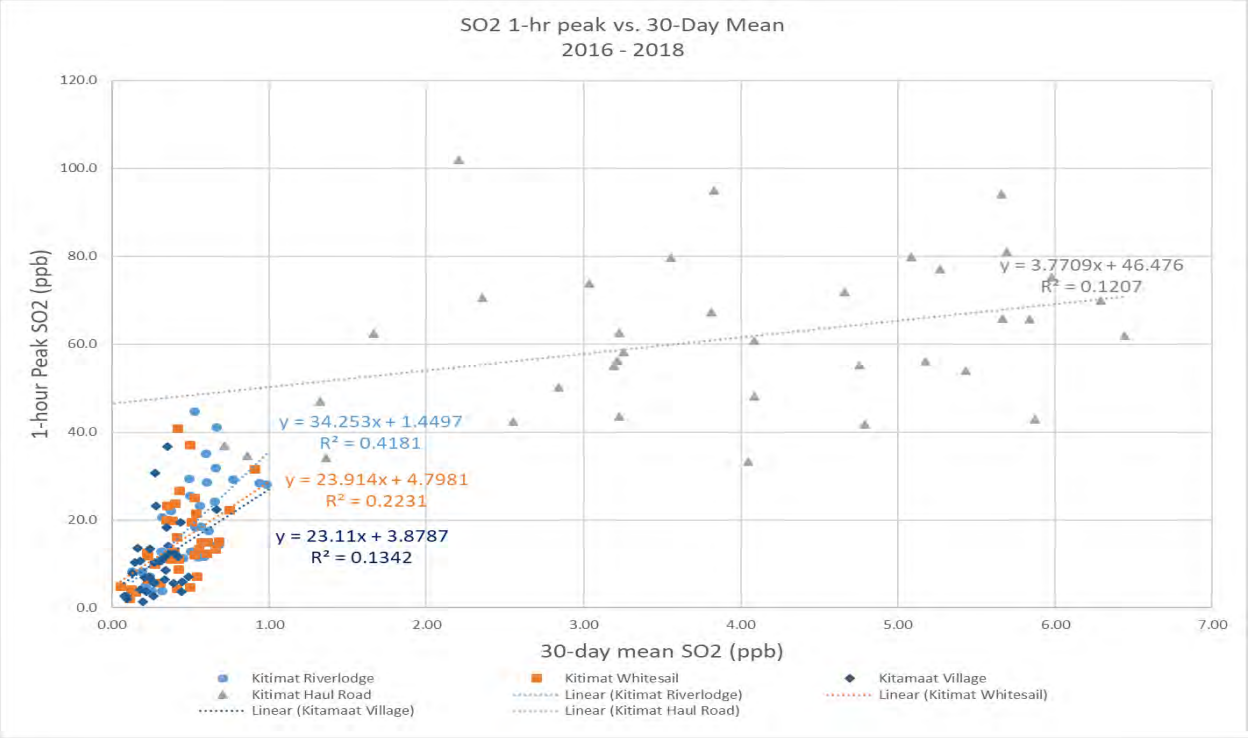


Figure A3-4. Continuous monitoring SO_2 1-hour peak versus 30-day mean concentrations (2016-2018; All Monitors, Linear Fit).

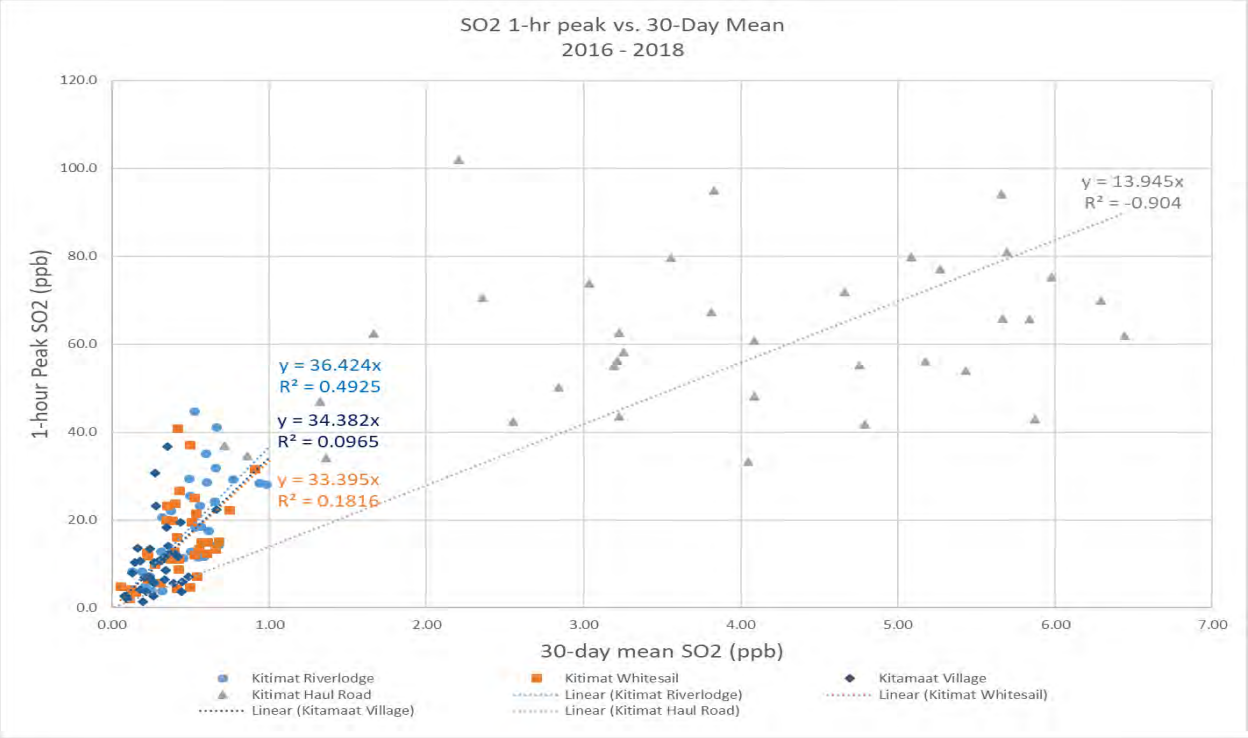


Figure A3-5. Continuous monitoring SO_2 1-hour peak versus 30-day mean concentrations (2016-2018; All Monitors, Linear Fit with 0 Intercept).

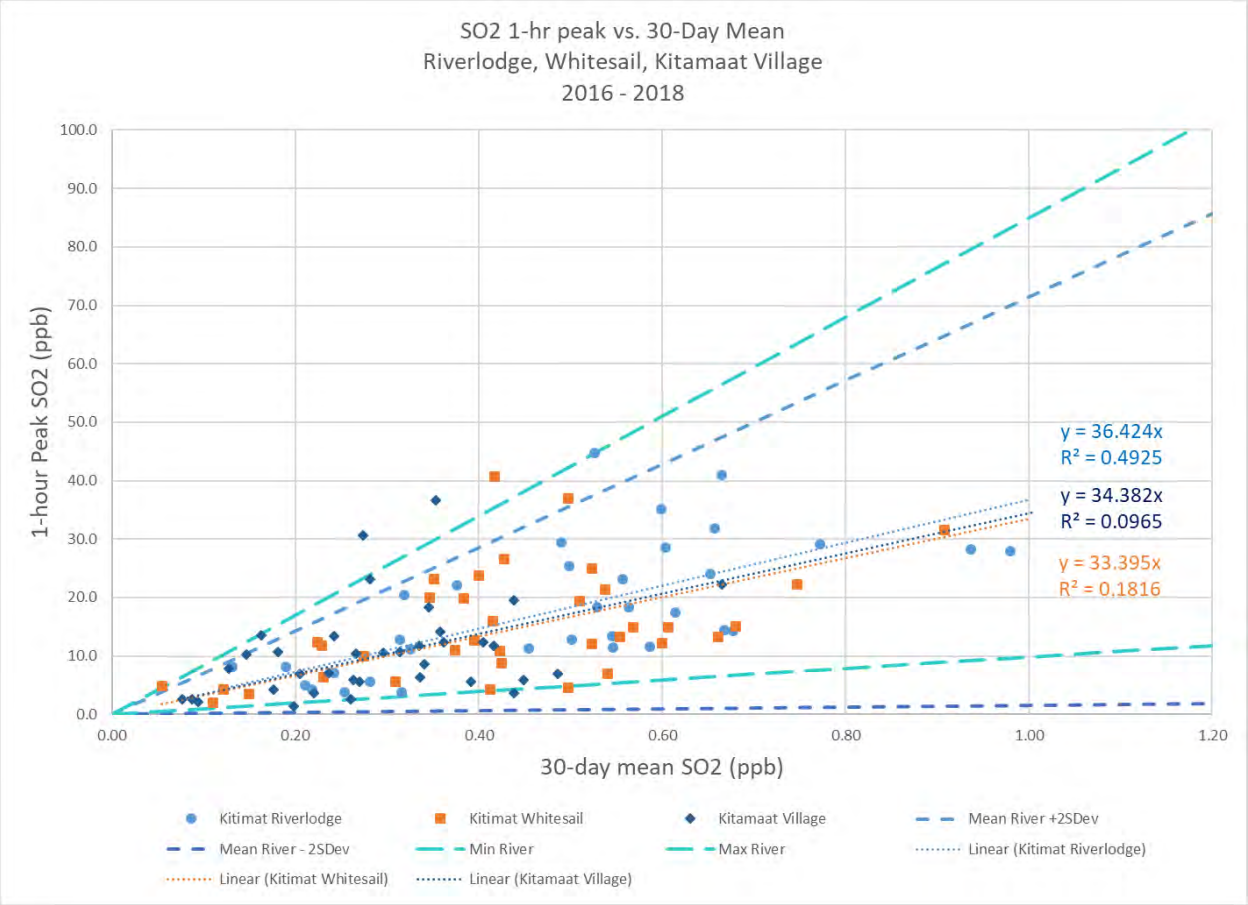


Figure A3-6. Continuous monitoring SO_2 1-hour peak versus 30-day mean concentrations (2016-2018; Riverlodge, Whitesail, Kitamaat Village; Linear Fit with Zero Intercept).

The wide range of peak to mean ratios and high variability (high standard deviation) in Table A3-1 and low R^2 values in Figures A3-4 through A3-6 indicate that the ratios are not sufficiently consistent to use this relationship to understand 1-hour peak concentrations based on 30-day average measurements. In other words, 30-day average measurements (such as the data available from passive sampling) do not provide meaningful information about the 1-hour peak concentrations. For example:

- If a 30-day sample of 0.5 ppb were measured near Riverlodge, using Figure A3-6, we see that the peak 1-hour concentration during the same period is most likely to be approximately 18 ppb (based on the mean peak-to-mean ratio, or the best-fit-line slope of 36.5), but it could be as high as 43 ppb or as low as approximately 5 ppb based on the maximum and minimum ratios.
- Similarly, if a 30-day concentration of 0.5 ppb were measured near Kitamaat Village, based on Figure A3-6 and the minimum and maximum ratios for the station, the peak 1-hour concentration during the same period could be as high as 56 ppb or as low as approximately 3.5 ppb.
- Even more extremely, if a 30-day concentration of 5 ppb were measured near Haul Road, based on and the minimum and maximum ratios for the station, the peak 1-hour

concentration during the same period could be as high as 251 ppb or as low as approximately 36 ppb. However, the minimum and maximum 1-hour peaks ranged from 33 ppb to only 102 ppb, indicating that applying an upper bound ratio to a 30-day mean concentration could vastly over-estimate the 1-hour peak.

In conclusion, we recommend that the 1-hour peak to 30-day average ratios should not be used in combination with passive sampler data for the purposes of understanding 1-hour peak concentrations (e.g., as may be needed for human health impact assessments).

3.1.3 Continuous monitoring network evaluation

Rio Tinto committed to evaluating the air monitoring network as part of the EEM program because KMP has changed the emissions profile from the smelter, which affects the spatial distribution of SO_2 ambient concentrations. Trinity completed Phase 1 of the Network Optimization using the 2006, 2008, and 2009 meteorological data similar to the data used for the STAR and 2015 – 2017 SO_2 monitoring data. The Phase 1 work began in 2015 with the submittal of the draft Terms of Reference for the optimization study, and the final report was submitted to ENV in April 2019. The phase 1 analysis following US EPA guidance[2] concluded that the Riverlodge monitor is in a suitable location to represent the highest concentrations expected within the Kitimat residential area; that Whitesail monitor location does not provide added benefit for measuring the maximum SO_2 air concentrations within Kitimat; and that the Kitamaat Village monitor is in the most suitable location within Kitamaat Village. A copy of the Phase 1 report is included in Section 3.1.9 of this appendix.

Phase 2 of the air quality network optimization, using the new 2016 to 2018 modelling results (local-scale) and incorporating data from the most recent SO_2 concentration monitoring is ongoing and initial results are presented in this Atmospheric Appendix Section 3.1.3. Rio Tinto submitted a revised version of the TOR addressing the comments received and focused on Phase 2 of the optimization in April 2019 (also included in Section 3.1.9 of this appendix). Rio Tinto will submit a revised version of the April 2019 TOR in 2020 to reflect the most up to date status of the available monitoring and modelling data.

The preliminary results presented in this appendix focus on the CALPUFF model results, analyzed following the methods detailed in the draft TOR and similar to those outlined in the Phase 1 report (both in Section 3.1.9 of this appendix). The procedure follows the US EPA guidance for the SO_2 national ambient air quality standard source oriented monitoring[3] with the goal of giving equal weight to highest concentrations over the three model years (in the form of the standard) and frequency (locations that would most frequently measure the highest concentration in a given day versus other modelled locations). Following the guidance, the approach also excludes locations that cannot be accessed due to terrain or other impediments prior to the data analysis. The following list summarizes the steps detailed in the TOR for evaluating SO_2 model results.

- **Step 1**: *Exclude* certain receptors from the model results (e.g., too steep in terrain, in the dense forest etc.).

[2] US EPA technical assistance document for "source-oriented monitoring" for SO_2 available at: https://www.epa.gov/sites/production/files/2016-06/documents/so2monitoringtad.pdf
[3] Ibid.

- **Step 2**: *Rank* the remaining receptors based on the modelled 3-yr average 99th percentile daily peak 1-hr concentrations.
- **Step 3:** *Rank* the receptors from Step 1 based on the total number of days in the 3-yr period modelled for which each receptor was the overall highest 1-hr concentration for the day
- **Step 4:** *Sum* the scores from the two ranking methods above for the receptors and *rank* these receptors from lowest score to highest to obtain a list of prioritized receptors.
- Lower numerical scores (i.e., higher ranks) indicate higher probability of experiencing high 1-hr SO_2 concentrations in the modelled domain.

Note that CALPUFF results mapping serves to prioritize the locations to evaluate through aerial and field surveys to potentially establish a new / relocated monitoring site. In this model results analysis step, equal weight is given to locations with the highest concentrations (99th percentile of the daily peak) and to locations with the highest frequency in which a receptor sees the highest daily maximum concentration among all receptors. The final evaluation will also consider continuous monitoring and passive sampler data in more detail as well as evaluate the suitability of potential monitoring sites in detail based on meeting siting criteria such as adequate distance from obstructions and long-term and secure access to property. Figures A3-7 through A3-44 below present the preliminary monitoring network evaluation model results based on the 2016-2018 CALPUFF model (local-scale).

3.1.3.1 Kitimat network evaluation maps, Excluded receptors

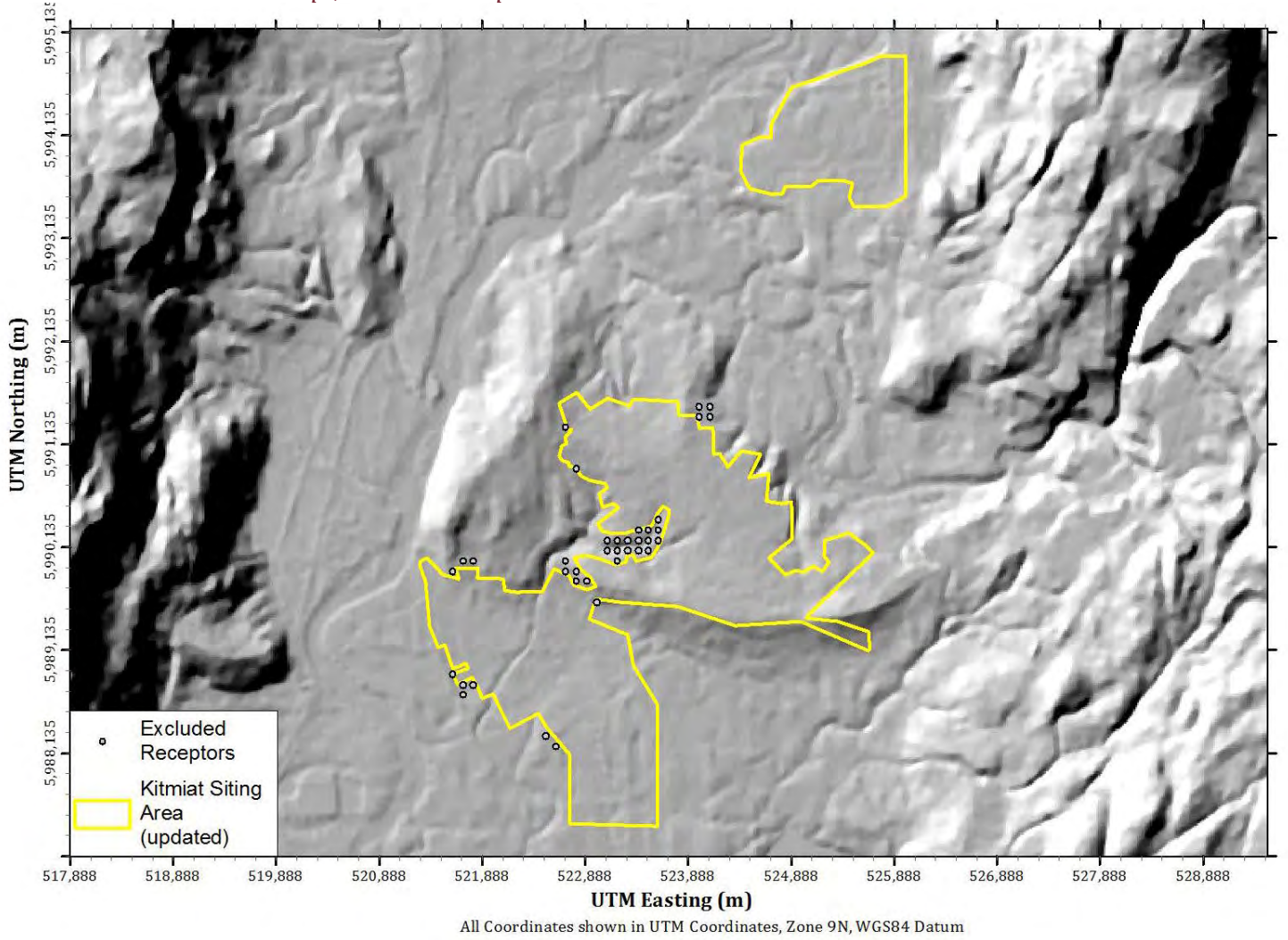


Figure A3-7. Network evaluation, excluded receptors, topographic map.

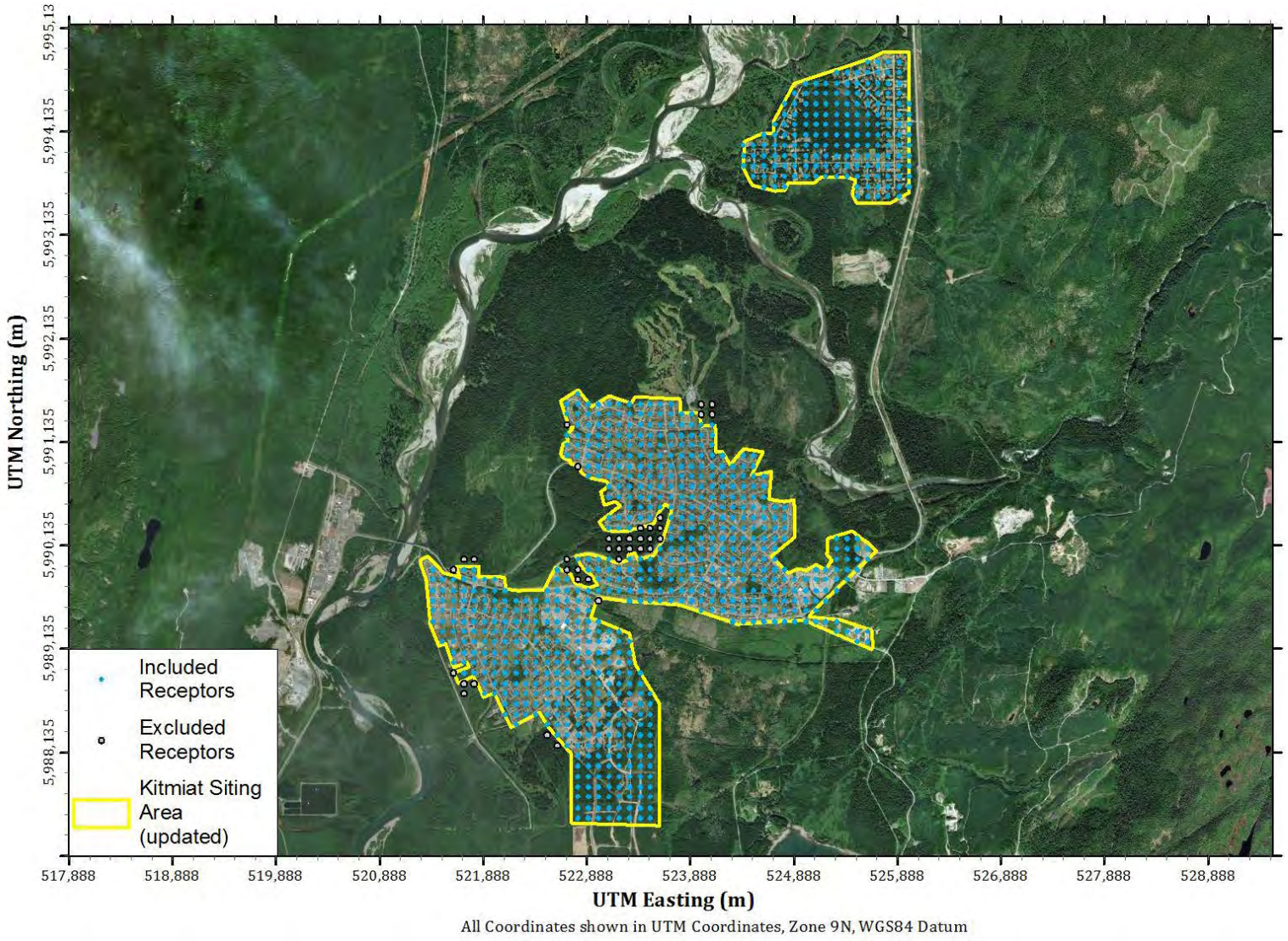
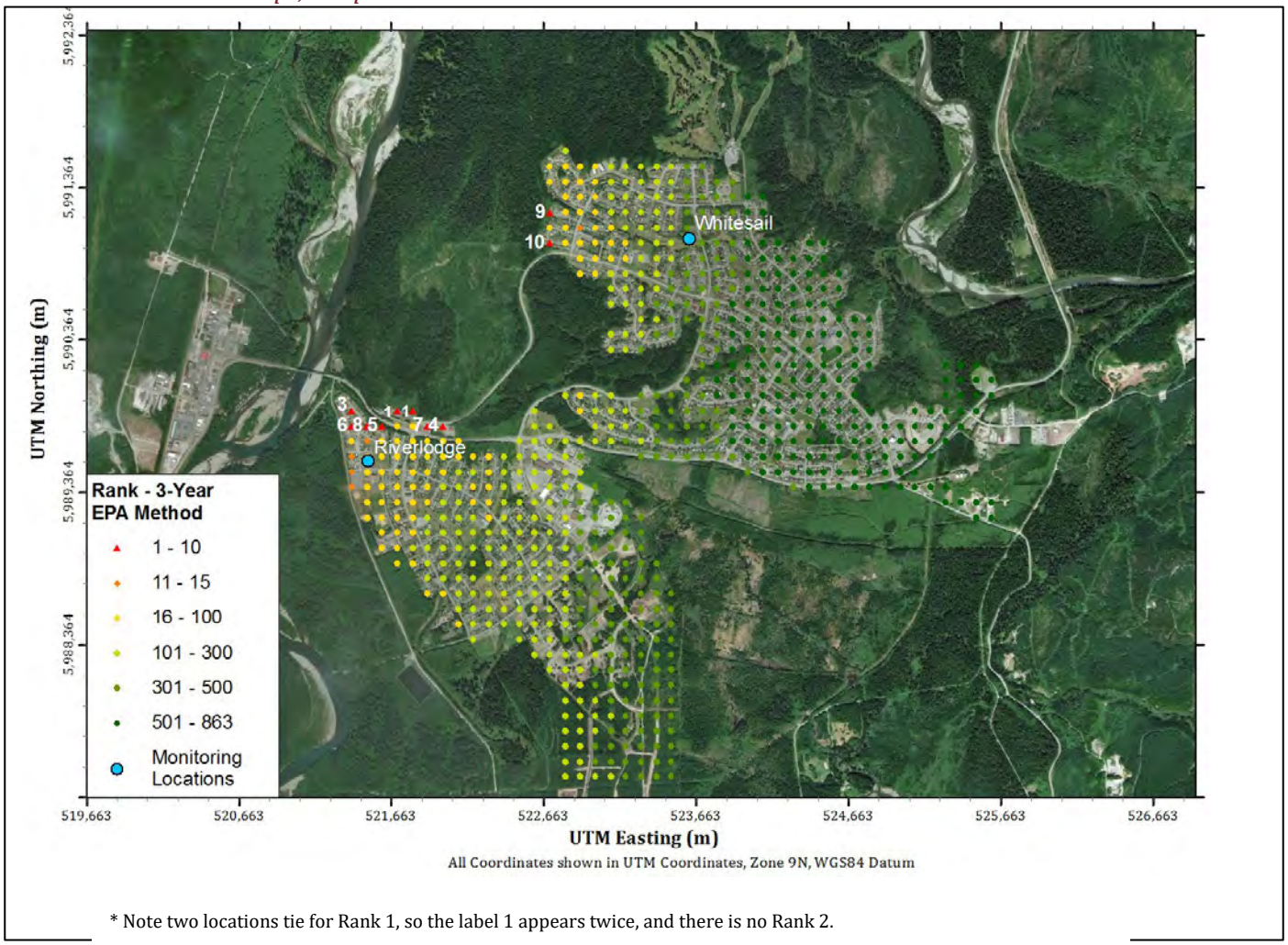


Figure A3-8. Network evaluation, excluded receptors, aerial map.

3.1.3.2 Kitimat network evaluation maps, 42 tpd scenario



* Note two locations tie for Rank 1, so the label 1 appears twice, and there is no Rank 2.

Figure A3-9. Network evaluation results, 2016-2018 meteorological data for Kitimat, *42 tpd scenario*, considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.
[Repeat of Figure 3-14 in main report for completeness]

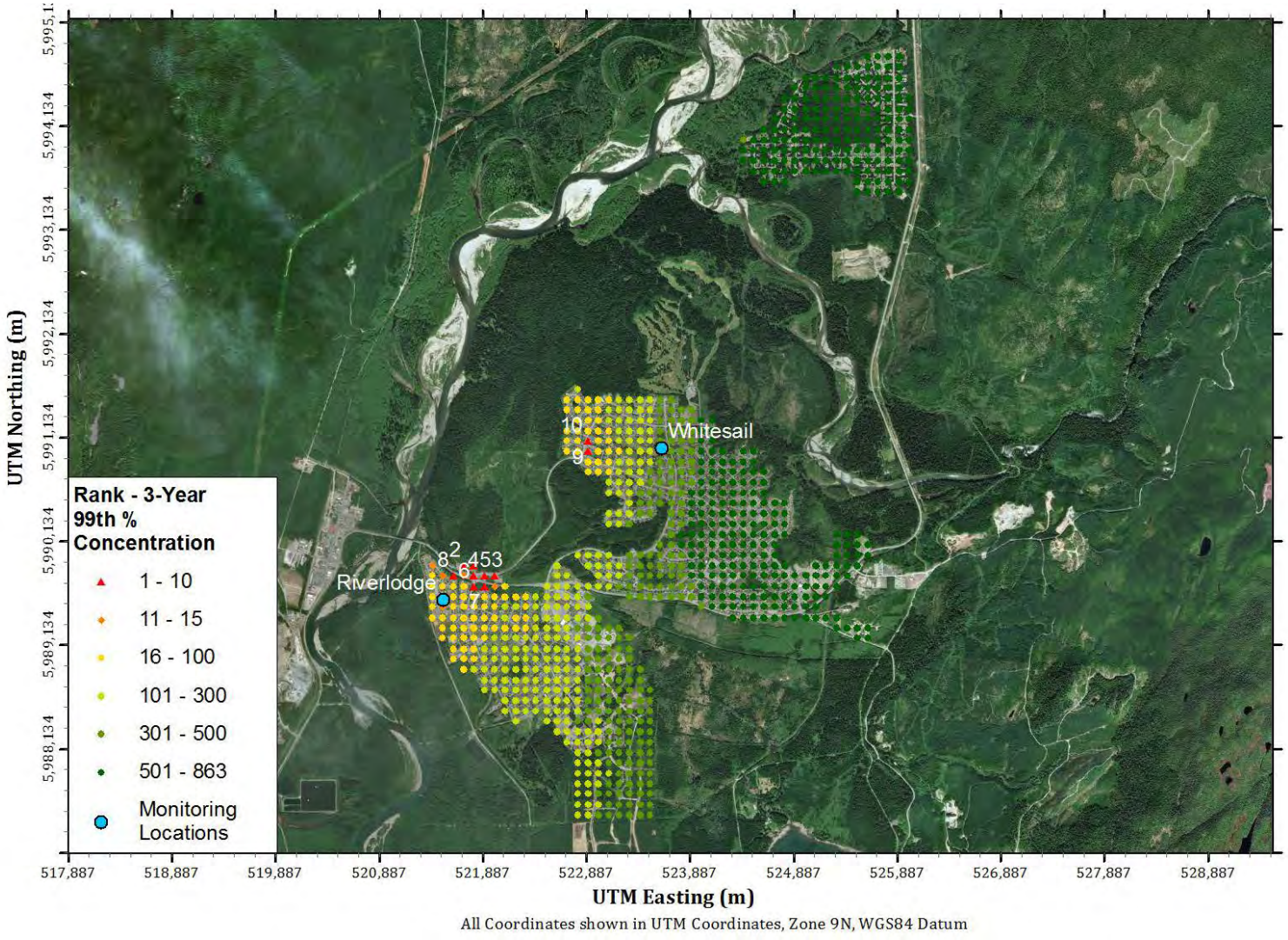


Figure A3-10. Network evaluation results, 2016-2018 meteorological data for Kitimat, *42 tpd scenario*, *ranking for only 99% daily 1-hour peak concentration*.

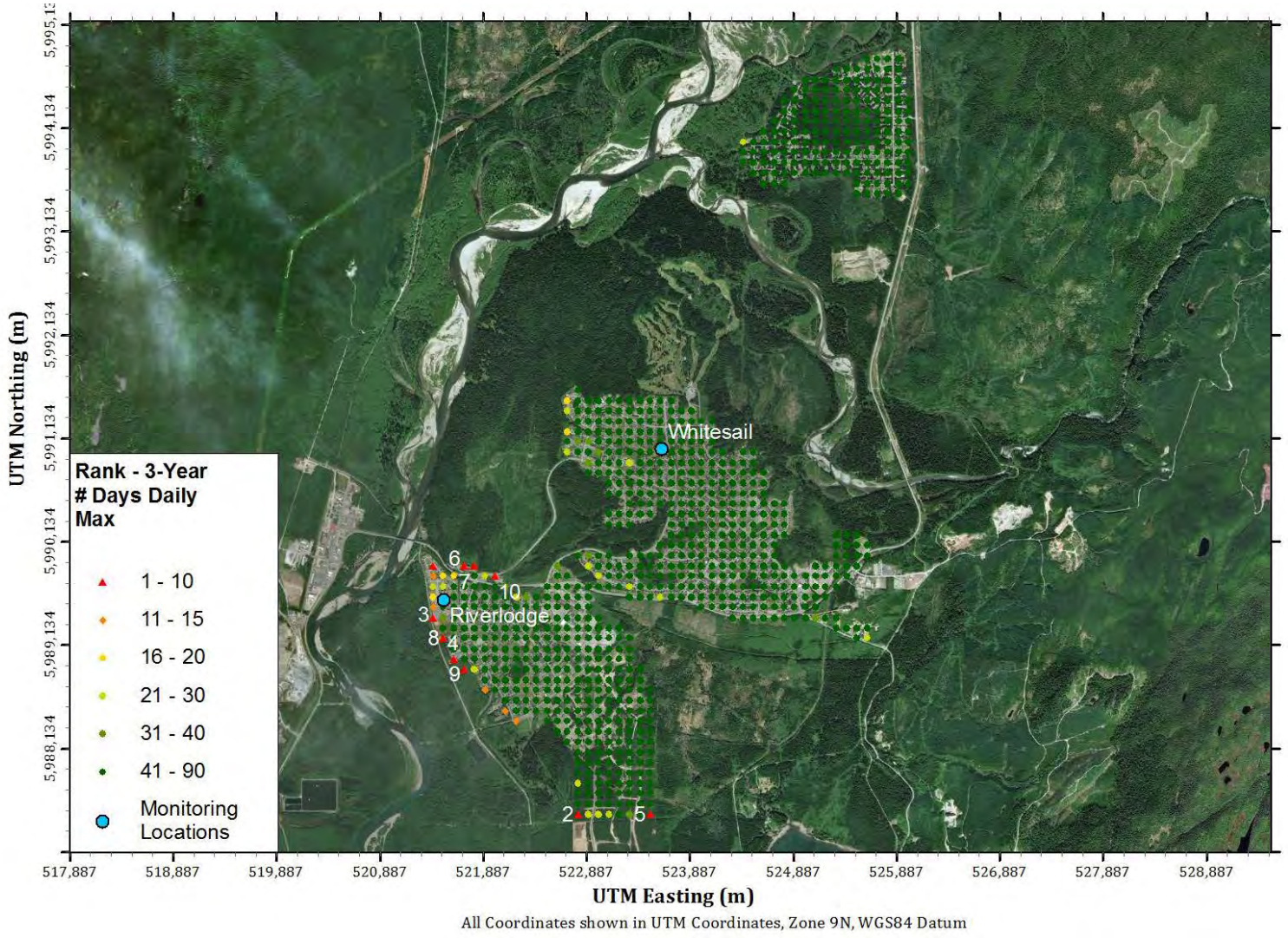


Figure A3-11. Network evaluation results, 2016-2018 meteorological data for Kitimat, *42 tpd scenario*, *ranking for only frequency at which the location is the highest among receptors*.

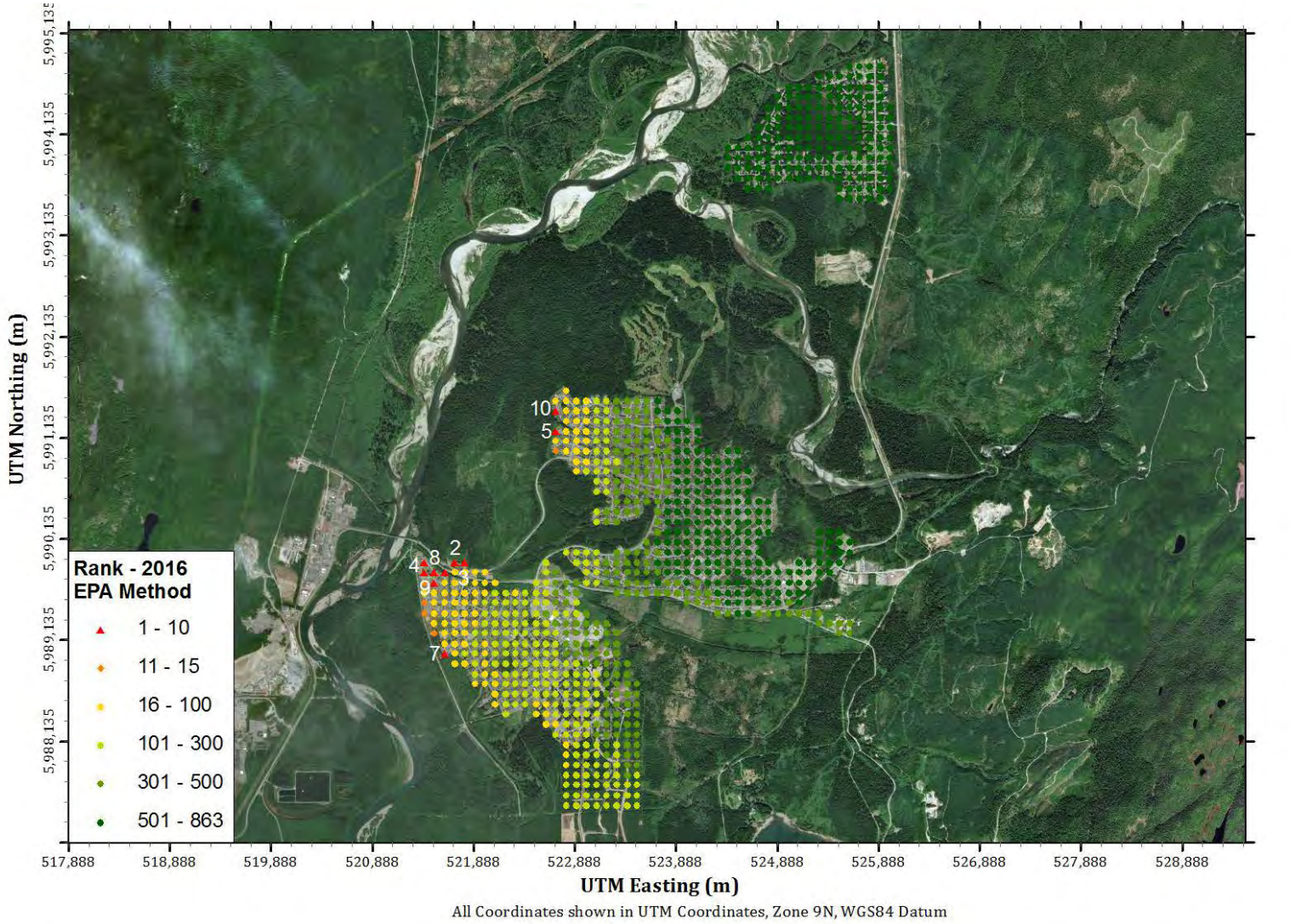


Figure A3-12. Network evaluation results, 2016 meteorological data for Kitimat, *42 tpd scenario*, considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.

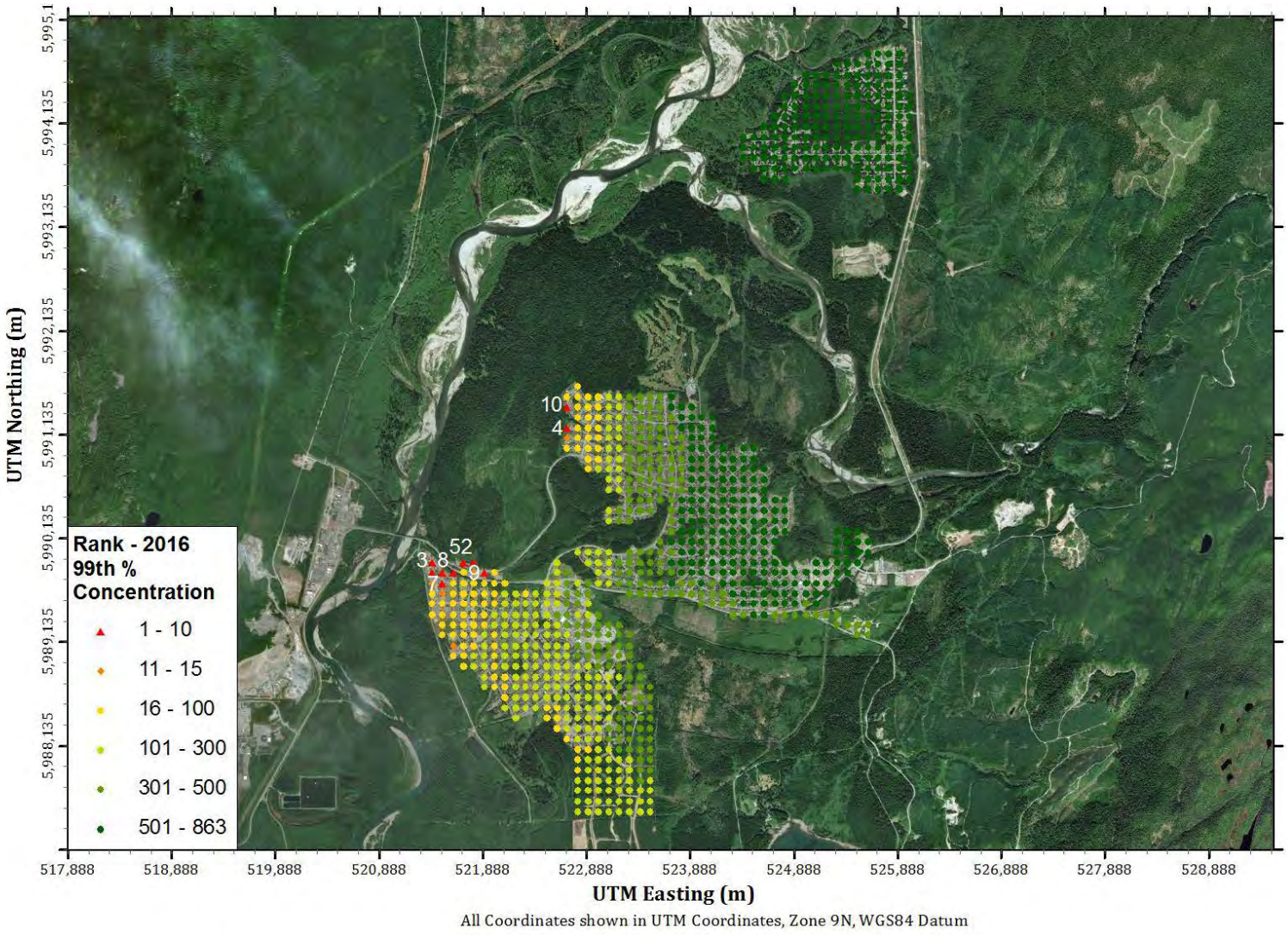


Figure A3-13. Network evaluation results, 2016 meteorological data for Kitimat, 42 tpd scenario, *ranking for only 99% daily 1-hour peak concentration*.

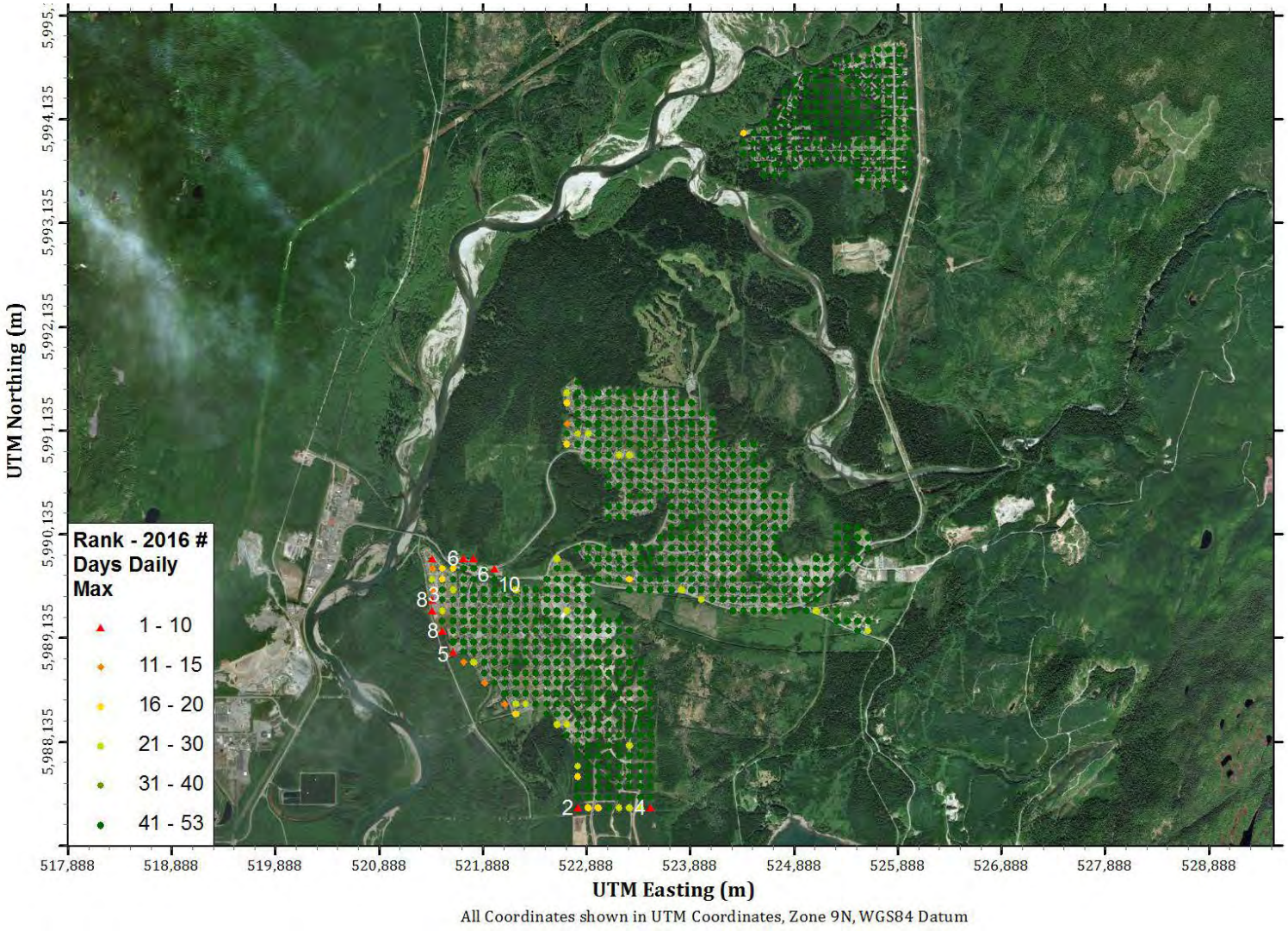


Figure A3-14. Network evaluation results, 2016 meteorological data for Kitimat, 42 tpd scenario, *ranking for only frequency at which the location is the highest among receptors.*

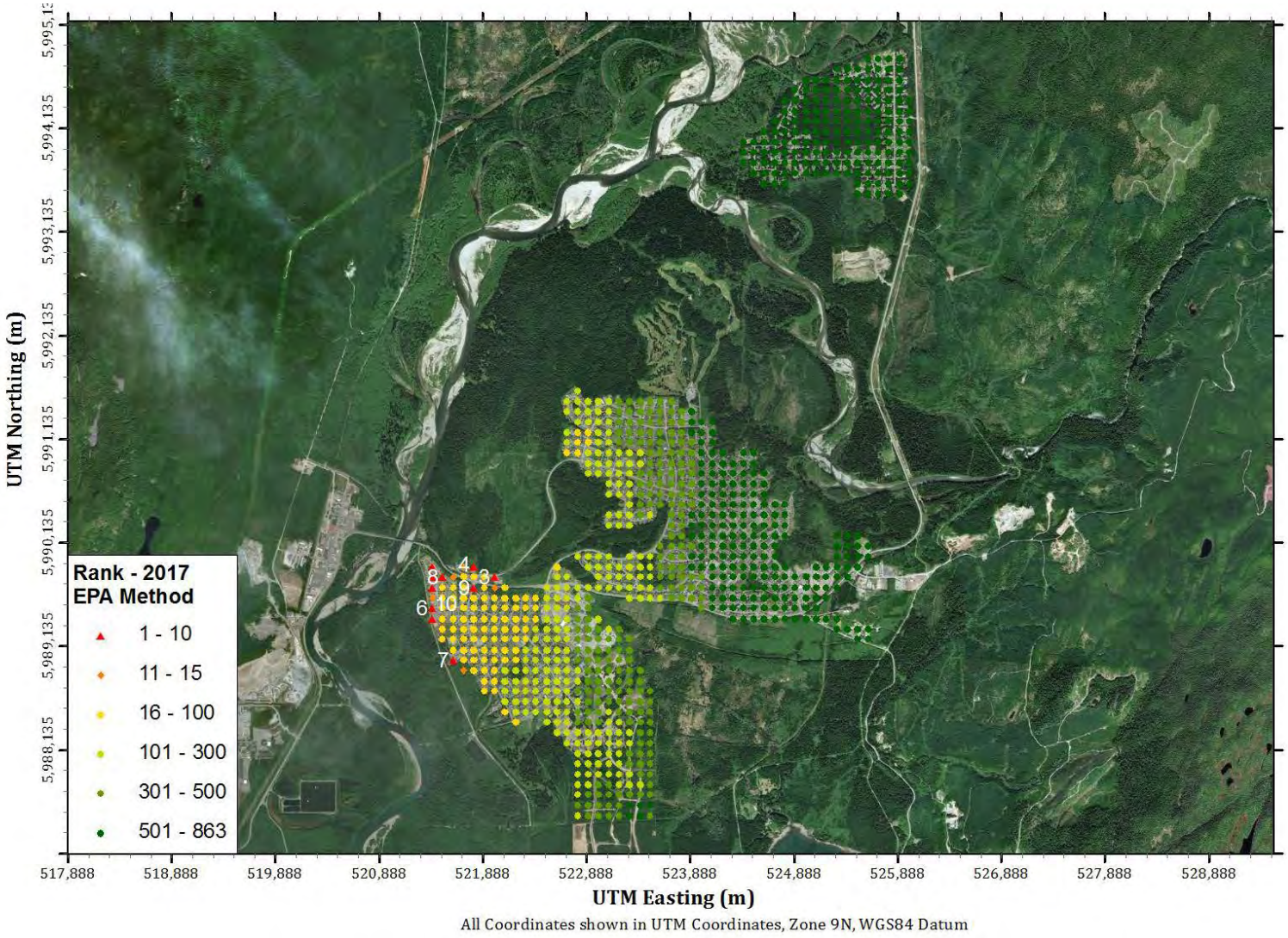


Figure A3-15. Network evaluation results, 2017 meteorological data for Kitimat, *42 tpd scenario*, considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.

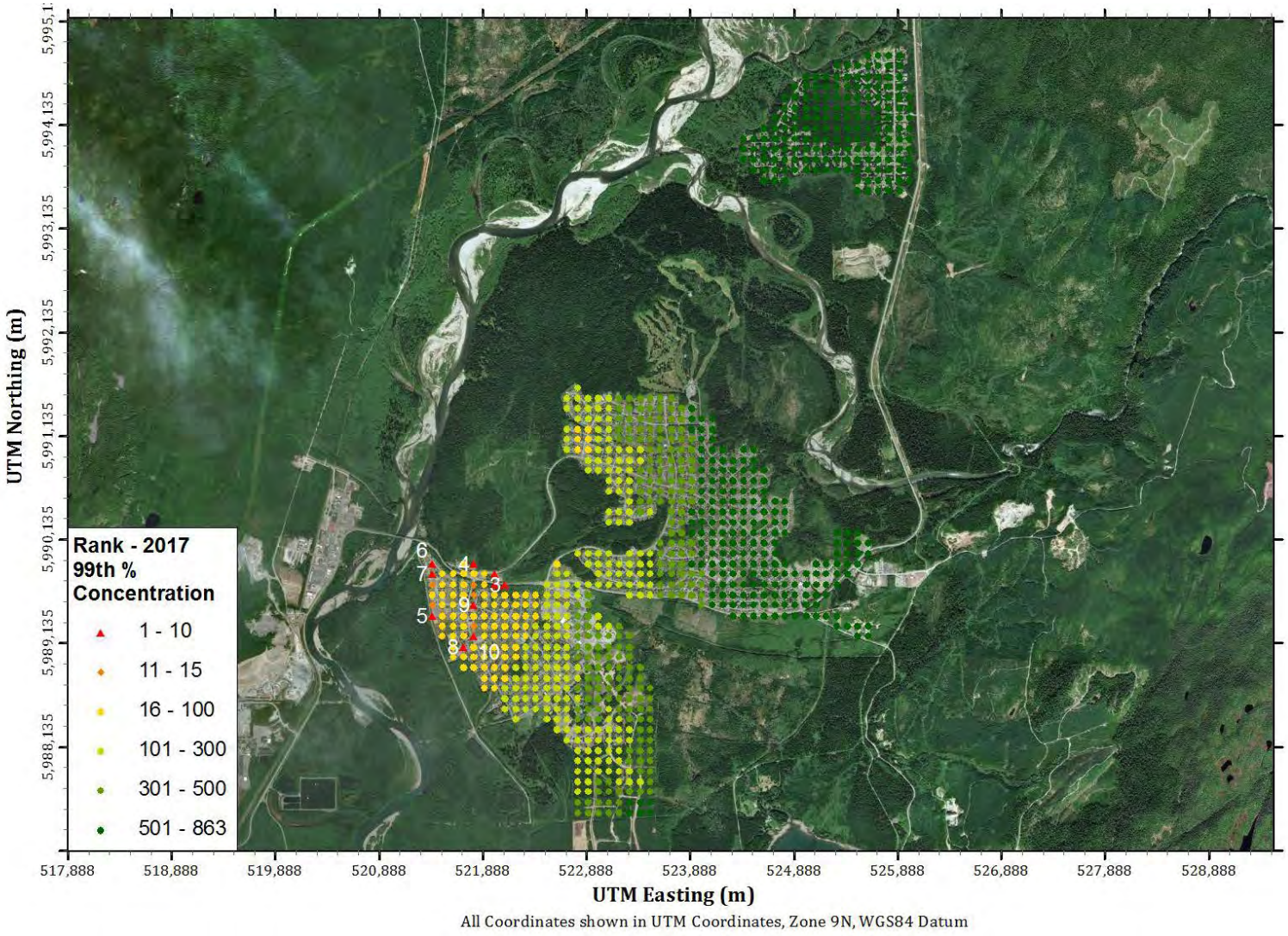


Figure A3-16. Network evaluation results, 2017 meteorological data for Kitimat, 42 tpd scenario, *ranking for only 99% daily 1-hour peak concentration*.

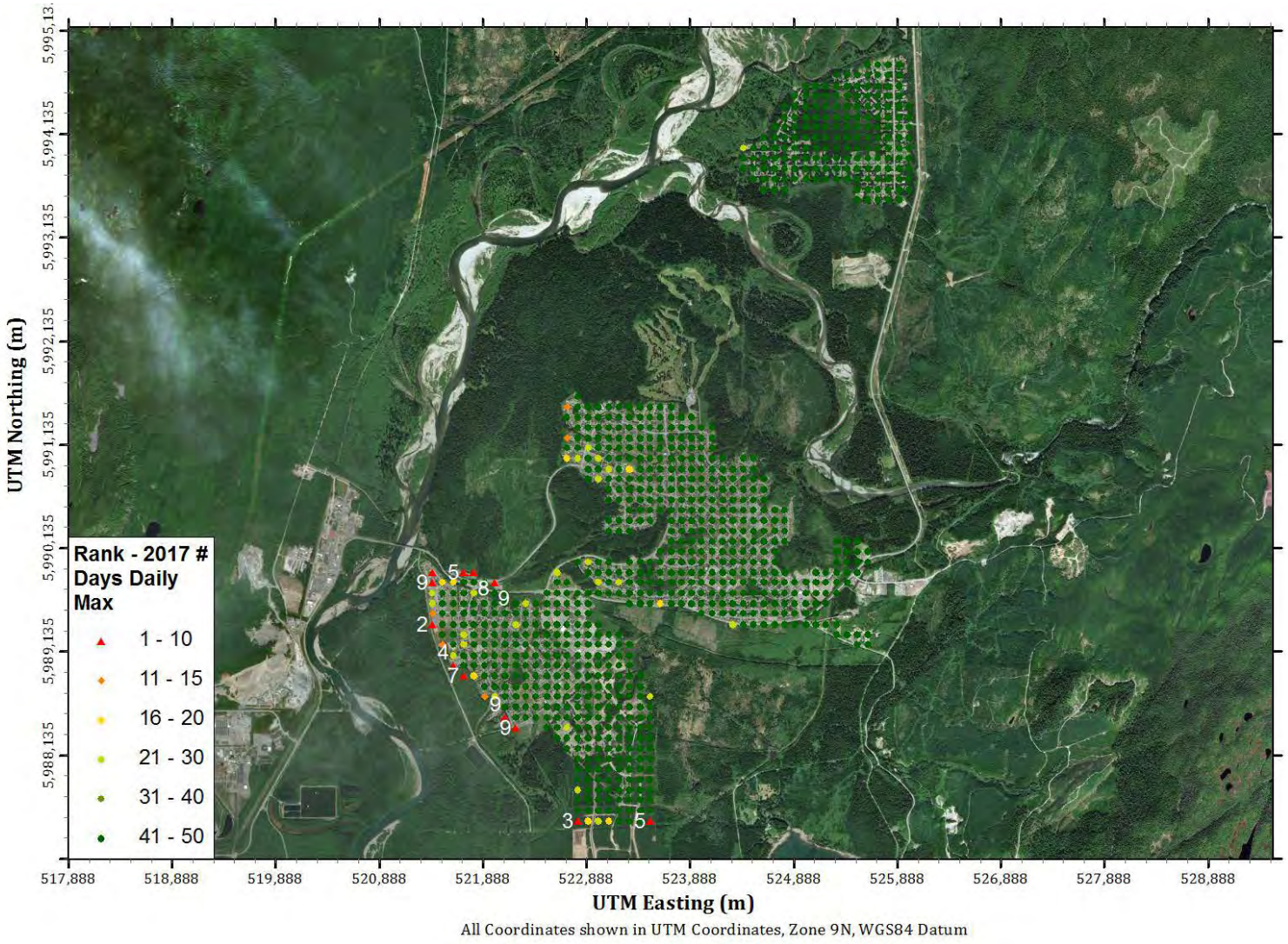


Figure A3-17. Network evaluation results, 2017 meteorological data for Kitimat, 42 tpd scenario, *ranking for only frequency at which the location is the highest among receptors.*

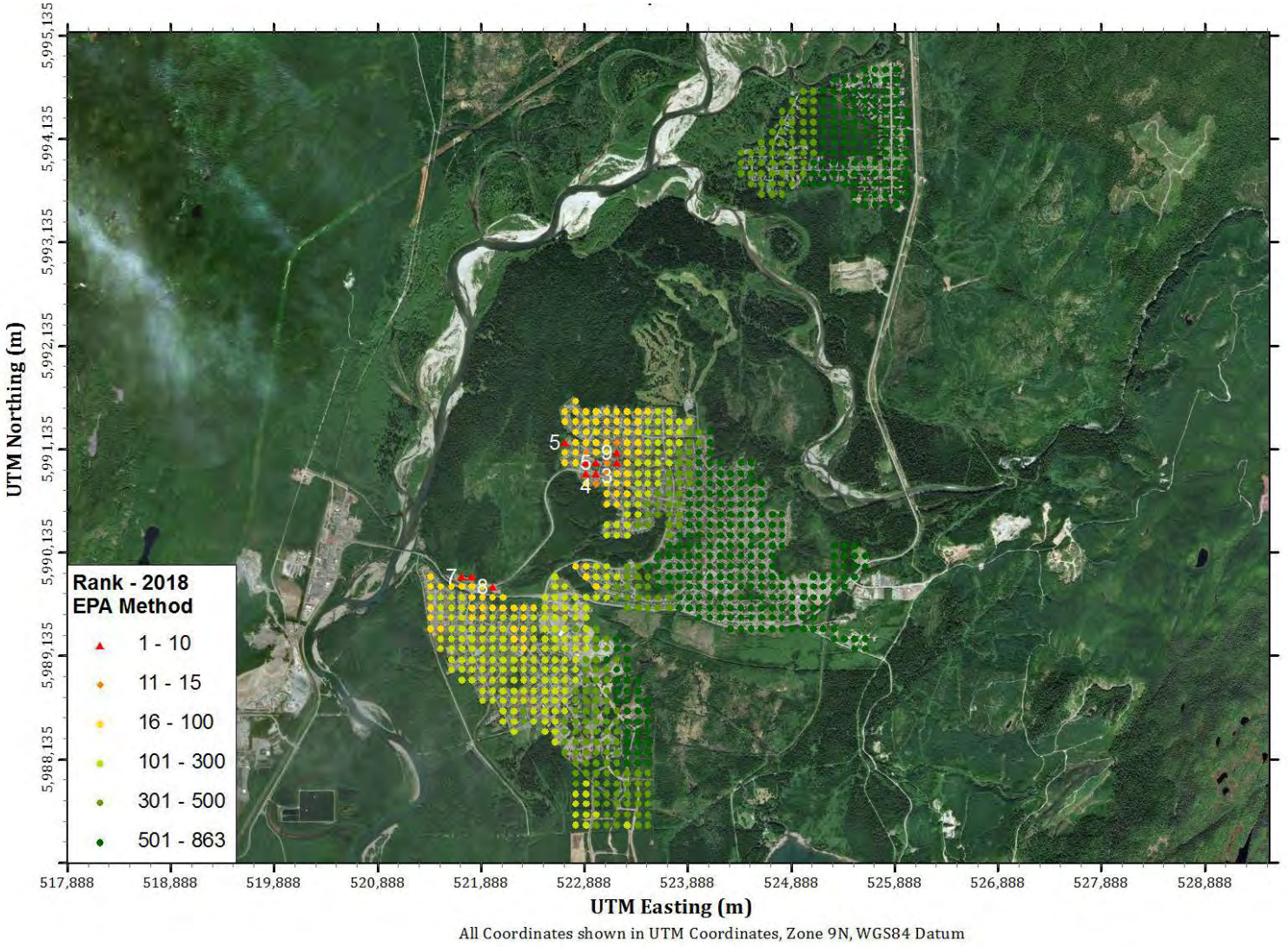


Figure A3-18. Network evaluation results, 2018 meteorological data for Kitimat, 42 tpd scenario, considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.

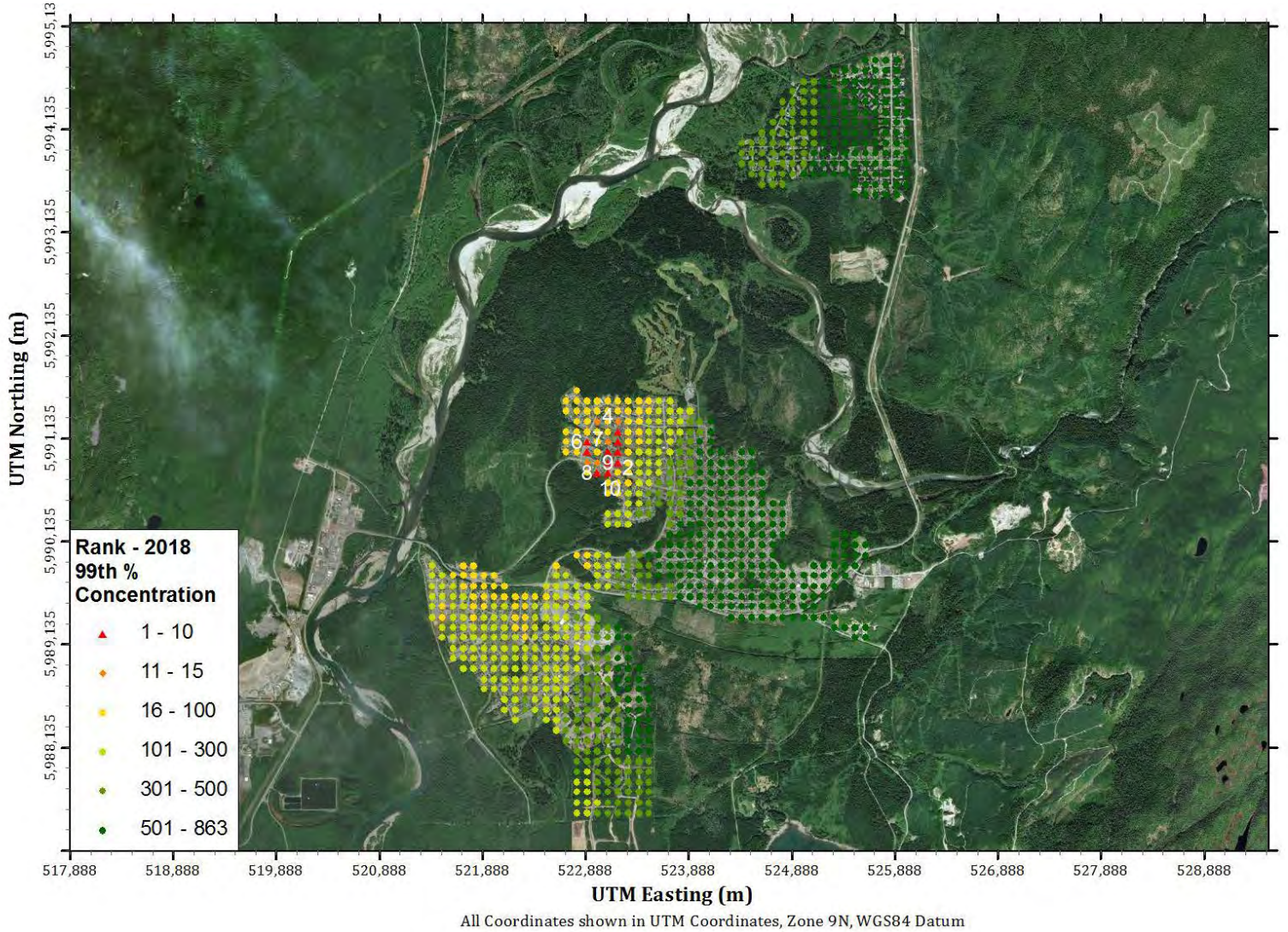


Figure A3-19. Network evaluation results, 2018 meteorological data for Kitimat, 42 tpd scenario, *ranking for only 99% daily 1-hour peak concentration*.

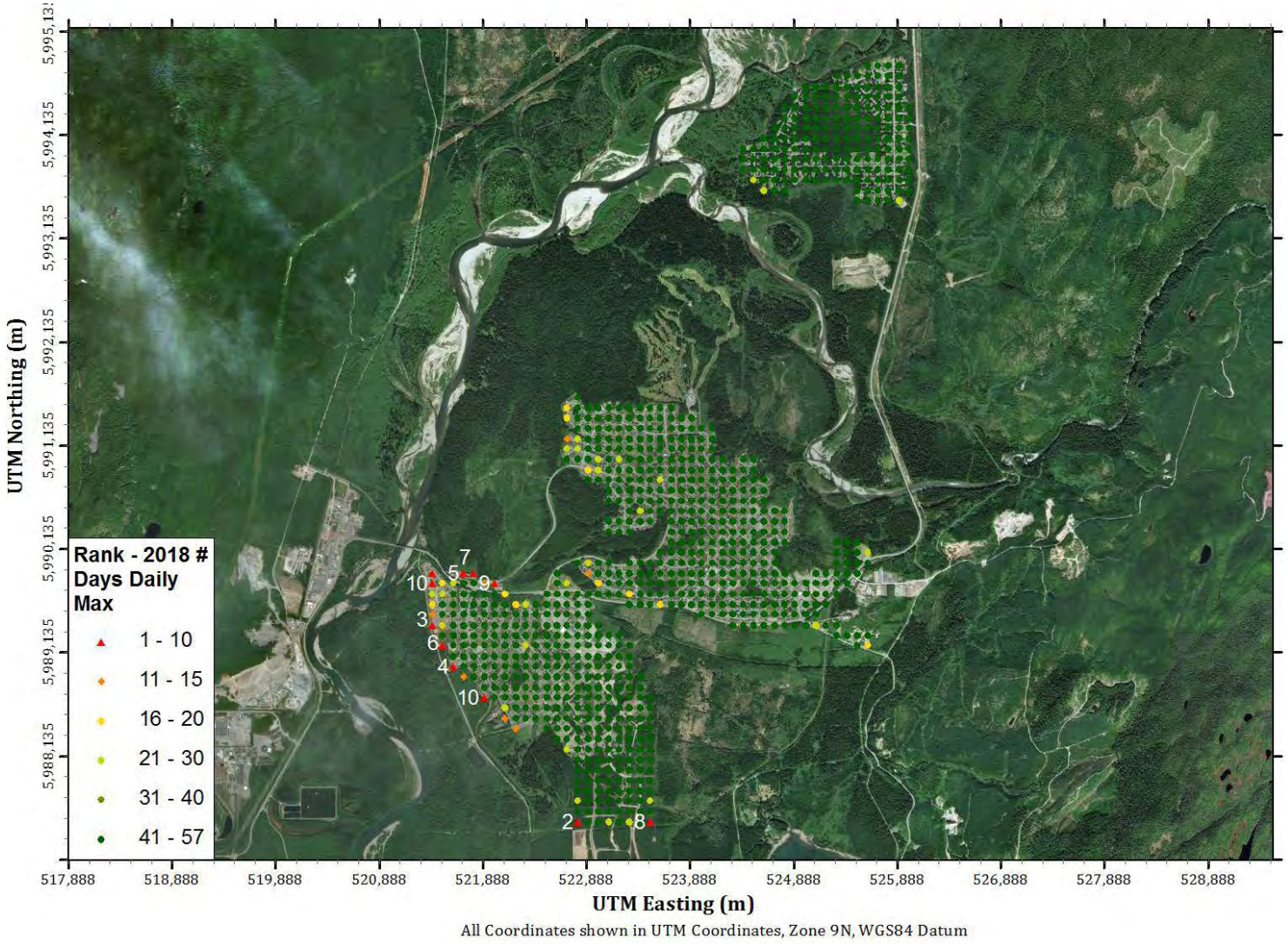


Figure A3-20. Network evaluation results, 2018 meteorological data for Kitimat, 42 tpd scenario, *ranking for only frequency at which the location is the highest among receptors.*

3.1.3.3 Kitimat network evaluation maps, Actual scenario

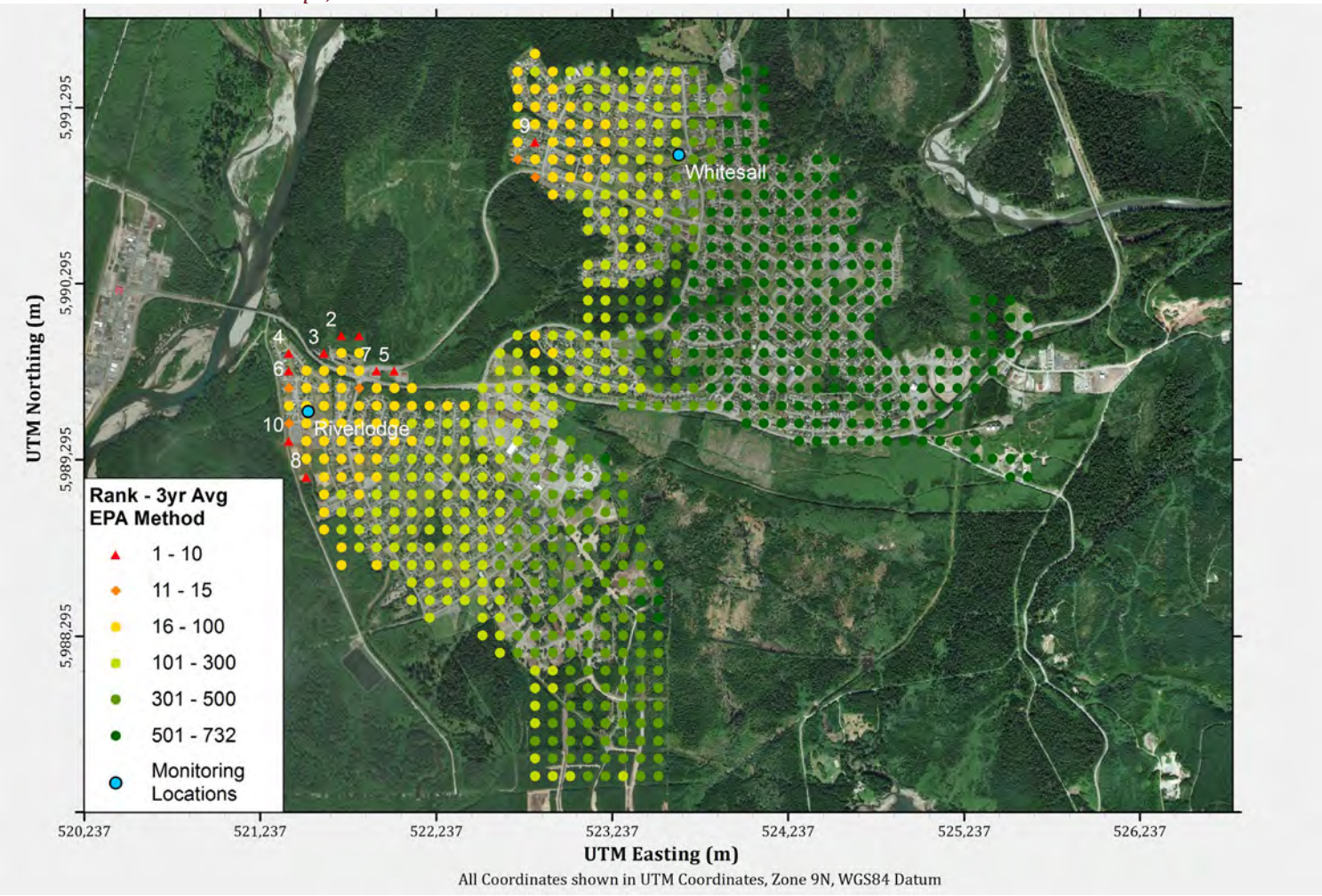


Figure A3-21. Network evaluation results, 2016-2018 meteorological data for Kitimat, *actual scenario (29.3 tpd)* , considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.
[Repeat of Figure 3-14 in main report for completeness.]

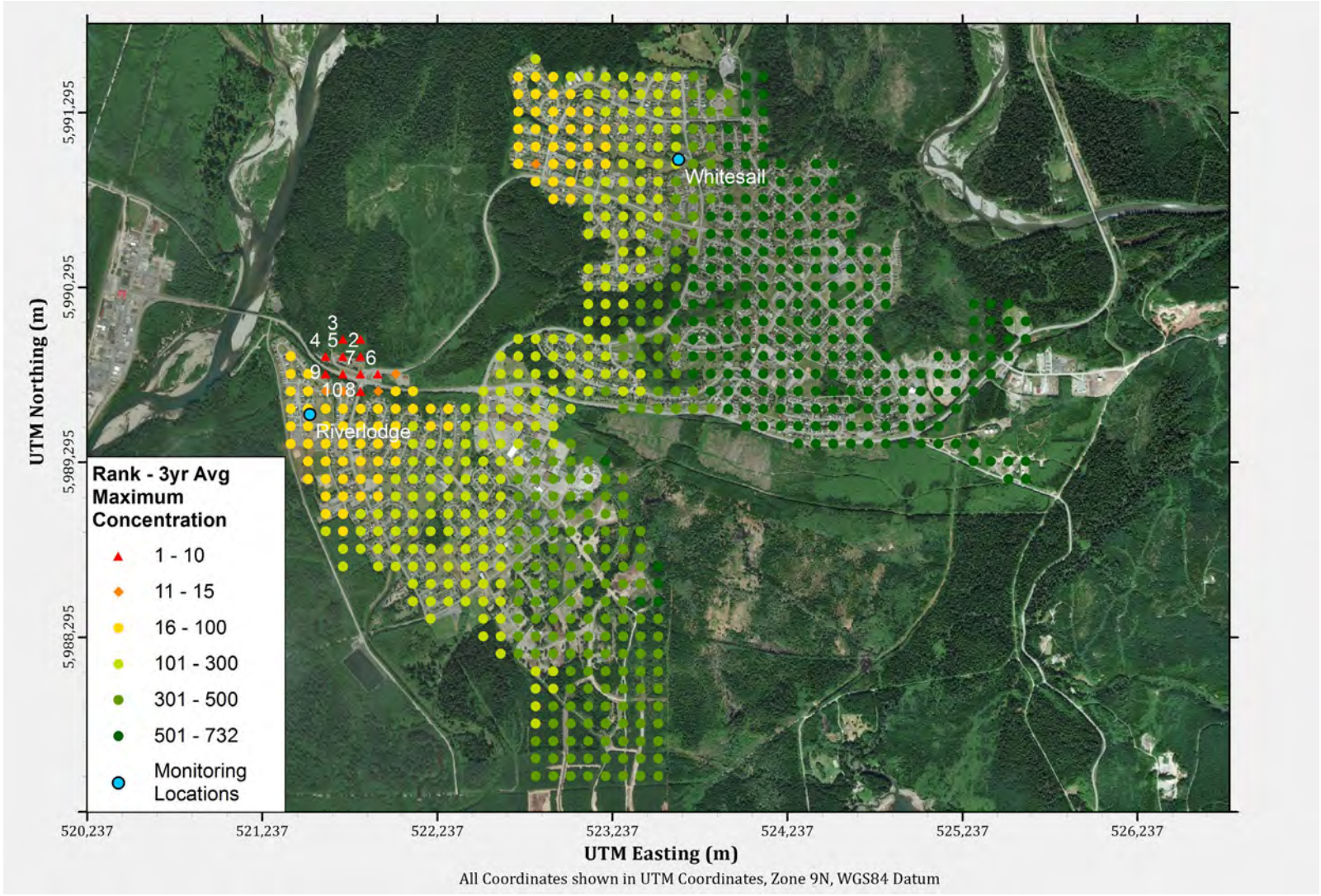


Figure A3-22. Network evaluation results, 2016-2018 meteorological data for Kitimat, *actual scenario (29.3 tpd)*, *ranking for only 99% daily 1-hour peak concentration*.

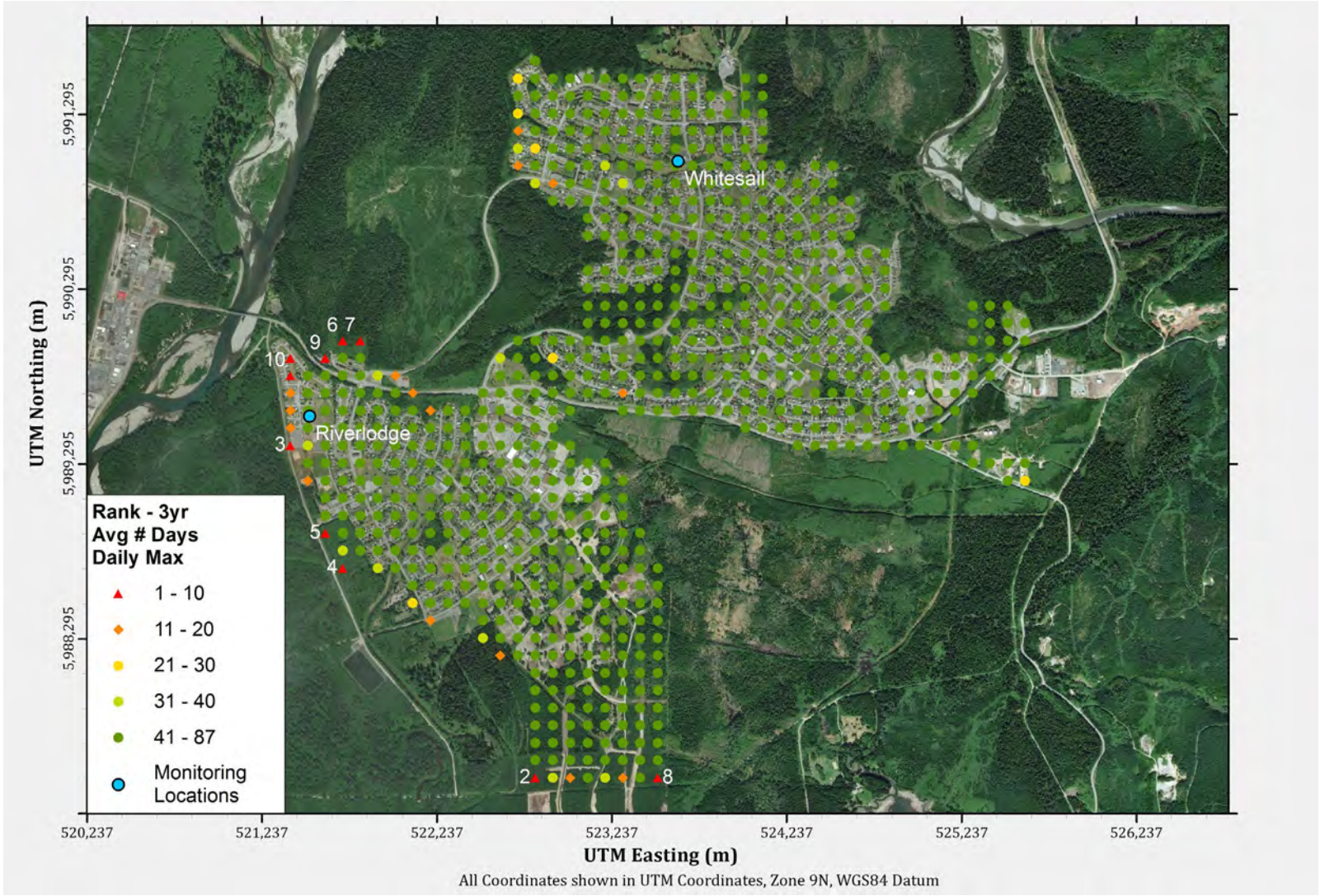


Figure A3-23. Network evaluation results, 2016-2018 meteorological data for Kitimat, *actual scenario (29.3 tpd)*, *ranking for only frequency at which the location is the highest among receptors*.

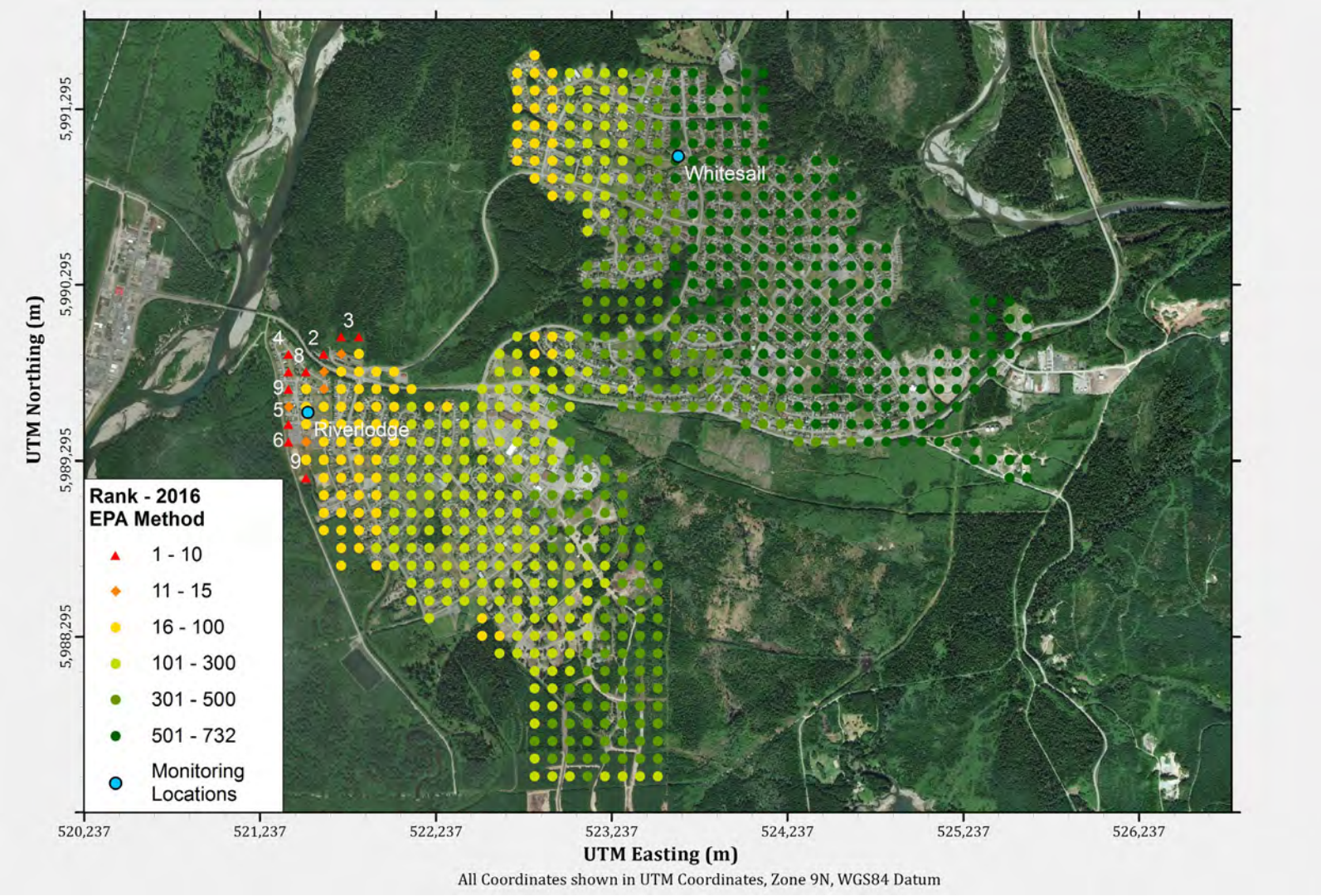


Figure A3-24. Network evaluation results, 2016 meteorological data for Kitimat, *actual scenario (29.3 tpd)* , considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.

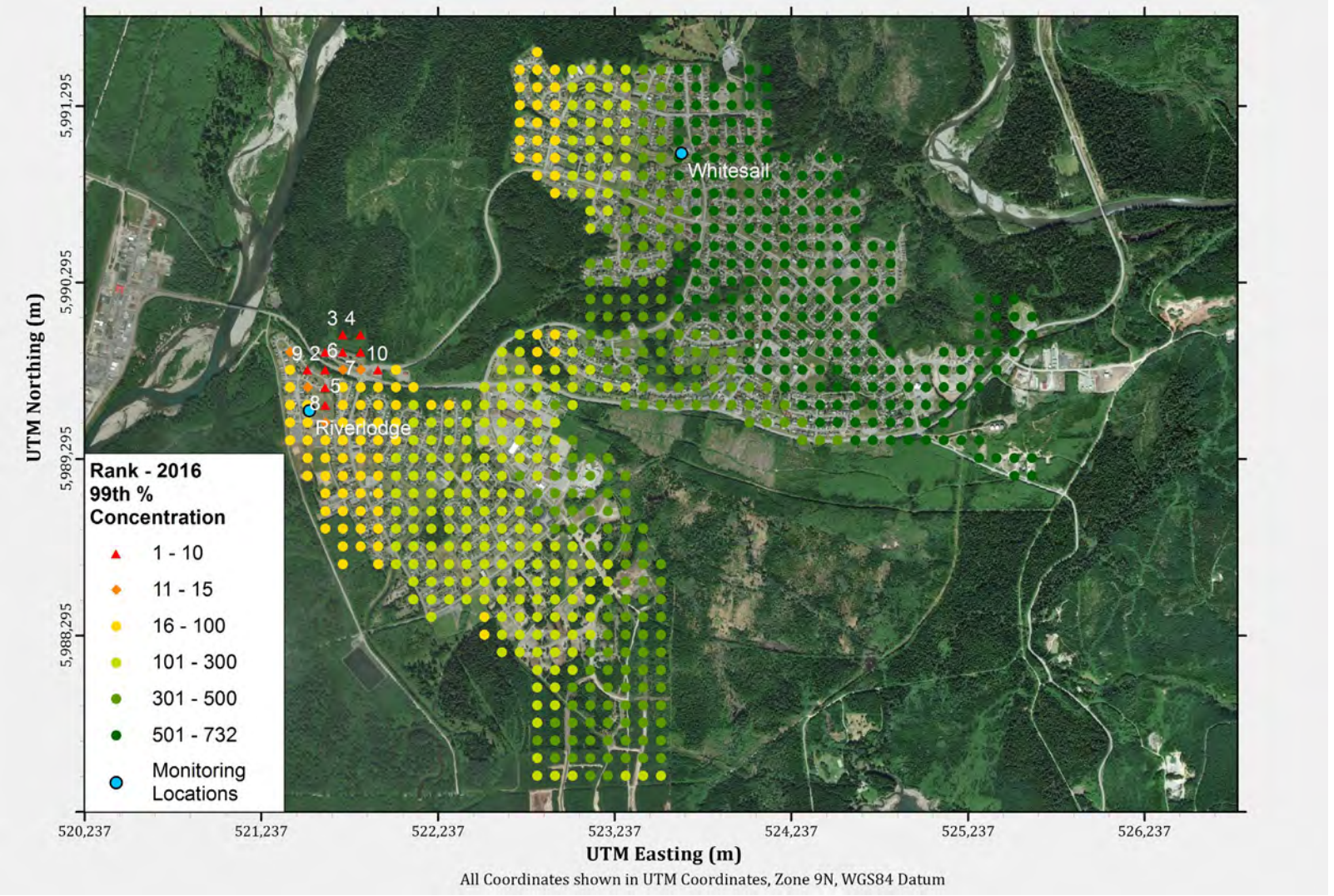


Figure A3-25. Network evaluation results, 2016 meteorological data for Kitimat, actual scenario (29.3 tpd), *ranking for only 99% daily 1-hour peak concentration*.

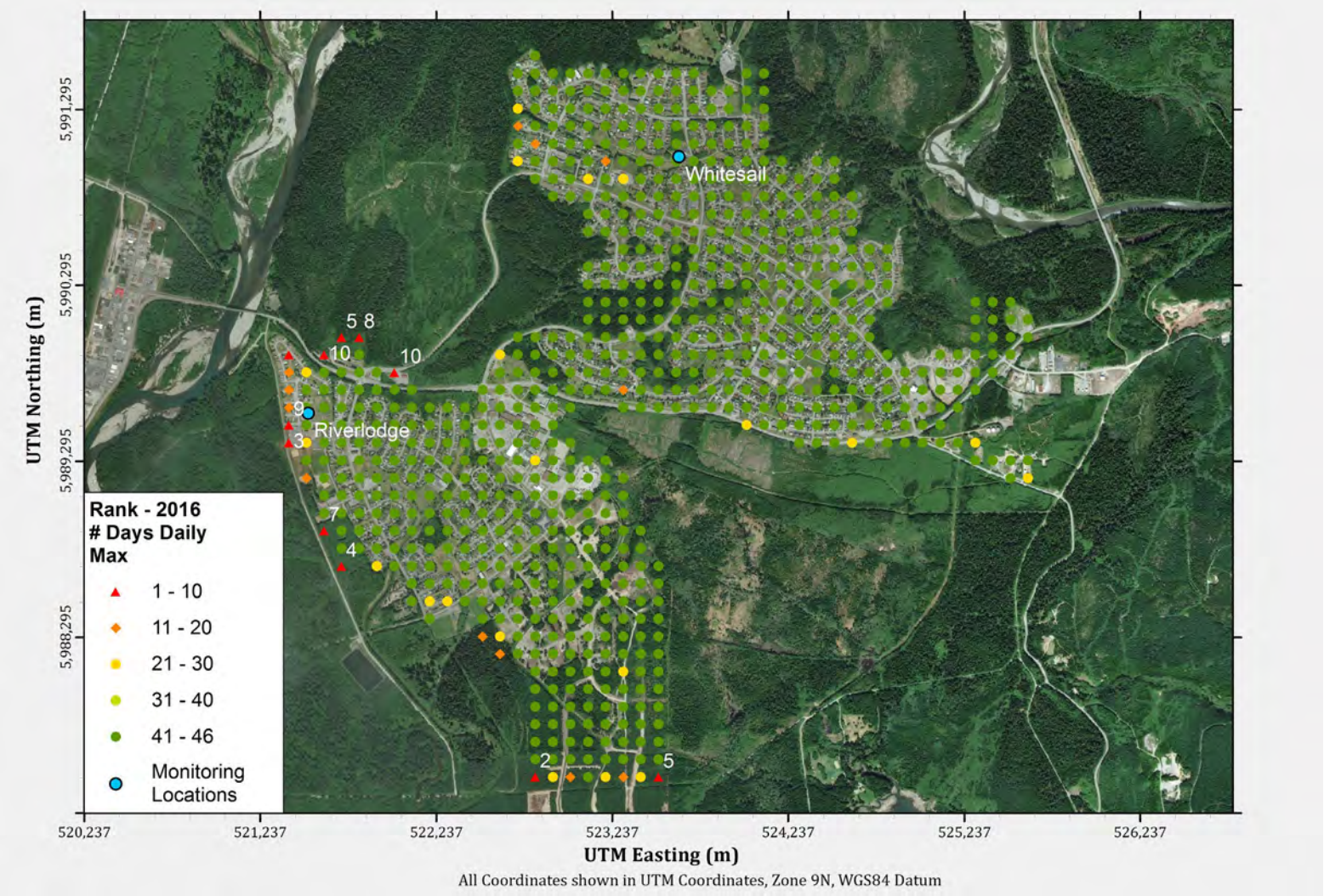


Figure A3-26. Network evaluation results, 2016 meteorological data for Kitimat, actual scenario (29.3 tpd), *ranking for only frequency at which the location is the highest among receptors.*

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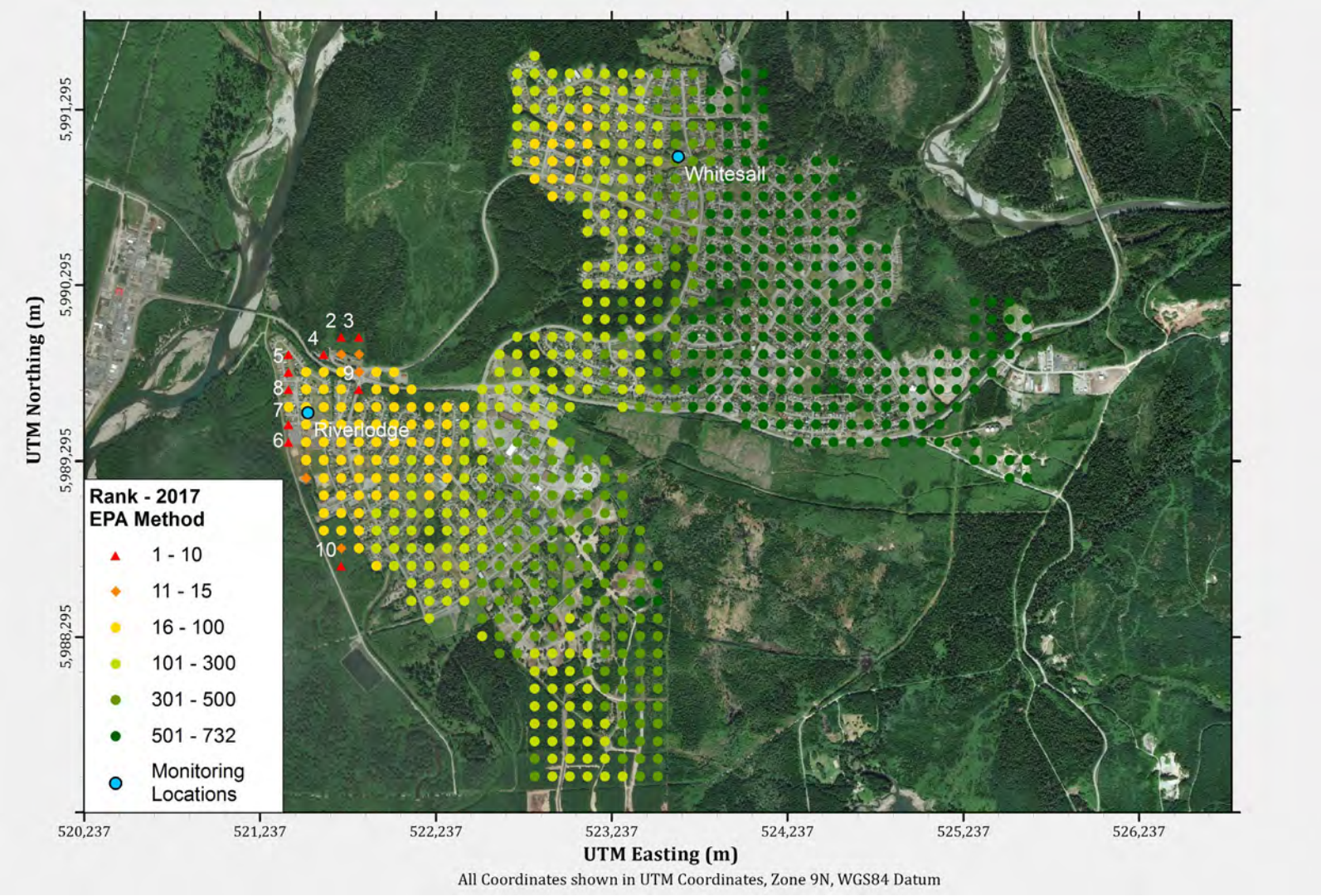


Figure A3-27. Network evaluation results, 2017 meteorological data for Kitimat, *actual scenario (29.3 tpd)*, considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.

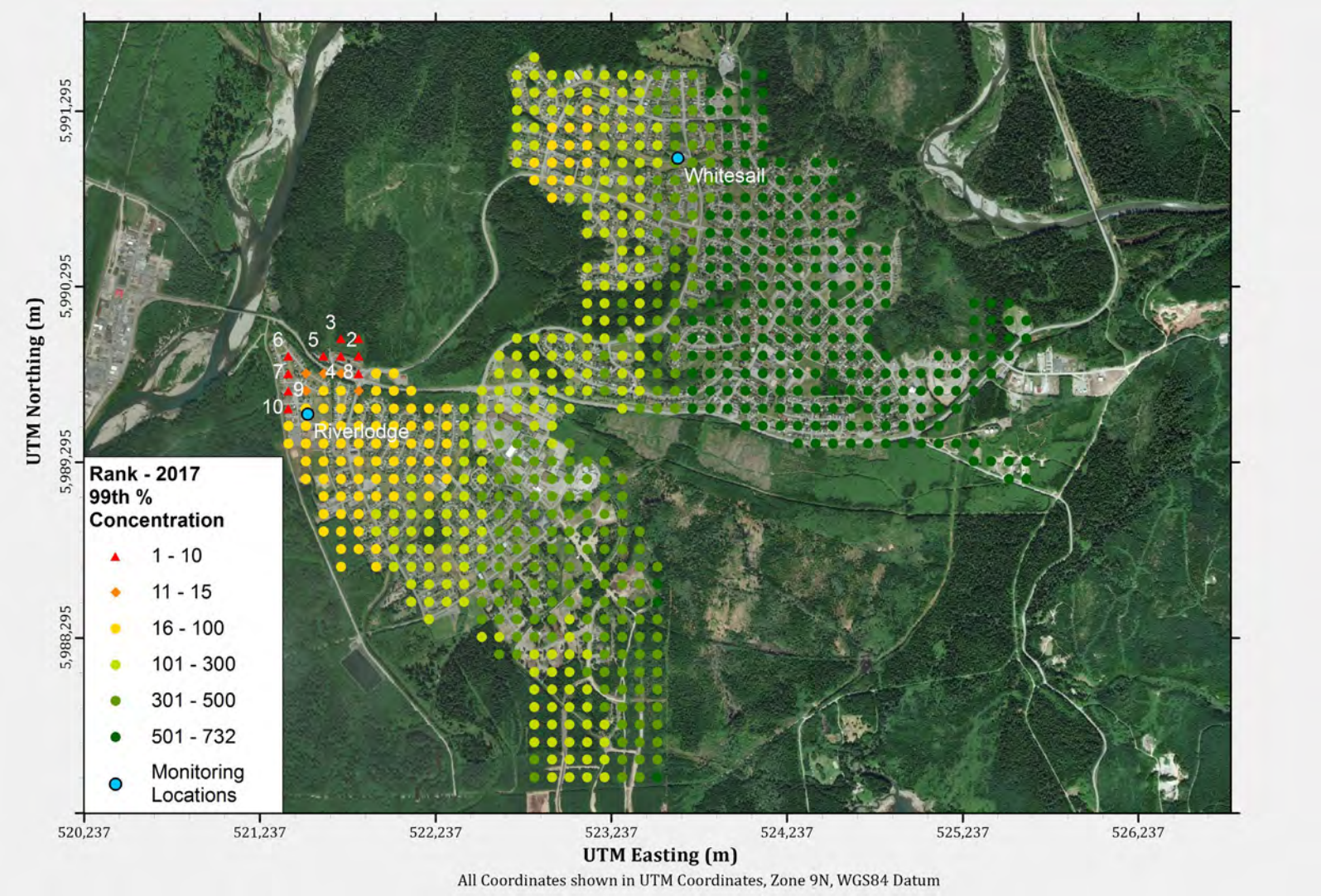


Figure A3-28. Network evaluation results, 2017 meteorological data for Kitimat, actual scenario (29.3 tpd), *ranking for only 99% daily 1-hour peak concentration*.

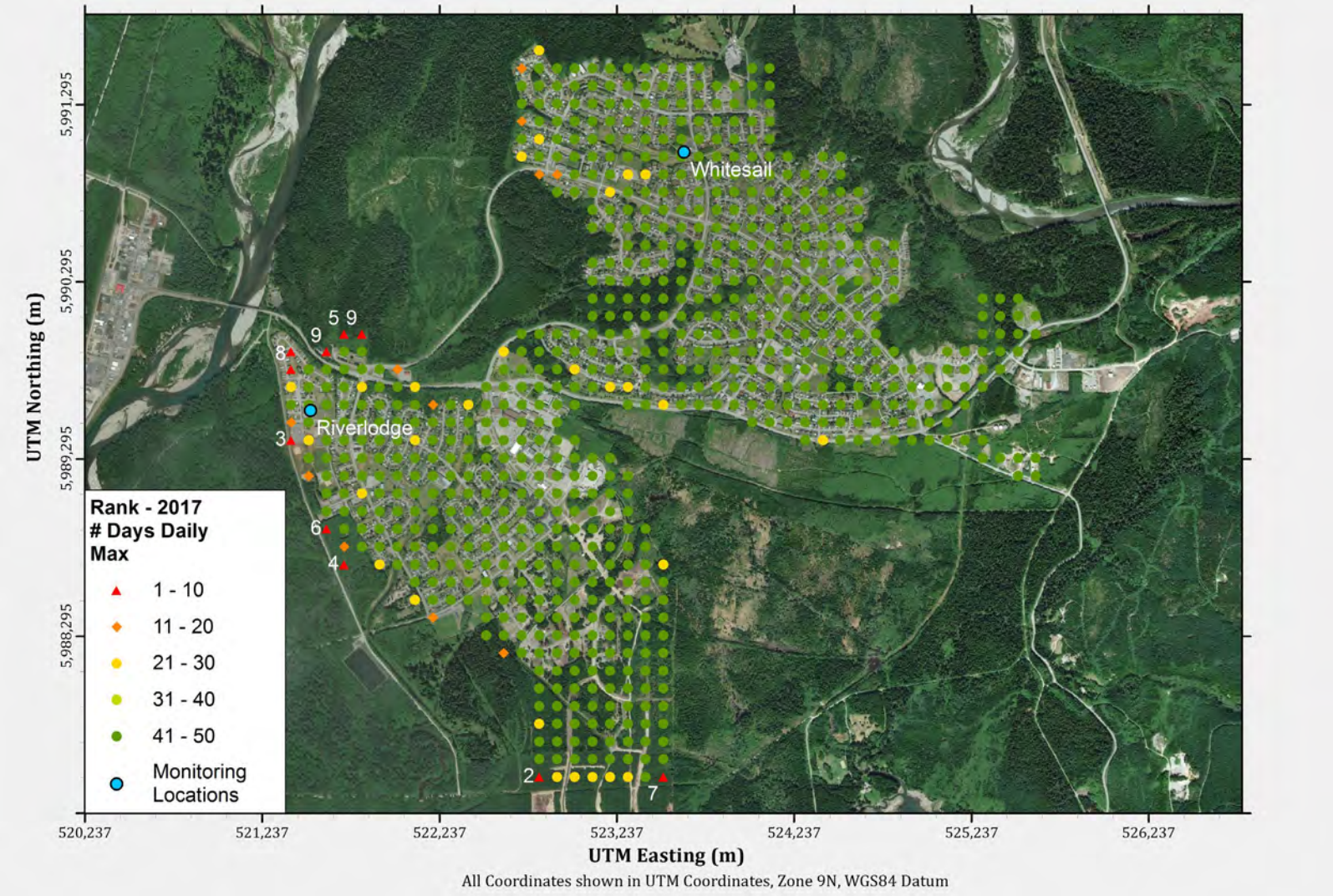


Figure A3-29. Network evaluation results, 2017 meteorological data for Kitimat, actual scenario (29.3 tpd), *ranking for only frequency at which the location is the highest among receptors.*

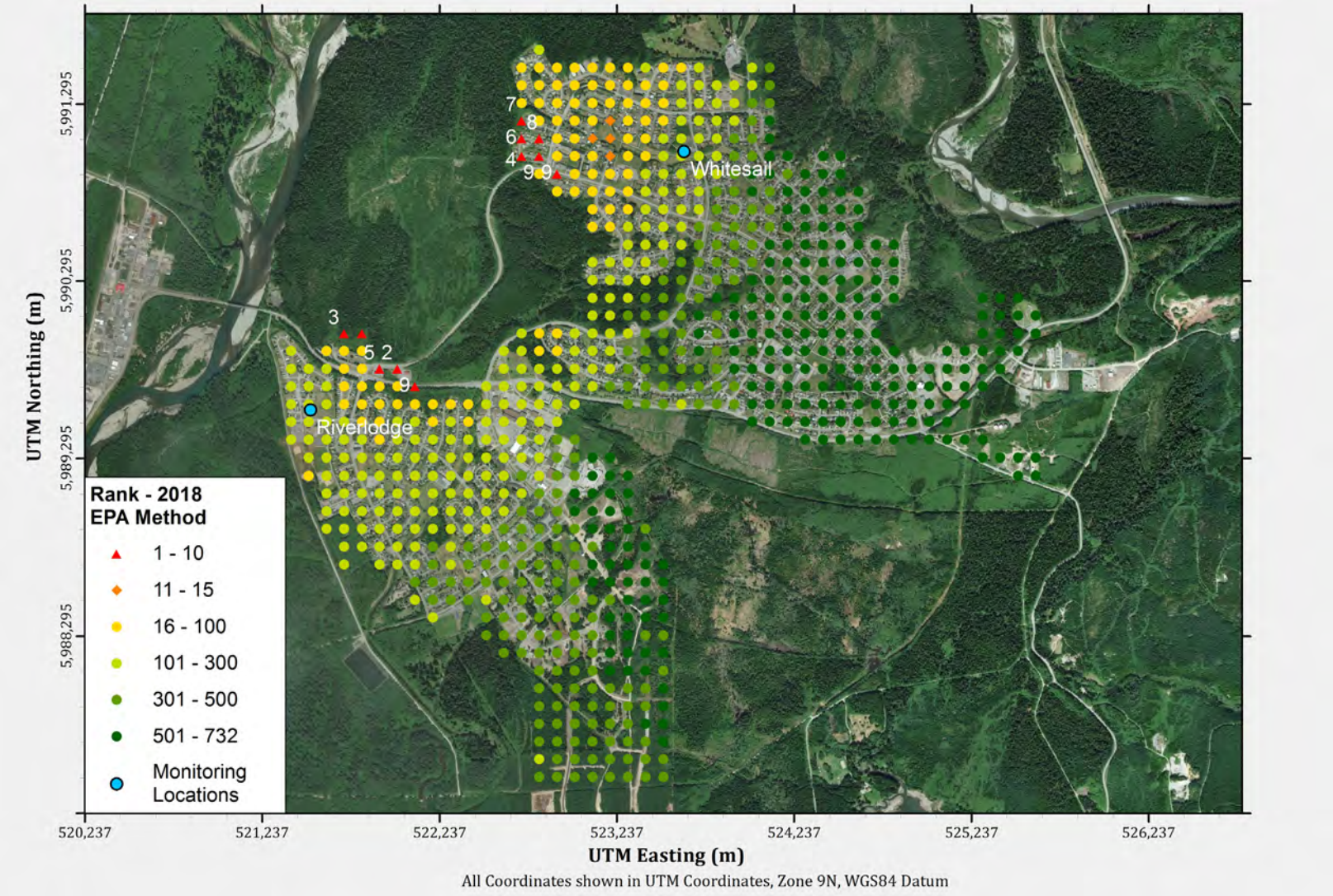


Figure A3-30. Network evaluation results, 2018 meteorological data for Kitimat, actual scenario (29.3 tpd), considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.

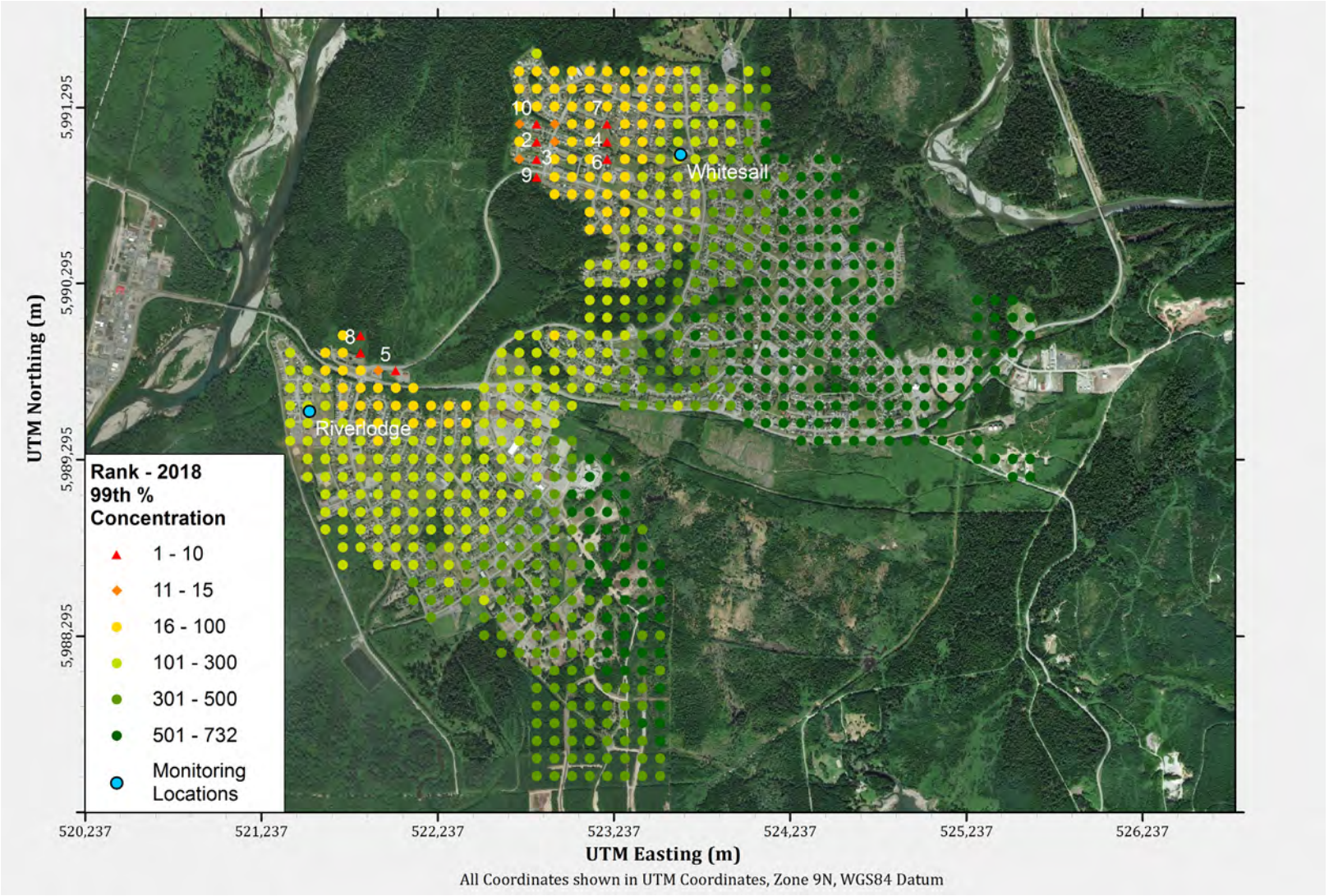


Figure A3-31. Network evaluation results, 2018 meteorological data for Kitimat, actual scenario (29.3 tpd), *ranking for only 99% daily 1-hour peak concentration*.

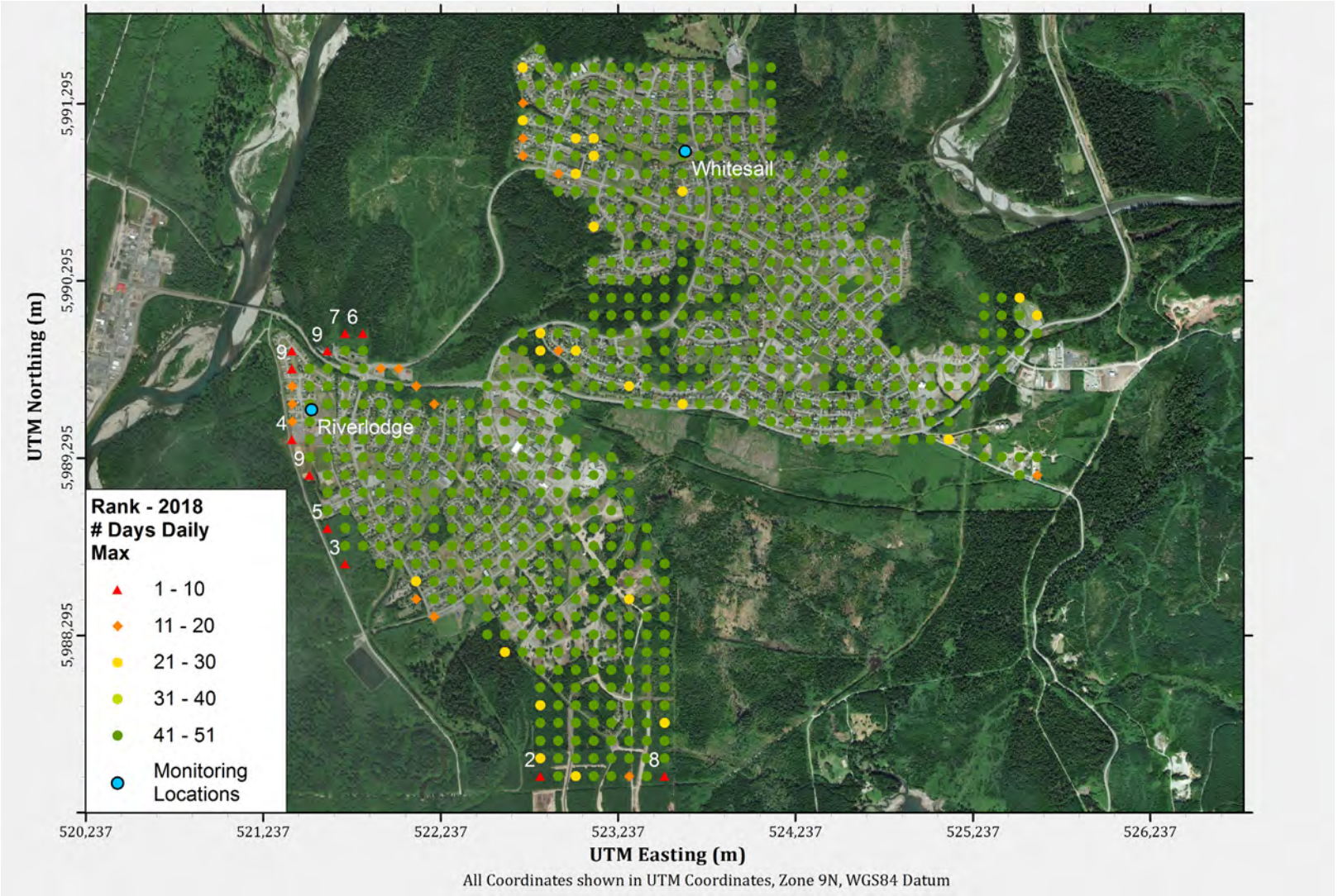


Figure A3-32. Network evaluation results, 2018 meteorological data for Kitimat, actual scenario (29.3 tpd), *ranking for only frequency at which the location is the highest among receptors.*

3.1.3.4 Kitamaat Village network evaluation maps, 42 tpd scenario

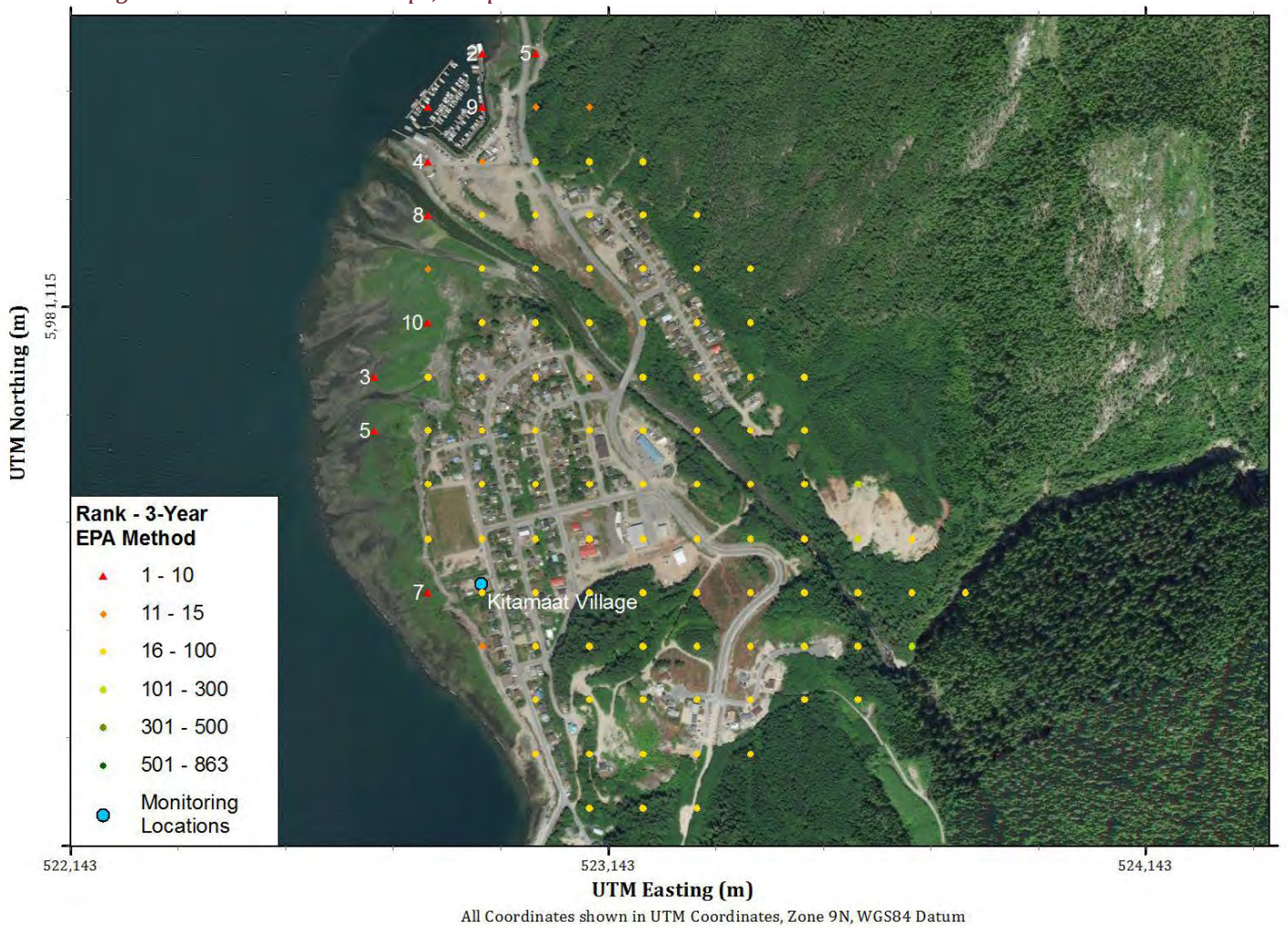


Figure A3-33. Network evaluation results, 2016-2018 meteorological data for Kitamaat Village, *42 tpd scenario*, considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.
[Repeat of Figure 3-14 in main report for completeness]



Figure A3-34. Network evaluation results, 2016-2018 meteorological data for Kitamaat Village, *42 tpd scenario*, *ranking for only 99% daily 1-hour peak concentration*.



Figure A3-35. Network evaluation results, 2016-2018 meteorological data for Kitamaat Village, *42 tpd scenario*, *ranking for only frequency at which the location is the highest among receptors*.



Figure A3-36. Network evaluation results, 2016 meteorological data for Kitamaat Village, *42 tpd scenario*, considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.



Figure A3-37. Network evaluation results, 2016 meteorological data for Kitamaat Village, 42 tpd scenario, *ranking for only 99% daily 1-hour peak concentration*.



Figure A3-38. Network evaluation results, 2016 meteorological data for Kitamaat Village, 42 tpd scenario, *ranking for only frequency at which the location is the highest among receptors.*



Figure A3-39. Network evaluation results, 2017 meteorological data for Kitamaat Village, *42 tpd scenario*, considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.



Figure A3-40. Network evaluation results, 2017 meteorological data for Kitamaat Village, 42 tpd scenario, *ranking for only 99% daily 1-hour peak concentration*.



Figure A3-41. Network evaluation results, 2017 meteorological data for Kitamaat Village, 42 tpd scenario, *ranking for only frequency at which the location is the highest among receptors.*



Figure A3-42. Network evaluation results, 2018 meteorological data for Kitamaat Village, 42 tpd scenario, considering *equal weighting* to 99% daily 1-hour peak concentration and frequency at which the location is the highest among receptors.



Figure A3-43. Network evaluation results, 2018 meteorological data for Kitamaat Village, 42 tpd scenario, *ranking for only 99% daily 1-hour peak concentration*.



Figure A3-44. Network evaluation results, 2018 meteorological data for Kitamaat Village, 42 tpd scenario, *ranking for only frequency at which the location is the highest among receptors.*

3.1.4 Passive sampler calibration

Passive SO_2 concentration data were calibrated to the continuous analyzers, the tables below show the calibration for the Kitimat Valley network based on the best fit line of passive and continuous data at Haul Road and Smeltersite (see Figure 3-8 in Section 3.1.3.2).

Table A3-2. Passive sulphur dioxide (SO_2) site ID, location (latitude, longitude), number of exposures (EXP), three-year average SO_2 (June–October) and annual Spring–Autumn (June–October) average during 2016, 2017 and 2018. All data are uncalibrated.

Site¥	Latitude	Longitude	EXP	SO_2 2016–2018	SO_2 2016	SO_2 2017	SO_2 2018
			n	µg/m³	µg/m³	µg/m³	µg/m³
A01	54.02931	–128.70192	13	10.59	8.80	10.79	11.80
A04	54.37721	–128.57734	12	0.73	0.61	0.76	0.79
V01	54.30437	–128.61655	11	1.93	1.81	1.93	2.03
V02	54.28593	–128.64471	10	1.58	1.47	1.38	1.83
V03	54.23226	–128.67892	9	3.05	3.02	4.25	2.52
V04	54.18131	–128.68178	11	1.33	0.93	2.05	1.33
V05	54.14140	–128.68559	11	4.32	3.17	4.86	4.73
V06	54.11443	–128.67961	11	3.30	2.30	3.21	4.23
V07	54.09294	–128.67343	9	1.50	1.35	1.91	0.88
V08	54.07872	–128.69531	9	5.47	3.94	5.85	6.81
V09	54.05111	–128.71008	11	7.30	4.74	7.01	9.72
V10	54.01693	–128.70958	10	9.53	7.20	10.42	11.06
V11	53.96473	–128.70387	11	10.71	7.75	12.34	11.28
V12	53.94320	–128.72061	11	6.81	5.06	7.31	7.69
V13	53.93831	–128.75015	7	7.29		7.50	7.04
V14	54.05997	–128.68704	10	3.05	2.09	3.17	3.52

¥ A represents ambient stations, and V represents the valley network sites; A01 is Haul Road and A04 is Lakelse Lake.

Table A3-3. Passive sulphur dioxide (SO_2) site ID, location (latitude, longitude), number of exposures (EXP), three-year average SO_2 (June–October) and annual Spring–Autumn (June–October) average during 2016, 2017 and 2018. All data are calibrated[$].

Site[¥]	Latitude	Longitude	EXP	SO_2 2016–2018	SO_2 2016	SO_2 2017	SO_2 2018
			n	µg/m³	µg/m³	µg/m³	µg/m³
A01	54.02931	–128.70192	13	11.71	9.85	11.91	12.96
A04	54.37721	–128.57734	12	1.50	1.38	1.54	1.57
V01	54.30437	–128.61655	11	2.74	2.62	2.74	2.85
V02	54.28593	–128.64471	10	2.39	2.27	2.18	2.65
V03	54.23226	–128.67892	9	3.90	3.88	5.14	3.36
V04	54.18131	–128.68178	11	2.12	1.71	2.87	2.12
V05	54.14140	–128.68559	11	5.22	4.03	5.78	5.64
V06	54.11443	–128.67961	11	4.16	3.13	4.07	5.13
V07	54.09294	–128.67343	9	2.30	2.14	2.72	1.66
V08	54.07872	–128.69531	9	6.40	4.82	6.80	7.79
V09	54.05111	–128.71008	11	8.30	5.65	8.00	10.80
V10	54.01693	–128.70958	10	10.61	8.19	11.53	12.19
V11	53.96473	–128.70387	11	11.83	8.77	13.51	12.41
V12	53.94320	–128.72061	11	7.80	5.98	8.31	8.71
V13	53.93831	–128.75015	7	8.29		8.51	8.03
V14	54.05997	–128.68704	10	3.90	2.91	4.03	4.39

¥ A represents ambient stations, and V represents the valley network sites; A01 is Haul Road and A04 is Lakelse Lake.
§ Calibrated SO_2 (µg/m³) = uncalibrated SO_2 (µg/m³) × 1.0344 + 0.7487

3.1.5 CALPUFF model methods details

Table A3-4 and Table A3-5 below present the model input parameters of each source of SO_2 at the Kitimat smelter. Point sources and line sources are shown in different tables because the CALPUFF model requires different information in order to simulate the plume rise and other dispersion model behavior from each source type. Table A3-6 and Table A3-7 show the modelled SO_2 emission rate of each source.

There are no other significant sources of SO_2 within the Kitimat airshed. Therefore, no other SO_2 sources are included in the model. In order to account for smaller regional sources of SO_2, baseline or background concentrations of 5.53 ppb (1hr) and 0.47 ppb (annual) from the Terrace Skeena Middle School monitor are added to model results to represent total future SO_2 concentrations. This approach of adding background concentrations based on Terrace monitoring is expected to over-predict SO_2 concentrations in non-populated areas because emissions of SO_2 from non-modelled sources (such as diesel burning engines) are much lower in non-populated areas. This approach would also double count any smelter emissions contributing to SO_2 at the Terrace monitor (however, smelter contribution of SO_2 at Terrace is expected to be very low).

For the 2016 – 2018 actual emission scenario, individual year data are used (i.e., 1-hour, 99th percentile daily peak SO_2 for 2016, 2017 and 2018 of 4.6, 5.9 and 6.1 ppb respectively), are added to each corresponding year). For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data. Williams Lake is the nearest SO_2 monitoring site with comparable population (about 10,000 population), located inland without industrial or marine sources of SO_2. Based on 2017 and 2018 data, the Williams Lake background SO_2 concentrations are 1.8 ppb for the 1-hour, 99th percentile daily peak and 0.26 ppb for the annual average.

Table A3-4. CALPUFF model point source input parameters

Source	Description	Location UTM East (km)	Location UTM North (km)	Height (m)	Base Elevation (m)	Diameter (m)	2018 [a] Gas Exit Velocity (m/s)	2018 [a] Stack Gas Exit Temp. (K)
PYRO	Pyroscrubber	519.774	5983.572	46.80	6.10	2.57	18.80	1244.85
COOLER	Cooler	519.718	5983.612	15.90	5.80	0.71	17.95	367.65
GTC_E	Gas Treatment Center East (GTC1)	519.559	5985.239	59.75	10.35	7.56	19.60	360.75
GTC_W	Gas Treatment Center West (GTC2)	519.441	5985.218	59.74	10.40	7.56	19.70	363.65
FTC	Fume Treatment Center (Anode Bake Furnace)	519.233	5985.429	50.37	15.95	2.18	15.20	377.65

[a] The exhaust gas velocity and temperature for future scenarios are based on the most recent (2018) stack test report. For 2016 and 2017 actual models, the parameters were based on the 2016 and 2017 stack test reports, respectively.

Table A3-5. CALPUFF model line source input parameters

Source	Description	South End Location UTM East (km)	South End Location UTM North (km)	North End Location UTM East (km)	North End Location UTM North (km)	Release Height (m)	Base Elevation (m)
1000_S	1000 South (Pot Line A, South)	519.674	5984.837	519.62	5985.11	23.05	10.10
1000_N	1000 North (Pot Line A, North)	519.619	5985.128	519.57	5985.41	23.05	10.10
2000_S	2000 South (Pot Line B, South)	519.605	5984.791	519.55	5985.10	23.05	10.10
2000_N	2000 North (Pot Line B, North)	519.550	5985.116	519.50	5985.39	23.05	10.10
3000_S	3000 South (Pot Line C, South)	519.553	5984.813	519.50	5985.08	23.05	10.10
3000_N	31000 North (Pot Line C, North)	519.501	5985.107	519.45	5985.39	23.05	10.10
4000_S	4000 South (Pot Line D, South)	519.484	5984.806	519.43	5985.07	23.05	10.10
4000_N	4000 North (Pot Line D, North)	519.432	5985.093	519.45	5985.38	23.05	10.10

Table A3-6. CALPUFF 35tpd and 42 tpd emission rates

Source	Description	Permitted Level at 42 t/d SO_2 (g/s)	Future Level at 35 t/d SO_2 (g/s)
PYRO	Pyroscrubber	106.25	84.60
COOLER	Cooler	8.24	6.56
GTC_E	Gas Treatment Center East (GTC1)	167.08	141.30
GTC_W	Gas Treatment Center West (GTC2)	167.08	141.30
FTC	Fume Treatment Center (Anode Bake Furnace)	34.09	28.48
1000_S	1000 South (Pot Line A, South)	0.42	0.36
1000_N	1000 North (Pot Line A, North)	0.42	0.36
2000_S	2000 South (Pot Line B, South)	0.42	0.36
2000_N	2000 North (Pot Line B, North)	0.42	0.36
3000_S	3000 South (Pot Line C, South)	0.42	0.36
3000_N	31000 North (Pot Line C, North)	0.42	0.36
4000_S	4000 South (Pot Line D, South)	0.42	0.36
4000_N	4000 North (Pot Line D, North)	0.42	0.36
Total Line Source (g/s)		**13.50**	**11.42**
Total Point Sources (g/s)		**482.74**	**402.24**
Total Facility-Wide (metric ton/day)		**42.00**	**35.00**

Table A3-7. CALPUFF actual emission rates

	Actual Monthly SO_2 Emissions – 2016											
Source	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**	**Jul-16**	**Aug-16**	**Sep-16**	**Oct-16**	**Nov-16**	**Dec-16**
	(g/s)	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**
PYRO	76.97	83.84	77.91	73.16	33.19	61.14	47.71	54.03	61.96	21.01	79.36	62.40
COOLER	5.97	6.50	6.04	5.68	2.58	4.74	3.70	4.19	4.81	1.63	6.16	4.84
GTC_E	73.68	96.69	113.52	113.86	123.99	119.61	112.65	112.66	115.44	114.66	105.84	112.36
GTC_W	73.68	96.69	113.52	113.86	123.99	119.61	112.65	112.66	115.44	114.66	105.84	112.36
FTC	25.37	18.38	23.56	36.04	33.69	30.40	35.04	15.28	19.99	43.95	64.49	57.95
1000_S	0.19	0.24	0.29	0.29	0.31	0.30	0.28	0.28	0.29	0.29	0.27	0.28
1000_N	0.19	0.24	0.29	0.29	0.31	0.30	0.28	0.28	0.29	0.29	0.27	0.28
2000_S	0.19	0.24	0.29	0.29	0.31	0.30	0.28	0.28	0.29	0.29	0.27	0.28
2000_N	0.19	0.24	0.29	0.29	0.31	0.30	0.28	0.28	0.29	0.29	0.27	0.28
3000_S	0.19	0.24	0.29	0.29	0.31	0.30	0.28	0.28	0.29	0.29	0.27	0.28
3000_N	0.19	0.24	0.29	0.29	0.31	0.30	0.28	0.28	0.29	0.29	0.27	0.28
4000_S	0.19	0.24	0.29	0.29	0.31	0.30	0.28	0.28	0.29	0.29	0.27	0.28
4000_N	0.19	0.24	0.29	0.29	0.31	0.30	0.28	0.28	0.29	0.29	0.27	0.28
Total (g/s)	**257.17**	**304.05**	**336.86**	**344.89**	**319.93**	**337.93**	**314.04**	**301.09**	**319.97**	**298.22**	**363.83**	**352.18**
Total (metric ton/day)	**22.22**	**26.27**	**29.10**	**29.80**	**27.64**	**29.20**	**27.13**	**26.01**	**27.65**	**25.77**	**31.44**	**30.43**

	Actual Monthly SO_2 Emissions - 2017											
Source	**Jan-17**	**Feb-17**	**Mar-17**	**Apr-17**	**May-17**	**Jun-17**	**Jul-17**	**Aug-17**	**Sep-17**	**Oct-17**	**Nov-17**	**Dec-17**
	(g/s)	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**
PYRO	54.62	69.77	60.81	64.05	13.77	73.28	76.92	86.95	65.19	12.29	43.33	48.34
COOLER	4.24	5.41	4.72	4.97	1.07	5.69	5.97	6.75	5.06	0.95	3.36	3.75
GTC_E	109.70	122.95	123.60	120.71	122.88	132.29	128.48	131.54	131.89	131.12	130.77	125.37
GTC_W	109.70	122.95	123.60	120.71	122.88	132.29	128.48	131.54	131.89	131.12	130.77	125.37
FTC	60.34	25.73	29.55	39.86	44.54	25.34	28.52	20.86	22.58	17.47	18.20	20.36
1000_S	0.28	0.31	0.31	0.30	0.31	0.33	0.32	0.33	0.33	0.33	0.33	0.32
1000_N	0.28	0.31	0.31	0.30	0.31	0.33	0.32	0.33	0.33	0.33	0.33	0.32
2000_S	0.28	0.31	0.31	0.30	0.31	0.33	0.32	0.33	0.33	0.33	0.33	0.32
2000_N	0.28	0.31	0.31	0.30	0.31	0.33	0.32	0.33	0.33	0.33	0.33	0.32
3000_S	0.28	0.31	0.31	0.30	0.31	0.33	0.32	0.33	0.33	0.33	0.33	0.32
3000_N	0.28	0.31	0.31	0.30	0.31	0.33	0.32	0.33	0.33	0.33	0.33	0.32
4000_S	0.28	0.31	0.31	0.30	0.31	0.33	0.32	0.33	0.33	0.33	0.33	0.32
4000_N	0.28	0.31	0.31	0.30	0.31	0.33	0.32	0.33	0.33	0.33	0.33	0.32
Total (g/s)	**340.81**	**349.30**	**344.77**	**352.74**	**307.62**	**371.56**	**370.96**	**380.28**	**359.28**	**295.59**	**329.06**	**325.72**
Total (metric ton/day)	**29.45**	**30.18**	**29.79**	**30.48**	**26.58**	**32.10**	**32.05**	**32.86**	**31.04**	**25.54**	**28.43**	**28.14**

	Actual Monthly SO_2 Emissions - 2018											
Source	**Jan-18**	**Feb-18**	**Mar-18**	**Apr-18**	**May-18**	**Jun-18**	**Jul-18**	**Aug-18**	**Sep-18**	**Oct-18**	**Nov-18**	**Dec-18**
	(g/s)	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**	**(g/s)**
PYRO	74.26	67.91	84.41	26.56	62.90	60.43	50.17	102.27	84.75	27.38	74.74	107.11
COOLER	5.76	5.27	6.55	2.06	4.88	4.69	3.89	7.93	6.58	2.12	5.80	8.31
GTC_E	125.07	124.16	121.03	121.64	120.32	117.72	130.65	133.22	133.22	132.78	120.45	125.39
GTC_W	125.07	124.16	121.03	121.64	120.32	117.72	130.65	133.22	133.22	132.78	120.45	125.39
FTC	13.41	25.16	34.15	18.57	22.44	32.23	25.54	39.89	44.22	20.49	12.70	29.76
1000_S	0.32	0.31	0.31	0.31	0.30	0.30	0.33	0.34	0.34	0.34	0.30	0.32
1000_N	0.32	0.31	0.31	0.31	0.30	0.30	0.33	0.34	0.34	0.34	0.30	0.32
2000_S	0.32	0.31	0.31	0.31	0.30	0.30	0.33	0.34	0.34	0.34	0.30	0.32
2000_N	0.32	0.31	0.31	0.31	0.30	0.30	0.33	0.34	0.34	0.34	0.30	0.32
3000_S	0.32	0.31	0.31	0.31	0.30	0.30	0.33	0.34	0.34	0.34	0.30	0.32
3000_N	0.32	0.31	0.31	0.31	0.30	0.30	0.33	0.34	0.34	0.34	0.30	0.32
4000_S	0.32	0.31	0.31	0.31	0.30	0.30	0.33	0.34	0.34	0.34	0.30	0.32
4000_N	0.32	0.31	0.31	0.31	0.30	0.30	0.33	0.34	0.34	0.34	0.30	0.32
Totals (g/s)	**346.10**	**349.16**	**369.61**	**292.92**	**333.28**	**335.17**	**343.54**	**419.22**	**404.67**	**318.23**	**336.56**	**398.50**
Total (metric ton/day)	**29.90**	**30.17**	**31.93**	**25.31**	**28.80**	**28.96**	**29.68**	**36.22**	**34.96**	**27.50**	**29.08**	**34.43**

Using the source inputs tabulated above, the CALPUFF model is run following the methods described in the detailed CALPUFF model plan, a copy of which is included in Section 3.1.9.

Figure A3-45 shows the local-scale receptors and property boundary of the Kitmat smelter. CALPUFF results denoted as offsite represent all locations on the boundary or anywhere outside the boundary shown in the figure.

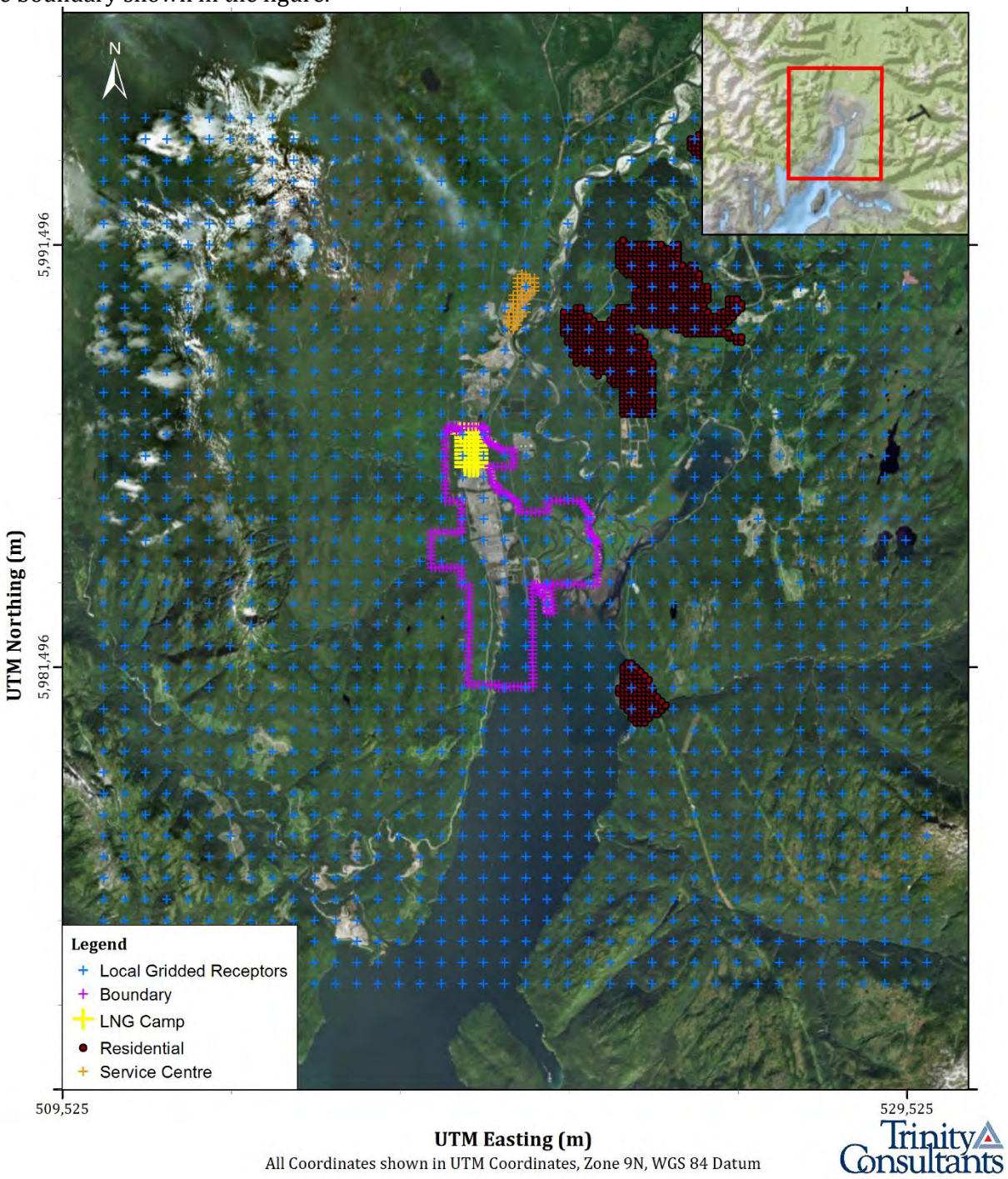


Figure A3-45. Kitimat Smelter local-scale and property receptors map.

3.1.6 Regional scale model performance evaluation

The SO_2 concentrations predicted by the new CALPUFF model for the actual scenario (actual emission rates, varying monthly) are compared to monitoring data to understand and evaluate the CALPUFF model performance. For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data. The lower, more realistic background values are needed for model evaluation, so we can better understand model performance in areas with low SO_2 concentrations. If the Terrace-Skeena background used for effects assessments had been used for model evaluation, the model results in low concentration areas would be skewed. For example, even if the model result had been zero, the comparison using Terrace-Skeena for background would have shown the model over-predicted annual average concentrations at Kitamaat Village and Whitesail, because the Terrace-Skeena annual average SO_2 concentrations were higher than the Kitamaat Village and Whitesail annual average concentrations.[4]

SO_2 concentration results are calculated by CALPUFF in units of micrograms per meter cubed ($\mu g/m^3$). However, this appendix often presents SO_2 results in units of parts per billion (ppb) in order to stay consistent with the monitoring data and the CAAQS. It is possible to move between ppb and $\mu g/m^3$ by a factor of 2.614 $(\mu g/m^3)/(ppb)$.[5]

In addition to the annual summary provided in the main report, evaluation of individual hourly results and maximum hourly summary results are also performed (Table A3-8 and Figure A3-46). The model over-predicted the 99th percentile of daily 1-hour peak concentration at all stations and years other than 2018 at Kitamaat Village. This one under prediction was only slightly lower (17 ppb model result compared to 18 ppb). For all other comparisons, the model over-predicted by 10% (2018 Riverlodge) to 51% (2016 Whitesail).[6]

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[4] The Terrace-Skeena annual average concentrations were 0.4 to 0.5 ppb in 2016 – 2018. The Kitamaat Village annual average concentrations were 0.20 to 0.38 ppb, and Whitesail annual average concentrations were 0.41 ppb in 2017 and 0.35 ppb in 2018.
Based on 2017 and 2018 data, the Williams Lake background concentrations are 1.8 ppb for the 1-hour, 99th percentile daily peak SO_2: 1.8 ppb; and 0.26 ppb for annual average.

[5] The 2.614 $(\mu g/m^3)/(ppb)$ factor converts from a mass concentration basis to a volume concentration basis of SO_2 based on the molecular weight of SO_2 and standard atmospheric conditions. In this case, standard conditions are 1 atm and approximately 25 C, precisely corresponding to the 1-hour SO_2 B.C. AQO levels listed of 70 ppb and 183 $\mu g/m^3$ (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/aqotable.pdf).

[6] Percentage under-prediction or over-prediction calculated as the difference between the CALUFF result and observation, as a percent of the CALPUFF result.

Table A3-8. Summary of regional scale CALPUFF model comparison to continuous monitoring data, 99th percentile of daily 1-hour peak SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)
	2016		2017		2018	
Kitamaat Village	20	25	12	17	18	17
Haul Road	75	99	66	100	74	84
Riverlodge	22	34	28	37	29	32
Whitesail	15	30	21	41	20	31

[1] Monitoring data 1-hour average for 2016, 2017, 2018.

[2] New CALPUFF results for actual scenario, regional-scale using actual smelter emission rates from 2016 to 2018, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (1.8 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background (5.53 ppb based on monitoring at Terrace-Skeena Middle School) are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments.

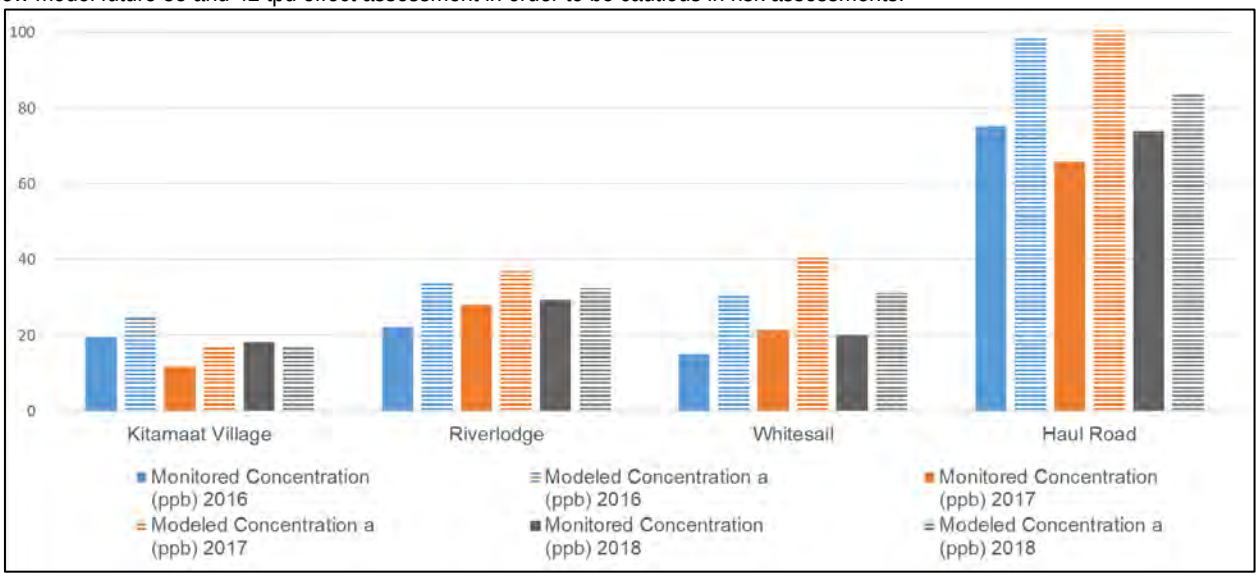


Figure A3-46. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, 99% of 1-hour daily peak, regional-scale (Williams Lake 1-hour background of 1.8 ppb applied).

Table A3-9 below provides the performance statistics for the regional-scale model. The root mean squared error (RMSE), mean bias error (MBE), and mean absolute error (MAE) represent the difference (or error) between the model result versus the observation at each monitor for each hour (paired in space and time as illustrated in Figure A3-47). The MBE represents the same differences seen when comparing the annual average concentrations (illustrated in Figure 3-18 of the main report). The MBE values indicate that the model overall slightly over-predicts at Kitamaat Village and Whitesail and over-predicts moderately at Haul Road and Riverlodge. The MAE indicates the mean error is larger when looking at absolute error for each hour, averaged over the three years. For example, the model over-predicts some hours and under-predicts some hours, which averages out to only 0.66 µg/m^3 for Kitamaat Village, but the average over-prediction or under-prediction is approximately 1.27 µg/m^3 when looking at the absolute difference. The percentages are provided to demonstrate that while the Haul Road has the largest

MBE and MAE on an absolute basis, the 17.7 µg/m^3 error put in context as a percentage of the monitored concentration is lower than Whitesail, which has an MAE of only 2.1 µg/m^3.

Table A3-9. Regional scale model performance evaluation statistics. Williams Lake annual background of .27 ppb, (0.69 µg/m^3) is applied.

Monitor	RMSE (µg/m^3)	MBE (µg/m^3)	MAE (µg/m^3)	MBE% [1]	MAE% [1]
Kitamaat Village	3.60	0.66	1.27	87%	167%
Haul Road	34.06	8.49	17.72	83%	174%
Riverlodge	9.47	2.86	3.71	235%	304%
Whitesail	6.16	1.21	2.10	109%	189%

[1] MBE% and MAE% are expressed as MBE and MAE divided by the annual average observed concentrations, respectively, at each receptor.

As discussed in Section 3.1.3.5 of the main report, dispersion models are not expected to agree perfectly when paired in time and space (as done for the Table A3-9 performance statistics). In addition, the ability to predict an accurate annual average and 99th percentile daily peak (even if the day is not the same) is the most important metric for evaluating the model's ability to accurately predict future concentrations or deposition rates to assess risk of impacts to receptors. As such, quantile-quantile plots (Q-Q plots) are commonly used to evaluate model performance. Figure A3-47 illustrates the comparison paired in time (max hour each day from 2016 to 2018 for visualizing), while Figure A3-48 compares the hourly model data (all hours from 2016 to 2018) versus monitoring data sorted highest to lowest (Q-Q plot). The comparisons illustrate that the model predicts concentrations and distribution similar to monitoring data at each station (e.g., Kitamaat Village concentrations are low (below 10 ppb) most days with a few (5 to 10) occurrences of 1-hour peaks in the 20 – 30 ppb range for both datasets). However, while the model's overall predictions compare closely to the monitored concentrations, the model results do not generally predict the peaks on the same day or hour.

The Q-Q plots in Figure A3-48 illustrate that the model generally predicts concentrations between 100% and 200% of the monitored concentrations, with the exception of slight under-prediction at Kitamaat Village for the two highest hours over three years and some over-prediction above 200% at the lowest quantile concentrations, particularly for Riverlodge and Haul Road.

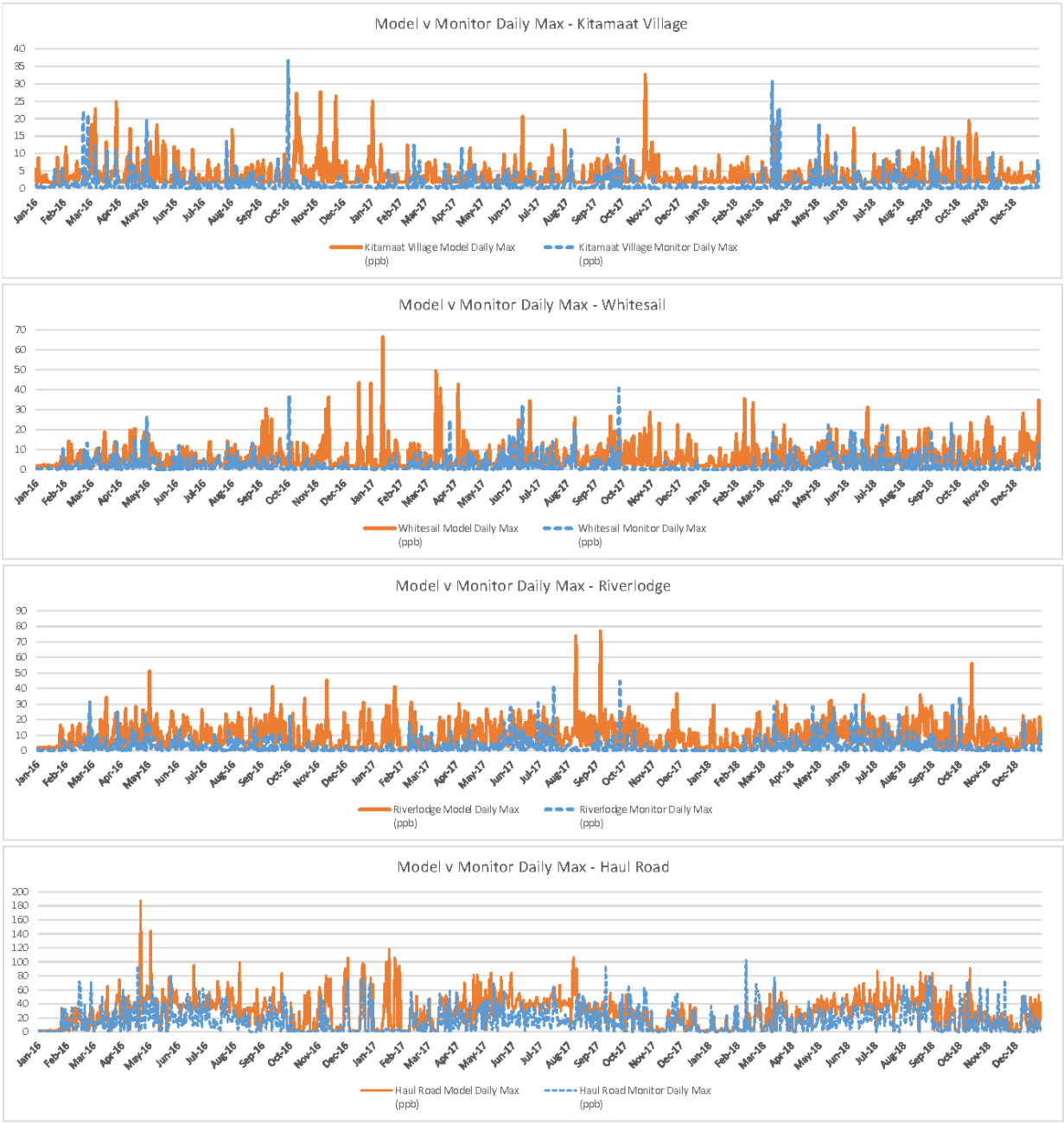


Figure A3-47. Comparison of modelled SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, timeseries (paired in time). The model data include the 1-hour background concentration (1.80 ppb). [Same as Figure 3-19 in main report.]

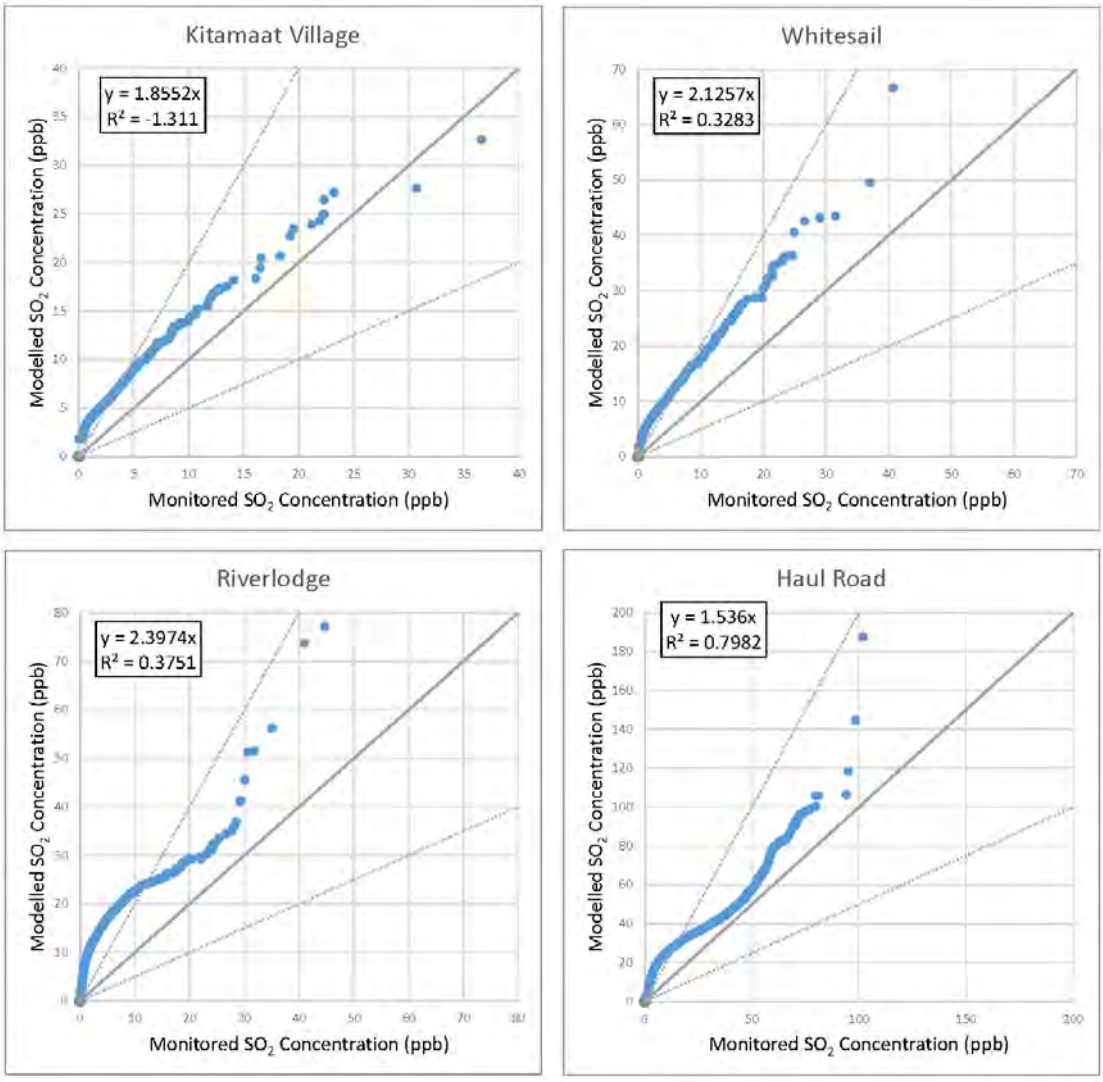


Figure A3-48. Comparison of modelled SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake). [Same as Figure 3-20 in main report.]

We also used the passive sampling measurements to evaluate the 2016–2018 CALPUFF model performance. Model data were averaged over the same periods as measured by the passive samplers for each sampling period at each site. As shown in the following tables and Figures A3-49 through A3-51 below (and Figure 3-21 of the main report), the regional CALPUFF model over-predicts long term (June – October) average concentrations in most locations (model results 150% to 500% of monitored concentrations), with a few comparisons over-predicting at a higher rate (most notably V00 on the east side of the valley at 5 µg/m^3 modelled compared to 0.34 µg/m^3 measured). Model concentrations at the few sites to the south of the smelter (V11 - V13) were generally lower the monitored concentrations (under-predictions), ranging from 61% (V13 in 2018) to 130% (V12 in 2016) of monitored concentrations. Site V10 near the smelter's west boundary, agreed closely with model results (model/monitor of 101%, 121%, and 102%).

These comparisons to passive monitoring data were considered when evaluating regional-scale model refinements, leading to a updates to the model that better matched the continuous monitoring data and passive monitoring data (Section 3.1.9, "Addendum to CALPUFF Model Plan Regional-Scale - *Memo_CALMET Hybrid_2019-0807*.pdf" and "Letter from ENV - *2019-08-23 CALPUFF Regional Model Protocol Changes.pd"f*).

Table A3-10. Regional scale model CALPUFF compared to passive monitoring data - 2016.

Sensor ID	UTM X (m)	UTM Y (m)	Passive Average [a] (µg/m³)	CALPUFF Average [b] (µg/m³)	CALPUFF/ Passive
V00	530,167	6,016,477	0.34	5.02	1457%
V01	524,948	6,017,458	1.80	5.38	300%
V02	523,130	6,015,390	1.47	5.49	373%
V03	520,931	6,009,416	2.99	5.73	192%
V04	520,767	6,003,740	0.92	8.80	959%
V05	520,539	5,999,300	3.17	11.29	356%
V06	520,944	5,996,297	2.27	9.22	406%
V07	521,361	5,993,907	1.35	6.54	483%
V08	519,935	5,992,321	3.94	13.05	331%
V09	518,980	5,989,246	4.68	24.03	513%
V10	519,028	5,985,441	7.13	7.23	101%
V11	519,426	5,979,635	7.53	5.79	77%
V12	518,339	5,977,238	4.96	6.45	130%
V14/U12	520,488	5,990,243	2.11	8.10	384%
A01	519,527	5,986,823	8.78	23.43	267%
A02	521,538	5,989,580	0.81	4.61	572%
A03	523,619	5,991,025	0.64	2.82	439%
A04	527,457	6,025,573	0.61	4.02	656%
U01	522,026	5,988,725	0.62	3.72	602%
U02	522,781	5,989,708	0.60	3.29	545%
U03	524,345	5,989,883	0.59	2.51	428%
U04	524,362	5,990,295	0.57	2.51	440%
U05	525,606	5,993,817	0.31	2.23	724%
U06	522,947	5,989,308	0.73	3.02	413%
U07	522,841	5,988,229	0.55	2.96	542%
U08	522,866	5,991,066	0.76	3.86	509%
U09	523,917	5,990,370	0.52	2.33	449%
U10	523,807	5,991,260	0.65	2.96	456%
U11	523,311	5,989,855	0.70	3.20	457%
U13	524,981	5,989,675	0.67	2.29	341%
U14	522,286	5,989,250	0.68	3.57	522%
U15	523,232	5,980,798	0.47	2.05	436%

[a] The passive data in this table is not adjusted for calibration with the continuous SO_2 analyzers.
[b] The following background value from Williams Lake is added to account for non-modelled sources of SO_2.

30-day Average Background:	0.46	ppb	1.21	(µg/m³)
(2nd High over 2017-2018, 96th%)			(1ppb = 2.614 µg/m³ SO_2)	

Table A3-11. Regional scale model CALPUFF compared to passive monitoring data - 2017.

Sensor ID	UTM X (m)	UTM Y (m)	Passive Average [a] (µg/m³)	CALPUFF Average [b] (µg/m³)	CALPUFF/ Passive
V01	524,948	6,017,458	1.97	5.53	280%
V02	523,130	6,015,390	1.52	5.05	332%
V03	520,931	6,009,416	4.24	7.27	171%
V04	520,767	6,003,740	2.05	10.48	512%
V04B	520,436	6,003,249	2.15	10.74	500%
V05	520,539	5,999,300	5.41	11.75	217%
V06	520,944	5,996,297	3.89	10.74	276%
V07	521,361	5,993,907	2.08	8.60	413%
V07B	520,285	5,993,190	3.48	13.26	381%
V08	519,935	5,992,321	6.18	13.38	216%
V09	518,980	5,989,246	7.88	29.54	375%
V10	519,028	5,985,441	10.40	12.59	121%
V12	518,339	5,977,238	5.36	5.84	109%
V13	516,405	5,976,686	5.50	3.61	66%
V14/U12	520,488	5,990,243	3.28	11.93	364%
A01	519,527	5,986,823	10.73	24.32	227%
A02	521,538	5,989,580	1.01	5.42	538%
A03	523,619	5,991,025	0.83	3.08	370%
A04	527,457	6,025,573	0.76	4.39	580%
U01	522,026	5,988,725	0.91	3.82	419%
U02	522,781	5,989,708	0.76	3.23	427%
U03	524,345	5,989,883	0.77	2.69	350%
U04	524,362	5,990,295	0.85	2.68	313%
U05	525,606	5,993,817	0.33	2.34	716%
U06	522,947	5,989,308	0.88	2.97	339%
U07	522,841	5,988,229	0.81	2.84	352%
U08	522,866	5,991,066	0.76	3.95	520%
U09	523,917	5,990,370	0.87	2.84	326%
U10	523,807	5,991,260	0.78	3.03	390%
U11	523,311	5,989,855	0.93	3.17	339%
U13	524,981	5,989,675	0.72	2.43	338%
U14	522,286	5,989,250	0.89	3.64	409%

[a] The passive data in this table is not adjusted for calibration with the continuous SO_2 analyzers.
[b] The following background value from Williams Lake is added to account for non-modelled sources of SO_2.
30-day Average Background: 0.46 ppb 1.21 (µg/m³)
(2nd High over 2017-2018, 96th%) (1ppb = 2.614 µg/m³ SO_2)

Table A3-12. Regional scale model CALPUFF compared to passive monitoring data - 2018.

Sensor ID	UTM X (m)	UTM Y (m)	Passive Average [a] (µg/m³)	CALPUFF Average [b] (µg/m³)	CALPUFF/ Passive
V01	524,948	6,017,458	2.00	4.87	244%
V02	523,130	6,015,390	1.76	4.68	266%
V03	520,931	6,009,416	2.45	5.58	228%
V04	520,767	6,003,740	1.27	8.52	668%
V05	520,539	5,999,300	4.63	11.02	238%
V06	520,944	5,996,297	4.16	10.63	256%
V07	521,361	5,993,907	0.88	7.41	844%
V08	519,935	5,992,321	6.69	13.01	194%
V09	518,980	5,989,246	9.38	27.64	295%
V10	519,028	5,985,441	10.63	10.88	102%
V11	519,426	5,979,635	11.70	7.12	61%
V12	518,339	5,977,238	7.84	7.59	97%
V13	516,405	5,976,686	7.21	4.74	66%
V14/U12	520,488	5,990,243	2.80	10.57	377%
A01	519,527	5,986,823	8.40	30.56	364%
A02	521,538	5,989,580	1.20	5.55	464%
A03	523,619	5,991,025	0.72	3.20	445%
A04	527,457	6,025,573	0.68	4.34	635%
U01	522,026	5,988,725	0.85	3.81	448%
U02	522,781	5,989,708	0.62	3.53	574%
U03a	523,984	5,989,481	0.77	2.91	380%
U04	524,362	5,990,295	0.61	2.77	450%
U05	525,606	5,993,817	0.45	2.60	575%
U06	522,947	5,989,308	1.10	2.98	270%
U07	522,841	5,988,229	0.53	2.85	536%
U08a	522,683	5,991,043	0.77	4.71	608%
U11a	522,799	5,990,020	0.61	3.55	583%
U13	524,981	5,989,675	0.58	2.56	444%
U14	522,286	5,989,250	0.80	3.69	463%
U16	522,304	5,989,595	0.74	3.90	530%
U17	521,727	5,989,826	1.03	5.44	531%
U18	521,445	5,989,757	1.15	6.12	532%
U19	521,599	5,989,102	0.77	5.22	674%
U20	522,962	5,987,562	0.53	2.67	499%

[a] The passive data in this table is not adjusted for calibration with the continuous SO_2 analyzers.
[b] The following background value from Williams Lake is added to account for non-modelled sources of SO_2.
30-day Average Background: 0.46 ppb 1.21 (µg/m³)
(2nd High over 2017-2018, 96th%) (1ppb = 2.614 µg/m³ SO_2)

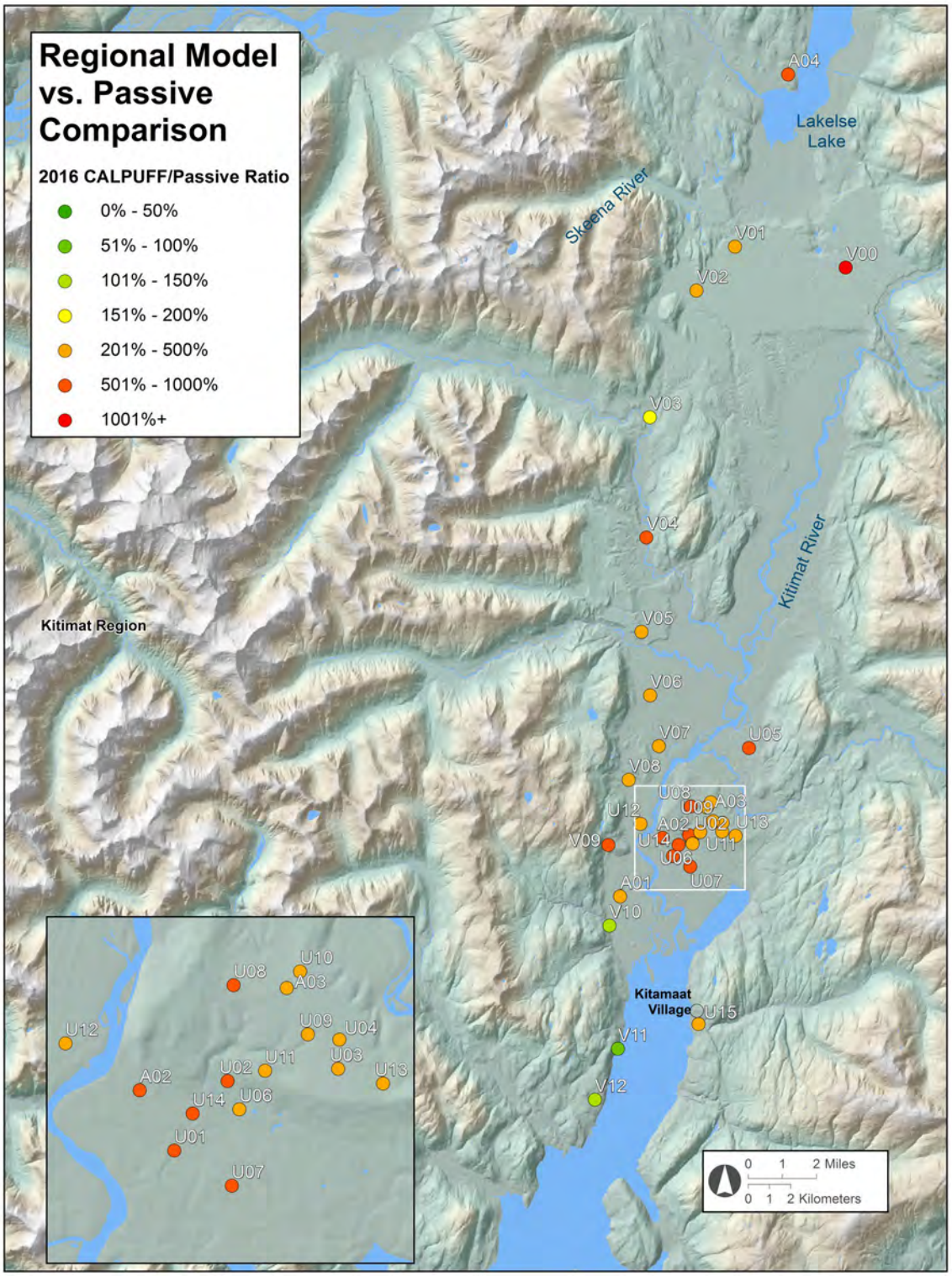


Figure A3-49. Map comparing modelled SO_2 concentrations (actual scenario) against passive monitoring SO_2, 2016. Passive sampling data are not calibrated. Model data include a background concentration based on Williams Lake 30-day average of 0.46 ppb (1.21 µg/m³).

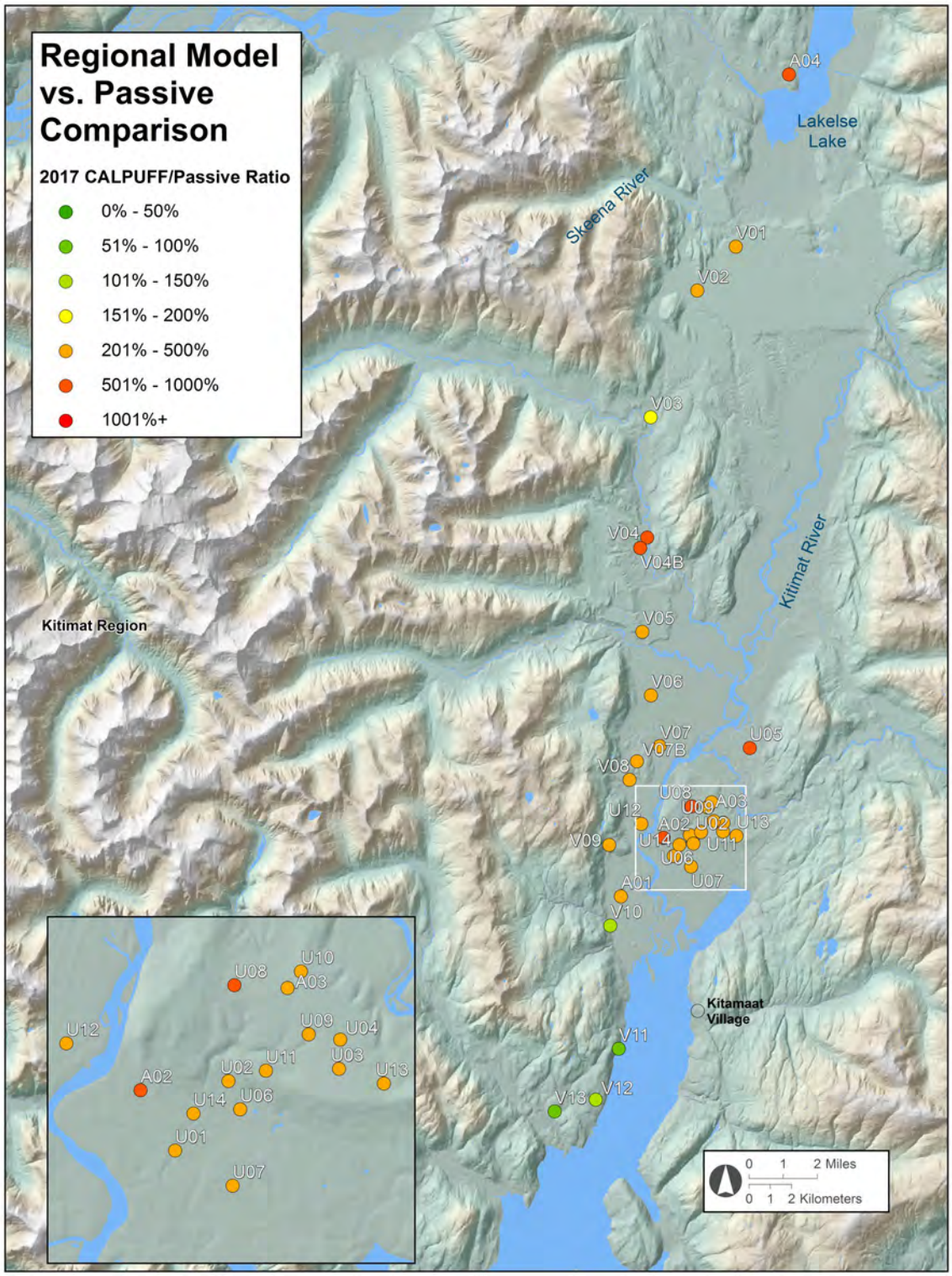


Figure A3-50. Map comparing modelled SO_2 concentrations (actual scenario) against passive monitoring SO_2, 2017. Passive sampling data are not calibrated. Model data include a background concentration based on Williams Lake 30-day average of 0.46 ppb (1.21 µg/m³).

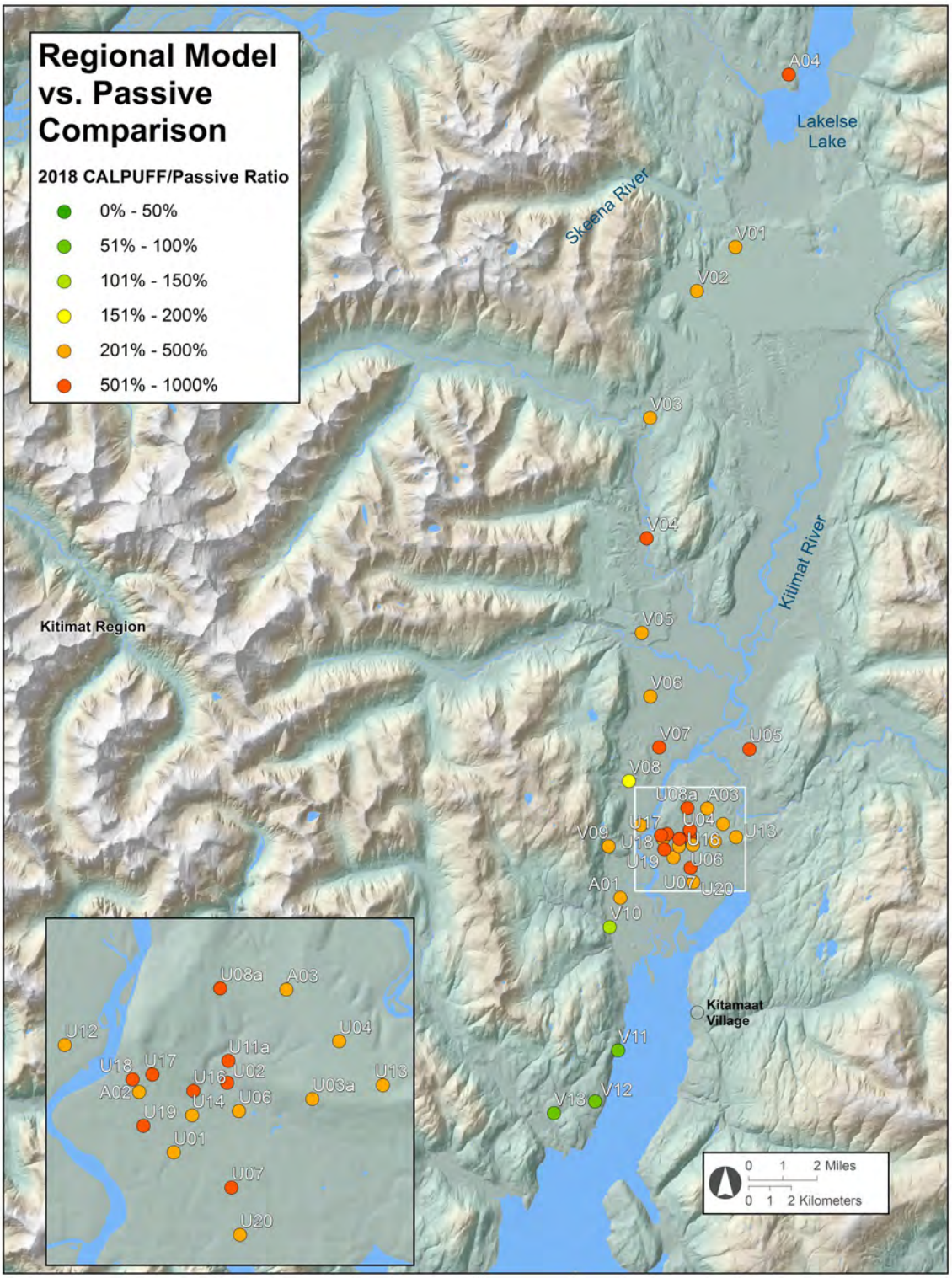


Figure A3-51. Map comparing modelled SO_2 concentrations (actual scenario) against passive monitoring SO_2, 2018. Passive sampling data are not calibrated. Model data include a background concentration based on Williams Lake 30-day average of 0.46 ppb (1.21 µg/m³).

3.1.7 Local scale model performance evaluation

The local scale model performance evaluation followed the same approach as the regional scale evaluation with the exception that the passive monitoring data comparison is not used.

- Actual scenario (actual emission rates, varying monthly) CALPUFF results are compared to continuous monitoring data.
- For model performance evaluation, more realistic background values are used based on Williams Lake SO_2 monitoring data.

Table A3-13 and Figure A3-52 summarize comparison of annual average concentrations estimated at each monitoring station compared to the monitoring data each year. Table A3-14 and Figure A3-53 summarize the 1-hour 99th percentile of daily peak concentrations. The local-scale model over-predicted both annual average and 99th percentile of daily 1-hour peak concentrations at all stations and years. The model over-predicted annual average concentrations by 16% (2016 Whitesail) to 74% (2016 Kitamaat Village) and 99th percentile of daily 1-hour peak at similar levels from 16% (2018 Whitesail) to 88% (2016 Kitamaat Village).[7] The local-scale model generally over-predicted concentrations more than the regional scale model, particularly at the Riverlodge monitor for annual average and the Kitamaat Village monitor for 1-hour.

Table A3-13. Summary of local scale CALPUFF model comparison to continuous monitoring data, annual average SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)
	2016		2017		2018	
Kitamaat Village	0.38	1.43	0.29	0.63	0.20	0.55
Haul Road	4.22	7.92	3.77	8.14	3.73	7.47
Riverlodge	0.50	1.64	0.43	1.49	0.47	1.54
Whitesail	0.53	0.63	0.41	0.53	0.34	0.61

[1] Monitoring data annual average for 2016, 2017, 2018.

[2] New CALPUFF results for actual scenario, local-scale using actual smelter emission rates from 2016 to 2018, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (0.26 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments. The annual average background concentration used for the new 2016 -2018 model is 0.47 ppb based on monitoring at Terrace-Skeena Middle School.

[7] Percentage under-prediction or over-prediction calculated as the difference between the CALUFF result and observation, as a percent of the CALPUFF result.

Table A3-14. Summary of local scale CALPUFF model comparison to continuous monitoring data, 99th percentile of daily 1-hour peak SO_2 (ppb).

	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)	Monitoring Data [1] (SO_2 ppb)	New CALPUFF [2] (SO_2 ppb)
	2016		2017		2018	
Kitamaat Village	20	157	12	52	18	23
Haul Road	75	97	66	119	74	113
Riverlodge	22	42	28	43	29	41
Whitesail	15	18	21	26	20	37

[1] Monitoring data 1-hour average for 2016, 2017, 2018.

[2] New CALPUFF results for actual scenario, local-scale using actual smelter emission rates from 2016 to 2018, varying monthly. Model results for performance evaluation apply a background based on Williams Lake (1.8 ppb), which is more appropriate to represent realistic results because we expect minimal contribution from non-smelter SO_2 for 2016 – 2018 actual conditions. Results with a higher background (5.53 ppb based on monitoring at Terrace-Skeena Middle School) are used for new model future 35 and 42 tpd effect assessment in order to be cautious in risk assessments.

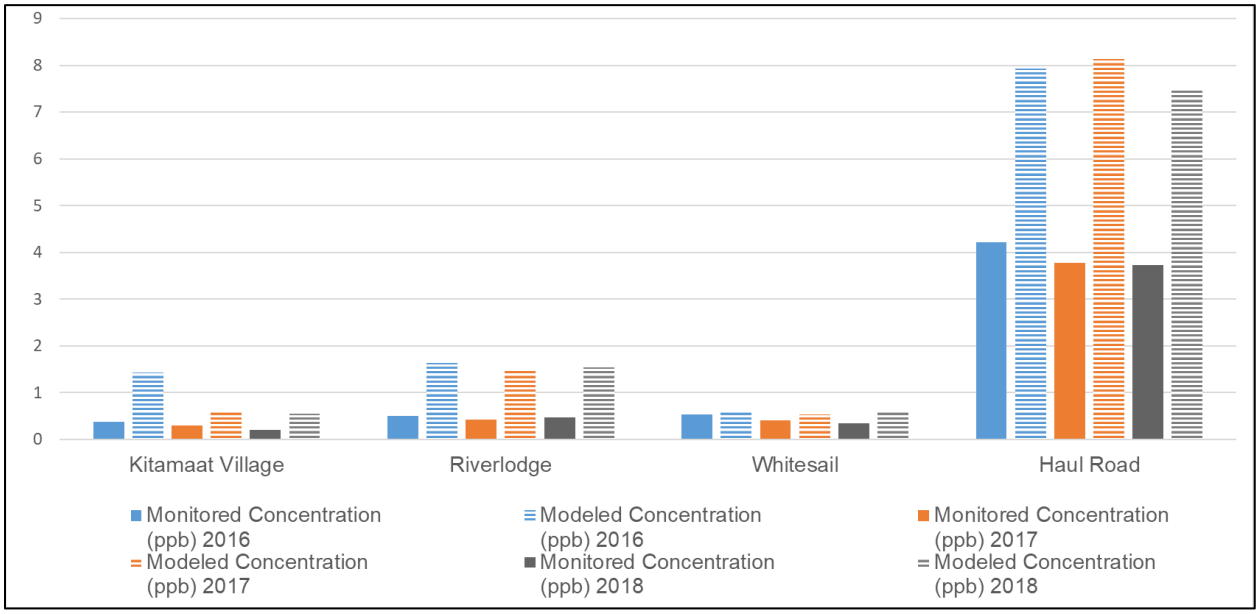


Figure A3-52. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, annual average, local-scale (Williams Lake annual background of 0.26 ppb applied).

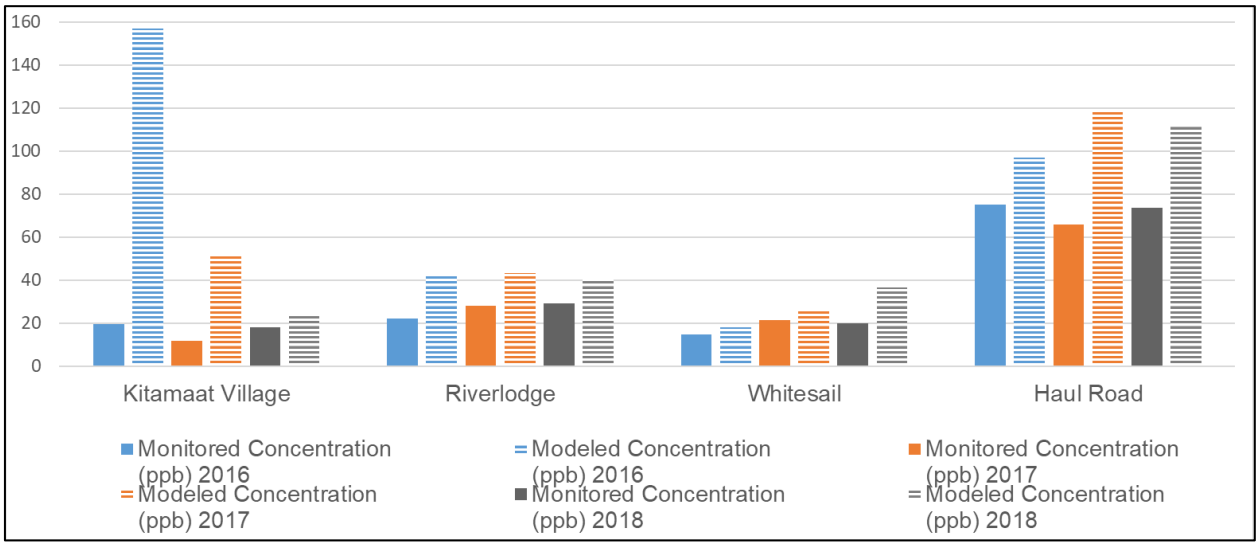


Figure A3-53. Continuous SO_2 (ppb) monitoring concentrations compared to new CALPUFF model results and scaled STAR model concentrations, 99% of 1-hour daily peak, local-scale (Williams Lake annual background of 1.8 ppb applied).

Table A3-9 below provides the performance statistics for the regional-scale model. The RMSE, MBE, and MAE represent the difference (or error) between the model result versus the observation at each monitor for each hour (paired in space and time). The MBE represents the same differences seen when comparing the annual average concentrations (illustrated in Figure A3-52). Like the regional scale performance, the MBE values indicate that the local-scale model overall slightly over-predicts at Kitamaat Village and Whitesail and over-predicts moderately at Haul Road and Riverlodge. The MAE and RMSE values are also similar to the regional scale evaluation, except the Kitamaat Village error is noticeably higher (meaning the local scale does not estimate as well at Kitamaat Village) and the Whitesail error values are noticeably lower (the local-scale model predicts better at Whitesail). These performance statistics and Q-Q plots (discussed below) were considered when evaluating the local-scale model refinement leading to a updates to the model that better matched the continuous monitoring data (Section 3.1.9, "Addendum to CALPUFF Model Plan Local-Scale - Local Model Performance Memo_2019-0916.pdf").

Table A3-15. Local scale model performance evaluation statistics. Williams Lake annual background of .27 ppb, (0.69 µg/m^3) is applied.

Monitor	RMSE (µg/m^3)	MBE (µg/m^3)	MAE (µg/m^3)	MBE% [1]	MAE% [1]
Kitamaat Village	10.54	1.51	2.12	199%	279%
Haul Road	37.95	10.29	19.04	101%	187%
Riverlodge	10.89	2.83	3.86	232%	316%
Whitesail	4.92	0.43	1.49	38%	133%

[1] MBE% and MAE% are expressed as MBE and MAE divided by the annual average observed concentrations, respectively, at each receptor.

The Q-Q plots in Figure A3-54 below illustrate the over-prediction at Kitamaat Village and relatively good performance at Whitesail as noted above, giving a more complete picture of how the values compare across the range of concentrations. Haul Road modelled concentrations generally fall within the 100% to 200% of monitored values for all but the highest and lowest concentrations. Riverlodge model results also show relatively good performance at the higher concentrations but over-predicts the annual average nearly three times and lower to mid range concentrations over three times.

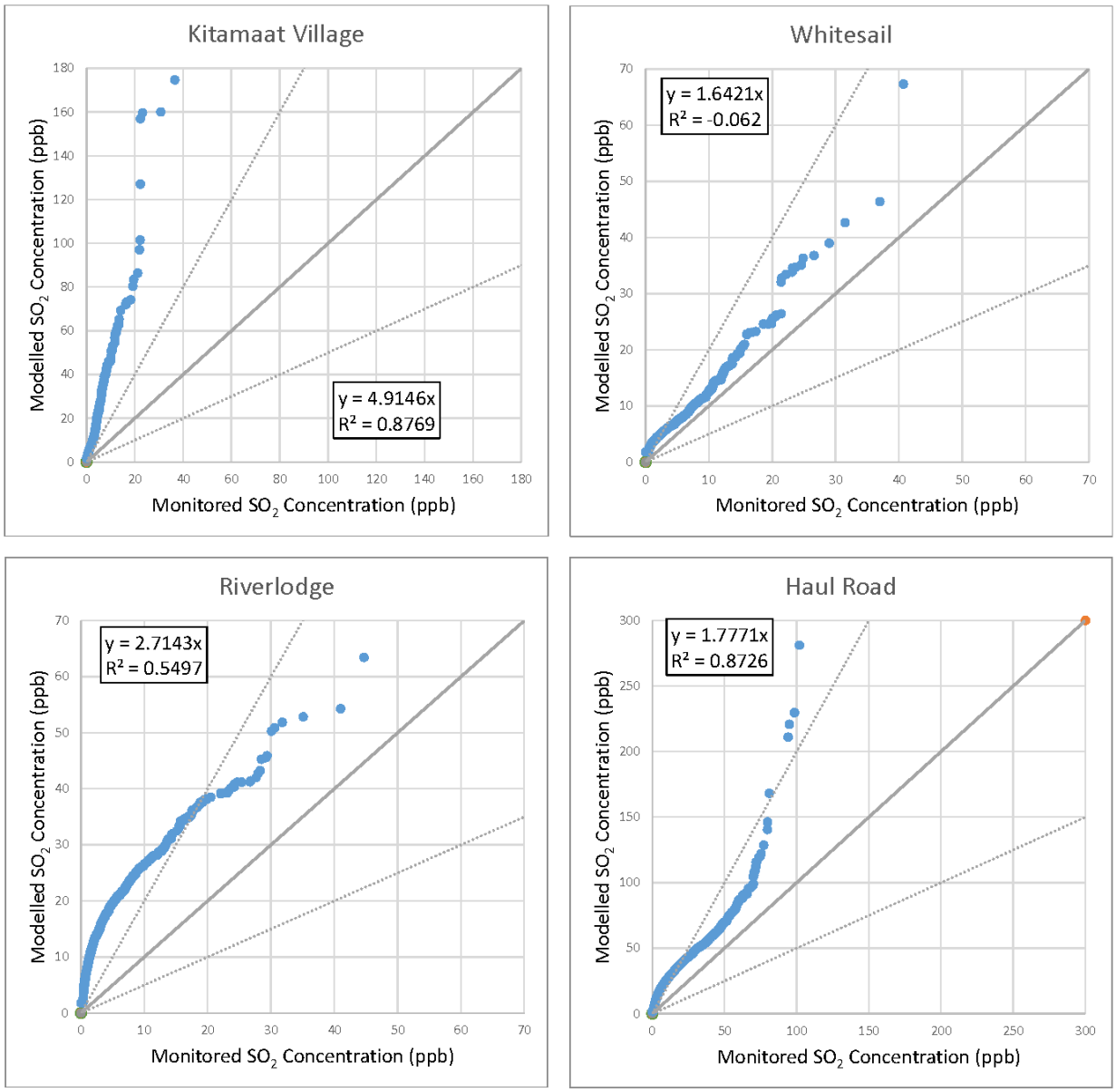


Figure A3-54. Comparison of local-scale modelled SO_2 concentrations (actual scenario) against continuous monitoring network SO_2, 2016-2018, Q-Q plot (ordered by rank). The 1-to-1 line (solid) and 2-to-1 lines (dashed) are shown. Best fit linear regression equation and R^2 value shown for 0 intercept. The model data include the model performance 1-hour background concentration (1.80 ppb at Williams Lake).

3.1.8 Additional CALPUFF results

The first two pages of tables in this section present a summary of the CALPUFF results in areas of interest for the local-scale model.

The second two pages of tables present the detailed regional scale CALPUFF results at specific points of interest (sensitive receptors, monitor sites, etc.). Note that results at vegetation sites were also modelled and analyzed at specific points, but the vegetation results are included in the vegetation section of the report and appendix.

The remainder of this appendix consists of 56 additional maps illustrating the results of the 2016-2018 CALPUFF model analysis. The list below specifies each table and figure in this section. Heading breaks in the list of figures denote breaks in the type of figure, and corresponding blank pages between figures are inserted to assist the reader in navigating the figures.

3.1.8.1 Tables

1. Modeled SO_2 concentrations offsite and areas of interest - 42tpd, 35 tpd, Actuals (ppb)
2. Modeled SO_2 concentrations offsite and areas of interest - 42tpd, 35 tpd, Actuals ($\mu g/m^3$)
3. Modeled SO_2 concentrations at discrete receptors of interest, 42tpd ($\mu g/m^3$)
4. Modeled SO_2 concentrations at discrete receptors of interest, Actuals ($\mu g/m^3$)

3.1.8.2 Maps

42 tpd scenario, 99th % of daily 1-hour peak

1. Modeled SO_2 concentrations, 42 tpd, 99th % of daily 1-hour peak, 3 year average, regional
2. Modeled SO_2 concentrations, 42 tpd, 99th % of daily 1-hour peak, 2016, regional
3. Modeled SO_2 concentrations, 42 tpd, 99th % of daily 1-hour peak, 2017, regional
4. Modeled SO_2 concentrations, 42 tpd, 99th % of daily 1-hour peak, 2018 regional
5. Modeled SO_2 concentrations, 42 tpd, 99th % of daily 1-hour peak, 3 year average, local
6. Modeled SO_2 concentrations, 42 tpd, 99th % of daily 1-hour peak, 2016, local
7. Modeled SO_2 concentrations, 42 tpd, 99th % of daily 1-hour peak, 2017, local
8. Modeled SO_2 concentrations, 42 tpd, 99th % of daily 1-hour peak, 2018 local

42 tpd scenario, annual average

9. Modeled SO_2 concentrations, 42 tpd, annual average, 3 year average, regional
10. Modeled SO_2 concentrations, 42 tpd, annual average, 2016, regional
11. Modeled SO_2 concentrations, 42 tpd, annual average, 2017, regional
12. Modeled SO_2 concentrations, 42 tpd, annual average, 2018 regional
13. Modeled SO_2 concentrations, 42 tpd, annual average, 3 year average, local
14. Modeled SO_2 concentrations, 42 tpd, annual average, 2016, local
15. Modeled SO_2 concentrations, 42 tpd, annual average, 2017, local
16. Modeled SO_2 concentrations, 42 tpd, annual average, 2018 local

42 tpd scenario, 98th % and 97.5th % of daily 1-hour peak

17. Modeled SO_2 concentrations, 42 tpd, 98th % of daily 1-hour peak, 3 year average, regional
18. Modeled SO_2 concentrations, 42 tpd, 98th % of daily 1-hour peak, 3 year average, local
19. Modeled SO_2 concentrations, 42 tpd, 97.5th % of daily 1-hour peak, 3 year average, regional
20. Modeled SO_2 concentrations, 42 tpd, 97.5th % of daily 1-hour peak, 3 year average, local

42 tpd scenario, 1-hour exceedances

21. Modeled SO_2 concentration exceedances, 1-hour averaging period, annual 3-year maximum, regional
22. Modeled SO_2 concentration exceedances, 1-hour averaging period, annual 3-year maximum, local

Sulphate deposition

23. Modeled SO_4 deposition, 42 tpd, annual average, 3 year average, regional
24. Modeled SO_4 deposition, Actuals, annual average, 3 year average, regional

35 tpd scenario, 99th % of daily 1-hour peak

25. Modeled SO_2 concentrations, 35 tpd, 99th % of daily 1-hour peak, 3 year average, regional
26. Modeled SO_2 concentrations, 35 tpd, 99th % of daily 1-hour peak, 2016, regional
27. Modeled SO_2 concentrations, 35 tpd, 99th % of daily 1-hour peak, 2017, regional
28. Modeled SO_2 concentrations, 35 tpd, 99th % of daily 1-hour peak, 2018 regional
29. Modeled SO_2 concentrations, 35 tpd, 99th % of daily 1-hour peak, 3 year average, local
30. Modeled SO_2 concentrations, 35 tpd, 99th % of daily 1-hour peak, 2016, local
31. Modeled SO_2 concentrations, 35 tpd, 99th % of daily 1-hour peak, 2017, local
32. Modeled SO_2 concentrations, 35 tpd, 99th % of daily 1-hour peak, 2018 local

35 tpd scenario, annual average

33. Modeled SO_2 concentrations, 35 tpd, annual average, 3 year average, regional
34. Modeled SO_2 concentrations, 35 tpd, annual average, 2016, regional
35. Modeled SO_2 concentrations, 35 tpd, annual average, 2017, regional
36. Modeled SO_2 concentrations, 35 tpd, annual average, 2018 regional
37. Modeled SO_2 concentrations, 35 tpd, annual average, 3 year average, local
38. Modeled SO_2 concentrations, 35 tpd, annual average, 2016, local
39. Modeled SO_2 concentrations, 35 tpd, annual average, 2017, local
40. Modeled SO_2 concentrations, 35 tpd, annual average, 2018 local

Actual scenario, 99th % of daily 1-hour peak

41. Modeled SO_2 concentrations, Actuals, 99th % of daily 1-hour peak, 3 year average, regional
42. Modeled SO_2 concentrations, Actuals, 99th % of daily 1-hour peak, 2016, regional
43. Modeled SO_2 concentrations, Actuals, 99th % of daily 1-hour peak, 2017, regional
44. Modeled SO_2 concentrations, Actuals, 99th % of daily 1-hour peak, 2018 regional
45. Modeled SO_2 concentrations, Actuals, 99th % of daily 1-hour peak, 3 year average, local
46. Modeled SO_2 concentrations, Actuals, 99th % of daily 1-hour peak, 2016, local
47. Modeled SO_2 concentrations, Actuals, 99th % of daily 1-hour peak, 2017, local
48. Modeled SO_2 concentrations, Actuals, 99th % of daily 1-hour peak, 2018 local

Actual scenario, annual average

49. Modeled SO_2 concentrations, Actuals, annual average, 3 year average, regional
50. Modeled SO_2 concentrations, Actuals, annual average, 2016, regional
51. Modeled SO_2 concentrations, Actuals, annual average, 2017, regional
52. Modeled SO_2 concentrations, Actuals, annual average, 2018 regional
53. Modeled SO_2 concentrations, Actuals, annual average, 3 year average, local
54. Modeled SO_2 concentrations, Actuals, annual average, 2016, local
55. Modeled SO_2 concentrations, Actuals, annual average, 2017, local
56. Modeled SO_2 concentrations, Actuals, annual average, 2018 local

42tpd SO_2 Local Scale CALPUFF Results Summary

Year	1-hr, 99th% Daily Peak Concentration [1] (ppb)				Annual Average Concentration [1] (ppb)			
	Max Offsite	Max Residential	Max LNG	Max Service Centre	Max Offsite	Max Residential	Max LNG	Max Service Centre
2016	554	218	167	104	19.1	2.5	18.0	5.5
2017	560	117	210	74	16.6	2.3	19.8	4.7
2018	640	75	209	69	18.2	2.3	18.5	4.2
3 Year Average	560	123	192	81	18.0	2.4	18.8	4.8
Objective [2]	70	70	70	70	5.0	5.0	5.0	5.0

[1] Background concentrations are included based on average SO_2 concentrations measured at the Terrace Skeena Middle School station in 2016, 2017 & 2018. The background concentration applied for the annual averaging period is 0.47 ppb, while the background concentration for the 1-hr averaging period is 5.53 ppb. Model results are converted to ppb based on the ratio of [70 ppb]/[183 µg/m^3] per the 1-hr SO_2 British Columbia air quality objective.

[2] Objectives are based on British Columbia air quality objectives. Where both Interim Provincial AQO and CAAQS are in place, the more stringent 2020 CAAQS is listed in this table.

35tpd SO_2 Local Scale CALPUFF Results Summary

Year	1-hr, 99th% Daily Peak Concentration [1] (ppb)				Annual Average Concentration [1] (ppb)			
	Max Offsite	Max Residential	Max LNG	Max Service Centre	Max Offsite	Max Residential	Max LNG	Max Service Centre
2016	462	183	140	88	15.8	2.1	15.1	4.6
2017	455	98	177	62	13.8	2.0	16.5	3.9
2018	535	63	176	58	15.0	1.9	15.5	3.6
3 Year Average	467	102	161	68	14.9	2.0	15.7	4.0
Objective [2]	70	70	70	70	5.0	5.0	5.0	5.0

[1] Background concentrations are included based on average SO_2 concentrations measured at the Terrace Skeena Middle School station in 2016, 2017 & 2018. The background concentration applied for the annual averaging period is 0.47 ppb, while the background concentration for the 1-hr averaging period is 5.53 ppb. Model results are converted to ppb based on the ratio of [70 ppb]/[183 µg/m^3] per the 1-hr SO_2 British Columbia air quality objective.

[2] Objectives are based on British Columbia air quality objectives. Where both Interim Provincial AQO and CAAQS are in place, the more stringent 2020 CAAQS is listed in this table.

Actuals SO_2 Local Scale CALPUFF Results Summary

Year	1-hr, 99th% Daily Peak Concentration [1,2] (ppb)				Annual Average Concentration [1,2] (ppb)			
	Max Offsite	Max Residential	Max LNG	Max Service Centre	Max Offsite	Max Residential	Max LNG	Max Service Centre
2016	386	179	181	76	13.7	2.0	16.1	4.2
2017	403	75	185	65	11.9	1.8	18.1	3.7
2018	514	60	159	63	13.4	1.8	16.4	3.3
3 Year Average	433	89	170	64	13.0	1.9	16.8	3.7
Objective [3]	70	70	70	70	5.0	5.0	5.0	5.0

[1] Background concentrations are based on SO_2 concentrations measured at the Terrace Skeena Middle School. The following background concentrations are used for each year:
2016: 4.6 ppb (1-hr); 0.5 ppb (annual)
2017: 5.9 ppb (1-hr); 0.5 ppb (annual)
2018: 6.1 ppb (1-hr); 0.4 ppb (annual)

[2] Model results are converted to ppb based on the ratio of [70 ppb]/[183 µg/m^3] per the 1-hr SO_2 British Columbia air quality objective.

[3] Objectives are based on British Columbia air quality objectives. Where both Interim Provincial AQO and CAAQS are in place, the more stringent 2020 CAAQS is listed in this table.

Note: Similar maximum offsite CALPUFF results for the regional-scale model are available in Section 5 (Vegetation) and associated Vegetation Appendices.

42tpd SO_2 Local Scale CALPUFF Results Summary

Year	1-hr, 99th% Daily Peak Concentration [1] ($\mu g/m^3$)				Annual Average Concentration [1] ($\mu g/m^3$)			
	Max Offsite	Max Residential	Max LNG	Max Service Centre	Max Offsite	Max Residential	Max LNG	Max Service Centre
2016	1449	569	436	272	49.8	6.6	47.2	14.3
2017	1463	307	548	192	43.5	6.1	51.8	12.3
2018	1672	196	547	181	47.5	5.9	48.5	11.0
3 Year Average	1465	322	502	211	46.9	6.2	49.2	12.5
Objective [2]	183	183	183	183	13	13	13	13

[1] Background concentrations are included based on average SO_2 concentrations measured at the Terrace Skeena Middle School station in 2016, 2017 & 2018. The background concentration applied for the annual averaging period is 0.47 ppb, while the background concentration for the 1-hr averaging period is 5.53 ppb. Background concentrations are converted to $\mu g/m^3$ based on the ratio of [183 $\mu g/m^3$]/[70 ppb] per the 1-hr SO_2 British Columbia air quality objective.

[2] Objectives are based on British Columbia air quality objectives. Where both Interim Provincial AQO and CAAQS are in place, the more stringent 2020 CAAQS is listed in this table.

35tpd SO_2 Local Scale CALPUFF Results Summary

Year	1-hr, 99th% Daily Peak Concentration [1] ($\mu g/m^3$)				Annual Average Concentration [1] ($\mu g/m^3$)			
	Max Offsite	Max Residential	Max LNG	Max Service Centre	Max Offsite	Max Residential	Max LNG	Max Service Centre
2016	1209	478	367	230	41.4	5.6	39.4	12.0
2017	1189	256	463	162	36.0	5.2	43.2	10.3
2018	1399	165	459	151	39.3	5.1	40.4	9.3
3 Year Average	1220	267	422	177	38.9	5.3	41.0	10.5
Objective [2]	183	183	183	183	13	13	13	13

[1] Background concentrations are included based on average SO_2 concentrations measured at the Terrace Skeena Middle School station in 2016, 2017 & 2018. The background concentration applied for the annual averaging period is 0.47 ppb, while the background concentration for the 1-hr averaging period is 5.53 ppb. Background concentrations are converted to $\mu g/m^3$ based on the ratio of [183 $\mu g/m^3$]/[70 ppb] per the 1-hr SO_2 British Columbia air quality objective.

[2] Objectives are based on British Columbia air quality objectives. Where both Interim Provincial AQO and CAAQS are in place, the more stringent 2020 CAAQS is listed in this table.

Actuals SO_2 Local Scale CALPUFF Results Summary

Year	1-hr, 99th% Daily Peak Concentration [1,2] ($\mu g/m^3$)				Annual Average Concentration [1,2] ($\mu g/m^3$)			
	Max Offsite	Max Residential	Max LNG	Max Service Centre	Max Offsite	Max Residential	Max LNG	Max Service Centre
2016	1009	469	474	198	35.9	5.2	42.1	11.0
2017	1053	196	483	171	31.0	4.8	47.4	9.6
2018	1345	158	415	165	35.0	4.7	42.7	8.7
3 Year Average	1133	232	444	168	34.0	4.9	44.0	9.7
Objective [3]	183	183	183	183	13	13	13	13

[1] Background concentrations are based on SO_2 concentrations measured at the Terrace Skeena Middle School. The following background concentrations are used for each year:
2016: 4.6 ppb (1-hr); 0.5 ppb (annual)
2017: 5.9 ppb (1-hr); 0.5 ppb (annual)
2018: 6.1 ppb (1-hr); 0.4 ppb (annual)

[2] Background concentrations are converted to $\mu g/m^3$ based on the ratio of [183 $\mu g/m^3$]/[70 ppb] per the 1-hr SO_2 British Columbia air quality objective.

[3] Objectives are based on British Columbia air quality objectives. Where both Interim Provincial AQO and CAAQS are in place, the more stringent 2020 CAAQS is listed in this table.

Note: Similar maximum offsite CALPUFF results for the regional-scale model are available in Section 5 (Vegetation) and associated Vegetation Appendices.

CALPUFF SO_2 Model Results at Discrete Receptors of Interest – 42tpd Emission Scenario

Rec No.	Group	UTM X (m)	UTM Y (m)	Ground Elevation (m)	1-hr, 99th% Daily Peak Concentration ($\mu g/m^3$)				Annual Average Concentration ($\mu g/m^3$)			
					2016	2017	2018	3-Year	2016	2017	2018	3-Year
1	MET	522,907	5,980,600	5.00	80.27	63.44	52.63	65.44	1.06	0.97	0.95	0.99
2	MET	520,189	5,983,566	0.01	249.48	185.54	293.42	242.81	4.18	3.91	4.56	4.21
3	MET	519,475	5,986,811	15.39	326.29	266.91	243.24	278.81	21.72	22.37	21.54	21.88
4	MET	523,617	5,991,026	96.00	87.95	82.73	82.90	84.53	1.91	2.05	2.49	2.15
5	MET	528,081	6,035,563	219.67	27.80	25.54	33.36	28.90	1.80	1.94	1.83	1.86
6	MET	526,040	6,041,226	68.00	24.58	16.97	21.78	21.11	1.08	1.17	1.03	1.09
7	AMBIENT	519,475	5,986,810	15.36	326.54	266.95	243.35	278.95	21.72	22.37	21.54	21.88
8	AMBIENT	519,525	5,986,824	15.83	316.07	248.89	234.38	266.45	20.35	20.84	20.09	20.43
9	AMBIENT	521,509	5,989,567	16.00	104.37	107.27	110.01	107.22	4.44	4.52	4.88	4.61
10	AMBIENT	521,537	5,989,575	15.48	102.90	107.41	106.69	105.67	4.35	4.44	4.80	4.53
11	AMBIENT	523,617	5,991,026	96.00	87.95	82.73	82.90	84.53	1.91	2.05	2.49	2.15
12	AMBIENT	523,619	5,991,031	96.00	87.90	82.63	82.96	84.49	1.91	2.05	2.49	2.15
13	AMBIENT	527,454	6,025,574	108.52	35.82	27.94	36.53	33.43	2.73	2.80	2.74	2.75
14	AMBIENT	525,405	6,041,636	69.60	25.73	16.13	23.11	21.66	1.00	1.09	0.94	1.01
15	VALLEY	518,339	5,977,238	124.77	154.43	150.63	151.41	152.16	11.35	10.81	10.68	10.94
16	VALLEY	519,428	5,979,638	63.89	139.81	161.97	201.29	167.69	9.16	9.24	9.13	9.17
17	VALLEY	519,029	5,985,444	34.90	281.18	251.89	476.18	336.42	6.54	7.41	7.90	7.29
18	VALLEY	518,981	5,989,247	164.63	198.94	205.58	257.69	220.74	18.28	21.15	20.89	20.10
19	VALLEY	520,485	5,990,239	20.03	121.44	101.72	110.56	111.24	8.92	9.06	8.85	8.94
20	VALLEY	519,935	5,992,323	63.63	156.00	105.16	119.83	127.00	10.91	11.03	10.97	10.97
21	VALLEY	521,359	5,993,912	27.00	119.12	99.59	93.64	104.12	6.32	6.85	6.81	6.66
22	VALLEY	520,944	5,996,301	68.47	136.21	115.78	110.33	120.77	8.15	8.67	8.38	8.40
23	VALLEY	520,540	5,999,300	114.00	150.22	156.54	187.96	164.91	8.65	8.89	8.58	8.70
24	VALLEY	520,768	6,003,741	98.00	132.05	134.86	184.11	150.34	6.07	6.14	6.13	6.11
25	VALLEY	520,929	6,009,411	128.18	96.42	105.58	99.13	100.38	4.02	3.73	3.71	3.82
26	VALLEY	523,129	6,015,393	198.23	110.02	78.56	71.35	86.64	3.52	3.27	3.18	3.32
27	VALLEY	530,167	6,016,479	215.00	80.59	86.47	82.22	83.09	4.80	5.93	6.04	5.59
28	VALLEY	524,951	6,017,455	211.16	86.54	71.52	61.85	73.30	3.77	3.66	3.48	3.64
29	URBAN	523,231	5,980,796	10.85	60.33	51.03	52.17	54.51	0.97	0.93	0.91	0.94
30	URBAN	522,963	5,987,559	13.00	72.49	100.65	104.93	92.69	1.50	1.57	1.89	1.65
31	URBAN	522,844	5,988,228	16.00	75.39	124.66	99.44	99.83	1.69	1.78	2.05	1.84
32	URBAN	522,029	5,988,724	10.05	97.44	85.92	100.56	94.64	2.80	2.65	3.15	2.87
33	URBAN	521,598	5,989,099	14.23	112.38	97.05	102.57	104.00	3.95	3.97	4.41	4.11
34	URBAN	522,285	5,989,251	17.41	88.75	86.36	83.64	86.25	2.56	2.46	2.97	2.66
35	URBAN	522,946	5,989,304	19.00	73.89	93.33	76.40	81.21	1.78	1.79	2.13	1.90
36	URBAN	523,984	5,989,477	100.75	68.52	131.65	109.05	103.07	1.60	1.90	2.04	1.85
37	URBAN	522,302	5,989,591	26.92	87.93	82.30	82.87	84.37	2.68	2.61	3.19	2.83
38	URBAN	524,984	5,989,676	97.00	63.08	56.07	59.08	59.41	1.22	1.20	1.41	1.28
39	URBAN	522,782	5,989,705	32.64	84.23	88.88	76.36	83.16	2.08	2.06	2.53	2.22
40	URBAN	521,446	5,989,752	18.00	102.76	97.45	107.51	102.57	4.72	4.83	5.19	4.91
41	URBAN	521,726	5,989,822	32.39	100.88	114.16	97.85	104.30	4.15	4.23	4.66	4.35
42	URBAN	523,310	5,989,850	86.31	106.78	110.62	79.67	99.02	2.02	2.12	2.46	2.20
43	URBAN	524,345	5,989,877	96.45	73.82	91.03	86.00	83.62	1.43	1.64	1.79	1.62
44	URBAN	522,802	5,990,019	58.07	91.22	97.12	87.59	91.98	2.30	2.32	2.88	2.50
45	URBAN	520,485	5,990,239	20.03	121.44	101.72	110.56	111.24	8.92	9.06	8.85	8.94
46	URBAN	524,366	5,990,293	93.00	61.51	86.58	81.07	76.39	1.42	1.61	1.78	1.60
47	URBAN	523,915	5,990,373	87.89	75.14	89.41	76.73	80.42	1.62	1.79	2.01	1.81
48	URBAN	522,684	5,991,045	99.10	94.38	113.69	144.77	117.61	3.09	3.23	4.21	3.51
49	URBAN	522,868	5,991,067	95.61	88.41	112.48	136.07	112.32	2.74	2.89	3.76	3.13
50	URBAN	523,807	5,991,257	99.94	81.94	89.33	85.15	85.47	1.82	1.99	2.40	2.07
51	URBAN	525,603	5,993,820	48.49	48.29	47.07	51.77	49.04	1.15	1.22	1.44	1.27
52	INTEREST	530,018	6,016,514	216.00	74.52	82.83	81.52	79.62	4.83	5.96	6.04	5.61
53	INTEREST	526,736	6,021,646	75.22	33.10	30.97	31.85	31.97	2.89	2.93	2.82	2.88
54	INTEREST	529,890	6,026,561	83.00	29.23	29.00	34.54	30.92	2.62	2.95	2.99	2.86
55	INTEREST	521,767	6,041,716	57.36	22.28	14.71	18.59	18.53	0.66	0.73	0.61	0.67
56	INTEREST	538,140	6,051,744	151.00	19.87	19.38	18.97	19.41	1.12	1.22	1.14	1.16
57	OTHER	521,126	5,983,007	2.28	132.37	95.58	126.37	118.11	2.01	1.80	2.03	1.95
58	RESERVE	525,158	5,987,435	16.72	49.14	50.09	59.13	52.79	0.89	0.88	1.02	0.93
59	MONITOR	517,980	5,976,259	96.09	120.87	119.38	112.09	117.45	9.07	9.06	9.01	9.05
60	MONITOR	517,933	5,976,978	155.46	169.33	133.62	153.67	152.21	11.11	11.06	10.98	11.05
61	MONITOR	522,900	5,980,610	5.00	81.60	63.49	52.41	65.83	1.06	0.97	0.95	0.99
62	MONITOR	519,641	5,980,751	47.98	233.00	196.05	271.97	233.67	10.83	10.25	10.61	10.56
63	MONITOR	519,039	5,985,501	34.97	389.67	344.45	415.35	383.16	6.89	7.89	8.20	7.66
64	MONITOR	519,504	5,985,723	19.00	329.10	216.81	300.20	282.04	18.55	19.13	19.42	19.03
65	MONITOR	522,793	5,986,243	11.70	80.48	92.04	88.67	87.06	1.34	1.38	1.66	1.46
66	MONITOR	518,833	5,986,820	20.99	237.73	236.63	219.42	231.26	14.92	18.68	17.53	17.04
67	MONITOR	519,537	5,986,895	15.66	294.87	243.12	230.96	256.32	20.06	20.53	19.78	20.12
68	MONITOR	522,028	5,988,796	8.91	93.78	86.25	98.06	92.70	2.81	2.66	3.18	2.88
69	MONITOR	519,027	5,989,286	167.56	199.94	204.63	289.40	231.32	18.47	21.23	21.08	20.26
70	MONITOR	524,363	5,989,372	103.78	71.70	90.45	103.76	88.63	1.46	1.64	1.83	1.64
71	MONITOR	521,552	5,989,569	15.04	100.91	107.67	105.46	104.68	4.30	4.38	4.75	4.48
72	MONITOR	522,623	5,989,740	30.40	90.55	86.27	79.79	85.54	2.25	2.23	2.73	2.40
73	MONITOR	524,495	5,990,287	93.56	63.58	78.88	69.98	70.81	1.36	1.53	1.70	1.53
74	MONITOR	520,371	5,990,701	19.00	117.55	107.22	103.98	109.58	9.34	9.57	9.19	9.37
75	MONITOR	523,576	5,991,141	94.50	85.69	78.79	91.86	85.45	1.94	2.08	2.56	2.19
76	MONITOR	519,960	5,992,333	62.42	152.86	105.94	121.95	126.92	10.87	11.00	10.92	10.93
77	MONITOR	524,434	5,994,688	21.11	50.90	57.02	67.46	58.46	1.54	1.76	2.28	1.86

CALPUFF SO_2 Model Results at Discrete Receptors of Interest – Actuals Emission Scenario

Rec No.	Group	UTM X (m)	UTM Y (m)	Ground Elevation (m)	1-hr, 99th% Daily Peak Concentration ($\mu g/m^3$)				Annual Average Concentration ($\mu g/m^3$)			
					2016	2017	2018	3-Yr	2016	2017	2018	3-Yr
1	MET	522,907	5,980,600	5.00	60.40	39.06	39.44	46.30	0.83	0.68	0.69	0.73
2	MET	520,189	5,983,566	0.01	216.67	142.83	225.06	194.85	3.76	2.96	3.61	3.44
3	MET	519,475	5,986,811	15.39	253.89	257.75	214.82	242.15	17.91	18.46	17.67	18.01
4	MET	523,617	5,991,026	96.00	74.79	101.36	76.84	84.33	1.46	1.55	1.90	1.64
5	MET	528,081	6,035,563	219.67	19.77	20.06	26.93	22.25	1.24	1.43	1.38	1.35
6	MET	526,040	6,041,226	68.00	16.86	13.73	16.72	15.77	0.75	0.87	0.78	0.80
7	AMBIENT	519,475	5,986,810	15.36	254.16	257.70	214.83	242.23	17.91	18.46	17.67	18.01
8	AMBIENT	519,525	5,986,824	15.83	254.83	259.47	212.10	242.13	16.49	16.93	16.34	16.59
9	AMBIENT	521,509	5,989,567	16.00	85.24	91.59	80.09	85.64	3.21	3.33	3.73	3.42
10	AMBIENT	521,537	5,989,575	15.48	84.85	96.42	80.04	87.10	3.15	3.27	3.67	3.36
11	AMBIENT	523,617	5,991,026	96.00	74.79	101.36	76.84	84.33	1.46	1.55	1.90	1.64
12	AMBIENT	523,619	5,991,031	96.00	74.57	101.30	76.82	84.23	1.46	1.55	1.90	1.64
13	AMBIENT	527,454	6,025,574	108.52	24.13	21.88	30.02	25.34	1.90	2.08	2.08	2.02
14	AMBIENT	525,405	6,041,636	69.60	17.64	12.40	17.45	15.83	0.70	0.81	0.71	0.74
15	VALLEY	518,339	5,977,238	124.77	126.59	111.82	114.10	117.50	9.24	7.60	8.18	8.34
16	VALLEY	519,428	5,979,638	63.89	137.33	124.04	124.62	128.66	8.63	7.04	6.98	7.55
17	VALLEY	519,029	5,985,444	34.90	292.82	331.82	443.01	355.88	4.80	5.54	6.16	5.50
18	VALLEY	518,981	5,989,247	164.63	223.27	225.61	220.79	223.22	14.35	17.63	16.91	16.30
19	VALLEY	520,485	5,990,239	20.03	92.23	85.47	92.46	90.05	6.90	6.97	6.93	6.94
20	VALLEY	519,935	5,992,323	63.63	124.43	98.40	131.82	118.22	8.48	8.75	8.73	8.65
21	VALLEY	521,359	5,993,912	27.00	90.60	108.91	94.66	98.06	4.89	5.33	5.36	5.19
22	VALLEY	520,944	5,996,301	68.47	123.14	120.51	100.42	114.69	6.31	6.80	6.68	6.60
23	VALLEY	520,540	5,999,300	114.00	111.13	123.23	187.14	140.50	6.51	6.95	6.83	6.76
24	VALLEY	520,768	6,003,741	98.00	96.60	104.57	155.38	118.85	4.43	4.78	4.87	4.69
25	VALLEY	520,929	6,009,411	128.18	80.43	91.79	89.88	87.37	2.91	2.88	2.93	2.91
26	VALLEY	523,129	6,015,393	198.23	70.40	63.99	54.21	62.87	2.50	2.48	2.47	2.48
27	VALLEY	530,167	6,016,479	215.00	52.89	65.87	63.54	60.77	3.28	4.30	4.49	4.03
28	VALLEY	524,951	6,017,455	211.16	60.63	58.03	46.86	55.17	2.65	2.74	2.67	2.69
29	URBAN	523,231	5,980,796	10.85	52.62	37.57	35.77	41.98	0.76	0.65	0.66	0.69
30	URBAN	522,963	5,987,559	13.00	54.87	90.20	66.90	70.66	1.14	1.19	1.33	1.22
31	URBAN	522,844	5,988,228	16.00	72.65	118.60	63.96	85.07	1.30	1.39	1.48	1.39
32	URBAN	522,029	5,988,724	10.05	73.73	75.50	73.92	74.38	2.01	1.89	2.36	2.09
33	URBAN	521,598	5,989,099	14.23	99.55	94.27	81.92	91.91	2.84	2.89	3.39	3.04
34	URBAN	522,285	5,989,251	17.41	78.45	65.91	65.87	70.08	1.87	1.78	2.24	1.96
35	URBAN	522,946	5,989,304	19.00	83.18	70.30	54.94	69.48	1.38	1.34	1.59	1.43
36	URBAN	523,984	5,989,477	100.75	59.22	132.19	58.39	83.27	1.30	1.45	1.47	1.41
37	URBAN	522,302	5,989,591	26.92	81.70	69.39	67.36	72.82	1.96	1.90	2.44	2.10
38	URBAN	524,984	5,989,676	97.00	73.86	42.10	41.74	52.57	1.08	0.87	1.01	0.99
39	URBAN	522,782	5,989,705	32.64	81.94	72.02	61.84	71.94	1.58	1.52	1.91	1.67
40	URBAN	521,446	5,989,752	18.00	92.51	83.05	86.33	87.30	3.44	3.56	3.97	3.66
41	URBAN	521,726	5,989,822	32.39	87.78	99.09	78.42	88.43	3.06	3.16	3.64	3.29
42	URBAN	523,310	5,989,850	86.31	149.82	138.84	60.63	116.43	1.58	1.62	1.86	1.69
43	URBAN	524,345	5,989,877	96.45	53.53	111.49	56.54	73.86	1.17	1.25	1.30	1.24
44	URBAN	522,802	5,990,019	58.07	107.47	87.25	75.24	89.99	1.75	1.72	2.20	1.89
45	URBAN	520,485	5,990,239	20.03	92.23	85.47	92.46	90.05	6.90	6.97	6.93	6.94
46	URBAN	524,366	5,990,293	93.00	52.80	93.76	51.99	66.18	1.13	1.23	1.30	1.22
47	URBAN	523,915	5,990,373	87.89	61.28	120.94	50.16	77.46	1.26	1.36	1.48	1.37
48	URBAN	522,684	5,991,045	99.10	88.79	106.63	131.23	108.88	2.33	2.38	3.33	2.68
49	URBAN	522,868	5,991,067	95.61	93.27	94.72	127.40	105.13	2.08	2.14	2.94	2.38
50	URBAN	523,807	5,991,257	99.94	62.30	103.62	71.06	79.00	1.40	1.51	1.83	1.58
51	URBAN	525,603	5,993,820	48.49	38.64	38.91	38.29	38.62	0.89	0.89	1.06	0.95
52	INTEREST	530,018	6,016,514	216.00	50.24	64.19	62.38	58.93	3.31	4.33	4.49	4.04
53	INTEREST	526,736	6,021,646	75.22	22.69	23.44	25.33	23.82	2.02	2.18	2.16	2.12
54	INTEREST	529,890	6,026,561	83.00	19.99	21.66	27.28	22.98	1.81	2.17	2.25	2.08
55	INTEREST	521,767	6,041,716	57.36	15.14	10.52	14.11	13.26	0.46	0.55	0.46	0.49
56	INTEREST	538,140	6,051,744	151.00	12.52	13.65	14.21	13.46	0.76	0.89	0.85	0.83
57	OTHER	521,126	5,983,007	2.28	109.09	75.55	90.17	91.61	1.65	1.26	1.53	1.48
58	RESERVE	525,158	5,987,435	16.72	35.67	32.01	38.18	35.28	0.67	0.63	0.74	0.68
59	MONITOR	517,980	5,976,259	96.09	105.93	93.09	86.82	95.28	7.38	6.35	6.90	6.88
60	MONITOR	517,933	5,976,978	155.46	124.87	102.65	122.46	116.66	8.72	7.87	8.50	8.36
61	MONITOR	522,900	5,980,610	5.00	60.30	39.04	39.51	46.29	0.83	0.68	0.69	0.73
62	MONITOR	519,641	5,980,751	47.98	172.44	160.67	184.48	172.53	9.94	7.77	8.11	8.61
63	MONITOR	519,039	5,985,501	34.97	337.28	508.75	507.17	451.07	5.17	6.20	6.68	6.02
64	MONITOR	519,504	5,985,723	19.00	253.20	233.92	277.27	254.80	13.05	14.02	14.92	14.00
65	MONITOR	522,793	5,986,243	11.70	55.60	62.74	66.14	61.49	0.99	0.96	1.21	1.05
66	MONITOR	518,833	5,986,820	20.99	239.14	249.43	212.41	233.66	13.08	17.33	16.02	15.48
67	MONITOR	519,537	5,986,895	15.66	236.14	250.78	203.98	230.30	16.20	16.63	16.03	16.29
68	MONITOR	522,028	5,988,796	8.91	77.09	73.20	73.92	74.74	2.02	1.91	2.38	2.10
69	MONITOR	519,027	5,989,286	167.56	227.72	208.19	230.16	222.02	14.46	17.62	17.02	16.37
70	MONITOR	524,363	5,989,372	103.78	66.07	101.95	74.83	80.95	1.27	1.25	1.33	1.28
71	MONITOR	521,552	5,989,569	15.04	85.98	98.63	80.08	88.23	3.12	3.23	3.63	3.33
72	MONITOR	522,623	5,989,740	30.40	70.44	72.46	65.41	69.44	1.69	1.63	2.07	1.79
73	MONITOR	524,495	5,990,287	93.56	50.99	89.74	48.20	62.98	1.10	1.16	1.24	1.17
74	MONITOR	520,371	5,990,701	19.00	95.19	92.94	90.77	92.97	7.25	7.39	7.23	7.29
75	MONITOR	523,576	5,991,141	94.50	77.97	93.34	74.60	81.97	1.48	1.57	1.96	1.67
76	MONITOR	519,960	5,992,333	62.42	127.13	99.16	136.94	121.08	8.46	8.72	8.69	8.62
77	MONITOR	524,434	5,994,688	21.11	44.84	45.86	54.49	48.40	1.16	1.32	1.73	1.40

Maps of 42 tpd scenario, 99th % of daily 1-hour peak

SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

Study Area (2019 Deposition Model Extent)

Continuous SO_2 Analyzer Station (note: Terrace station is owned and operated by the province)

1hr, 4th Highest Day, 3-year (2016, 2017, 2018) Average Modelled [SO_2] ("42 tpd" scenario) Including Background Concentration (ppb)

0-17.5: Below 2025 CAAQS

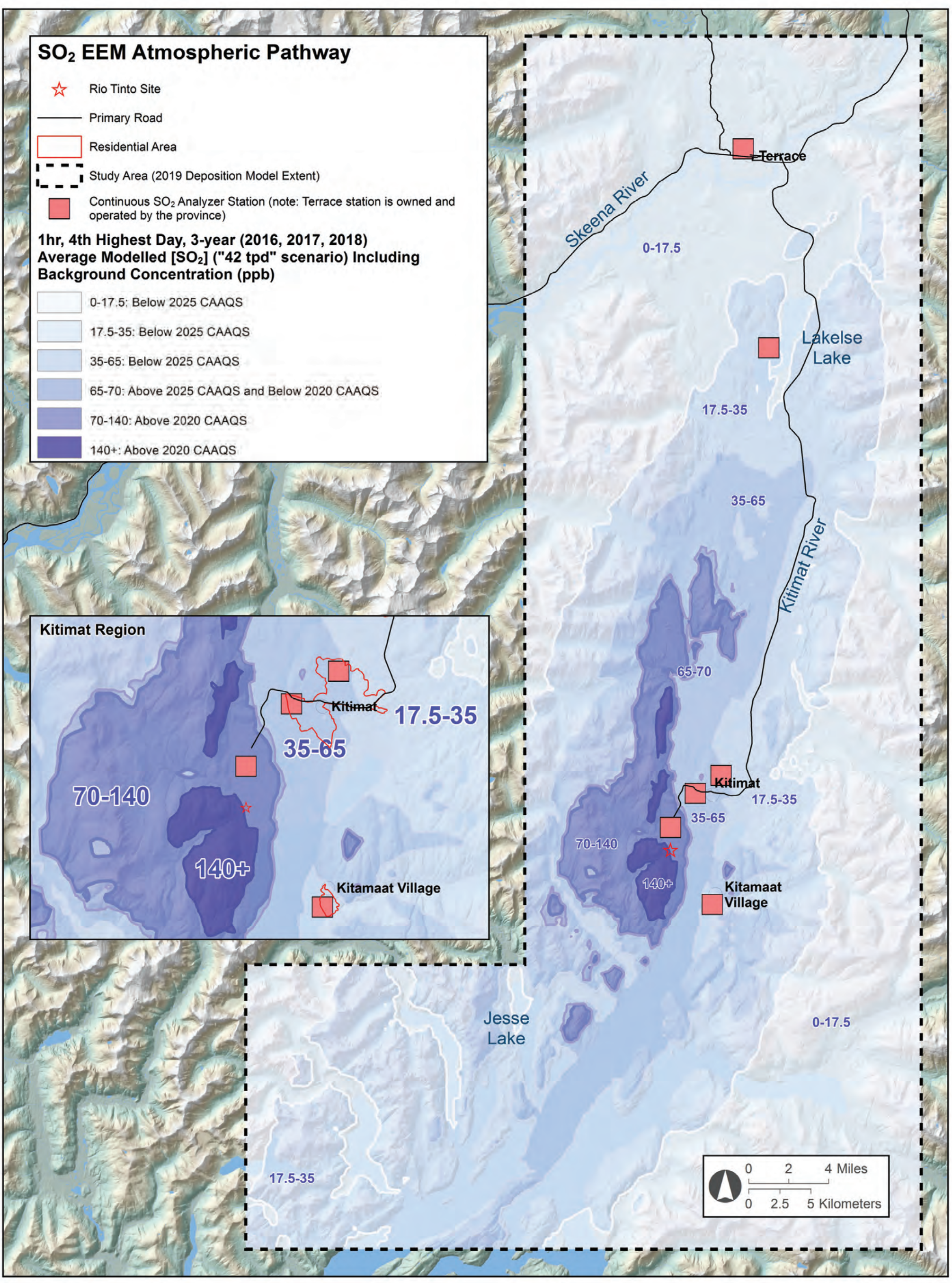
17.5-35: Below 2025 CAAQS

35-65: Below 2025 CAAQS

65-70: Above 2025 CAAQS and Below 2020 CAAQS

70-140: Above 2020 CAAQS

140+: Above 2020 CAAQS



SO_2 EEM Atmospheric Pathway

☆ Rio Tinto Site

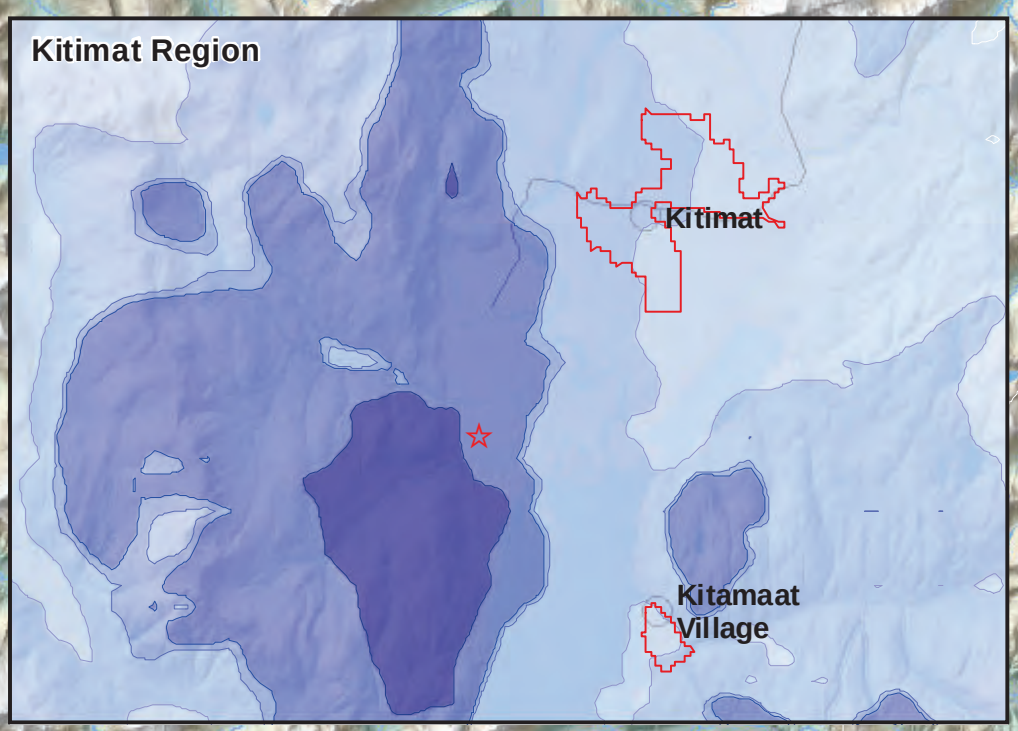
Primary Road

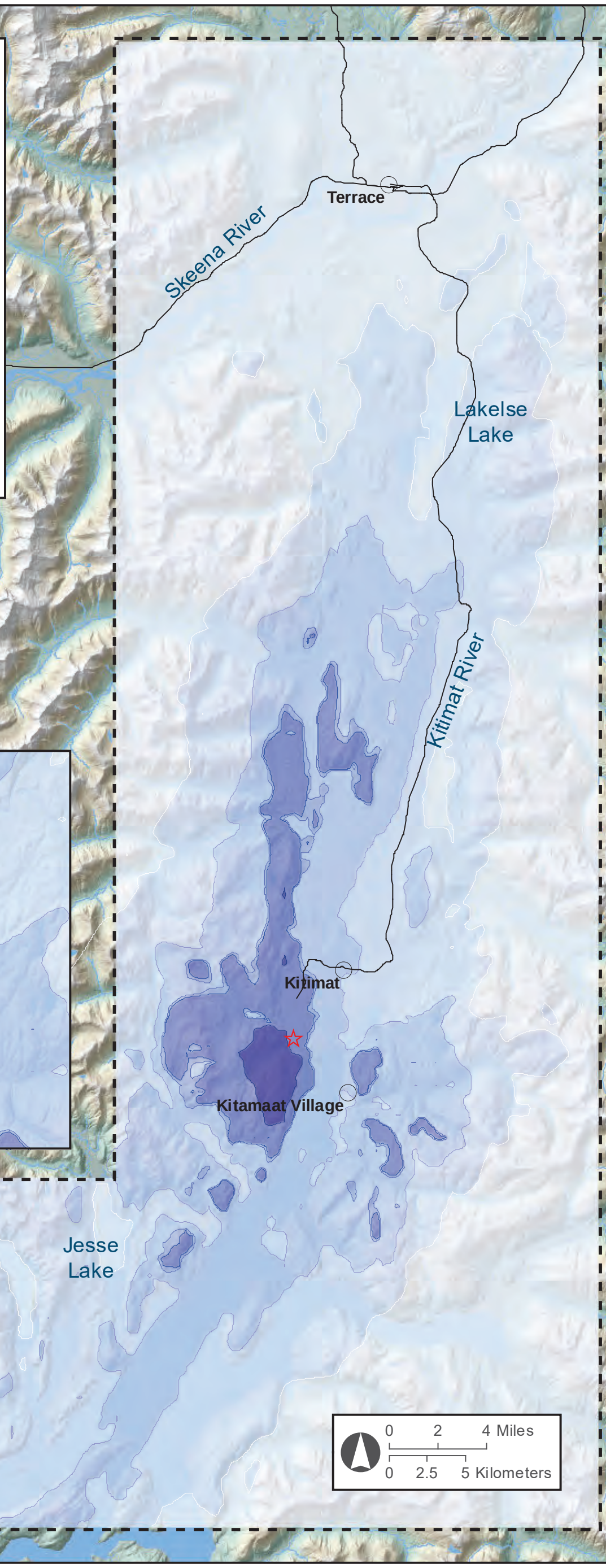
Study Area (2019 Deposition Model Extent)

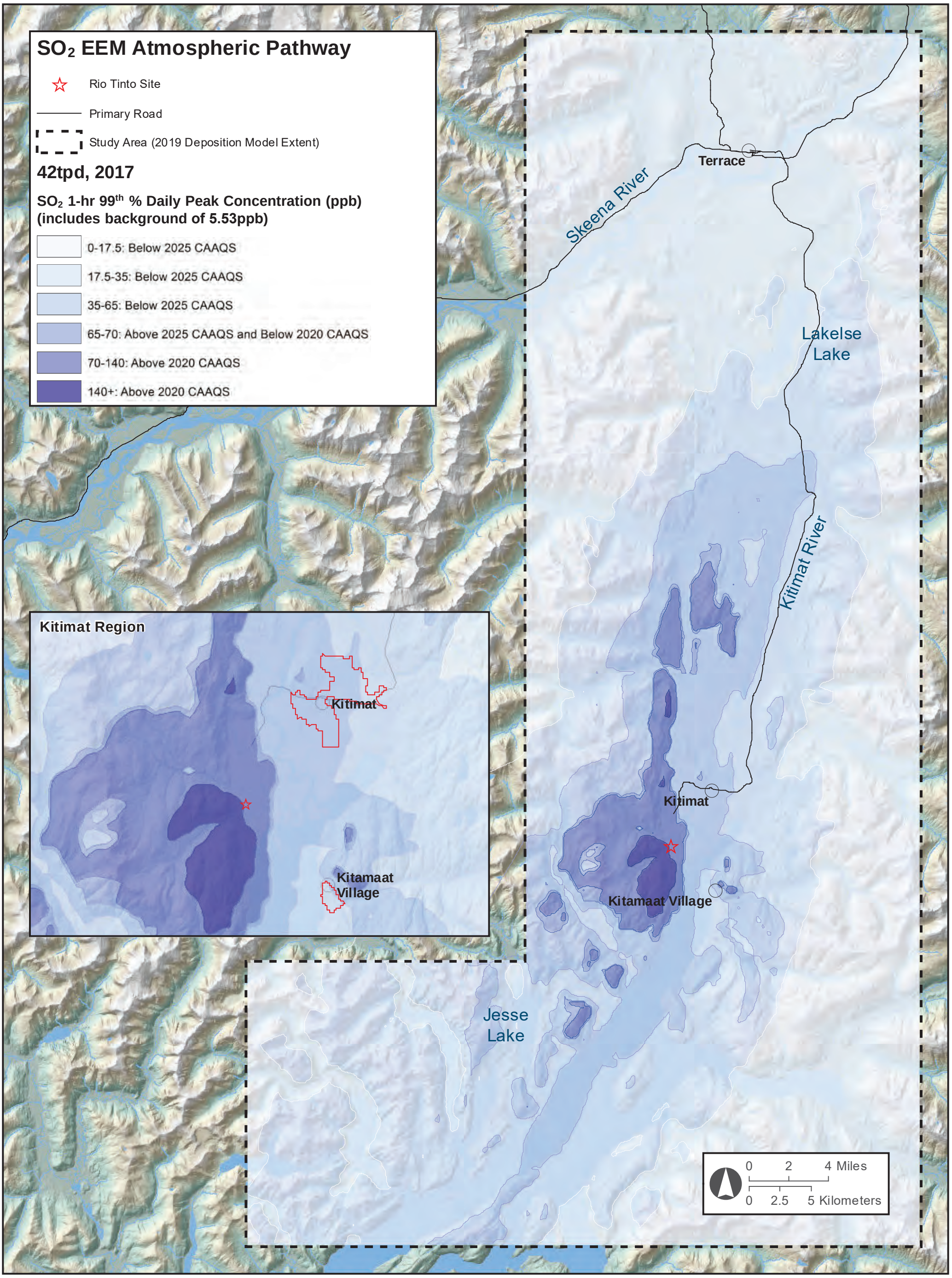
42tpd, 2016

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
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- 70-140: Above 2020 CAAQS
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SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area (2019 Deposition Model Extent)
42tpd, 2017
SO2 1-hr 99th % Daily Peak Concentration (ppb)
(includes background of 5.53ppb)
0-17.5: Below 2025 CAAQS
17.5-35: Below 2025 CAAQS
35-65: Below 2025 CAAQS
65-70: Above 2025 CAAQS and Below 2020 CAAQS
70-140: Above 2020 CAAQS
140+: Above 2020 CAAQS
Kitimat Region
Kitimat
Kitamaat Village
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers

SO_2 EEM Atmospheric Pathway

Rio Tinto Site

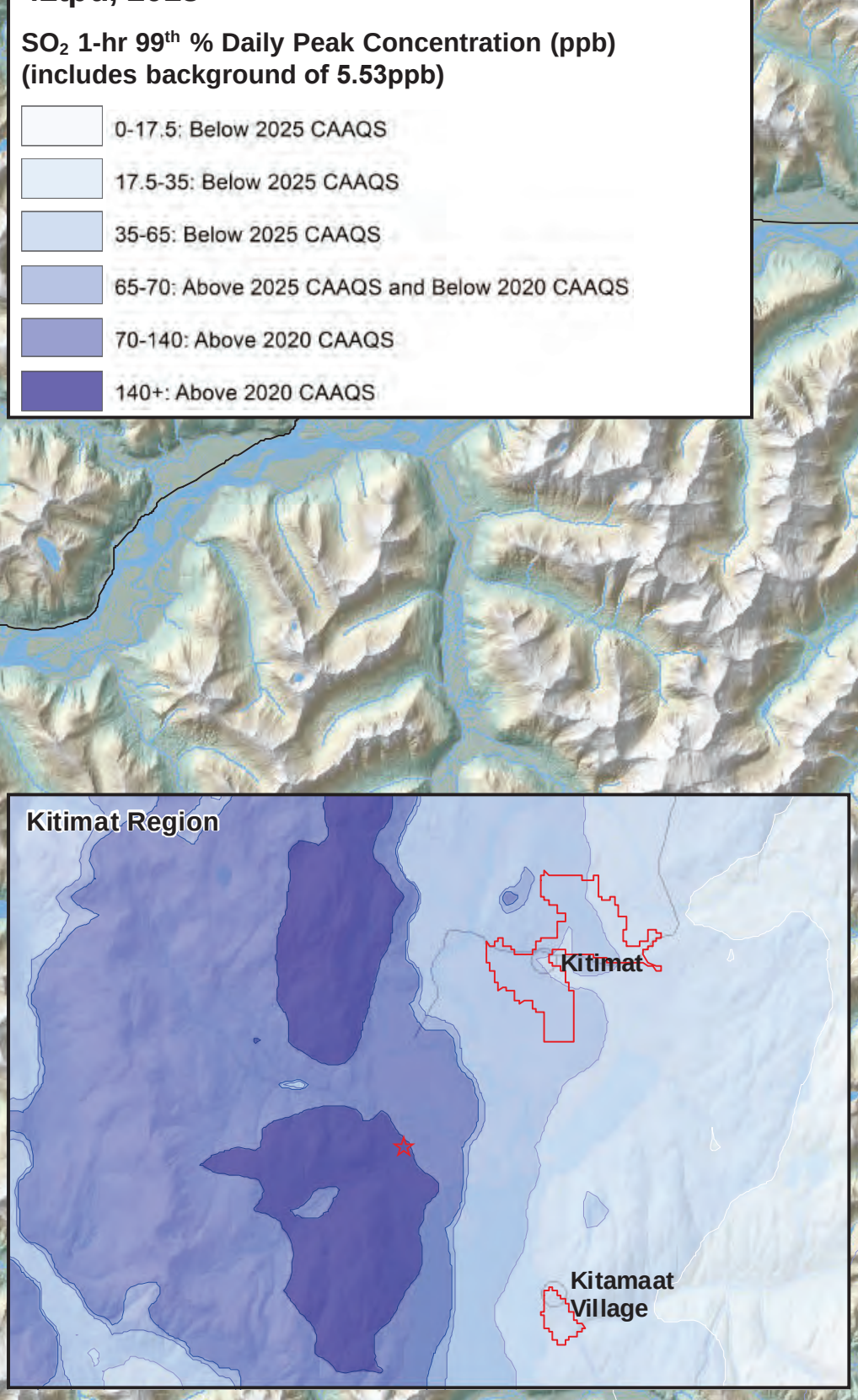
Primary Road

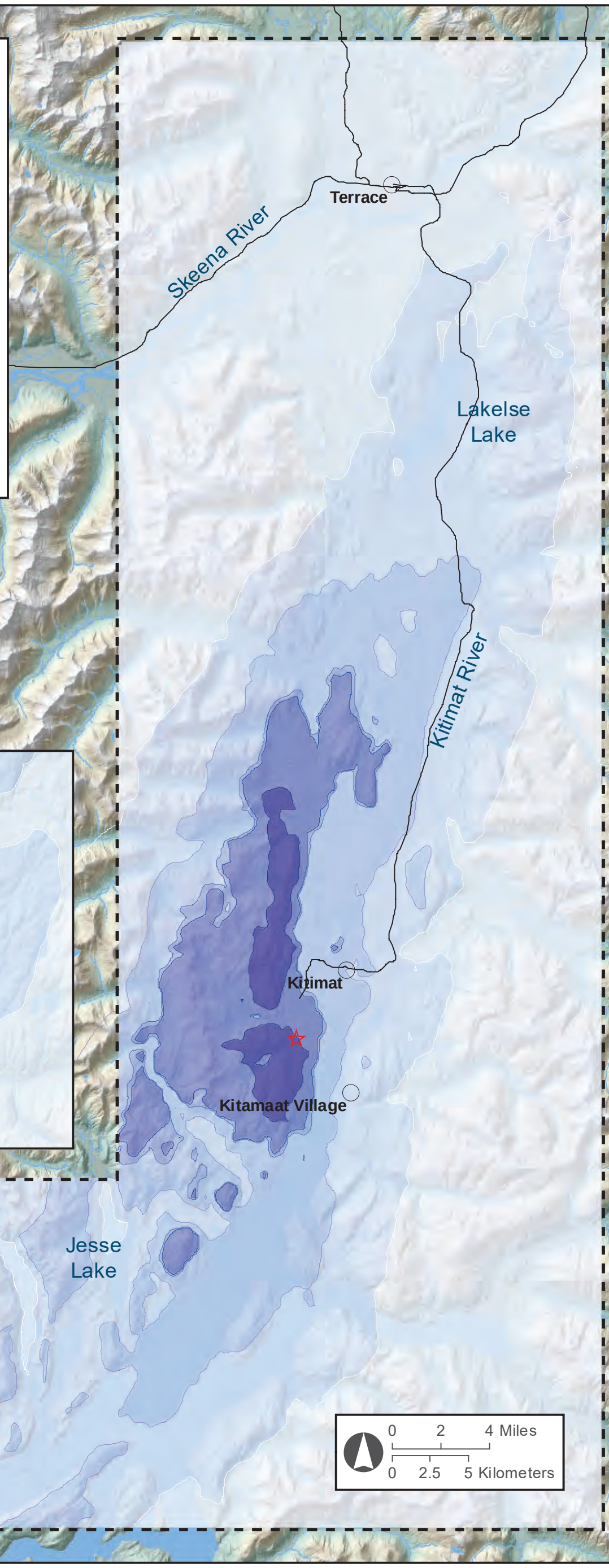
Study Area (2019 Deposition Model Extent)

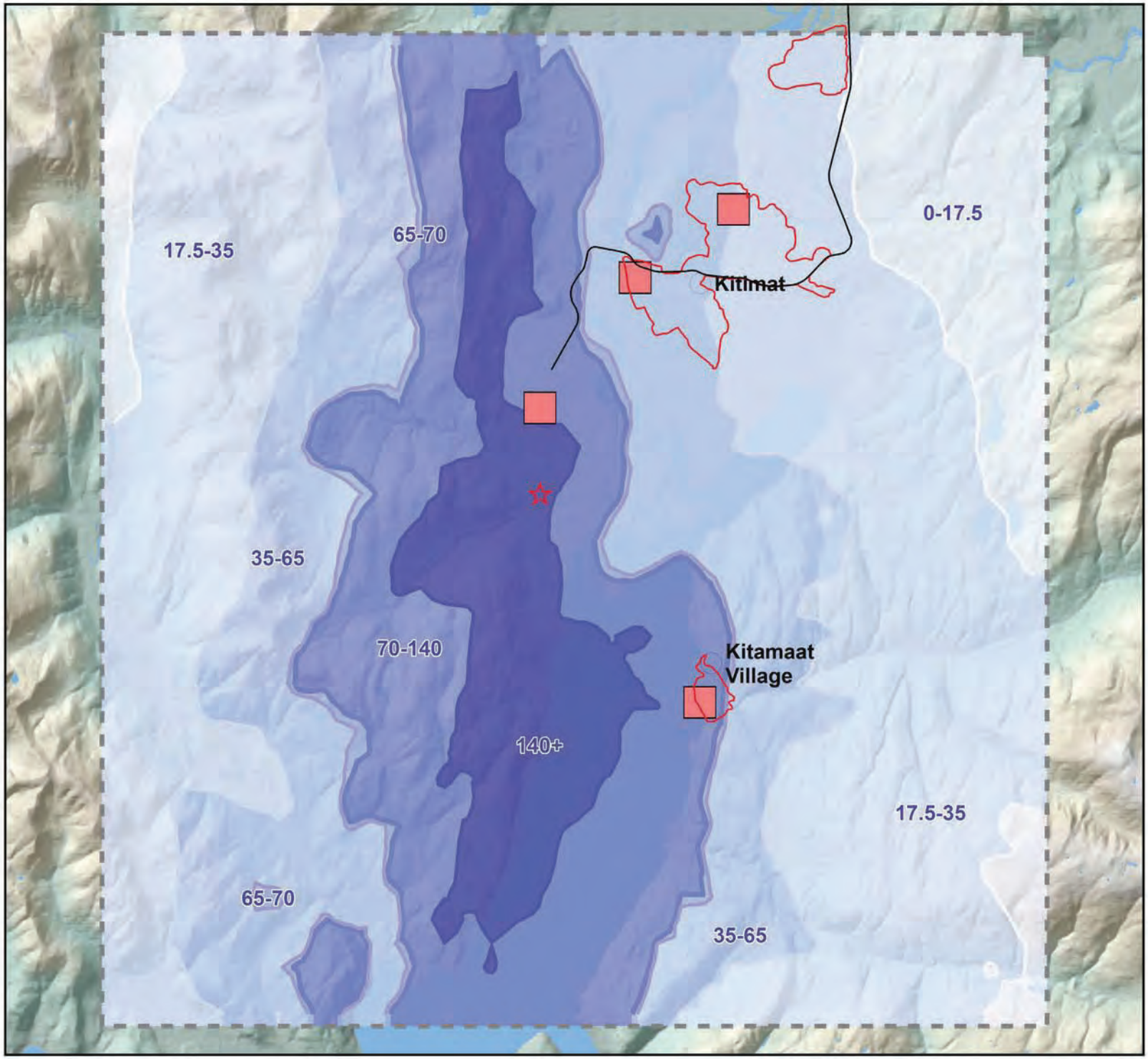
42tpd, 2018

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS







SO_2 EEM Atmospheric Pathway

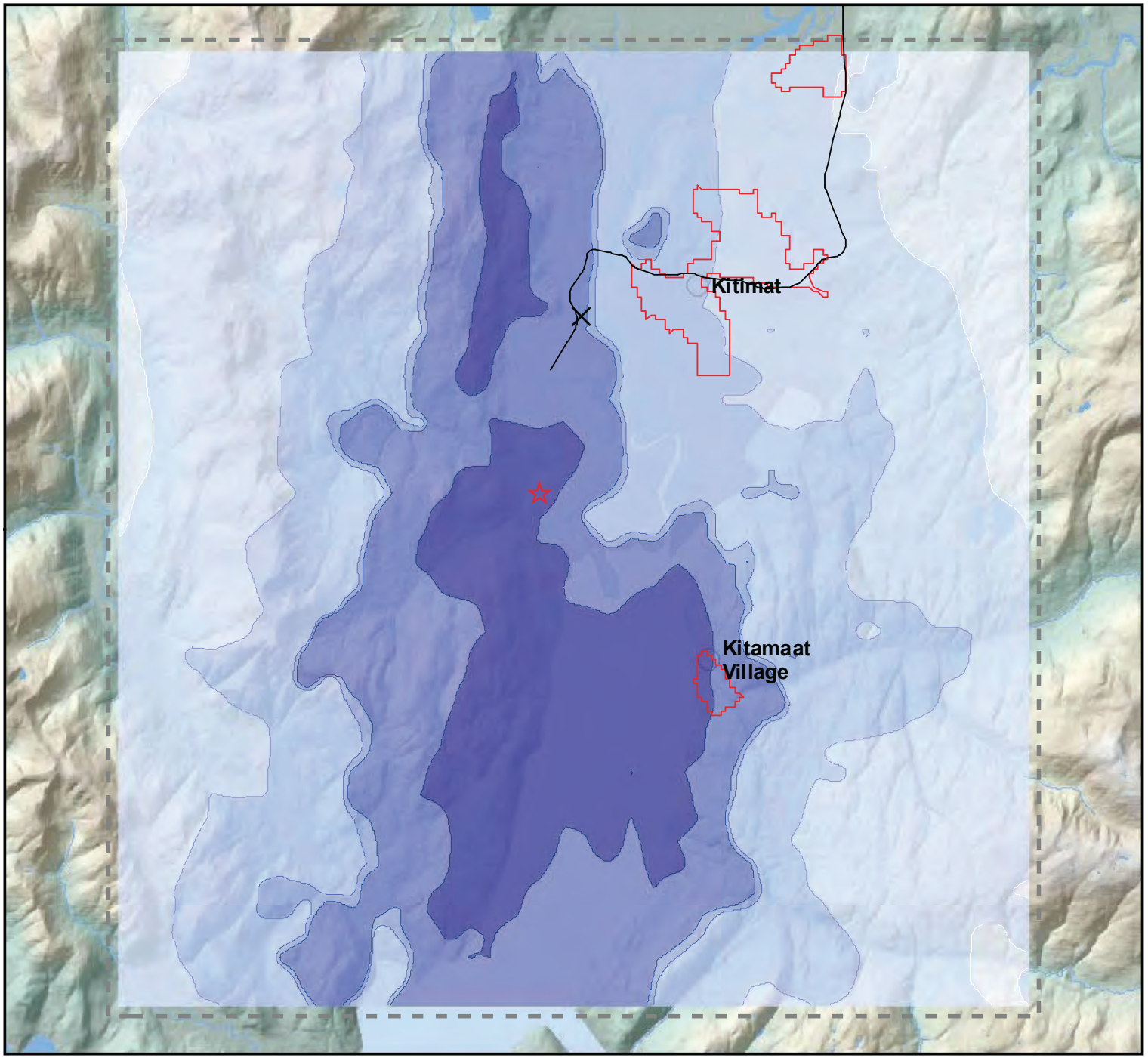
- Rio Tinto Site
- Primary Road
- Residential Area
- Study Area (2019 Local [SO_2] Model)
- Continuous SO_2 Analyzer Station

1hr, 4th Highest Day, 3-year (2016, 2017, 2018) Average Modelled [SO_2] ("42 tpd" scenario) Including Background Concentration (ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

0 0.85 1.7 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

Residential Area

Study Area (2019 Local [SO_2] Model)

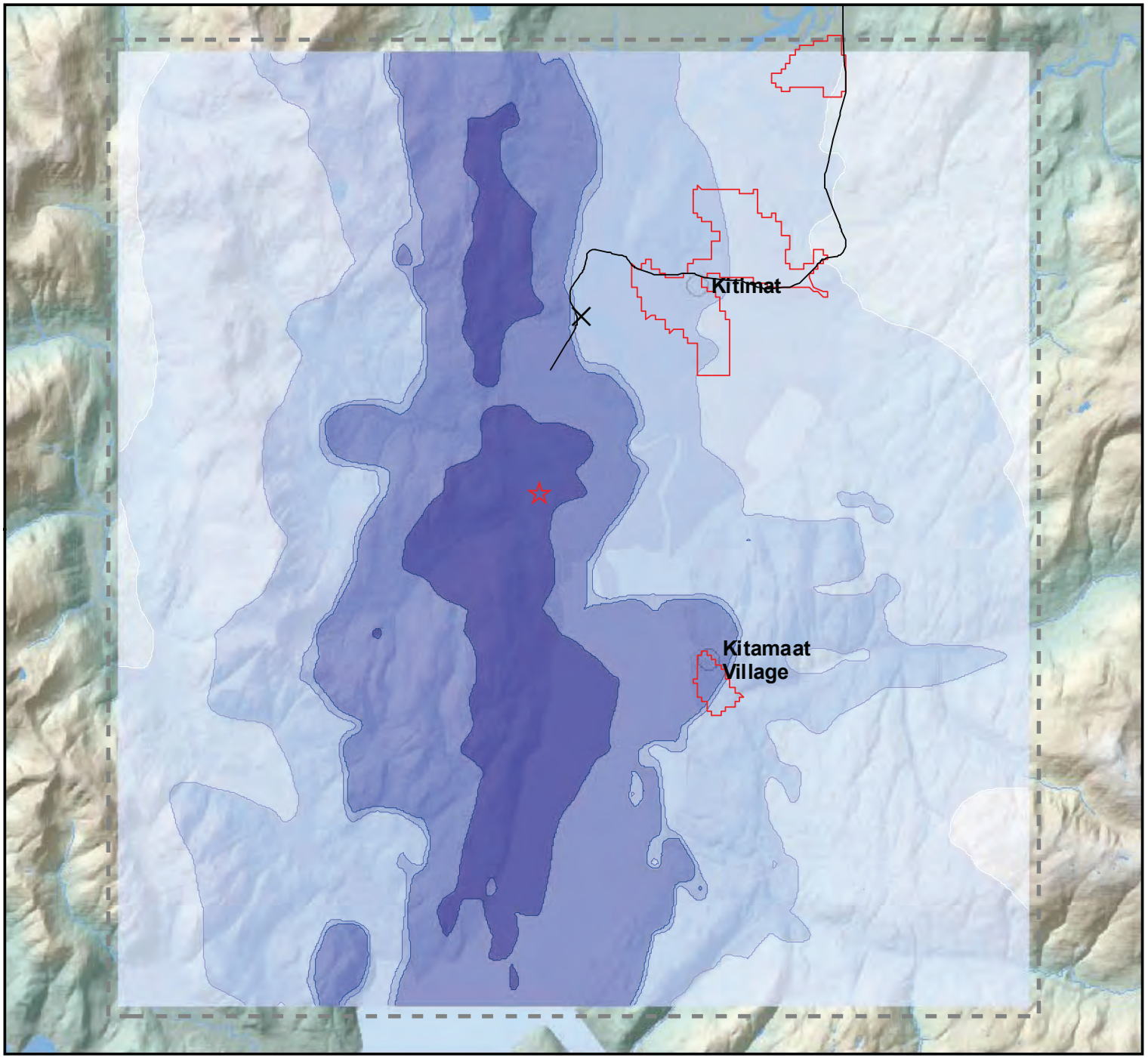
42tpd, 2016

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area (2019 Local [SO_2] Model)

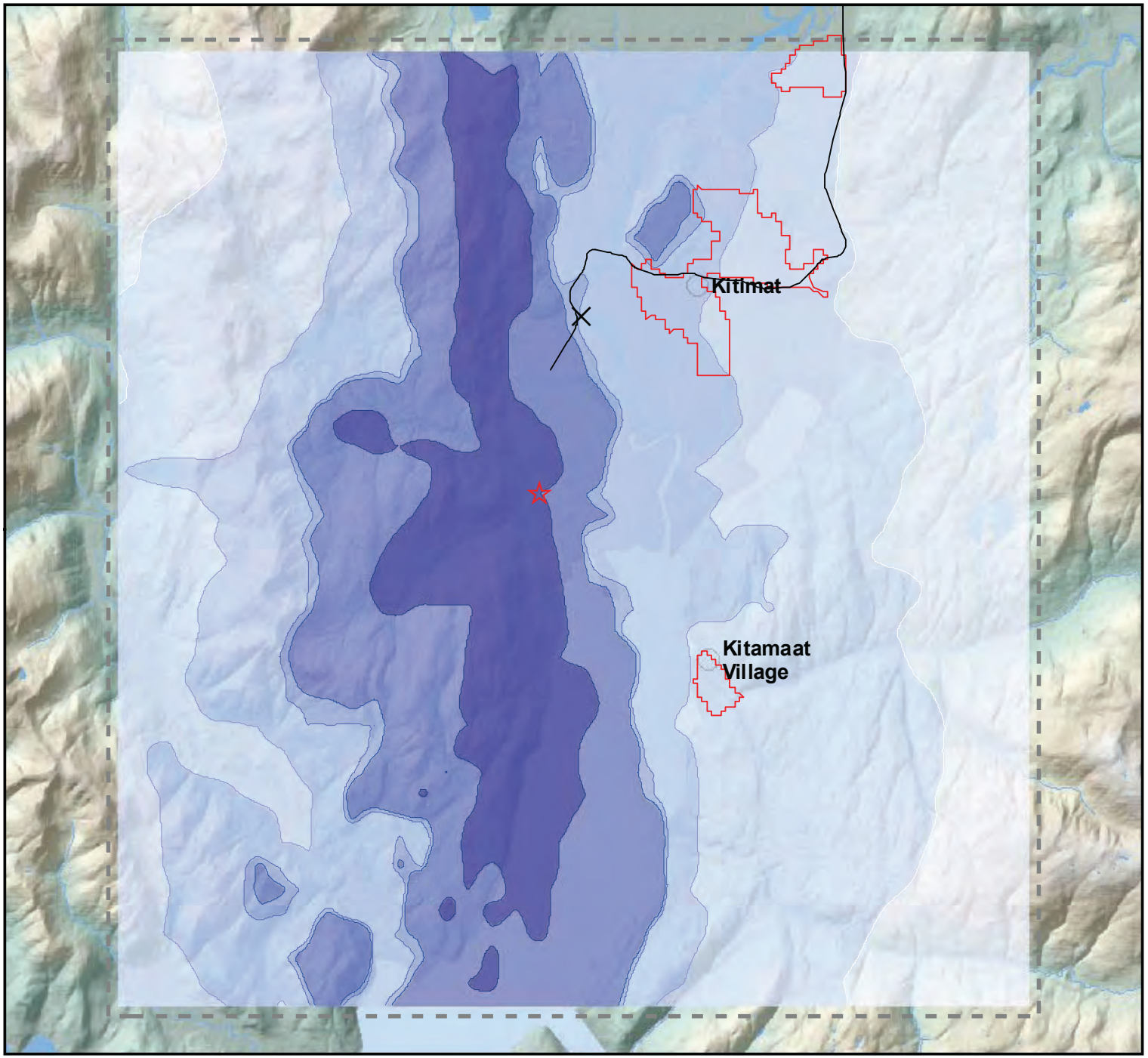
42tpd, 2017

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

Residential Area

Study Area (2019 Local [SO_2] Model)

42tpd, 2018

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
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- 140+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers

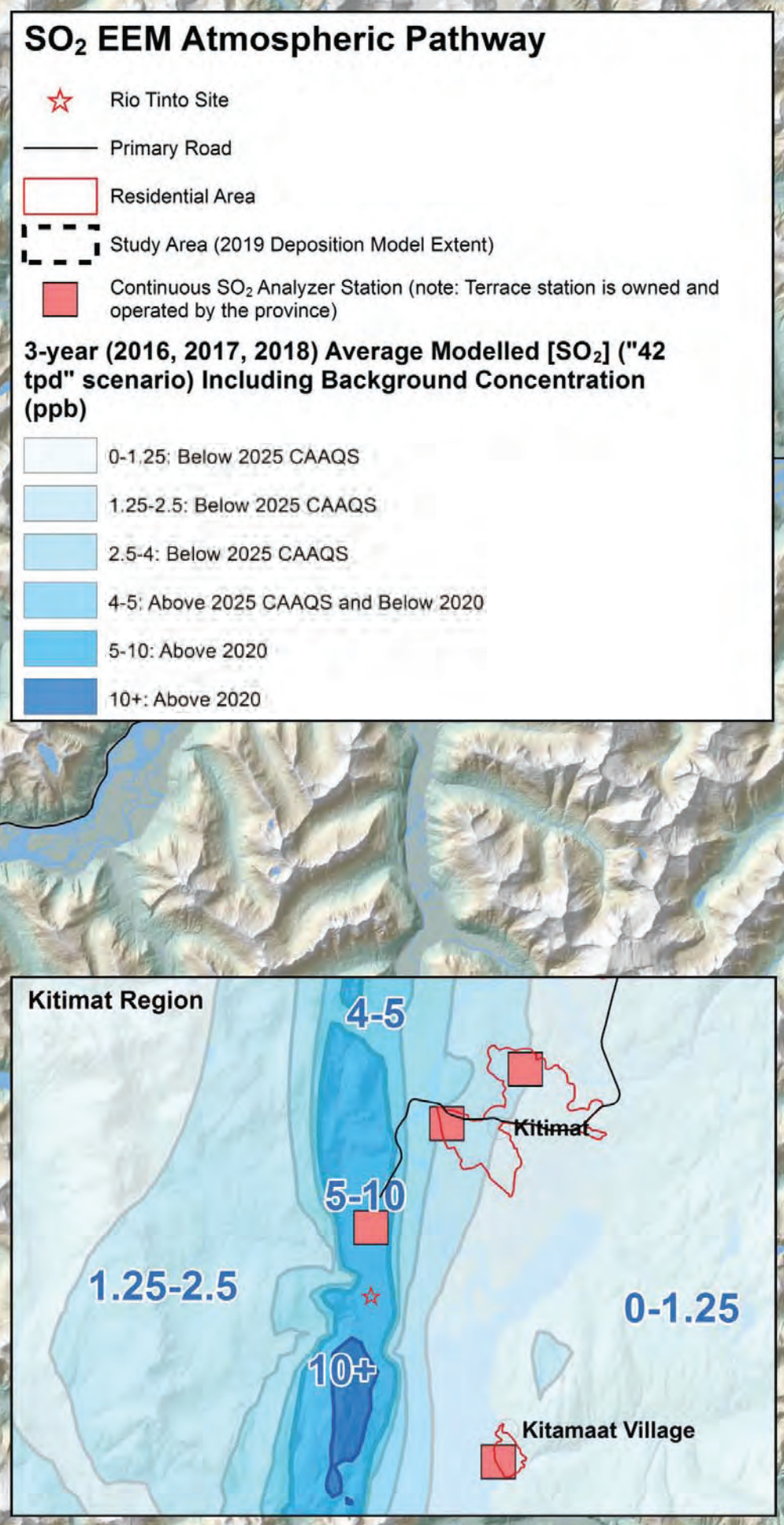
Maps of 42 tpd scenario, annual average

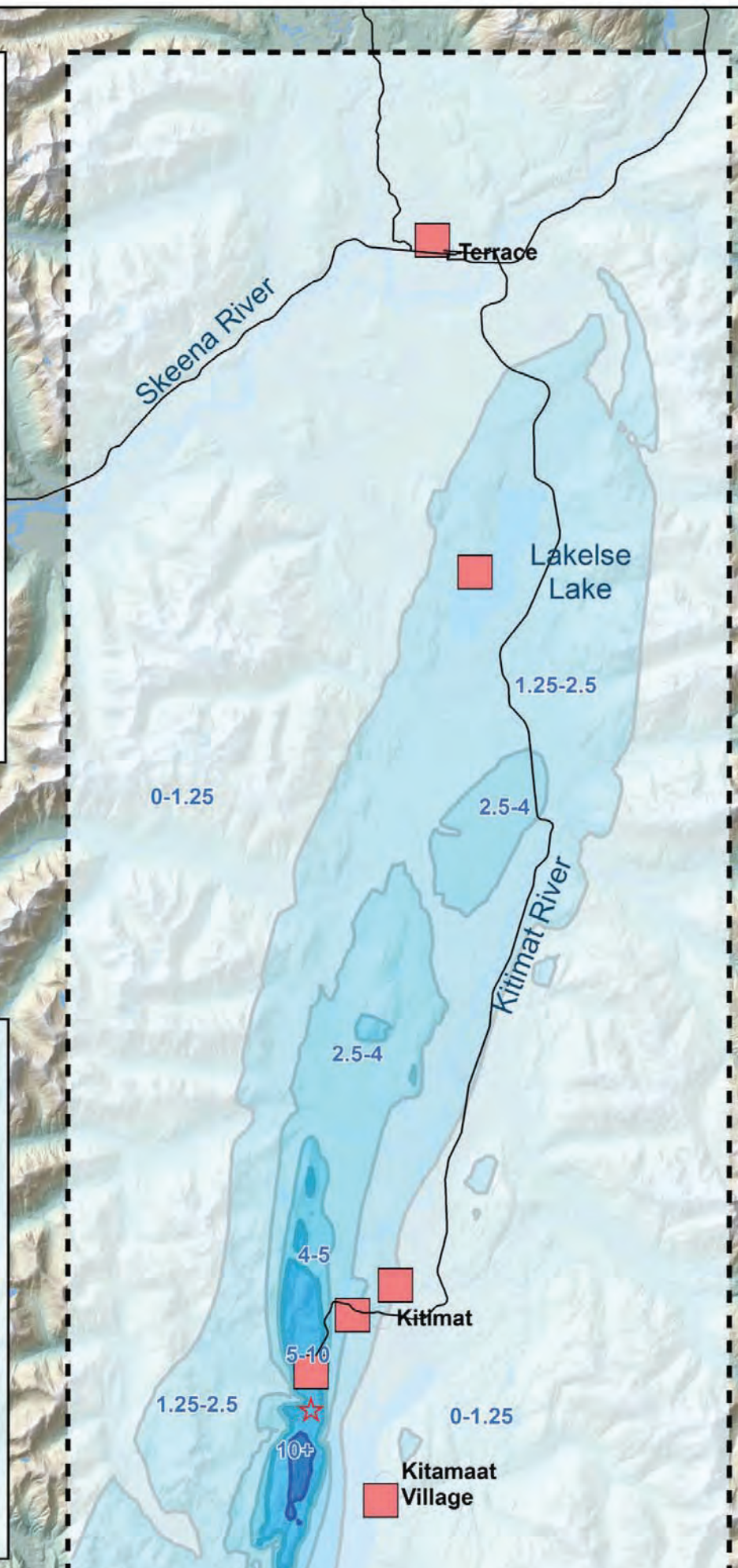
SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Primary Road
- Residential Area
- Study Area (2019 Deposition Model Extent)
- Continuous SO_2 Analyzer Station (note: Terrace station is owned and operated by the province)

3-year (2016, 2017, 2018) Average Modelled [SO_2] ("42 tpd" scenario) Including Background Concentration (ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
- 2.5-4: Below 2025 CAAQS
- 4-5: Above 2025 CAAQS and Below 2020
- 5-10: Above 2020
- 10+: Above 2020





SO_2 EEM Atmospheric Pathway

☆ Rio Tinto Site

Primary Road

Study Area (2019 Deposition Model Extent)

42tpd, 2016

SO_2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
- 2.5-4: Below 2025 CAAQS
- 4-5: Above 2025 CAAQS and Below 2020
- 5-10: Above 2020
- 10+: Above 2020

Terrace

Skeena River

Lakelse Lake

Kitimat River

Kitimat

Kitamaat Village

Jesse Lake

Kitimat Region

Kitimat

Kitamaat Village

0 2 4 Miles

0 2.5 5 Kilometers

SO_2 EEM Atmospheric Pathway

☆ Rio Tinto Site

Primary Road

Study Area (2019 Deposition Model Extent)

42tpd, 2017

SO_2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
- 2.5-4: Below 2025 CAAQS
- 4-5: Above 2025 CAAQS and Below 2020
- 5-10: Above 2020
- 10+: Above 2020

Terrace

Skeena River

Lakelse Lake

Kitimat River

Kitimat

Kitamaat Village

Jesse Lake

Kitimat Region

Kitimat

Kitamaat Village

0 2 4 Miles

0 2.5 5 Kilometers

SO_2 EEM Atmospheric Pathway

☆ Rio Tinto Site

Primary Road

Study Area (2019 Deposition Model Extent)

42tpd, 2018

SO_2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
- 2.5-4: Below 2025 CAAQS
- 4-5: Above 2025 CAAQS and Below 2020
- 5-10: Above 2020
- 10+: Above 2020

Terrace

Skeena River

Lakelse Lake

Kitimat River

Kitimat

Kitamaat Village

Jesse Lake

Kitimat Region

Kitimat

Kitamaat Village

0 2 4 Miles

0 2.5 5 Kilometers



SO_2 EEM Atmospheric Pathway

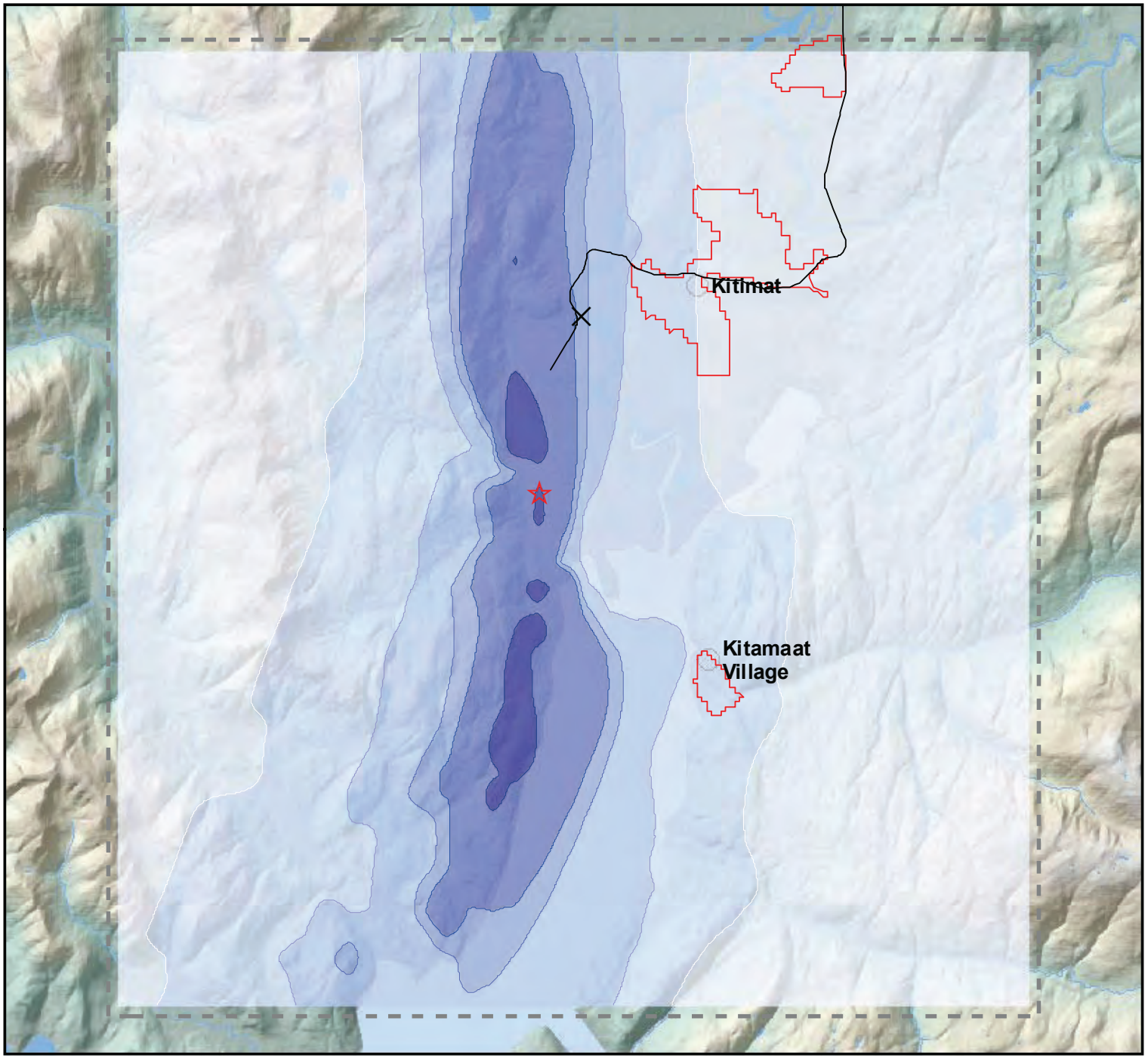
- Rio Tinto Site
- Primary Road
- Residential Area
- Study Area (2019 Local [SO_2] Model)
- Continuous SO_2 Analyzer Station

3-year (2016, 2017, 2018) Average Modelled [SO_2] ("42 tpd" scenario) Including Background Concentration (ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
- 2.5-4: Below 2025 CAAQS
- 4-5: Above 2025 CAAQS and Below 2020 CAAQS
- 5-10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.85 1.7 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

Residential Area

Study Area (2019 Local [SO_2] Model)

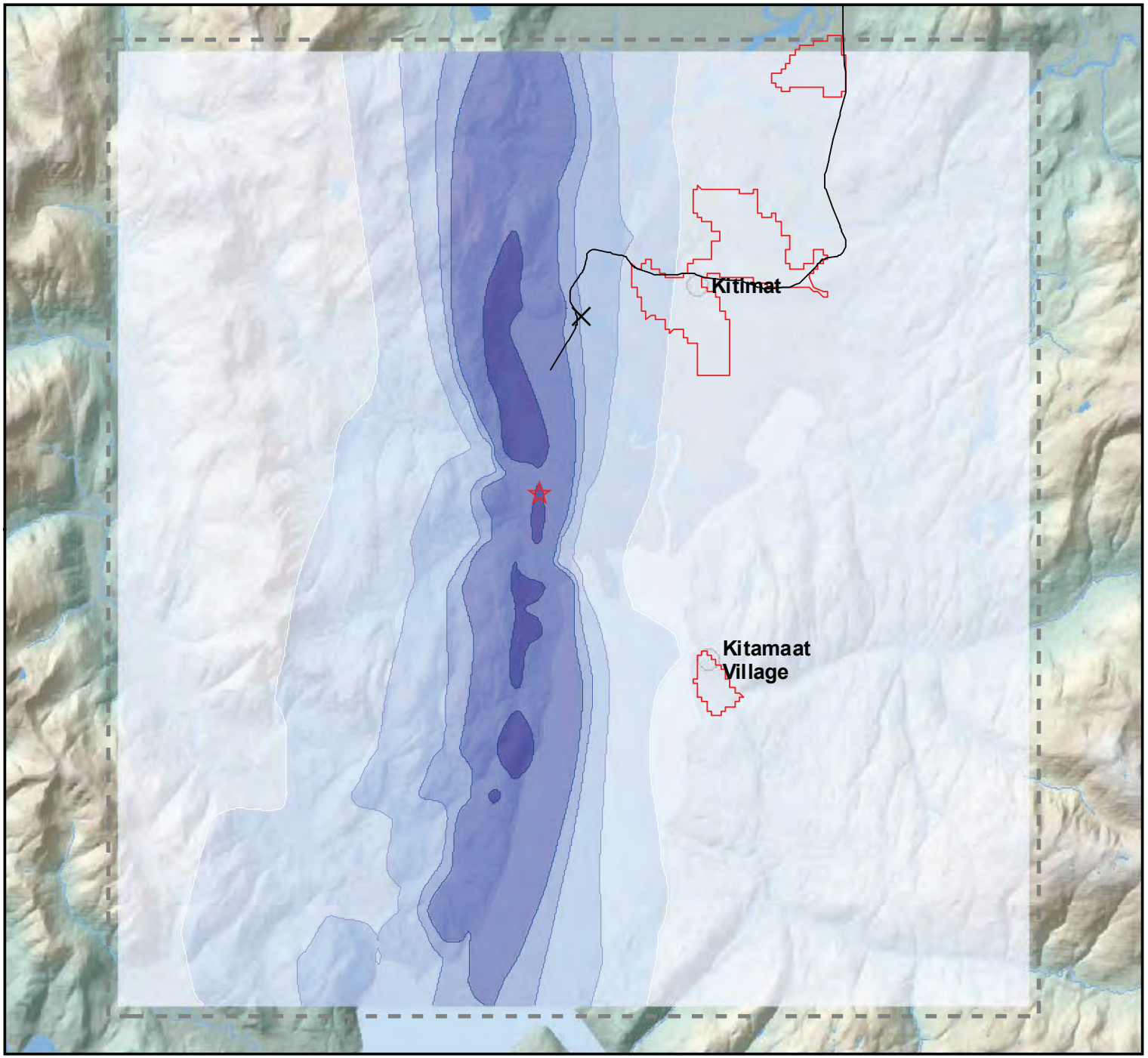
42tpd, 2016

SO_2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
- 2.5-4: Below 2025 CAAQS
- 4-5: Above 2025 CAAQS and Below 2020 CAAQS
- 5-10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

Residential Area

Study Area (2019 Local [SO_2] Model)

42tpd, 2017

SO_2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)

0-1.25: Below 2025 CAAQS

1.25-2.5: Below 2025 CAAQS

2.5-4: Below 2025 CAAQS

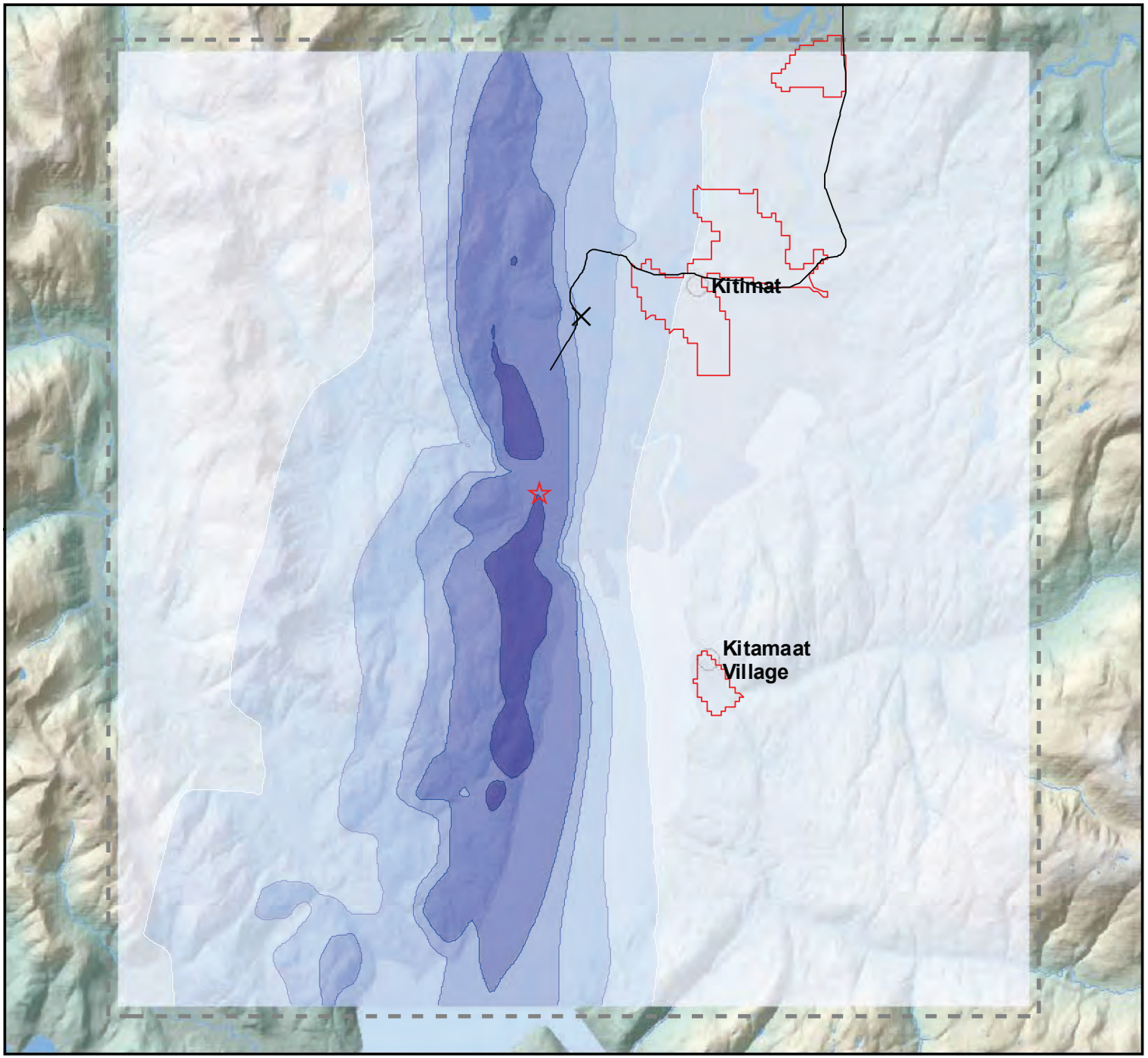
4-5: Above 2025 CAAQS and Below 2020 CAAQS

5-10: Above 2020 CAAQS

10+ Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

Residential Area

Study Area (2019 Local [SO_2] Model)

42tpd, 2018

SO_2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
- 2.5-4: Below 2025 CAAQS
- 4-5: Above 2025 CAAQS and Below 2020 CAAQS
- 5-10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers

Maps of 42 tpd scenario, 98th % and 97.5th % of daily 1-hour peak

SO_2 EEM Atmospheric Pathway

☆ Rio Tinto Site

Primary Road

42 tpd, 3-Year Average

SO_2 1-hr 98th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

Terrace

Skeena River

Lakelse Lake

Kitimat River

Kitimat

Kitamaat Village

Jesse Lake

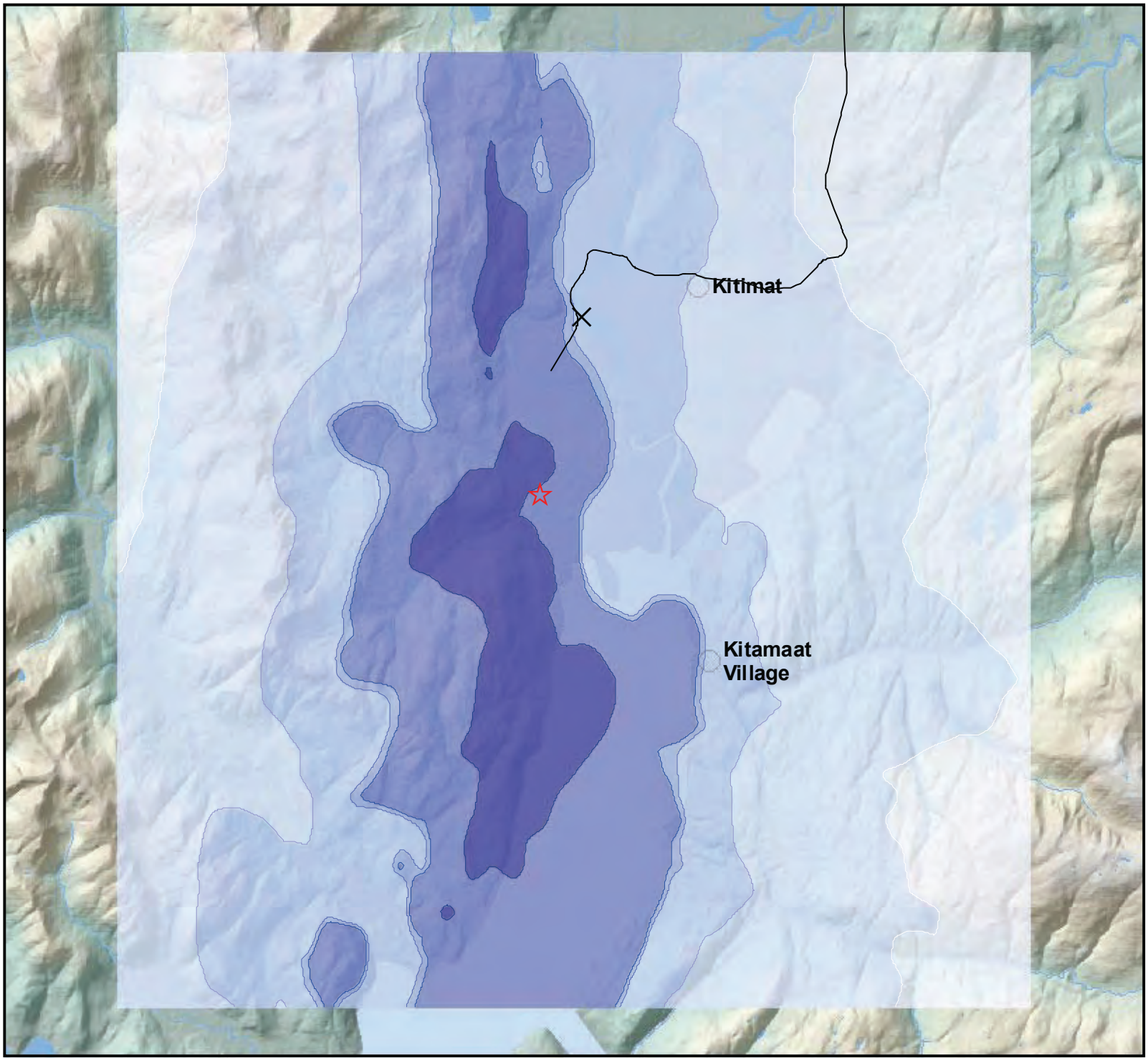
Kitimat Region

Kitimat

Kitamaat Village

0 2 4 Miles

0 2.5 5 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

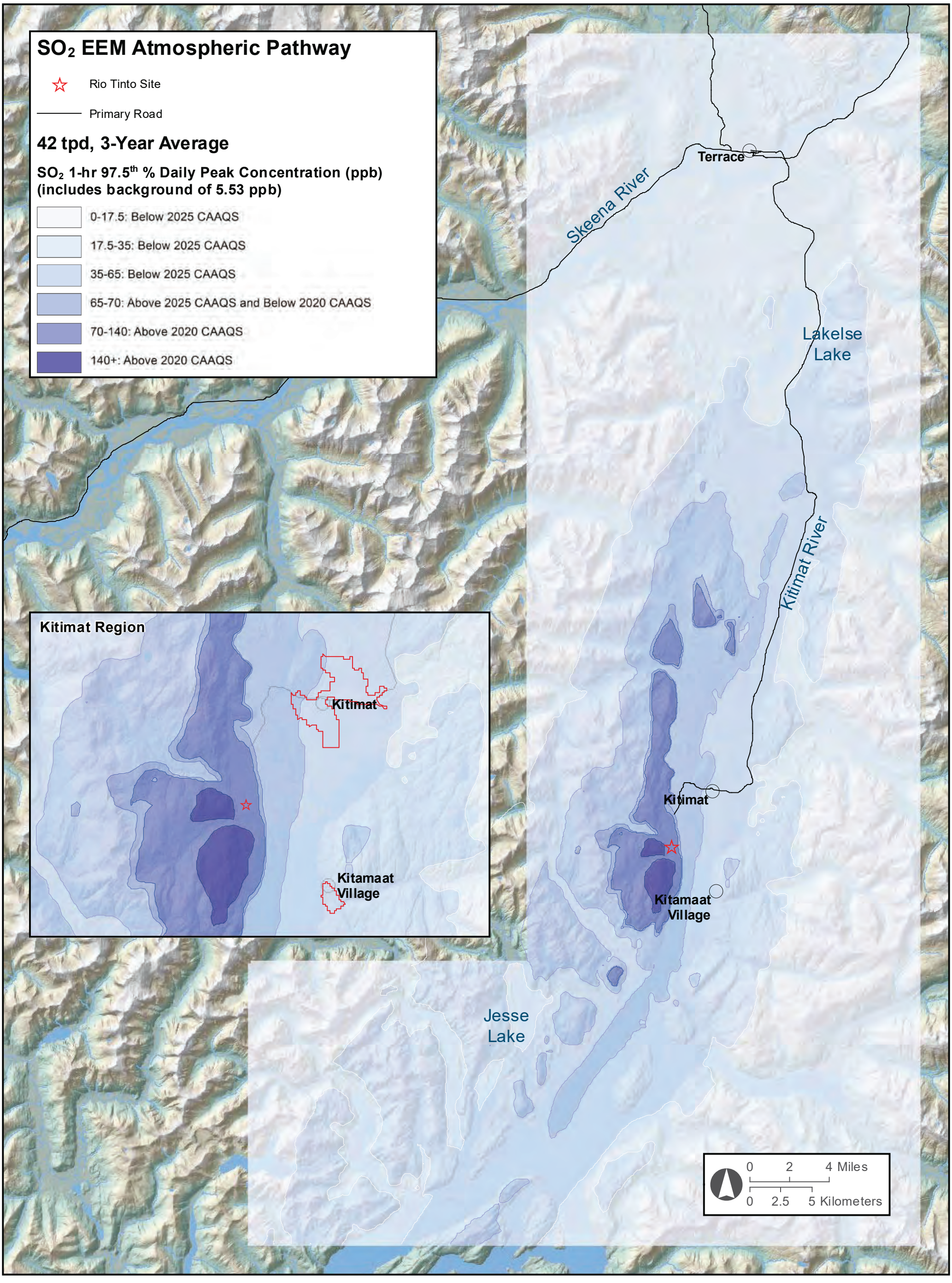
42 tpd, 3-Year Average

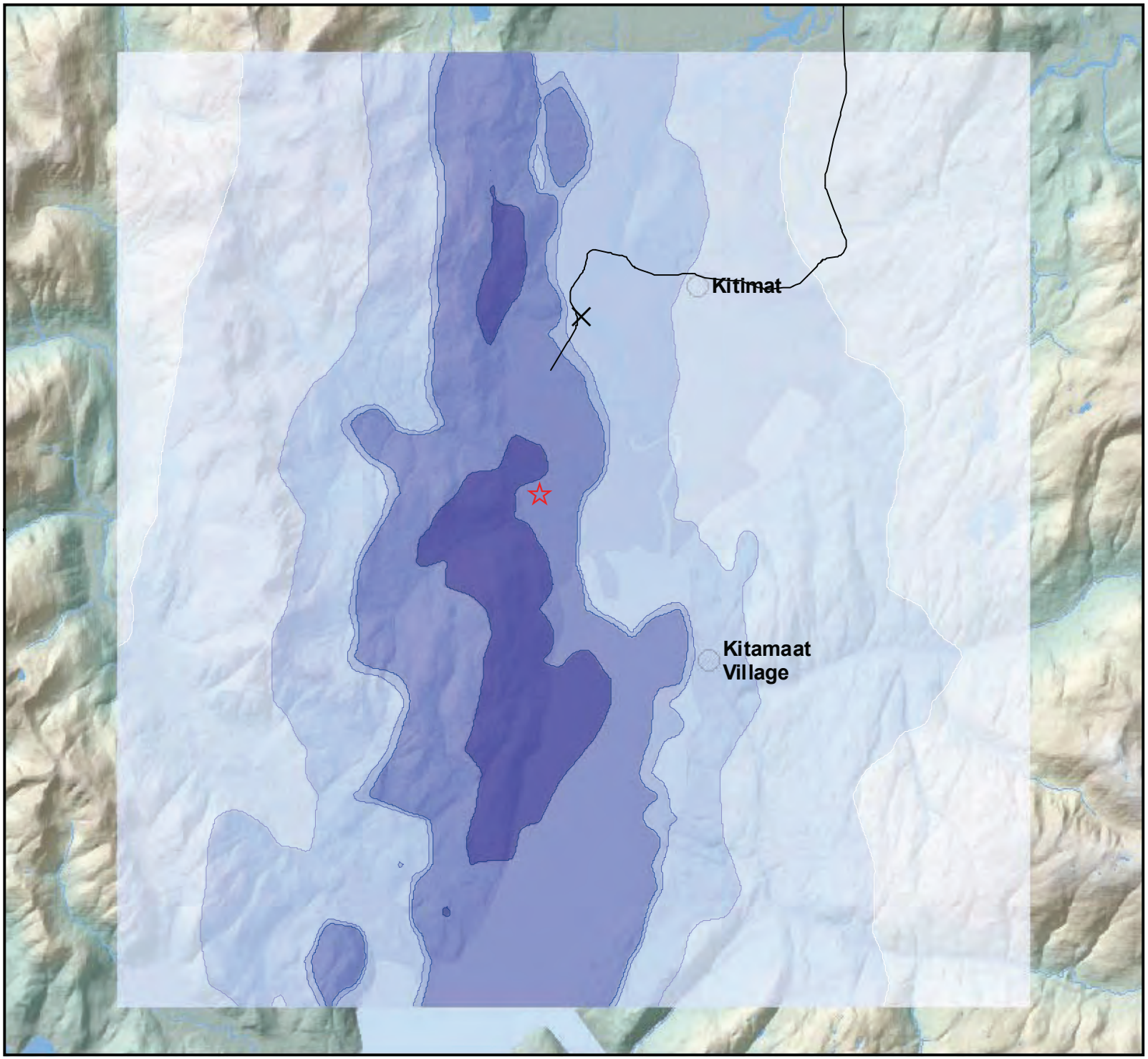
SO_2 1-hr 98th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
42 tpd, 3-Year Average
SO_2 1-hr 97.5th % Daily Peak Concentration (ppb)
(includes background of 5.53 ppb)
0-17.5: Below 2025 CAAQS
17.5-35: Below 2025 CAAQS
35-65: Below 2025 CAAQS
65-70: Above 2025 CAAQS and Below 2020 CAAQS
70-140: Above 2020 CAAQS
140+: Above 2020 CAAQS
Kitimat Region
Kitimat
Kitamaat Village
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

42 tpd, 3-Year Average

SO_2 1-hr 97.5th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers

42 tpd scenario, 1-hour exceedance maps

SO_2 EEM Atmospheric Pathway

☆ Rio Tinto Site

——— Primary Road

2016 - 2018 Maximum Number of Exceedances each Year - 42tpd

 # 1-hr 99th % Exceedances. Threshold: 70 ppb, minus individual year background concentrations.

- 0
- 1 - 3
- 4 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 787

Terrace

Skeena River

Lakelse Lake

Kitimat River

Kitimat Region

Kitimat

Kitamaat Village

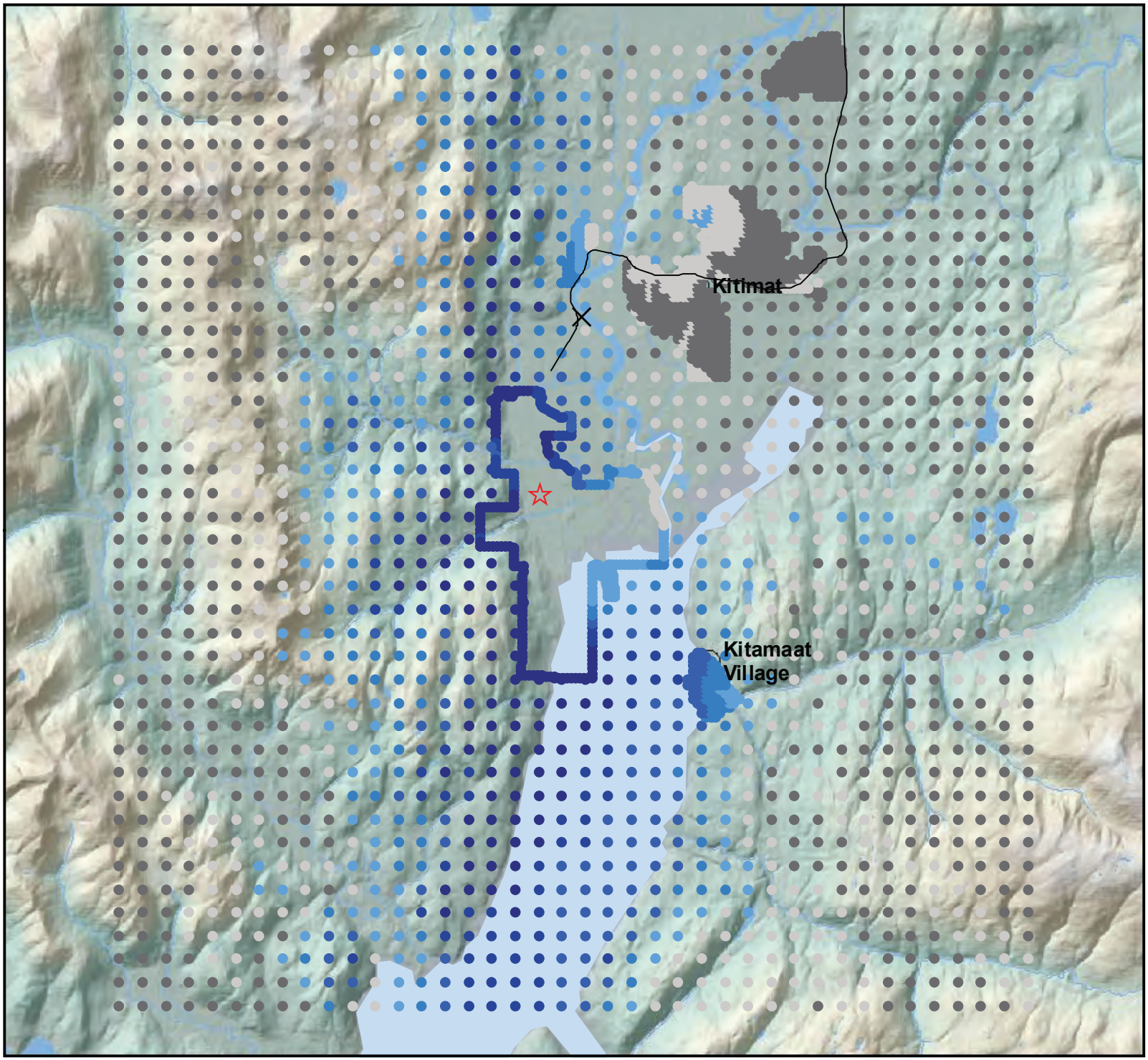
Kitimat

Kitamaat Village

Jesse Lake

0 2 4 Miles

0 2.5 5 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

2016 - 2018 Maximum Annual Exceedances - 42tpd

 # 1-hr 99th % Exceedances. Threshold: 70 ppb, minus individual year background concentrations.

- 0
- 1 - 3
- 4 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 787

0 0.9 1.8 Miles

0 1 2 Kilometers

Sulphate deposition maps

SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Residential Area

Study Area (2019 Deposition Model Extent)

Total Sulphur Deposition

3-year (2016, 2017, 2018) Average Modelled Total Sulphur Deposition - 7.5 kg SO_4^{2-}/ha/yr isopleth ("42 tpd" scenario)

3-Year (2016, 2017, 2018) Average Modeled SO_4 Deposition ("42tpd" scenario) (kg/ha/yr)

10 - 19

20 - 29

30 - 39

40 - 49

50 - 99

100 - 199

200 - 299

300+

Terrace

Skeena River

Lakelse Lake

Kitimat River

Kitimat

Kitamaat Village

Kitimat Region

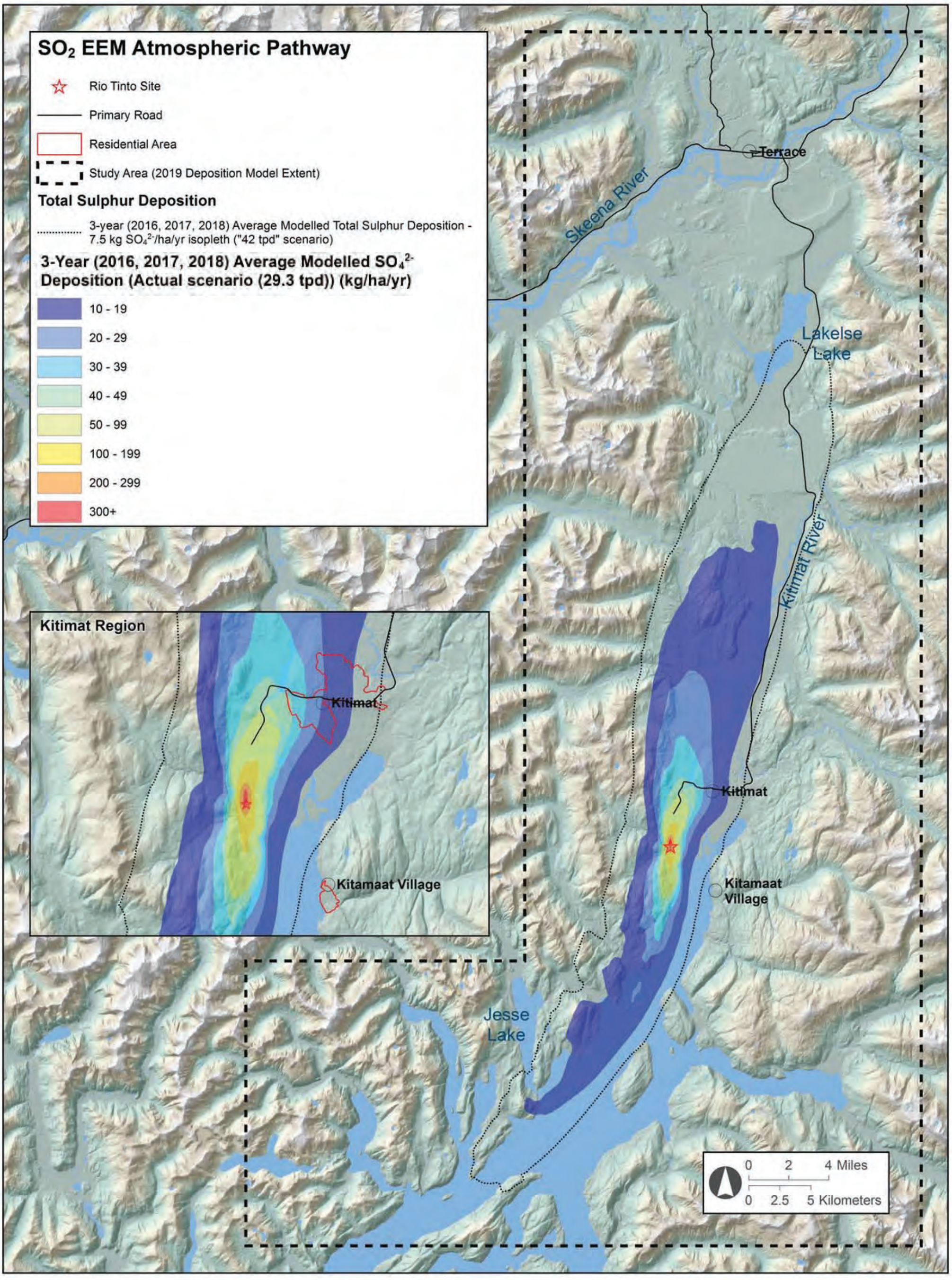
Kitimat

Kitamaat Village

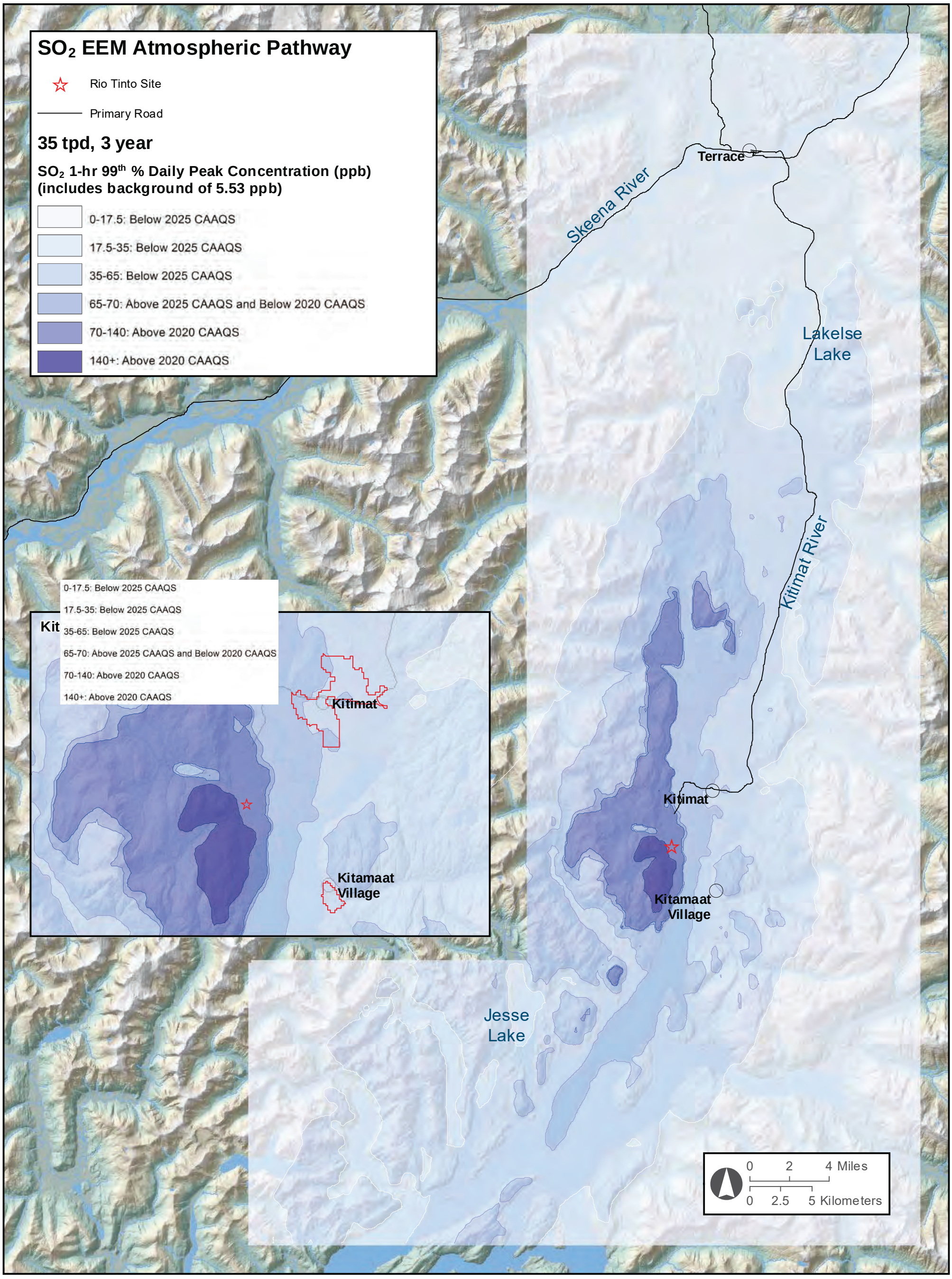
Jesse Lake

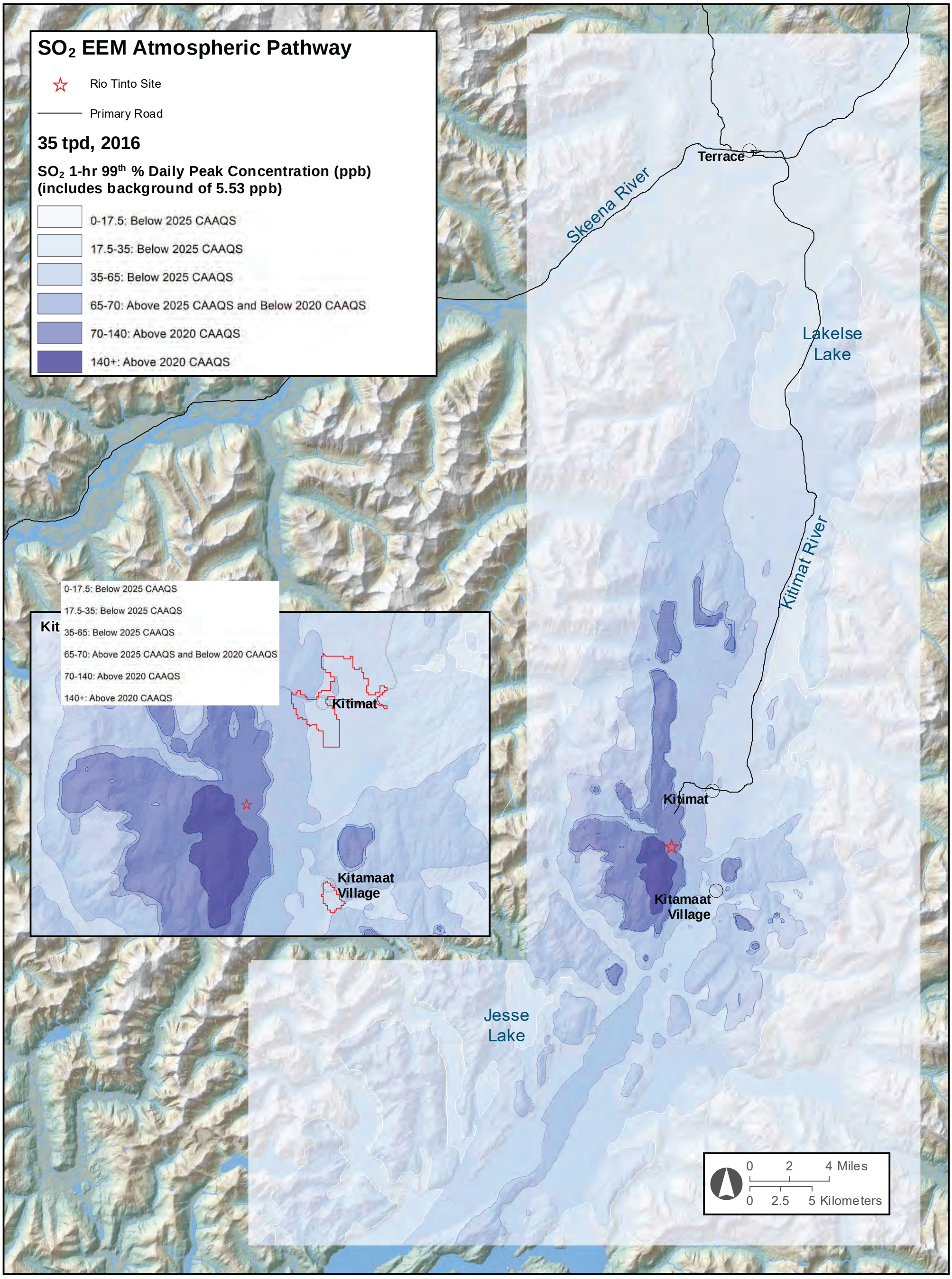
0 2 4 Miles

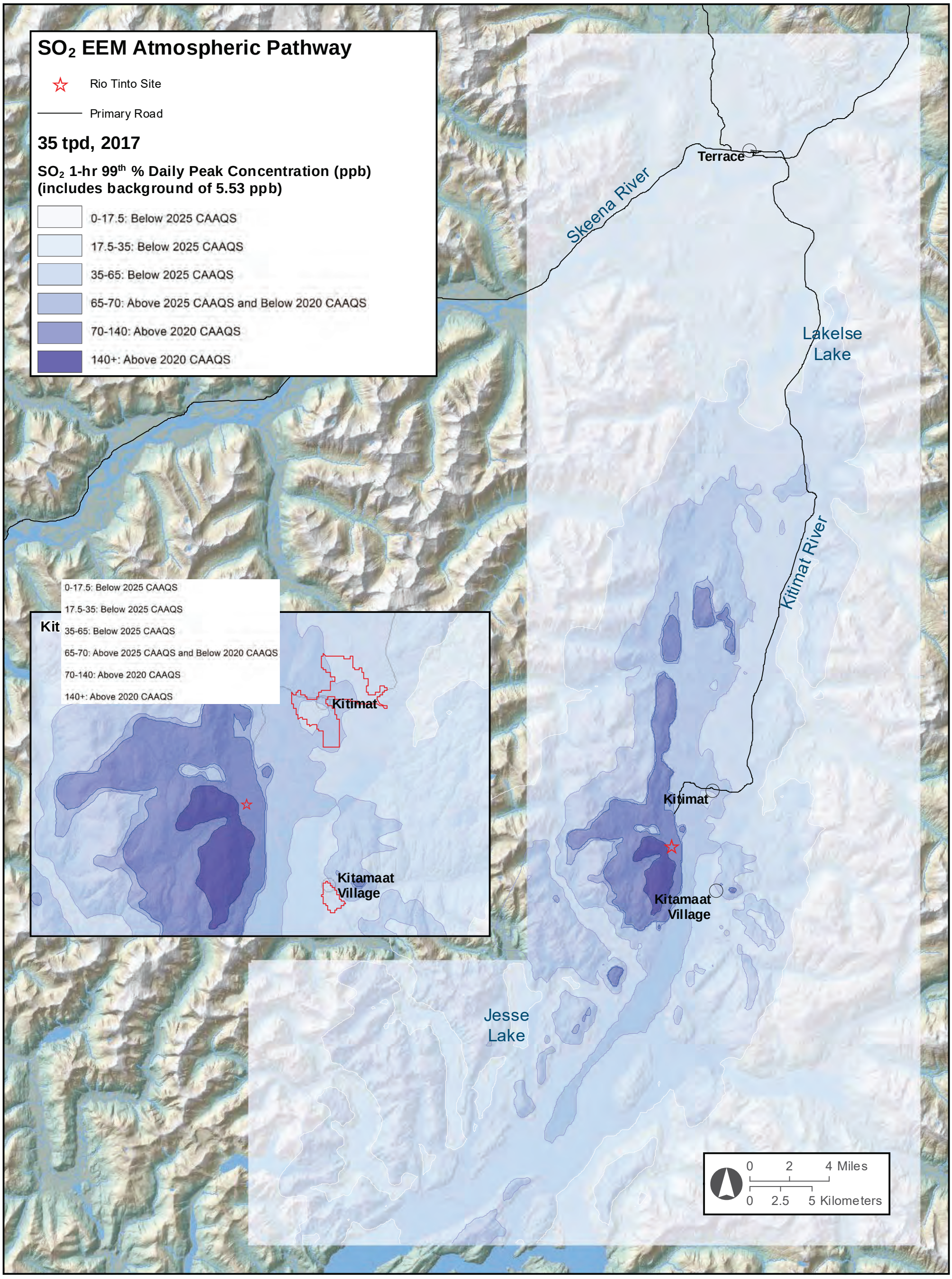
0 2.5 5 Kilometers

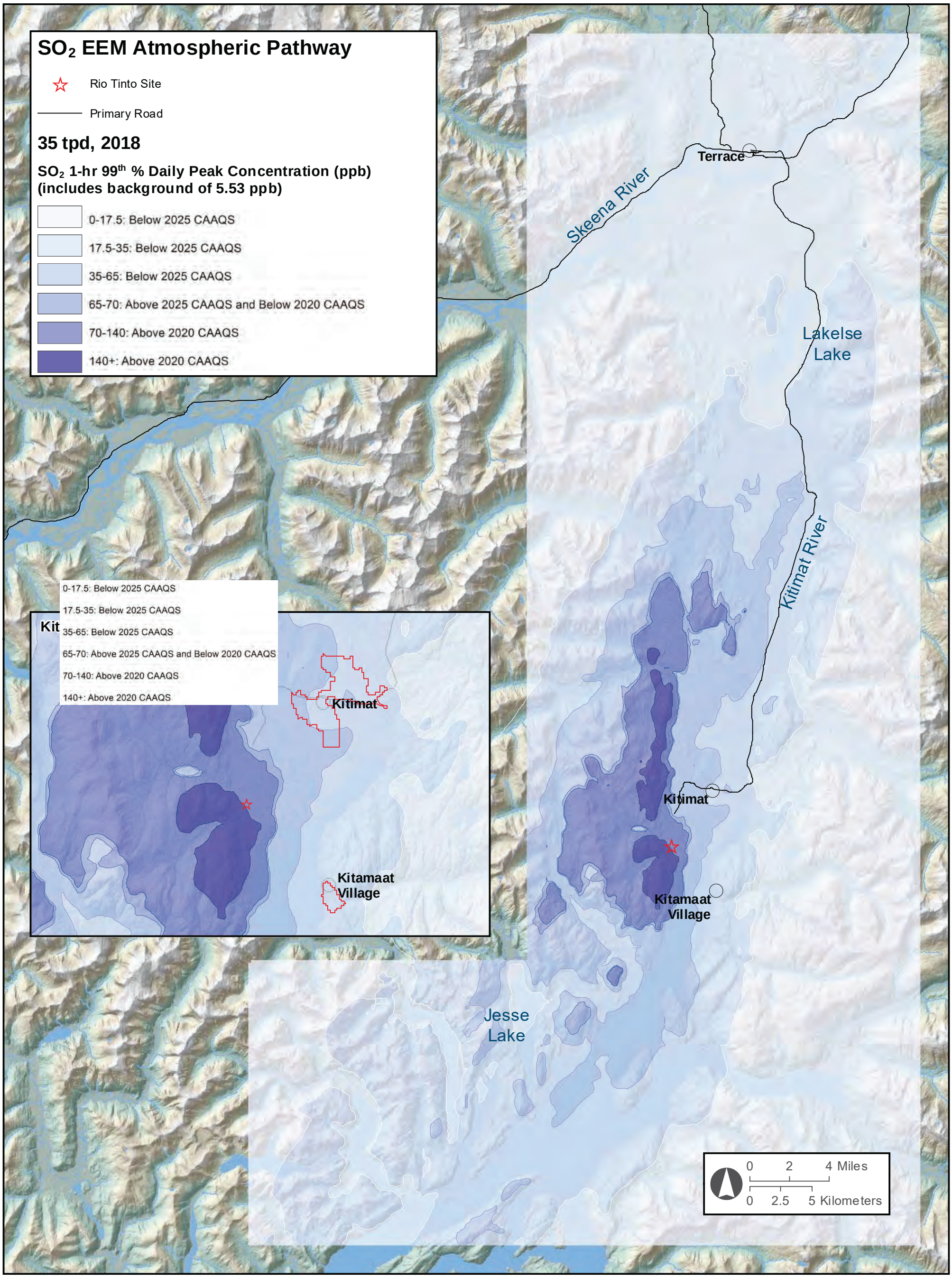

SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Residential Area
Study Area (2019 Deposition Model Extent)
Total Sulphur Deposition
3-year (2016, 2017, 2018) Average Modelled Total Sulphur Deposition - 7.5 kg SO4 2-/ha/yr isopleth ("42 tpd" scenario)
3-Year (2016, 2017, 2018) Average Modelled SO4 2- Deposition (Actual scenario (29.3 tpd)) (kg/ha/yr)
10 - 19
20 - 29
30 - 39
40 - 49
50 - 99
100 - 199
200 - 299
300+
Kitimat Region
Kitimat
Kitamaat Village
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers

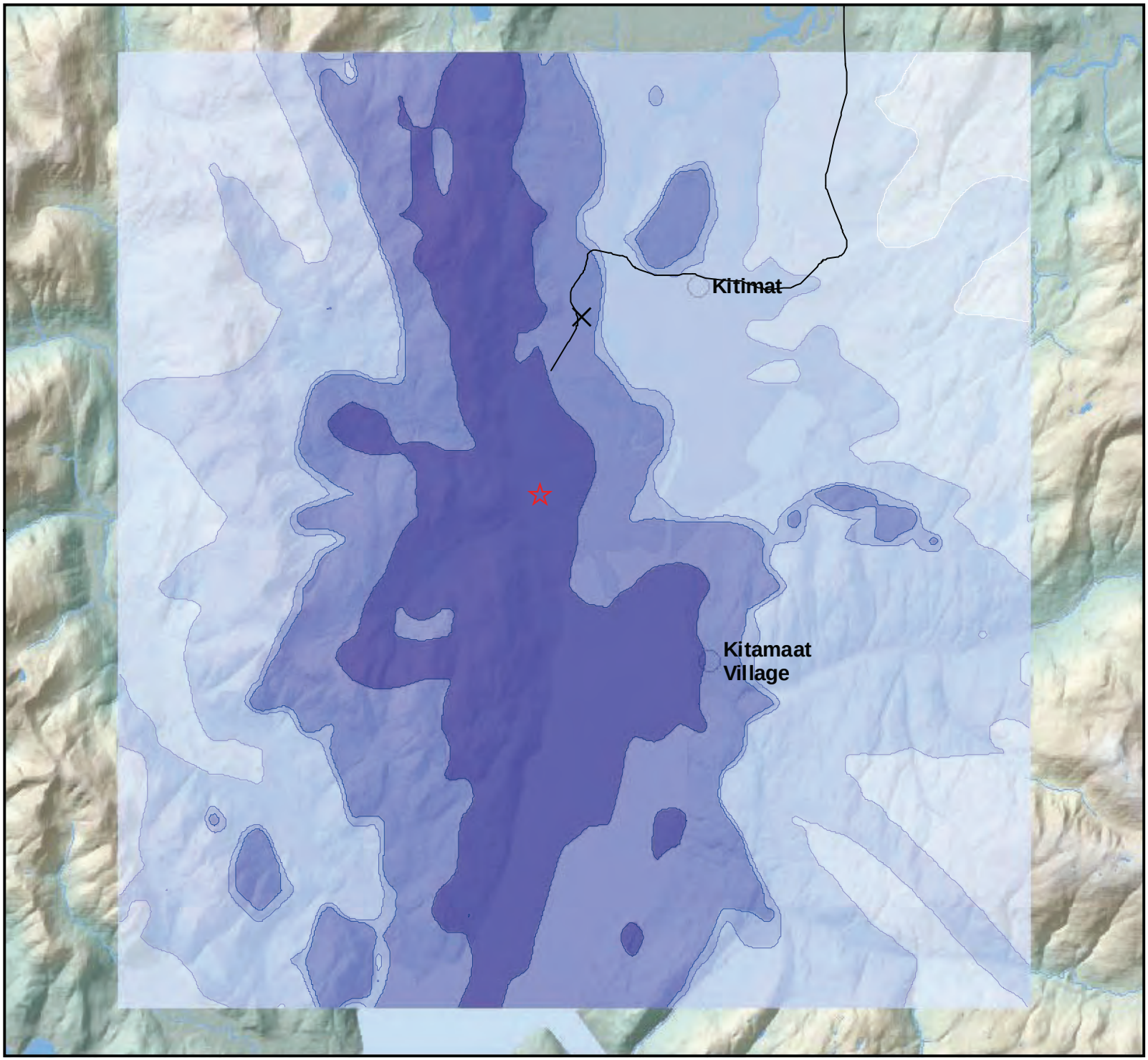
Maps of 35 tpd scenario, 99th % of daily 1-hour peak


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
35 tpd, 3 year
SO_2 1-hr 99th % Daily Peak Concentration (ppb)
(includes background of 5.53 ppb)
0-17.5: Below 2025 CAAQS
17.5-35: Below 2025 CAAQS
35-65: Below 2025 CAAQS
65-70: Above 2025 CAAQS and Below 2020 CAAQS
70-140: Above 2020 CAAQS
140+: Above 2020 CAAQS
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers


SO_2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
35 tpd, 2016
SO_2 1-hr 99th % Daily Peak Concentration (ppb)
(includes background of 5.53 ppb)
0-17.5: Below 2025 CAAQS
17.5-35: Below 2025 CAAQS
35-65: Below 2025 CAAQS
65-70: Above 2025 CAAQS and Below 2020 CAAQS
70-140: Above 2020 CAAQS
140+: Above 2020 CAAQS
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
35 tpd, 2017
SO2 1-hr 99th % Daily Peak Concentration (ppb)
(includes background of 5.53 ppb)
0-17.5: Below 2025 CAAQS
17.5-35: Below 2025 CAAQS
35-65: Below 2025 CAAQS
65-70: Above 2025 CAAQS and Below 2020 CAAQS
70-140: Above 2020 CAAQS
140+: Above 2020 CAAQS
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
35 tpd, 2018
SO2 1-hr 99th % Daily Peak Concentration (ppb)
(includes background of 5.53 ppb)
0-17.5: Below 2025 CAAQS
17.5-35: Below 2025 CAAQS
35-65: Below 2025 CAAQS
65-70: Above 2025 CAAQS and Below 2020 CAAQS
70-140: Above 2020 CAAQS
140+: Above 2020 CAAQS
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

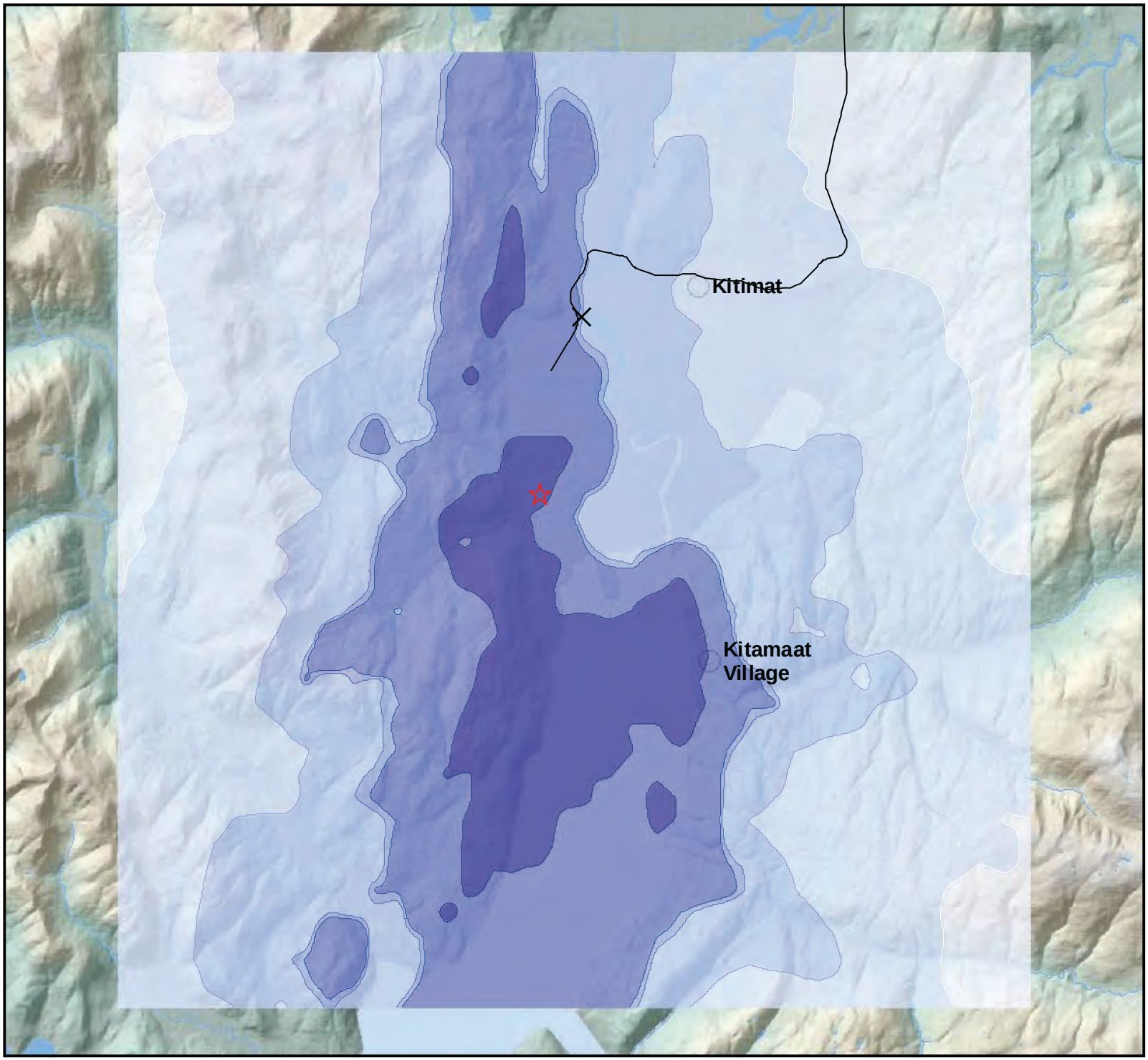
35 tpd, 3 year

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

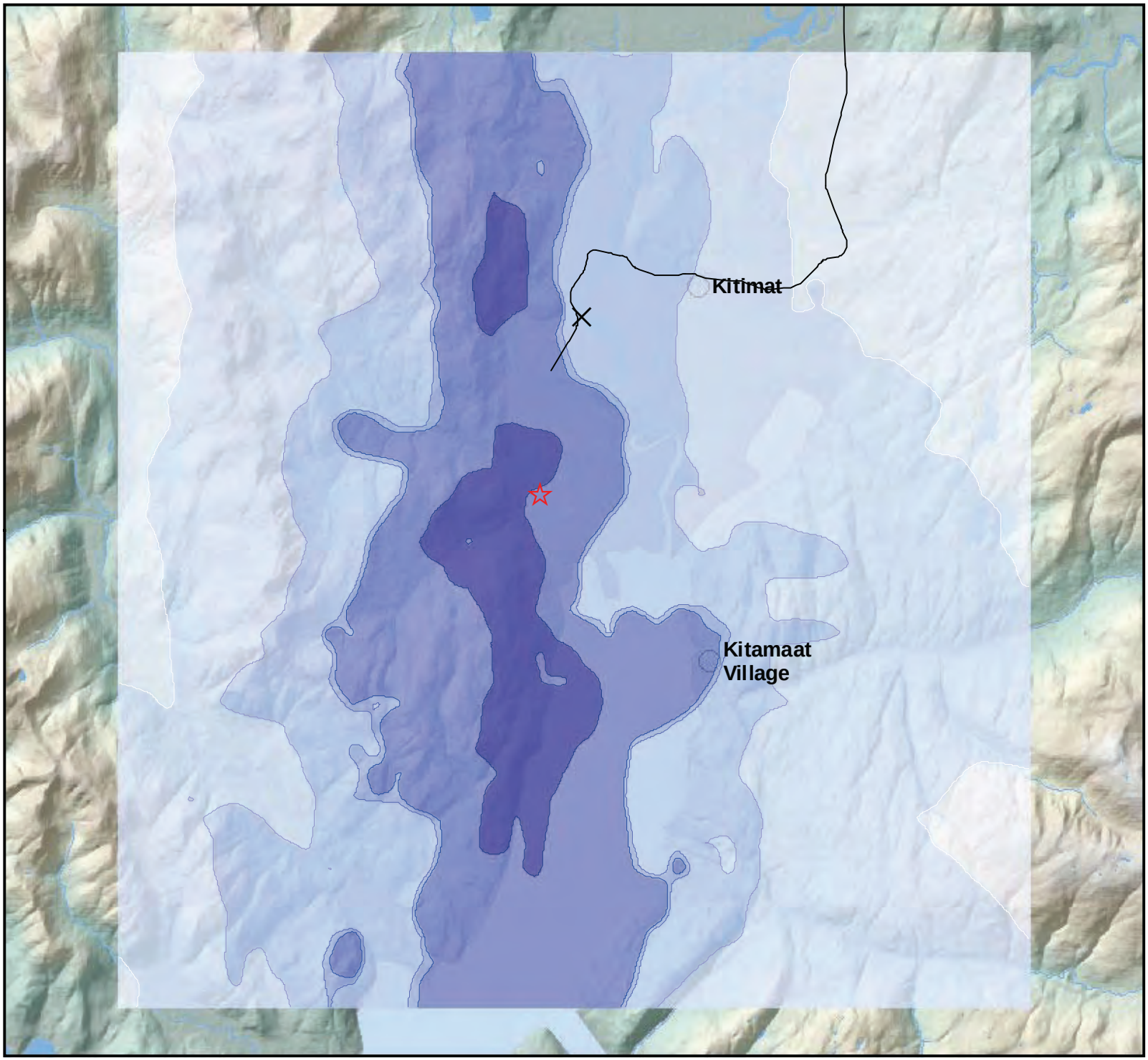
35 tpd, 2016

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

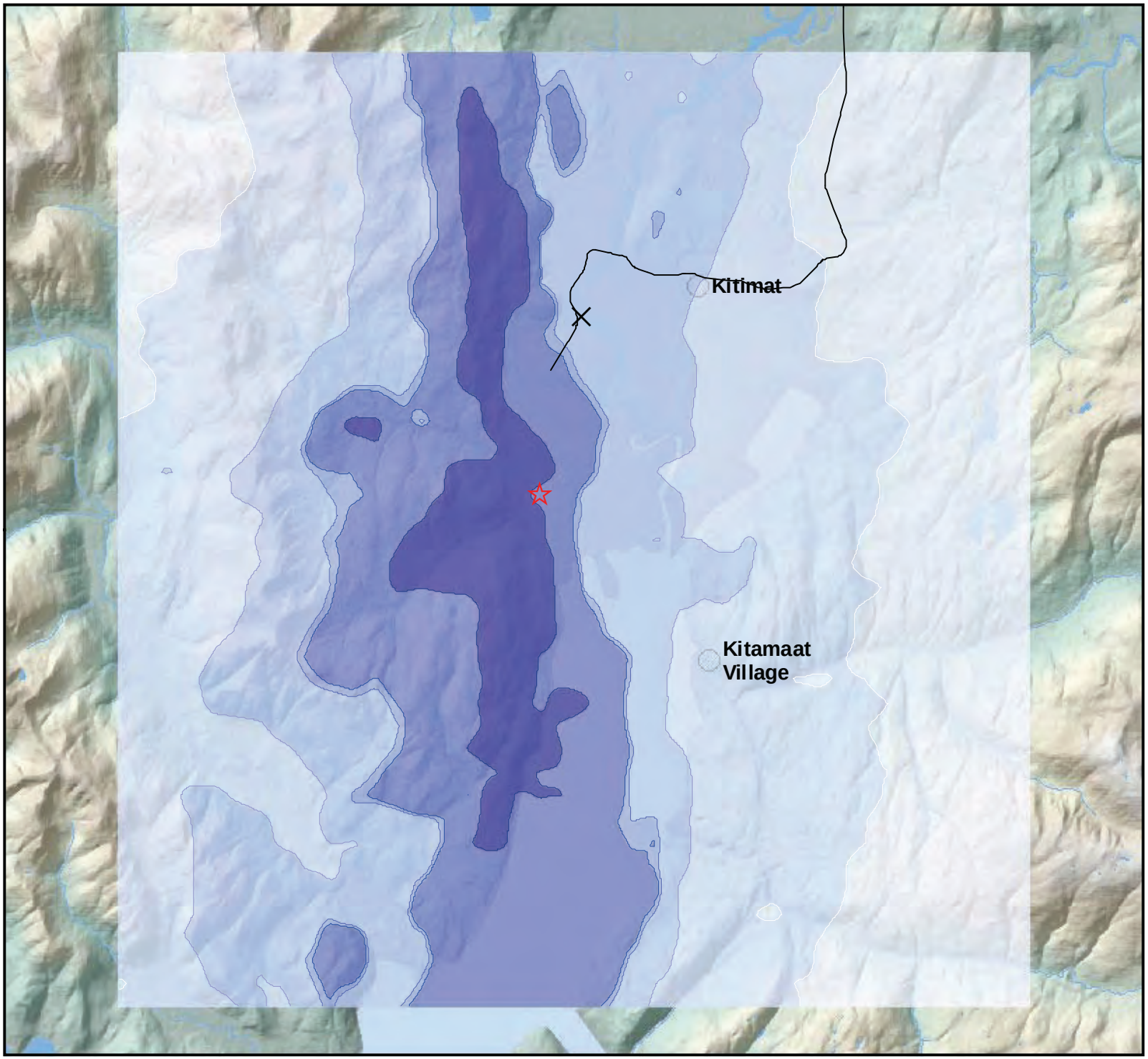
35 tpd, 2017

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

35 tpd, 2018

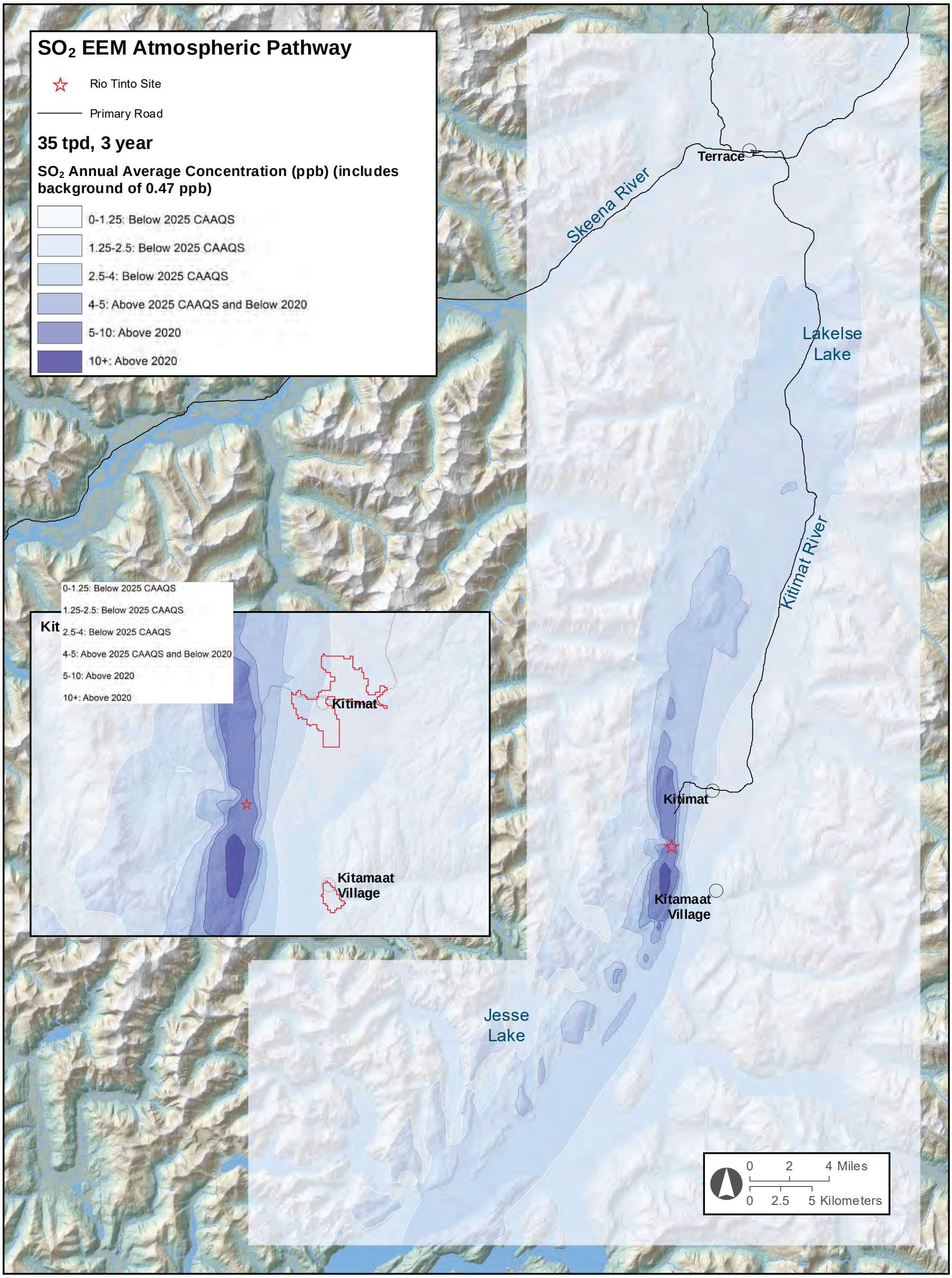
SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

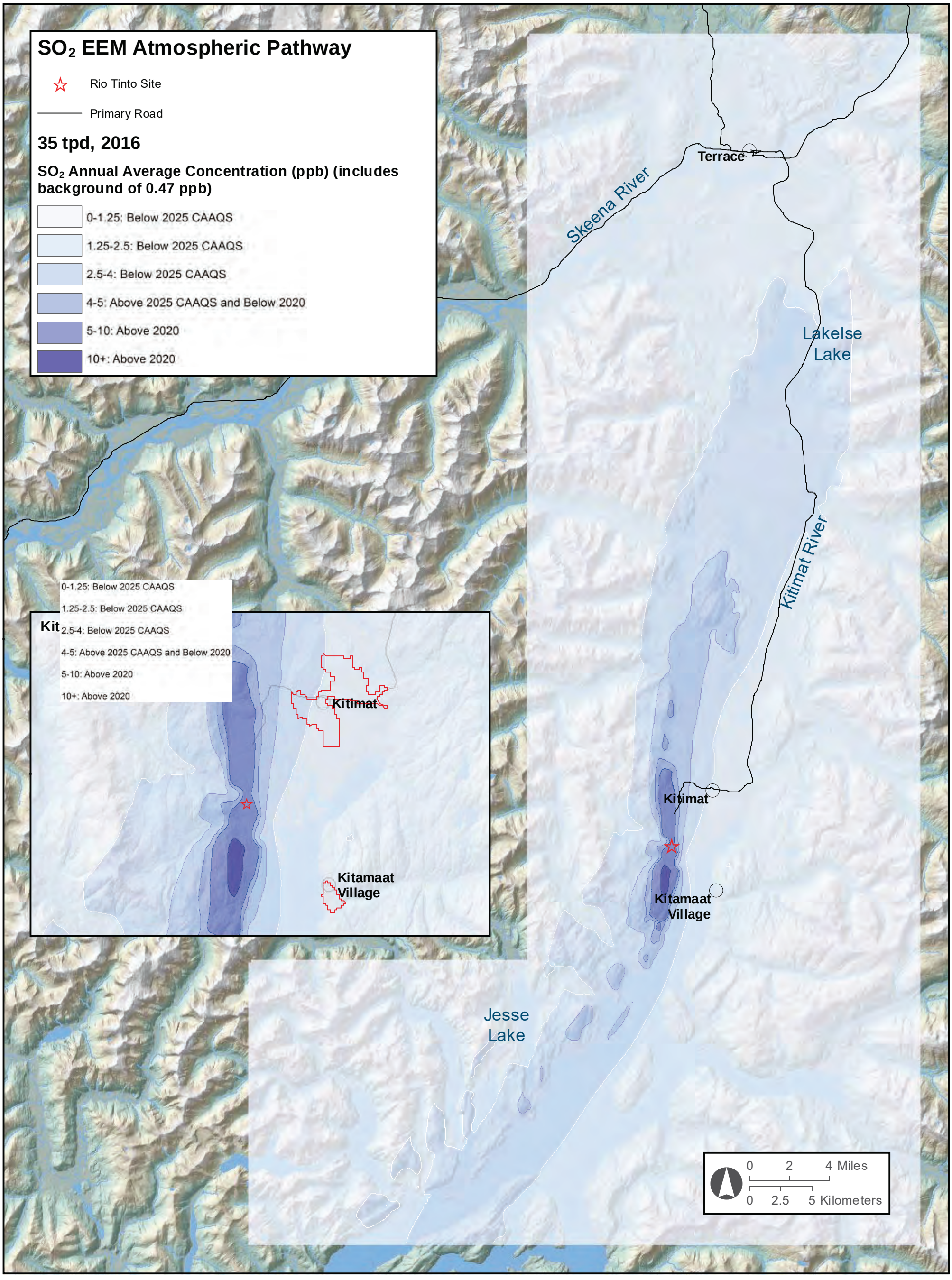
- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
- 70-140: Above 2020 CAAQS
- 140+: Above 2020 CAAQS

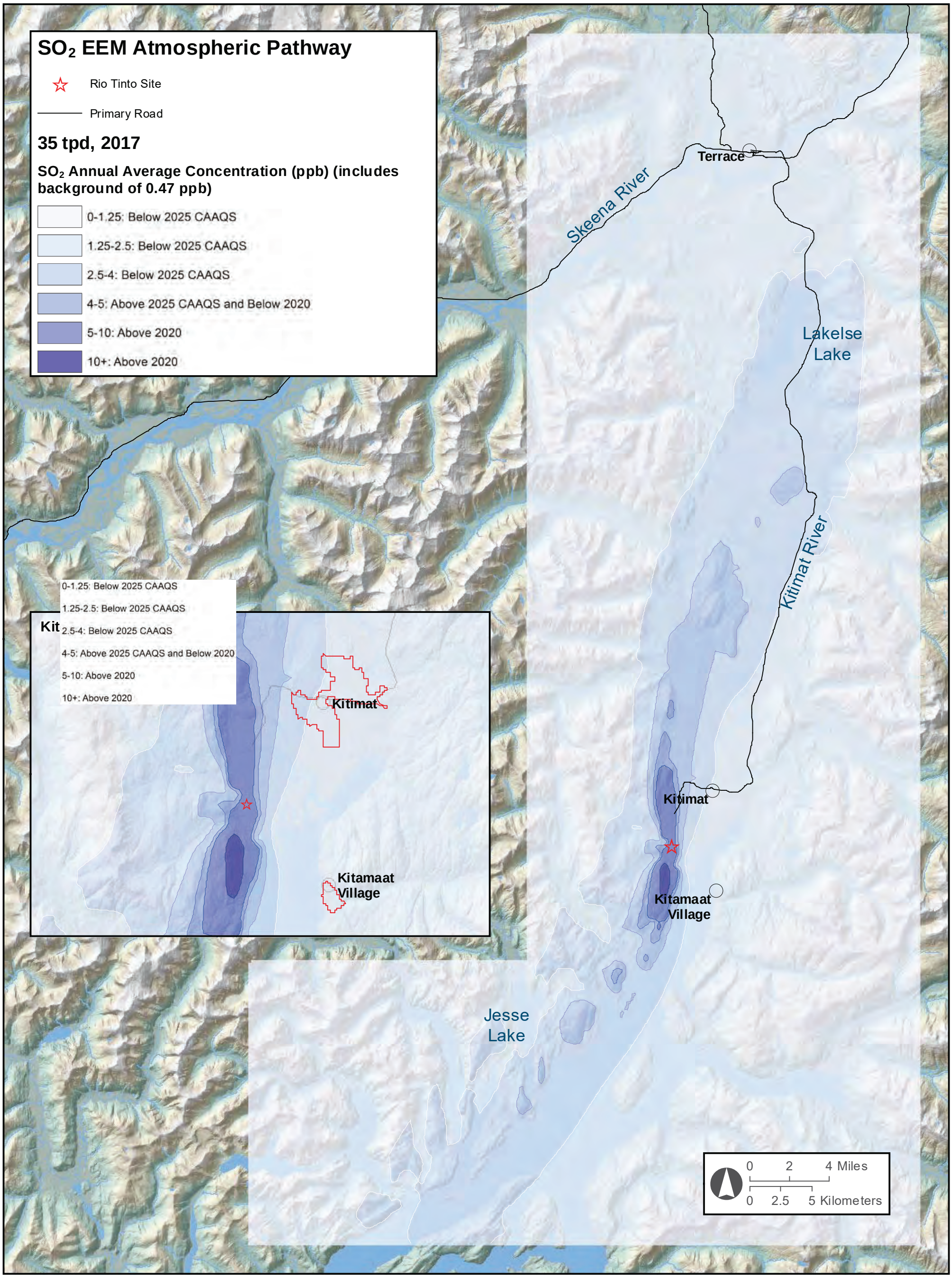
0 0.9 1.8 Miles

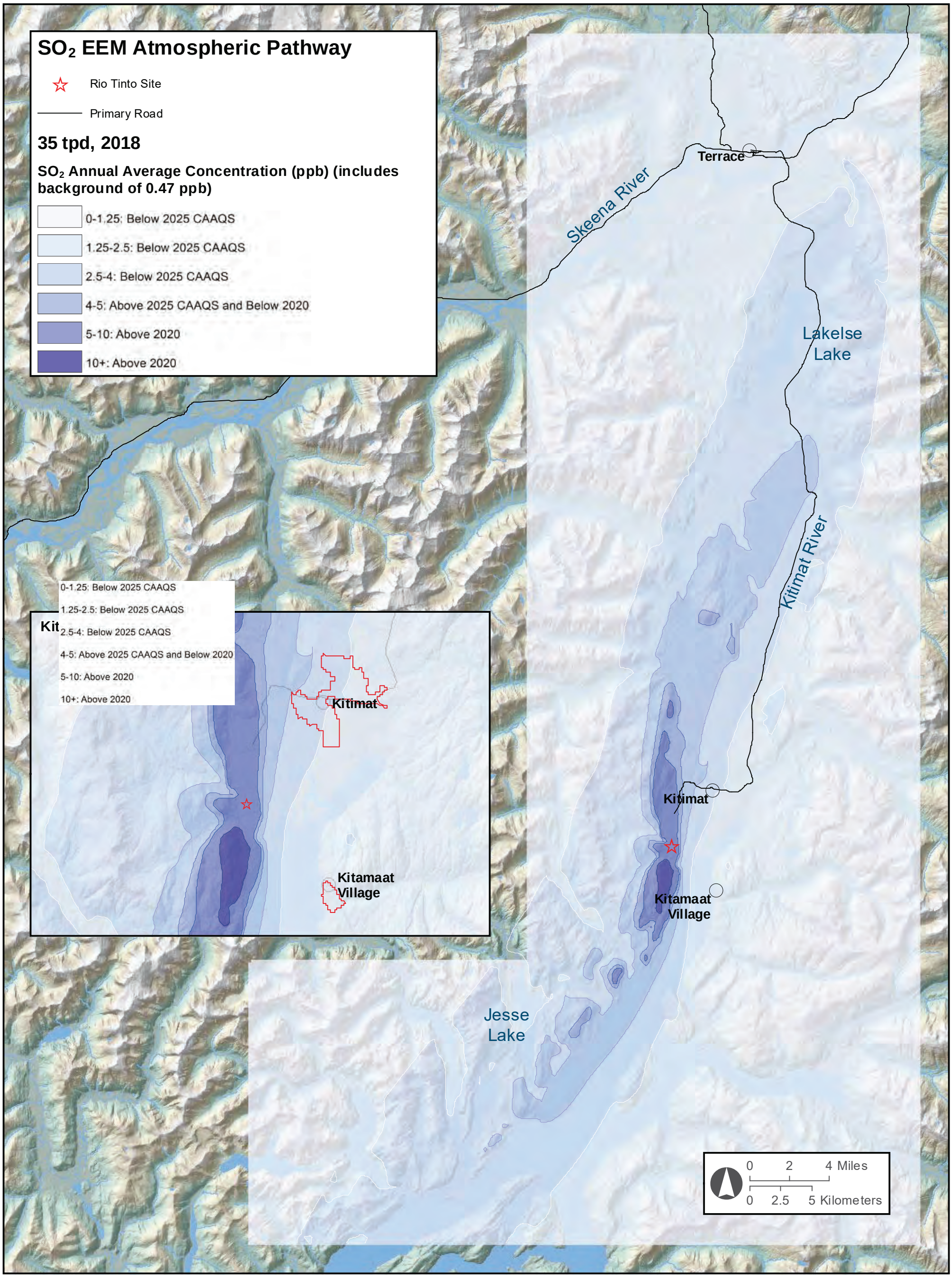
0 1 2 Kilometers

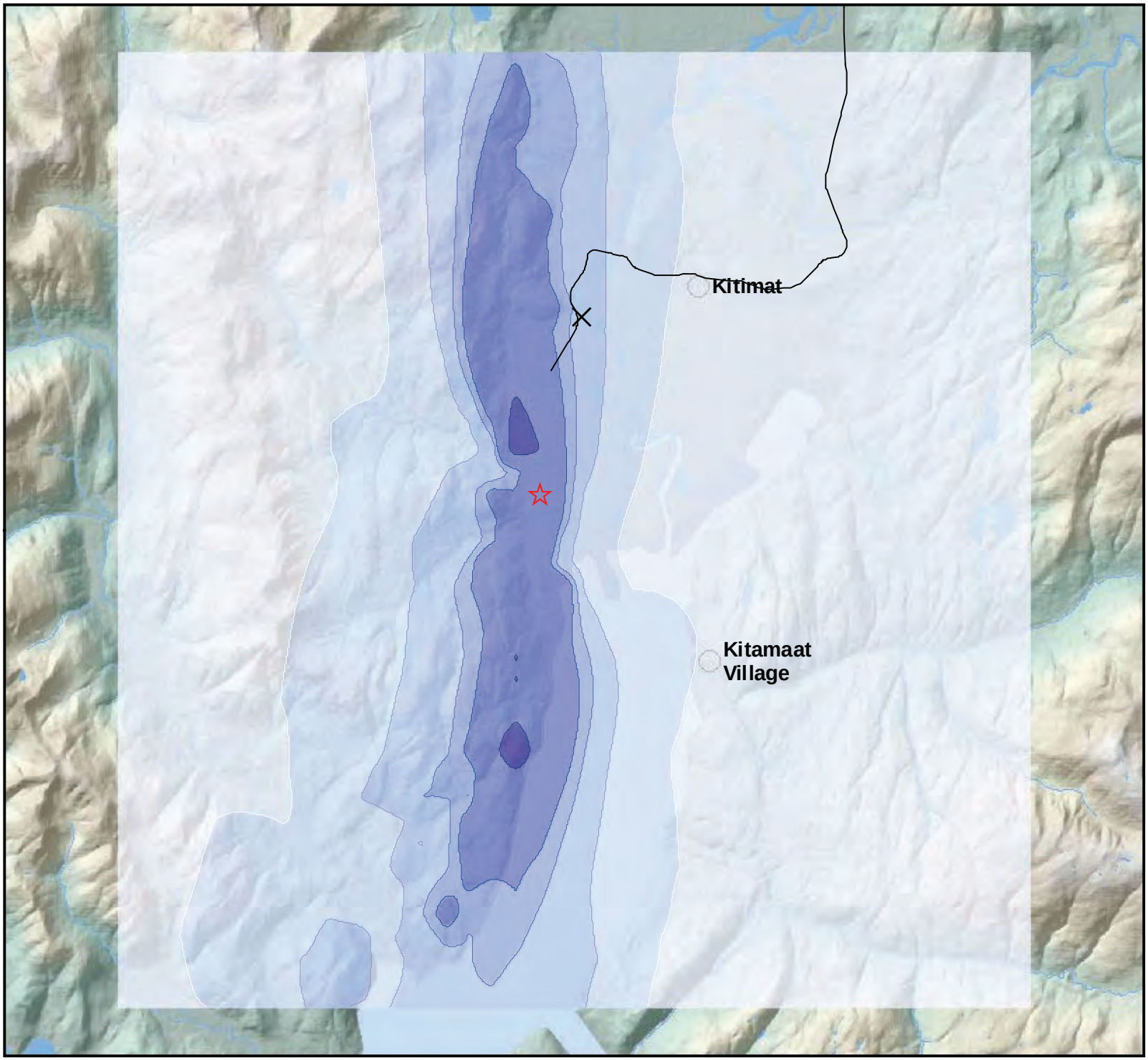
Maps of 35 tpd scenario, annual average


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
35 tpd, 3 year
SO2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)
0-1.25: Below 2025 CAAQS
1.25-2.5: Below 2025 CAAQS
2.5-4: Below 2025 CAAQS
4-5: Above 2025 CAAQS and Below 2020
5-10: Above 2020
10+: Above 2020
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
35 tpd, 2016
SO2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)
0-1.25: Below 2025 CAAQS
1.25-2.5: Below 2025 CAAQS
2.5-4: Below 2025 CAAQS
4-5: Above 2025 CAAQS and Below 2020
5-10: Above 2020
10+: Above 2020
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
35 tpd, 2017
SO2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)
0-1.25: Below 2025 CAAQS
1.25-2.5: Below 2025 CAAQS
2.5-4: Below 2025 CAAQS
4-5: Above 2025 CAAQS and Below 2020
5-10: Above 2020
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Terrace
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Rio Tinto Site
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Terrace
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Jesse Lake
0 2 4 Miles
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SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

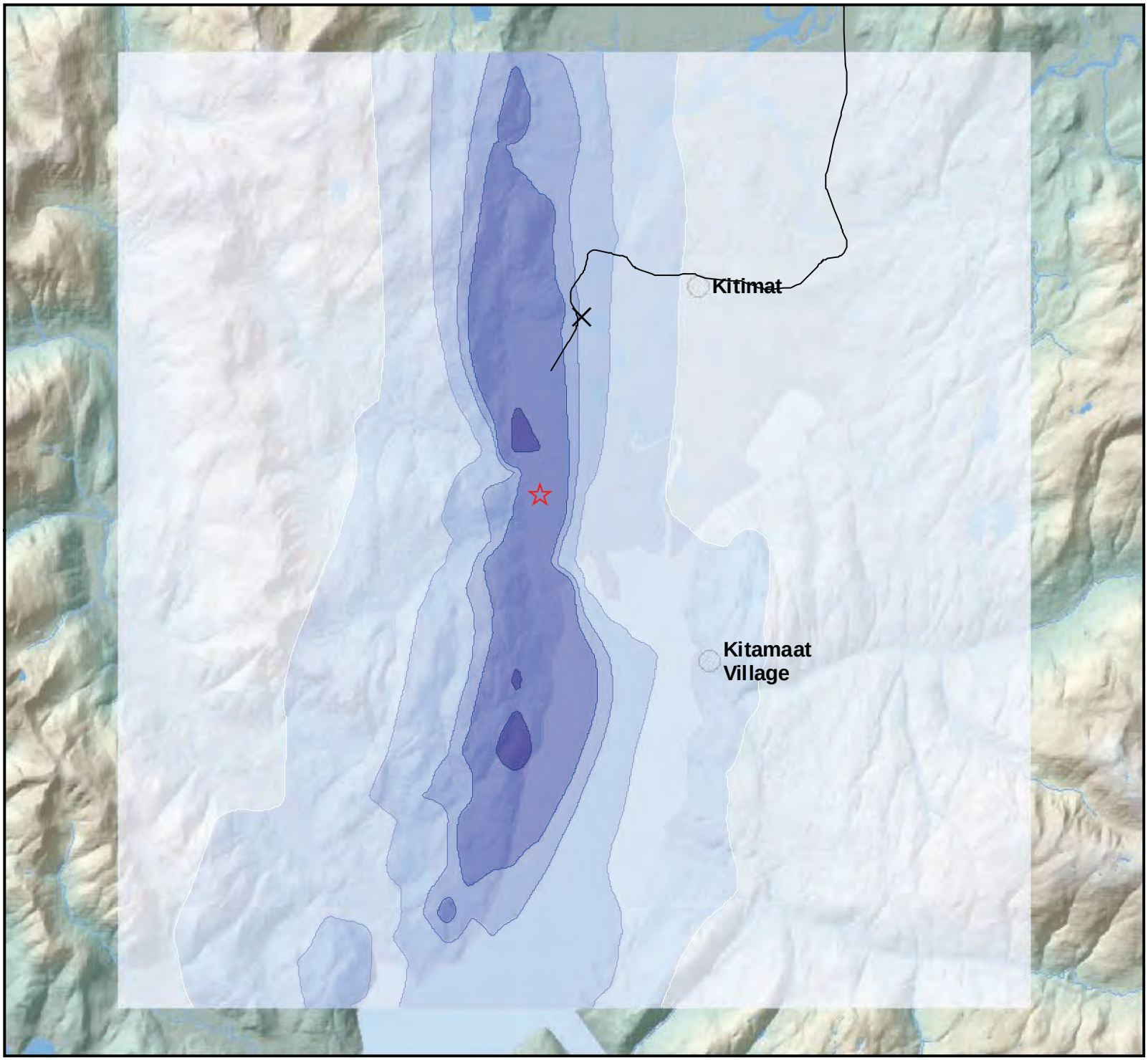
35 tpd, 3 year

SO_2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
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0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

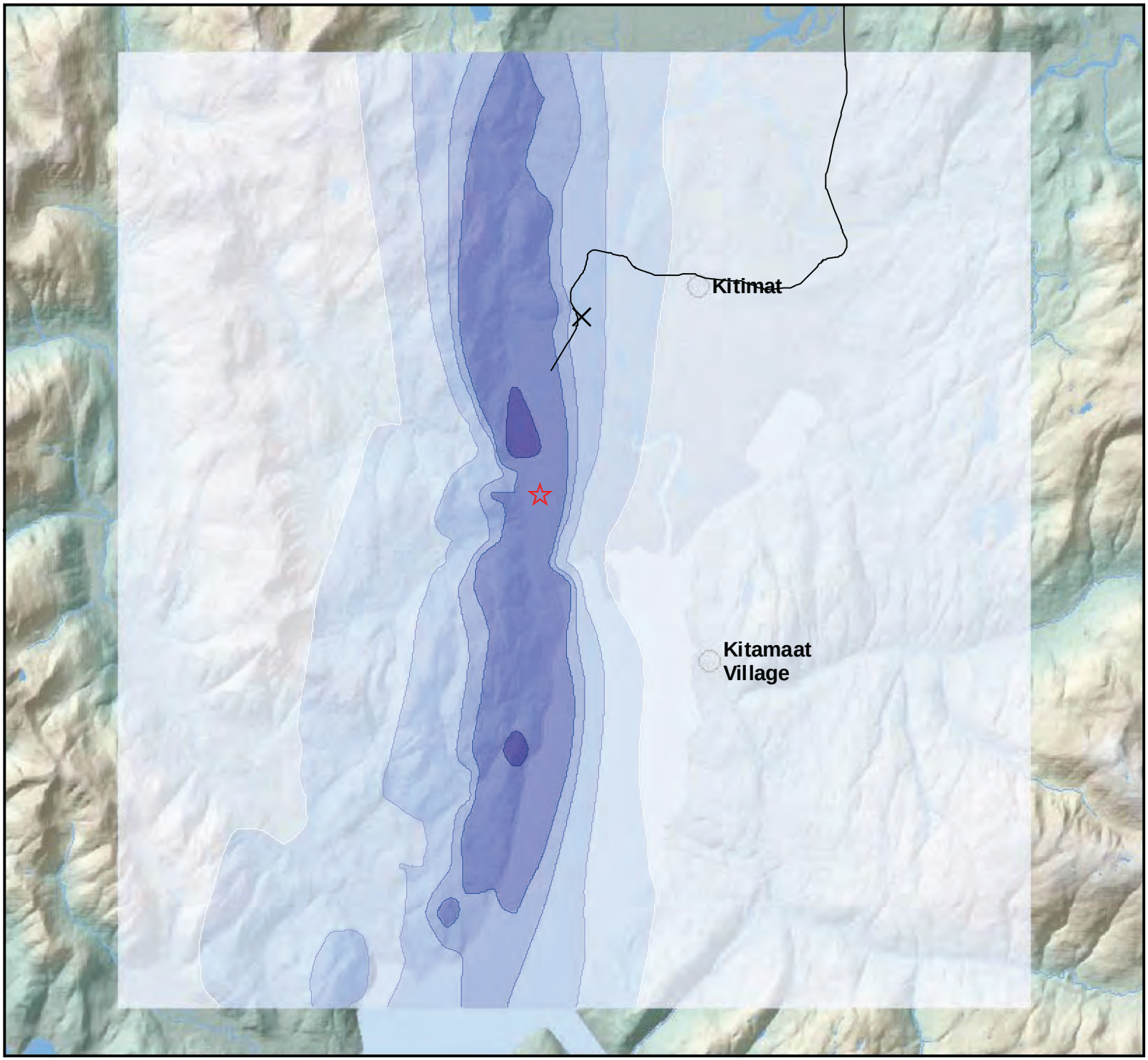
35 tpd, 2016

SO_2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)

- 0-1.25: Below 2025 CAAQS
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SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

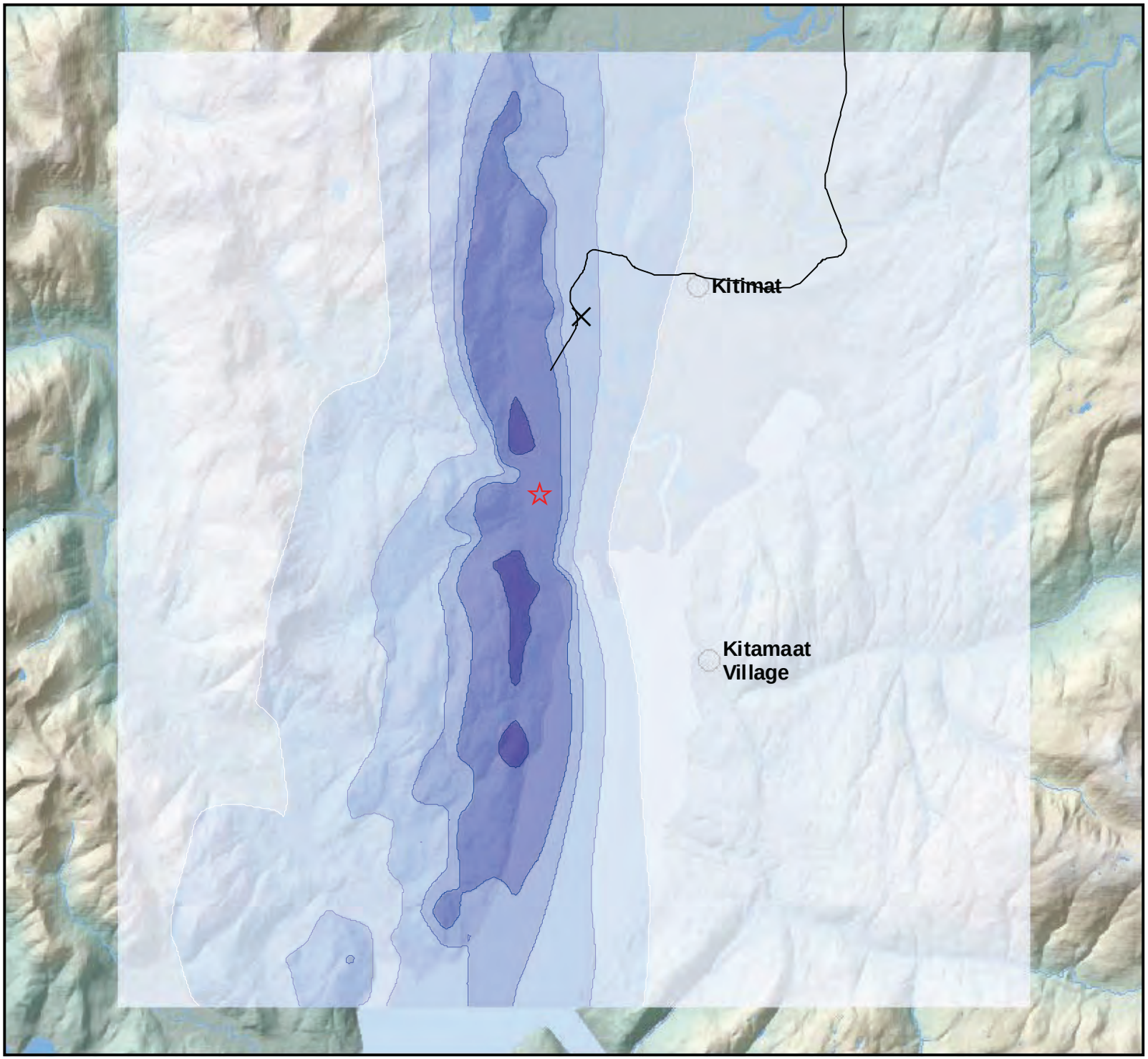
35 tpd, 2017

SO_2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
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- 4-5: Above 2025 CAAQS and Below 2020 CAAQS
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0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

35 tpd, 2018

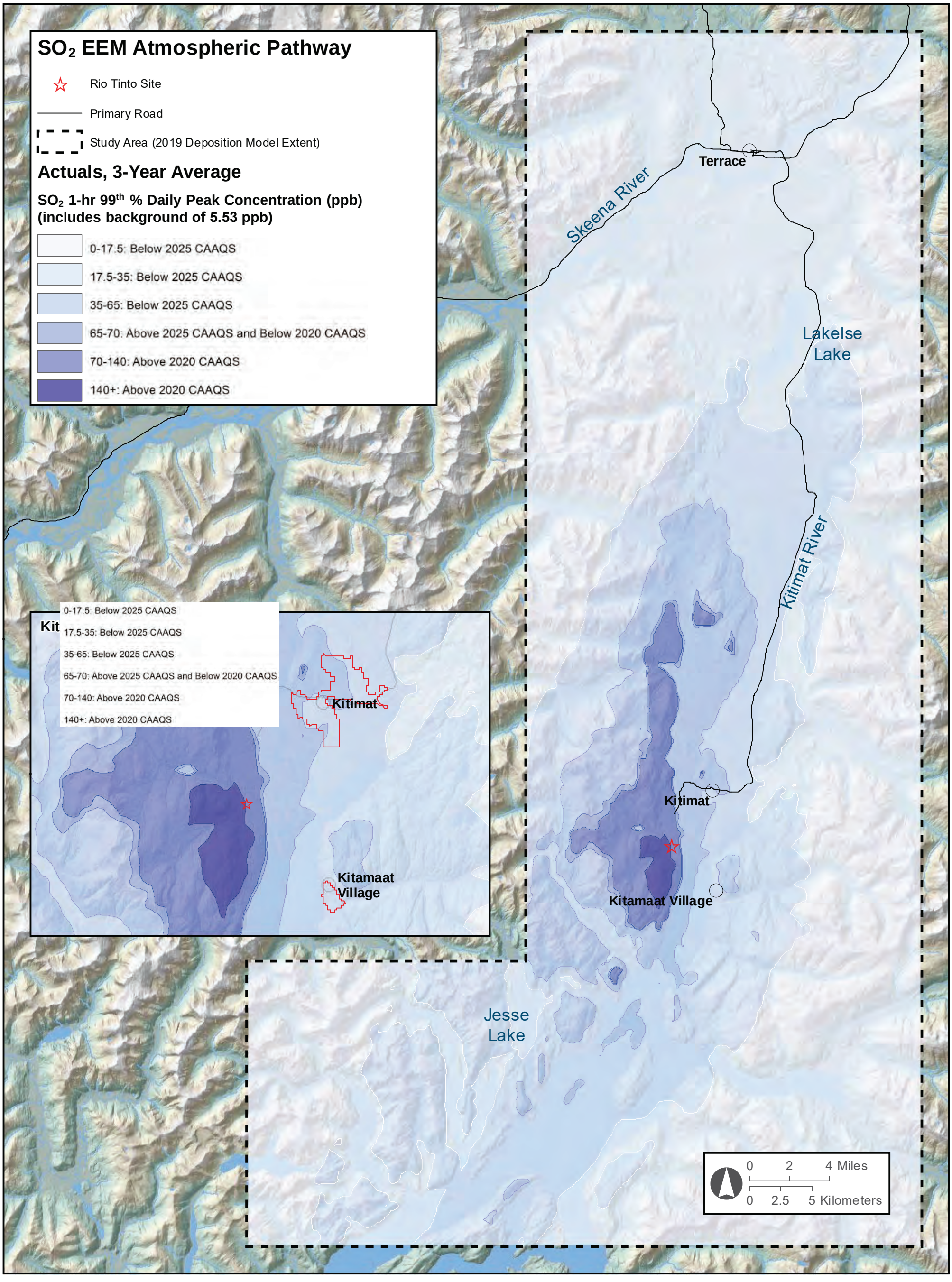
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- 4-5: Above 2025 CAAQS and Below 2020 CAAQS
- 5-10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers

Maps of actual scenario, 99th % of daily 1-hour peak


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area (2019 Deposition Model Extent)
Actuals, 3-Year Average
SO2 1-hr 99th % Daily Peak Concentration (ppb)
(includes background of 5.53 ppb)
0-17.5: Below 2025 CAAQS
17.5-35: Below 2025 CAAQS
35-65: Below 2025 CAAQS
65-70: Above 2025 CAAQS and Below 2020 CAAQS
70-140: Above 2020 CAAQS
140+: Above 2020 CAAQS
Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers

SO_2 EEM Atmospheric Pathway

☆ Rio Tinto Site

Primary Road

Study Area (2019 Deposition Model Extent)

Actuals, 2016

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 4.6 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
- 65-70: Above 2025 CAAQS and Below 2020 CAAQS
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Kit

Kitimat

Kitamaat Village

Skeena River

Terrace

Lakelse Lake

Kitimat River

Kitimat

Kitamaat Village

Jesse Lake

0 2 4 Miles

0 2.5 5 Kilometers

SO_2 EEM Atmospheric Pathway

☆ Rio Tinto Site

Primary Road

Study Area (2019 Deposition Model Extent)

Actuals, 2017

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.9 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
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Kitimat

Kitamaat Village

Jesse Lake

0 2 4 Miles

0 2.5 5 Kilometers

SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Study Area (2019 Deposition Model Extent)

Actuals, 2018

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 6.1 ppb)

0-17.5: Below 2025 CAAQS

17.5-35: Below 2025 CAAQS

35-65: Below 2025 CAAQS

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Skeena River

Lakelse Lake

Kitimat River

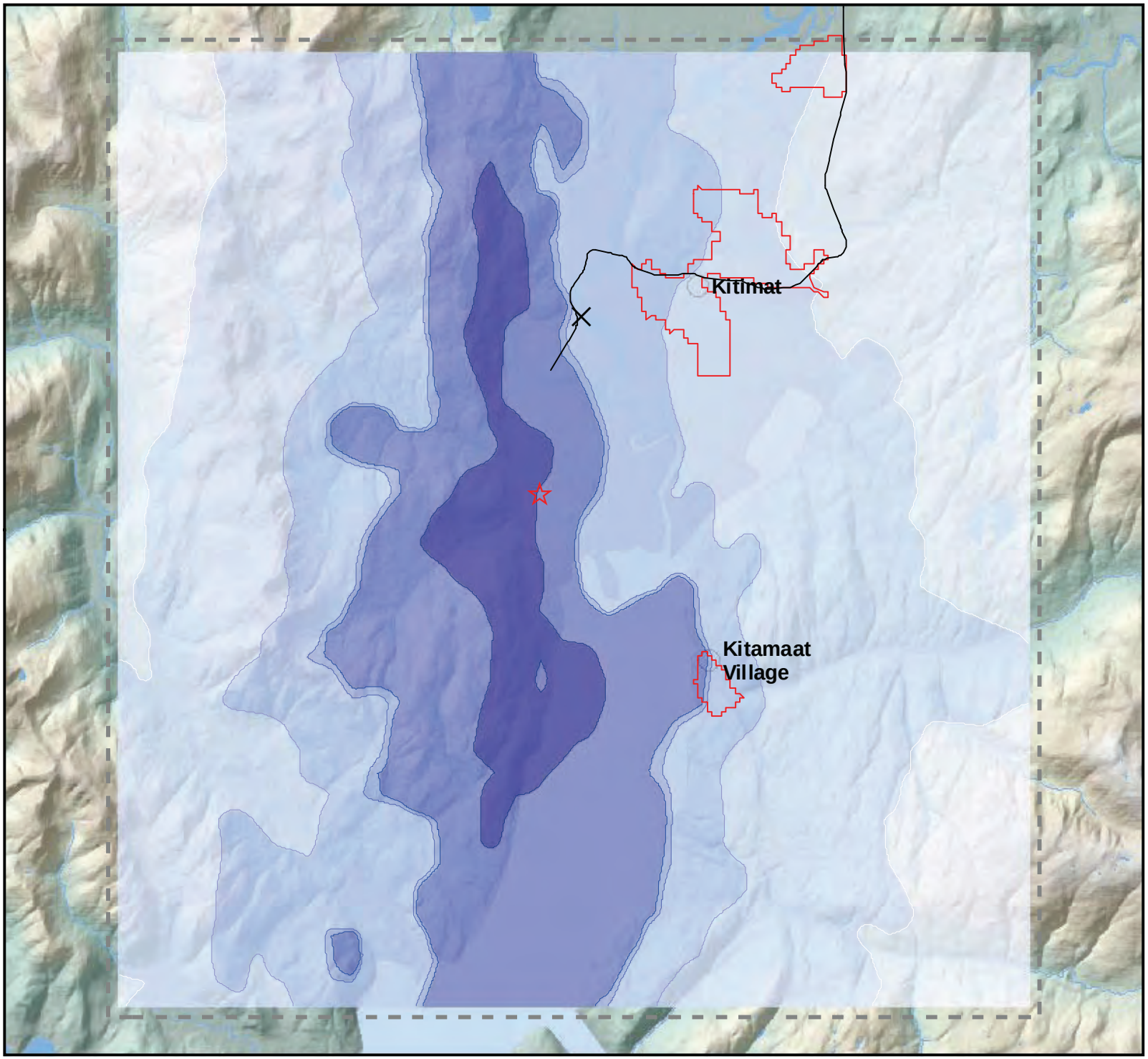
Kitimat

Kitamaat Village

Jesse Lake

0 2 4 Miles

0 2.5 5 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area (2019 Local [SO_2] Model)

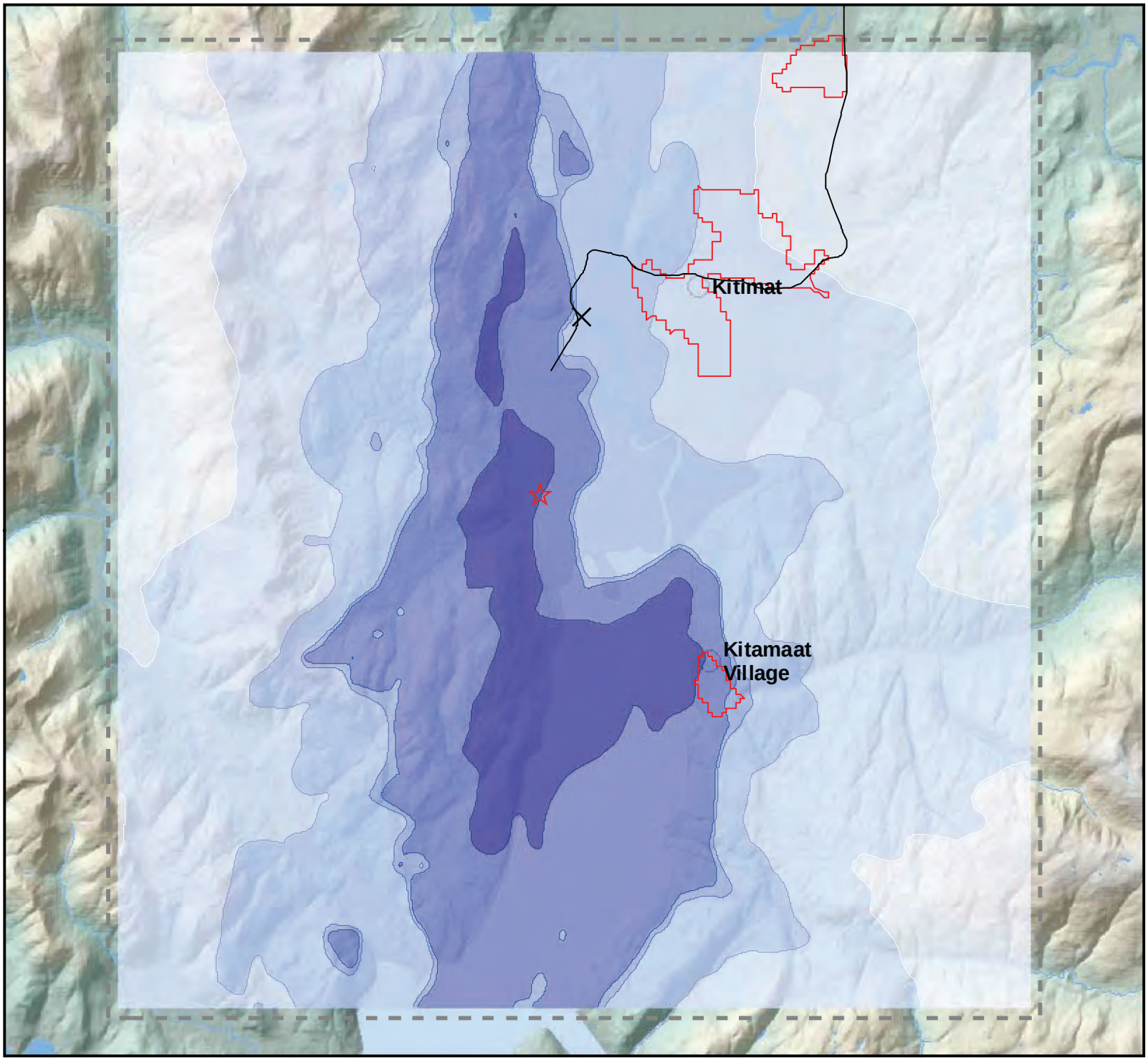
Actuals, 3-Year Average

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.53 ppb)

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SO_2 EEM Atmospheric Pathway

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- Primary Road
- Residential Area
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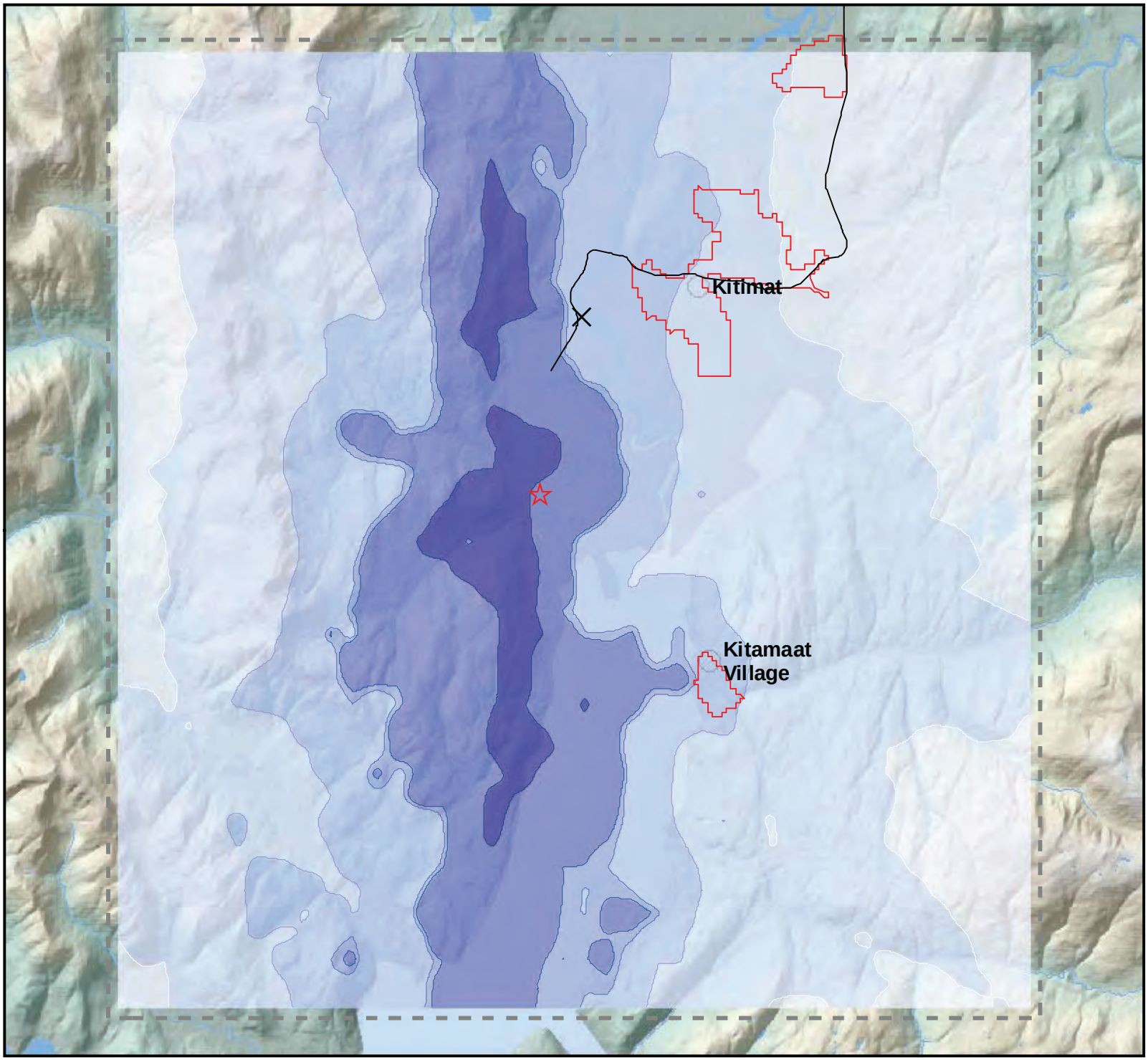
Actuals, 2016

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 4.6 ppb)

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
- 35-65: Below 2025 CAAQS
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0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area (2019 Local [SO_2] Model)

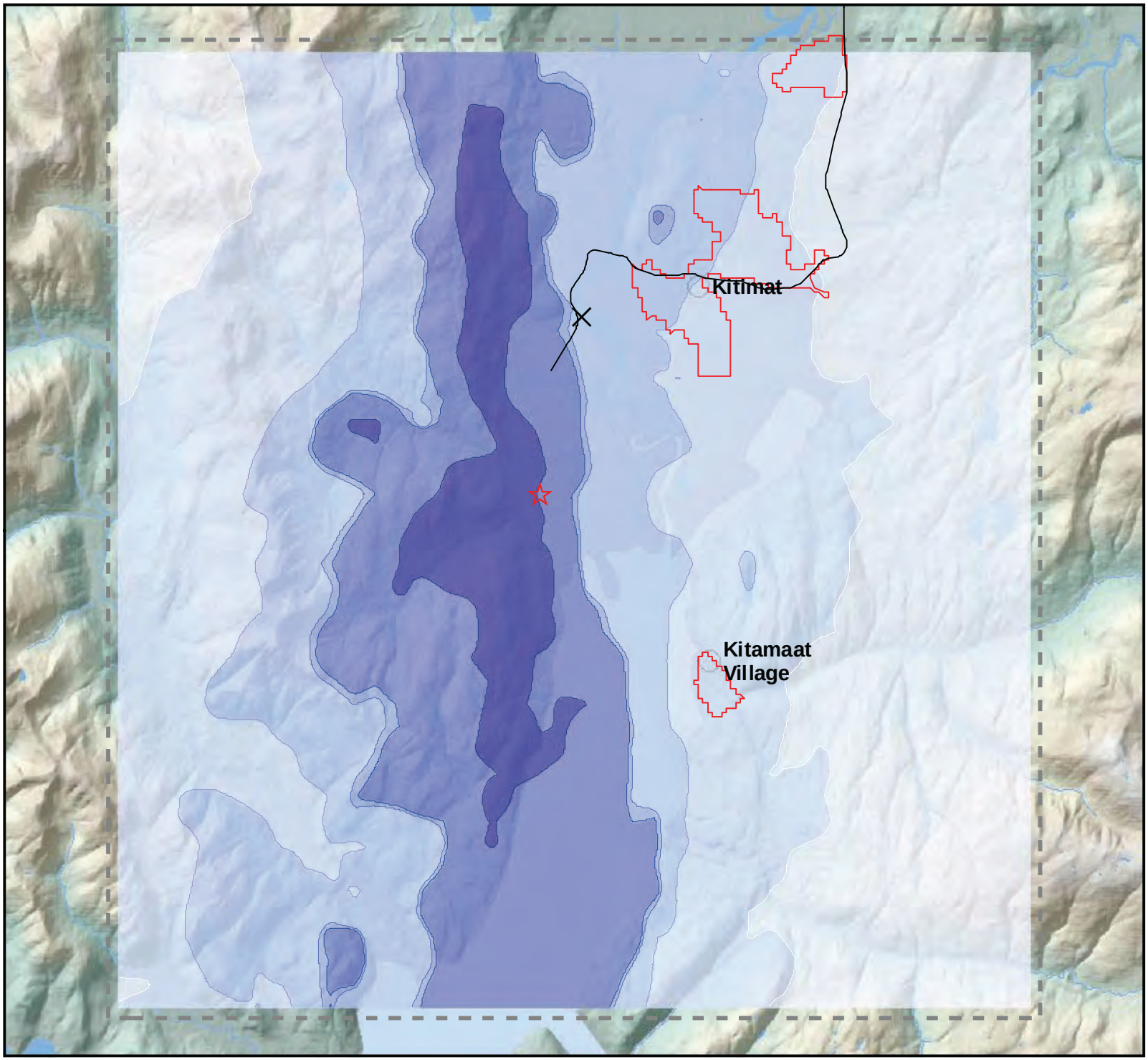
Actuals, 2017

SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 5.9 ppb))

- 0-17.5: Below 2025 CAAQS
- 17.5-35: Below 2025 CAAQS
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SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area (2019 Local [SO_2] Model)

Actuals, 2018

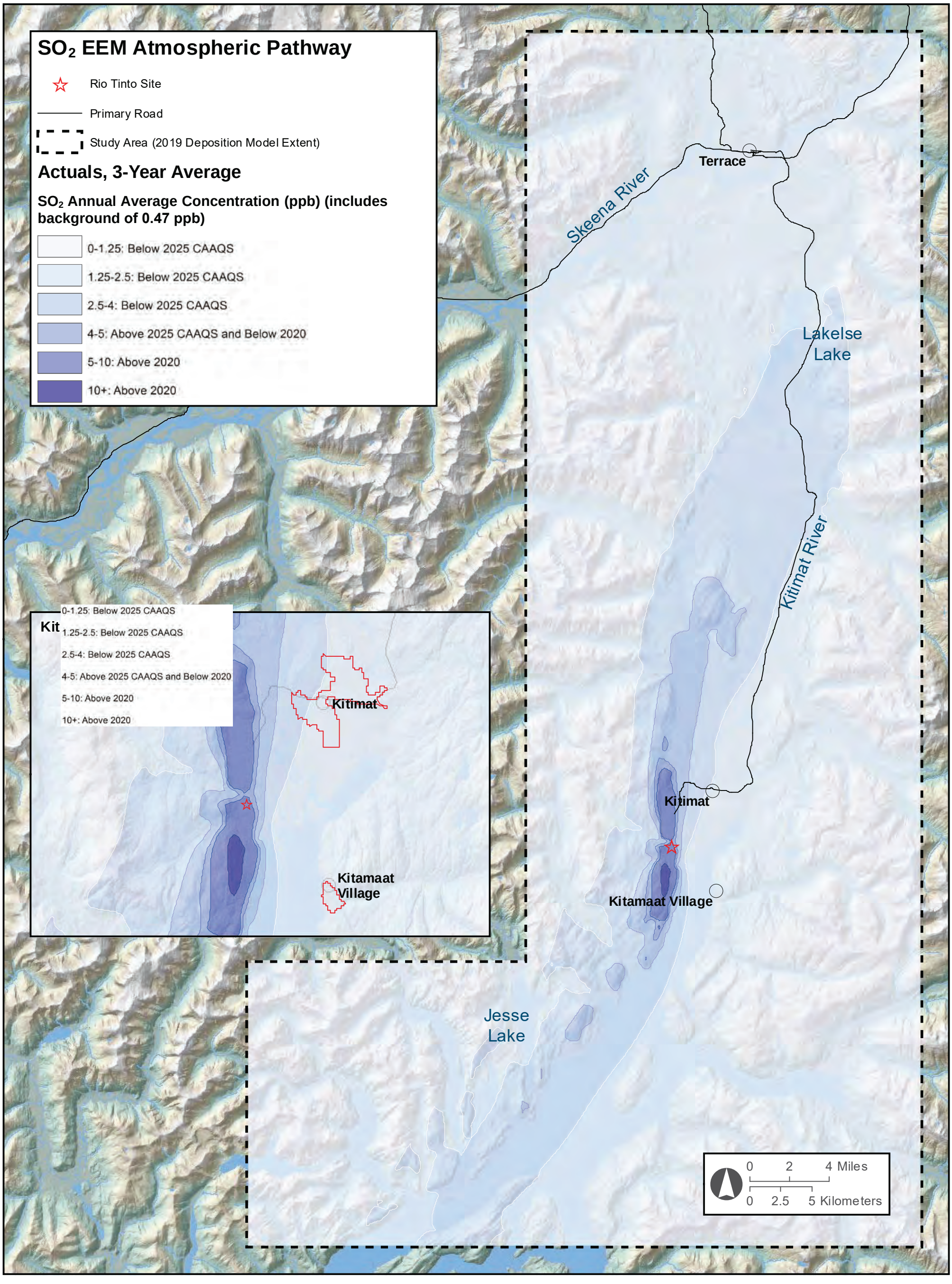
SO_2 1-hr 99th % Daily Peak Concentration (ppb) (includes background of 6.1 ppb)

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- 140+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers

Maps of actual scenario, annual average


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area (2019 Deposition Model Extent)
Actuals, 3-Year Average
SO2 Annual Average Concentration (ppb) (includes background of 0.47 ppb)
0-1.25: Below 2025 CAAQS
1.25-2.5: Below 2025 CAAQS
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Terrace
Skeena River
Lakelse Lake
Kitimat River
Kitimat
Kitamaat Village
Jesse Lake
0 2 4 Miles
0 2.5 5 Kilometers

SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Study Area (2019 Deposition Model Extent)

Actuals, 2016

SO_2 Annual Average Concentration (ppb) (includes background of 0.5 ppb)

0-1.25: Below 2025 CAAQS

1.25-2.5: Below 2025 CAAQS

2.5-4: Below 2025 CAAQS

4-5: Above 2025 CAAQS and Below 2020

5-10: Above 2020

10+: Above 2020

Terrace

Skeena River

Lakelse Lake

Kitimat River

Kitimat

Kitamaat Village

Jesse Lake

0 2 4 Miles

0 2.5 5 Kilometers

SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Primary Road

Study Area (2019 Deposition Model Extent)

Actuals, 2017

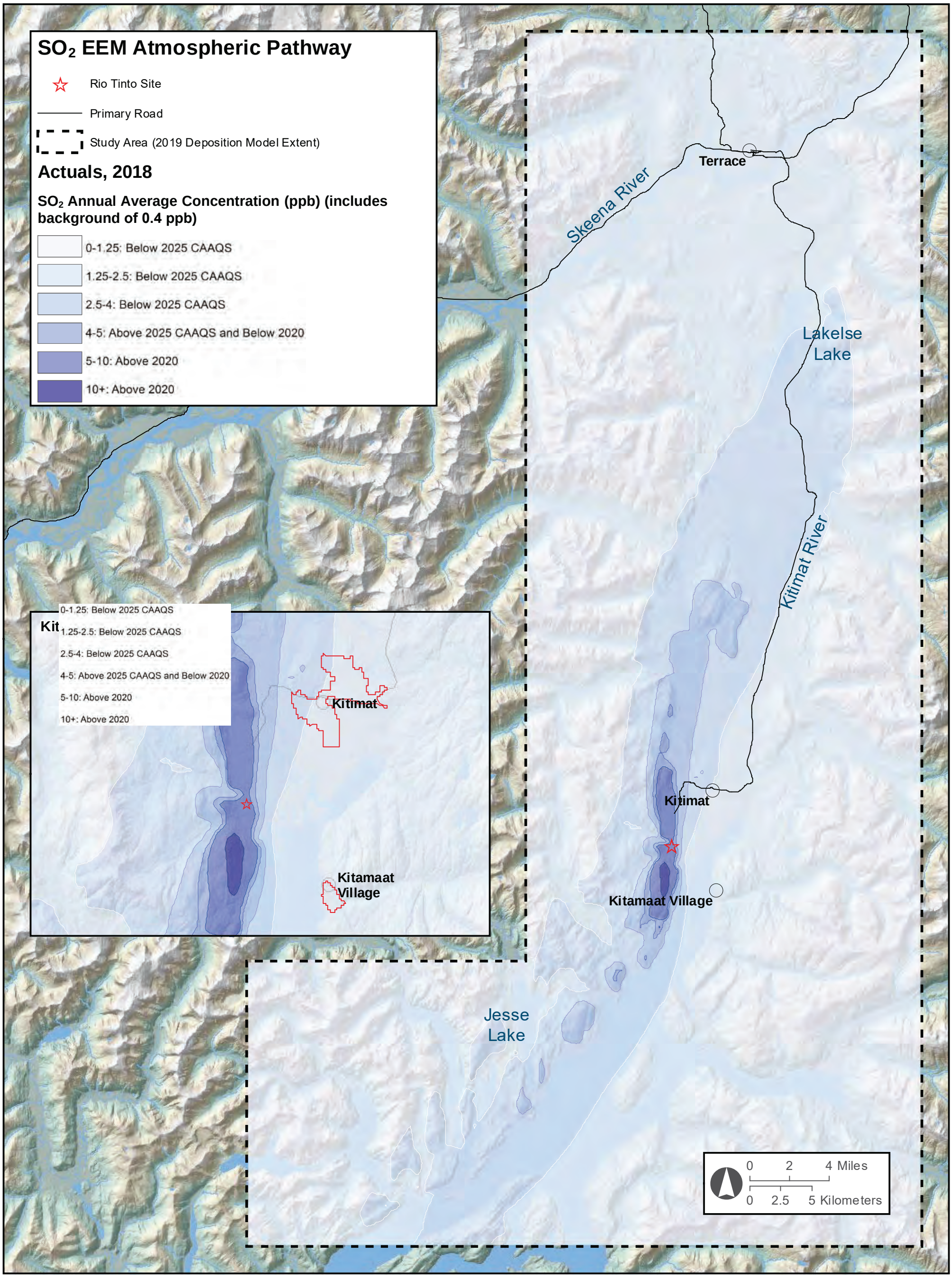
SO_2 Annual Average Concentration (ppb) (includes background of 0.5 ppb)

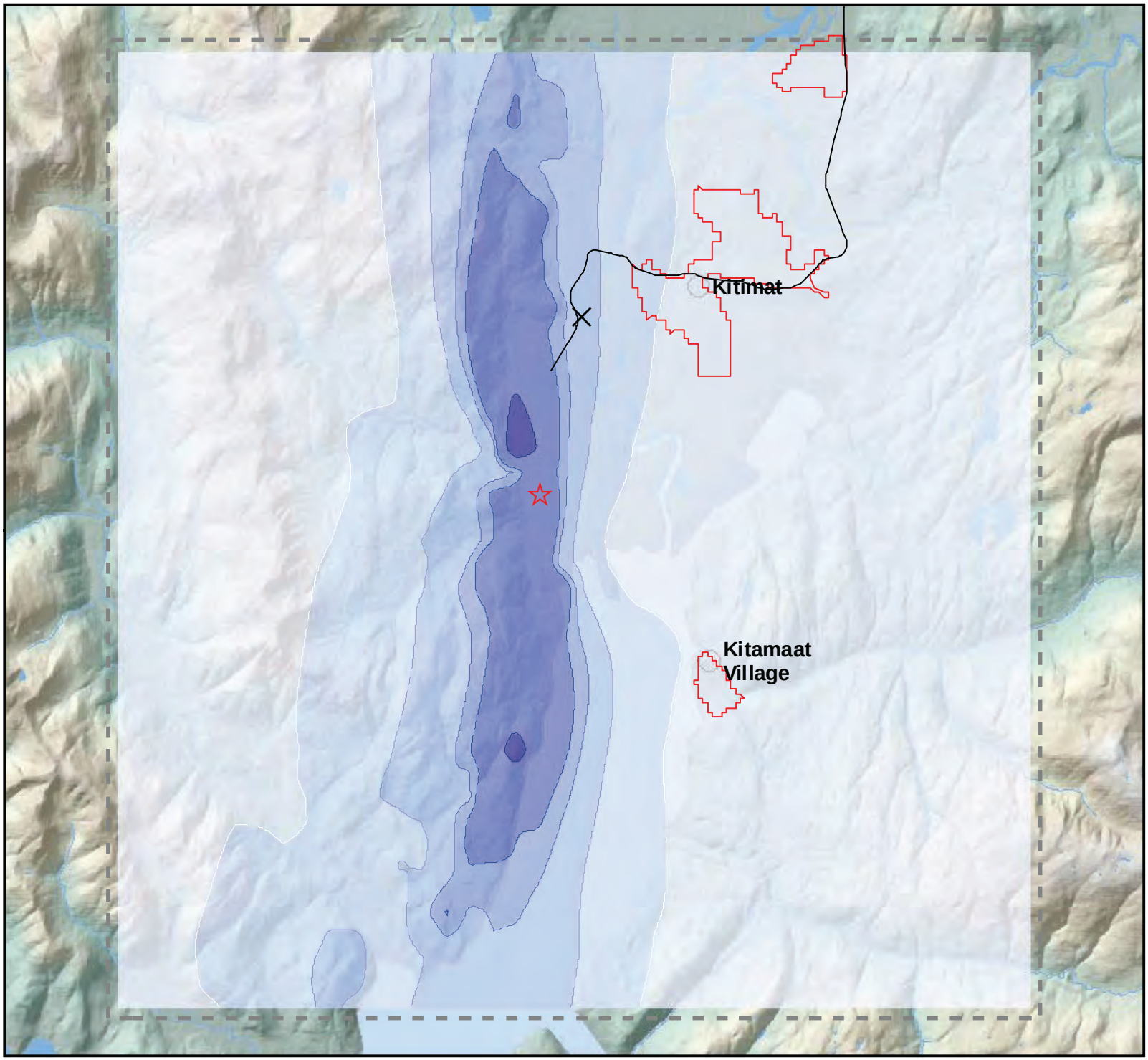
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Terrace
Skeena River
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Jesse Lake

0 2 4 Miles
0 2.5 5 Kilometers


SO2 EEM Atmospheric Pathway
Rio Tinto Site
Primary Road
Study Area (2019 Deposition Model Extent)
Actuals, 2018
SO2 Annual Average Concentration (ppb) (includes background of 0.4 ppb)
0-1.25: Below 2025 CAAQS
1.25-2.5: Below 2025 CAAQS
2.5-4: Below 2025 CAAQS
4-5: Above 2025 CAAQS and Below 2020
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0 2 4 Miles
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SO_2 EEM Atmospheric Pathway

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- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area (2019 Local [SO_2] Model)

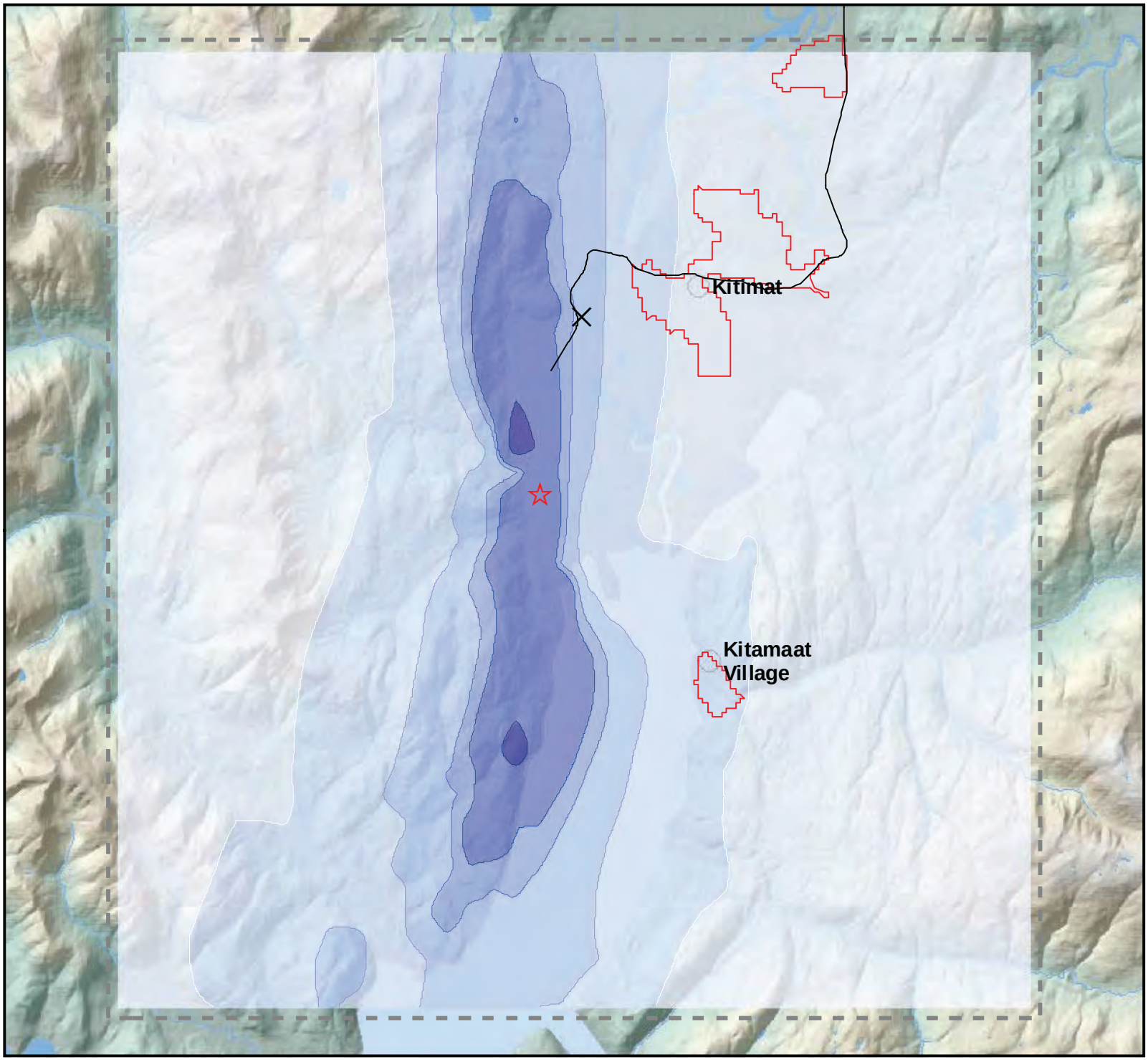
Actuals, 3-Year Average

SO_2 Annual Average Concentration (ppb)(includes background of 0.47 ppb)

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SO_2 EEM Atmospheric Pathway

- Rio Tinto Site
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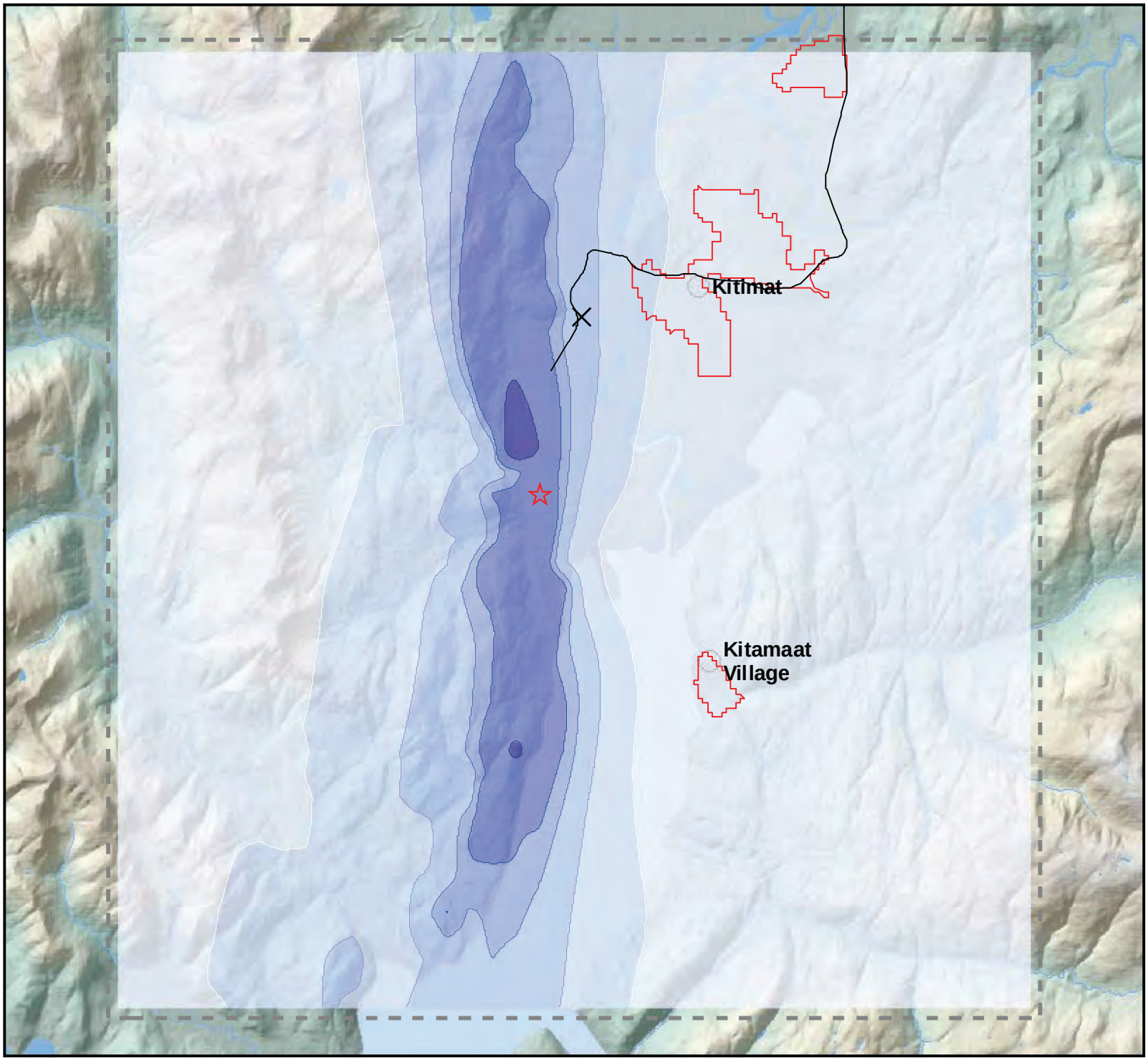
Actuals, 2016

SO_2 Annual Average Concentration (ppb) (includes background of 0.5 ppb)

- 0-1.25: Below 2025 CAAQS
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SO_2 EEM Atmospheric Pathway

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- Kitimat River Water Intake
- Primary Road
- Residential Area
- Study Area (2019 Local [SO_2] Model)

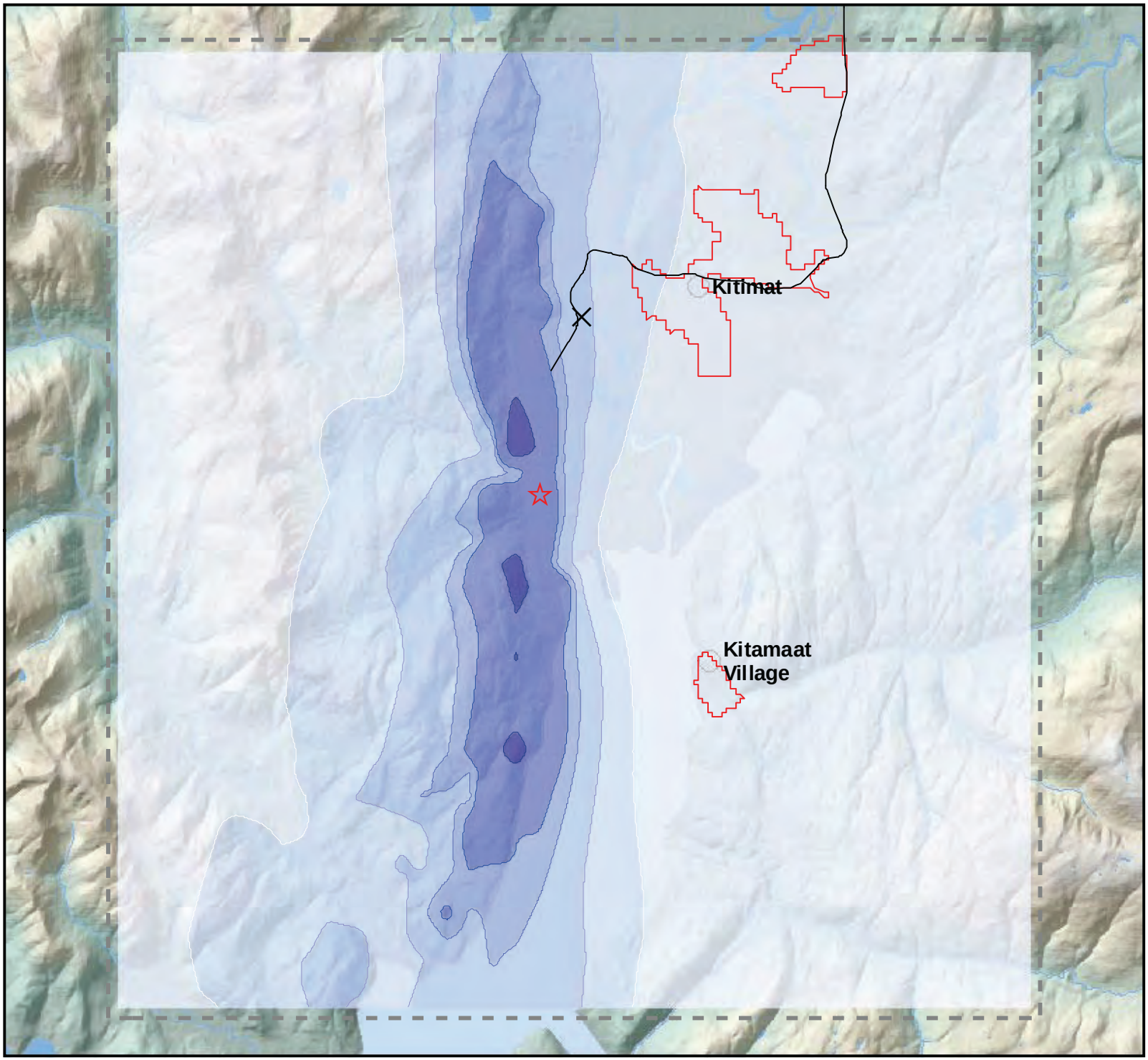
Actuals, 2017

SO_2 Annual Average Concentration (ppb) (includes background of 0.5 ppb)

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0 0.9 1.8 Miles

0 1 2 Kilometers



SO_2 EEM Atmospheric Pathway

Rio Tinto Site

Kitimat River Water Intake

Primary Road

Residential Area

Study Area (2019 Local [SO_2] Model)

Actuals, 2018

SO_2 Annual Average Concentration (ppb) (includes background of 0.4 ppb)

- 0-1.25: Below 2025 CAAQS
- 1.25-2.5: Below 2025 CAAQS
- 2.5-4: Below 2025 CAAQS
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- 5-10: Above 2020 CAAQS
- 10+: Above 2020 CAAQS

0 0.9 1.8 Miles

0 1 2 Kilometers

3.1.9 Previously submitted reports

Monitoring Network Evaluation (Methods and Results):

- Phase 1 Air Quality Network Evaluation - *RT NoMM5 Network Rationalization_2019-0408*
- Draft ToR for Phase 2 - B2. TermsofReference_NetworkOptimization_Phase2_2019-0412

Model Methods

- Detail Model Plan (including copy of STAR model protocol)
- Detail Model Plan Approval

Model Refinement (preliminary model evaluation model methods plan updates)

- Addendum to CALPUFF Model Plan Regional-Scale - *Memo_CALMET Hybrid_2019-0807.pdf*
- Letter from ENV - *2019-08-23 CALPUFF Regional Model Protocol Changes.pdf*
- Addendum to CALPUFF Model Plan Local-Scale - *Local Model Performance Memo_2019-0916.pdf*

REPORT
RTA Kitimat Smelter

Air Quality Network Evaluation

Prepared By:

Anna Henolson – Managing Consultant
Hui Cheng – Senior Consultant

TRINITY CONSULTANTS
20819 72nd Avenue South
Suite 610
Kent, WA 98032
(253) 867-5600

April 2019

Environmental solutions delivered uncommonly well

EXECUTIVE SUMMARY

Rio Tinto BC Works (Rio Tinto) engaged Trinity Consultants (Trinity) to evaluate Rio Tinto's wholly owned and operated ambient air quality monitoring network in and near Kitimat, BC. The Kitimat Modernization Project (KMP) has changed the emissions profile the smelter, which will affect the spatial distribution of SO_2 ambient concentrations. As such, Rio Tinto committed to evaluating the air monitoring network as part of the SO_2 environmental effects monitoring (SO_2 EEM) program. The purpose of this work is to fulfill Rio Tinto's commitment in the SO_2 EEM program for rationalization of the air quality monitoring network.

Following U.S. EPA guidance,[1] Trinity analyzed the results from air dispersion modelling of SO_2 emissions from the smelter. The results of this analysis show that the Riverlodge monitor is in a suitable location to represent the highest concentrations expected within the Kitimat residential area.

Trinity also analyzed the results from recent air quality monitoring from continuous monitors and from passive samplers. The SO_2 ambient air quality monitoring data confirms conclusions that the Riverlodge continuous monitoring station is in a suitable location to represent the highest concentrations expected within the Kitimat residential area. In particular, the SO_2 passive sampling at the Riverlodge site measured the highest monthly concentration and the highest overall average concentration among all the passive sampler locations within the Kitimat residential area.

The air dispersion model results and monitoring data both support the conclusion that the Riverlodge continuous monitoring station is in a suitable location to represent the highest concentrations expected within the Kitimat residential area. Therefore, there is no benefit in relocating this air monitoring station or adding new SO_2 monitoring stations within the Kitimat residential area.

[1] US EPA technical assistance document for "source-oriented monitoring" for SO_2 available at: https://www.epa.gov/sites/production/files/2016-06/documents/so2monitoringtad.pdf

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1.1. INTRODUCTION

Rio Tinto BC Works (Rio Tinto) engaged Trinity Consultants (Trinity) to evaluate Rio Tinto's wholly owned and operated ambient air quality monitoring network in Kitimat, BC and the surrounding area in order to optimize the network to meet the current needs of monitoring emissions from the Kitimat aluminum smelter. The existing network was established to measure air concentrations in the Kitimat area due to gaseous fluoride, SO_2, particulate, and polycyclic aromatic hydrocarbon (PAH) emissions from Rio Tinto's 60-year-old primary aluminum smelter. However, the Kitimat Modernization Project (KMP) has changed the emissions profile of the smelter, which affects the spatial distribution of ambient concentrations. As such, Rio Tinto committed to evaluating the air monitoring network as part of the SO_2 environmental effects monitoring (SO_2 EEM) program. The scope of this evaluation is limited to the SO_2 continuous monitoring network.

The purpose of this work is to fulfill Rio Tinto's commitment in the SO_2 EEM program for rationalization of the SO_2 air quality monitoring network.

1.2. BACKGROUND

1.2.1. Description of the Kitimat Modernization Project and Associated SO_2 Technical Assessment Report

Rio Tinto undertook the KMP to modernize the 60-year old vertical stud Söderburg (VSS) Aluminum smelter with state of the art AP-4X pre-bake smelting technology. The new aluminum smelting technology is more efficient, producing more aluminum per kilowatt hour of electricity than the smelting technology previously in use. As a result, the upgraded Kitimat Smelter has the capability to increase both the production of aluminum and the consumption of petroleum coke, which is the primary source of sulphur emissions. Rio Tinto received a permit amendment to add the new SO_2 emission sources associated with a modern pre-bake aluminum smelting process, as well as to increase the permitted limit on SO_2 emissions from 27 tonnes per day (t/d) to a new limit of 42 t/d. Fluoride, total particulate, and PAH emissions are decreasing as a result of the modernization of the smelter.

Trinity conducted CALPUFF dispersion modelling of SO_2 emissions from the smelter as part of the SO_2 Technical Assessment Report (STAR) prepared in support of Rio Tinto's permit amendment. The scope of the technical assessment 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 included three years of meteorological data: 2006, 2008, and 2009, and predicted results of SO_2 concentrations and total sulphur deposition. Results were calculated at 100-meter spaced resolution in residential areas in Kitimat and Kitamaat Village, and at 500 meter resolution in all other areas of the valley extending north through Terrace.

1.2.2. Description of the existing network

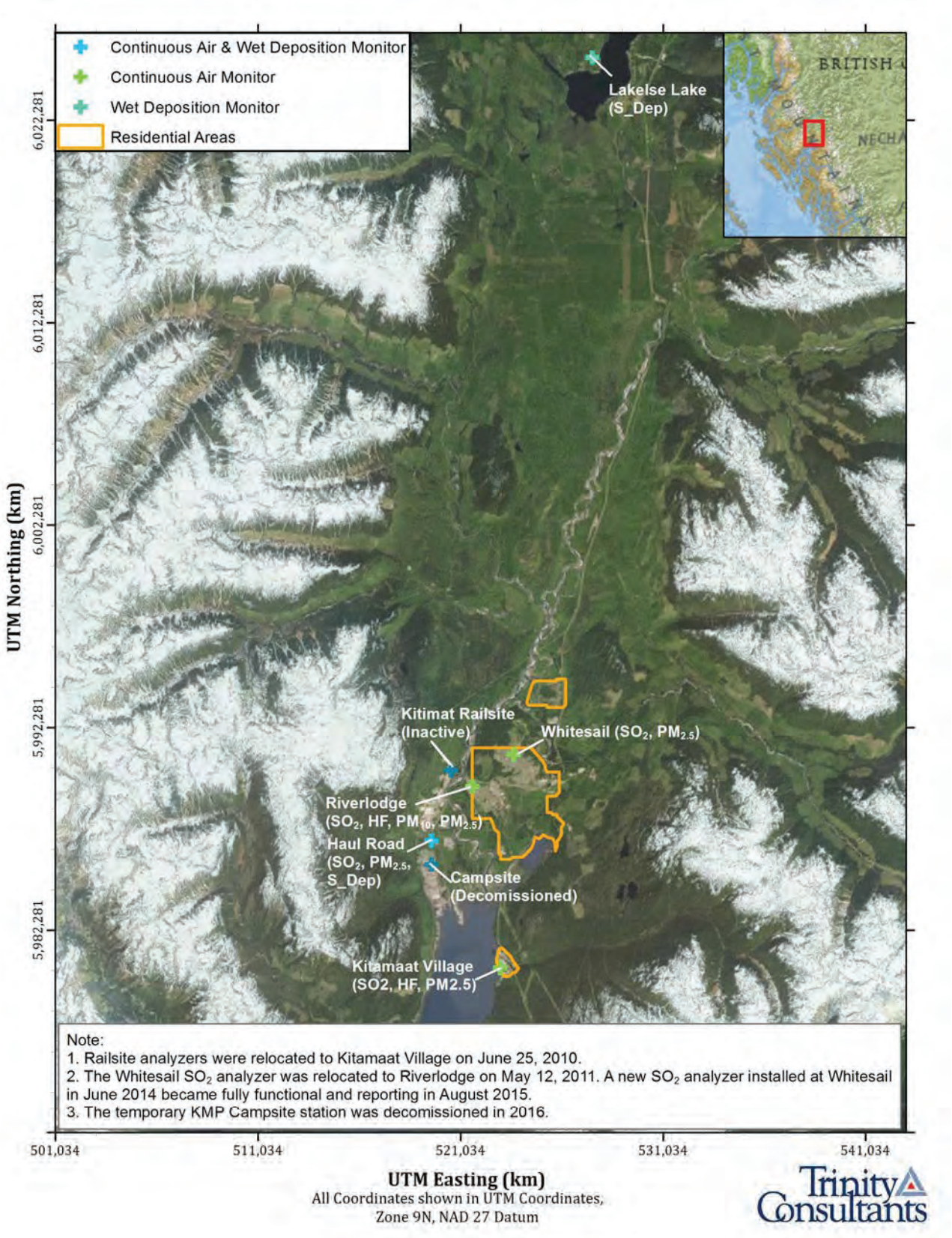
Figure 1-1 depicts the existing air quality continuous analyzer monitoring network, and also includes the location of the two wet deposition stations (one of which was recently established as part of the EEM program). Two sites that historically measured air concentrations are also included in the figure to provide a complete

history of the network.[2] The network currently includes four continuous SO_2 analyzers located at the following sites: Haul Road, Riverlodge, Whitesail,[3] and Kitamaat Village. A fifth station (not pictured) established by BC MOE in Terrace can also be used to help assess SO_2 emissions from the Smelter.

[2] The KMP Camp (Smeltersite) monitor station was decommissioned in 2016 due to the camp's close and 3rd party development of the campsite lands. The railsite analyzers were relocated to Kitimaat Village on June 25, 2010.

[3] The Whitesail SO_2 analyzer was relocated to Riverlodge on May 12, 2011. A new SO_2 analyzer was installed at Whitesail in June 2014 with limited data logging capabilities. The new analyzer (a Thermo Scientific 43i SO_2 Analyzer) became fully functional and reporting starting August 2015.

Figure 1-1. Existing Air Continuous Monitoring Network



1.2.3. CALPUFF Dispersion Modelling with No MM5 Data

The previous modelling effort as part of the STAR development used "Full CALMET" meteorological data for three years: 2006, 2008 and 2009. The Full CALMET dataset was generated from 5th generation mesoscale model output ("MM5" data), surface air station observations, and upper air station observations.[4] A sensitivity study showed that the STAR results likely predicted locations of artificially elevated SO_2 concentrations, particularly in residential areas.[5] This study compared surface and upper air meteorological observations without the MM5 dataset, called the "No MM5" dataset versus the STAR Full CALMET results. Appendix B of this report includes a detailed comparison of the Full CALMET compared to the No MM5 results.

The over-predictions produced by the Full CALMET model were protective during the permitting assessment period, but can be misleading when it comes to evaluating the most suitable location for monitoring sites in the Kitimat residential area. Therefore, to support the optimization effort, Trinity conducted No MM5 CALPUFF modelling for the entire year with evaluations of post-KMP. Other procedures followed in this additional modelling effort followed the procedures described in the *CALPUFF Modelling Protocol* [6]

1.3. SCOPE OF REPORT

This report describes the purpose, scope, methodology, and results to evaluate and optimize the air quality network in Kitimat using existing information. This existing information includes the 2006, 2008, 2009 "NoMM5" CALPUFF model results and monitoring data from continuous monitors and from the SO_2 passive sampling network.

[4] Details to the Full CALMET meteorological data methodology may be found in Section 3 of Appendix 7.6-1 of STAR.

[5] Section 7.6.1.3.3.5 of the STAR summarized the sensitivity study conducted for a single month from each meteorological year, using surface and upper air meteorological observations without the MM5 dataset, called the "No MM5" dataset. The detailed results of the study were presented in Appendix 7.6.2 of the STAR. The results of the study showed that the model results using Full CALMET are more conservative, and may be overly conservative particularly in residential areas due to the MM5 wind fields conflicting with the local surface station observations.

[6] *CALPUFF Modelling Protocol*, Appendix 7.6-1 of STAR.

2. PURPOSE AND OBJECTIVES

The purpose of the air quality monitoring network evaluation effort is to ensure that the network meets the needs for monitoring smelter emissions under the post-KMP scenario. The objective of this effort is to evaluate the location of existing residential continuous SO_2 monitoring station locations based on the best information currently available.

2.1.1. Objectives of Air Quality Monitoring Network

Through discussions with BC MOE, the primary objectives of the air quality monitoring network in Kitimat have been identified in the draft ToR:

Primary Objectives of Air Quality Monitoring Network

1. Measure attainment of provincial objectives
2. Enable an understanding of the impact of Rio Tinto's Smelter emissions
3. Enable advisories by BC MOE and Northern Health Authority; and management actions by Rio Tinto[7]
4. Enable use of data for future health studies

These primary and secondary objectives are expected to be achieved by establishing (or verifying) sites established to measure:

A. **Hot spots** – post-KMP maximum SO_2 or other smelter related emission concentrations at any offsite location with potential impacts to human health or sensitive environments.
B. **Population centers** – location representative of population center(s) that also is expected to measure post-KMP maximum concentrations within communities/residential areas.
C. **Background** – locations where model predictions show no or low SO_2 and other smelter related concentration increases from the smelter. This location should be able to serve as a background monitor in the area for dispersion modelling purposes (to add to results when the smelter is modelled), and also to verify that the model was not under-predicting the extent of the smelter plume (or areas where SO_2 concentrations are expected to increase as a result of emissions from the smelter).

For all of the above objectives, historical data will provide benefit, and maintaining a continuous record will be weighed during the optimization process.

[7] Updated per comment from BC MOE.

3. SCOPE OF AIR QUALITY NETWORK EVALUATION

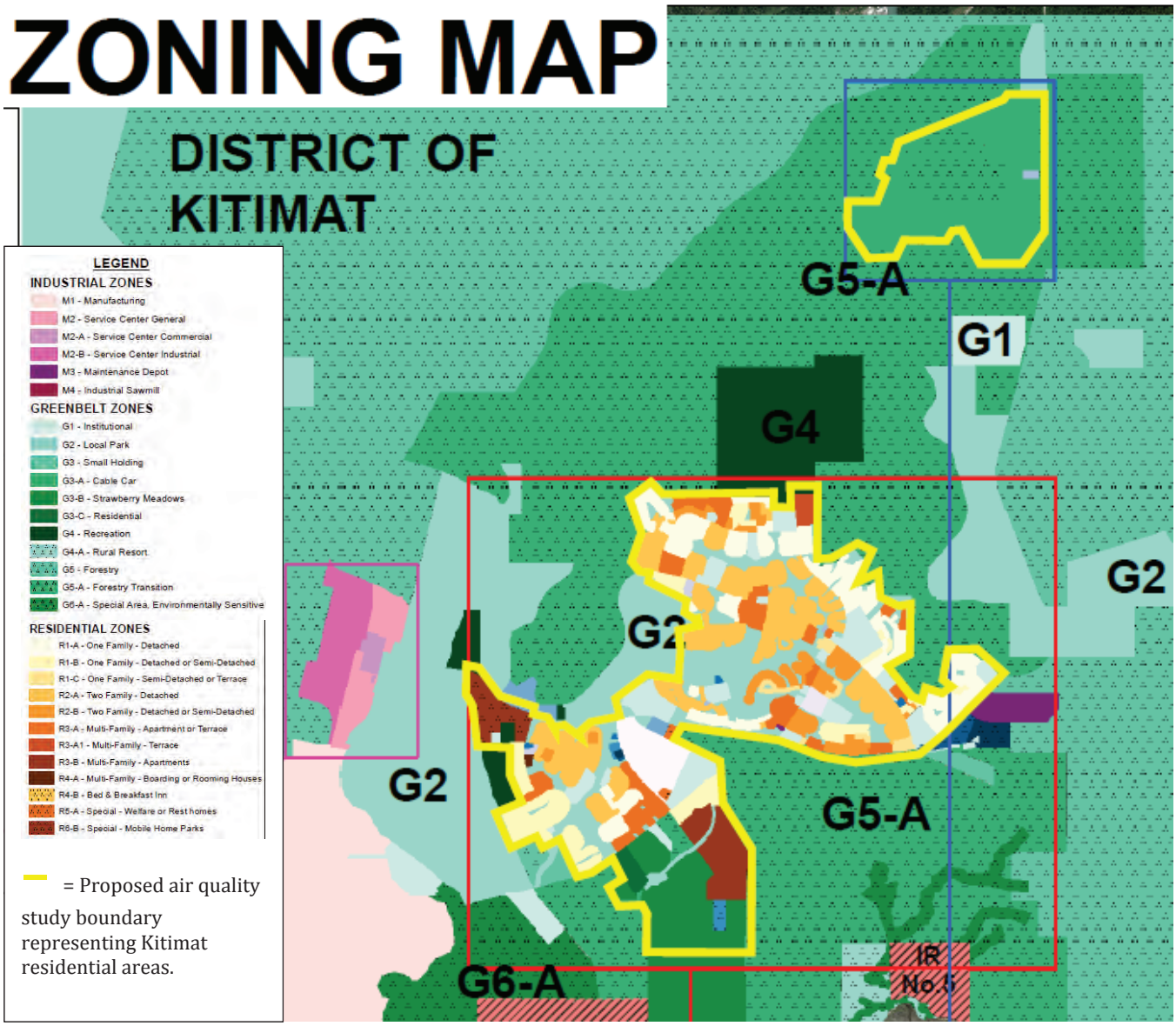
The scope of this network evaluation is limited to evaluating the location of the residential SO_2 continuous monitoring stations.

Additionally, the spatial scope of this evaluation is limited to the Kitimat residential area as shown in Figure 3-1 below, and the Kitamaat Village. In order to identify the most appropriate location for siting monitor(s) in the Kitimat residential area, the evaluation of the Kitimat residential area is bound by the established residential/commercial zoning borders based on Kitimat Zoning Map.[8]

The evaluation of the network relies primarily on the "No MM5" SO_2 dispersion modelling analysis discussed in Section 1.2.4. Exploratory monitoring using passive samplers was conducted in 2016 and 2017.The data available from the existing continuous monitoring stations and the new passive sampling network are also considered.

[8] Available here https://www.kitimat.ca/en/business-and-development/resources/Documents/District-of-Kitimat-Zoning-Map.pdf.

Figure 3-1. Kitimat Zoning Map and Boundary of Kitimat Residential Areas



4. METHODOLOGY AND PROCEDURES

The air quality monitoring network optimization is based on the modelling analyses conducted in support of the SO_2 Technical Assessment Report, updated to use the No MM5 meteorological dataset as discussed in Section 1.2.4. The model results are analyzed following the current US EPA technical support document for "source-oriented SO_2 monitoring"[9] and (if applicable) siting criteria found in: *BC Air Monitoring Site Selection and Exposure Criteria*, and *Environment Canada MSC Guidelines for Co-operative Climatological Autostations*.

The list below outlines the procedures for optimizing the air monitoring network.

1. Generate detailed GIS maps of Post-KMP model results following the EPA guidance:
   - **Step 1**: *Exclude* certain receptors from the residential area (e.g., too steep in terrain, in the dense forest etc.). This step was conducted using GIS software with receptors overlaid on aerial imagery and terrain data.
   - **Step 2**: *Rank* the remaining receptors (667 in total) with the modelled 3-yr average 99th percentile daily peak 1-hr concentrations. This step was completed in an Excel spreadsheet.
     → identifies locations that are potentially with highest maximum concentrations;
   - **Step 3:** *Rank* the 667 receptors candidates from Step 2 with the total number of days in the 3-yr period modelled for which each receptor was the overall highest 1-hr concentration for the day
   - → identifies locations with highest frequency in which a receptor sees the highest daily maximum concentrations among all receptors. This step was also completed in the Excel spreadsheet.
   - **Step 4:** *Sum* the scores from the two ranking methods above for the 667 receptors and *rank* these receptors from lowest score to highest to obtain a list of prioritized receptors.
     Lower numerical scores (i.e., higher ranks) indicate higher probability of experiencing high 1-hr SO_2 concentrations in the modelled domain. This step was also completed in the Excel spreadsheet.

   Note that mapping serves to prioritize the locations that are be first evaluated to potentially establish a new / relocated monitoring site. In this first step, equal weight is given to locations with the highest concentrations (99th percentile of the daily peak) and to locations with the highest frequency in which a receptor sees the highest daily maximum concentration among all receptors.
2. Compare locations of prioritized receptors at residential areas to locations of existing monitors. This step was completed in GIS software.
3. Identify any possible monitoring sites with higher priority locations than existing monitors.
4. Assess each possible higher priority location against US EPA, BC MOE, and Environment Canada monitor siting criteria. Initial assessment of meeting siting criteria was completed using GIS software, looking particularly for obstructions of buildings and trees.
5. Weigh the benefits of relocating stations or establishing new stations, and make recommendations based on the comparison to model results as outlined above, as well as:
   - Spatial accuracy and uncertainty in modelling results
   - Review of historic monitoring data and analyzer range and accuracy
   - Benefits of maintaining a continuous record from historic stations
   - The important optimization criteria outlined below

[9] US EPA technical assistance document for "source-oriented monitoring" available at: https://www.epa.gov/sites/production/files/2016-06/documents/so2monitoringtad.pdf

Several important optimization criteria must be taken into account for optimizing the location of the monitoring stations:

1. Suitability of the existing locations to meet the above primary objectives
2. Fulfillment of the required siting criteria for an air quality and meteorology monitoring station
   Including but not limited to:
   a. Avoiding of influence from local emission sources in close proximity
   b. Locating an adequate distance from obstructions (trees and buildings)
3. Long term and secure access to property
4. A readily accessible and stable electrical power supply capable of servicing an air quality monitoring station
5. Overall cost of the air quality monitoring network (capital and operating costs)

This section discusses the network evaluation following the methodology discussed in Section 4 using the monitoring data and No MM5 model data.

5.1. MONITORING RESULTS – CONTINUOUS ANALYZERS

Figure 5-1 and Figure 5-2 below present the monitoring results at the two existing monitors at the Kitimat residential area for the life of the SO_2 monitors. The monitors met data completeness criteria for all periods other than Quarter 1 and 2 of 2015 for Whitesail, as summarized in Table 5-1 below.

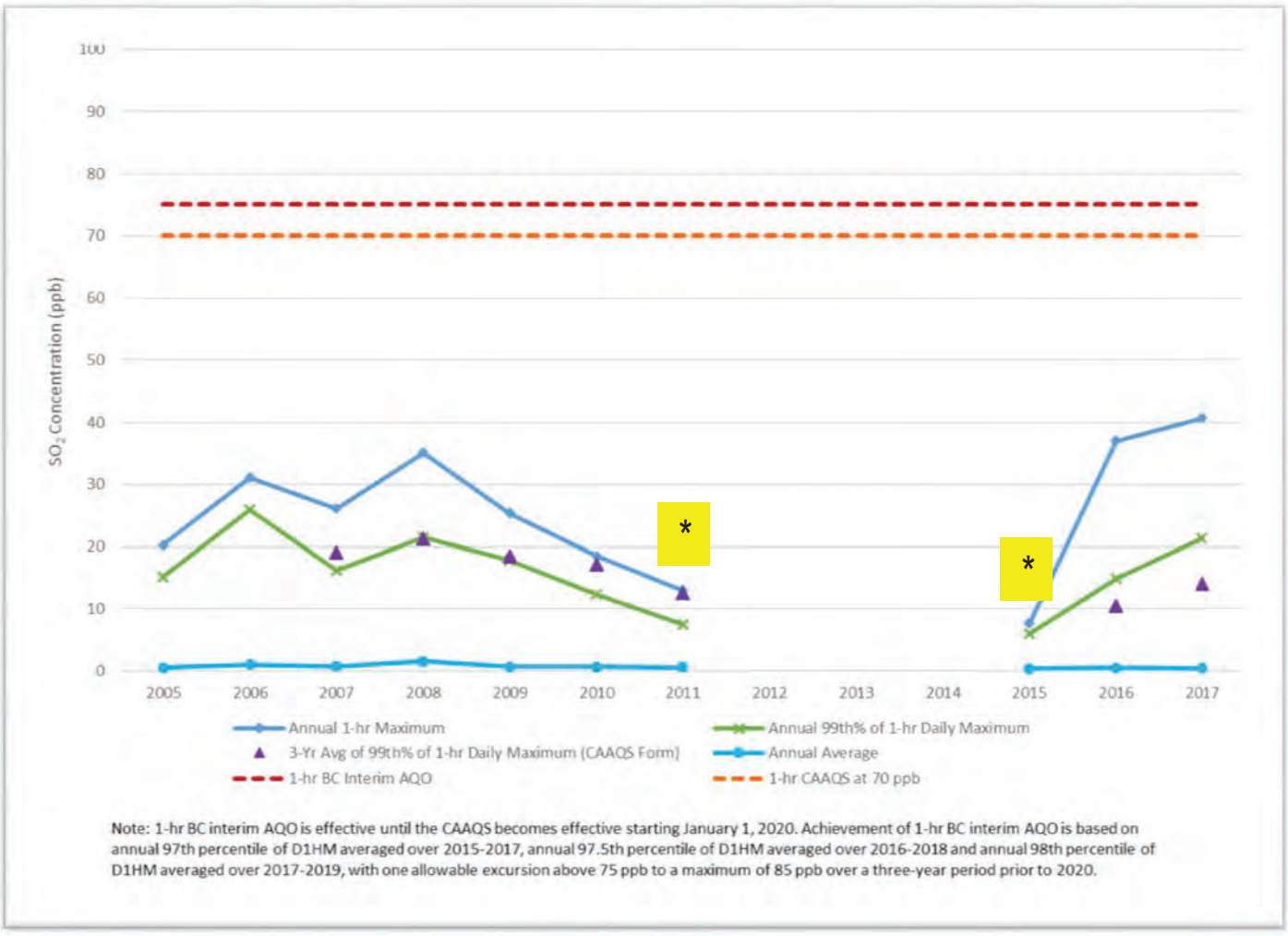
Table 5-1. SO_2 Continuous Monitoring Data Completeness Summary [1]

	2015		2016		2017	
	Kitimat Riverlodge	Kitimat Whitesail	Kitimat Riverlodge	Kitimat Whitesail	Kitimat Riverlodge	Kitimat Whitesail
Quarter 1	96.7%	0.0% [2]	100.0%	100.0%	100.0%	100.0%
Quarter 2	100.0%	0.0% [2]	100.0%	100.0%	100.0%	100.0%
Quarter 3	100.0%	64.1%	100.0%	97.8%	100.0%	100.0%
Quarter 4	100.0%	97.8%	100.0%	100.0%	100.0%	98.9%
Annual	99.2%	40.8% [2]	100.0%	99.5%	100.0%	99.7%

Notes
1. Values represent percentage of days with 18 hours or more of valid data (or at least one hour over the over the objective, but this case did not occur in these data sets).
2. Per Appendix I of the ***Guidance on Application of Provincial Air Quality Objectives for SO_2*** guidance document: *The data set should be considered complete if there are available at least 60% of all daily maximum 1-hour measurements in each quarter (i.e. Jan-Mar, Apr-Jun, Jul-Sep and Oct-Dec) and 75% of all daily-maximum 1-hour measurements in each year. Years that do not meet data availability criteria but which exceed the IAAQO should be flagged and retained for reporting.*
Years that do not meet completeness criteria are marked in Figures 5-1 and 5-2 below.
3. Earlier years were also evaluated for completeness and incomplete years are marked on in Figures 5-1 and 5-2 below.

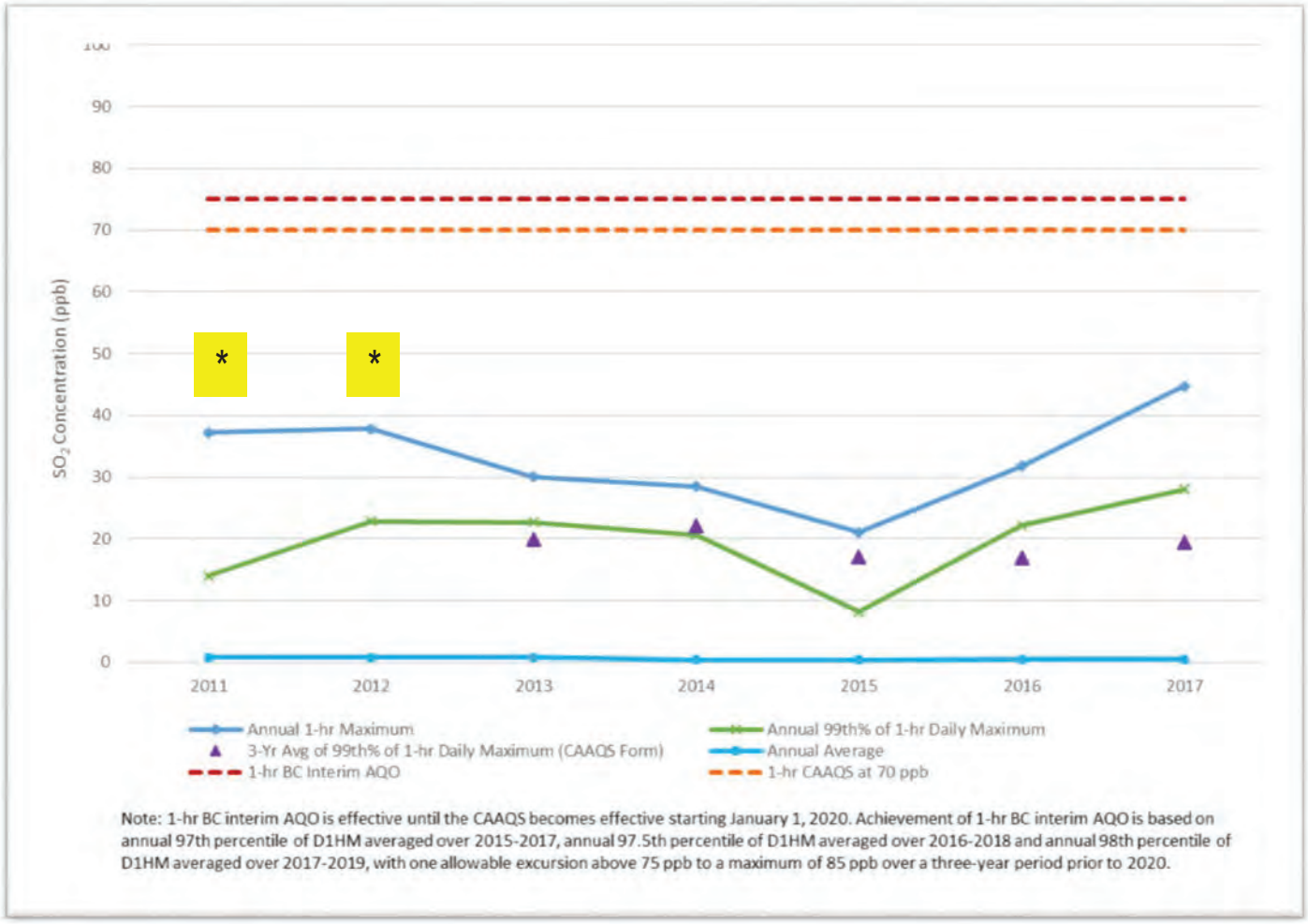
The observed SO_2 concentrations are summarized in different forms to compare to the relevant forms of standard and objectives, including the Canadian Ambient Air Quality Standard (CAAQS) and BC interim air quality objective (AQO). As shown in Figure 5-1 and Figure 5-2, the concentrations at Riverlodge and Whitesail are well below the CAAQS and BC 1-hr interim AQO. The latest year (2017) represents a year for the Kitimat Smelter with post-KMP at full operations and SO_2 emissions at approximately 70% of the permitted level. At these levels, 2017 observed SO_2 concentrations in the Kitimat residential area are well below the CAAQS and AQO. Additionally, since measured concentrations are also well below 70% of the standards, even if the smelter emissions were at the permitted level, concentrations would still be expected to be below the CAAQS and AQO.

Figure 5-1. Monitored SO_2 Concentrations at Whitesail (2005-2017)



* Whitesail had incomplete data in 2011 and 2015; therefore, the annual values shown for 2011 and 2015 should be considered as partial information, and 3-year average for 2011 and 2015-2017 should be considered partial information.

Figure 5-2. Monitored SO_2 Concentrations at Riverlodge (2011-2017)



* Riverlodge had incomplete data in 2011 and 2012; therefore, the annual values shown for 2011 and 2012 should be considered as partial information, and 3-year average for 2013 and 2014 should be considered partial information.

The continuous monitoring data also informs of the accuracy of the No MM5 and Full CALMET model results at the residential continuous monitoring stations.

- STAR/Full CALMET predicted SO_2 concentrations at Whitesail were well above measured levels for all averaging periods and forms. In particular, the 99th percentile daily peak result was modelled to be 91 ppb (3-year average 99% daily peak, modelled at 42 tpd) versus monitored to be 21 ppb (99% daily peak of monitored value from 2017, measured from 29.7 tpd actual emissions). Conversely, the NoMM5 results are similar to 2017 while still somewhat conservative: modelled to be 38 ppb (3-year average 99% daily peak, No MM5 modelled at 42 tpd) versus monitored to be 21 ppb (99% daily peak of monitored value from 2017, measured from 29.7 tpd actual emissions). Adjusting for actual emissions, No MM5 results would have been approximately 27 ppb at 29.7 tpd, comparing very closely to the 21 ppb monitored concentration.

- STAR/Full CALMET predicted SO_2 concentrations at Riverlodge were also well above measured levels for all averaging periods and forms. In particular, the 99th percentile daily peak result was modelled to be 111 ppb (3-year average 99% daily peak, modelled at 42 tpd) versus 28 ppb (99% daily peak of monitored value

from 2017, measured from 29.7 tpd actual emissions). Conversely, the NoMM5 results are similar to 2017 while still somewhat conservative: modelled to be 64 ppb (3-year average 99% daily peak, No MM5 modelled at 42 tpd) versus 28 ppb (99% daily peak of monitored value from 2017, measured from 29.7 tpd actual emissions). Adjusting for actual emissions, No MM5 results would have been approximately 45 ppb at 29.7 tpd, comparing closer but still somewhat conservatively to the 28 ppb monitored concentration.

5.2. MONITORING RESULTS - PASSIVE SAMPLING

A network of passive samplers was established in the Kitimat Valley starting in 2016[10], and the network employed IVL passive SO_2 samplers as a result of a pilot study and the public consultation in the 2016 workshop.[11] The passive sampling network is not included in the scope of the SO_2 continuous monitoring network evaluated in this network review; rather, the passive sampling results are informative to show the SO_2 plume path from the Kitimat Smelter and inform the network evaluation. The 2015 pilot study evaluation of the performance of passive monitoring samplers shows good agreement between the IVL samplers and the reference continuous analyzers (Haul Road, Riverlodge, and Smeltersite). Appendix C includes a copy of the April 2016 report describing this evaluation of the 2015 pilot study.

Additionally, 2016 and 2017 data have shown relatively good agreement with reference monitors (Haul Road, Riverlodge, and Whitesail). A full review of 2015 to 2018 passive sampling data will be including as part of the EEM Comprehensive Review.

The sampling results collected over 2016 and 2017 in the residential areas are summarized in

[10] Note that a passive sampling program was in place prior to 2016, but these results were for limited locations for preliminary studies.

[11] See KMP EEM Reports for 2016 and 2017 for more details.

Table 5-2. Figure 5-3 and Figure 5-4 present the maximum monthly and period average passive sampling results for 2016 and 2017, respectively. The overall pattern of the passive sampling results corroborate the No MM5 model results, with a general pattern of higher concentrations to the west (closer to the smelter) and lower concentrations to the east (away from the smelter and the general plume path).

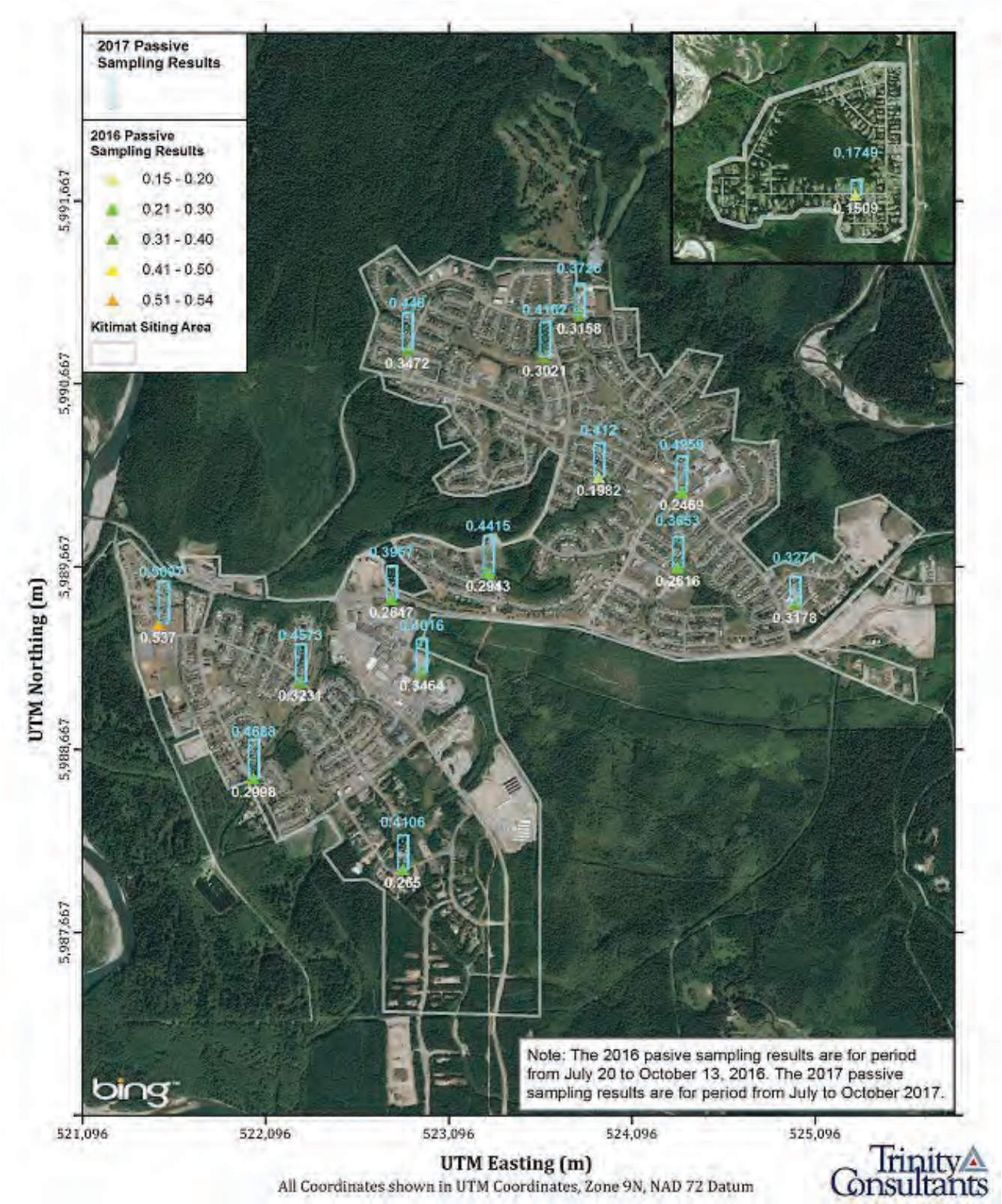
The Riverlodge station represents the location with the highest SO_2 concentrations measured by the passive samplers in the residential area, and Whitesail station ranks near the middle of concentrations measured within the Kitimat residential area.

Table 5-2. Passive Sampling Results

ID	Site Name	Latitude	Longitude	2016 Results (ppb)		2017 Results (ppb)	
				Max [1]	Ave [2]	Max [1]	Ave [2]
A02	Riverlodge station	54.05389	-128.67144	0.54	0.31	0.50	0.38
A03	Whitesail station	54.06691	-128.63913	0.30	0.25	0.42	0.32
U01	Low Channel	54.04629	-128.66356	0.30	0.24	0.47	0.35
U02	Kitimat City Centre MAML	54.05507	-128.65199	0.26	0.23	0.40	0.29
U03	Nechako Elementary	54.05655	-128.6281	0.26	0.22	0.37	0.29
U04	Mount Elizabeth School	54.06028	-128.62775	0.25	0.22	0.43	0.33
U05	Cable Car residential area	54.09192	-128.60854	0.15	0.12	0.17	0.12
U06	Kitimat General Hospital	54.05146	-128.64951	0.35	0.28	0.40	0.33
U07	Blueberry Street	54.04179	-128.65115	0.26	0.21	0.41	0.31
U08	Anderson Street	54.06731	-128.65057	0.35	0.29	0.45	0.29
U09	Fulmar Street	54.06102	-128.63463	0.20	0.20	0.41	0.33
U10	Kitimat Valley Institute	54.06897	-128.6362	0.32	0.25	0.37	0.30
U11	Kitimat City High	54.05635	-128.64391	0.29	0.27	0.44	0.36
U13	St. Anthony's Elementary	54.05471	-128.61835	0.32	0.26	0.33	0.27
U14	Kildala Elementary	54.05101	-128.65961	0.32	0.26	0.46	0.34
U15	Haisla Nation Council	53.97498	-128.64581	0.23	0.18	NA	NA

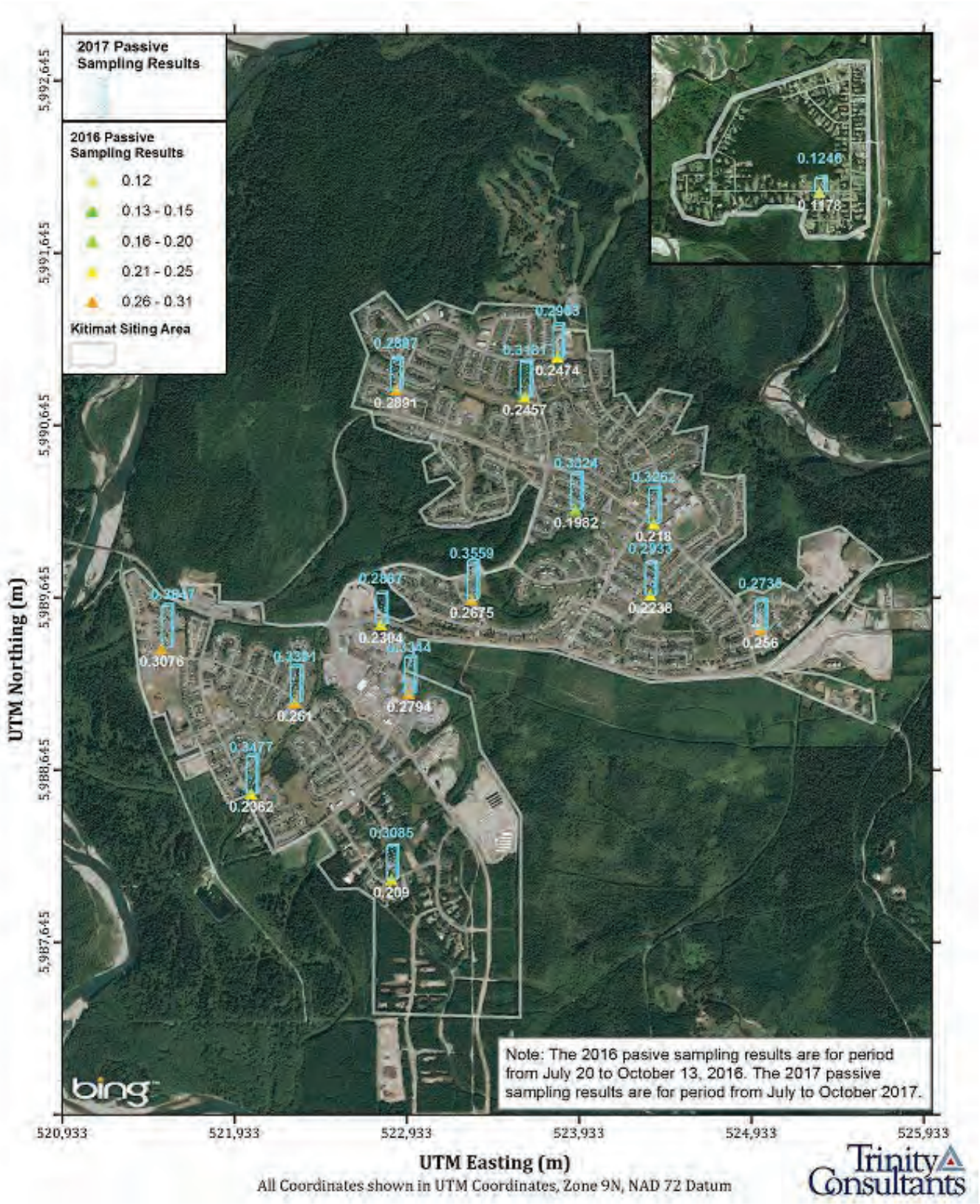
[1] Maximum results represent the maximum monthly concentration collected at the location within the exposure period.
[2] Average results represent the period average concentration collected at the location within the exposure period.

Figure 5-3. Maximum Monthly SO_2 Concentrations (ppb)



Note that Table 5-2, 2nd and 4th column from the right show these values in a more readable format.

Figure 5-4. Period Average SO_2 Concentrations (ppb)



Note that Table 5-2, 1st and 3rd column from the right show these values in a more readable format.

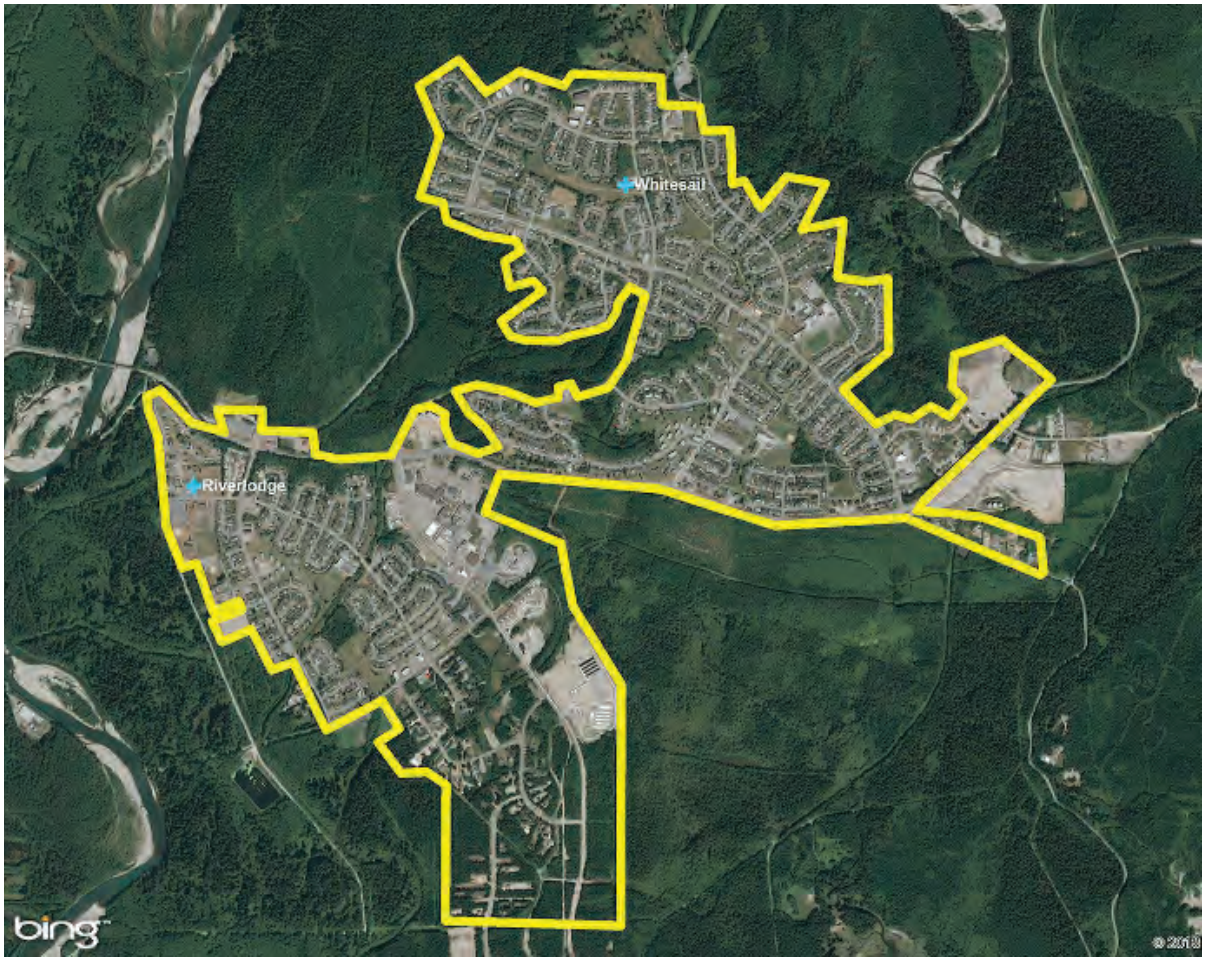
5.3. SITING RESULTS USING NO MM5 DATA

As discussed in Section 1.2.3, 5.1, and Appendix A, model results with No MM5 data are more realistic representations of the air concentrations compared to the model results with Full CALMET data, due to the conflicting wind fields in the Full CALMET data. Therefore, the No MM5 model output dataset is used to assess the appropriate locations for siting an SO_2 monitoring station within the Kitimat residential area.

Step 1: Determine Siting Area

In order to identify the most appropriate location for siting monitors in the Kitimat residential area, the evaluation is bound by from the known residential area based on Kitimat Zoning Map as discussed in Section 3.[12] Certain areas that are not suitable for siting a monitor are excluded, such as locations that are on steep hills and in the dense forest. The area used (after exclusion) for this siting exercise is depicted in Figure 5-5. Note that the exclusion process is completed with the best available aerial imagery (Bing Maps), but field evaluation would also be needed for the final determination on the best location for moving or placing a new ambient air monitor.

Figure 5-5. Kitimat Siting Area (Aerial Imagery)

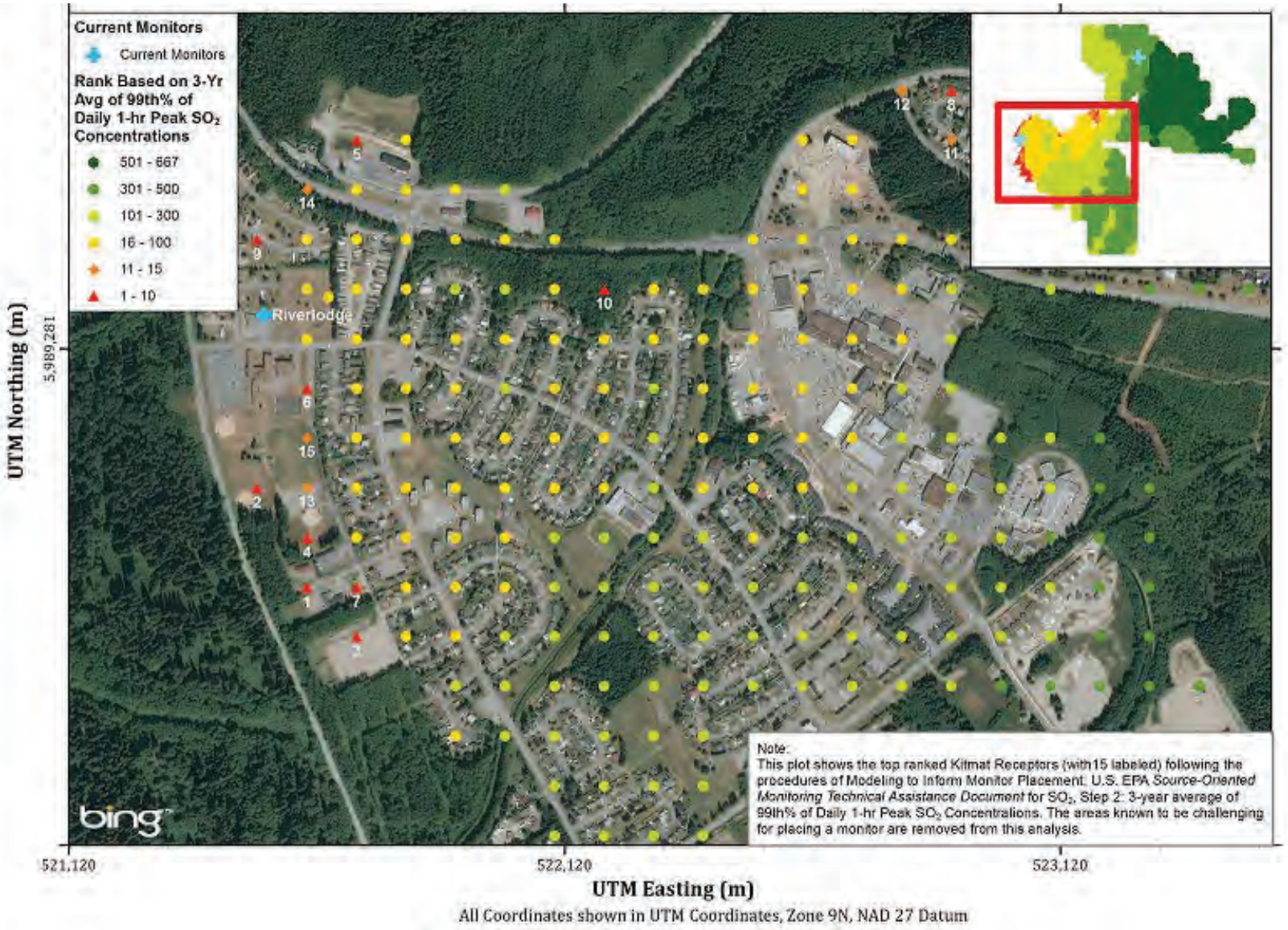


[12] The Kitimat zoning map is available here https://www.kitimat.ca/en/business-and-development/resources/Documents/District-of-Kitimat-Zoning-Map.pdf.

Step 2: Rank Receptors with High Concentrations

In this step, the remaining receptors (667 in total) are ranked based on the modelled 3-year average 99th percentile daily peak 1-hr concentrations from the No MM5 modelling analysis. The purpose of this step is to identify the locations that will potentially measure the highest peak concentrations. Each receptor is ranked and assigned the rank number from highest to lowest. The ranking results from this step are shown in Figure 5-6. The results in Figure 5-6 show the locations with the highest concentrations are located on the west side of Kitimat and a few (3 of the top 15 ranked receptors) are north of Kitimat City Centre.

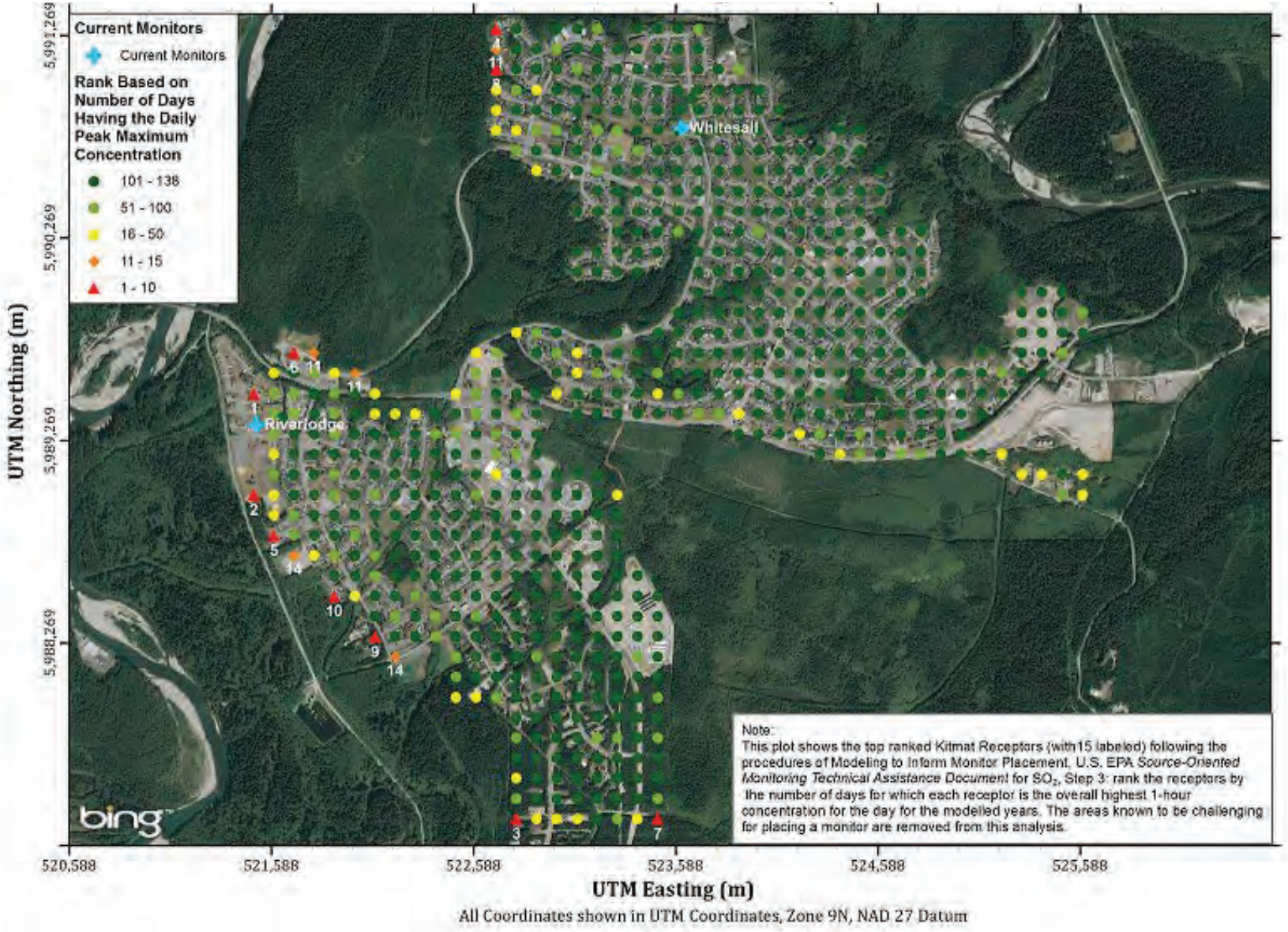
Figure 5-6. Kitimat Residential Receptors SO_2 Concentration Ranking
Based on 2006, 2008 and 2009 NoMM5 CALPUFF Modelling Results for Scenario 3A, 42 t/d SO_2, 3.8% Sulphur



Step 3: Rank Receptors based on Frequency

In this step, the 667 receptors from Step 2 are ranked based on the total number of days in the modelled 3-year period for which each receptor was the overall highest 1-hr concentration for the day. The purpose of this step is to identify the locations that have the highest frequency that a receptor would experience the highest daily maximum concentrations among all receptors. Each receptor is ranked based on the frequency and assigned a rank based on the total number of days from highest to lowest. The ranking result for this step is presented in Figure 5-7, which shows that the receptors likely to see high SO_2 concentrations are on the west side of the Kitimat residential area. Two of the top ranked 15 locations are on the south side, on the southern border of Strawberry Meadows.

Figure 5-7. Kitimat Residential Receptors Frequency of High SO_2 Concentrations Ranking Based on 2006, 2008 and 2009 NoMM5 CALPUFF Modelling Results for Scenario 3A, 42 td SO_2 3.8% Sulphur



Step 4: Sum High Concentration and Frequency Scores to Determine Overall Rank

In this step, the rank values from the two ranking methods under Step 2 and Step 3 are summed as the final "score" – giving equal weight to high concentrations and to frequency. Then these receptors are ranked from lowest score to highest. Lower numerical scores indicate higher probability of experiencing high 1-hr SO_2 concentrations in the modelled domain. Figure 5-8 shows the rank result for all receptors evaluated within the Kitimat residential area, with the sensitive receptors included in the CALPUFF modelling analysis labeled. As seen in Figure 5-8, the high ranked receptor locations are not near any of the sensitive receptor locations (with the exception of Riverlodge, which was included as a point of interest, because of the monitoring station). Figure 5-9 is further zoomed in focusing on the area with the top 15 ranked receptors. As shown in Figure 5-9, 12 of the top ranked 15 receptors are located on the western border of Kitimat near the Riverlodge monitoring station. As such the Riverlodge station falls within the area identified from the No MM5 modelling results for the best area to site a residential monitor.

Table 5-3 summarizes the information regarding the top 15 siting locations from Step 4, and their distances and directions to the existing Riverlodge and Whitesail monitor stations. As shown in Table 5-3, all of the top 15 siting locations (except for 11th highest location) are within the 1 km from the Riverlodge monitor station.

Table 5-3. Top 15 Siting Locations and Relative Locations to the Existing Monitor Stations

Receptor ID	Total Rank	Distance to Riverlodge (m)	Direction from Riverlodge	Distance to Whitesail (m)	Direction from Whitesail
1554	1st	350	South	2800	Southwest
2462	2nd	560	South-southeast	2860	Southwest
1595	3rd	150	North	2500	Southwest
2850	4th	400	North-northeast	2200	Southwest
2425	5th	670	South-southeast	2860	Southwest
2500	6th	450	South-southeast	2780	Southwest
2724	7th	780	East	1930	Southwest
2851	8th	450	Northeast	2130	Southwest
2629	9th	170	Southeast	2600	Southwest
2723	10th	680	East	2010	Southwest
2905	11th	1360	East-Northeast	1300	Southwest
2542	12th	360	South-southeast	2710	Southwest
2805	13th	270	North-northeast	2350	Southwest
2426	14th	700	South-southeast	2800	Southwest
2463	15th	580	South-southeast	2790	Southwest

Note that the modelled Riverlodge and Whitesail monitor locations in the CALPUFF modelling analysis were approximately 150 meters different from the actual monitor locations with the improvement of the aerial imagery reference technology over the years. The modelled Riverlodge monitor location (Receptor ID 12) is not on the top 15 ranked siting locations in Table 5-3. However, it would likely be within the top 5 ranked siting

locations if the precise Riverlodge monitor station location were modelled, because the 1st and 3rd ranked locations are the nearest receptors directly north and directly south of the Riverlodge monitoring station.[13]

[13] Note that there are modelled receptors closer to Riverlode to the east; however, the receptors to the north and south (with a similar Easting coordinate) are expected to be most similar to the Riverlodge location, because of spatial pattern of higher concentrations on the entire western boundary.

Figure 5-8. Kitimat Residential Siting Results Following EPA Method
Based on 2006, 2008 and 2009 NoMM5 CALPUFF Modelling Results for Scenario 3A, 42 td SO_2 3.8% Sulphur

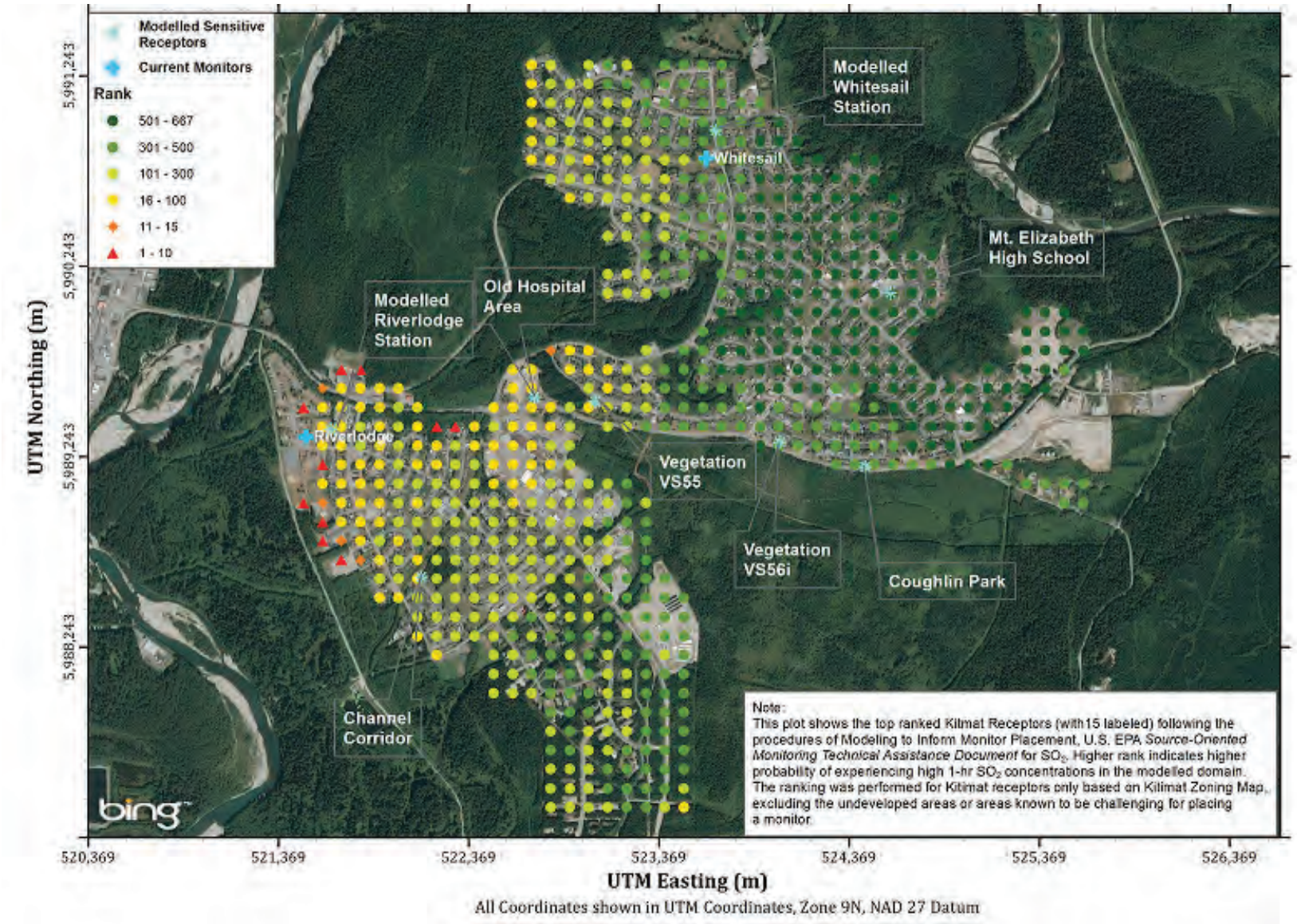
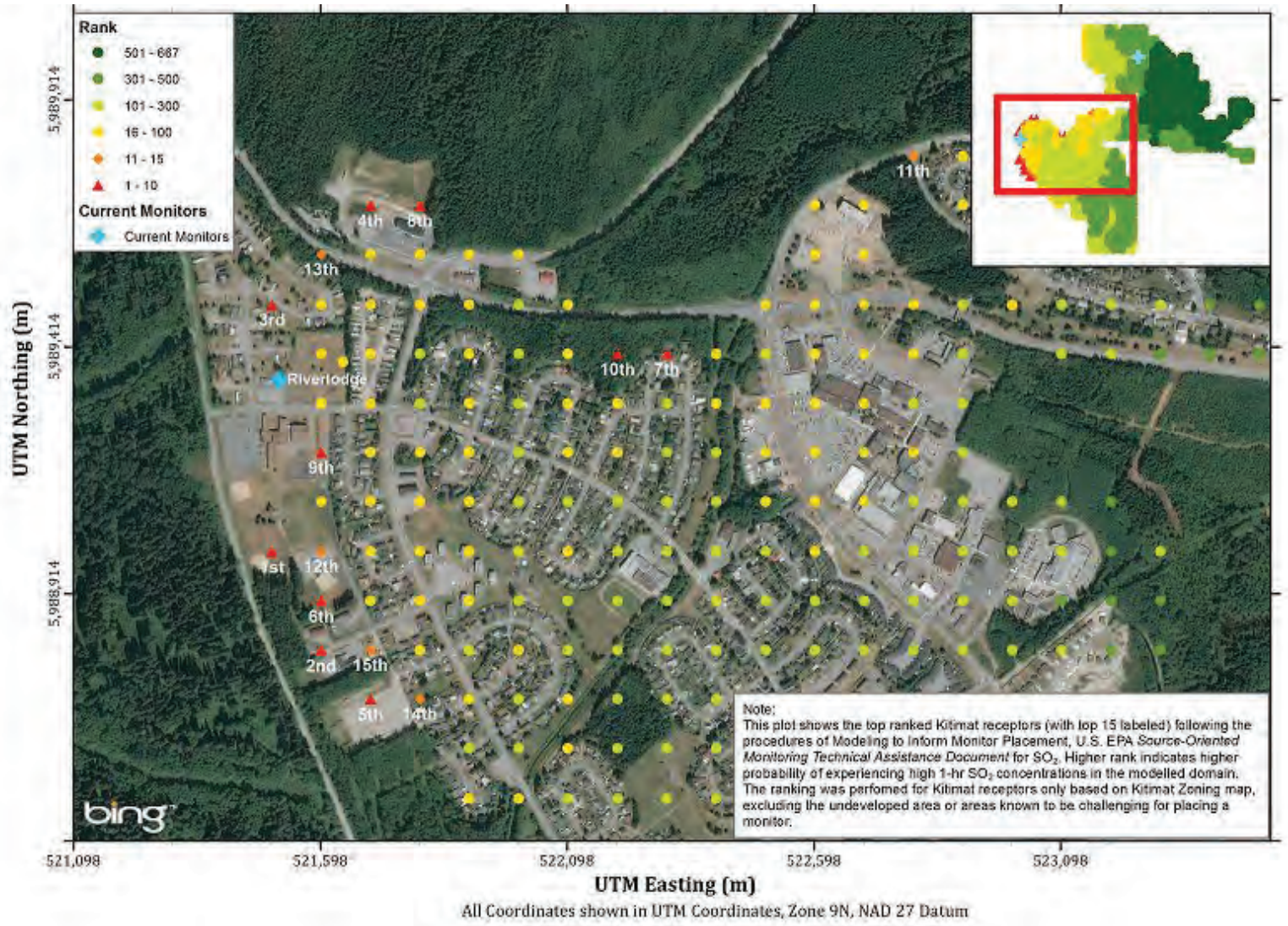


Figure 5-9. Kitimat Siting Results Following EPA Method – Top 15
Based on 2006, 2008 and 2009 NoMM5 CALPUFF Modelling Results for SO_2 Scenario 3A, 42 td SO_2 3.8% Sulphur



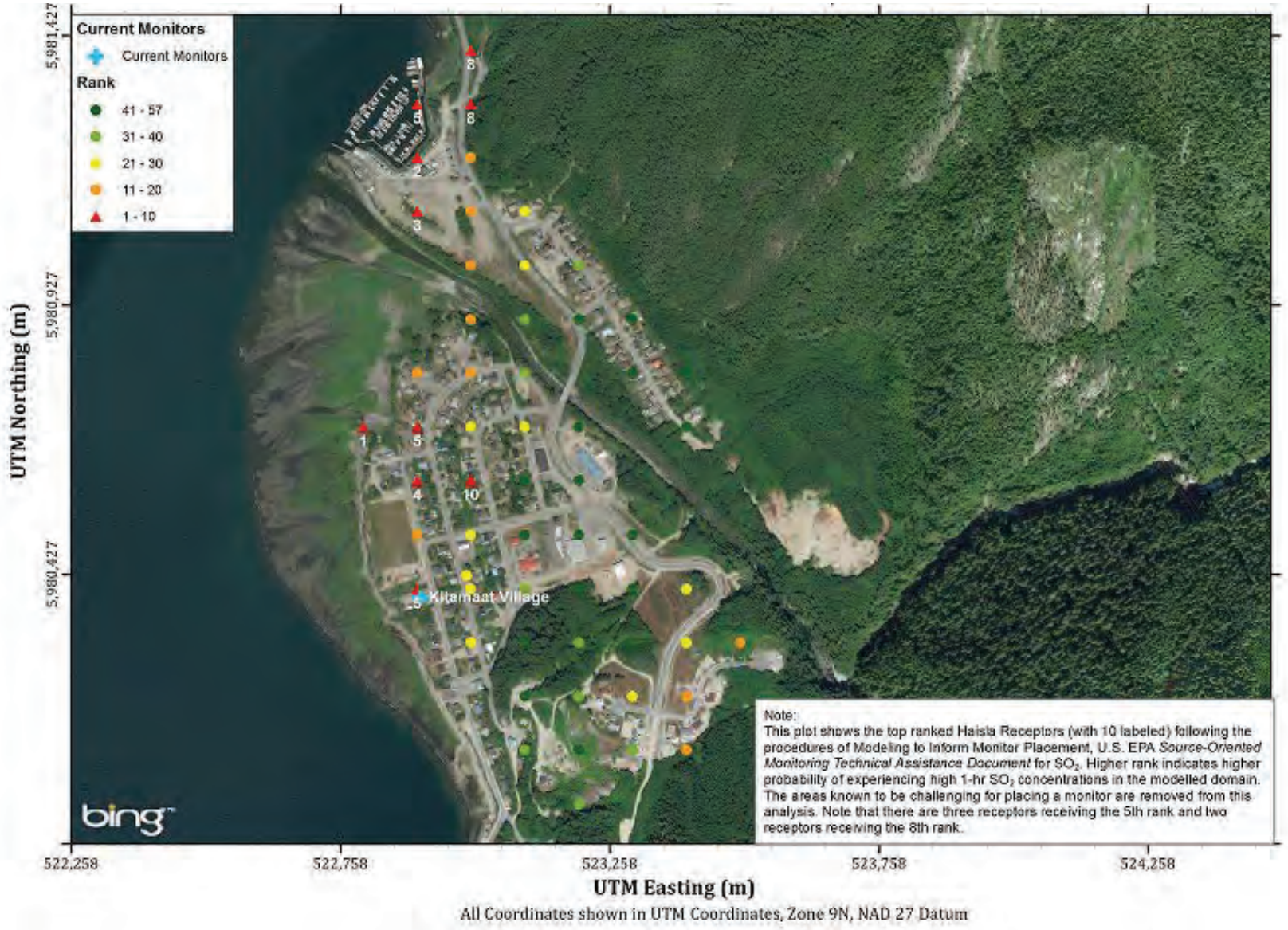
5.3.1. Siting Results for Individual Years in Kitimat Area

Monitoring siting was also performed for each of the modelled years with No MM5 data by ranking receptors with the annually modelled average 99th percentile daily peak 1-hr concentrations in Step 2 and the total number of days in the modelled year in Step 3 instead of using the 3-year data. The individual year siting results are presented in Appendix C. As expected, there are variations of the top ranked receptors for each modelled year. However, the top 15 receptors for all three years are generally in the area immediately west and north of Kitimat townsite, and in the vicinity of the Riverlodge monitor station.

5.3.2. Siting Results at Kitamaat Village

The 57 modelled receptors, including the Kitamaat Village monitor location, within the Kitamaat Village were ranked following the EPA method described above. The ranking results are shown in Figure 5-10. As shown in Figure 5-10, the modelled Kitamaat Village monitor location is approximately 120 meters from the precise Kitamaat Village monitor location. The precise Kitamaat Village monitor location is adjacent a 5th ranked receptor (two tied for 5th). The minimal distance to the top ranked receptor and the immediate proximity to a 5th ranked receptor indicate that the existing Kitamaat Village monitor is appropriately located to measure the high concentrations in the Kitamaat Village area. Additionally, the marine area where several of the top ranked receptors reside would not be suitable for a monitoring station, because the marine emissions could interfere with ambient concentrations, and because the marine area is not representative of the residential area.

Figure 5-10. Top Ranked Haisla Receptors Following EPA Method
Based on 2006, 2008 and 2009 NoMM5 CALPUFF Modelling Results for SO_2 Scenario 3A, 42 t/d SO_2, 3.8% Sulphur



6.1. KITIMAT RESIDENTIAL AREA

Based on the analysis of the No MM5 model results following the US EPA guidance for siting source-oriented SO_2 monitoring stations, the Riverlodge monitor is located in a suitable location to represent the highest concentrations expected within the Kitimat residential area. While the model predicts that the 1st ranked location approximately 350 meters to the south of Riverlodge may experience higher concentrations, the fact that the top ranked receptors vary year-to-year (e.g., in 2008, the top ranked receptor was north of Riverlodge) indicate a low degree of confidence that model predictions based on 2006, 2008, and 2009 accurately predict that one receptor will experience higher concentrations than other locations within only a few hundred meters. Therefore, moving an established station such a short distance is not warranted. Additionally, the value of the historic data at this location, the disadvantage of downtime during the moving period, and costs of the move outweigh the small possible benefit of moving the station this short distance.

The monitoring data also supports the conclusion that the Riverlodge continuous monitoring station is in a suitable location to represent the highest concentrations expected within the Kitimat residential area.

For the reasons outlined above, there is no benefit in relocating the Riverlodge air monitoring station or adding new SO_2 monitoring stations within the Kitimat residential area.

6.2. KITAMAAT VILLAGE

As discussed in Section 5.3.2, the existing Kitamaat Village monitor is appropriately located to measure the highest predicted concentrations in the Kitamaat Village area, based on the analysis of the No MM5 model results following the US EPA guidance for siting source-oriented SO_2 monitoring stations. No other more suitable locations were identified based on the model study.

APPENDIX A: FULL CALMET CONFLICTING WIND FIELDS AND NO MM5 SENSITIVITY STUDIES

The previous modelling effort as part of the STAR development used "Full CALMET" data for three years: 2006, 2008 and 2009. The Full CALMET data was generated from 5th generation mesoscale model output ("MM5" data), surface air station observations, and upper air station observations. Trinity conducted a sensitivity study using surface and upper air meteorological station observations without the MM5 dataset, called the "No MM5" dataset. The results of the study showed that the STAR results likely predicted locations of artificially elevated SO_2 concentrations, particularly in residential areas. These artificially elevated concentrations are likely caused by conflicting wind fields.

Conflicting Wind Field Example

The conflicting wind fields produced by CALMET's integration of mesoscale wind fields combined with surface observations likely caused artificial stagnant conditions in the CALPUFF model resulting in artificially elevated SO_2 concentrations in locations of the convergence zones. One such location appears to the south-southwest of the Whitesail meteorological station where mesoscale winds from the south and/or southwest converged with Whitesail observed winds from the north and/or northwest, as illustrated in Figure A-1 below. The CALMET model resolves these conflicting wind directions and speeds by blending between the mesoscale winds and the surface observation winds in the area immediately surrounding the surface station, often resulting in near zero wind speeds at the point of convergence. Additionally, when the puff traveling from the smelter toward Whitesail encounters winds from the opposite direction, the puff stops (stagnates) and may transport back south, overlapping with trailing puffs and causing artificial build-up of emissions.

Figures A-1 and A-2 show the same hour corresponding to the highest modelled concentration at the receptor with the greatest number of exceedances in the residential area. Figure A-1 shows a plot of the complete near-field domain with wind vectors and meteorological stations (Whitesail is labeled KIW), and Figure A-2 shows the same hour (and same wind vectors) zoomed-in and overlaid with the modelled concentrations for that hour. As shown in Figure A-1, the wind direction near the Whitesail station (slightly northeast of the marked receptor) is from the north (pointing southward) and with very low speed, while winds in all surrounding locations are from the south (pointing northward), or from the southwest/southeast and with greater speeds. Figure A-2 illustrates how this conflicting wind condition correlates with high modelled concentrations precisely in the convergence zone (between the vector pointing southwest near Whitesail and the vectors pointing northeast between Whitesail and the smelter).

Figure A-1. 2006 Full CALMET wind fields during hour of highest concentration at highest exceeding receptor

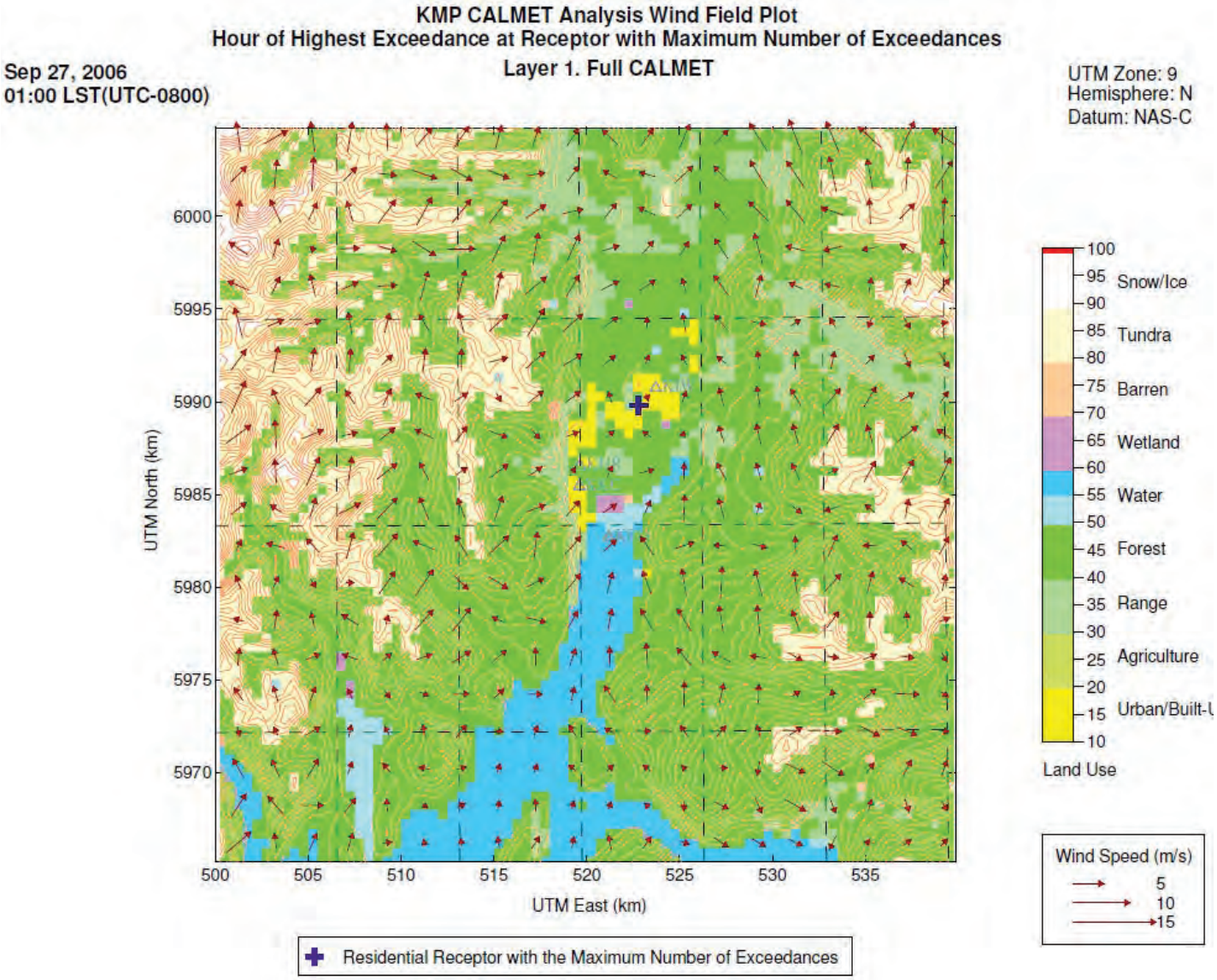
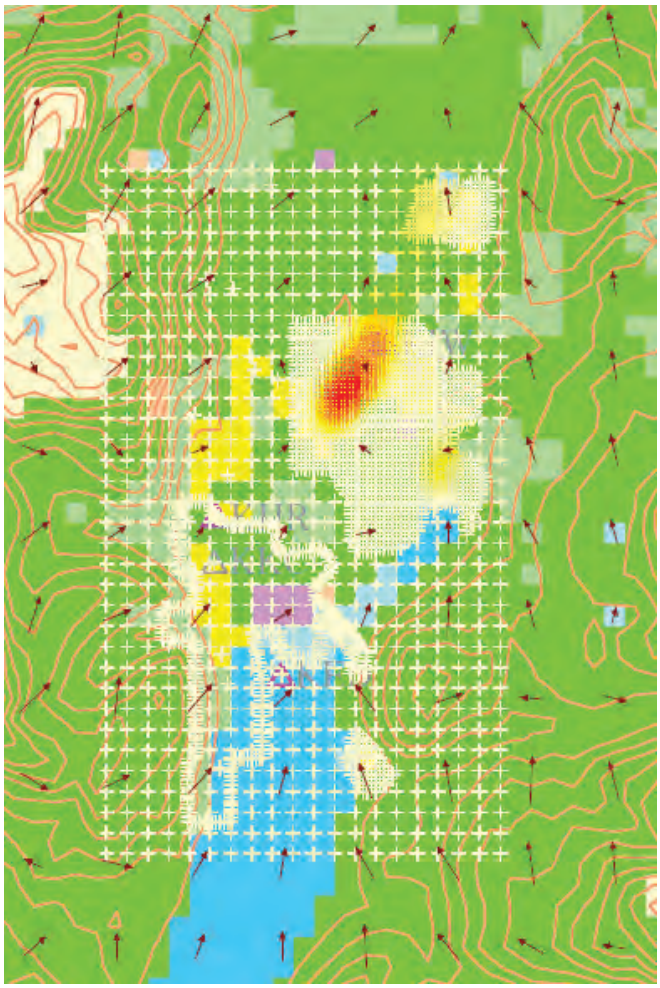


Figure A-2. 2006 Full CALMET wind fields during hour of highest concentration at highest exceeding receptor, overlaid with concurrent modelled concentrations



No MM5 Modelling Study – Single Month

Section 7.6.1.3.3.5 of the STAR presented the sensitivity study conducted for a single month from each meteorological year, and the results of the study showed that the overall spatial distribution is similar between the study results using Full CALMET dataset and No MM5 dataset. However, it also concluded that the model results using Full CALMET are more conservative, and may be overly conservative particularly in residential areas due to the MM5 wind fields conflicting with the local surface station observations. Additionally, while the overall spatial distribution was similar, the Full CALMET model predicted some "hot spot" locations within the residential area in locations where a higher concentrations would not be expected (i.e.., when a plume impinges on a hillside, this causes areas of localized elevated concentrations, but this is not the case for most or all of the high concentration areas in the Kitimat residential area). The figures from Section 7.6.1.3.3.5 of the STAR showed that the highest STAR predictions in the Kitimat residential areas were absent when using the No MM5 dataset. Figure A-3 below repeats the 2006 figures, which show the study month 1-hour maximum concentrations for pre-KMP conditions using the STAR model compared to using the No MM5 (surface-only) dataset. In the study month, the STAR Full CALMET model predicted a high concentration near Minnette Bay at 767 µg/m^3, while the No MM5 model predicted approximately 200 µg/m^3 in the same area (marked with a yellow circle both maps).

Figure A-3. 2006 Pre-KMP April Study Month - Full CALMET (STAR) (left) versus Surface-Only (right) 1-hour Maximum Model Results (Reproduction of first two figures in STAR Appendix 7.6-2)

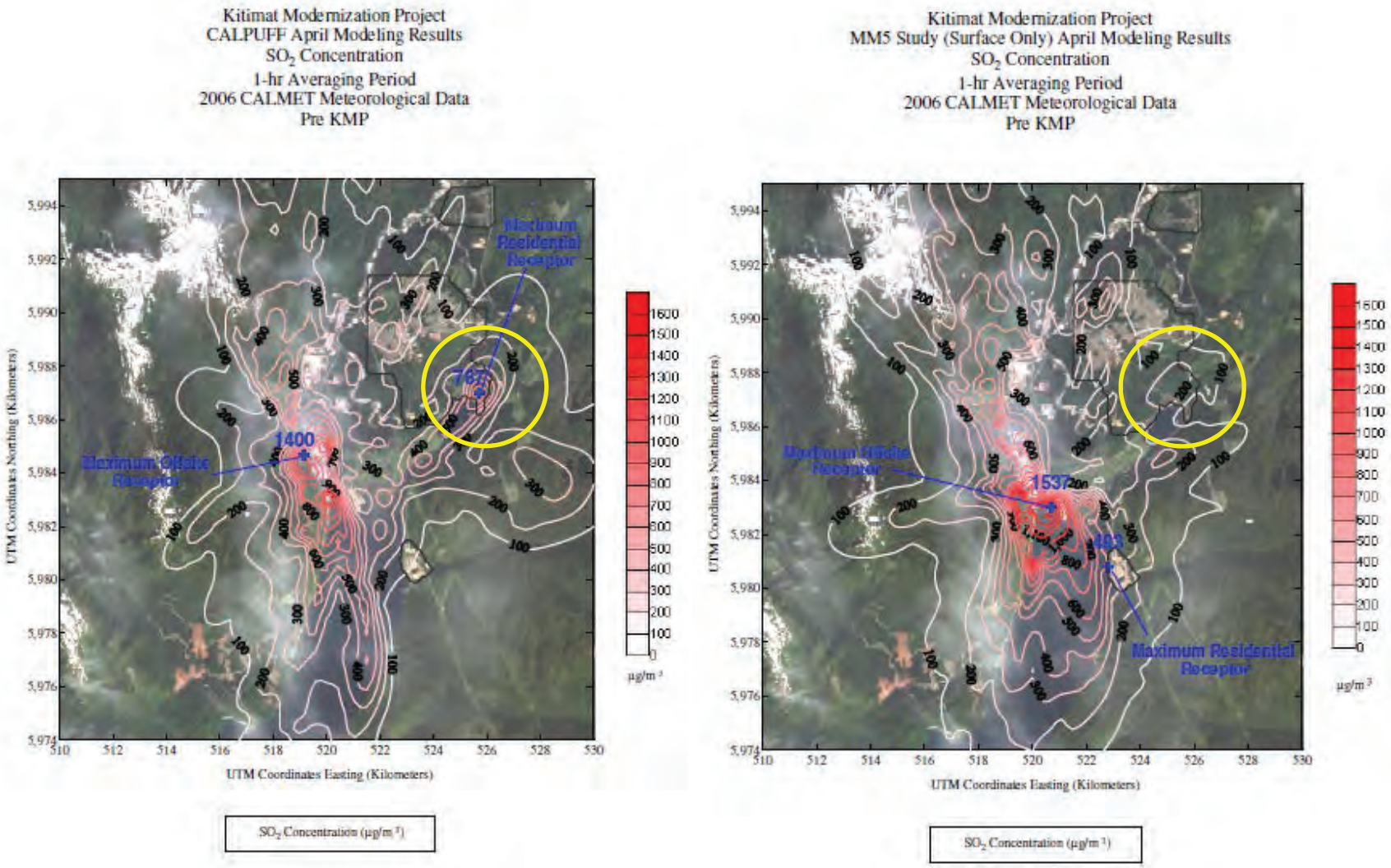
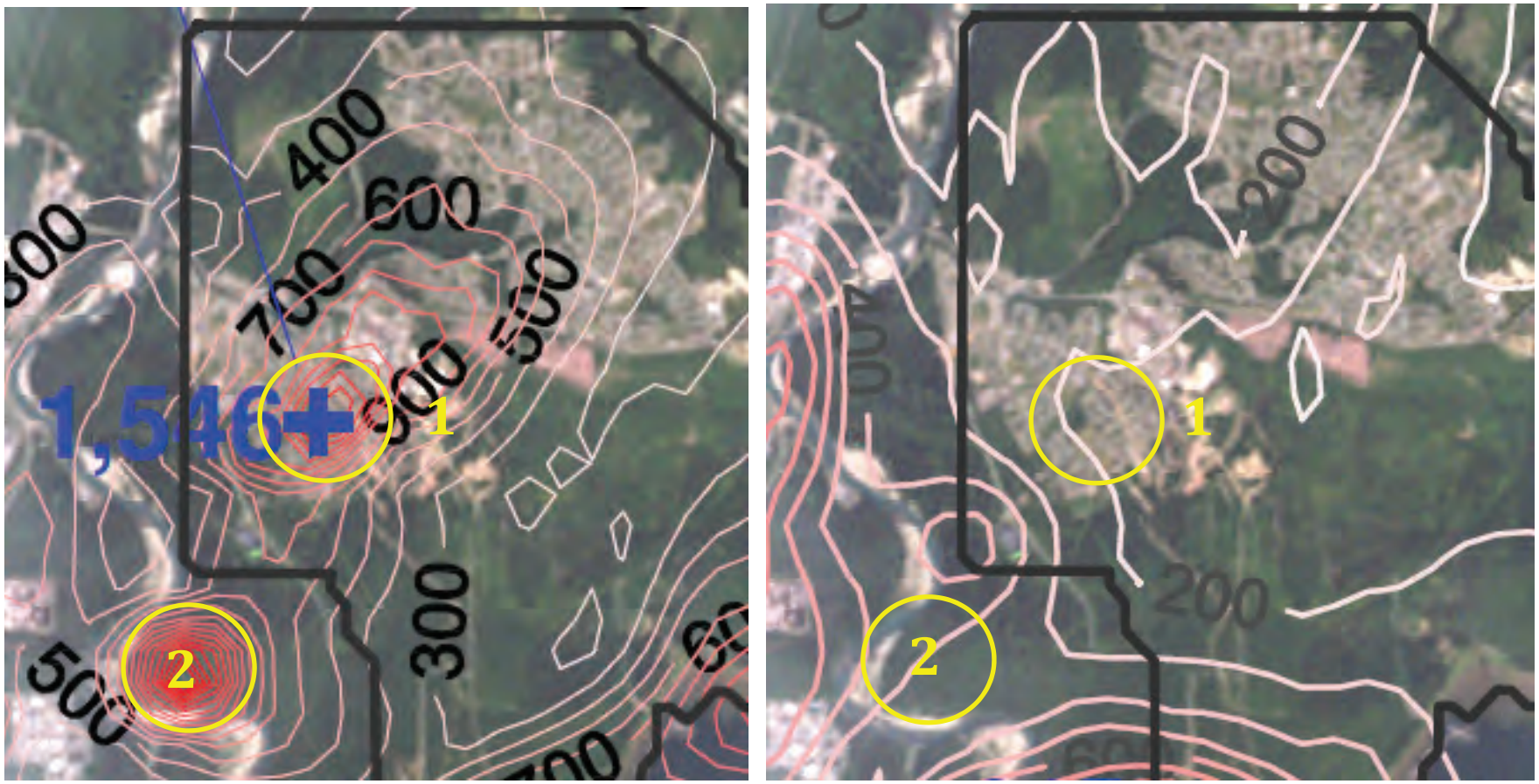


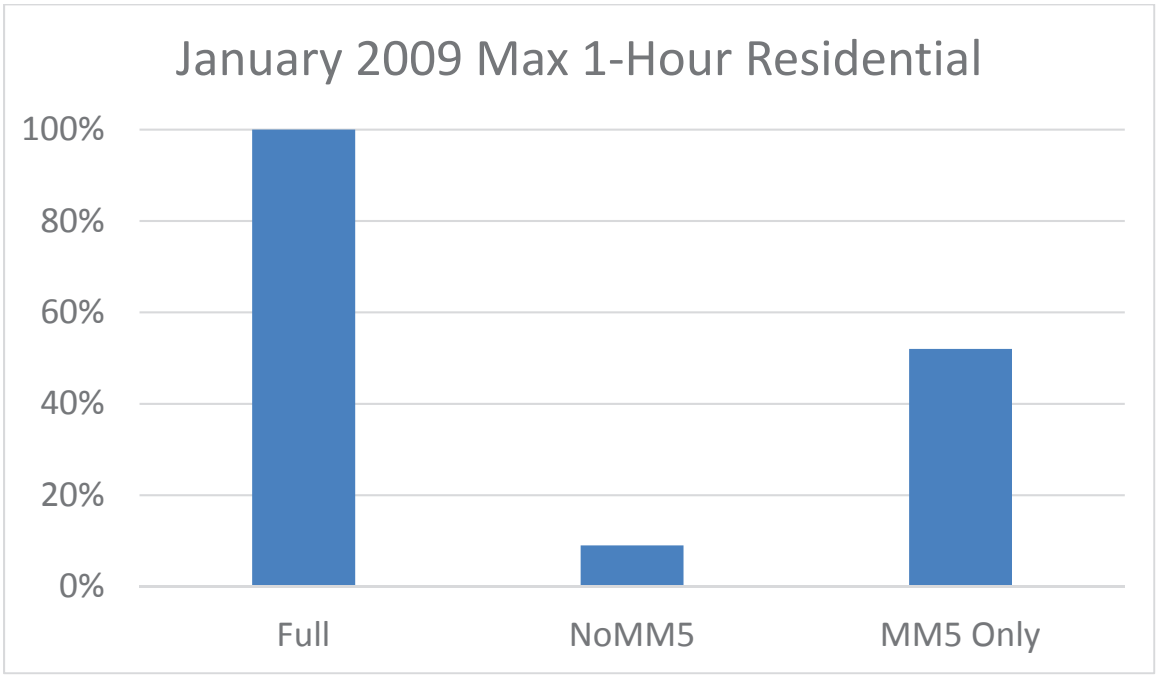
Figure A-4. 2006 Post-KMP (Full Year) - Full CALMET (STAR) (left) versus Surface-Only (right) 1-hour Maximum Model Results



The single-month No MM5 sensitivity study also showed that the predicted concentration using the Full CALMET data at Whitesail[14] for study months is 245% of the monitored value on average, and the predicted concentration using No MM5 data is 99% of the monitored value on average. These comparisons to actual monitored data indicate the No MM5 dataset predicts concentrations that agree much closer with measured concentrations, particularly in the residential area.

Trinity also conducted a second sensitivity study for the maximum month of 2009 (January 2009), comparing the No MM5, Full CALMET, and also MM5-only meteorological datasets. This study further supported the conclusion that the high concentrations in the residential areas are caused by artificial conditions from the conflicting wind fields. In this study, the Full CALMET results (1-hour maximum) are 10 times higher than the No MM5 results, and are approximately double those of the MM5-only results (see Figure A-5 below). This study ruled out the possibility that the MM5 dataset by itself included some realistic (or unrealistic) meteorological conditions that led to the elevated concentrations predicted by the STAR model in January 2009.

Figure A-5. January 2009 MM5 Sensitivity Study Results



NoMM5 Modelling Study – Extended to All Months

Trinity has conducted a more complete No MM5 modelling study to assess the predicted impacts using a CALMET dataset without the mesoscale data (using only the surface and upper air station observations) for all months of all modelled year (2006, 2008, and 2009). Figure A-4 (above) more broadly demonstrates that when using surface-only meteorological data for the entire year of 2006 (post-KMP), two high concentration locations

[14] Note that Riverlodge was not included in this study, because it was not collecting SO2 concentration data in 2006, 20008, and 2009.

are drastically lower, and not higher than surrounding areas. Additionally, no comparable "hot spots" are appear in the residential area when viewing the No MM5 results compared to the STAR results.

The all-months No MM5 modelling study shows substantially lower residential concentrations as summarized in Table A-1.

Table A-1. Modelled 1-hr Concentrations

Year	Full CALMET Maximum Modelled 1-hr Concentration [a] ($\mu g/m^3$)		No MM5 Maximum Modelled 1-hr Concentration [a] ($\mu g/m^3$)	
	Offsite	Residential	Offsite	Residential
2006	2,630	1,546	2,037	915
2008	1,979	978	1,939	421
2009	1,918	1,918	3,143	709

[a] The modelled concentrations include a background of 1.5 ppb (3.9 $\mu g/m^3$).

The Full CALMET results for the maximum 1-hour concentrations are approximately double those using the No MM5 dataset. Further, the maximum 3-year average of 99th percentile of 1-hr daily peak concentration in residential areas with Full CALMET is over three times (322%) of the result using No MM5 data for the Post-KMP scenario.

The wind field study, pre-KMP single- month study, post-KMP January 2009 study, and post-KMP all-months studies all support the conclusion that the highest modelled concentrations in the residential areas are caused by artificial conflicting wind fields. Therefore, in order to predict accurate locations for monitor siting purposes, the No MM5 dataset should be used for the Kitimat air quality monitoring network optimization process.

APPENDIX B: SITING RESULTS BASED ON INDIVIDUAL YEAR NO MM5 DATA

Figure B-1. Top Ranked Residential Kitimat Receptors Following EPA Method
Based on 2006, NoMM5 CALPUFF Modelling Results for SO_2 Scenario 3A, 42 t/d SO_2, 3.8% Sulphur

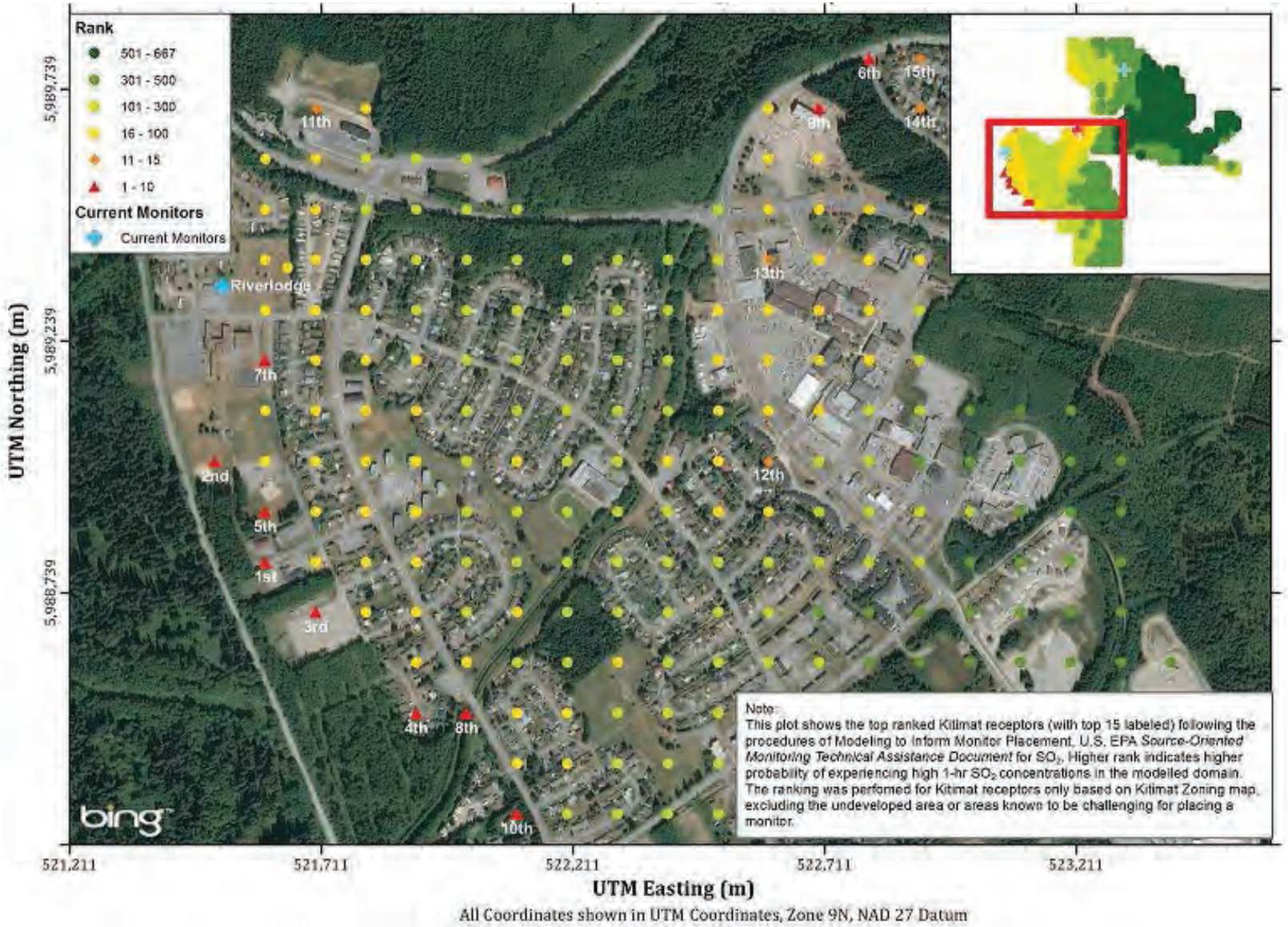


Figure B-2. Top Ranked Residential Kitimat Receptors Following EPA Method
Based on 2008 NoMM5 CALPUFF Modelling Results for SO_2 Scenario 3A, 42 t/d SO_2, 3.8% Sulphur

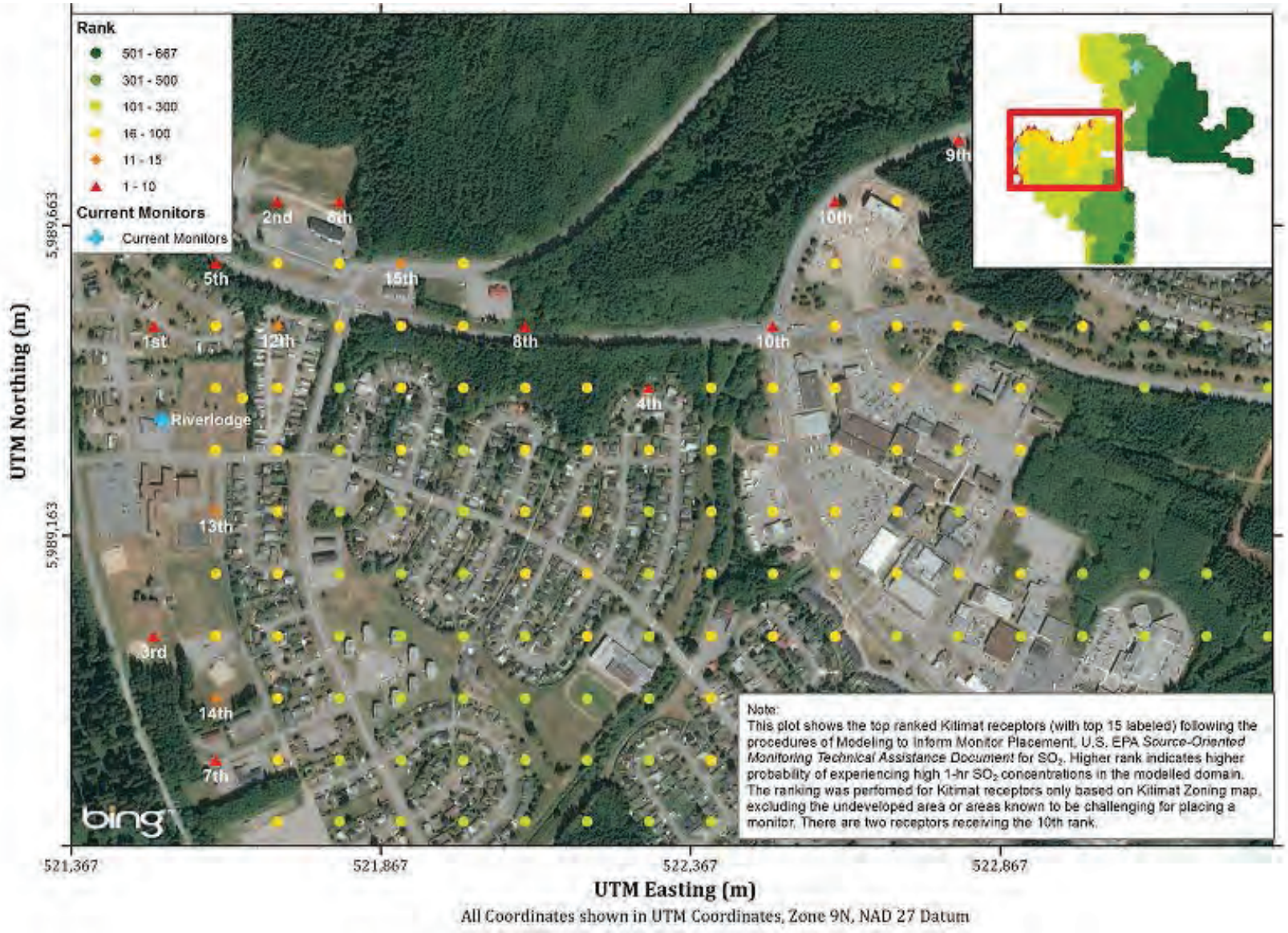
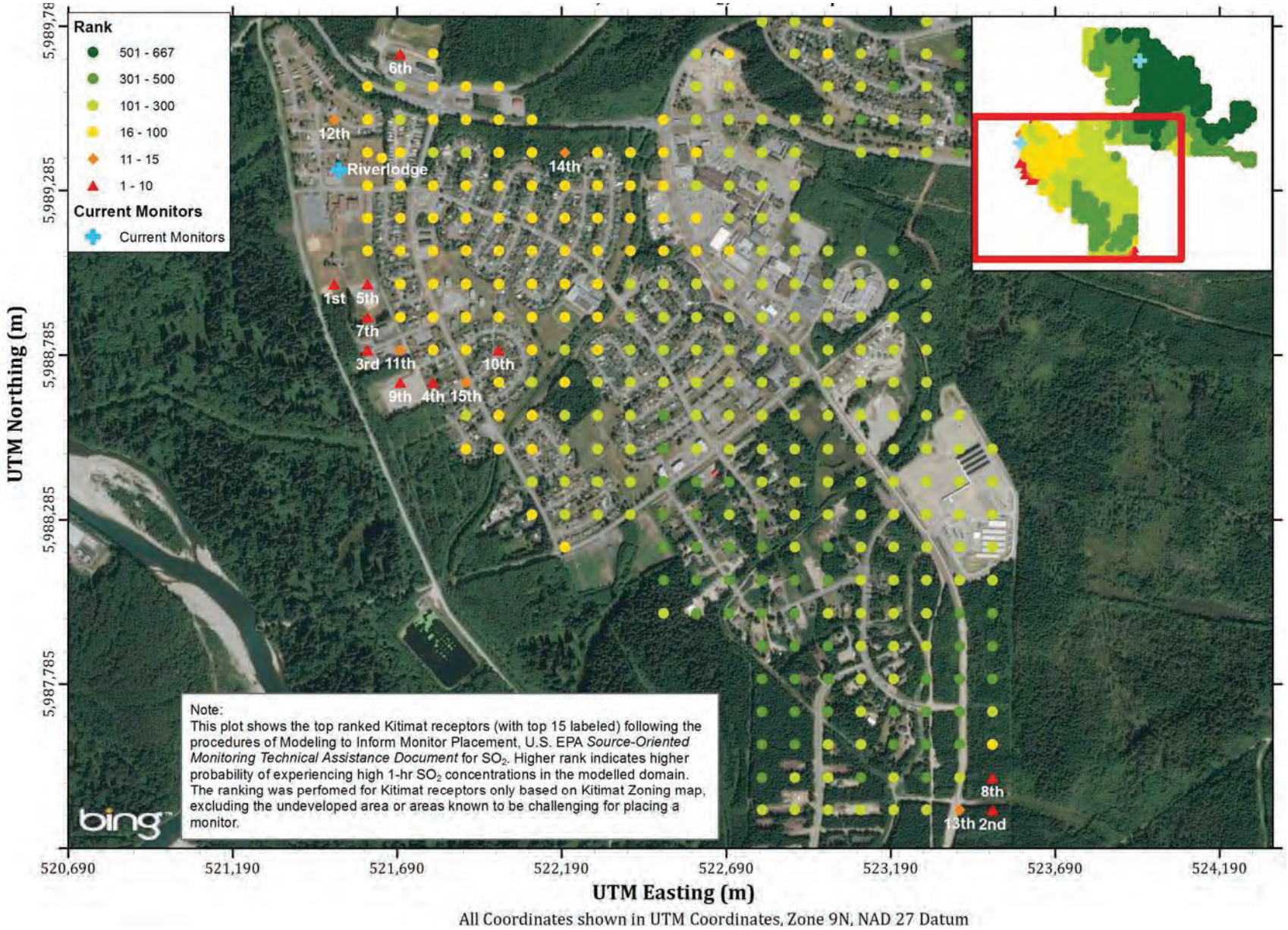


Figure B-3. Top Ranked Residential Kitimat Receptors Following EPA Method
Based on 2009 NoMM5 CALPUFF Modelling Results for SO_2 Scenario 3A, 42 t/d SO_2, 3.8% Sulphur



All Coordinates shown in UTM Coordinates, Zone 9N, NAD 27 Datum

APPENDIX C: EVALUATION OF PASSIVE SAMPLERS

Rio Tinto Alcan

KMP SO_2 EEM Program – Technical Memo P03

Atmospheric Sulphur Dioxide
Passive Diffusive Sampler Network: 2015 Pilot Study Results

April 2016

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1 Overview

A pilot study to evaluate the performance of passive sulphur dioxide (SO_2) samplers against active (continuous) SO_2 monitors was proposed under the Environmental Effects Monitoring (EEM) program prior to re-establishment of a passive sampler network (see Technical Memo P02: Passive Diffusive Sampler Network: Pilot Study, March 2015).

Passive samplers will be deemed effective, i.e., reliable for network deployment, if they exhibit: (a) a high correlation with continuous SO_2 monitors (e.g., $r \geq 0.8$), and (b) low variability between replicate exposures.

Passive samplers were co-deployed across three monitoring stations (reflecting a gradient in SO_2 air concentrations) during summer 2015. This memo briefly describes the results of the pilot study.

2 Study Design

The pilot study was carried out between 24 July and 16 October 2015 (12 weeks). Two commercial samplers with carbonate-based membrane coatings (IVL and AGAT) were co-located with continuous samplers (Figure 1) at three monitoring stations (Figure 2) spanning a gradient in atmospheric SO_2 (Kitimat Smeltersite [KMP], Haul Road and Riverlodge [highest to lowest SO_2]). Passive samplers were deployed in duplicate at each station for two-week and four-week exposures to evaluate the effect of exposure length on sampler performance. The pilot study included six two-week and three four-week deployments (see Table 1).

The deployment and collection of passive samplers was carried out by WSP (Jim Young). Following deployment all samplers were returned to their manufacturer for analysis.

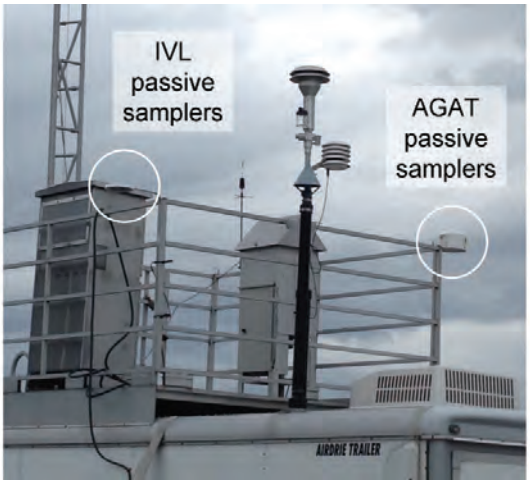


Figure 1. Deployment of passive diffusive samplers (obtained from IVL and AGAT) at continuous sulphur dioxide monitoring station. For further details on passive samplers see: IVL: www.diffusivesampling.ivl.se, and AGAT Laboratories: www.agatlabs.com/energy/air-quality-monitoring/passive-monitoring.cfm.



Figure 2. Location of continuous sulphur dioxide monitoring stations with co-deployment of passive samplers during the 2015 pilot study. Kitimat Smeltersite [KMP] (latitude: 54.01951, longitude: –128.70257, elevation: 2), Haul Road (latitude: 54.02919, longitude: –128.70269, elevation: 11) and Riverlodge (latitude: 54.05389, longitude: –128.67144, elevation: 18).

Table 1. Deployment number and date for the two-week and four-week passive sampler exposures. The average air temperature at the Kitimat Smeltersite and Riverlodge stations is also shown.

Exposure	Deployment #	Deployment date (dd/mm/yyyy)	Temperature (°C)	
			Kitimat Smeltersite	Riverlodge
Two-week	1	24/07/2015	15.9	15.2
	2	07/08/2015	17.2	16.5
	3	21/08/2015	13.4	12.7
	4	08/09/2015	12.3	11.1
	5	18/09/2015	10.5	8.8
	6	02/10/2015	10.1	7.9
Four-week	1	24/07/2015	16.5	15.8
	2	21/08/2015	12.8	11.9
	3	18/09/2015	10.3	8.4

3 Results

Average SO_2 concentrations during the study period (24 July–16 October) measured by the active monitors ranged from 0.3 ppb (Riverlodge) to 3.1 ppb (Smeltersite), with ambient concentrations approximately five higher at Haul Road compared with Riverlodge, and eight times higher at Smeltersite compared to Riverlodge (Tables 2 and 3). In general, concentrations were higher during the summer months (July and August), consistent with temperature (Figure 1, Tables 1 and 2).

Average SO_2 estimated by the passive samplers (IVL and AGAT) during the study period showed a similar range in air concentrations ranging from 0.2 [0.2] ppb (AGAT [IVL] Riverlodge) to 2.8 [3.1] ppb (AGAT [IVL] Smeltersite). Moreover, average SO_2 estimated by the passive samplers showed a strong linear relationship with the active data during both two-week (IVL R^2 = 0.99; AGAT R^2 = 0.98) and four-week (IVL R^2 = 0.99; AGAT R^2 = 0.98) exposures (Figure 4).

While IVL and AGAT passive samplers showed a strong linear relationship to the active data, the difference between replicate samplers was lower for IVL, notably lower for the four-week exposures (see Table 2 and 3). In addition, the majority of observations at Riverlodge were at the limit detection (0.2 ppb) or below detection for the AGAT samplers (5 of 9 observations were < 0.2 ppb; Table 2 and 3). Overall the two-week and four-week exposures showed a similar relationship to the active data but four-week exposures had lower difference between replicates and lower difference (%) between active and passive air concentrations (for Smeltersite and Haul Road).

4 Conclusion

Passive samplers showed a strong linear relationship with the active data for ambient SO_2. However, the IVL samplers showed a slightly better relationship, with a lower difference between replicates and lower difference between passive and active observations compared with AGAT samplers (more so for four-week exposures). More importantly, the majority of observations at Riverlodge were below detection for the AGAT samplers. However, the low atmospheric concentrations at Riverlodge were also a challenge for the IVL samplers.

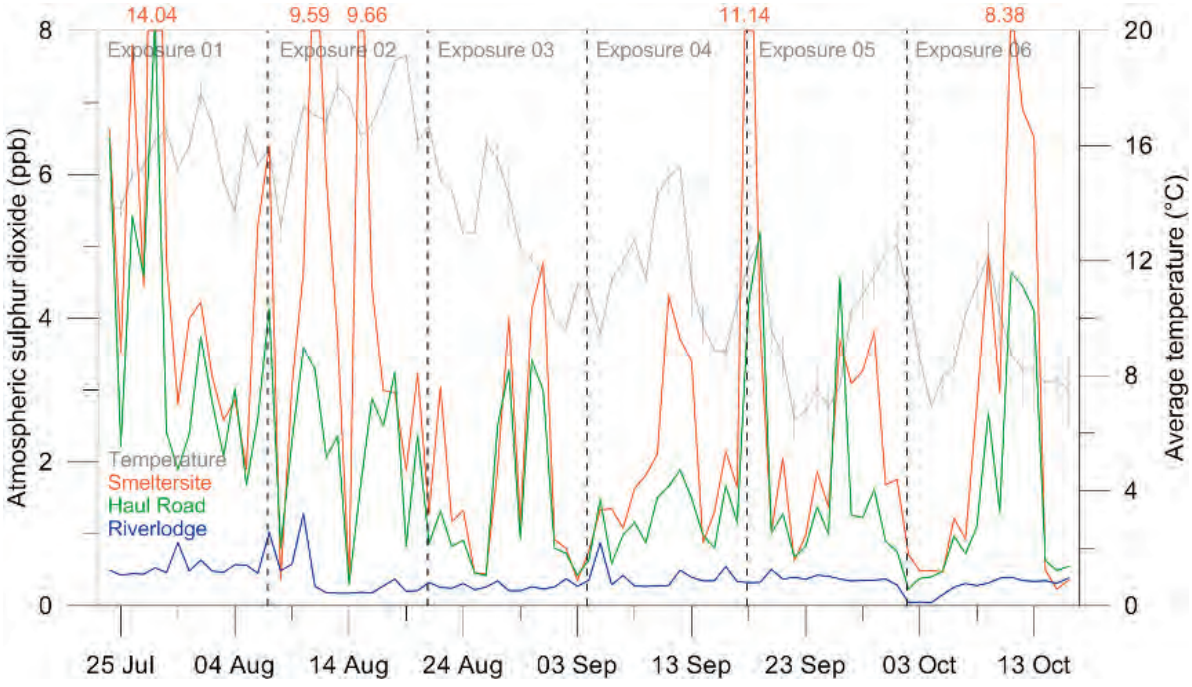


Figure 3. Daily ambient atmospheric sulphur dioxide (ppb) measured at Kitimat Smeltersite (orange), Haul Road (green) and Riverlodge (blue) during the period 24 July–16 October 2015. The average air temperature at Kitimat Smeltersite and Riverlodge is also shown (grey) with daily variation between the stations indicated by the vertical lines.

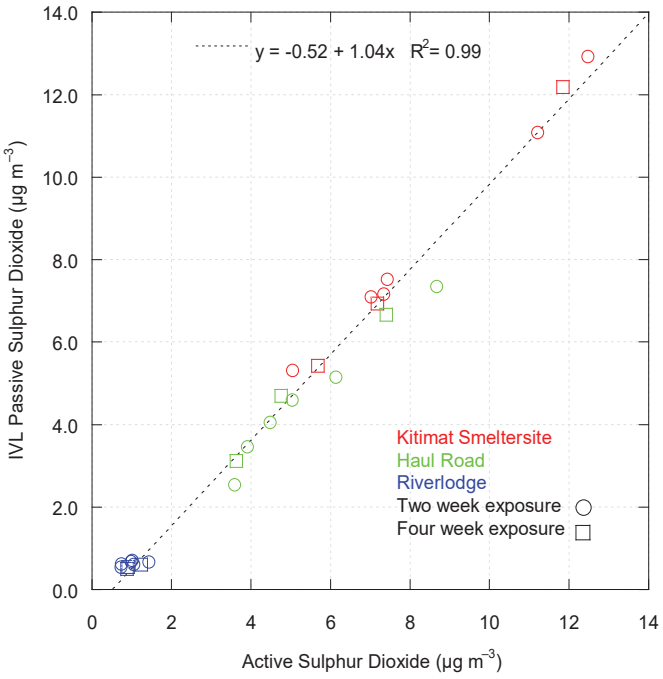


Figure 4. Comparison of IVL passive diffusive samplers for sulphur dioxide against continuous measurements at Kitimat Smeltersite (red), Haul Road (green) and Riverlodge (blue) during 24 July–16 October 2015. Passive samplers were deployed in duplicate at each stations for two-week (open circle) and four-week (open square) exposures.

Table 2. Average ambient sulphur dioxide (ppb) during two-week exposures for active (ACT) and passive (IVL and AGAT) samplers co-deployed at three staitons (Kitimat Smeltersite, Haul Road and Riverlodge). See Table 1 for deployment dates. The difference (%) in replicate (n = 2) passive samplers and the difference (%) between active and passive samplers is also given.

Station	Deployment	Sulphur dioxide (ppb)			Replicates (%)		Active (%)	
		ACT	IVL	AGAT	IVL	AGAT	IVL	AGAT
Smeltersite	1	4.62	4.73	4.65	5.5	10.8	2.4	0.7
	2	4.17	4.10	3.75	0.5	2.7	1.8	10.1
	3	1.85	1.96	1.75	3.9	17.1	5.6	5.5
	4	2.72	2.72	2.20	3.1	9.1	0.0	19.0
	5	2.55	2.58	2.15	3.2	14.0	1.1	15.7
	6	2.66	2.62	2.00	2.6	0.0	1.7	24.9
Haul Road	1	3.21	2.69	2.60	17.0	30.8	16.1	18.9
	2	2.28	1.90	1.85	11.6	5.4	16.7	18.9
	3	1.43	1.27	1.10	9.2	18.2	11.3	23.3
	4	1.31	0.92	0.70	13.4	0.0	30.2	46.6
	5	1.82	1.66	1.30	12.4	15.4	8.8	28.7
	6	1.62	1.47	1.20	4.7	0.0	9.2	26.0
Riverlodge	1	0.53	0.24	0.20	0.0	0.0	54.0	62.0
	2	0.39	0.22	0.30	20.9	0.0	42.3	22.8
	3	0.27	0.23	0.20	3.2	0.0	16.5	26.0
	4	0.36	0.24	<0.2	35.4	–	32.2	–
	5	0.37	0.25	<0.2	13.7	–	31.5	–
	6	0.26	0.20	<0.2	0.0	–	26.0	–

Table 3. Average ambient sulphur dioxide (ppb) during four-week exposures for active (ACT) and passive (IVL and AGAT) samplers co-deployed at three staitons (Kitimat Smeltersite, Haul Road and Riverlodge). See Table 1 for deployment dates. The difference (%) in replicate (n = 2) passive samplers and the difference (%) between acitive and passive samplers is also given.

Station	Deployment	Sulphur dioxide (ppb)			Replicates (%)		Active (%)	
		ACT	IVL	AGAT	IVL	AGAT	IVL	AGAT
Smeltersite	1	4.40	4.50	4.35	6.2	6.9	2.3	0.5
	2	2.08	1.97	1.90	8.5	10.5	5.3	4.5
	3	2.61	2.49	2.40	2.9	8.3	4.6	4.1
Haul Road	1	2.74	2.46	2.40	0.3	33.3	10.4	6.7
	2	1.33	1.13	0.95	3.9	10.5	15.2	16.6
	3	1.72	1.68	1.40	4.8	14.3	2.6	10.3
Riverlodge	1	0.46	0.22	0.20	6.1	0.0	51.4	39.2
	2	0.33	0.20	<0.2	5.1	–	40.6	–
	3	0.32	0.18	<0.2	5.9	–	44.3	–

DRAFT TERMS OF REFERENCE

Air Quality Network Optimization Phase 2
Draft Terms of Reference for
Rio Tinto Alcan's Kitimat Ambient Air Quality Monitoring Program

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April 2019

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1.1. INTRODUCTION

Rio Tinto engaged Trinity Consultants (Trinity) to evaluate the Rio Tinto's wholly owned and operated ambient air quality monitoring network in Kitimat, BC, and the surrounding area in order to optimize the network to meet the current needs of monitoring emissions from the Kitimat aluminum smelter. The existing network was established to measure air concentrations in the Kitimat area due to gaseous fluoride, SO_2, particulate, and polycyclic aromatic hydrocarbon (PAH) emissions from Rio Tinto Alcan's 60-year-old primary aluminum smelter. However, the Kitimat Modernization Project (KMP) will affect the air emissions spatial distribution and possibly affect the objectives of the monitoring network. As such, Rio Tinto Alcan committed to evaluating the air monitoring network as part of the SO_2 environmental effects monitoring (SO_2 EEM) program.

In 2015, a draft ToR for the air quality monitoring network optimization was provided to the British Columbia Ministry of Environment and climate change (ENV) and other stakeholders for review and comment. Comments were received and discussed in January through June 2016, This version of the draft Terms of Reference (ToR) addresses the comments received.

Additionally, an initial network evaluation (Phase 1) using the best available data was conducted and submitted to ENV in June 2017. Phase 2 of the network optimization will incorporate new modelling using 2016 to 2018 meteorological data and incorporate data from the ongoing Multi-Seasonal Air Quality Study[1]. This draft ToR serves to outline the purpose and objectives, scope, methods and procedures, and expected deliverables and timeline of this Phase 2 of the air quality monitoring network optimization effort.

1.2. BACKGROUND

1.2.1. Description of the Kitimat Modernization Project and Associated SO_2 Technical Assessment Report

Rio Tinto is undertaking the Kitimat Modernization Project (KMP) to modernizing the Aluminum Smelter with state of the art AP-4X pre-bake smelting technology. KMP will replace the existing 60 year old smelter with vertical stud Söderburg (VSS) technology. The new aluminum smelting technology is more efficient, producing more aluminum per kilowatt hour of electricity than the smelting technology in current use. As a result, the Kitimat Smelter will increase both the production of aluminum and the consumption of petroleum coke, the primary source of sulphur emissions. Rio Tinto received a permit amendment to add the new SO_2 emission sources associated with a modern pre-bake aluminum smelting process, as well as to increase the permitted limit on SO_2 emissions from the current 27 tonnes per day (t/d) to a new limit of 42 t/d. Fluoride, total particulate, and PAH emissions will decrease with the modernization of the smelter.

[1] Rio Tinto is conducting a Multi-Seasonal Air Quality Study in order to inform the network optimization process and the network's ability to measure Rio Tinto's Health KPI. Rio Tinto is submitting this framework for the SO2 Network Optimization and Multi-Seasonal Air Quality Study in order to facilitate consultation of the study design with the British Columbia Ministry of Environment and climate change (ENV). After receiving comments and/or holding discussions with ENV on the framework, a detailed SO2 Network Optimization and Multi-Seasonal Air Quality Study Design Report will be provided to ENV and to the Kitimat Public Advisory Committee (KPAC) for detailed consultation. While related to the network optimization, the Multi-Seasonal Air Quality Study is a separate effort with a separate Terms of Reference and report.

Trinity conducted CALPUFF dispersion modelling of SO_2 emissions from the smelter as part of the SO_2 Technical Assessment Report (STAR) prepared in support of Rio Tinto's permit amendment. The scope of the technical assessment focused solely on total SO_2 emissions from the modernized Kitimat Aluminum Smelter and their associated impacts on human health and the environment. Other emissions that are typical of the aluminum smelting process, such as hydrogen fluoride emissions and particulates, were not within the scope of the STAR but were evaluated as part of the P2 permit amendment. The dispersion modelling included three years of meteorological data: 2006, 2008, and 2009, and predicted results of SO_2 concentrations and total sulphur deposition. Results were calculated at 100-meter spaced resolution in residential areas in Kitimat and Kitamaat Village, and at 500 meter resolution in all other areas of the valley extending north through Terrace.

1.2.2. Description of the existing network

Figure 1-1 depicts the existing air quality continuous analyzer monitoring network and also includes the location of the two wet deposition stations (one of which was recently established as part of the EEM program). Two sites that historically measured air concentrations are also included in the figure to provide a complete history of the network. The network currently includes:

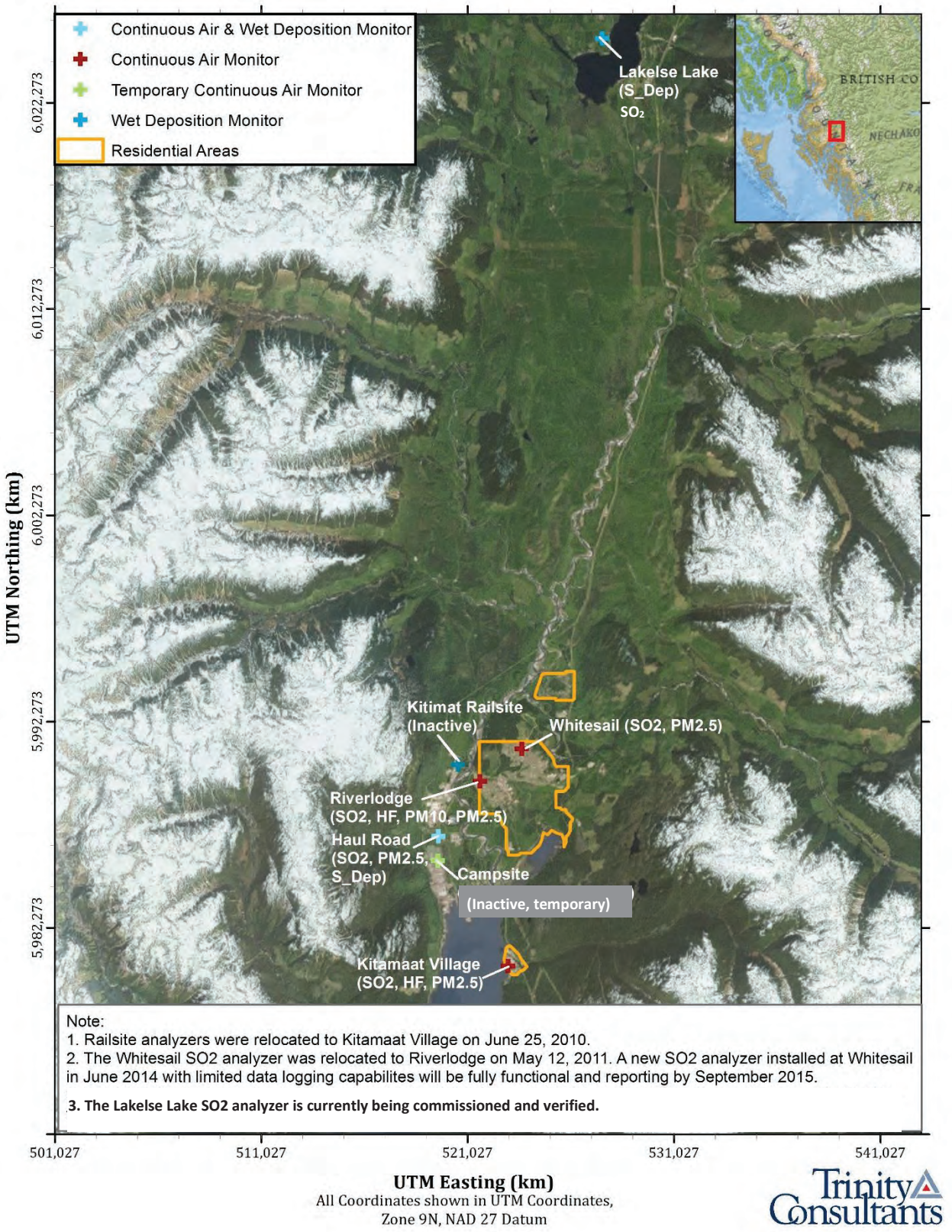
- Five continuous SO_2 analyzers located at the following sites: Haul Road, Riverlodge, Whitesail,[2] Kitamaat Village, and Lakelse Lake[3]. A sixth station (not pictured) was established by ENV in Terrace that will be used to help assess SO_2 emissions from the Smelter.
- Four $PM_{2.5}$ monitors at the following sites: Haul Road, Riverlodge, Whitesail, and Kitamaat Village.
- Three hydrogen fluoride monitors at the following sites: Riverlodge, Kitamaat Village, and KMP Camp (or Smeltersite).
- Two deposition monitors pictured, located at Haul Road and at Lakelse Lake.

Additionally, PAH monitoring is conducted through sampling at the following sites: Haul Road, Whitesail, and Kitamaat Village. The sampling frequency for PAHs typically occurs every 6th day as per the National Air Pollution Surveillance (NAPS) schedule. The PAH samples and rain chemistry (wet deposition samples) are sent to an external laboratory for analysis.

[2] The Whitesail SO_2 analyzer was relocated to Riverlodge on May 12, 2011. A new SO2 analyzer was installed at Whitesail in June 2014 with limited data logging capabilities. The new analyzer (a Thermo Scientific 43i SO_2 Analyzer) became fully functional and reporting in August 2015.

[3] The Lakelse Lake SO_2 analyzer was relocated from the temporary KMP Camp (Smeltersite) monitor station. It has been installed, and Rio Tinto is working with ENV to verify the site meets siting criteria.

Figure 1-1. Existing Air Continuous Monitoring Network



The purpose of the air quality monitoring network optimization effort is to ensure that the network will meet the needs for monitoring smelter emissions under the post-KMP scenario. In order to meet this goal, the purpose and objectives of the air quality network itself needs to be established as part of this ToR.

Through discussions with MOE, the primary objectives of the air quality monitoring network in Kitimat have been identified:

Primary Objectives of Air Quality Monitoring Network

1. Measure attainment of provincial objectives
2. Enable an understanding of the impact of Rio Tinto's Smelter emissions
3. Enable advisories by ENV and Northern Health; and management actions by Rio Tinto [4]
    a. For example, (near) real-time public notification of air quality measurements (and potential health-related messaging).[5]
4. Enable use of data for future health studies

Provided there is no additional cost to be borne by Rio Tinto, data from network should also be useful for future modelling exercises by proponents or others within the airshed, useful for evaluating past and future modelling analyses, and useful for obtaining estimates of wet and dry deposition.

These primary and secondary objectives are expected to be achieved by establishing (on verifying) sites established to measure:

A. **Hot spots** – post-KMP maximum SO_2 or other smelter related emission concentrations at any offsite location with potential impacts to human health or sensitive environments.
B. **Population centers** – location representative of population center(s) that also is expected to measure post-KMP maximum concentrations within communities/residential areas. Locations where susceptible subpopulations are present will also be considered.
C. **Background** – locations where model predictions show no or low SO_2 and other smelter related concentration increases from the smelter. This location should be able to serve as a background monitor in the area for dispersion modelling purposes (to add to results when the smelter is modelled), and also to verify that the model was not under-predicting the extent of the smelter plume (or areas where SO_2 concentrations are expected to increase as a result of emissions from the smelter).

For all of the above objectives, historical data will provide benefit, and maintaining a continuous record will be weighed during the optimization process.

[4] Updated to specifically include annual average maps per comment from ENV.

[5] Note that a pilot program of an air quality advisory system has been implemented by ENV for six communities in northwest and central BC, including Kitimat. Users can subscribe to receive email and/or text notifications.

3. SCOPE OF AIR QUALITY NETWORK OPTIMIZATION

The primary focus of this network optimization is related to SO_2 but all other emissions will be considered (particulate, hydrogen fluoride, and PAH). Note that NO_2 is not within the scope of this network, because NO_X is not a significant emission from the smelter. Both the number of stations and location(s) will be assessed. Consideration will also be given to the previously established wet deposition monitors, but the location of the deposition monitors themselves will not be evaluated. The measurements from the continuous SO_2 analyzers can be used to estimate dry sulphur deposition, but the scope of this optimization will not include any deposition calculations or evaluation of dry deposition calculation methods. The scope of the SO_2 monitoring network evaluation is limited to fixed continuous analyzers (does not include passive samplers); however, the passive sampling results inform the network evaluation by showing the SO_2 plume path from the Kitimat Smelter and identifying possible locations with higher SO2 concentrations.

The Phase 1 network evaluation was limited in scope to using existing modelling and monitoring data. The Phase 2 evaluation of the network will rely on new 2016 – 2018 dispersion modelling and exploratory monitoring through the Multi-Seasonal Air Quality Study (which includes passive monitoring and semi-mobile monitoring). The spatial boundary and timeline of the Multi-Seasonal Air Quality Study will be defined in a separate scoping document. In general, the Multi-Seasonal Air Quality Study spatial boundary will be limited to residential and commercial areas of Kitimat, including Cable Car, Strawberry Meadows, Kitamaat Village, and the commercial areas of Service Centre. The data collection time period for the semi-mobile monitoring station will be approximately 18 months, depending on the number of locations selected for temporary continuous monitoring.

The spatial boundary study domain of the air quality network evaluation of populated areas includes residential urban areas and the service centre.

4.1. METHOLODOLOGY OVERVIEW

The phase 2 air quality monitoring network optimization will primarily rely on:

- the new 2016 – 2018 modelling analyses combined with the current US EPA technical support document for "source-oriented SO_2 monitoring,"[6] and
- the monitoring data collected from the Multi-Seasonal Air Quality Study.

Additionally, candidate monitoring station locations must meet siting criteria found in *BC Air Monitoring Site Selection and Exposure Criteria*, and *Environment Canada MSC Guidelines for Co-operative Climatological Autostations*.

4.1.1. Summary of 2016 – 2018 Dispersion Model Study

Rio Tinto is planning to perform air quality dispersion modelling using CALMET and CALPUFF in order to support the Environmental Effects Monitoring (EEM) program comprehensive review. New meteorological data from 2016 to 2018 will be processed and used in the CALPUFF model.

A complete CALPUFF and CALMET modelling plan detailing the strategies was provided to ENV in March 2019. In summary, Rio Tinto is proposing to perform the 2016 - 2018 CALPUFF modelling analysis consistent with the methodologies used for the Sulphur Dioxide Technical Assessment Report (STAR) dated April 2013,[7,8] with the exception of some key changes:

- Meteorological years 2016-2018 will be used.
- The local-scale analysis will use meteorological data processed using surface station and upper air station data and not mesoscale meteorological data (also known as Obs-Only mode).
- The regional-scale analysis will use meteorological data processed using Weather Research and Forecasting (WRF) data developed by Trinity. This regional scale CALMET using WRF will be run in no-obs mode to avoid conflicting wind fields encountered in the STAR approach.
- The domain for this meteorological data will be nearly identical to the domain used in the STAR, but extended south 24 km to include better coverage of the final STAR receptor grid, which was also extended south.
- The UTM coordinate system, WGS 84 ellipsoid will be used as opposed to the UTM, NAD 27 used in STAR, which will allow Qualified Professionals, the Ministry, and the public to better understand model inputs and outputs using readily available tools such as Google Earth.

[6] The February 2016 US EPA technical support document for "source-oriented SO_2 monitoring" is available at: https://www.epa.gov/sites/production/files/2016-06/documents/so2monitoringtad.pdf
The modeling TAD is also relevant: https://www.epa.gov/sites/production/files/2016-06/documents/so2modelingtad.pdf

[7] 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 3: Appendices for Final Report. Prepared for Rio Tinto Alcan, Kitimat, B.C..

[8] The STAR Modelling Protocol included as Attachment 2 for reference.

- Precipitation data will be obtained from the Haul Road and Lakelse Lake wet deposition stations.

The new CALPUFF model will first use actual 2016-2018 emission data in order to compare model output to actual observed concentrations from existing monitoring stations. If needed, the CALPUFF model may be refined to more accurately estimate monitored concentrations. Then, the future 42 tpd permit scenario will be modelled using the 2016 to 2018 CALMET data, and these results will be used in the phase 2 network optimization effort.

4.1.2. Summary of Multi-Seasonal Air Quality Study

The Multi-Seasonal Air Quality Study will include data from the existing fixed continuous monitoring stations, semi-mobile air quality monitoring station, and passive samplers. A robust data analysis will be performed once all data are collected. The spatial scope of the Multi-Seasonal Air Quality Study will be limited to residential and commercial areas of Kitimat.

This section provides framework of the methodology for the SO_2 Network Optimization and Multi-Seasonal Air Quality Study. A separate detailed Multi-Seasonal Air Quality Study Design will be provided to ENV and to the Kitimat Public Advisory Committee (KPAC) for consultation.

Data from three sources will be used to characterize spatial and temporal variation. The three different data sources will be used as follows:

1. Fixed stations
    a. Analyze seasonal variability in SO_2 concentrations and correlations with co-located meteorological data.
    b. Represent ambient concentrations within the "grid" in which the monitor is located to inform spatial variability.
    c. Compare study period to historic data.
        i. Compare CALPUFF predictions (STAR model and new model) of pre vs post-KMP to monitoring data.
    d. Continue to verify the accuracy of the passive samplers.
2. Semi-mobile air quality monitoring station
    a. Analyze seasonal variability in SO_2 concentrations and correlations with co-located meteorological data.
        i. Seasonal variability at mobile air quality monitoring station locations will be limited to shorter periods. The time period that the mobile air quality monitoring station will remain at a given location will be defined in the separate scoping document. The minimum time will correspond to the monthly passive sampler collection period.
        ii. The framework initially proposes returning the monitor to given location once per season, prioritizing collecting more complete seasonal data over a higher number of mobile air quality monitoring station locations.
        iii. Decommissioning and recommissioning expected to take a minimum of 3 days (1 for decommission, 1 for recommission, 1 day for calibration of instrumentation).
    b. Represent ambient concentrations within the "grid" in which the monitor is located to inform spatial variability.
3. Passive monitoring
    a. Analyze seasonal variability in SO_2 concentrations.
    b. Represent ambient concentrations to inform spatial variability of plume throughout Kitimat residential areas.

4.2. PROPOSED NETWORK OPTIMIZATION PROCEDURE

The list below outlines the proposed procedures for optimizing the air monitoring network.

1. Generate detailed GIS maps of Permit Scenario modelled concentrations of: 1-hour 99th percentile daily maximum SO_2, annual SO_2, 98th percentile 24-hour and annual $PM_{2.5}$, 1-hour and 30-day hydrogen fluoride, and annual benzo[a]pyrene (as a surrogate for PAH) for each year focused on areas of modelled maxima and of existing monitors.
    a. Mapping serves to prioritize the locations that would likely be first evaluated to potentially establish a new monitoring site:
        i. Locations with the highest maximum concentrations.
        ii. Locations with the highest frequency in which a receptor sees the highest daily maximum concentration among all receptors.
        iii. Locations with highest annual average concentrations.[9]
    b. Prioritization mapping will also include a map overlaying population information and locations of sensitive subpopulations[10] with modelling output as part of the review of the site for the population oriented monitor.
        i. Annual average SO_2 concentration maps will also be generated for the purpose of evaluating population-oriented monitors that may be used for human health studies, because annual average concentrations have been found to be a better indicator of increased risk of asthmatic events.[11]
        ii. Human health experts[12] will be consulted in order to include the most important location considerations of SO_2 monitors for human health studies.
    c. For SO2, generate detailed GIS maps of Permit Scenario 1-hour model results following the EPA guidance:

Step 1: *Exclude* certain receptors from the residential area (e.g., too steep in terrain, in the dense forest etc.). This step was conducted using GIS software with receptors overlaid on aerial imagery and terrain data.

Step 2: *Rank* the remaining receptors (667 in total) with the modelled 3-yr average 99th percentile daily peak 1-hr concentrations. This step was completed in an Excel spreadsheet.

identifies locations that are potentially with highest maximum concentrations;

Step 3: *Rank* the 667 receptors candidates from Step 2 with the total number of days in the 3-yr period modelled for which each receptor was the overall highest 1-hr concentration for the day → identifies locations with highest frequency in which a receptor sees the highest daily maximum concentrations among all receptors. This step was also completed in the Excel spreadsheet.

Step 4: *Sum* the scores from the two ranking methods above for the 667 receptors and *rank* these receptors from lowest score to highest to obtain a list of prioritized receptors.

Lower numerical scores (i.e., higher ranks) indicate higher probability of experiencing high 1-hr SO_2 concentrations in the modelled domain. This step was also completed in the Excel spreadsheet.

Note that mapping serves to prioritize the locations that are be first evaluated to potentially establish a new / relocated monitoring site. In this first step, equal weight is given to locations with the highest concentrations (99th percentile of the daily peak) and to locations with the highest frequency in which a receptor sees the highest daily maximum concentration among all receptors.

    d. Monitoring data from the Multi-Seasonal Air Quality Study will also be mapped.

[9] Added annual average maps per ENV comment.

[10] Locations of sensitive subpopulations include areas where people with asthma, COPD, the elderly, and children could be located such as schools, hospitals, medical clinics, care centres, and daycares.

[11] The annual average SO_2 concentration relationship to increased risk of asthmatic events is based on relationships determined by Risk Sciences International from the results presented in the STAR.

[12] These human health experts will be third party Qualified Professionals hired by Rio Tinto. This human health QP would identify important locations in the community, which can then be reviewed by provincial health agencies for accuracy.

        i. Locations which monitoring data confirm model data will be given higher priority.
        ii. Locations with higher passive monitor results will be considered for temporary monitoring.
        iii. Locations that the semi-mobile monitor measures to have high concentrations will be given highest priority for future permanent continuous monitoring.
2. Compare locations of prioritized receptors at residential/commercial and non-residential (i.e., fenceline or hot spot) areas to locations of existing monitors.
3. Identify any possible monitoring sites with higher priority locations than existing monitors.
4. Assess each possible higher priority location against US EPA, BCMOE, and Environment Canada monitor siting criteria.
5. Weigh the benefits of relocating stations, establishing new stations, or removing stations, and make recommendations based on the comparison to model results as outlined above, as well as:
    a. Spatial accuracy and uncertainty in modelling results
    b. Review of historic monitoring data and analyzer range and accuracy
    c. Benefits of maintaining a continuous record from historic stations
    d. Engagement with the Kitimat Public Advisory Committee (KPAC)
    e. The important optimization criteria outlined below

Several important optimization criteria must be taken into account for optimizing the location of the monitoring stations:

1. Suitability of the existing locations to meet the above primary objectives
2. The required siting criteria for an air quality and meteorology monitoring station
3. Long term and secure access to property
4. A readily accessible and stable electrical power supply capable of servicing an air quality monitoring station
5. Overall cost of the air quality monitoring network (capital and operating costs)

5. TIMELINE, DELIVERABLES, AND STAKEHOLDER INVOLVEMENT

The first step in this Phase 2 Network Optimization will be to finalize the ToR based on this draft ToR through seeking feedback and comments from ENV, Haisla First Nation and the KPAC. It will be important to engage the community early in the process during this scoping stage, in particular to reach agreement on the scope and purpose of the monitoring network optimization effort, and the purpose and objectives of the monitoring network itself.

After the ToR has been finalized, Trinity will prepare a draft report detailing the air quality monitoring network optimization procedures and results, and provide this draft to MOE and Rio Tinto for review and comment. The draft report will also include recommendations to establish any new stations or relocate any existing stations, and recommend a timeline for completing any recommended changes.

Trinity and Rio Tinto will also consult the KPAC on the draft air quality network optimization report and recommendations by submitting the report to the KPAC and presenting a summary of the draft report and recommendations at a KPAC meeting.

After all input and feedback has been gathered from stakeholders, the optimization report and recommendations will be finalized. The target completion date of the final optimization report is September 30, 2021.

- April 12 – Terms of Reference to BC MOE
- April 30 – Initial feedback from BC MOE
- May 30 – Draft Detailed Multi-Seasonal Air Quality Study Design Report to BC MOE and KPAC
- June 15 – Feedback from BC MOE and KPAC
- June 30 – Issue final Detailed Multi-Seasonal Air Quality Study Design Report to BC MOE
- June 30 – Agreement on final detailed plan from BC MOE
- July 1 – Target date for commencing monitoring
- December 31, 2020 – Target date for stopping monitoring
- March 31, 2021 – Draft report to BC MOE and KPAC
- June 30, 2021 – Comments from BCMOE and KPAC
- September 30, 2021 – Finalize report

APPENDIX A: 2015 TOR COMMENTS AND RESPONSE TRACKING TABLE

Commenter/Date	Comment	Response
Arvind Saraswat (MOE) Jan-29-2016	On page 2-1, change Objective 2 to: "Enable advisories by BC MoE and Northern Health; and management actions by RTA". This wording acknowledges the collaborative role of BC MoE and NH in issuance of advisories and the anticipated role of the proponent in management actions during advisories.	Acknowledged, the ToR will be updated as suggested.
Arvind Saraswat (MOE) Jan-29-2016	Evaluation of meteorological data needs should also be considered a part of the network optimization exercise. It is generally preferable to co-locate meteorological observations with ambient monitors.	Acknowledged, the ToR will reflect that monitoring station sites preferentially should also include co-located metrological stations, with more stringent siting requirements related to clearance from obstructions.
Arvind Saraswat (MOE) Jan-29-2016	On page 4-1, include annual average concentration maps for SO2.	We agree that it is appropriate to include annual average concentration maps for SO2. The discussion and analysis will balance capturing both short-term peaks and locations with the highest long-term average.
Arvind Saraswat (MOE) Jan-29-2016	Define KOT on page 1-1.	Acknowledged, the ToR will be updated as suggested.
Arvind Saraswat (MOE) Jan-29-2016	On page 2-1, footnote can be updated to replace "new information" with "a province-wide objective".	Acknowledged, the ToR will be updated as suggested.
Arvind Saraswat (MOE) Jan-29-2016	NH and BCCDC have questioned the sole reliance on past dispersion modeling results for network optimization. The agencies also make recommendations on how their concerns could be addressed. The proponent needs to update the TOR to address the concerns raised by the two agencies.	Please see responses to the NH comments below in the related topics.
Arvind Saraswat (MOE) Jan-29-2016	Address other comments (attached) by NH.	Please see responses to the NH comments below.
Northern Health January 2016	Please confirm that the attainment of provincial objectives includes the Provincial Interim Air Quality Objectives for NO2 and SO2 (2014)	Acknowledged, the ToR will be updated as suggested.

Commenter/Date	Comment	Response
Northern Health January 2016	We have some concerns that the evaluation of the current monitoring network and future monitoring needs will be based primarily on the CALPUFF modelling that has been done for the STAR. The same CALPUFF model was used for the Kitimat Airshed Assessment (ESSA, 2014) and yielded very little variability for the eight different emission scenarios that were modelled. The lack of variability of these results adds uncertainty to the reliability of the CALPUFF model in this airshed. Given the many assumptions that went into the STAR modelling exercise, we recommend that the Network Optimization take into account: ▪ historical air quality data, which, if combined with the wind data may be just as useful as the Calpuff output. It would be beneficial to express measured concentrations of all pollutants at each site on days when they are predominantly downwind from the facility compared with days when they are predominantly upwind. ▪ Further, some spatial interpolation between these measurements might help to identify hotspots or confirm hotspots identified by the Calpuff results. ▪ Exploratory monitoring/ground truthing. While this currently does not comprise part of the TOR, we recommend that the modelling work be supplemented by mobile monitoring or similar once the plant is operational to ensure that the modelling accurately reflects reality. Overall, real data should be used as much as possible to complement and support the work done with the modelled result. The Monitor Network Optimization program should not rely exclusively on the modelling work. Furthermore, consideration should be given to incorporating a continuous evaluation/adaptive management process to allow for changes to the monitoring network if/when unforeseen results are observed.	The lack of variability in the Kitimat Airshed Assessment (KAA) is not a cause for uncertainty regarding the reliability of the CALPUFF model in the airshed. The differences and lack therefore between the various scenarios matched expectations, as discussed in the KAA due to less variability in emission sources between the scenarios. Considering historical data is a worthwhile aspect to include in the network optimization. However, it should be noted that the type of comparison described to "express measured concentrations of all pollutants at each site on days when they are predominantly downwind from the facility compared with days when they are predominant upwind" would not yield new information related to the best locations under KMP operation. The analysis could serve as a verification of existing locations; however, with the KMP ramp-up and emission levels being very low, this verification would not be representative of full post-project production. Looking at historic data (pre-KMP) would be expected to show a strong correlation for SO2 and HF, and a somewhat weaker correlation for PM (the pollutant that would emanate from other sources other than the smelter). However, this verification that the monitors were located in appropriately under pre-KMP would not verify locations under post-KMP. Information related to concentrations due to future operations cannot be measured, hence the need to use a model to predict concentrations under future configurations. Regarding spatial interpolation using measurements, performing spatial interpolation between a limited number of monitors (4 - 5 for SO2) would yield misleading results, particularly because of the non-uniform spatial distribution of concentrations (due primarily to the complex terrain in the vicinity of the facility). Additionally, it is not
Northern Health January 2016	In addition to including a map overlaying population density with modelling outputs, we recommend mapping sensitive receptors (e.g. playgrounds, schools, daycares, senior housing, etc.). It notes that human health experts will be consulted in order to include the most important location considerations for SO2. Please clarify who these experts will be. We would ask that RTA provide their own health experts that can identify these important locations in the community which can be reviewed by provincial health agencies for accuracy. Recommendations on relocating or establishing new stations should also include an assessment of the adequacy of the density and location for the purpose of identifying health impacts and conducting health studies.	Acknowledged, the ToR will be updated as suggested.

Commenter/Date	Comment	Response
Northern Health January 2016	Please ensure that health agencies are including in this process. Northern Health has concerns that we've received reports from RTA that the plant has already been started before this work has been completed. How will we know that there are no health impacts occurring during startup of the KMP facility in the absence of good and relevant monitoring data?	The existing network is providing high quality, reliable and relevant monitoring data. Furthermore, KMP SO2 emissions in 2015 were well below pre-KMP emissions levels, with the maximum month of less than 20 tonnes per day compared to the pre-KMP permit limit of 27 tonnes per day.
Candice Wilson (Haisla Nation Council) December 14, 2015	Continuity of data coming from the Kitamaat Village Station to ensure the effects of the new smelter area accounted for within the community.	Acknowledged.
Rebecca Abernethy (MOE) June 30, 2016	The placement of monitoring stations should take into account the locations with the highest SO2 concentrations where people may be located (even temporarily). This is especially important for model results at an hourly level (and sub-hourly if that was modelled), not only the 99th percentile locations, because people are exposed to all of the concentrations that occur, not only a percentage of them. A similar principle should be applied to other pollutants (PM2.5, PAHs, HF). As an example, the Service Centre represents a location where people (including members of the general population, and therefore potentially the more susceptible subpopulation) spend time, along with areas along the Kitimat River where people sometimes spend time recreationally.	Acknowledged that locations with highest SO2 concentrations where people may be located should be considered and the ToR will be updated accordingly. To clarify, the Service Centre will be added to the scope of locations to consider population-oriented monitor placement; however, priorities related to community concern, value for human health studies, and historic data in similar locations will also be weighed. Additionally, the 99th percentile of the concentrations serves as a very first step for experts to narrow down certain areas to be evaluated for the hot spots, and not necessarily mean that the highest modelled concentrations are not considered in the analysis. Furthermore, the high SO2 concentrations are directly affected by the meteorological condition, and the highest concentration could be caused by a rare event. Therefore, relying primarily on 99th percentile of the concentrations would accurately locate the possible hot spots.
Rebecca Abernethy (MOE) June 30, 2016	Section 1.2.2 should be updated to reflect the current status of the existing network (e.g. KMP Camp / Smeltersite station has been removed). Perhaps a description or table of the historical monitoring network (such as which stations have been located where, measuring what parameters, and the months / years they were in operation) should be included.	Acknowledged, the ToR will be updated as suggested.
Rebecca Abernethy (MOE) June 30, 2016	Under Section 2, Primary Objectives of Air Quality Monitoring Network, language to the effect of '(near) real-time public notification of air quality measurements (and potential health-related messaging)' could be added either as a separate point, or to point 2.	Acknowledged, the ToR will be updated as suggested.
Rebecca Abernethy (MOE) June 30, 2016	Under Section 2, Primary Objectives of Air Quality Monitoring Network, in points A-C, commentary with a focus on susceptible subpopulations to SO2 exposure, including people with asthma, COPD, the elderly, and children could be added. That is, in addition to wanting to look at hotspots where the general population may be located, we want to ensure that concentrations where susceptible subpopulations may be located (such as near schools, hospitals, medical clinics, care centres, daycares, etc.) are also taken into account.	Acknowledged, the ToR will be updated as suggested. The locations where susceptible populations are present will be evaluated in the analysis. In particular, the Human Health experts will evaluate the benefits of different aspects of the network to provide input for human health studies and to assess human health effects from the smelter emissions.

Commenter/Date	Comment	Response
Rebecca Abernethy (MOE) June 30, 2016	In addition to reviewing the modelling predictions completed for the STAR report, some confirmation or verification of SO2 hotspots in the Kitimat area could be completed via mobile monitoring. This could entail driving a vehicle (low or zero SO2 emitting) around the community for a period of weeks, covering the time of day, season and meteorological conditions when existing modelling and monitoring data suggest the hourly / sub-hourly SO2 concentrations could be highest. This process will help to confirm whether modelling results accurately reflect actual concentrations measured in the community, in more locations than the fixed monitoring stations. Mobile monitoring, for the identification of hotspots and development of land use regression models, has been conducted in numerous other locations and contexts in BC, albeit primarily for PM, but the underlying purpose is similar.	Mobile monitoring for SO2 may be feasible, but current technology would not measure a low enough range to gather meaningful data in residential areas where SO2 concentrations are generally low (i.e., if a vehicle were driven around the community with the type of handheld SO2 monitor that could be used on a moving vehicle, the readings would most read zeros). However, it is acknowledged and agreed that monitoring can and should be used to confirm modelled predictions prior to making any permanent changes to the continuous monitoring network. It *is* possible to use passive samplers to help confirm spatial distribution of modelled concentrations. Since passive samplers cannot measure short-term maximum concentrations, mobile monitors (whether handheld analyzers or a semi-mobile station such as the station previously located at KMP Camp), could be placed in locations confirmed by the passive samplers to also assess short-term (hourly and sub-hourly) peak concentrations.
Rebecca Abernethy (MOE) June 30, 2016	For historical record, and to compare pre and post-KMP SO2 concentrations, one or more current stations should remain in the same location.	Acknowledged.
Frazer McKenzie, May 20, 2016	Footnote 2 bottom of page 2-1: refers to "… attainment of the provincial objectives means that the SO2 monitor siting will focus on the 99th percentile of the 1-hour daily maximum …" The rationalization process needs to also consider the 3-year average of this metric, and include the isopleths that were produced for this form of the ambient air standard.	Acknowledged, the ToR will be updated as suggested.
Frazer McKenzie, May 20, 2016	Top of page 4-1: refers to "… optimization will be based on the modelling analyses conducted in support of the SO2 Technical Assessment Report …" The rationalization process needs to take into account all modelling conducted to date, including all pertinent post-STAR modelling.	Acknowledged.

Commenter/Date	Comment	Response
Frazer McKenzie, May 20, 2016	Reviewing the 1-hr average concentration ADM outputs from the STAR shows that an extreme concentration peak has the potential to occur near city centre to the east (2009) and south-east (2006) of the Riverlodge station. These peaks show: (1) very high concentration gradients; and (2) variability in location of the extreme peak from year-to-year. This means that, for a given station location in this area, in one year it might catch the peak, and in another year show a very low result relative to the actual peak. Thus, no single location of a monitor in this local area will be expected to capture the absolute peak in any given year. This raises the following questions in relation to design of the ambient air network: · To what degree do we accept that any given ambient air network will generally not capture the absolute peak in a local area? Does this translate into a design criteria for the ambient air network (i.e., what tolerance for missing the absolute peak is acceptable in monitoring for hot spots)? · Can use of more years of modelling (based on different meteorological years) help improve the confidence in siting locations of ambient air stations to capture peaks? · Should ADM be incorporated into the attainment assessment protocol to estimate levels and locations of absolute peaks in local areas? If so, does this affect the design of the ambient air network in any way (i.e., would the ambient air network look different if ADM were to be incorporated into the attainment assessment protocol compared to if not – would the network need to have a lot more monitors if ADM was not incorporated into the attainment assessment protocol)? · Should the design of the ambient air network be checked from time to time, based on reviewing of recent monitoring data relative to historic data, to determine its ability to achieve its primary objectives (notably, in detecting concentration peaks in local areas)? Should the EEM Plan be updated to include a periodic check on the design of the ambient air network in meeting its objectives (e.g., a check 5 and/or 10 years after next network reconfiguration)? · What is the effect of the form of the US EPA/draft CAAQS ambient air standard for SO2 in "averaging" out the variation in local area peaks? That is, what is the pattern of the peaks for a "rolling" isopleth (e.g., with 10 years of met data modeling, for instance) for this form of the standard? To what degree, if any at all, does this "averaging out" address the above	The updated ToR will take these questions into consideration. According to the US EPA, "a concentration-based form averaged over three years would better reflect the continuum of health risk posed by increasing SO2 concentrations (i.e., the percentage of asthmatics affected and the severity of the response increases with increasing SO2 concentrations) by giving proportionally greater weight to years when 1-hour daily maximum SO2 concentrations are well above the level of the standard, than just above the level of the standard." This averaging form of the standard stems from the consideration of the health risks, which is a vital piece to consider to establish the ambient monitoring network. Additionally, U.S. EPA guidance specifies that a 5-year average should be taken to compare to the 1-hour SO2 NAAQS when using a typical 5 year meteorological dataset.
Frazer McKenzie, May 20, 2016	Given that the US EPA SO2 monitoring and modeling TAD documents were recently updated (February 2016), they should be included in the TofR (i.e., replace footnote 3 bottom of page 4-1 with the actual document reference, and include the modeling TAD as it may help inform aspects of item 3 above).	Acknowledged. We will use the most recent versions of all reference documents, and the ToR will be updated to reflect this approach.
Frazer McKenzie, May 20, 2016	The current EEM Plan identifies that the informative indicator for the human health line-of-evidence is the "predicted annual number of SO2-associated respiratory responses (3-year rolling average)". Another objective, therefore, of the ambient air network would be in support of this informative indicator. The TofR need to address this objective as well.	Acknowledged, the ToR will be updated as suggested.
Frazer McKenzie, May 20, 2016	The rationalization report is to include clear explanation of how the final design of the ambient air network meets all four of the primary objectives listed on page 2-1, and the (proposed additional) objective of supporting the informative indicator.	Acknowledged, the final report will include a clear explanation as suggested.
Frazer McKenzie, May 20, 2016	Consider adding to the list of sensitive receptors for mapping purposes (as per NH's comment on Section 4-1, item 1, in their comment table), the popular camping/fishing location on the river bar on the other side of the Kitimat River from the fish hatchery, Hospital Beach, and any other popular local recreational sites in the vicinity of the smelter (i.e., within significant influence of the SO2 emissions as mapped by ADM outputs).	Acknowledged, the ToR will be updated as suggested.

Commenter/Date	Comment	Response
Frazer McKenzie, May 20, 2016	The rationalization process should provide specific assessment of need, or not, of monitoring for the Service Centre area, fish hatchery area (where there appears to be potential for a peak), and Cable Car subdivision, and include discussion of these areas in the reporting out of results.	Acknowledged, the ToR will be updated as suggested.
Frazer McKenzie, May 20, 2016	Currently, the TofR states that "… the scope of this optimization does not include passive samplers."(page 3-1) Today, however, you mentioned the potential for use of passive samplers in helping to optimize the ambient air network. If so, the TofR will need to clearly identify scope, objectives, methods and procedures, milestones, timelines, and overall study design, for incorporating passive samplers into the rationalization process.	Acknowledged, the ToR will be updated as suggested. The intention of the original ToR statement is that the passive sampling network design would not be evaluated as part of the network optimization; however, it has become clear that the passive samplers can be used as a tool in the continuous network evaluation.
Frazer McKenzie, May 20, 2016	Currently, the TofR states that "… no new exploratory monitoring will be conducted as part of the optimization process".(page 3-1) Today you also mentioned the potential for use of the MAML and/or the campsite station as roving stations for exploratory purposes in the rationalization process. If so, as with passive samplers, the Tof R will need to clearly identify scope, objectives, methods and procedures, milestones, timelines, and overall study design, for incorporating roving exploratory ambient air stations into the rationalization process.	Acknowledged, the ToR will be updated as suggested.
Frazer McKenzie, May 20, 2016	The TofR need to outline a proposed rationalization process, with a timeline and major milestones, including, but not necessarily limited to: steps and milestones for completing the TofR, steps and milestones for conducting the rationalization assessment work, the completion and circulation of a draft report, consultation with human health experts (as per 1-b-ii of Methodology and Procedures), stakeholder and First Nation consultation means and methods (stakeholder list, consultation steps, etc.) on the draft report, reporting out of consultations results, preparation and submission of final report, (accounting for) approval of final ambient air network design, and implementation and completion date(s) of changes (if any) to the final ambient air network.	Acknowledged, the ToR will be updated as suggested.
Frazer McKenzie, May 20, 2016	Please have all comments on the August 4, 2015 draft TofR compiled into a list, and the draft TofR appropriately updated, and then have both (the comments compilation list, and updated TofR) distributed to invitees at least a week ahead of the June 22-23 air quality workshop.	Acknowledged, the comments received from stakeholders and our responses will be included in the finalized ToR.

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trinityconsultants.com

VIA E-MAIL: Ben.Weinstein@gov.bc.ca

May 13, 2019

Mr. Benjamin Weinstein
Air Quality Meteorologist
British Columbia Ministry of Environment & Climate Change Strategy
400 – 640 Borland Street
Williams Lake, B.C. V2G 4T1

RE: Rio Tinto CALPUFF and CALMET Model Plan for Environmental Effects Monitoring Program

Dear Mr. Weinstein:

Rio Tinto operates an aluminum smelter located in Kitimat, BC (the Kitimat Smelter). Rio Tinto is planning to perform meteorological data processing using CALMET and CALPUFF in order to support the Environmental Effects Monitoring (EEM) program. New meteorological data from 2016 to 2018 will be processed.

Attachment 1 to this letter includes a complete CALPUFF and CALMET modelling plan detailing the strategies that will be used to perform meteorological data processing and the CALPUFF dispersion modelling. In summary, Rio Tinto is proposing to perform the 2016 - 2018 CALPUFF modelling analysis consistent with the methodologies used for the Sulphur Dioxide Technical Assessment Report (STAR) dated April 2013,[1,2] with the exception of some key changes:

- Meteorological years 2016-2018 will be used.
- The local-scale analysis will use meteorological data processed using surface station only(also known as Obs-Only mode).
  That is, the local scale analysis will not use Weather Research and Forecasting (WRF) or 5th generation mesoscale model MM5) for gridded input.
  - However, a pseudo upper air station from WRF output will be used to represent the upper air data because no upper air data are available within the Kitimat valley. The location will be from the WRF grid cell closest to the GTC stacks.
- The regional-scale analysis will use meteorological data processed using Weather Research and Forecasting (WRF) data developed by Trinity. The domain for this meteorological data will be nearly identical to the domain used in the STAR protocol, but extended south 24 km to include better coverage of the final STAR receptor grid, which was also extended south. Trinity is proposing to run the CALMET model in no-obs mode to avoid conflicting wind fields encountered in the STAR approach.

[1] **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 3: Appendices for Final Report. Prepared for Rio Tinto Alcan, Kitimat, B.C..

[2] The STAR Modelling Protocol included as Attachment 2 for reference.

- The UTM coordinate system, WGS 84 ellipsoid will be used as opposed to the UTM, NAD 27 used in the STAR approach, which will allow Qualified Professionals, the Ministry, and the public to better understand model inputs and outputs using readily available tools such as Google Earth.
- Precipitation data will be obtained from the Haul Road and Lakelse Lake wet deposition stations.

CALMET output will be evaluated and the evaluation results provided to the British Columbia Ministry of Environment & Climate Change Strategy prior to running full CALPUFF models (test models may be run to evaluate the functionality of the CALMET dataset).

The attached plan also addresses comments received from British Columbia Ministry of Environment & Climate Change Strategy on April 24, 2019.

If you have any questions or comments about the information presented in this letter, please do not hesitate to call me at (253) 867-5600 ext. 1008.

Sincerely,

Trinity Consultants



ANNA HENOLSON
Managing Consultant
Attachments

cc:

Ms. Karen Moores (British Columbia Ministry of Environment & Climate Change Strategy)
Mr. Arvind Saraswat (British Columbia Ministry of Environment & Climate Change Strategy)
Ms. Donna Haga (British Columbia Ministry of Environment & Climate Change Strategy)
Mr. Shawn Zettler (Rio Tinto)
Mr. Jonathan Bernier (Rio Tinto)

ATTACHMENT 1

CALMET and CALPUFF Dispersion Modelling Plan

Note that the answers are filled out in blue font.

DETAILED CALMET and CALPUFF Dispersion Modelling Plan

An electronic version of this plan is available from:
www.bcairquality.ca/reports/model-plans-instructions.html

GENERAL

Date: May 13, 2019

Facility Name, Company, Location (Lat, Long):

> Kitimat Smelter, Rio Tinto, 1 Smeltersite Road, Kitimat, BC, Canada V8C 2H2 (54°00'40.8"N, 128°41'51.8"W)

Air Quality Consultant and Contact Name:

> Anna Henolson and Hui Cheng, Trinity Consultants

Ministry Contact Name: Benjamin Weinstein, Donna Haga, Arvind Saraswat, and Karen Moores

Level of Assessment (1, 2 or 3) and also provide rational for the proposed level of assessment:

> Level 3: CALPUFF. The facility is located in a valley with complex wind patterns. A modelling analysis using CALPUFF was performed for the Kitimat Modernization Project in 2013. Trinity proposes to use the same methods for this modelling analysis.

Does this plan follow a modelling approach similar to that taken in a previous air quality assessment already reviewed and accepted by the Ministry? If so, provide the project name and Ministry contact:

> Kitimat Modernization Project SO2 Technical Assessment Report (STAR) dated April 2013. Ed Hoffman, Frazer McKenzie, and Benjamin Weinstein. The modeling protocol for STAR (STAR Protocol) is attached for reference and is cited throughout this modelling plan.

PROJECT DESCRIPTION AND GEOGRAPHIC SETTING

Provide an overview of the project description, including process description and the purpose of the dispersion modelling study.

> Rio Tinto plans to conduct SO_2 dispersion modelling in order to support the Environmental Effects Monitoring (EEM) program. Model results will be used to inform the SO_2 monitoring network optimization process, comprehensive EEM review, and predictions for future operating scenarios. The model will use actual emissions data from 2016 to 2018 and will include the permitted operation scenario at 42 tonne SO_2 per day. Results will be compared to Canadian Ambient Air Quality Standards (CAAQS) and Rio Tinto's Key Performance Indicator (KPI).

Provide a description of the following:

- Terrain characteristics within domain: flat terrain or complex terrain (i.e., will complex flow need to be considered?)
    - Complex terrain with complex flow. Proposing to use CALPUFF to account for complex flow which is consistent with previous modelling approach.
- Dominant land cover: urban, rural, industrial, agricultural, forested, rock, water, grassland
    - Dominant land cover: Forest.

DISPERSION MODEL

Selected Dispersion Model:

- List model(s) and version to be used (see Section 2).
    - Latest versions:
      CALPUFF v7.2.1 Level 150618, CALMET v6.5.0, Level 150223; CALPOST v7.1.0, Level 141010; CALSUM v7.0.0, Level 150330; POSTUTIL v7.0.0, Level 150207.
      Also use all associated pre-processors: http://www.src.com/calpuff/download/mod7_codes.htm

- Specify any non-guideline models or versions (i.e., beta-test versions) planned for use (Section 2.3.1). Provide rationale.
    - N/A

- If modifications to any of the models are planned, provide a description and the rationale (Section 2.3.2).
    - N/A

Default Switch Settings

- For AERMOD identify any switch settings that will be different than the recommended defaults (Section 7.7). Provide rationale. N/A

- For CALMET/CALPUFF identify any key switch settings in CALMET and CALPUFF that will be different from the "black (do not touch)" defaults as per Tables 6.2 and 7.1. Provide rationale.
    - All switch settings will be consistent with the "black (do not touch)" defaults as per Tables 6.2 and 7.1.
    - For local-scale meteorological processing, switch settings will be consistent with STAR, except that CALMET data for this modelling study will not use mesoscale meteorological data.
    - Similar to STAR approach, regional-scale meteorological processing will use Weather Research and Forecasting (WRF) data developed by Trinity Consultants, but in no-obs mode only to avoid conflicting wind fields.
    - For local-scale meteorological processing, switch settings will be consistent with STAR (Table 3-3, page 3-9), except that CALMET data for the local domain in this modelling study will not use mesoscale meteorological data.

- Similar to STAR approach, regional-scale meteorological processing will use Weather Research and Forecasting (WRF) data developed by Trinity Consultants, but in no-obs mode only to avoid conflicting wind fields.
- Additionally, as recommended by the Ministry, Trinity re-evaluated the TERRAD value. Based on the peak-to-peak distance at the mouth of the Kitimat Valley of approximately 20 km, Trinity proposes a TERRAD value of 10 km.
- As also noted by the Ministry, the LVARY setting is set to F.

- If the CALMET model is used, provide:
  - a CALMET domain map that also shows the locations of surface meteorological stations and upper air stations
  - The domain maps are attached (Figure A-1 and Figure A-2 at the end of this plan) showing the locations of the surface meteorological stations.
    - Local-scale meteorological processing will use a similar domain approach as STAR protocol.
      - Receptor SW corner is the same as STAR: 510 km easting and 5974 km Northing, extending same distance 20 km east and 21 km north.
      - Recirculation zone of 18 to 20 cells in STAR yielded 9 – 10 km between receptor and boundary of CALMET/CALPUFF.
        Proposed recirculation zone of 20 cells for current effort will yield 15 km between receptor boundary and boundary of CALMET/CALPUFF domain.
      - SW corner of local CALMET: 505 km easting, 5969 km northing
    - Regional-scale processing will use a nearly identical domain as STAR protocol, but extended to the south 24 km to include better coverage of the receptor grid.
      - Recirculation zone is seven (7) 4 km cells yielding 28 km between receptor boundary and boundary of CALMET/CALPUFF domain.
      - SW corner of regional 4 km WRF: 468 km easting, 5914 km northing
        SW corner of regional 4 km CALMET: 480 km easting, 5926 km northing
      - SW corner of regional 1.33 km WRF: 508 km easting, 5954 km northing
        SW corner of regional 1.33 km CALMET: 512 km easting, 5958 km northing
  - anticipated grid resolution: local scale:_250_ (m), regional:_1.333 km and 4km
  - number of grids in X and Y direction: Local Scale (250 m: NX = __120____ ,NY = __124_____)
    Regional Scale: (4 km: NX = __22____ ,NY = __38_ ; 1.333 km: NX = 18 , NW = 66)
  - vertical levels (m): __0, 20, 40, 60, 100, 160, 200, 300, 500, 1000, 1500, 2000, 3000, 4000.

- AERMOD and Receptors

If the AERMET/AERMOD model is used, provide the following:

- proposed receptor grid spacing (see Section 7.2):an AERMET/AERMOD domain map that shows the locations of surface meteorological stations, upper air stations and receptor grid
- anticipated sensitive receptors (see Section 7.4) and also indicate them on the domain map (if applicable) receptor (flagpole) height (m) (see Section 7.5):

CALPUFF and Receptors

If the CALPUFF model is used, provide the following:

- proposed receptor grid spacing (see Section 7.2):
  Local scale model:
  - 100 meter spacing in residential areas
  - 100 meter spacing in areas of interest (Service Centre commercial area and LNG Canada workforce accommodation centre)
  - 100 meter spacing or smaller along property boundary
  - 500 m spacing throughout local receptor domain
    (Receptor SW corner is the same as STAR: 510 km easting and 5974 km Northing, extending same distance 20 km east and 21 km north.)

  Regional scale model:
  - 500 m spacing throughout Kitimat Valley extending from Rio Tinto property boundary Receptors will be placed consistent with STAR protocol.
  - 100 meter spacing or smaller along property boundary
- a map of the CALPUFF domain and receptor grid
  - CALPUFF domain maps are provided in Figures A-1 and A-2. Receptor maps are provided in Figures A-3 through A-6.

- attach anticipated sensitive receptors (see Section 7.4)) and also indicate them on the CALPUFF domain map (if applicable)
  - Sensitive receptors for points of interest will be placed similar to approach in STAR protocol. Figures A-5 and A-6 provide a map of the individual discrete sensitive receptors.
  - Areas of interest also include the LNG Canada and Service Centre, in which 100 m spaced receptors will be placed (shown in Figure A-4).

- receptor (flagpole) height (m) (see Section 7.5):
  - Ground level, consistent with STAR model.

PLANNED MODEL OUTPUT: AIR QUALITY ASSESSMENT NEEDS

Output Requirements for

What model output is required for decision makers and stakeholders? (i.e. what is the purpose of the assessment?). Circle as appropriate.

- Air Quality: **concentrations**, **depositions**, visibility, fogging, icing, other (specify)

Tables and Figures for Level 1 Assessment:

- maximum concentration of contaminants predicted including location and corresponding meteorological conditions
- printout of AERSCREEN model output

Tables and Figures for Level 2 and 3 Assessments (see detailed list in Section 8.3.2):

- spatial distribution maps of air quality parameters (maximums, exceedance frequencies, annual averages)

  SO_2 concentration maps will show the entire domain, both local scale and regional scale

  CAAQS:
  - SO_2 1-hour: 99th percentile of daily peak, 3-year average
    - Exceedance maps of daily 1-hour max over 70 ppb (183 ug/m^3), if exceedances occur
  - SO_2 annual average, 3-year average
  - Maps will delineate both the 2020 and 2025 CAAQS values, if these isopleths are present in the figure.

  CAAQS-Related:
  - SO_2 1-hour: 99th percentile of daily peak, each year
  - SO_2 annual average, each year

  KPI:
  - SO_2 1-hour 97.5th percentile of daily 1-hour max, averaged over 2016-2018
  - SO_2 1-hour 98th percentile of daily 1-hour max, averaged over 2017-2019
    with one allowable excursion above 75 ppb to a maximum of 85 ppb over a three-year period prior to 2020
    - Exceedance maps of daily 1-hour max over 75 ppb (196 ug/m^3), if exceedances occur

  Sulphur deposition:
  - 3-year average sulphur deposition
  - Entire domain, regional scale only

- tables of maximum short and long time average air quality parameters (locations and associated meteorological conditions)
  Will provide tables of the maximum concentrations in form of standards/indicators listed in previous bullet (for maps).
  - Results will be provided for each discrete receptor (point of interest), and the maximum within the following groups of gridded receptors: offsite, residential, Service Centre commercial area, and LNGC workforce accommodation centre.

- tables of air quality parameters at select receptors of interest (maximums, frequency distributions)
  Air quality parameters for sensitive receptors will be consistent with all other receptors

- tables of air quality parameters under certain emission situations (upsets, start-up)
  None. All scenarios use either actual or maximum emissions.
- output spatial scale: near-field (<10 km)/ local (<50 km), regional (>50 km)

    - Near-field / Local-scale CALMET/CALPUFF is 40 km x 40 km with receptors within the domain placed out to approximately 10 – 12 km from the smelter (to allow for some recirculation).
    - Regional scale output (for 3-year average deposition results) will be separate from local-scale output.

- special output required for vegetation, health risk or visibility assessments
  Tables needed for vegetation assessment will also be included (e.g., maximum offsite growing season average)
  Data needed for health assessment will be provided if needed (e.g., all hourly data in residential areas)
- other (specify):
  Deposition output at coarse grid receptors, lake sample locations, and soil sample locations will be provided in Excel or CSV files to water and soil impact assessments.

EMISSION SOURCES AND CHARACTERISTICS

Provide a map showing the source locations, buildings, and facility fence line.

Sources modeled, buildings modeled and facility boundary are similar to STAR protocol. However, the sources and buildings are reviewed and updated to reflect as-built locations and dimensions. Additionally, the fenceline has changed slightly since the STAR report, most notably the future location of LNG Canada is now outside the Rio Tinto fenceline. The updated fenceline used in this model analysis is shown in Figure A-4.

Model Emission Scenarios

If applicable, describe the different model emission scenarios required for the assessment if multiple options are under consideration. For example, different source characteristics (stack dimensions, emission rates) or source arrangements (locations, types, buildings) may need separate modelling runs to examine the air quality implications of different scenarios.

- Facility emissions using actual emission data from 2016, 2017, and 2018
- Future emissions using permitted emission level of 42 tonne SO_2 per day
- Future emissions using emission level of 35 tpd

Contaminants Emitted for Each Emission Scenario

Provide the following details of the sources to be modelled:

- Sulphur dioxide (SO_2) is the only pollutant that will be modelled. Results will be focused on SO_2 concentrations and sulphur deposition.
- Other pollutants are emitted from these stacks. However, the scope of this model plan (and official assessment associated with this model plan) is limited to SO_2.

Specify Source, Type, Contaminants (extend Table as necessary)

Source	Type: Point (P), Area (A), Line (L), Volume(V), etc. Indicate type	Contaminants (SO_2, NO_2, $PM_{2.5}$*. . .)	Basis of Emissions (Section 3.3)
Gas Treatment Center East (GTC_E)	P	SO_2	_x__approved/proposed emission limits _x_ other (specify) mass balance for SO_2
Gas Treatment Center East (GTC_W)	P	SO_2	_x__approved/proposed emission limits _x_ other (specify) mass balance for SO_2
Anode Bake Furnace / Fume Treatment Center (FTC)	P	SO_2	_x__approved/proposed emission limits _x_ other (specify) mass balance for SO_2
Calciner Pyroscrubber (PYRO)	P	SO_2	_x__approved/proposed emission limits _x_ other (specify) mass balance for SO_2
Calciner Cooler (COOLER)	P	SO_2	_x__approved/proposed emission limits _x_ other (specify) mass balance for SO_2
Potline roof vents (POT)	L	SO_2	_x__approved/proposed emission limits _x_other (specify) mass balance for SO_2

***** for PM emissions indicate whether it is filterable, or filterable + condensable, or if unknown (see Section 3.6)

** Only sources emitting SO_2 are included in this table because the study is focused on SO_2. Other pollutants such as particulate matter, fluoride, and NOx are emitted from these stacks. However, the scope of this model plan (and official assessment associated with this model plan) is limited to SO_2.

See attached emission inventory showing the SO_2 emission rates and stack parameters for each emission scenario and year. Note that stack velocity[1] and temperature parameters for actual 2016 - 2018 operation are based on the stack tests from the corresponding years. If more than one test took place in a given year, the average of the test during that year are used.

Stack parameters for future operation are based on 2018 stack tests because 2018 best represents future conditions (i.e., full production). Future emission rates are based on the future sulphur emission distribution using

[1] Stack velocity as reported in the stack test is used directly rather than flow rate because stack velocity is the directly measured parameter and because the diameter of each stack at the sample port is consistent with the diameter at the exit.

company projections of production and sulphur content in each stream (e.g., coke, green anodes, baked anodes, etc.).

Actual emissions from 2016 to 2018 levels are based on material balance calculations, representing monthly average emission rates. The material balance calculations are consistent with source test data as summarized in the following tables. The SO_2 emission rate in tons per day from each test is listed first based on the rate directly reported in the source test report, followed by a corrected SO_2 emission rate based on using more accurately measured inner stack diameters. Note the corrected SO_2 rate from the calciner is lower for 2017 and higher for 2018 because different inner diameters were used in the source test report calculations.

The corrected source test emission rates are 8% lower than monthly average material balance rates in 2017, and 4% higher than monthly average material balance rates in 2018. These differences are within the expected range due to day-to-day variation measured during a test versus the monthly average represented by material balance calculations.

SO_2 Emission Rate Comparison (tpd) - 2017				
	15-Dec-17	**24-Oct-17**	**21-Dec-17**	*****
	GTC	**FTC**	**Calc**	**Plant-Wide**
Test – Reported	21.9	1.0	5.5	*28.5*
Test - Corrected for Dia	19.3	1.0	5.4	*25.7*
Material Balance				
Monthly Average - Month of Test	21.88	1.51	4.50	27.9
Monthly Average - December	21.88	1.76	4.50	28.1
Difference				
% Diff without correction	0%	-32%	22%	2%
% difference with correction	-12%	-33%	20%	-8%
* Plant wide is listed by summing results in each column. However, because the test were not simultaneous, the plant-wide total for stack tests does not accurately represent plant-wide emissions. Material balance totals are listed both for only December and by summing the month associated with the test date for each source.				

SO_2 Emission Rate Comparison (tpd) - 2018				
	22-Oct-18	**5-Oct-18**	**6-Sep-18**	*****
	GTC	**FTC**	**Calc**	**Plant-Wide**
Test – Reported	29.2	2.1	5.7	*37.0*
Test - Corrected for Dia	25.7	2.0	6.3	*34.0*
Material Balance				
Monthly Average - Month of Test	23.18	1.77	7.89	32.8
Monthly Average - October	23.18	1.77	2.55	27.5
Difference				
% Diff without correction	26%	18%	-28%	13%
% difference with correction	11%	15%	-20%	4%
* Plant wide is listed by summing results in each column. However, because the test were not simultaneous, the plant-wide total for stack tests does not accurately represent plant-wide emissions. Material balance totals are listed both for only October and by summing the month associated with the test date for each source.				

Source Emission Rate Variability

Do emissions have sub-hourly variation (e.g., blow-down flares with high emission peaks during the hour)? If so, describe the approach to assess air quality implications of those sub-hourly high emission peaks.

No.

Describe the approach to assess air quality implications under the 25, 50, 75% emission scenario. See Section 3.4.2.

N/A. Reduced capacity scenarios are not expected to occur at the smelter, because all key processes operate at steady state, near maximum capacity.

If there are batch processes, provide a temporal emission profile (emission rate vs time) for each batch process.

N/A

Describe anticipated abnormal emission scenarios (e.g., start-up and shut-down) and their anticipated frequency of occurrence. See Section 3.4.3.

Start-up and shutdown events are expected to be extremely infrequent.

BASELINE CONCENTRATION

- Indicate method used to determine baseline concentrations for each pollutant (Section 8.1):

  ___x__monitoring data (Section 8.1.1 and 8.1.2)

  _____establish monitoring program (Section 8.1.3)

  _____modelled sources (Section 8.1.5)

  _____other method (describe)

- If existing monitoring data to be used, complete the following Table:

Representative Air Quality Measurements

Station Name (Lat./Long./ or indicate on map)	Period of Record (start/end date)	Contaminants Measured
Terrace Skeena Middle School (54.52167°, -128.6075 °)	**2016-2018 (SO2)**	**SO_2**

SO_2 concentrations measured at the Terrace Skeena Middle School station will be added to model results to predict total ambient SO_2 concentrations. The same statistical form of monitoring data will be added to each set of results

- 1-hour, 99th percentile daily peak SO_2 for 2016, 2017 and 2018:
  4.6, 5.9 and 6.1 ppb, respectively added to each corresponding year for actual emission scenario
  - 3-year average results and future scenarios will use average of three years: 5.53 ppb.
- Annual average SO_2 for 2016, 2017 and 2018:
  0.5, 0.5, and 0.4 ppb, respectively added to each corresponding year for actual emission scenario
  - 3-year average results and future scenarios will use average of three years: 0.47 ppb

Note that monitoring data from other stations (Haul Road, Riverlodge, Whitesail, Kitamaat Village, Lakelse Lake, etc.) will also be used when reviewing model results. However, for the purpose of adding concentrations to model results of the Kitimat Smelter SO_2 emissions, the monitor station should be minimally influenced by the smelter emissions.

- If baseline concentrations are anticipated to change in the future due to planned significant reductions or increases in emissions, provide a description of how these will be accounted for (e.g., construction of a nearby new facility or the planned decommissioning of a currently operating facility) and the uncertainties involved in estimating future emissions.
  No changes are expected that would result in substantial increase or decrease in ambient SO_2 concentrations.

BUILDING DOWNWASH

- Potential for building downwash. Please provide rational if building downwash is not modelled.
  NA. Building downwash is modelled.

- If building downwash included, provide a site map to indicate buildings to be processed by BPIP-PRIME, and also complete the following Table: Buildings processed by BPIP-PRIME will include those processed according to STAR protocol. As-built locations and dimensions will be verified and updated as needed. A map is provided in Figure A-7.

  For building heights, see Table A-1 included at the end of this document.

GEOPHYSICAL DATA INPUT

<u>Topography and Land Use Data</u>

- Terrain data (specify source of data) and an elevation map for the model domain:
  - Elevation data used with TERREL for CALMET grid elevations obtained from SRTM 3. See Figure A-8.
  - Elevation data for buildings, sources and receptors will be generated using the latest version of AERMAP v18081. Digital Elevation Model (DEM) data used to run AERMAP obtained from GeoBase Canadian Digital Elevation Data, which were used for STAR modelling (STAR Protocol, Section 3.1.1 Terrain Data, pg. 3-1).

- Land use data (specify source of data) and a land use map for the model domain:
  - The land use will be reviewed against recent aerial imagery for changes that have occurred that would result in a change in land use (e.g., expansion of urban areas). As recommended by the Ministry (October 29, 2018 memorandum P2-00001 from Benjamin Weinstein to Shawn Zettler),

LCC vector data (available online at: http://ftp.maps.canada.ca/pub/nrcan rncan/vector/geobase lcc csc/shp en/) are used. See Figures A-9 and A-10 for the land use data maps attached.

- Consistent with STAR modelling (STAR Protocol, Section 3.1.2 Land Use Data, pg. 3-3), minor revisions to the land use characteristics near the land-water interface are made in order for the land use categories along the coastline to be consistent with the coastline data obtained and QA'd for use with the sub-grid TIBL module.

Surface Characteristics

For AERSCREEN, provide seasonal values of surface characteristics (surface roughness, albedo and Bowen ratio) for input to MAKEMET.

For Level 2 and 3 Assessments, Indicate if recommended seasonally varied surface characteristics (surface roughness, albedo, Bowen ratio, etc.) (see Section 4.3 and 4.4) are used for the dispersion modelling study. If not, provide the proposed surface characteristics and the rationales.
Seasonal surface characteristics from BC Dispersion Modelling Guidelines (ENV, 2015) will be used (Tables 4.8 through 4.12). The land cover translation table follows Table 4.14 of the Guideline with the following exceptions:

- Cloud (11) and Shadow (12) will be treated as missing.
- The Douglas Channel will be categorized as large water body (CALMET code 55) rather than small water body) CALMET code 50.

Slight adjustments to the season assignments will be made per discussion between Trinity and the Ministry. Season assignment will follow the Ministry's recommendation in Table 1 of the October 29, 2018 memorandum P2-00001 from Benjamin Weinstein to Shawn Zettler:

Table 1: Seasonal assignments for the CALMET geo.dat file.

Month	January	February	March 1-15	March 16-31	April	May	June
Season	4	4	4	5	5	5	1
Month	**July**	**August 1 - 15**	**August 16 - 31**	**September**	**October**	**November**	**December**
Season	1	1	2	2	3	3	4

METEOROLOGICAL DATA INPUT (FOR LEVEL 2 AND 3 ASSESSMENTS ONLY)

Surface Meteorological Data

If surface observation data are used, provide a map with the location of each surface meteorological station identified and also provide the following:

Surface observations are used for local scale CALMET only. Attached local scale domain map shows station locations.

Surface Met Data and Location (lat/long or indicate on map)[4]	Data Source MOE, MV, MSC, Site Specific, other (specify) [1]	Period of Record (start/end data) [2]	% of Wind Speeds = 0.0 [3,5]	Anemometer Height (m)	Parameters
Terrace (Airport)	NCDC	2016-2018	2.41%, 5.19%	10	TEMP, WDIR, WSPD, Ceiling, Pressure, RH, Cloud Cover
Kitamaat Village (Kitimat Haisla Village)	MOE	2016-2018	0%, 0%	10	TEMP, WDIR, WSPD
Kitimat Haul Rd.	MOE, NADP (Precip)	2016-2018	0.11%, 0.05%	10	TEMP, WDIR, WSPD, PRECIP
Kitimat Whitesail	MOE	2016-2018	0.00%, 0.05%	10	TEMP, WDIR, WSPD, RH
Kitimat Yacht Club	MOE	2016-2018	0.57%, 0.64%	10	TEMP, WDIR, WSPD
Lakelse Lake	NADP	2016 - 2018	NA	NA	PRECIP

1. If data from a non - Ministry, MV or MSC station are planned to be used, follow guidance in Section 5.2.3
2. For data completeness and data filling, follow guidance in Section 5.5
3. For light and no wind conditions, follow guidance in Section 5.6
4. Riverlodge data are not included because the station does not meet meteorological siting criteria and one more temperature data source does not add value to the CALMET output. Smeltersite data are not included because Smeltersite data were only collected through June 2, 2016.
5. Wind speed statistics for 2016-2017 dataset.

Upper-Air Meteorological Data

If upper air meteorological data are used provide the following:

Station Name	Period of Record (start/end date) [1]	Distance between the Upper Air Station and Project (km)
N/A		

1. For data completeness and data filling, follow guidance in Section 5.5.

A pseudo station from WRF output will be used. The location will be from the grid cell closest to the GTC stacks. See following section for WRF information.

NWP Model Output

If NWP output (different than the province-wide WRF output) used provide the following:

- Mesoscale Meteorological Model (Name\Version\Model Configuration): WRF Version 3.7
- Model Output Provider: Trinity Consultants, Inc.
- Domain (attach a map showing the horizontal extent): Consistent with STAR (STAR Protocol, Section 2.2 Modeling Domain, pg. 2-1). Regional domain extended south 24 km. See attached domain maps.
- Horizontal and Vertical Grid Resolution and Height of Each Vertical Level:
  - CALMET Horizontal: 250 m grid resolution for local scale. 1333 m grid resolution for regional scale.
  - WRF Horizontal: Two-way nesting method. 12 km resolution for the parent domain; 4 km resolution for the nest domain; 1.333 km resolution covering regional receptor grid.
  - WRF Vertical: Uses vertical levels defined in the 1-degree by 1-degree gridded NCEP FNL (Final) Operational Global Analysis data (ds083.2 GRIB2 data).
    - For data before 05/12/2016, it will have 27 levels:
    Ground, 10 mbar, 20, 30, 50, 70, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000. (Unit mbar)
    - For data on 5/12/2016 and later, it will have 32 levels:
    Ground, 1 mbar, 2, 3, 5, 7, 10, 20, 30, 50, 70, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 925, 950, 975, 1000. (Unit mbar)
    (https://rda.ucar.edu/datasets/ds083.2/#metadata/detailed.html?_do=y&view=level)
- Data Period (start/end date): January 1 2016 – January 1, 2019
  Four Dimensional Data Assimilation is applied (Yes or No): Yes

NWP model output use (circle one below for the selected dispersion model):

- AERMET/AERMOD:
  - Extract pseudo surface station and pseudo upper air sounding (as input to AERMET), or
  - Create .SFC and .PFL files (AERMOD-ready files, skip AERMET)

- CALMET:
  - **NWP only**, or
  - Surface station and NWP, or
  - Surface station, upper air sounding, and NWP, or
  - Other (specify): Note that the local scale CALMET is surface station only with pseudo upper air from WRF

TREATMENTS

NO to NO_2 Conversion:

N/A. NO2 is not modelled.

Identify the method to be used (Section 8.2).

_____Ambient Ratio Method

- indicate monitoring station(s)

_____OLM:

- specify O_3 concentration and how it was selected,
- if non default in-stack ratios are used, specify and provide rationale.

_____PVMRM (for AERSCREEN and AERMOD only):

- specify O_3 concentration and how it was selected,
- if non default equilibrium ratios and/or in- stack ratios are used, specify and provide rationale.

Chemical Transformation:

- Specify transformation method and provide details on inputs if Secondary $PM_{2.5}$, Acid Deposition or Visibility effects are to be estimated. Depending on the transformation method, this could include ammonia, ozone, hydrogen peroxide concentrations, nighttime loss and formation rates for nitrates and sulphates.
    - Methods consistent with STAR protocol (MCHEM = MESOPUFF II, same ammonia and ozone background)
      However, other chemistry options (e.g., RIVAD scheme with ISOROPPIA) may be explored to improve estimates of wet deposition (to more closely match the wet deposition monitoring data at Haul Road and Lakelse Lake).

Particle Deposition:

- If non-recommended particle size distributions (see Section 3.6) are used, provide Table of particle emission (including heavy meals if modelled) size/density distribution and indicate the basis for the Table.
    - N/A. Proposed approach follows Section 3.6 recommendations
    - Particle size distribution based on stack test data or emissions data from similar sources.
    - Particulate-phase dry deposition will be modeled for SO_2, NO_3, F_p $PM_{2.5}$, and PM_{10}.
      Gas-phase dry deposition fluxes will be modeled for SO_2, NO_X, HNO_3, and gaseous fluoride.
      Both consistent with STAR protocol.

Stagnation:

- Provide an estimate of the frequency of stagnation based local meteorological data if available. If AERMOD is proposed, provide methodology on how stagnation periods will be treated (see Section 10.2).
    - Consistent with STAR model approach, using CALPUFF.

Shore/Coastal Effects:

- If included, indicate whether sub-grid-scale Thermal Internal Boundary Layer option is selected along with the required input coastline coordinate data (see Section 10.3).

- Consistent with STAR. The SGTIBL option will be enabled, and the coastline location data for the Douglas channel will be specified (see STAR modeling protocol)

Plume Condensation (Fogging) and Icing:

- Indicate if this will be included (Section 10.6).
  - Fogging and icing will not be included.

QUALITY MANAGEMENT PROGRAM

Model Input Data

Indicate the tests that will be undertaken to assure the quality of the inputs. All model inputs (except for source input data) will be based on previously approved approach.
All QA/QC checks listed below will be performed.

For the geophysical input data:

- contour plot of topography
- plots of land use and land cover

For the meteorological data:

- wind rose (annual and/or seasonal)
- frequency distribution of surface wind speeds
- average hourly temperature plot (annual and/or seasonal)

If NWP output is used, describe the tests undertaken to assure the quality of the output (Section 6.1)

- wind rose at selected locations and heights (annual and/or seasonal)
- average hourly temperature plot at selected locations and heights (annual and/or seasonal)
- wind field plots for selected periods that indicate topographic influences such as channeling and thermally generated flows

Model Output Data

For CALMET/CALPUFF applications, provide a list of the tests conducted to confirm the quality of the model output (intermediate pre-processing files and concentration/deposition predictions).
All QA/QC checks listed below will be performed.

With respect to the pre-processed files that are prepared for CALPUFF input, there are several tests listed in Section 9.1.1 and 9.1.2 to check the output from the pre-processing utility programs to confirm that they have been properly processed. These are related to checking:

- terrain, land use
- sources (locations and elevation) and emission characteristics
- meteorological data (locations) and tests in confirm proper processing of the raw meteorological data (units, parameters)
- receptor locations and elevations

For CALMET output there are several tests listed in Section 9.1.3 to test the quality of the generated meteorological fields. These are related to reviewing the following:
All model inputs (except for source input data) will be based on previously approved approach.

All QA/QC checks listed below will be performed.

- wind field maps (surface and different elevations) for select periods where topographic influences (channeling, thermally driven flows) would be evident
- wind roses and selected locations and elevations (annual, seasonal)
- frequency distributions of various meteorological parameters (annual, seasonal) such as PG-stability class, mixing heights
- plots of hourly average parameters such as temperature, mixing height, precipitation at key locations (seasonal and annual)

Note: The Ministry may require all computer files associated with the modelling to be submitted upon request.

The QA/QC procedures for the CALMET processing will be performed as described in the BC Dispersion Modelling Guideline (and summarized above), and will specifically include the following assessments as recommended by the Ministry (October 29, 2018 memorandum P2-00001 from Benjamin Weinstein to Shawn Zettler):

- *Local scale CALMET: qualitative assessment of weather variables (e.g.: windfield, temperature, etc.) across the model domain in space and time (i.e.: spatiotemporal) that demonstrates general intuitive agreement with weather processes.*
- *Regional scale CALMET:*
    - *A qualitative spatiotemporal assessment of weather variables (e.g.: windfield, temperature, etc.) across the model domain that demonstrates general intuitive agreement with weather processes, and*
    - *A quantitative evaluation of weather variables (e.g.: wind speed, wind direction, temperature, etc.) using metrics identified in the [memorandum's] Appendix titled "Relevant Statistical Metrics for Model Evaluation".*

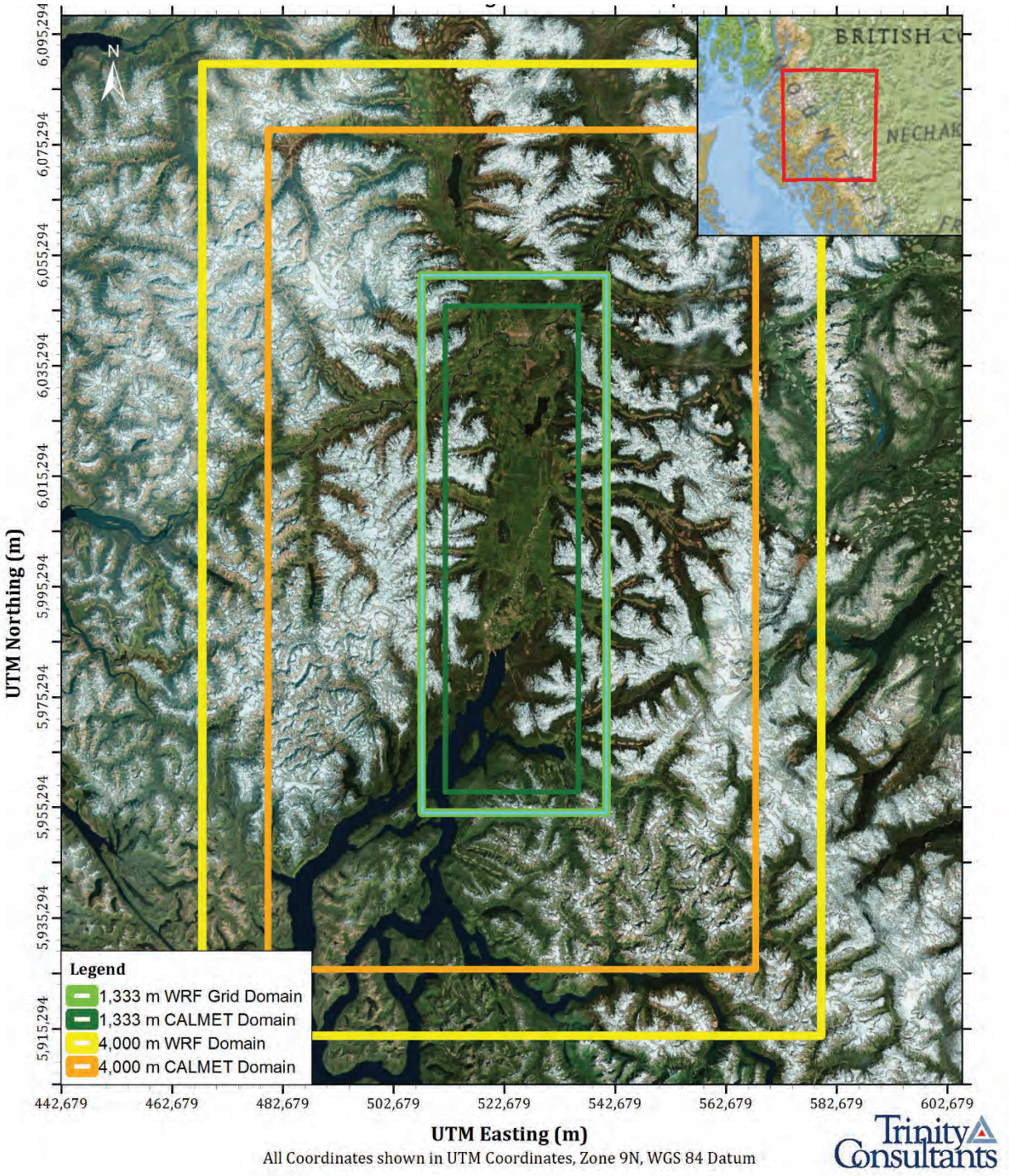
MINISTRY REVIEW OF PLAN AND REVISIONS

A modelling plan can change over the course of developing the air quality assessment so acceptance of the initial submission of the plan is on the basis of the best information provided to date. Changes to the plan (additions, modifications) should be noted and agreed to with the Ministry as necessary. An updated Dispersion Modelling Plan may be necessary.

Ministry Acceptance of Original Plan (Name):_____

Date:_____

Figure A-1. WRF/CALMET Regional Domain Map



Note: Extent of regional CALPUFF receptors align with 1,333 m WRF Domain.

Figure A-2. CALMET Local Scale Domain Map and Surface Meteorological Stations

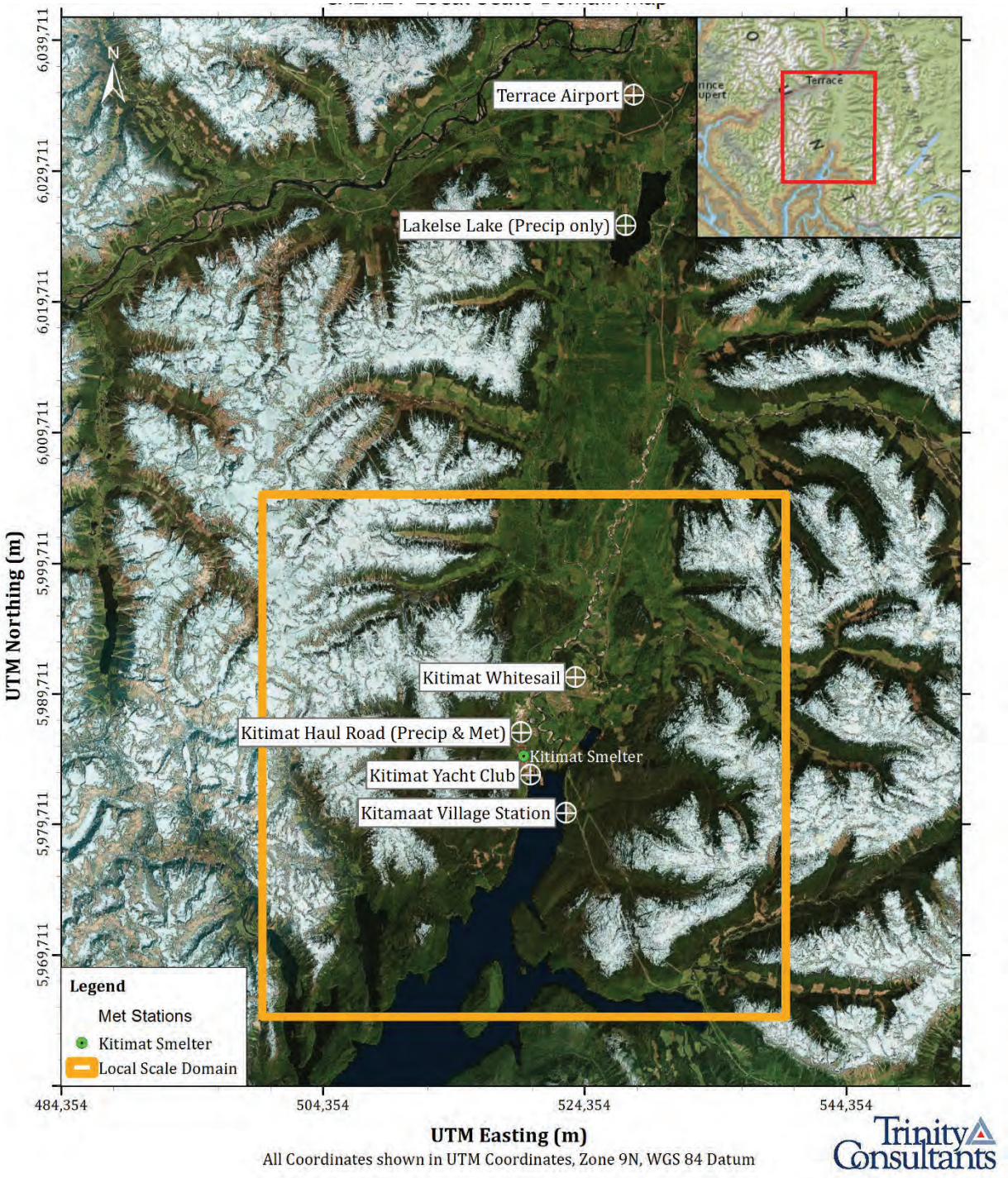


Figure A-3. CALPUFF Gridded Receptors – Regional Scale

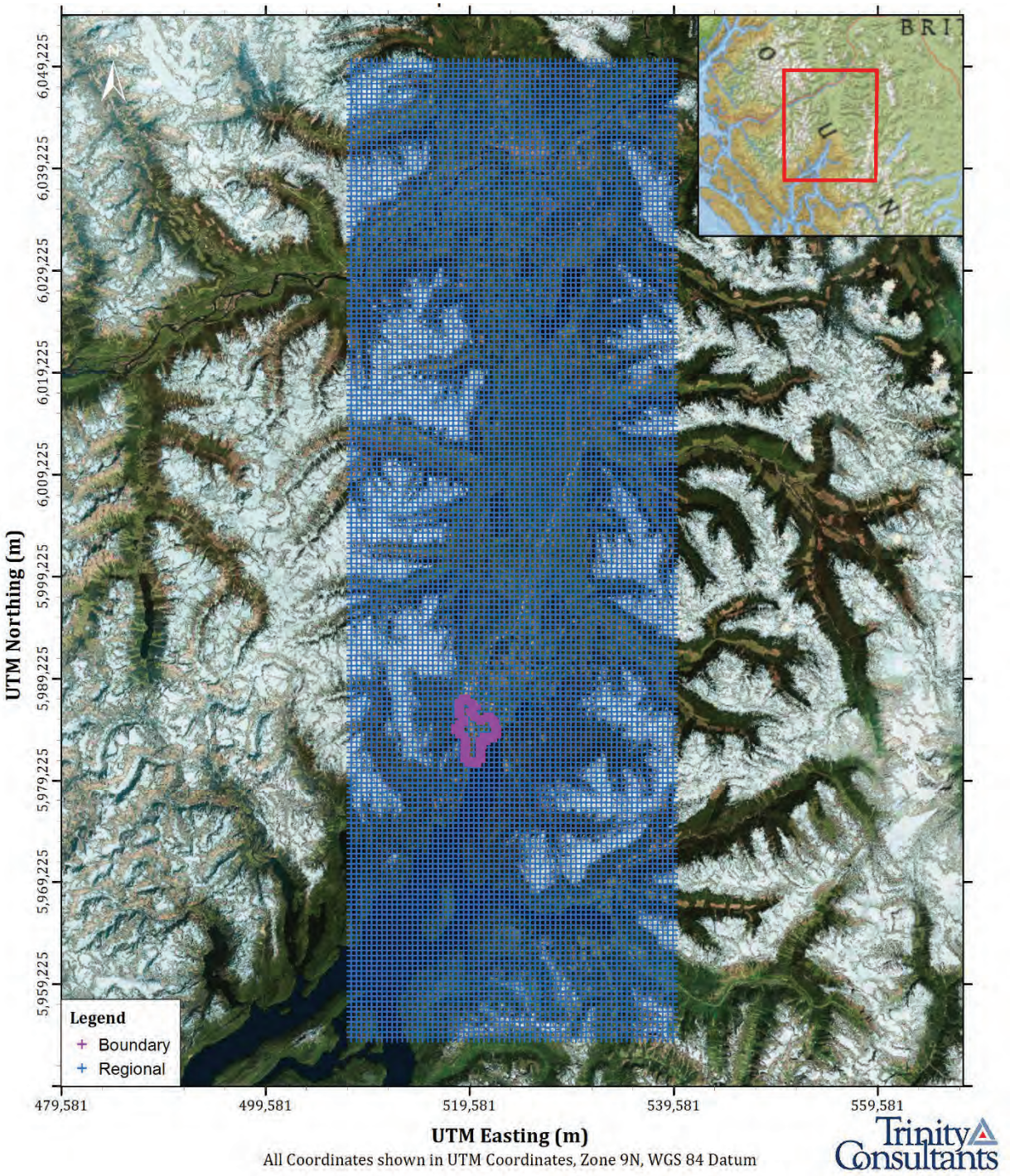
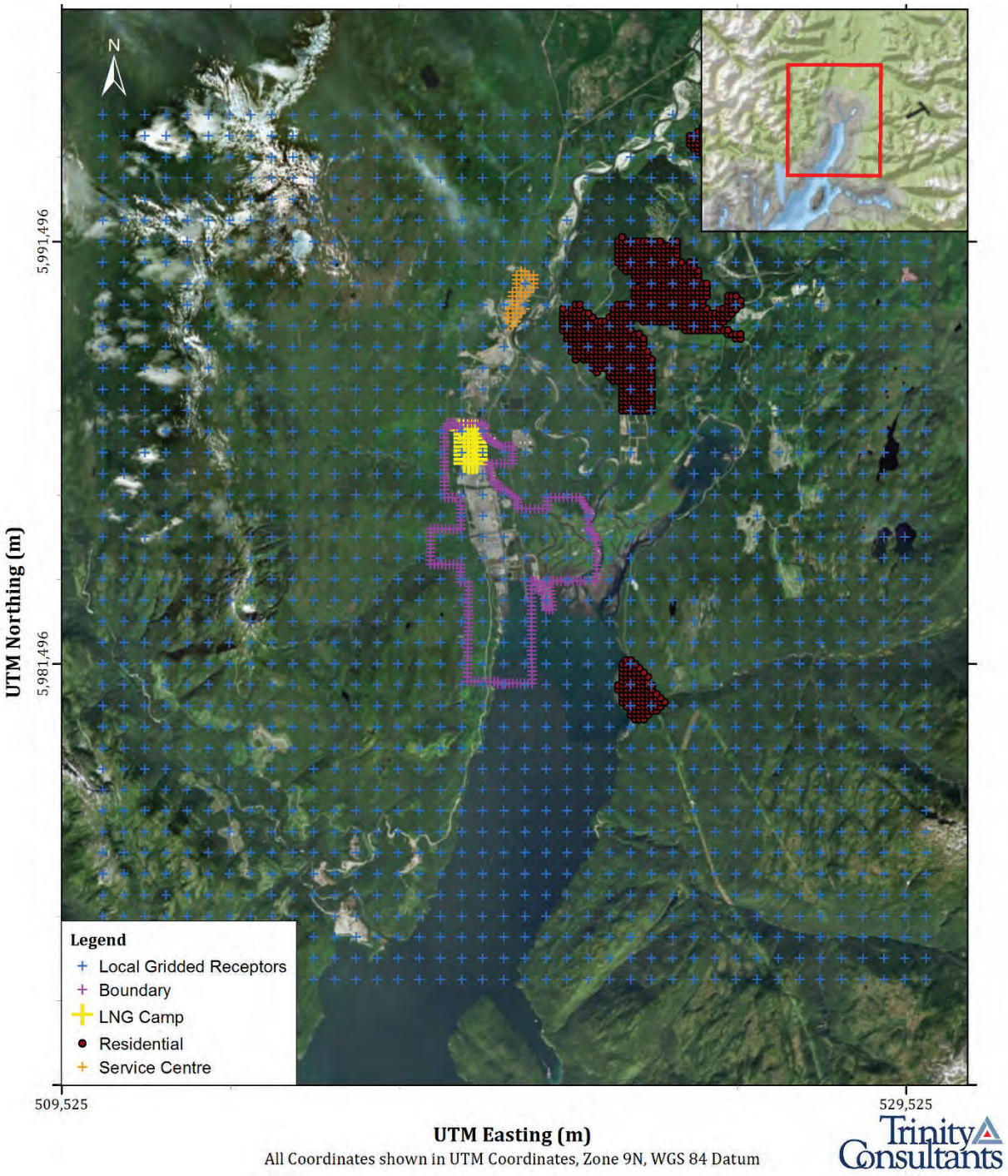


Figure A-4. CALPUFF Residential Gridded Receptors – Local Scale



See property bounary map on last page of this Attachmen 1 (PDF page 32) for basis of property boundary and leased land boundary for the LNG Canada Workforce Accommodation Centre.

Figure A-5. CALPUFF Receptors of Interest – Regional Scale

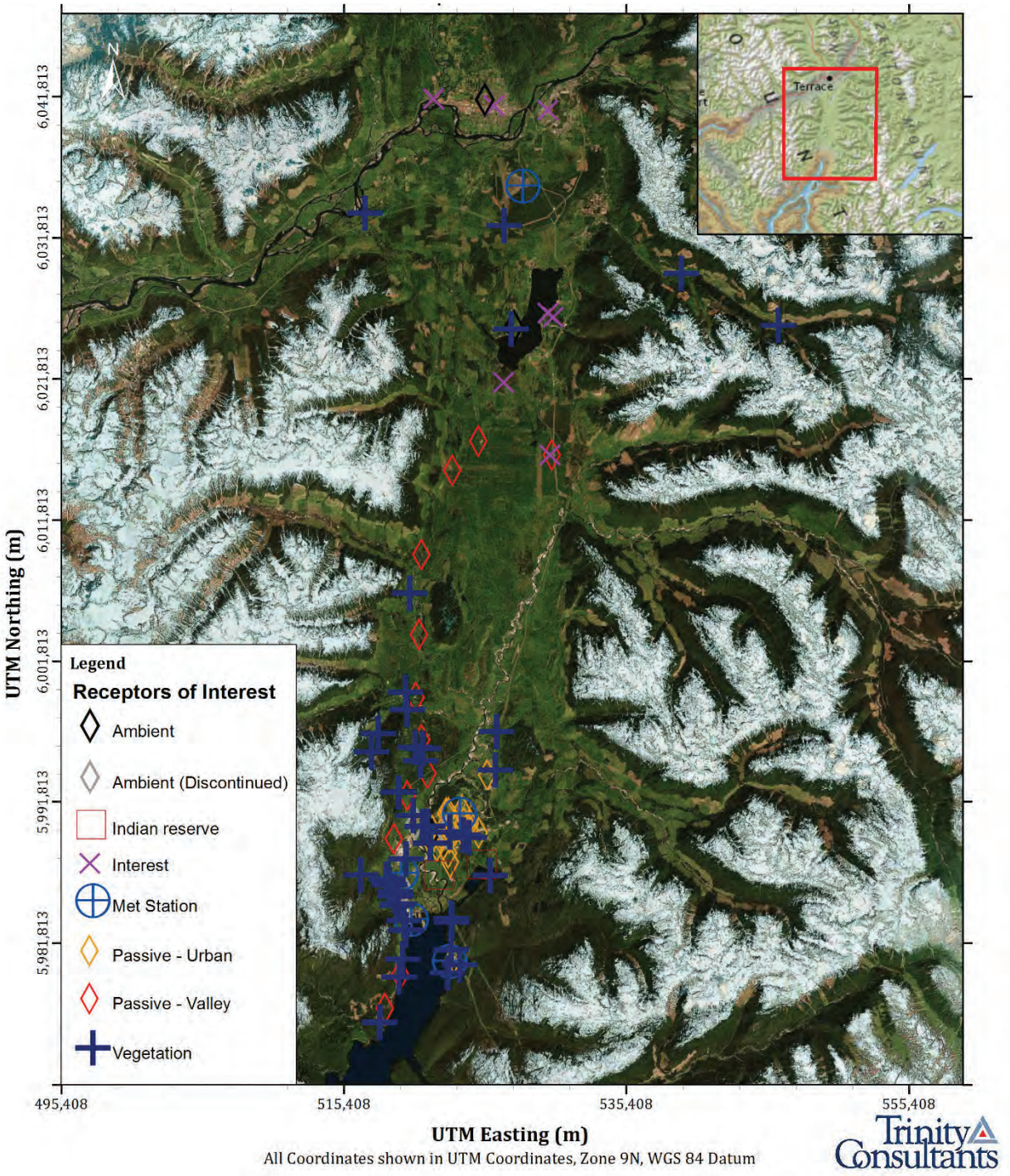


Figure A-6. CALPUFF Receptors of Interest – Local Scale

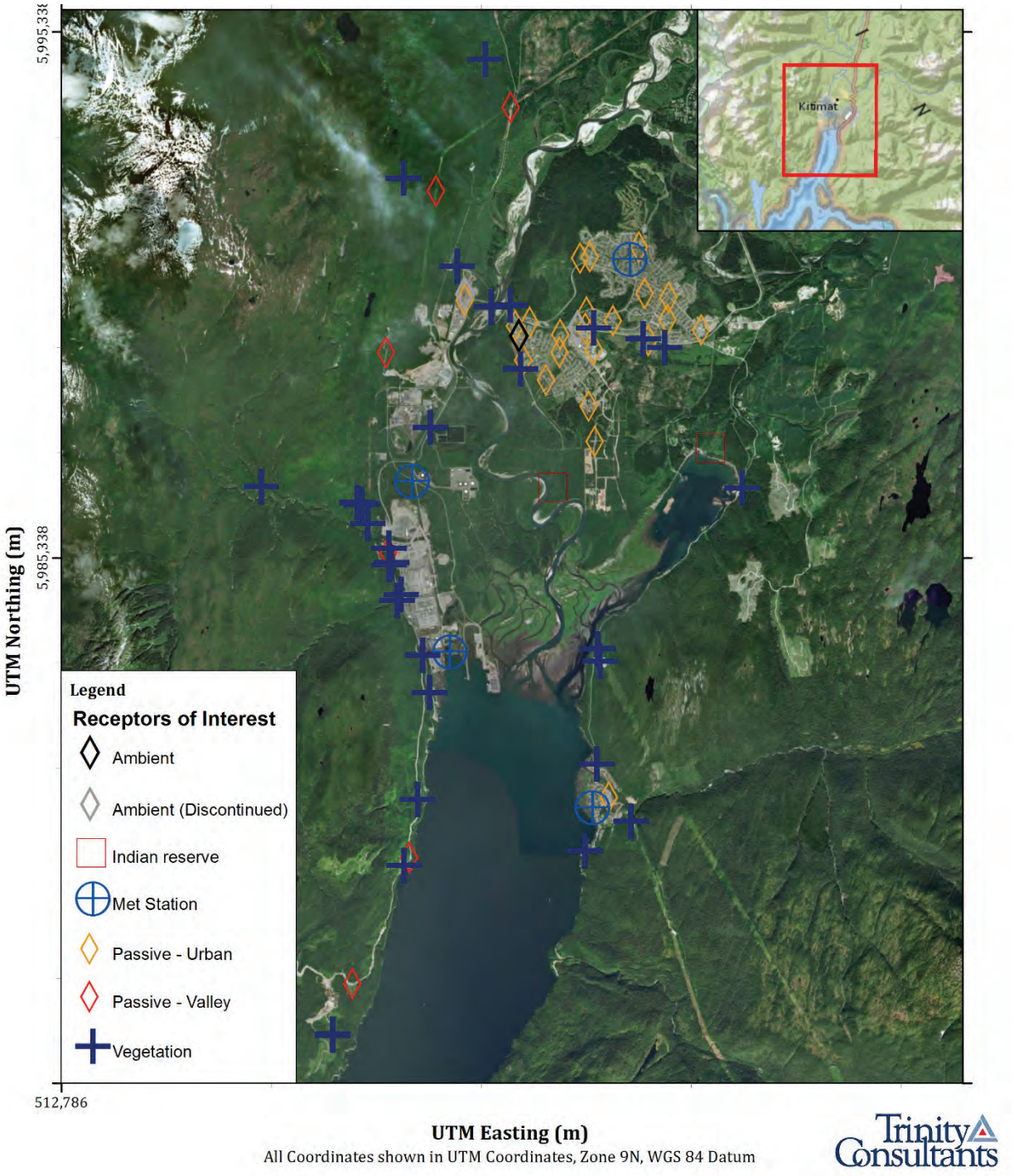


Figure A-7. Site Map Showing Buildings for CALPUFF Downwash



Figure A-8. Terrain – Processed (CALMET-Ready)

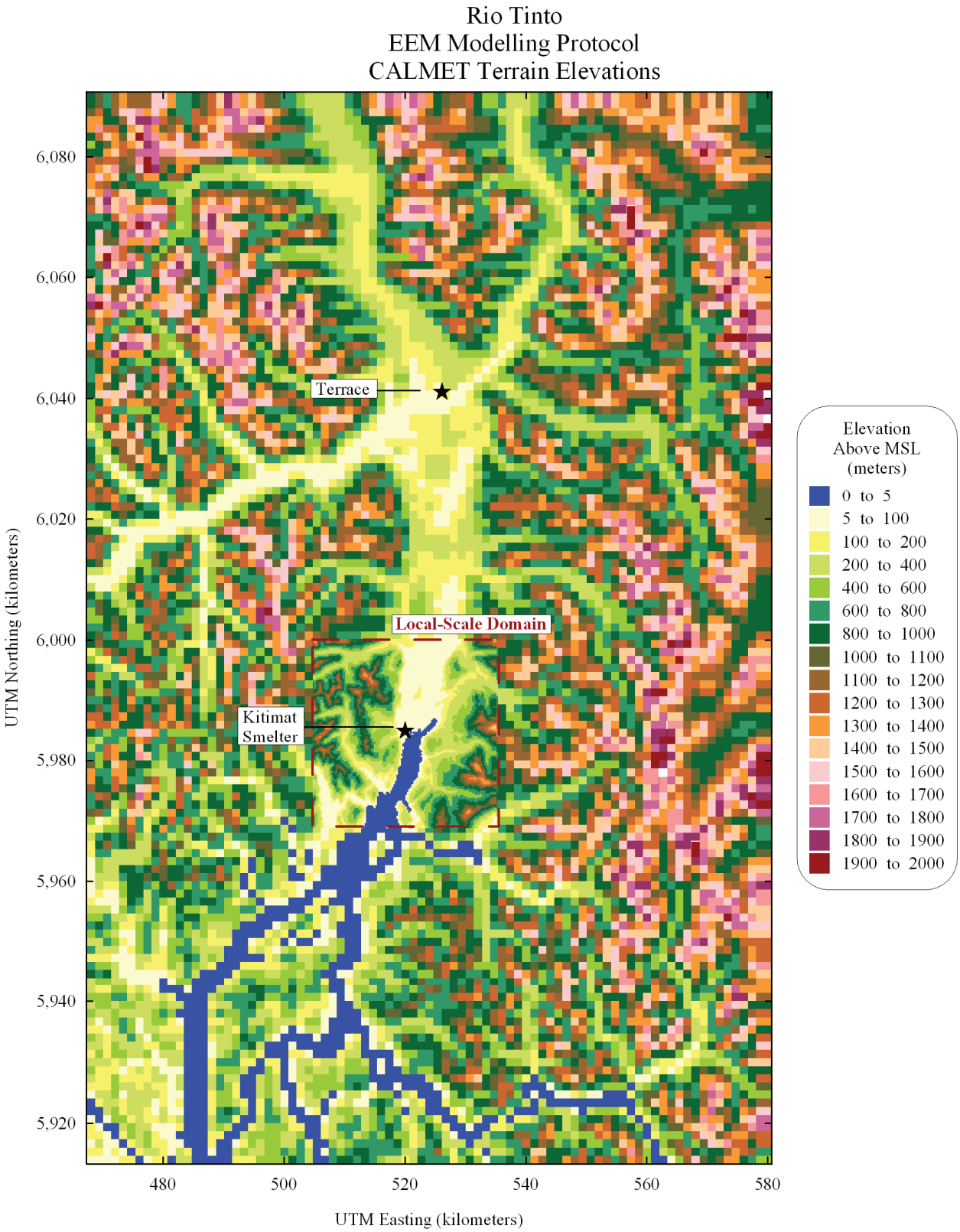


Figure A-9. LCC Land Cover Data

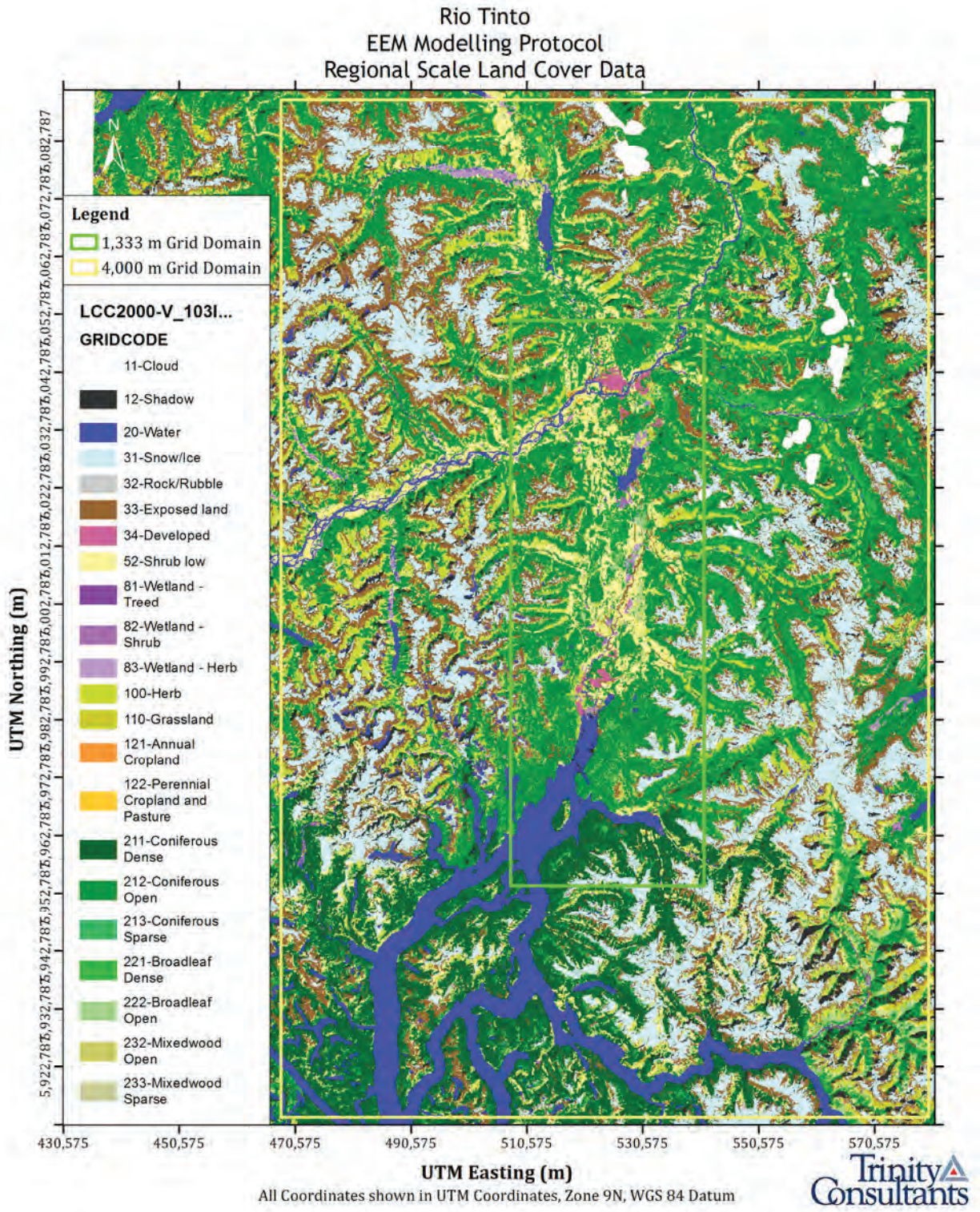


Figure A-10. Land Use – Processed (CALMET-Ready), Local Scale

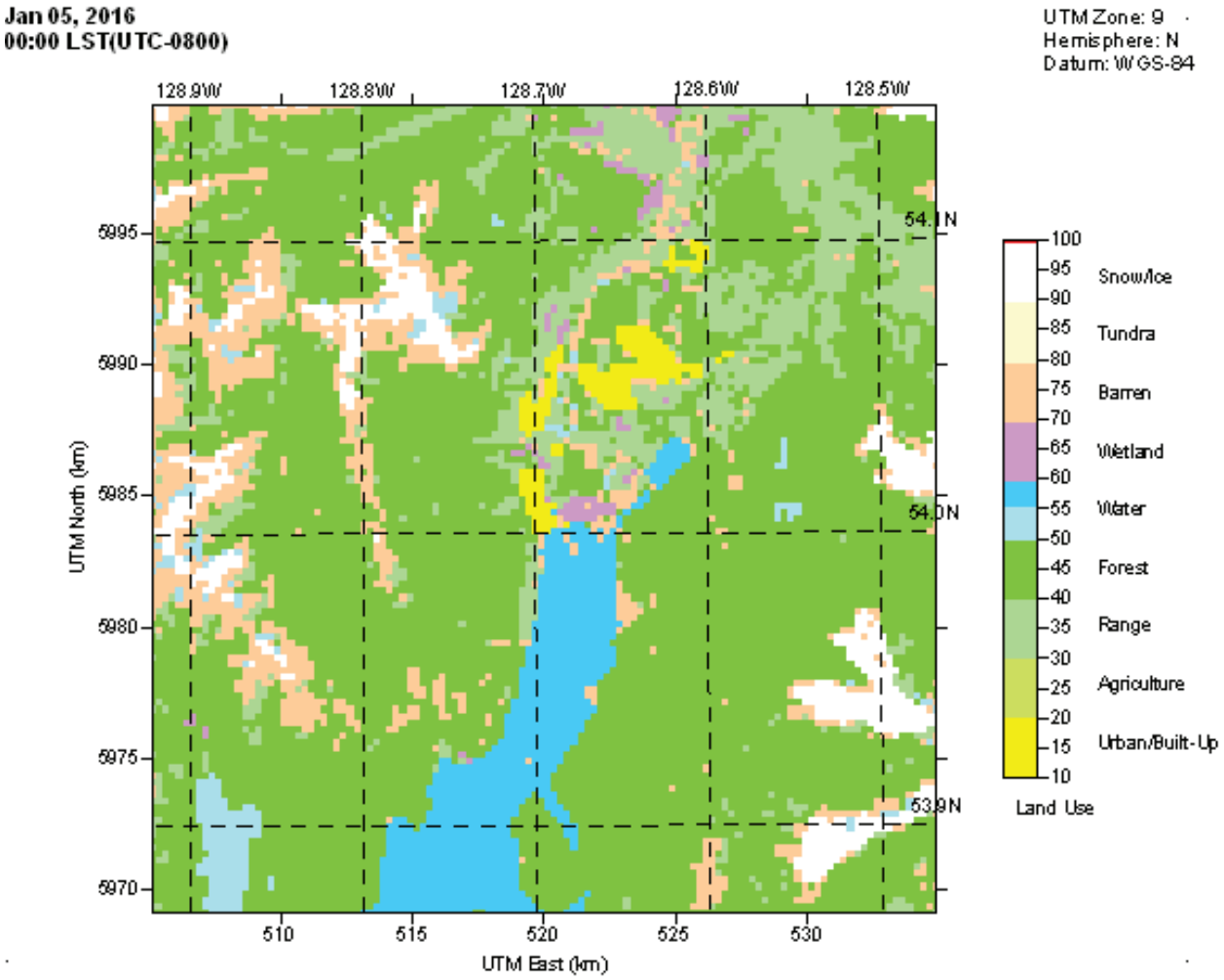


Figure A-11. Land Use – Processed (CALMET-Ready), Enlarged

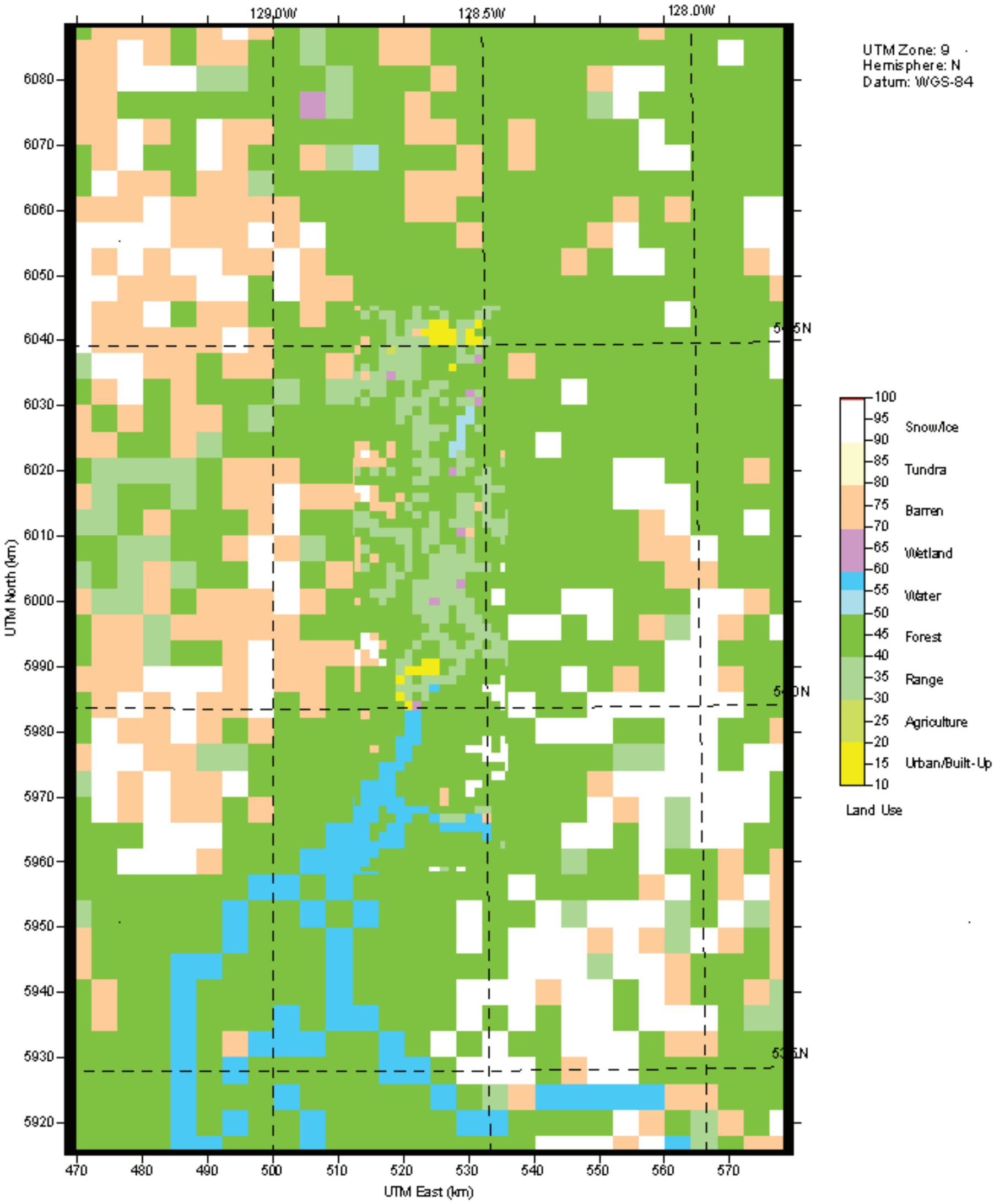


Table A-1. Building Parameters for CALPUFF Downwash

Buildings included in model
All cooridnates in UTM **WGS84**

Rectangular

WGS 84

		SW Corner					
ID	**Description**	**X Coord (m)**	**Y Coord (m)**	**Elevation (m)**	**Height (m)**	**X Length (m)**	**Y Length (m)**
CSTB	Alcan No. 216	519715.0	5985258.6	15.2	21.8	82.4	72.3
5220	Baking Furnace	519190.7	5985342.1	18.0	27.0	40.8	234.8
CSTA	-510	519902.2	5984240.6	9.8	14.0	78.4	159.9
5810	Anode Butt & Carbon Recycling Building	519698.6	5983595.2	5.0	18.0	24.2	41.6
5160	Handling/Storage - Green Anode/Cathode	519765.6	5983775.5	10.0	10.0	24.7	54.8
5130	Paste Area Equipment	519785.7	5983803.2	10.0	40.0	10.8	30.0
2470	Compressed Air	519721.4	5984843.6	10.3	13.2	38.1	20.6
5421	Anode Cleaning and Handling	519162.5	5985575.6	18.0	15.0	11.6	51.7
5410	Green and Backed Anode Storage	519204.2	5985531.0	18.0	18.0	132.0	19.5
5610	Anode Components Recycling Buildings	519356.3	5985492.0	14.1	19.6	116.7	49.7
5310	ABF Fume Treatment	519245.8	5985374.4	15.4	30.0	22.3	53.4
5710	Bath Recycling Building	519278.2	5985427.0	12.1	33.0	10.5	49.8
5611	Carbon Area Office	519482.9	5985527.9	14.1	12.9	27.0	36.0
7460	Cafeteria	519543.3	5985534.2	15.2	12.0	80.0	30.0
5910	Pallet Storage	519348.1	5985413.6	12.1	12.0	257.0	50.2
6121	Casthouse Cooling Water Treatment	519735.5	5985445.3	10.2	8.0	25.0	47.3
6620	Casthouse Building	519669.9	5985378.6	10.2	12.7	96.7	120.6
4420	Lining / Delining	519716.3	5985011.5	10.0	22.0	26.1	97.0
4450	PTA Maintenance Shop	519695.9	5985124.5	10.0	25.0	30.0	32.0
6260	Tac/Crucible Skimming Station	519648.6	5985363.1	12.5	14.7	17.2	34.2
4214	Reduction Potline 6D	519499.0	5984757.2	10.1	23.5	26.3	639.1
4213	Reduction Potline 6C	519567.4	5984769.6	10.1	23.5	26.3	639.1
4212	Reduction Potline 6B	519617.0	5984778.5	10.1	23.5	26.3	639.1
4211	Reduction Potline 6A	519685.5	5984790.8	10.1	23.5	26.3	639.1
4302	Pot Gas Treatment - GTC +2, West	519471.4	5985111.2	10.1	37.0	24.5	108.0
4301	Pot Gas Treatment - GTC +1, East	519589.5	5985132.5	10.1	37.0	24.5	108.0
4480	Cathode Sealing	519757.0	5984969.0	10.7	14.0	27.6	68.1

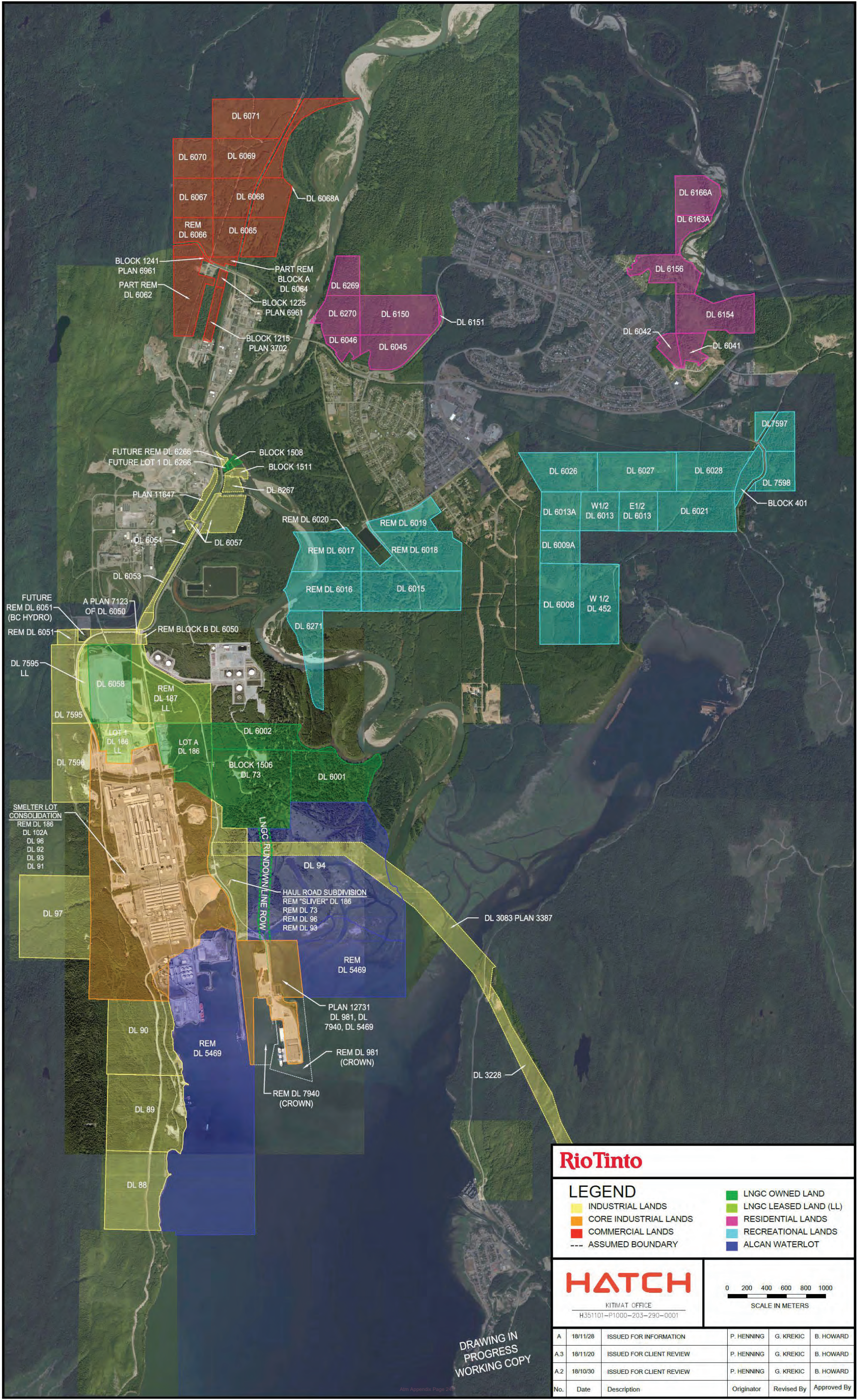
Circular

		SW Corner				
ID	**Desc**	**X Coord (m)**	**Y Coord (m)**	**Elevation (m)**	**Height (m)**	**Radius (m)**
3321	Calcined Coke Storage Silo	519745.6	5983661.6	9.3	37.0	12.5
3310	Fresh Alumna Handling & Storage	519805.7	5984743.0	9.5	33.0	16.5

Polygon

		SW Corner			
ID	**Desc**	**X Coord (m)**	**Y Coord (m)**	**Elevation (m)**	**Height (m)**
BLOCKA	Block A	519655.1	5983995.6	13.0	14.0
BLOCKB	Block B	519572.9	5984341.0	14.0	17.0
SILOS	Coke Storage Silos	519700.0	5983671.1	10.0	35.0
PASTE	Paste Plant	519772.1	5983728.5	10.0	48.8

All building locations, dimensions, and heights will checked against as-built measurements.



No.	Date	Description	Originator	Revised By	Approved By
A	18/11/28	ISSUED FOR INFORMATION	P. HENNING	G. KREKIC	B. HOWARD
A.3	18/11/20	ISSUED FOR CLIENT REVIEW	P. HENNING	G. KREKIC	B. HOWARD
A.2	18/10/30	ISSUED FOR CLIENT REVIEW	P. HENNING	G. KREKIC	B. HOWARD

ATTACHMENT 2

Modelling Protocol for STAR

Kitimat Modernization Project SO_2 Permit Amendment

SO_2 Technical Assessment Report

Appendix 7.6-1

CALPUFF Modelling Protocol

CALPUFF MODELING PROTOCOL
RIO TINTO ALCAN – BRITISH COLUMBIA KITIMAT WORKS

KITIMAT, BRITISH COLUMBIA

Prepared by:

Mr. Aaron M. Day – Principal Consultant
Ms. Anna Henolson – Senior Consultant
Ms. Anupama Krishnan – Consultant

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1. PROJECT BACKGROUND

Rio Tinto Alcan (RTA) operates an aluminum smelter in Kitimat, British Columbia (Kitimat Smelter) at the head of the Douglas Channel. In the smelter, alumina or aluminum oxide extracted from bauxite is reduced to aluminum metal. This process takes place in rectangular, insulated electric cells commonly referred to as pots. The metal is produced in the molten state and cast into ingots of various qualities for export to customers.

In the process of producing aluminum, carbon anodes are consumed during the electrolytic reduction of alumina (Al_2O_3) to aluminum. The carbon anodes are generated from petroleum coke that contains a small portion of sulfur. During the smelting process, this sulfur is emitted to the environment primarily as sulfur dioxide (SO_2).

The potroom roofs are the largest source of particulate matter (PM) emissions at the Kitimat Smelter. The remaining PM emissions occur from the potroom dry scrubbers, casting furnaces, coke calciner pyroscrubber, coke calciner cooler, and various sources controlled by several dust collectors (e.g., anode paste plant, material handling). Particulate and gaseous fluoride from the potrooms are controlled by the dry scrubbers.

RTA is proposing a project to rebuild and modernize the Kitimat facility (Kitimat Modernization Project; or KMP). In July 2009, a detailed CALPUFF modeling report was completed using the design parameters for KMP available at that time. Since that time, new design parameters for KMP were provided by RTA. The current KMP will consist of demolishing the existing pot lines, installing new AP-3X technology, and installing a new baking furnace. The Kitimat Smelter will have an annual capacity of approximately 420,000 tonnes of aluminum following the proposed project.[1] The air emissions of SO_2, nitrogen oxides (NO_X), hydrogen fluoride (HF), PM_{10}, and $PM_{2.5}$ will be affected by the proposed project. It is anticipated that emissions of SO_2 will increase, but that all other pollutant emissions will decrease as a result of the project.

A revised dispersion modeling analysis will be conducted using the new KMP design parameters to better understand the environmental implications associated with change in emissions from the Kitimat Smelter. In addition to the new KMP design parameters, the revised dispersion modeling analysis will use three years of meteorological data, and updated modeling methodology. This modeling protocol describes all the methods that will be used to conduct the revised air dispersion modeling analysis, and highlights those methods that differ from the CALPUFF modeling analysis completed in July 2009.

1.1 OBJECTIVE

The objective of this document is to provide a protocol summarizing the modeling methods and procedures that will be followed to conduct a CALPUFF dispersion modeling analysis for the Kitimat Smelter. The modeling methods and procedures will be used to determine the impact of increased

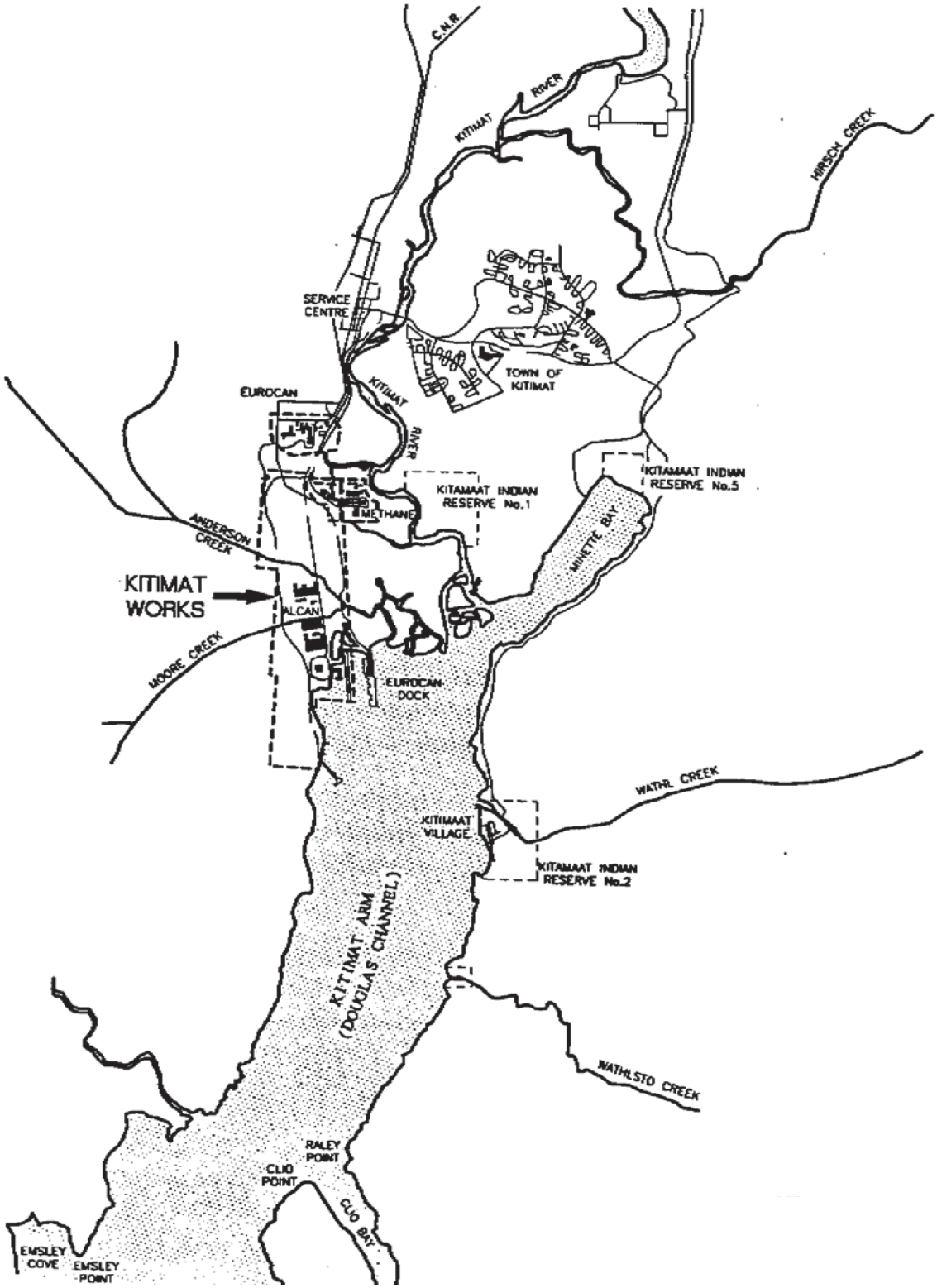
[1] The name plate capacity of the existing facility is approximately 275,000 tonnes of aluminum annually.

emissions due to the proposed modernization project at the Kitimat Smelter. This protocol has been developed in cooperation with the Ministry of Environment (MOE). RTA requests that the MOE provide written approval of the procedures described in this protocol.

1.2 LOCATION OF FACILITY

The Kitimat Smelter is located along Smeltersite Road just southwest of Kitimat, British Columbia. Figure 1-1 of this document contains an area map showing RTA's property boundary and buildings relative to predominant features such as highways, railroads, streams, and rivers.

FIGURE 1-1. KITIMAT AREA MAP



The main components of the CALPUFF modeling system are the CALMET, CALPUFF, and CALPOST models. CALMET is the meteorological model that generates hourly three-dimensional meteorological fields such as wind and temperature. CALPUFF simulates the non-steady state transport, dispersion, and chemical transformation of air pollutants emitted from a source in "puffs". CALPUFF calculates hourly concentrations of specified pollutants at each specified receptor in a modeling domain. CALPOST is the post-processor for CALPUFF that computes impacts from a source based on the pollutant concentrations that were output by CALPUFF.

2.1 MODEL VERSIONS

The versions of the CALPUFF modeling system programs that are proposed for conducting RTA's dispersion modeling analysis are listed in Table 2-1.

TABLE 2-1. CALPUFF MODELING SYSTEM VERSIONS

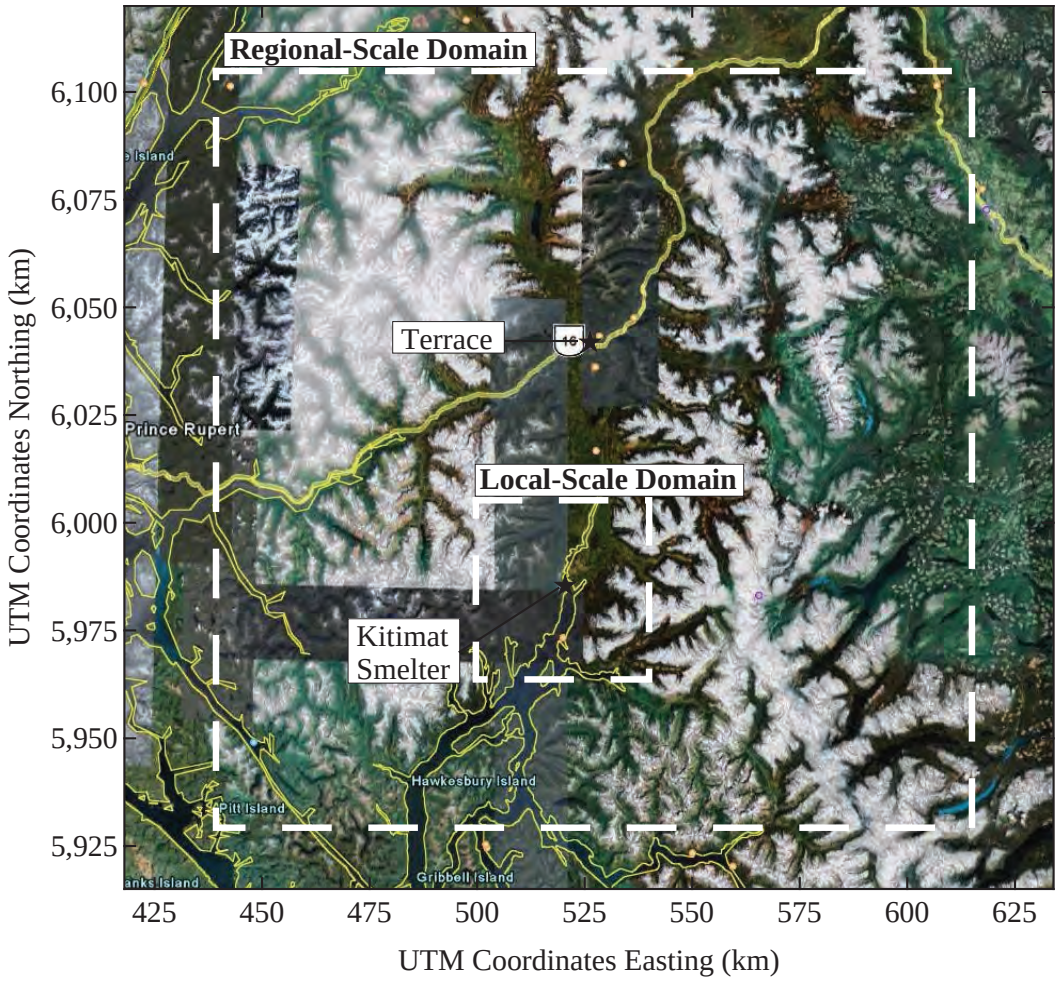
Program	Version	Level
CALMET	6.334	110421
CALPUFF	6.42	110325
CALPOST	6.292	110406
CALSUM	1.4	110301
POSTUTIL	1.641	110225

2.2 MODELING DOMAIN

The CALPUFF modeling system utilizes three modeling grids: the meteorological grid, the computational grid, and the sampling grid (or receptor grid). The meteorological grid is the system of grid points at which meteorological fields are developed with CALMET. The computational grid determines the computational area for a CALPUFF run. The sampling grid defines the locations where the ground level concentration and/or deposition results are determined and stored within the CALPUFF output files. In the case of the proposed analysis, discrete receptors are used rather than gridded receptors, so the sampling area is defined as those locations where discrete receptors are specified. Puffs are advected and tracked only while within the computational grid. The meteorological grid is defined so that it covers the areas of concern and gives enough marginal buffer area for puff transport and dispersion. A plot of the proposed meteorological and computational modeling domain is provided in Figure 2-1. The domain is set to extend at least 50 km in all directions beyond the Kitimat Smelter, significant terrain features, and receptors. The map projection for the modeling domain will be Universal Transverse Mercator (UTM), and the datum will be the North American Datum 27 (NAD 27). The southwest corner will be set to 439.0 km UTM Easting, 5,929.0 km UTM Northing, corresponding to Latitude 53.508ºN and Longitude

129.921ºW.[2] The meteorological grid spacing will be 4 km, resulting in 44 grid points in the X direction and 44 grid points in the Y direction, or finer. For local scale modeling, a more refined meteorological grid is required. Therefore, a second meteorological grid will extend 20 km from the RTA Kitimat Smelter, with a grid spacing of 500 meters, resulting in 80 grid points in the X direction and 80 grid points in the Y direction. The boundary of the local-scale grid is also shown in Figure 2-1.

FIGURE 2-1. METEOROLOGICAL AND COMPUTATION MODELING DOMAINS



[2] All Universal Transverse Mercator (UTM) coordinates are in North American Datum (NAD) 27, Zone 9.

3. CALMET METEOROLOGICAL PROCESSOR

The CALMET meteorological processor will be used to generate the meteorological data for CALPUFF. CALMET is the meteorological processor that compiles meteorological data from raw observations of surface and upper air conditions, precipitation measurements, mesoscale model output, and geophysical parameters into a single hourly, gridded data set for input into CALPUFF. CALMET will be used to assimilate data for surface station observations, upper air station observations, precipitation station observations, and mesoscale model output to develop the meteorological field.

3.1 GEOPHYSICAL DATA

CALMET requires geophysical data to characterize the terrain and land use parameters that potentially affect dispersion. Terrain features affect flows and create turbulence in the atmosphere and are potentially subjected to higher concentrations of elevated puffs. Different land use types exhibit variable characteristics such as surface roughness, albedo, Bowen ratio, and leaf-area index that also effect turbulence and dispersion. RTA proposes to use the same geophysical datasets and processing methods that were used for the KMP modeling for meteorological year 2006. The methods used for the 2006 CALMET analyses are proposed to be used for the 2008 and 2009 CALMET analyses and are described in more detail below.

3.1.1 TERRAIN DATA

Terrain data collected for the original CALMET analysis conducted for KMP modeling that used meteorological year 2006 will be used for the proposed revised CALMET modeling analysis.

Terrain data for the regional-scale modeling domain were obtained from 3 arc-second GeoBase Canadian Digital Elevation Data Level 1 digital elevation model (DEM) at 1:250,000 scale or approximately 90 meter resolution. Terrain data for the local-scale modeling domain were obtained from 0.75 arc-second GeoBase digital elevation model (DEM) at 1:50,000 scale or approximately 30 meter resolution.[3]

The terrain data were processed using the TERREL (Version 3.684) program to generate grid-cell elevation averages across the modeling domain. A plot of the TERREL land elevations based on this processing is provided in Figure 3-1. Figure 3-2 provides a 3-D contour plot of the Kitimat Valley.[4]

[3] It should be noted that the original modeling protocol proposed using 3 arc-second GeoBase Canadian Digital Elevation Data Level 1 digital elevation model (DEM) at 1-degree (1:250,000 scale or approximately 90 meter resolution) to process both the 4 kilometer CALMET data set and the 500 meter CALMET data set. However, the 0.75 arc-second data was found to better represent the surrounding terrain in the near-field. Therefore, the 0.75 arc-second data will be used to process the 500 meter local scale CALMET data set.

[4] It should be noted that a newer version of TERREL has been released since the time of the original terrain processing; however, no changes to the terrain output would be expected if the elevation data were reprocessed with the latest version of TERREL.

FIGURE 3-1. PLOT OF LAND ELEVATION

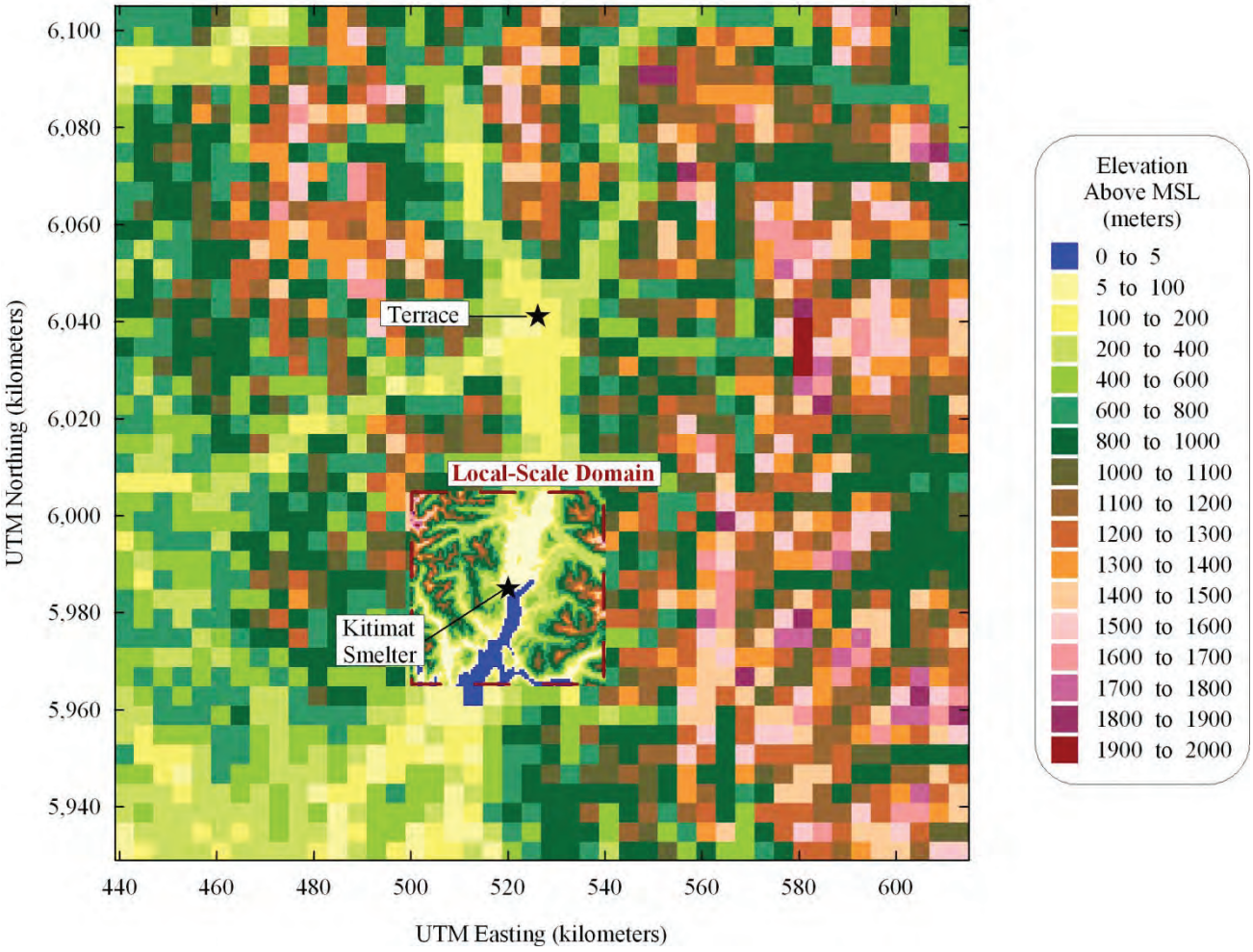
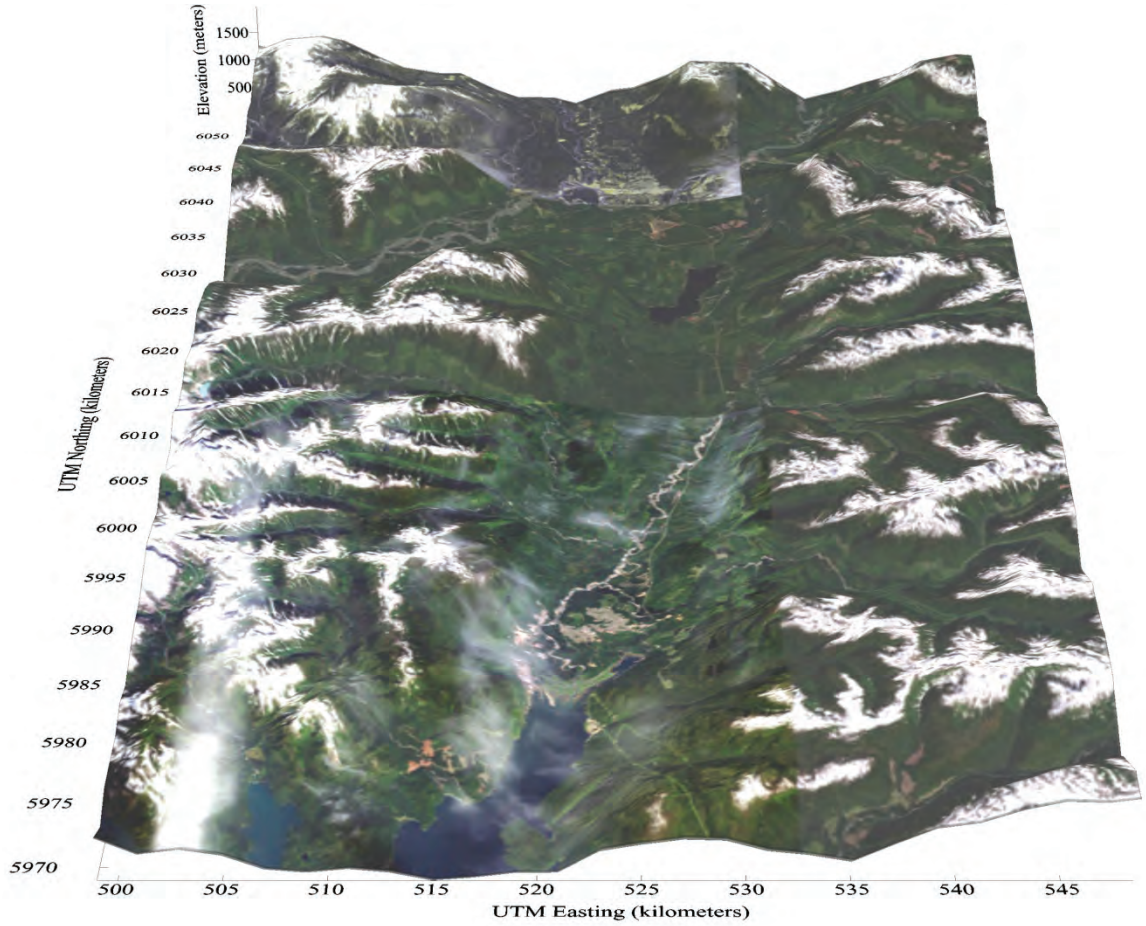


FIGURE 3-2. 3D TERRAIN PLOT



3.1.2 LAND USE DATA

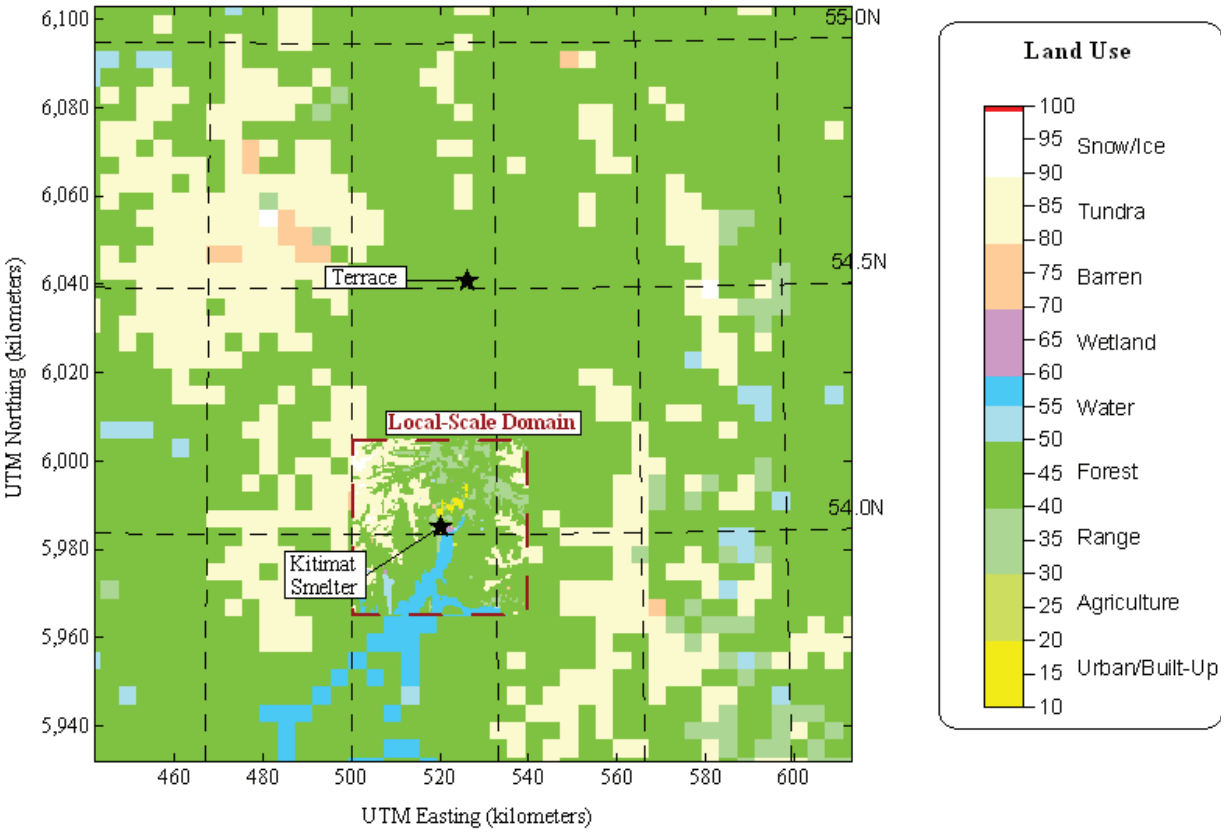
The land use land cover (LULC) data collected for the original CALMET analysis conducted for KMP modeling that used meteorological year 2006 will be used for the proposed revised CALMET modeling analysis.

The LULC data, obtained from the USGS North American land cover characteristics data set, are used in order to determine the land use for the regional-scale modeling domain. The Baseline Thematic Mapping (BTM) data set is used to determine the land use characteristics for the local-scale modeling domain. Minor revisions to the land use characteristics near the land-water interface are made in order for the land use categories along the coastline to be consistent with the coastline data obtained and QA'd for use with the sub-grid TIBL module.[5] A plot of the land use based on the USGS data for the modeling domain is provided in Figure 3-3. A table detailing the land use properties (surface roughness, albedo, bowen ratio,

[5] The sub-grid TIBL module requires that the coastline data points pass through cells with at least one water cell and one land cell adjacent to the cell containing the point(s). A total of five regional scale (4 km spacing) cells and fifteen local scale (500 meter spacing) cells are updated, based on fine resolution aerial and/or satellite images and the refined coastline data.

soil heat flux parameter, anthropogenic heat flux, and leaf area index) assigned to each land use category is provided in Appendix A.

FIGURE 3-3. PLOT OF LAND USE



3.1.3 COMPILING TERRAIN AND LAND USE DATA

The terrain data files output by the TERELL program and the LULC files output by the CTGPROC program are uploaded into the MAKEGEO program to create a geophysical data file that will be input into CALMET.[6]

3.2 METEOROLOGICAL DATA

CALMET will be used to assimilate data for years 2006, 2008, and 2009 using mesoscale model output, surface station observations, upper air station observations, and National Oceanic and Atmosphere Administrations (NOAA) buoy station observations to develop the meteorological field.[7]

[6] The geophysical preprocessors (i.e., the TERREL, CTGPROC, and MAKEGEO programs) are available for download at http://www.src.com/calpuff/download/epa_codes.htm.

[7] Note that no hourly precipitation observation data is available in the meteorological domain. Therefore, the MM5 data will be used for precipitation information.

3.2.1 SELECTION OF METEOROLOGICAL YEARS

The previous CALMET and CALPUFF analysis conducted for the original KMP design used one year of meteorological data from the most recent year of data available when the modeling process commenced (meteorological year 2006). RTA proposes to use two additional years of meteorological data for this revised CALMET analysis, 2008 and 2009, as requested and approved by MOE.[8] Per EPA regulatory guidelines, "[t]he model user should acquire enough meteorological data to ensure that worst-case meteorological conditions are adequately represented in the model results." Use of at least one year of site specific data or five years of national weather service data is required.[9] Multiple meteorological stations near the Kitimat Smelter are considered site specific and will be used to develop the CALMET dataset. Therefore, use of one year of these meteorological data would meet the requirements specified by the U.S. EPA. However, because multiple years of site specific surface observation data are available, use of three years of meteorological data is proposed for this analysis. Years 2008, and 2009 are selected, because these years are the most recent, readily available years of complete and representative data. MOE has approved the 2008 and 2009 meteorological surface data, based on MOE's level of comfort in the QA/QC status of the data, as well as comfort that the frequency and intensity of wind from the south will adequately represent worst-case meteorological conditions.[10] Year 2006 will also be used (processed following the current protocol), because the data for that year are complete, readily available, and previously approved by MOE.

3.2.2 MESOSCALE MODEL METEOROLOGICAL DATA

Hourly mesoscale data with 4 kilometer grid resolution will be used as the initial guess field in developing the CALMET meteorological data. A 5th generation mesoscale model meteorological data set (or MM5 data) for two years (2008 and 2009) will be generated for this analysis. In addition to these two years, previously generated MM5 data for 2006 will be used in the proposed CALMET and CALPUFF analyses.[11]

The MM5 data set will be generated using National Centers for Environmental Prediction (NCEP) Global Final (FNL) Analyses (1.0 x 1.0 degree grids covering the entire globe every six hours) as the background data of MM5 run. NCEP Automated Data Processing (ADP) Global Surface and Upper Air Observations data sets are digested by LITTLE_R module of MM5 into initialization data sets of MM5 run. These ADP data sets are operationally collected

[8] Meeting between Mr. Ben Weinstein and Frazer McKenzie, MOE; Anna Henolson, Trinity Consultants; and Mr. Shawn Zettler, RTA; July 26, 2011.

[9] U.S. EPA, Office of Air Quality Planning and Standards, *Guideline on Air Quality Models (Revised)* (Research Triangle Park, NC: FR Vol. 70, No. 216, 2005), 70 FR 68243-68244.

[10] Meeting between Mr. Ben Weinstein and Frazer McKenzie, MOE; Anna Henolson, Trinity Consultants; and Mr. Shawn Zettler, RTA; July 26, 2011.

[11] The 2006 MM5 dataset was generated during the previous modeling effort conducted in 2007 and 2008, while the 2008 and 2009 MM5 datasets are generated as part of the current modeling effort. The CALMET processing for 2006, 2008, and 2009 is run (or rerun in the case of meteorological year 2006) with the input settings specified in the current protocol, including both MM5 and surface station data.

by NCEP into three-hourly or six-hourly files and in recent years can include hourly and even some 20-minute reports. They include land and marine reports received via the Global Telecommunications System (GTS). Generally, ADP observation data sets include most of observation stations. However, the ADP data is not guaranteed to include all observation stations. Thus, meteorological data from specific surface, upper air, and buoy stations as described in the following sections will be included as observations in the CALMET run.

According to the recommendations based on primary evaluation of area-specific conditions (e.g., terrain, land use, and other climatic characteristics), the following physical parameter options will be applied for the MM5 modeling.

- Cloud Microphysics: Reisner II
- Cumulus Parameterization: GRELL
- Planetary Boundary Layer: MRF
- Land Surface Model: 5-Layer Model
- Radiation: RRTM
- Shallow Convection: NONE
- Varying SST with time: 'Yes'

The MM5 data will be processed using CALMM5 Version 3.01 to create a 3D.DAT file formatted for input into CALMET.

A study will be conducted to evaluate the sensitivity in the CALPUFF results from using a combination of MM5 and surface station data in the near field, by repeating the CALMET and CALPUFF analyses using only surface station data. The study will include one month from each of the 2006, 2008, and 2009 meteorological years for the pre-KMP emissions scenario, based on the month expected to have worst-case concentrations at the continuous SO_2 monitoring station locations. The modeled SO_2 concentrations from this study will be compared to the SO_2 monitoring data recorded at the continuous monitoring stations.

3.2.3 SURFACE METEOROLOGICAL DATA

Parameters affecting turbulent dispersion that are observed hourly at surface stations include wind speed and direction, temperature, cloud cover and ceiling, relative humidity, and precipitation type. Data from the stations will be processed for use in CALMET using the SMERGE program, Version 5.661. Table 3-1 presents the surface stations that will be evaluated for use as observation input for the CALMET meteorological data processing.

TABLE 3-1. SURFACE OBSERVATION STATIONS

Surface Station	Location UTM E (km)	Location UTM N (km)	Elevation	Data Source	Time Period
Holland Rock	411.972	6002.754	5	NCDC [a]	2008-2009
Lucy Island Lightstation	388.510	6023.633	26	NCDC [a]	06, 08, 09
Bonilla Island	391.790	5928.945	15	NCDC [a]	06, 08, 09
Terrace [b]	527.134	6035.372	217	NCDC [a,b]	06, 08, 09
Prince Rupert Awos	405.774	6015.788	35	NCDC [a]	06, 08, 09
Stewart Airport	438.695	6198.869	7	NCDC [a]	06, 08, 09
Kitimat Eurocan Dock	521.197	5982.823	0	MOE	06, 08, 09
Kitimal Haul Rd.	519.635	5986.637	9	MOE	06, 08, 09
Kitwanga School	562.817	6108.077	239	MOE	2008-2009
Kitimat Whitesail	523.725	5990.838	91	MOE	06, 08, 09
New Hazelton School	589.996	6122.799	328	MOE	2008-2009
Smithers St. Josephs [b]	578.993	6071.176	495	MOE [b]	2008-2009
Terrace Access Centre [b]	526.142	6041.055	67	MOE [b]	2008-2009
Telkwa	625.513	6062.008	514	MOE	2008-2009
Kitimat KMP	519.596	5985.542	13	MOE	2009

[a] Data obtained from National Climatic Data Center.

[b] Where both provincial (MOE data source) and federal (NCDC data source) exist (e.g., Smithers), the CALMET analysis preferentially uses provincial sites, provided the data quality of the provincial sites is approximately equal to or better than the federal sites. Therefore, the NCDC Smithers meteorological station is not included for years 2008 and 2009. Both the MOE and NCDC sites for Terrace are included, because meteorological conditions at the Terrace airport are expected to be different than conditions at the Terrace Access Centre.

3.2.4 UPPER AIR METEOROLOGICAL DATA

Observations of meteorological conditions in the upper atmosphere provide a profile of turbulence from the surface through the depth of the boundary layer in which dispersion occurs. Upper air data are collected by balloons launched simultaneously across the observation network at 0000 Greenwich Mean Time (GMT) (16:00 in BC) and 1200 GMT (04:00 in BC). Sensors observe pressure, wind speed and direction, and temperature (among other parameters) as the balloon rises through the atmosphere. The upper air observation network is less dense than surface observation points since upper air conditions vary less and are generally not as affected by local effects (e.g., terrain or water bodies). The upper air stations that are proposed for use in this analysis are listed in Table 3-2 below. Data from the stations will be processed for use in CALMET using EPA's READ62 program and included as observations in the CALMET processing.[12]

[12] RTA plans to use both upper air stations individually as observation input data for the CALPMET processing. However, if there are severe data quality issues, a single combined file will be created for use, with Annette Island data treated preferentially.

TABLE 3-2. UPPER AIR OBSERVATION STATIONS

Upper Air Station	Location		Data Source	Time Period
	Latitude	Longitude		
Annette Island	55.030	-131.570	NCDC [a]	2006, 2008, 2009
Port Hardy	50.683	-127.367	NCDC [a]	2006, 2008, 2009

[a] Data obtained from National Climatic Data Center.

3.2.5 BUOY METEOROLOGICAL DATA

The effects of land/sea breeze on ambient pollutant concentrations will be considered in this analysis. Therefore, it is necessary to include observations of nearby buoy stations in the CALMET analysis. The closest stations are buoy station 46181, Nanakwa Shoal, and station 46185, South Hecate Strait, and are proposed for use this analysis. Data from the station will be prepared by filling missing hour records with the CALMET missing parameter value (9999). No adjustments to the data will occur.

3.3 CALMET CONTROL PARAMETERS

This analysis will apply the recommended CALMET control parameters presented in Table 9.6 of the "Guidelines For Air Quality Dispersion Modelling In British Columbia."[13] For switch settings that have multiple or variable recommended settings, appropriate settings will be used based on expert judgment. Table 3-3 presents the CALMET switch settings that will be used in this modeling analysis. A sample CALMET input file specifying all switch settings will be provided in the modeling report.

[13] The "Guidelines For Air Dispersion Modelling in British Columbia" document was downloaded from http://www.bcairquality.ca/reports/air_disp_model_08.html, July 21, 2011.

TABLE 3-3. CALMET INPUT GROUP 5 SWITCH SETTINGS

Option	Parameter	Value
Wind field model selection variable.	IWFCOD	1
Compute Froude number adjustment effects?	IFRADJ	1
Compute kinematic effects?	IKINE	0
Use O'Brien procedure for adjustment of the vertical velocity?	IOBR	0
Compute slope flows?	ISLOPE	1
Extrapolate surface wind observations to upper layers?	IEXTRP	-4
Extrapolate calm winds aloft?	ICALM	0
Layer-dependent biases.	BIAS	(see below) [a]
BIAS = -1 , -1 , -1 , -1 , -1 , -1 , 0 , 1 , 1 , 1 !		
Min. distance between upper air station and surface station for which extrapolation of surface winds will be allowed.	RMIN2	-1
Gridded prognostic wind field model output fields.	IPROG	14
Use varying radius of influence?	LVARY	T
Max radius of influence over land in the surface layer.	RMAX1	10
Max radius of influence over land aloft.	RMAX2	40
Max radius of influence of influence over water.	RMAX3	100
Min. radius of influence used in the wind field interpolation	RMIN	0.1
Radius of influence of terrain features	TERRAD	15
Distance from a surface station at which the station observations and 1st guess field are equally weighted.	R1	2
Distance from an upper air station at which the observation and 1st guess field are equally weighted.	R2	5
Relative weighting of the prognostic wind field data.	RPROG	NA [b]
Maximum acceptable divergence in the divergence min. procedure.	DIVLIM	5x10-6
Maximum number of iterations in the divergence min. procedure.	NITER	50
Number of passes in the smoothing procedure.	NSMTH	2, 4 [c]
Max number of stns used in each layer for the interpolation of data to a grid point	NINTR2	99
Critical Froude number.	CRITFN	1
Empirical factor controlling the influence of kinematic effects.	ALPHA	0.1
Multiplicative scaling factor for extrapolation of sfc observations to upper layers.	FEXTR2	NA [d]
Number of barriers to interpolation of the wind fields.	NBAR	0
X and Y coordinates of barriers. (XBBAR, YBBAR, XEBAR, YEBAR)	_ _BAR	NA [e]
Diagnostic module surface temperature option.	IDIOPT1	0
Diagnostic module sfc. met station to use.	ISURFT	8
Diagnostic module domain-averaged lapse rate option.	IDIOPT2	0
Diagnostic module upper air stn met station to use for lapse rate.	IUPT	1
Depth through which the domain-scale lapse rate is computed.	ZUPT	200
Initial guess field wind components	IDIOPT3	0
Upper air station to use for domain-scale winds.	IUPWND	-1
Bottom and top of layer through which the initial guess winds are computed.	ZUPWND	1, 1000

[a] The bias levels are set to -1 for layers below the mountain peaks surrounding the Kitimat valley, and 1 and the upper levels. The 4th level from the top (1200 meters to 2000 meters) is set to a bias of 0.

[b] RPROG is only included if IPROG is set to 1.

[c] As recommended in the "BC Guidelines For Air Quality Dispersion Modelling In British Columbia," 2 is used for the lowest layer and 4 is used for all subsequent layers.

[d] FEXTR2 is only used if IEXTRP is set to 3 or -3.

[e] The XBBAR, YBBAR, XEBAR, YEBAR variables are only included if NBAR>0.

3.4 CALMET QA/QC PROCEDURES

The Quality Assurance (QA) procedures for the CALMET processing will be performed as specified in Sections 10.2.1 of the B.C. Dispersion Modelling Guidelines and as further described below.

The elements of the QA process for the CALMET processing include preparation of wind rose (using observed, MM5 and CALMET-derived data), including examination of the data as a function of season and time of day (e.g., 4am, 10am, 4pm wind roses), time series analyses, and presentation of 2-D vector plots illustrating terrain effects/sea breeze circulation or other features of the flow expected to occur within the domain. For example, 2-D vector plots produced during light wind speed stable conditions (e.g., early morning such as 4 am) will be used as a good assessment of the performance of the CALMET model configuration and switches in reproducing terrain effects because these conditions are likely to maximize the terrain impacts in the model. Season wind roses at 4 am, 10 am and 4 pm may be evaluated as they are expected to show the development of sea breeze circulations that may be important for certain areas within the domain. Location-specific QA of CALMET simulation of the physical processes expected to be important at areas of interest will be conducted. Specifically, in addition to the time series plots for wind and direction, wind roses (depicting frequency of wind speed and direction) will be generated from CALMET data for comparison to wind roses generated directly from surface observation data at (e.g., at Haul Road, Eurocan Dock, and Kitamaat Village meteorological stations).

Additionally, the CALPUFF modeling system contains built-in features to facilitate quality assurance of the modeling results. These include the automatic production of "QA" files for various datasets, including geophysical fields and imbedded tracking of model options and switches within the output files from the major modeling units of the modeling system. The Graphical User Interface system (GUI) provided as part of the latest CALPUFF modeling system allows these QA files to be displayed graphically. The graphic QA files related to the CALMET processing will be reviewed to identify any inaccurate data as part of the QA procedures.

Appendix B to this report presents initial QA 2-D vector and time series plots generated to assess the influence of the KMP Camp meteorological station. While the plots show some discontinuities in wind speed and direction near the KMP Camp station during some of the sample hours, it has been determined that the overall influence of the station will result in CALMET wind fields that more closely correspond to observed meteorological conditions. For this reason, RTA proposes to include the KMP Camp meteorological station for use as observation input for the CALMET meteorological data processing.

The CALPUFF model uses the output file from CALMET together with source, receptor, and chemical reaction information to predict hourly concentration impacts. RTA proposes to conduct a three-year CALPUFF analysis for several emissions scenarios using data and model settings as described below.

4.1 EMISSIONS SOURCE DATA

Emissions of PM_{10}, $PM_{2.5}$, SO_2, NO_X, and HF from the sources affected by the proposed modernization project at the Kitimat Smelter, as listed in Table 4-2, will be included in the analysis. Calculated maximum emissions in grams per second (g/s) will be modeled.

The CALPUFF dispersion model allows emission units to be represented as point, line, area, or volume sources. For point sources (e.g., dry scrubber stacks) with unobstructed vertical releases, actual stack parameters (i.e., height, diameter, exhaust gas temperature, and gas exit velocity) will be used in the modeling analyses. For area or volume sources, if any, actual source parameters (i.e., effective height and initial size data) will be used in the modeling analysis.

The CALPUFF dispersion model also allows buoyancy to be considered when modeling elevated temperature line sources (e.g., potlines). However, each CALPUFF model input and output file allows only one average buoyancy flux parameter to be used for all line sources. For this reason, RTA will run separate model runs, each with a subset of the smelter's potlines, to allow for the use of different average buoyancy flux parameters to be applied to similar potlines. Similar potlines will be grouped together based on similarities in their exit velocities and line source widths.

For the post-KMP modeling analysis, all roof vents will have the same exit velocity and width; thus, all post-KMP roof vents will be grouped together. Since buoyancy changes between winter and summer months, two separate post-KMP CALPUFF model runs will be conducted for the post-KMP potline roof vents: one using a buoyancy flux based on the average temperature over the winter half of the year, and one using a buoyancy flux based on the average temperature during the summer half of the year.

For the pre-KMP modeling analysis, potlines 1 and 2 have a different velocity than potlines 3, 4, 5, 7, and 8; therefore, potlines 1 and 2 will be grouped together, and potlines 3, 4, 5, 7, and 8 will be grouped together.

In all cases the buoyancy flux parameter is calculated by the following equation.

$$F_b = \frac{g * L * W_m * w * \Delta T}{T_s}$$

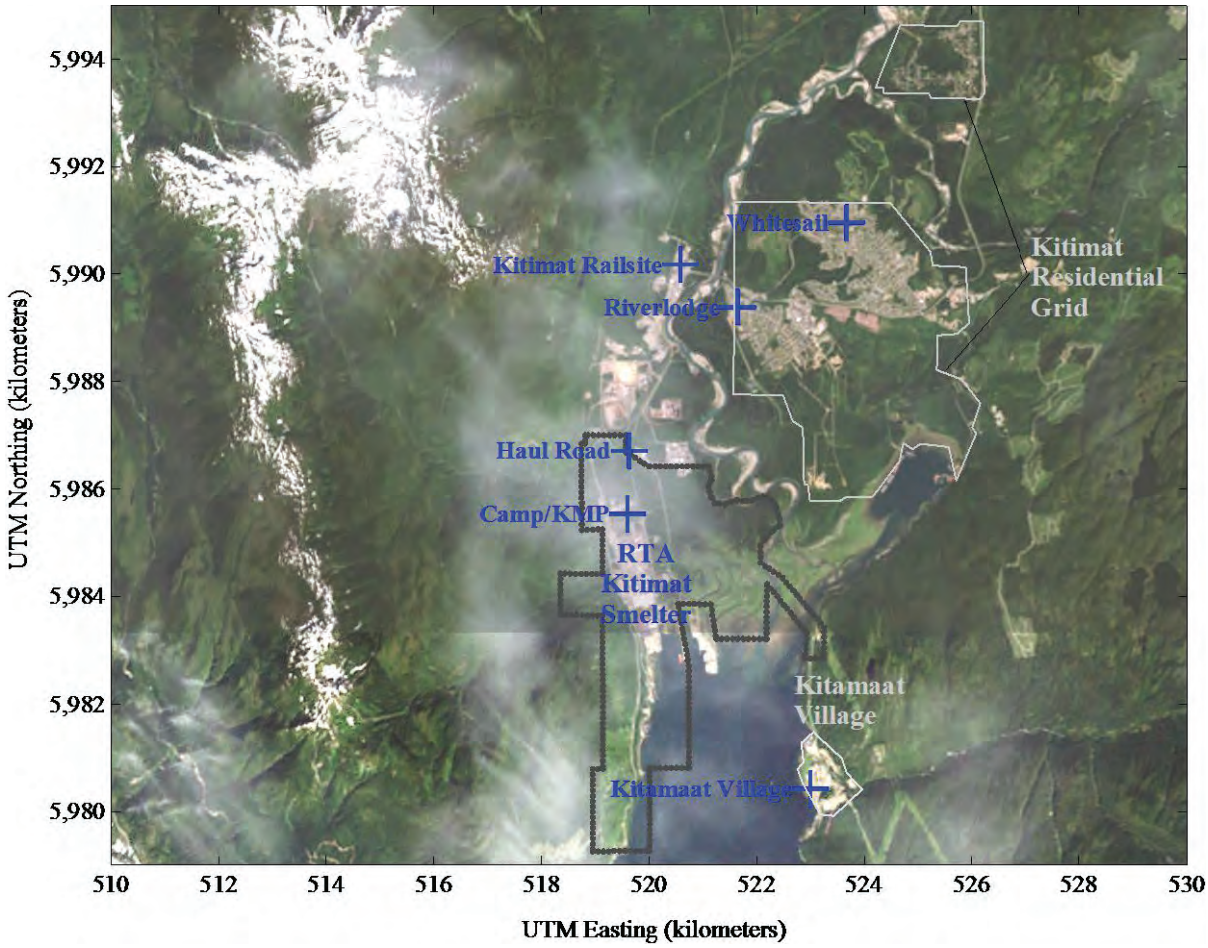
where:

F_b = Buoyancy Flux [=] m^4/s^3

g = Acceleration of Gravity [=] 9.81 m/s^2
L = Line Source Length [=] m
W_m = Line Source Width [=] m
w = Exit Velocity [=] m/s
ΔT = Exit Gas Temperature – Ambient Air Temperature [=] K
T_s = Exit Gas Temperature [=] K

Figure 4-1 provides a map of the Kitimat Smelter indicating the location of the property line and nearby monitoring stations. A detailed plot plan indicating the location of each modeled source and a process flow diagram are provided in Appendix C.

FIGURE 4-1. KITIMAT SMELTER AREA MAP



4.2 EMISSIONS MODELING SCENARIOS

Table 4-2 presents the sources located at the Kitimat Smelter that will have a change in emissions as a result of the modernization project. RTA proposes to conduct a CALPUFF analysis for four modeling scenarios. One scenario, the "Pre-KMP" scenario will represent the emissions from the Smelter during 2006, 2008, and 2009 operations. Three scenarios will be modeled to predict the post-project concentrations from the proposed emission rates after KMP is complete. "Scenario 1A" will

modeling scenarios. One scenario, the "Pre-KMP" scenario will represent the emissions from the Smelter during 2006, 2008, and 2009 operations. Three scenarios will be modeled to predict the post-project concentrations from the proposed emission rates after KMP is complete. "Scenario 1A" will represent post-project emission rates from the Kitimat smelter assuming a coke sulfur content of 3.5%, "Scenario 2A" will represent post-project emission rates from the Kitimat smelter assuming a coke sulfur content of 2.9 %, and "Scenario 3A" will represent post-project emission rates from the smelter assuming a coke sulfur content of 3.8%. All of the above scenarios will be representative of a production rate of 420,600 ton Aluminum per year. Table 4-1 presents a summary of the post-KMP modeling scenarios. The sources listed as "Existing" or "New Source" in Table 4-2 will be included in the post-project modeling scenarios. The sources listed as "Existing" or "Source to be removed" will be included in the pre-project modeling scenario.

TABLE 4-1. SUMMARY OF MODELING SCENARIOS

Scnario:	**Scenario 2A**	**Scenario 1A**	**Scenario 3A**
Percentage Sulfur in Coke	2.90%	3.50%	3.80%
Total Emissions (tpd SO2)	32.4	38.9	41.8

Including the pre-project modeling scenario will provide a baseline against which the post-project predicted concentrations can be compared. Additionally, the estimated concentrations using the pre-KMP emission rates can be compared to 2006/2008/2009 monitoring data to provide better understanding of how the CALPUFF modeling results compare to actual measured concentrations.

Table 4-2 also specifies the source group assigned to each source in order to conduct a contribution analysis for specific events and to determine the maximum ambient concentrations caused by each source group.

Table 4-3 and Table 4-4 present the modeling parameters for the pre-KMP and post-KMP modeling scenarios, respectively. Table 4-5 and Table 4-6 present the pre-KMP and post-KMP emission rates that will be used for each modeling scenario.

For the previous CALPUFF modeling analysis completed in 2009, MOE provided a list of nearby sources that were considered in the dispersion modeling analysis. However, during recent discussions, MOE confirmed that this revised analysis need only consider impacts from the Kitimat Smelter.[14]

[14] Conference call between Mr. Ben Weinstein and Frazer McKenzie, MOE; Anna Henolson, Trinity Consultants; and Mr. Shawn Zettler, RTA; July 7, 2011.

TABLE 4-2. LIST OF SOURCES AT THE KITIMAT SMELTER

Emission Source	Description	Status for Proposed Project	Point Type	Basis of Emissions	Contaminants	Pre-Project Source Group	Post-Project Source Group
~~DS1~~	Dry Scrubber #1	Source to be removed	P	NA	SO_2, HF	Dry Scrubbers	N/A
~~DS2~~	Dry Scrubber #2	Source to be removed	P	NA	SO_2, HF	Dry Scrubbers	N/A
~~DS3~~	Dry Scrubber #3	Source to be removed	P	NA	SO_2, HF	Dry Scrubbers	N/A
~~DS4~~	Dry Scrubber #4	Source to be removed	P	NA	SO_2, HF	Dry Scrubbers	N/A
~~DS5~~	Dry Scrubber #5	Source to be removed	P	NA	SO_2, HF	Dry Scrubbers	N/A
~~DS6~~	Dry Scrubber #6	Source to be removed	P	NA	SO_2, HF	Dry Scrubbers	N/A
~~DS7~~	Dry Scrubber #7	Source to be removed	P	NA	SO_2, HF	Dry Scrubbers	N/A
~~DS8~~	Dry Scrubber #8	Source to be removed	P	NA	SO_2, HF	Dry Scrubbers	N/A
PYRO	Pyro Scrubber	Existing source	P	Proposed EL [a]	SO_2, NO_x, PM_{10}, and $PM_{2.5}$	Calcining	Calcining
COOLER	Calciner Cooler	Existing source	P	Proposed EL [a,b]	SO_2, PM_{10}, and $PM_{2.5}$	Calcining	Calcining
~~L1C~~	Potroom 1c	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 1-2	N/A
~~L2A~~	Potroom 2a	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 1-2	N/A
~~L2B~~	Potroom 2b	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 1-2	N/A
~~L2C~~	Potroom 2c	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 1-2	N/A
~~L3A~~	Potroom 3a	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 3-8	N/A
~~L3B~~	Potroom 3b	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 3-8	N/A
~~L4A~~	Potroom 4a	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 3-8	N/A
~~L4B~~	Potroom 4b	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 3-8	N/A
~~L5A~~	Potroom 5a	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 3-8	N/A
~~L5B~~	Potroom 5b	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 3-8	N/A
~~L7B~~	Potroom 7b	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 3-8	N/A
~~L8A~~	Potroom 8a	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 3-8	N/A
~~L8B~~	Potroom 8b	Source to be removed	L	NA	SO_2, HF, PM_{10}, and $PM_{2.5}$	Potrooms 3-8	N/A
~~F1~~	Casting DC 1 Furnace 1	Source to be removed	P	NA	HF, PM_{10}, and $PM_{2.5}$	Casting A	N/A
~~F2~~	Casting DC 1 Furnace 2	Source to be removed	P	NA	HF, PM_{10}, and $PM_{2.5}$	Casting A	N/A
~~F5~~	Casting DC 3 Furnace 5	Source to be removed	P	NA	HF, PM_{10}, and $PM_{2.5}$	Casting A	N/A
~~F6~~	Casting DC 3 Furnace 6	Source to be removed	P	NA	HF, PM_{10}, and $PM_{2.5}$	Casting A	N/A
F41	Casting DC 4 Furnace 41	Existing source	P	Proposed EL [a]	NO_x, HF, PM_{10}, and $PM_{2.5}$	Casting B	Casting B
F42	Casting DC 4 Furnace 42	Existing source	P	Proposed EL [a]	NO_x, HF, PM_{10}, and $PM_{2.5}$	Casting B	Casting B
FC1	Casting C Furnace 1	New source	P	Proposed EL [a]	NO_x, HF, PM_{10}, and $PM_{2.5}$	N/A	Casting C
FC2	Casting C Furnace 2	New source	P	Proposed EL [a]	NO_x, HF, PM_{10}, and $PM_{2.5}$	N/A	Casting C
FC3	Casting C Furnace 3	New source	P	Proposed EL [a]	NO_x, HF, PM_{10}, and $PM_{2.5}$	N/A	Casting C
GTC1	Gas Treatment Center Stack 1	New source	P	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	GTC
GTC2	Gas Treatment Center Stack 2	New source	P	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	GTC
FTC	Fume Treatment Center (Baking Furnace)	New source	P	Proposed EL [a]	SO_2, NO_x, HF, PM_{10}, and $PM_{2.5}$	N/A	FTC
PASTE	Paste Plant Stack	New source	P	Proposed EL [a]	PM_{10}, and $PM_{2.5}$	N/A	PASTE
Bath	Bath Treatment	New source	L	Proposed EL [a]	PM_{10}, and $PM_{2.5}$	N/A	Bath
PS	Pallet Storage	New source	L	Proposed EL [a]	HF	N/A	PS
PotA_N	Potroom A North Vent	New source	L	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	Potrooms A-D
PotA_S	Potroom A South Vent	New source	L	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	Potrooms A-D
PotB_N	Potroom B North Vent	New source	L	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	Potrooms A-D
PotB_S	Potroom B South Vent	New source	L	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	Potrooms A-D
PotC_S	Potroom C North Vent	New source	L	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	Potrooms A-D
PotC_S	Potroom C South Vent	New source	L	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	Potrooms A-D
PotD_S	Potroom D North Vent	New source	L	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	Potrooms A-D
PotD_S	Potroom D South Vent	New source	L	Proposed EL [a]	SO_2, HF, PM_{10}, and $PM_{2.5}$	N/A	Potrooms A-D

[a] All emissions used for this dispersion modeling analysis are based on proposed emissions levels provided by RTA. As the processes at the Kitimat Smelter will operate continuously, the annual average emissions represent the maximum short-term emission rate. Therefore, a single emission value is assumed to apply for the entire simulation period.

[b] The calciner cooler emission factor is determined based on a 345 day production year, but the emission rate is assumed to occur continuously for modeling purposes. This assumption results in a conservative (i.e., higher than expected) maximum short-term emission rate.

TABLE 4-3. PRE-KMP SOURCE PARAMETERS

Emission Source	Description	Type of Source	UTM Easting (km)	UTM Northing (km)	UTM Easting (km)	UTM Northing (km)	Stack Height (m)	Base Elevation (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temperature (K)	Average Buoyancy (m^4/s^3)
DS1	Dry Scrubber #1	Point Source	519.824	5983.902	--	--	22.68	13.70	1.23	26.5	365	--
DS2	Dry Scrubber #2	Point Source	519.812	5983.972	--	--	22.68	13.70	1.23	23.9	365	--
DS3	Dry Scrubber #3	Point Source	519.739	5984.204	--	--	23.74	14.36	1.40	18.2	365	--
DS4	Dry Scrubber #4	Point Source	519.755	5984.279	--	--	23.74	14.36	1.22	18.2	365	--
DS5	Dry Scrubber #5	Point Source	519.759	5984.327	--	--	23.74	14.36	1.22	18.2	365	--
DS6	Dry Scrubber #6	Point Source	519.636	5984.854	--	--	25.68	14.00	1.22	16.4	357	--
DS7	Dry Scrubber #7	Point Source	519.564	5984.878	--	--	23.47	14.30	1.53	16.4	357	--
DS8	Dry Scrubber #8	Point Source	519.561	5984.910	--	--	26.40	14.30	1.73	12.8	357	--
PYRO	Pyro Scrubber	Point Source	519.890	5983.391	--	--	45.70	9.40	2.59	22.6	1207	--
COOLER	Calciner Cooler	Point Source	519.834	5983.434	--	--	15.20	9.40	0.71	21.0	370	
L1C[5]	Potline 1c	Line Source	519.728	5983.891	520.073	5983.954	14.00	13.70	--	--	--	571
L2A[5]	Potline 2a	Line Source	519.721	5983.930	520.065	5983.993	14.00	13.70	--	--	--	571
L2B[5]	Potline 2b	Line Source	519.716	5983.963	520.059	5984.025	14.00	13.70	--	--	--	571
L2C[5]	Potline 2c	Line Source	519.709	5983.996	520.053	5984.058	14.00	13.70	--	--	--	571
L3A[5]	Potline 3a	Line Source	519.677	5984.177	520.031	5984.241	18.00	14.20	--	--	--	1411
L3B[5]	Potline 3b	Line Source	519.671	5984.211	520.025	5984.275	18.00	14.20	--	--	--	1411
L4A[5]	Potline 4a	Line Source	519.665	5984.245	520.019	5984.309	18.00	14.20	--	--	--	1411
L4B[5]	Potline 4b	Line Source	519.659	5984.279	520.012	5984.344	18.00	14.20	--	--	--	1411
L5A[5]	Potline 5a	Line Source	519.652	5984.313	520.006	5984.378	18.00	14.20	--	--	--	1411
L5B[6]	Potline 5b	Line Source	519.646	5984.348	520.000	5984.411	18.00	14.20	--	--	--	1411
L7B[5]	Potline 7b	Line Source	519.489	5984.861	519.893	5984.935	18.00	14.00	--	--	--	1411
L8A[5]	Potline 8a	Line Source	519.483	5984.895	519.887	5984.968	18.00	14.00	--	--	--	1411
L8B[5]	Potline 8b	Line Source	519.477	5984.929	519.881	5985.002	18.00	14.00	--	--	--	1411
F1	Casting DC 1 Furnace 1	Point Source	520.016	5984.072	--	--	29.82	15.29	0.97	23.7	476	--
F2	Casting DC 1 Furnace 2	Point Source	520.012	5984.299	--	--	29.82	15.29	0.97	23.7	476	--
F5	Casting DC 3 Furnace 5	Point Source	520.017	5984.197	--	--	30.67	15.29	0.76	38.1	425	--
F6	Casting DC 3 Furnace 6	Point Source	520.020	5984.197	--	--	30.67	15.29	0.76	38.1	425	--
F41	Casting DC 4 Furnace 41	Point Source	519.844	5985.099	--	--	33.53	15.24	0.91	28.8	608	--
F42	Casting DC 4 Furnace 42	Point Source	519.849	5985.099	--	--	33.53	15.24	0.91	28.8	608	--

TABLE 4-4. POST-KMP SOURCE PARAMETERS

Emission Source	Description	Type of Source	UTM Easting (km)	UTM Northing (km)	UTM Easting (km)	UTM Northing (km)	Stack Height (m)	Base Elevation (m)	Stack Diameter (m)	Exit Velocity (m/s)	Summer Temperature (K)	Winter Temperature (K)	Summer Buoyancy (m^4/s^3)	Winter Buoyancy (m^4/s^3)
PYRO	Pyro Scrubber	Point Source	519.886	5983.375	--	--	46.50	5.80	2.57	21.96	1208	1208	--	--
COOLER	Calciner Cooler	Point Source	519.828	5983.417	--	--	15.20	6.20	0.71	20.36	374	374	--	--
F41	Casting DC 4 (B) Furnace 41	Point Source	519.824	5985.096	--	--	34.06	12.25	0.89	23.40	608	608	--	--
F42	Casting DC 4 (B) Furnace 42	Point Source	519.829	5985.097	--	--	34.06	12.25	0.89	23.40	608	608	--	--
FC1	Casting C Furnace 1	Point Source	519.817	5985.231	--	--	25.00	10.16	1.30	7.0	573	573	--	--
FC2-3	Casting C Furnace 2/3	Point Source	519.782	5985.224	--	--	25.00	10.16	1.30	7.0	573	573	--	--
GTC1	Gas Treatment Center Stack 1	Point Source	519.667	5985.050	--	--	60.00	10.10	7.00	17.0	373	373	--	--
GTC2	Gas Treatment Center Stack 2	Point Source	519.549	5985.028	--	--	60.00	10.10	7.00	17.0	373	373	--	--
FTC	Fume Treatment Center Stack	Point Source	519.349	5985.196	--	--	50.00	15.42	2.00	14.0	373	373	--	--
Bath	Bath Dust Collector	Line Source	519.368	5985.265	519.368	5,985.266	40.00	15.40	1.12	14.0	307	295.47	--	--
PS	Pallet Storage Roof Vent	Line Source	519.436	5985.250	519.633	5985.285	12.00	12.11	--	--	--	--	171.1	178.2
PotA_N	Potline A North	Line Source	519.729	5984.930	519.673	5985.212	23.50	10.10	--	--	--	--	595.58	619.70
PotA_S	Potline A South	Line Source	519.785	5984.620	519.733	5984.908	23.50	10.10	--	--	--	--	595.58	619.70
PotB_N	Potline B North	Line Source	519.660	5984.918	519.605	5985.200	23.50	10.10	--	--	--	--	595.58	619.70
PotB_S	Potline B South	Line Source	519.716	5984.608	519.664	5984.896	23.50	10.10	--	--	--	--	595.58	619.70
PotC_N	Potline C North	Line Source	519.611	5984.909	519.555	5985.191	23.50	10.10	--	--	--	--	595.58	619.70
PotC_S	Potline C South	Line Source	519.667	5984.599	519.615	5984.887	23.50	10.10	--	--	--	--	595.58	619.70
PotD_N	Potline D North	Line Source	519.542	5984.897	519.487	5985.179	23.50	10.10	--	--	--	--	595.58	619.70
PotD_S	Potline D South	Line Source	519.598	5984.587	519.546	5984.875	23.50	10.10	--	--	--	--	595.58	619.70
Paste Plant	Paste Plant	Point Source	519.891	5983.564	--	--	50.00	10.00	1.23	14.0	292	280.47	--	--

TABLE 4-5. PRE-KMP EMISSION RATES

	Year 2006					Year 2008					Year 2009				
Emission Source	**SO_2 (g/s)**	**NOx (g/s)**	**Fluoride-G (g/s)**	**PM_{10} (g/s)**	**$PM_{2.5}$ (g/s)**	**SO_2 (g/s)**	**NOx (g/s)**	**Fluoride-G (g/s)**	**PM_{10} (g/s)**	**$PM_{2.5}$ (g/s)**	**SO_2 (g/s)**	**NOx (g/s)**	**Fluoride-G (g/s)**	**PM_{10} (g/s)**	**$PM_{2.5}$ (g/s)**
DS1	1.70E+01	6.12E-04	6.55E-02	1.52E-01	1.33E-01	1.71E+01	6.44E-04	8.69E-02	1.08E-01	9.48E-02	1.54E+01	6.35E-04	1.06E-01	1.02E-01	8.91E-02
DS2	1.73E+01	1.82E-03	6.50E-02	7.02E-02	6.15E-02	1.72E+01	1.91E-03	5.43E-02	8.60E-02	7.54E-02	1.60E+01	1.83E-03	8.37E-02	1.11E-01	9.73E-02
DS3	2.17E+01	1.54E-03	1.57E-01	7.10E-02	6.23E-02	2.13E+01	1.59E-03	1.07E-01	2.65E-01	2.32E-01	1.74E+01	1.37E-03	1.24E-01	1.93E-01	1.69E-01
DS4	2.20E+01	1.56E-03	3.90E-02	7.10E-02	6.23E-02	2.14E+01	1.60E-03	3.74E-02	2.65E-01	2.32E-01	1.87E+01	1.48E-03	7.58E-02	1.93E-01	1.69E-01
DS5	2.12E+01	1.50E-03	9.92E-02	7.10E-02	6.23E-02	2.12E+01	1.59E-03	1.12E-01	2.65E-01	2.32E-01	1.85E+01	1.46E-03	1.65E-01	1.93E-01	1.69E-01
DS6	1.20E+01	8.50E-04	1.32E-01	8.18E-02	7.17E-02	1.19E+01	8.87E-04	6.27E-02	1.46E-01	1.28E-01	8.96E+00	7.06E-04	5.86E-02	1.39E-01	1.22E-01
DS7	1.24E+01	8.85E-04	1.11E-01	5.43E-02	4.75E-02	1.19E+01	8.79E-04	7.40E-02	1.30E-01	1.14E-01	1.01E+01	8.02E-04	1.15E-01	1.21E-01	1.06E-01
DS8	1.24E+01	8.77E-04	2.08E-01	1.09E-01	9.54E-02	1.19E+01	9.02E-04	1.27E-01	1.59E-01	1.39E-01	1.01E+01	7.86E-04	1.75E-01	1.58E-01	1.39E-01
PYRO	9.47E+01	7.63E+00	NA	2.21E+00	1.93E+00	7.32E+01	8.16E+00	NA	2.59E+00	2.27E+00	7.06E+01	8.16E+00	NA	2.64E+00	2.31E+00
COOLER	2.53E+00	2.04E-01	NA	4.21E-01	3.68E-01	1.95E+00	2.18E-01	NA	6.18E-01	5.41E-01	1.88E+00	2.18E-01	NA	3.32E-01	2.91E-01
L1C[5]	1.53E+00	1.08E-04	6.95E-01	8.51E-01	4.66E-01	1.52E+00	1.14E-04	6.75E-01	1.19E+00	6.54E-01	1.42E+00	1.12E-04	9.78E-01	1.26E+00	6.92E-01
L2A[5]	1.48E+00	1.05E-04	6.66E-01	8.15E-01	4.47E-01	1.49E+00	1.11E-04	6.55E-01	1.16E+00	6.35E-01	1.29E+00	1.02E-04	8.76E-01	1.13E+00	6.20E-01
L2B[5]	1.54E+00	1.09E-04	7.05E-01	8.62E-01	4.73E-01	1.50E+00	1.12E-04	6.65E-01	1.18E+00	6.45E-01	1.41E+00	1.11E-04	9.74E-01	1.26E+00	6.89E-01
L2C[5]	1.52E+00	1.08E-04	6.90E-01	8.44E-01	4.63E-01	1.53E+00	1.14E-04	6.79E-01	1.20E+00	6.58E-01	1.40E+00	1.11E-04	9.60E-01	1.24E+00	6.79E-01
L3A[5]	1.92E+00	1.36E-04	1.59E+00	1.04E+00	5.71E-01	1.92E+00	1.43E-04	2.29E+00	1.46E+00	8.01E-01	1.49E+00	1.17E-04	2.28E+00	1.30E+00	7.10E-01
L3B[5]	1.91E+00	1.35E-04	1.60E+00	1.05E+00	5.74E-01	1.84E+00	1.38E-04	2.17E+00	1.39E+00	7.60E-01	1.58E+00	1.25E-04	2.42E+00	1.37E+00	7.53E-01
L4A[5]	1.94E+00	1.38E-04	1.18E+00	1.03E+00	5.65E-01	1.86E+00	1.39E-04	1.23E+00	1.40E+00	7.66E-01	1.66E+00	1.31E-04	1.49E+00	1.44E+00	7.88E-01
L4B[5]	1.95E+00	1.38E-04	1.19E+00	1.04E+00	5.70E-01	1.91E+00	1.43E-04	1.28E+00	1.46E+00	7.99E-01	1.65E+00	1.30E-04	1.47E+00	1.42E+00	7.78E-01
L5A[5]	1.89E+00	1.34E-04	9.80E-01	9.89E-01	5.42E-01	1.87E+00	1.40E-04	1.80E+00	1.40E+00	7.65E-01	1.72E+00	1.36E-04	2.20E+00	1.48E+00	8.11E-01
L5B[6]	1.85E+00	1.31E-04	9.70E-01	9.78E-01	5.36E-01	1.87E+00	1.40E-04	1.79E+00	1.39E+00	7.62E-01	1.54E+00	1.21E-04	1.94E+00	1.30E+00	7.15E-01
L7B[5]	2.12E+00	1.50E-04	1.16E+00	1.21E+00	6.62E-01	2.10E+00	1.57E-04	1.33E+00	1.69E+00	9.28E-01	1.58E+00	1.25E-04	1.42E+00	1.46E+00	8.02E-01
L8A[5]	2.20E+00	1.56E-04	1.16E+00	1.21E+00	6.65E-01	2.10E+00	1.55E-04	1.23E+00	1.57E+00	8.62E-01	1.78E+00	1.42E-04	1.52E+00	1.57E+00	8.59E-01
L8B[5]	2.20E+00	1.55E-04	1.15E+00	1.20E+00	6.58E-01	2.10E+00	1.59E-04	1.28E+00	1.63E+00	8.95E-01	1.78E+00	1.39E-04	1.47E+00	1.52E+00	8.32E-01
F1	0.00E+00	1.80E-03	NA	4.41E-02	3.15E-02	0.00E+00	1.05E-01	NA	3.99E-02	2.85E-02	0.00E+00	9.84E-02	NA	7.21E-02	5.15E-02
F2	0.00E+00	1.82E-03	NA	4.41E-02	3.15E-02	0.00E+00	1.10E-01	NA	3.99E-02	2.85E-02	0.00E+00	9.84E-02	NA	7.21E-02	5.15E-02
F5	0.00E+00	1.85E-03	NA	5.84E-02	4.17E-02	0.00E+00	6.06E-02	NA	2.56E-02	1.83E-02	0.00E+00	5.99E-04	NA	2.56E-02	1.83E-02
F6	0.00E+00	1.79E-03	NA	5.84E-02	4.17E-02	0.00E+00	5.82E-02	NA	2.56E-02	1.83E-02	0.00E+00	4.50E-04	NA	2.56E-02	1.83E-02
F41	0.00E+00	2.81E-03	NA	1.53E-01	1.09E-01	0.00E+00	1.27E-01	NA	2.26E-02	1.61E-02	0.00E+00	1.26E-01	NA	1.92E-02	1.37E-02
F42	0.00E+00	2.83E-03	NA	1.53E-01	1.09E-01	0.00E+00	1.22E-01	NA	2.26E-02	1.61E-02	0.00E+00	1.26E-01	NA	1.92E-02	1.37E-02

TABLE 4-6. POST-KMP EMISSION RATES

Emission Source	SO_2 (g/s)			NOx (g/s)	Fluoride-G (g/s)	Fluoride-P (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	SO_2 (tonne/yr)			NOx (tonne/yr)	Fluoride-G (tonne/yr)	Fluoride-P (tonne/yr)	PM_{10} (tonne/yr)	$PM_{2.5}$ (tonne/yr)
	Case 2A	Case 1A	Case 3A						Case 2A	Case 1A	Case 3A					
PYRO	6.755E+01	8.31E+01	8.70E+01	8.574E+00	0.000E+00	0.000E+00	3.60E+00	3.60E+00	2,130	2,622	2,745	270	0	0	114	114
COOLER	1.803E+00	2.22E+00	2.32E+00	0.000E+00	0.000E+00	0.000E+00	6.40E-01	6.40E-01	57	70	73	0	0	0	20	20
F41	0.000E+00	0.000E+00	0.000E+00	8.324E-02	0.000E+00	0.000E+00	8.94E-01	8.94E-01	0	0	0	3	0	0	28	28
F42	0.000E+00	0.000E+00	0.000E+00	8.324E-02	0.000E+00	0.000E+00	8.94E-01	8.94E-01	0	0	0	3	0	0	28	28
FC1	0.000E+00	0.000E+00	0.000E+00	8.324E-02	0.000E+00	0.000E+00	1.80E-01	1.80E-01	0	0	0	3	0	0	6	6
FC2-3	0.000E+00	0.000E+00	0.000E+00	8.324E-02	0.000E+00	0.000E+00	1.80E-01	1.80E-01	0	0	0	3	0	0	6	6
GTC1	1.418E+02	1.70E+02	1.84E+02	0.000E+00	3.268E-01	1.534E-01	2.25E+00	2.25E+00	4,472	5,358	5,791	0	10	5	71	71
GTC2	1.418E+02	1.70E+02	1.84E+02	0.000E+00	3.268E-01	1.534E-01	2.25E+00	2.25E+00	4,472	5,358	5,791	0	10	5	71	71
FTC	1.614E+01	1.87E+01	2.00E+01	6.437E-01	2.134E-02	2.667E-02	2.40E-01	2.40E-01	509	589	631	20	1	1	8	8
Bath	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.001E-02	1.33E-01	1.33E-01	0	0	0	0	0	1	4	4
PS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.067E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0	34	0	0	0
PotA_N	7.24E-01	8.67E-01	9.37E-01	0.0E+00	6.0E-01	3.0E-01	6.67E-01	5.83E-01	23	27	30	0	19	9	21	18
PotA_S	7.24E-01	8.67E-01	9.37E-01	0.0E+00	6.0E-01	3.0E-01	6.67E-01	5.83E-01	23	27	30	0	19	9	21	18
PotB_N	7.24E-01	8.67E-01	9.37E-01	0.0E+00	6.0E-01	3.0E-01	6.67E-01	5.83E-01	23	27	30	0	19	9	21	18
PotB_S	7.24E-01	8.67E-01	9.37E-01	0.0E+00	6.0E-01	3.0E-01	6.67E-01	5.83E-01	23	27	30	0	19	9	21	18
PotC_N	7.24E-01	8.67E-01	9.37E-01	0.0E+00	6.0E-01	3.0E-01	6.67E-01	5.83E-01	23	27	30	0	19	9	21	18
PotC_S	7.24E-01	8.67E-01	9.37E-01	0.0E+00	6.0E-01	3.0E-01	6.67E-01	5.83E-01	23	27	30	0	19	9	21	18
PotD_N	7.24E-01	8.67E-01	9.37E-01	0.0E+00	6.0E-01	3.0E-01	6.67E-01	5.83E-01	23	27	30	0	19	9	21	18
PotD_S	7.24E-01	8.67E-01	9.37E-01	0.0E+00	6.0E-01	3.0E-01	6.67E-01	5.83E-01	23	27	30	0	19	9	21	18
PASTE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-01	1.98E-01	0	0	0	0	0	0	6	6

4.3 RECEPTORS

MOE provided areas and individual points where receptors should be placed in order to evaluate impacts of particular interest. The receptors used for this analysis are selected based on MOE guidance to assess impacts in the areas and points of interest. Terrain elevations for receptors will be taken from digital elevation models (DEMs) referenced in Section 3.1.1. Elevations will be converted from the terrain data grid spacing to the receptor grid spacing by interpolating from the four terrain data elevation values closest to the modeling object point using the CALPUFF system's TERREL processor (Version 3.684) to determine elevations at the defined receptor intervals. The following sections describe the receptors where impacts from the Kitimat Smelter will be predicted.

4.3.1 GRIDDED RECEPTORS

MOE provided the town Kitimat and Kitamaat Village as the area of interest that a fine grid should be placed to capture the impacts in residential areas. In addition, a coarse grid will be included covering the area from approximately 25 kilometers south of the Kitimat Smelter property line through Terrace. This coarse grid will cover the Kitimat Valley as well as Terrace itself. Finally, receptor points will be added along the fenceline of the Kitimat Smelter.

The spacing for the grids will be as follows:
1) a "property line" grid consisting of evenly-spaced receptors 100 meters apart placed along the Kitimat property line
2) a "fine" grid containing 100-meter spaced receptors
3) a "coarse" grid that contains 500-m spaced receptors

Figure 4-2 presents a map illustrating the placement of all fine and course grid receptors relative to the smelter and Kitimat. Figure 4-3 presents a detailed map showing only the residential receptors.

FIGURE 4-2. PLOT OF GRIDDED RECEPTORS

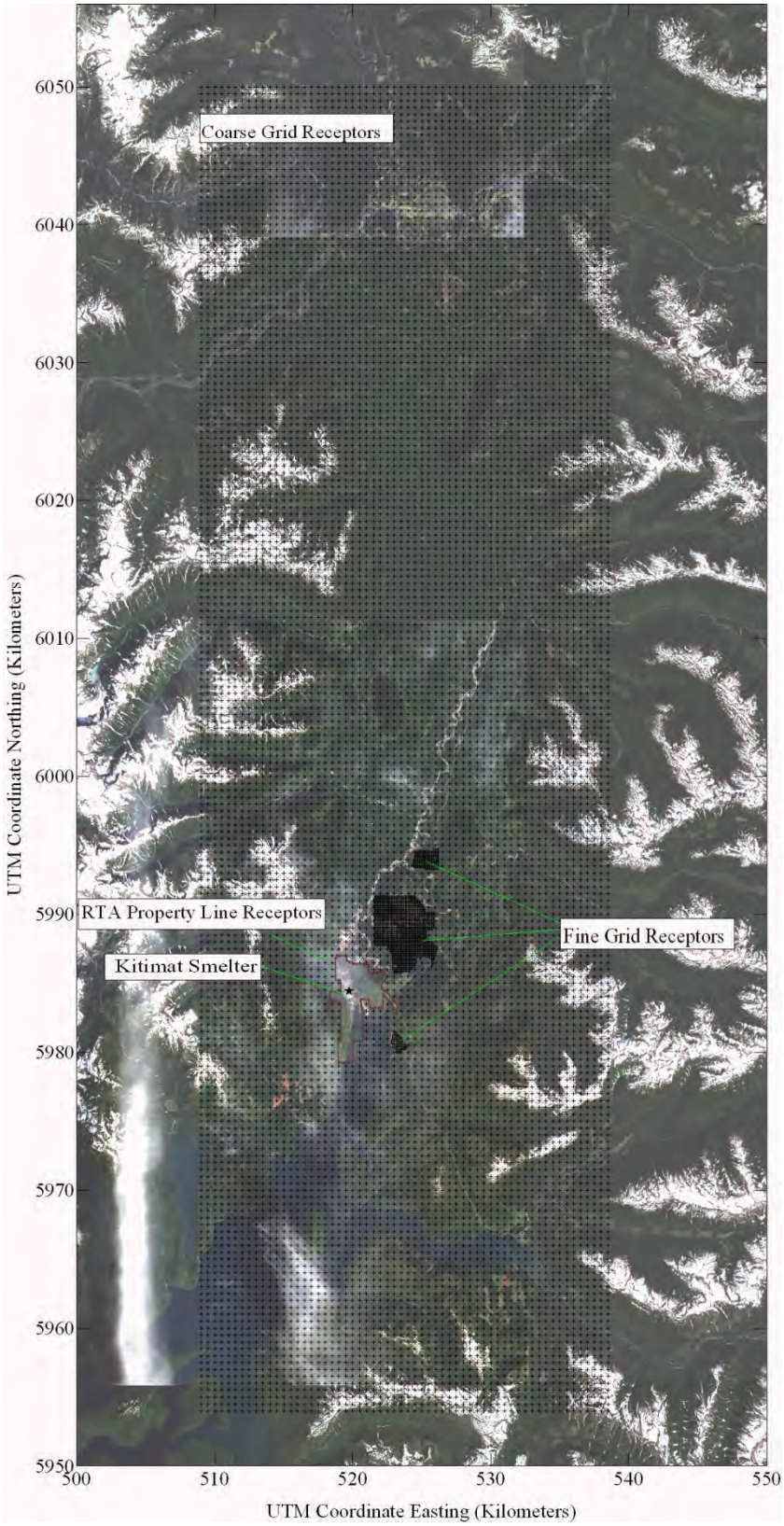
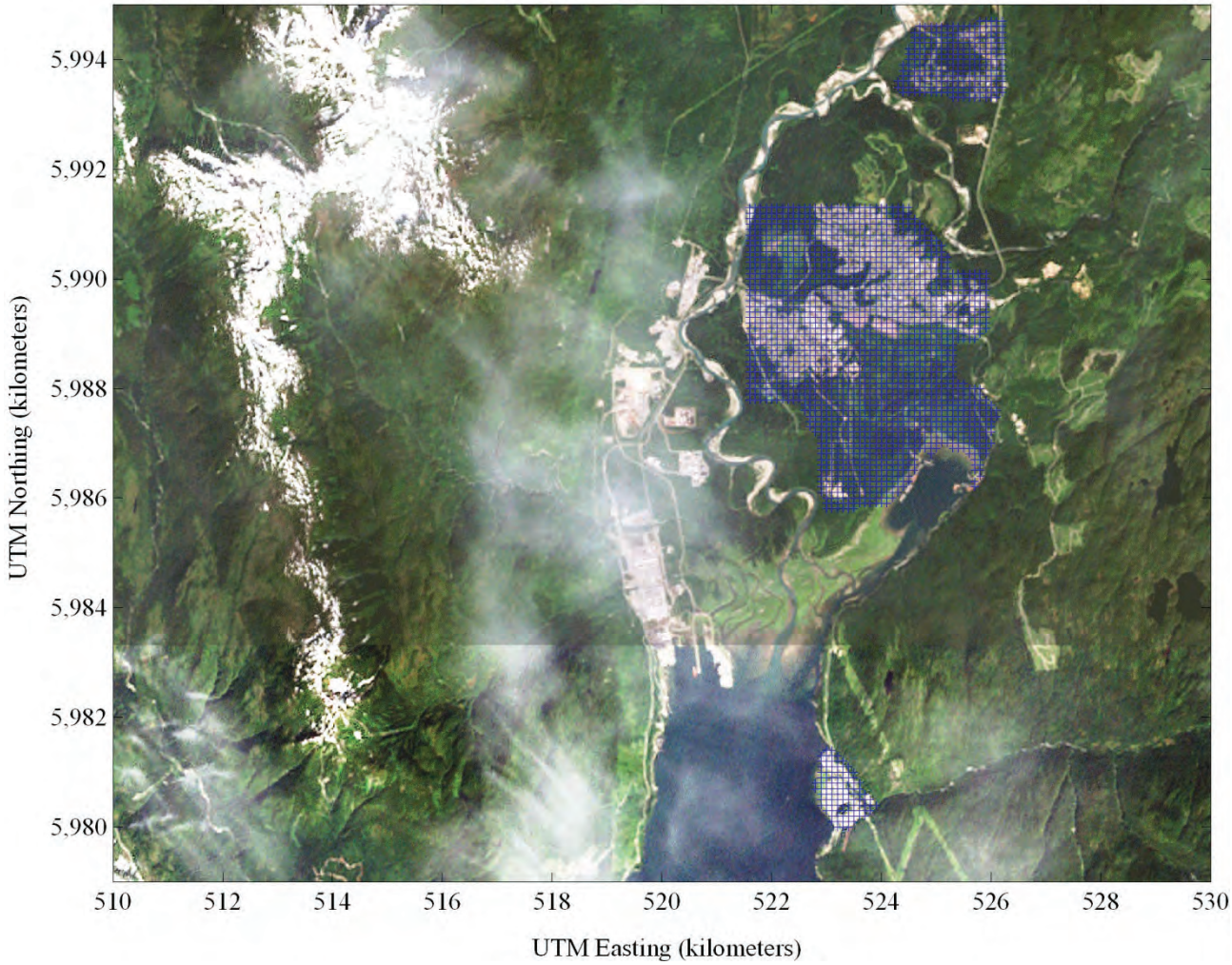


FIGURE 4-3. PLOT OF RESIDENTIAL GRIDDED RECEPTORS



4.3.2 INDIVIDUAL (DISCRETE) RECEPTORS

MOE also provided individual points where receptors should be placed to evaluate impacts at specific points of interest, as shown in Table 4-7. Individual receptors will be placed on the identified points of interest.

TABLE 4-7. RECEPTORS OF INTEREST

Points of Interest	Location [a] UTM E NAD 27 (km)	UTM N NAD 27 (km)
Bish Site 1	519.733	5980.566
Rifle Range	519.131	5985.316
KMP Monitoring Station	519.596	5985.538
Smeltersite Road (Bend)	518.925	5986.635
Haul Rd Monitoring Station	519.629	5986.710
Sand Hill	519.119	5989.101
PNG Station	520.463	5990.516
Mt. Clague Trail (Under Power Line	520.052	5992.148
Kitamaat Monitoring Station	522.992	5980.425
Kitimat River (Low Spot)	522.885	5986.058
Channel Corridor	522.120	5988.611
Riverlodge Monitoring Station	521.644	5989.384
Old Hospital Area (MAML)	522.715	5989.555
Coughlin Park	524.455	5989.187
Mt. Elizabeth High School	524.587	5990.102
Whitesail Monitoring Station	523.668	5990.956
Cablecar	524.526	5994.503
South of Smelter / Bish FSR	519.411	5979.291
Cablecar	526.257	5994.002
Helicopter Sites	516.707	5986.517
Helicopter Sites	520.969	5994.649
Kitimat	521.125	5989.946
Kitimat	521.453	5989.960
Kitimat	524.005	5989.317
Minette Bay / Kitimaat Village	523.746	5980.153
Minette Bay / Kitimaat Village	523.097	5981.237
Minette Bay / Kitimaat Village	523.116	5983.436
Minette Bay / Kitimaat Village	525.869	5986.495
Close to Smelter	519.919	5987.637
Close to Smelter	518.619	5986.182
Close to Smelter	518.533	5986.213
Close to Smelter	518.734	5985.813
Close to Smelter	519.777	5983.306
Close to Smelter	519.912	5982.595
Close to Smelter	519.195	5984.932
Close to Smelter	519.132	5985.052
Wedeene FSR / Eurocan Haulage Road	519.409	5992.365
Kitimat Railsite	520.580	5990.176
Kitamaat Indian Reserve 1	522.250	5986.500
Minette Bay (IR 5)	525.250	5987.250
Kitimat Eurocan Dock	521.218	5982.822
Near Hiking Trail Parking Lot A	518.025	5976.793
South of Smelter / Bish FSR	518.072	5976.074
South of Smelter / Bish FSR	518.068	5976.093

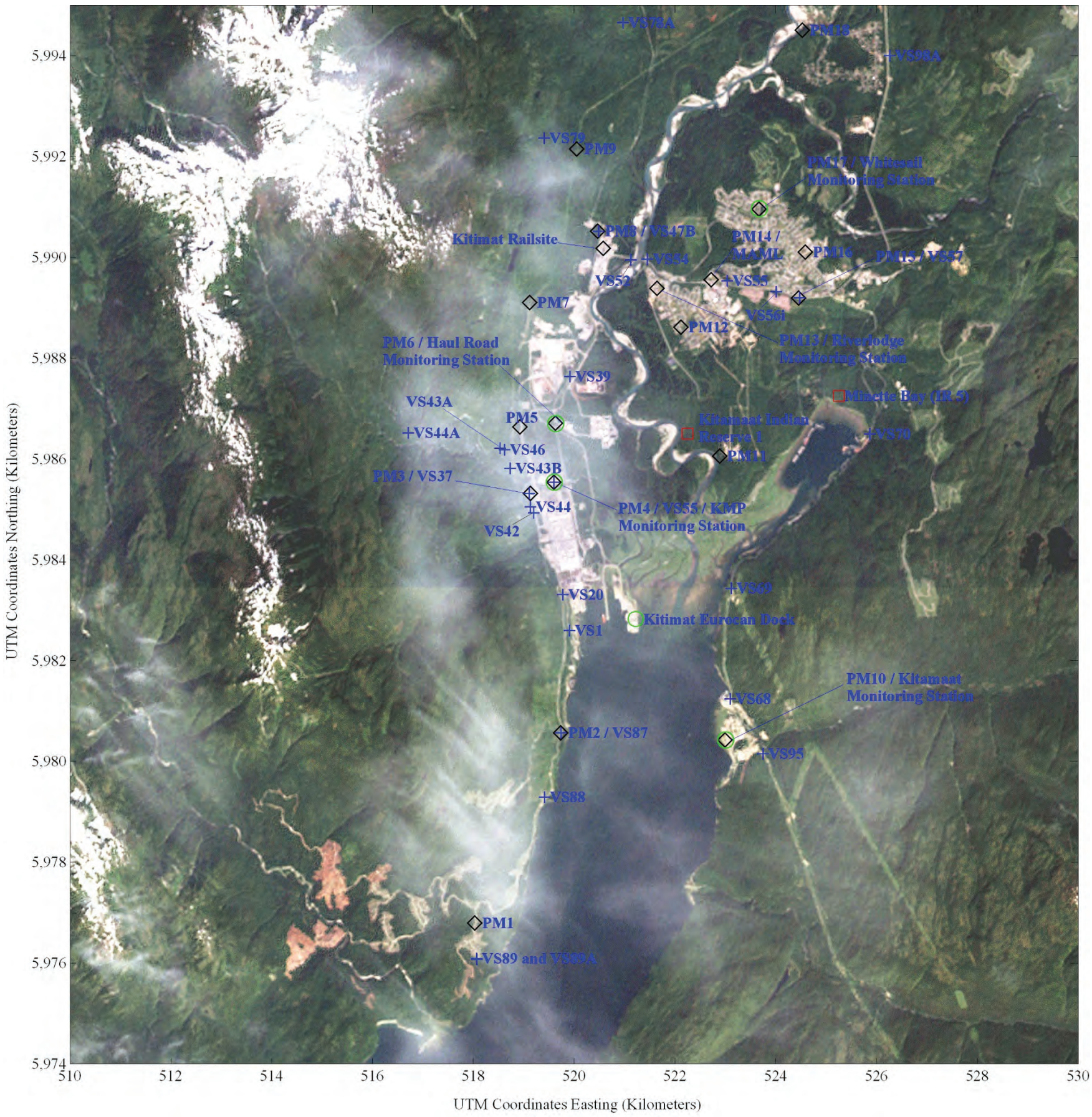
Points of Interest	Location [a] UTM E NAD 27 (km)	UTM N NAD 27 (km)
Kitimat	523.036	5989.531
Williams Creek Valley	536.0188	6031.023
Cablecar	526.3368	5996.748
Helicopter Sites	517.4888	5995.301
Helicopter Sites	517.9768	5996.562
Lakelse	517.0258	6033.386
Lakelse	527.3568	6025.198
Lakelse	526.8888	6032.564
Wedeene FSR / Eurocan Haulage Road	520.1658	6006.533
Wedeene FSR / Eurocan Haulage Road	520.1118	5999.721
Wedeene FSR / Eurocan Haulage Road	520.5708	5995.553
Wedeene FSR / Eurocan Haulage Road	519.9848	5998.29
Lakelse lake Porvincial Park	530.3498	6026.077
Thornhill Firehall	529.9598	6040.7489
Kitsumkalum	521.8588	6041.5309
Kitselas	538.2318	6051.5589
Terrace Airport	528.173	6035.378
Terrace, BC Access Centre	526.132	6041.041
Lakelse Lake Wetlands Park	526.828	6021.461
Lakelse Lake Park Furlong Bay Campground	529.982	6026.376
Onion Lake Cross Country Ski Head Trail	530.1098	6016.329

[a] All Universal Transverse Mercator (UTM) coordinates are in North American Datum (NAD) 27, Zone 9.

[b] Locations are approximated based on data provided on the British Columbia Parks websites for each area, as accessed on October 8, 2007.

Figure 4-4 and Figure 4-5 present maps showing the individual receptors of interest near the Kitimat Smelter and located at long-range distances, respectively.

FIGURE 4-4. NEAR-FIELD PLOT OF INDIVIDUAL DISCRETE RECEPTORS



Vegetation Site
Passive/Continuous Monitor
Indian Reserve
Meteorological Station

FIGURE 4-5. LONG-RANGE PLOT OF INDIVIDUAL DISCRETE RECEPTORS

4.4 CHEMICAL REACTIONS

RTA proposes to use the MESOPUFF-II chemical transformation algorithms, where the concentrations of NO_2, SO_2, ammonium sulfate, ammonium nitrate, nitric acid, and PM_{10} may be tracked.[15] There are two user-selected input parameters that affect the MESOPUFF II chemical transformation. These are the background ammonia concentration and ozone concentration.

4.4.1 OZONE

The ozone concentration can either be included in CALPUFF as a single, typical background value appropriate for the modeling region, or the ozone concentration can be included in CALPUFF as hourly ozone data from one or more ozone monitoring stations. For this analysis, a background value of 80 parts per billion (ppb) will be used (default value provided by CALPUFF).[16] During the modeling analysis, a sensitivity study will be completed as part of the CALPUFF QA/QC process to determine the sensitivity of the ozone background on SO_2 concentrations and total sulfur deposition results. The study will be conducted for conditions during which the largest difference between the default ozone and more realistic ozone values are expected. Since lower ozone background is expected during winter months, the study will be conducted for the month of January, 2009, using a background concentration of 35 ppb ozone (the lower end of the range of ozone values specified by MOE).

4.4.2 AMMONIA

The Interagency Workgroup for Air Quality Modeling (IWAQM) Phase 2 report[17] recommends background ammonia concentrations of 0.5 ppb for forest, 1.0 ppb for arid lands, and 10 ppb for grasslands. Given that the majority of the region immediately surrounding Kitimat is forested land, RTA proposes a constant background value of 0.5 ppb for ammonia.

4.5 BUILDING WAKE EFFECTS (DOWNWASH)

The emissions units at the Kitimat Smelter are evaluated in terms of their proximity to nearby structures. The purpose of this evaluation is to determine if stack discharges might become caught in the turbulent wakes of these structures. Wind blowing around a building creates zones of turbulence that are greater than if the building were absent. The CALPUFF dispersion model provides for treatment of building wake effects that, for certain emissions units (point sources), uses wind direction-specific building

[15] NO_x emissions from the facility are not modeled.

[16] If a more appropriate background ozone value is available from data for the Kitimat, BC area, then this more appropriate value will be used.

[17] United States National Park Service – Air Resources Division, U.S.D.A. Forest Service – Air Program, and U.S. Fish and Wildlife Service – Air Quality Branch, *Interagency Workgroup for Air Quality Modeling Phase 2Summary Report and Recommendations for Modeling Long Range Transport Impacts*, December 1998.

dimensions following the algorithms developed by Schulman and Hanna.[18] The minimum stack height not subject to the effects of downwash is defined by the formula:[19]

$G = H + 1.5L$

Where: G = Minimum Good Engineering Practice (GEP) stack height
H = Height of the structure
L = Lesser dimension (height or projected width of structure)

This equation is limited to stacks located within 5L of the structure. Stacks located at distances greater than 5L are not subject to the wake effects of the structure. If there is more than one stack at a given facility, the above equation must be successively applied to each stack. If more than one structure is involved, the equations must also be successively applied to each structure.

Direction-specific building dimensions and the dominant downwash structure parameters used as input to the dispersion models will be determined using the *BREEZE-WAKE/BPIP* or the *BREEZE-WAKE/BPIP PRIME* software, developed by Trinity Consultants, Inc. (Trinity). This software automates the process of using the algorithms of the U.S. EPA's sanctioned Building Profile Input Program (BPIP), version 04112 and *BREEZE*® BPIP PRIME (BPIPP), version 04274.[20] BPIP and BPIPP are designed to incorporate the concepts and procedures expressed in the GEP Technical Support document, the Building Downwash Guidance document, and other related documents. There is no difference in the results between using the *BREEZE-WAKE/BPIP* and the BPIPPRM application recommended by the Ministry. This analysis will use the BPIP PRIME unless difficulties arise during CLAPUFF runs (i.e., unless PRIME causes CALPUFF to crash), in which case BPIP without PRIME will be applied. It is expected that the use of CALPUFF Version 6.42 will allow the use of BPIP PRIME.

The output from the building downwash analysis includes the names and dimensions of the structures generating wake effects and the locations and heights of the affected emission sources (i.e., stacks). In addition, the output contains a summary of the dominant structure for each emissions source (considering all wind directions) and the actual structure height and projected widths for all wind directions.

4.6 CALPUFF MODEL CONTROL PARAMETERS

This analysis will apply the recommended CALPUFF control parameters presented in Table 9.7 of the "Guidelines For Air Quality Dispersion Modelling In British Columbia." The only CALPUFF switch setting for which a required or recommended setting is not provided is the "dispersion coefficients switch setting" (MDISP). As the goal of this CALPUFF analysis is to determine near-field impacts of the

18 L.L. Schulman, S.R. Hanna, Evaluation of Downwash Modifications to the Industrial Source Complex Model, *JAPCA* 36:258-264, 1986.

19 United States Environmental Protection Agency, Office of Air Quality Planning and Standards, *Guidelines for Determination of Good Engineering Practice Stack Height (Technical Support Document for the Stack Height Regulations) (Revised)*, Research Triangle Park, North Carolina, EPA 450/4-80-023R, June, 1985.

20 U. S. Environmental Protection Agency, User's Guide to the Building Profile Input Program, Research Triangle Park, NC, EPA-454/R-93-038.

modernization project, the dispersion coefficients switch setting is set to MDISP 2 , as recommended for near-field impacts. [21] It should also be noted that chemical transformation, wet removal, and dry deposition pollutant removal are modeled, as recommended in the "Guidelines For Air Quality Dispersion Modelling In British Columbia." The mass of a pollutant in a given puff decreases as the puff travels through time and space as a result of that pollutant being chemically transformed, removed due to wet deposition, or removed due to dry deposition.

In addition to the CALPUFF control parameters presented in Table 9.7 of the "Guidelines For Air Quality Dispersion Modelling In British Columbia," CALPUFF Version 6.42 includes the several new control parameters (not included in CALPUFF Version 5.8) that must be specified. Table 4-8 presents these new control parameters and the corresponding values that will be used in this analysis.

TABLE 4-8. NEW CALPUFF MODEL CONTROL PARAMETERS

Option	Parameter	Value
Method used to compute plume rise for point sources not subject to building downwash (Default = 1)	MRISE	1
Liquid water content flag (used only if MAQCHEM = 1) (Default =1)	MLWC	1
Partial plume penetration of elevated inversion modeled for buoyant area sources (Default = 1)	MPARTLBA	1
Ammonia vertical averaging option (Used only if MCHEM = 6 or 7, and MNH3 = 1) (Default = 1)	MAVGNH3	1
Maximum sigma z (m) allowed to avoid numerical problem in calculating virtual time or distance (Default = 5.0e06)	SZCAP_M	5.0E-6
Search radius (number of cells) for nearest land and water cells used in the subgrid TIBL module (Default = 4)	NLUTIBL	4

4.6.1 SUBGRID TIBL OPTION

CALPUFF simulates the effects of water bodies on plume transport, dispersion and deposition. One of these effects is the sudden changes that occur at the coastline of a major body of water, characterized by the thermal internal boundary layer (TIBL). A subgrid TIBL option is provided in CALPUFF to better resolve the relationship between the coastline and source locations during periods conducive to onshore fumigation events. This option will be enabled in the proposed CALPUFF analysis (MSGTIBL = 1), and the coastline location data for the Douglas Channel will be specified to better resolve coastal interaction effects.

4.6.2 SUBGRID SCALE COMPLEX TERRAIN OPTION

A subgrid complex terrain option (CTSG module) is provided in CALPUFF to better resolve important terrain features beyond the computational grid resolution (500 meters for local scale terrain and 4 km for regional scale terrain for the proposed analysis). This CTSG option will be enabled in the proposed CALPUFF analysis (MCTSG = 1) and the location, height, and other necessary data for each terrain

[21] Note that for the MDISP3 switch setting, CALPUFF uses Pasquill-Gifford coefficients for rural areas and McEllroy-Pooler for urban areas automatically based on land use in the CALMET data.

feature will be specified to better resolve concentrations at these features. MOE provided four terrain features that will be included. Figure 4-6 shows the location of each terrain feature.

The CTSG module is not commonly utilized, and the effect of the module on results is unknown. Additionally, the CTSG module may not successfully run for all meteorological conditions. In order to analyze the effect of the CTSG module on modeled concentrations at the hill receptors, a comparison CALPUFF analysis for one month is conducted with and without the CTSG module. Results of the comparison are included in Table 4-9.

FIGURE 4-6. PLOT OF MODELED TERRAIN FEATURES

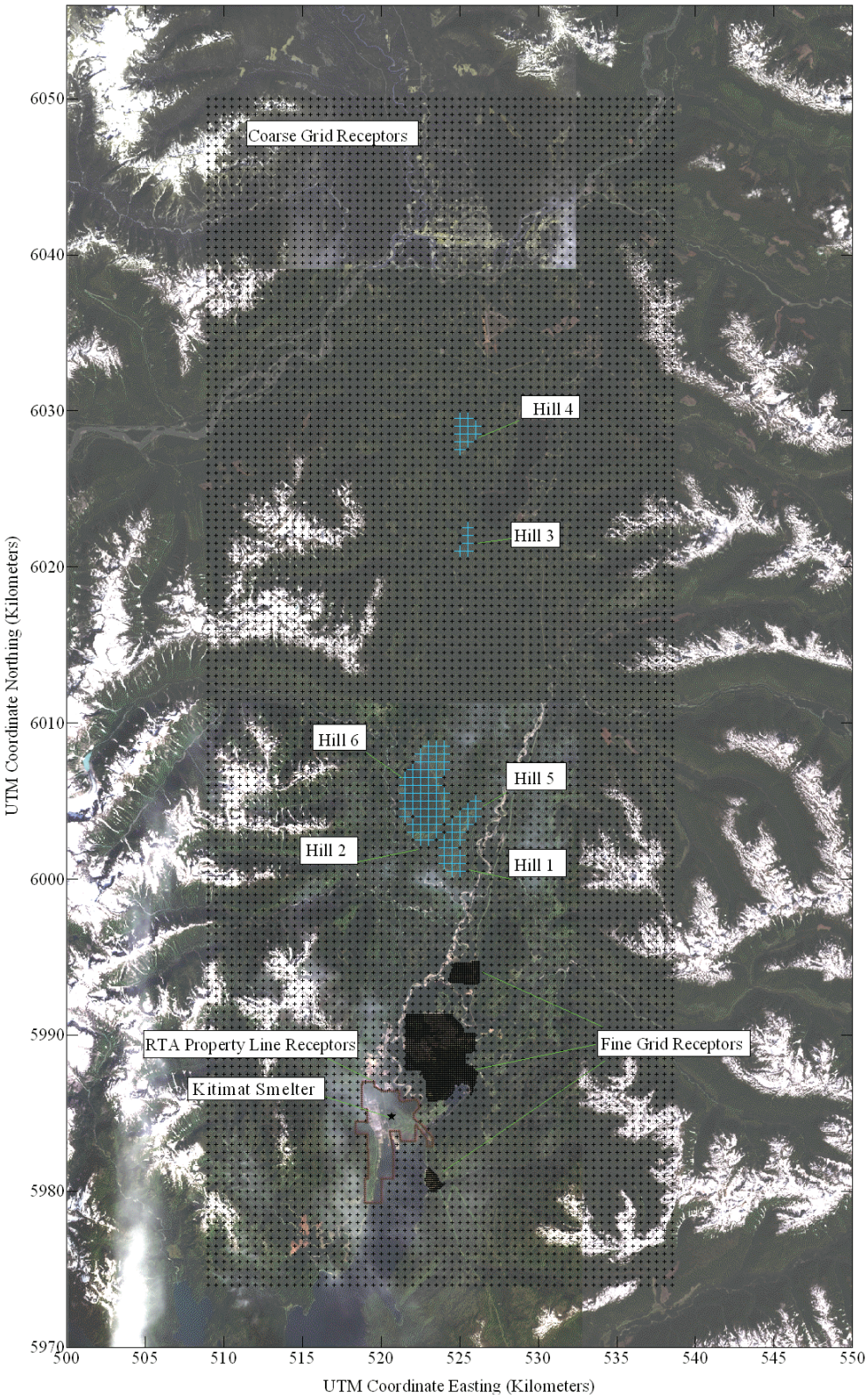


TABLE 4-9. RESULTS OF CTSG MODULE COMPARISON

Hill Feature	Averaging Period	Maximum Monthly Average Concentration (µg/m3)		Percent Change with CTSG
		Without CTSG	With CTSG	
ALL	Monthly	4.28	5.25	23%
Hill 1		4.01	1.36	-66%
Hill 2		4.28	2.89	-32%
Hill 3		3.03	1.56	-49%
Hill 4		2.55	1.31	-49%
Hill 5		4.08	1.40	-66%
Hill 6		4.08	5.25	29%

The maximum monthly average concentration over all the receptors at the hills was higher with the CTSG module turned on than without. However, considering a hill by hill comparison, the maximum monthly average concentration at only one of the six terrain features is higher with the CTSG module turned on than without the module. Receptors at the other five hills experience a decrease in concentrations when the CTSG module is used. A receptor by receptor comparison, included in Appendix D, shows that the concentrations decrease from 21% to 88% at all receptors except one, which has a 37% increase. This indicates that the CTSG module is expected to decrease modeled concentrations at most hill receptors, depending on the specific hill feature modeled.

If the conclusion of the deposition analysis (comparison between the soil or water critical loading levels and the deposition results) at any of these hill receptors could change (from acceptable to not acceptable or vice versa) by conducting a refined analysis using the CTSG module , then refined modeling with CTSG module will likely be included in the modeling analysis.

4.7 MODELING ANALYSES

These modeling analyses will predict ambient concentrations of PM_{10}, $PM_{2.5}$, SO_2, NO_X, and HF as well as deposition of PM_{10}, SO_2, NO_X and SO_4. The modeling output will include concentration contour maps of these air quality parameters, tables of maximum short and long term average air quality parameters, tables showing the maximum source group contribution, and tables presenting air quality parameters at the receptors of interest presented in Table 4-7.

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4.7.1 MODELED CONCENTRATION

The resulting concentrations of PM_{10}, $PM_{2.5}$, SO_2, NO_X, and HF from this air dispersion modeling analysis will be compared against the Ambient Air Pollution Control Objectives for British Columbia to demonstrate that increased emissions from the Kitimat Smelter do not cause or contribute to an exceedance of the objectives. The objectives are summarized in Table 4-10.

TABLE 4-10. AIR QUALITY OBJECTIVES AND STANDARDS (μg/m^3)

Contaminant	Averaging Period	Canada (Maximum Desired)	Canada (Maximum Acceptable)	Canada (Maximum Tolerable)	B.C. PCO Minimum of Range	B.C. PCO Maximum of Range	WHO	U.S. EPA
Hydrogen Fluoride	1 hour	NL [a]	NL	NL	NL [b]	NL [b]	NA	NA
Sulphur Dioxide	1 hour	450	900	NL	450	900	500	196 [c]
	3 hour	NL	NL	NL	375	665	NL	NL
	24 hour	150	300	800	160	260	20	365 [d]
	Annual	30	60	NL	25	50	NL	80
Nitrogen Dioxide	1 hour	NL	400	1000	NL	NL	NA	NA
	24 hour	NL	200	300	NL	NL	NA	NA
	Annual	60	100	NL	NL	NL	NA	NA
PM_{10}	24 hour	NL	NL	NL	50		NA	NA
$PM_{2.5}$	24 hour	30 [e]			25 [e]		NA	NA
	Annual	NL			8		NA	NA

[a] NL indicates No Limit appears in the table provided on B.C. MOE's PCO.

[b] No BC air pollution control objectives have been established for hydrogen fluoride. However, modeled concentrations will be compared to the following hydrogen fluoride objectives proposed by Risk Sciences International:

1 hour: 1000 ppb

24 hour: 40 ppb

30 day: 40 ppb

[c] Based on three-year average of the 99th percentile of the annual distribution of daily maximum 1-hour concentrations

[d] Not to be exceeded more than once per calendar year.

[e] Based on annual 98th percentile value, averaged over three consecutive years.

4.7.2 BACKGROUND CONCENTRATION

Concentrations of PM_{10} and $PM_{2.5}$, as measured at the nearby Riverlodge residential monitoring station will be considered in the analysis of PM_{10} and $PM_{2.5}$ The appropriate monitored concentrations (98^{th} percentile of the 1-hour, 3-hour, and 24-hour averaging periods, and the annual average) will be combined with the modeled concentrations at all locations.

Concentrations of SO_2 as measured at the nearby Kitamaat Village monitoring station will be considered in the analysis of the residential ambient air quality impacts. The appropriate monitored concentration (98^{th} percentile of the 1-hour, 3-hour, and 24-hour averaging periods, and the annual average) will be combined with the modeled concentrations at all locations.

Background concentrations of hydrogen fluoride will not be included, as the smelter is the only source of hydrogen fluoride in the region.

TABLE 4-11. BACKGROUND CONCENTRATIONS

Contaminant	Averaging Period	Background Concentration
Sulphur Dioxide	1 hour	1.5 ppb
	3 hour	1.5 ppb
	24 hour	1.2 ppb
	Annual	0.4 ppb
PM_{10}	24 hour	19 $\mu g/m^3$
$PM_{2.5}$	24 hour	8.8 $\mu g/m^3$
	Annual	2.8 $\mu g/m^3$

4.7.3 DEPOSITION ANALYSIS

Gas-phase dry deposition fluxes will be modeled for SO_2, NO_X, HNO_3, and gaseous fluoride. Particulate-phase dry deposition will be modeled for SO_4, NO_3, particulate fluoride, and PM_{10}. Wet deposition will be modeled for all pollutants. The sum of wet and dry deposition fluxes for SO_2 and SO_4 will represent the total sulfur deposition as follows:

$$Sulfur\ Deposition\ (kg/ha/yr) = \left(flux_{SO2} + flux_{SO4} \right)_{wet} + \left(flux_{SO2} + flux_{SO4} \right)_{dry}$$

4.7.4 MODELING RESULTS

Trinity will develop different sets of modeling results for the various groups of qualified professionals. These results are expected to be presented directly or indirectly in the Technical Assessment Report. The following list summarizes the modeling results that will be developed.

General Results / Human Health

- Concentration summary tables comparing maximum residential and maximum offsite concentrations to the published ambient air quality objectives and standards listed in Table 4-10.
- Concentration summary tables providing maximum concentrations of each pollutant for each relevant averaging period at each point of interest listed in Table 4-7.
- Concentration contour plots for each pollutant and average period of interest.

Vegetation

- Concentration contour plots for pollutants and averaging periods of interest (same as general plots).
- Concentration plots showing locations with concentrations above minimum levels of concern (e.g., 0.25 ppm, 3-hour average, growing season only).
- Frequency information for receptors above the minimum level of concern (e.g., number of receptors with 2nd high or 3rd high concentration above minimum level of concern, frequency plots, etc.)

Soil/Water Deposition

- Total sulfur (as SO_4) deposition contour plots (average over three years).
- Results data with three year average deposition at each receptor for each pollutant (total sulfur, total nitrogen, gaseous fluoride, particulate fluoride, and PM_{10}).

4.8 CALPUFF QA/QC PROCEDURES

The Quality Assurance (QA) procedures for the CALPUFF analyses will be performed as specified in Sections 10.2.1 of the B.C. Dispersion Modelling Guidelines and as further described below.

The quality assurance of the source and emissions data is a major component of the CALPUFF modeling. Also, it is common for errors in source coordinates and related projection/datum parameters to occur. Therefore, confirmation of the source locations in relation to the modeling coordinates will be conducted as part of the modeling QA.

The CALPUFF modeling system contains built-in features to facilitate quality assurance of the modeling results. These include the automatic production of "QA" files for various datasets, including geophysical fields, sources, receptors, and imbedded tracking of model options and switches within the output files from the major modeling units of the modeling system. The Graphical User Interface system (GUI) provided as part of the latest CALPUFF modeling system allows these QA files to be displayed graphically. The graphic QA files will be reviewed to identify any inaccurate data as part of the QA procedures.

Part of the CALPUFF modeling system's built-in QA capabilities is a variable tracking system that retains the control file inputs for CALMET and CALPUFF in the output files create by the models. This information includes the Version and Level numbers of the processor codes and main model codes used in the simulations as well as the control files from the main models (CALMET and CALPUFF). The information from the preprocessing steps and the CALMET and CALPUFF model simulations is all carried forward and saved in the CALPUFF/postprocessor output files so that the final concentration/flux files contain a history of the model options and switch settings. The switch settings provided in the control file will be compared with the switch setting actually used in the model simulations to confirm no variations have occurred.

5. SUMMARY

RTA is proposing to modernize their aluminum smelter located in Kitimat, British Columbia (Kitimat Smelter) at the head of the Douglas Channel. As a result of the proposed project, RTA is conducting air dispersion modeling to better understand the environmental implications associated with increased SO_2 emissions from the Kitimat Smelter. A detailed CALPUFF modeling analysis was completed in July 2009 using the design parameters for KMP available at that time. Since that time, new design parameters for KMP were provided by RTA. A revised dispersion modeling analysis will be conducted using the new KMP design parameters. The revised dispersion modeling analysis will also use three years of meteorological data, and updated modeling methodology. The objective of this document is to provide a protocol summarizing the modeling methods and procedures that will be followed to conduct a revised CALPUFF dispersion modeling analysis for the current design parameters for KMP. This protocol has been developed in cooperation with the Ministry of Environment (MOE). RTA respectfully requests that the MOE provide written approval of the procedures described in this protocol.

APPENDIX A

LAND USE CATEGORY MAPPING

Default CALMET Land Use Categories and Associated Geophysical Parameters
Based on the U.S. Geological Survey Land Use Classification System
(14-Category System)

Land Use Type	Description	Surface Roughness (m)	Albedo	Bowen Ratio	Soil Heat Flux Parameter	Anthropogenic Heat Flux (W/m^2)	Leaf Area Index
10	Urban or Built-up Land	1.0	0.18	1.5	.25	0.0	0.2
20	Agricultural Land - Unirrigated	0.25	0.15	1.0	15	0.0	3.0
-20*	Agricultural Land - Irrigated	0.25	0.15	0.5	15	0.0	3.0
30	Rangeland	0.05	0.25	1.0	15	0.0	0.5
40	Forest Land	1.0	0.10	1.0	.15	0.0	7.0
51	Small Water Body	0.001	0.10	0.0	1.0	0.0	0.0
54	Bays and Estuaries	0.001	0.10	0.0	1.0	0.0	0.0
55	Large Water Body	0.001	0.10	0.0	1.0	0.0	0.0
60	Wetland	1.0	0.10	0.5	.25	0.0	2.0
61	Forested Wetland	1.0	0.1	0.5	0.25	0.0	2.0
62	Nonforested Wetland	0.2	0.1	0.1	0.25	0.0	1.0
70	Barren Land	0.05	0.30	1.0	.15	0.0	0.05
80	Tundra	20	0.30	0.5	.15	0.0	0.0
90	Perennial Snow or Ice	20	0.70	0.5	15	0.0	0.0

* Negative values indicate "irrigated" land use

*Table obtained from CALMET User's Guide:

Scire, Robe, Fernau, Yamaratino. A User's Guide for the CALMET Meteorlogical Model (Version 5). Januarary 2000.

APPENDIX B

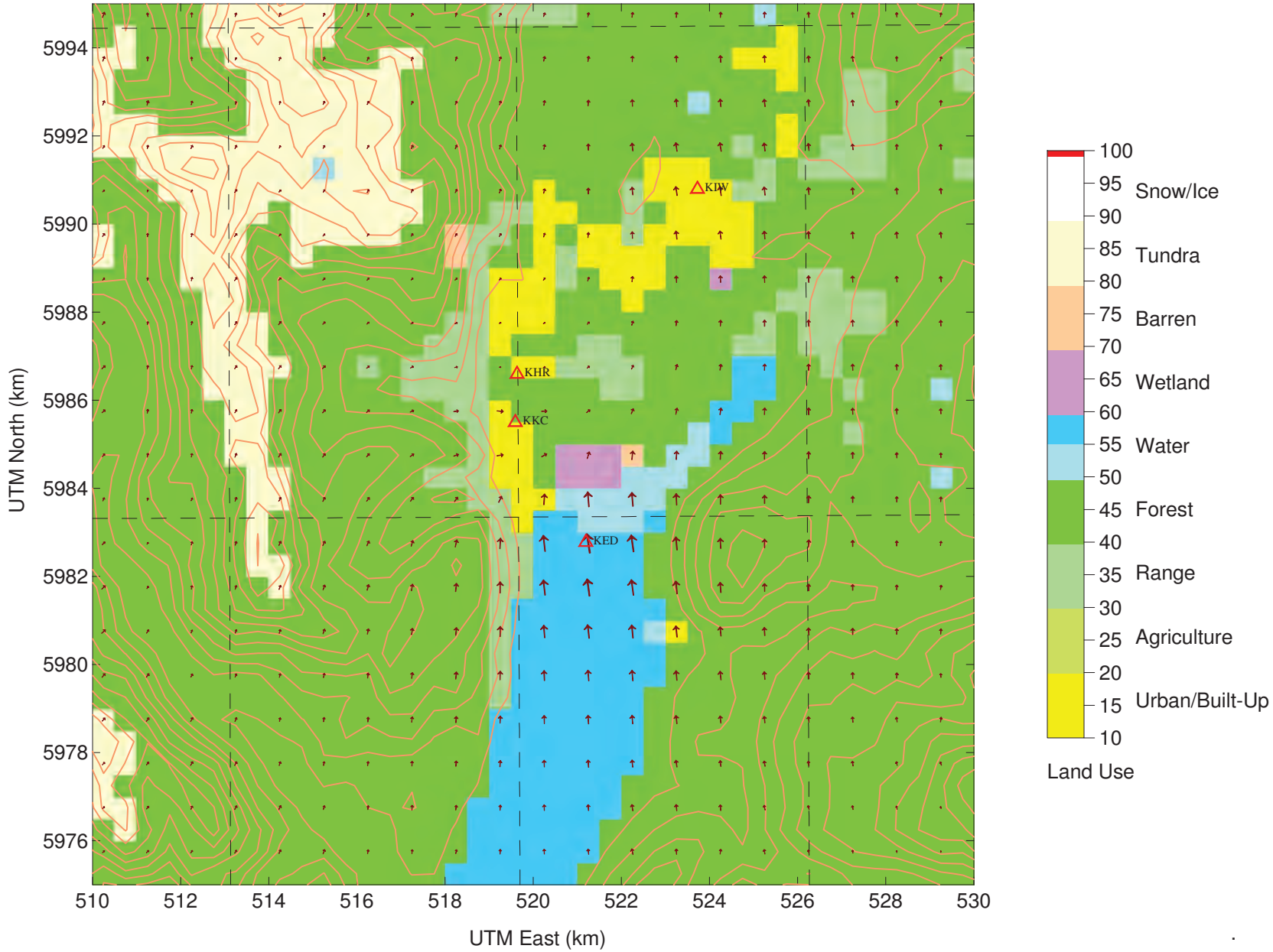
INITIAL CALMET QA/QC PLOTS

2D Vector Plots
Time Series Plots

Aug 15, 2009
04:00 LST(UTC-0800)

KMP CALMET Wind Field
with KMP Camp Station

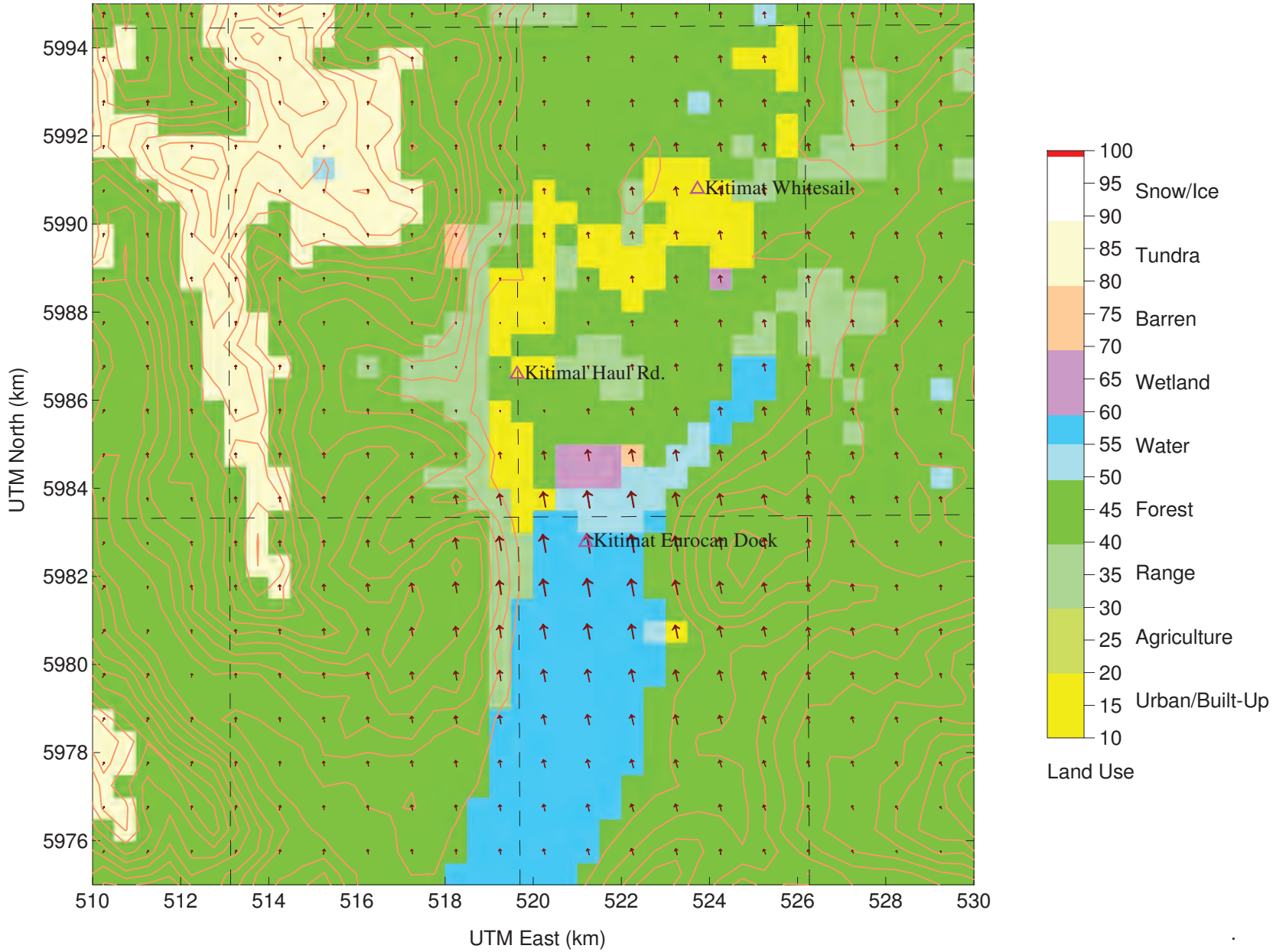
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Hemisphere: N
Datum: NAS-C



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KMP CALMET Analysis Wind Field Plot without KMP Camp Station

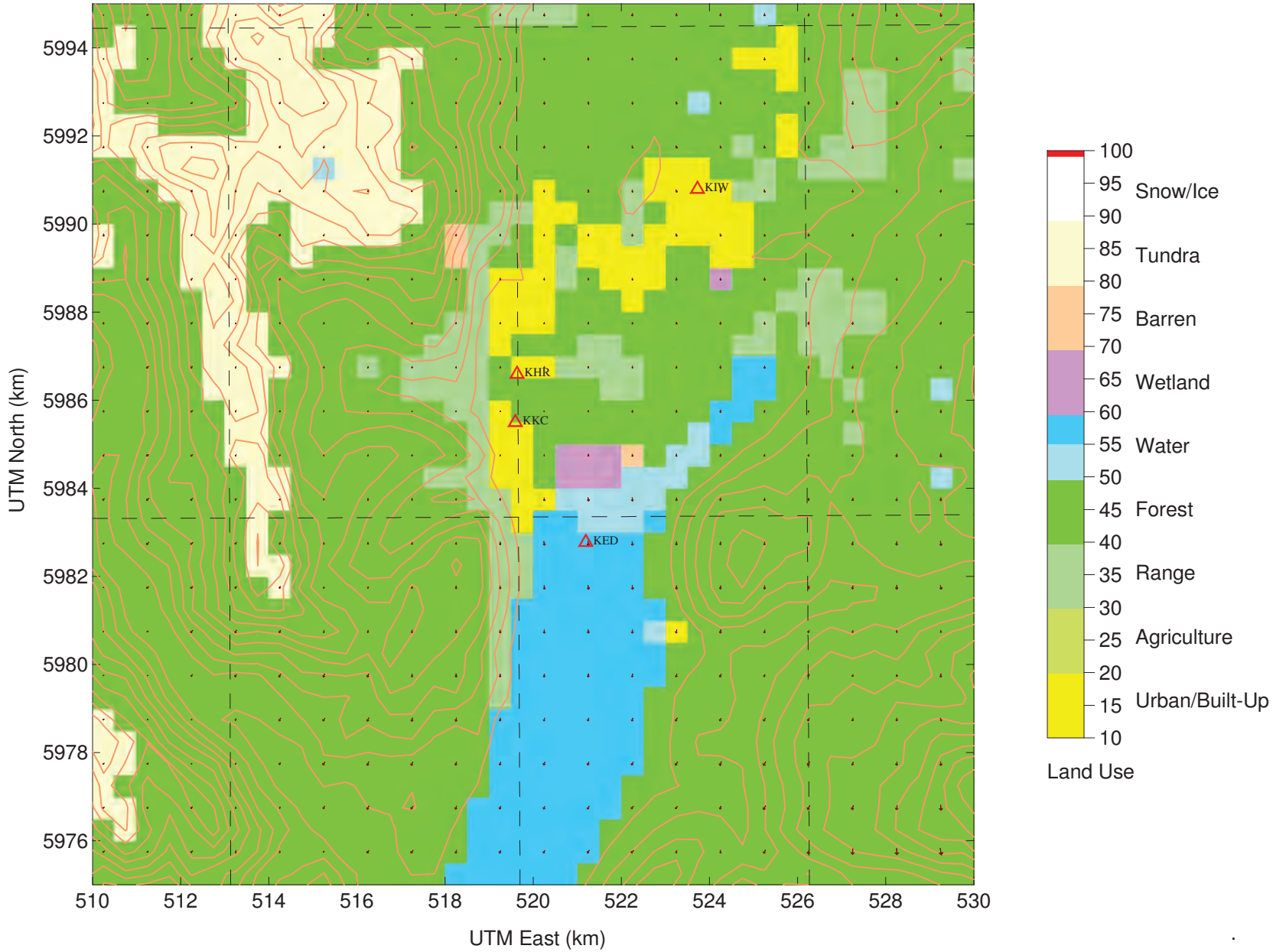
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Datum: NAS-C



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KMP CALMET Analysis Wind Field Plot with KMP Camp Station

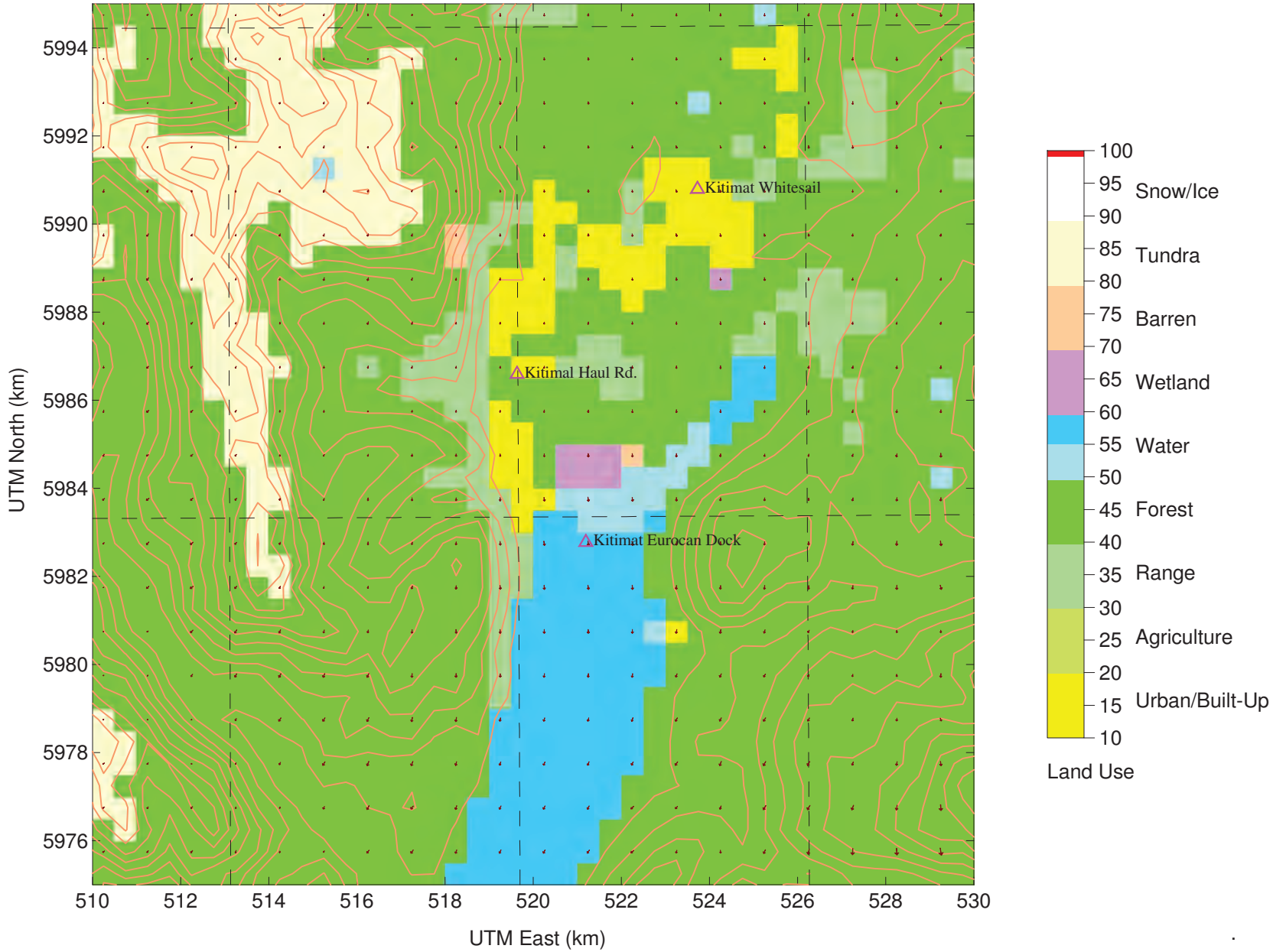
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KMP CALMET Analysis Wind Field Plot without KMP Camp Station

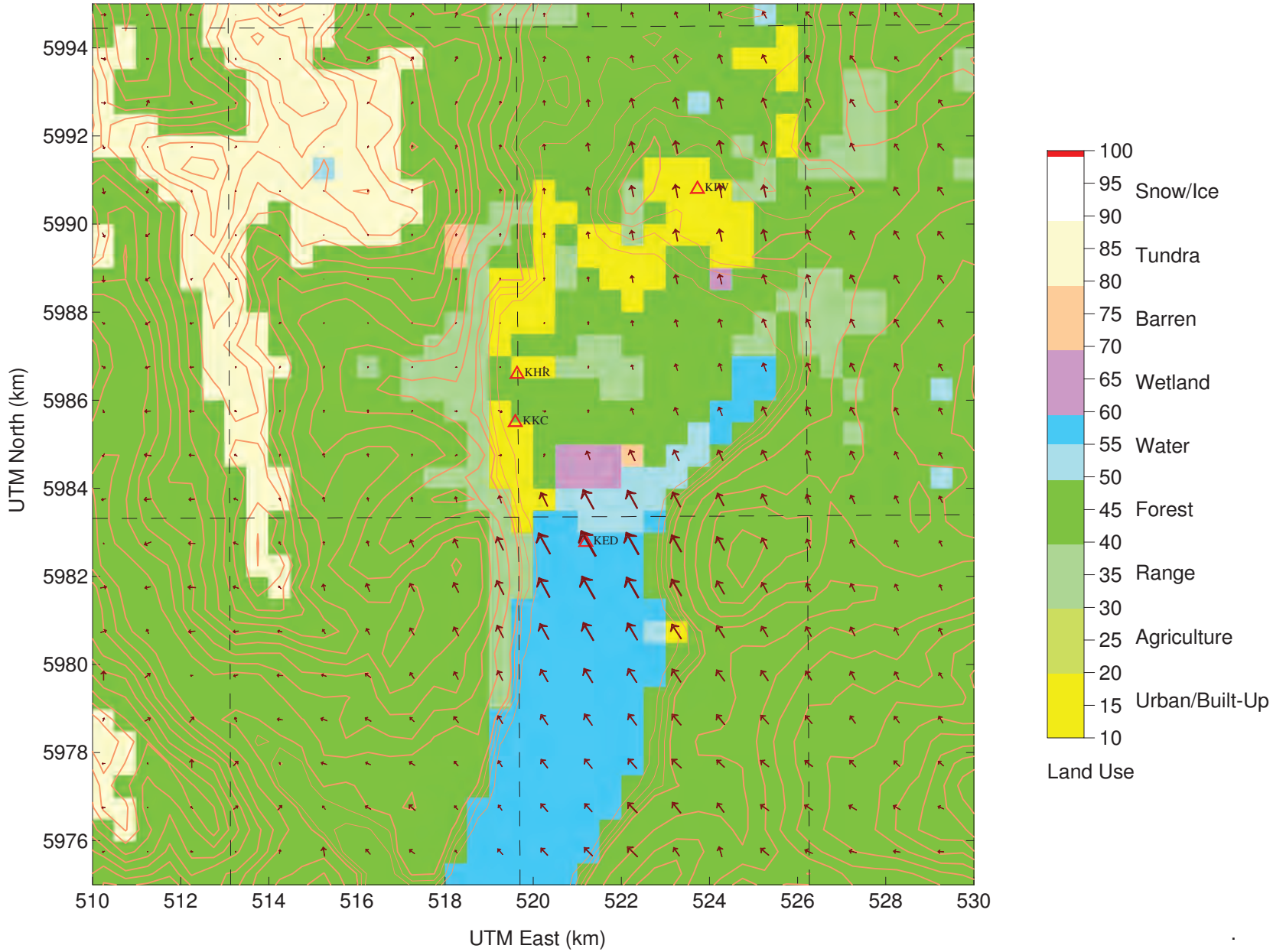
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Hemisphere: N
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KMP CALMET Analysis Wind Field Plot
with KMP Camp Station

Aug 15, 2009
20:00 LST(UTC-0800)

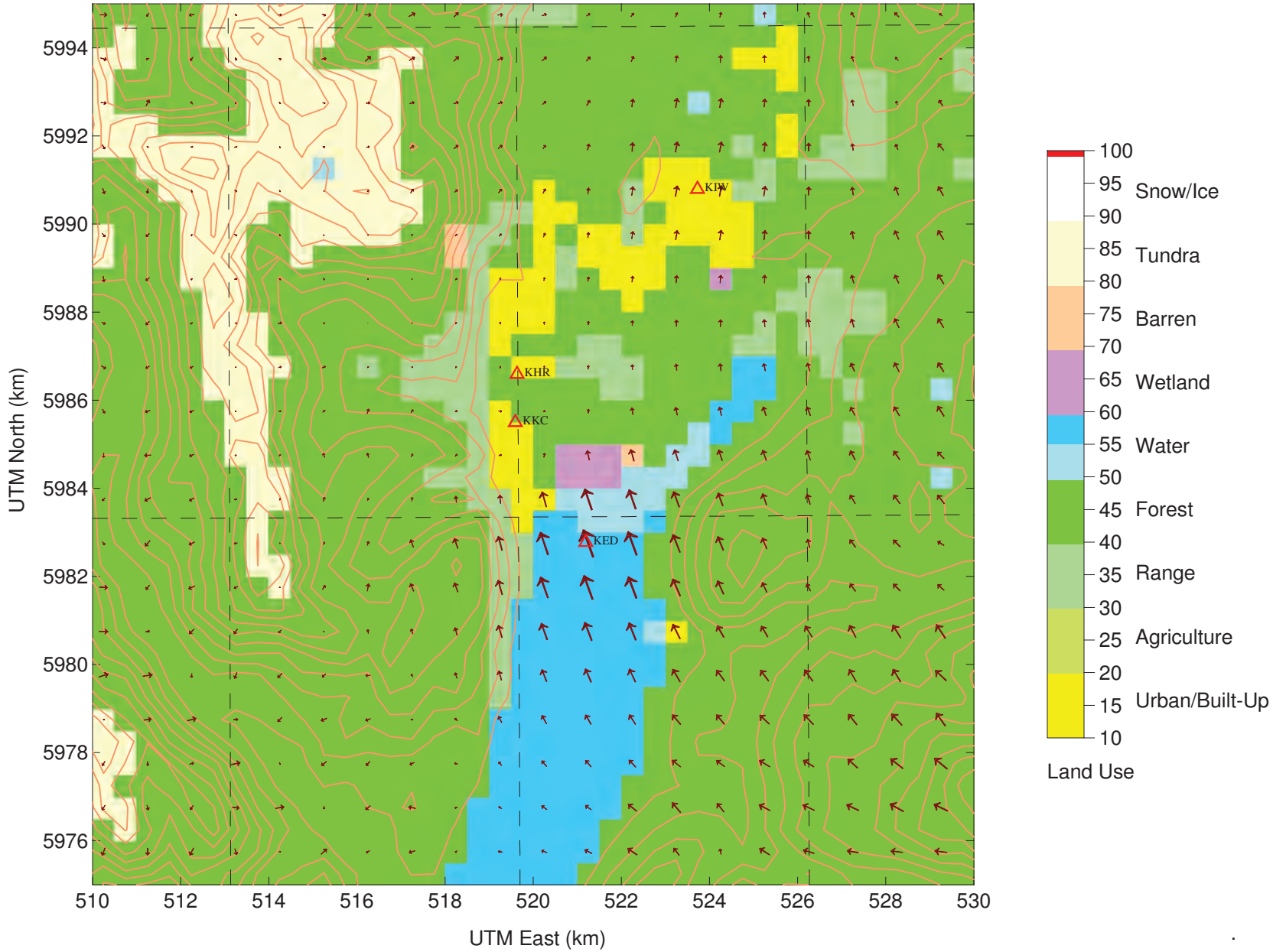
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KMP CALMET Analysis Wind Field Plot with KMP Camp Station

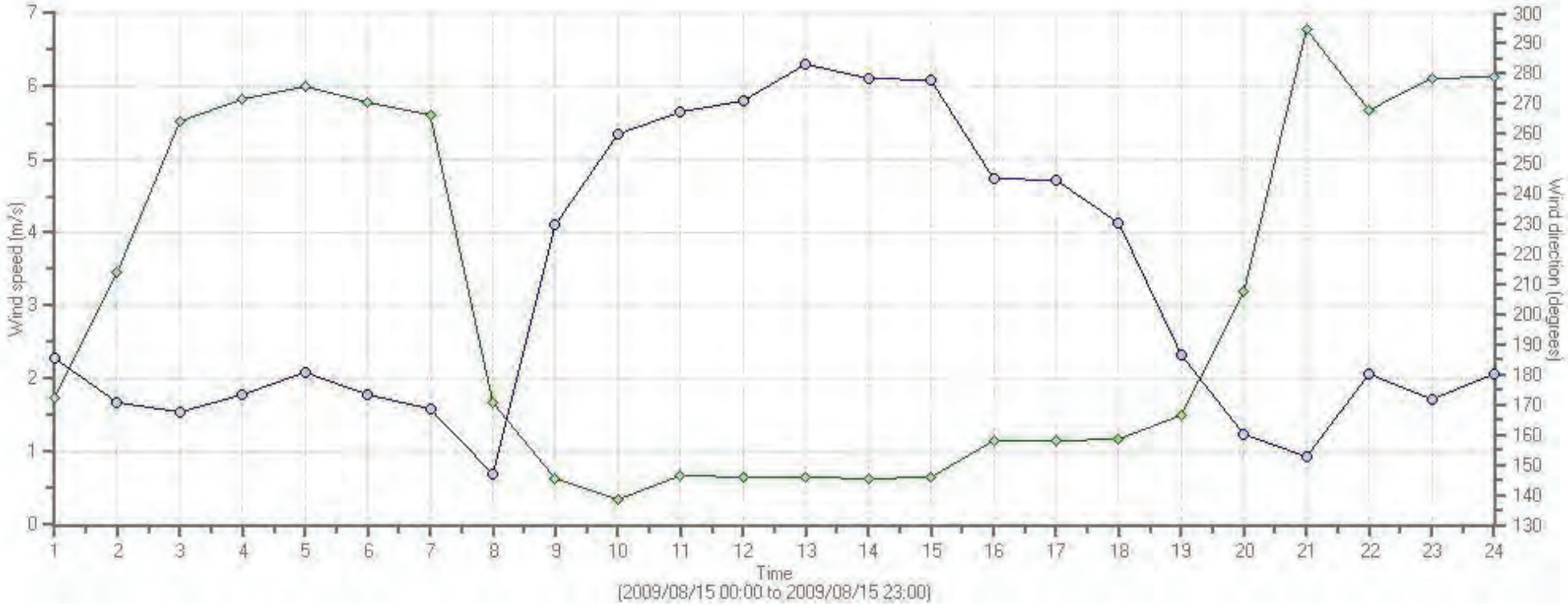
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Hemisphere: N
Datum: NAS-C



Wind speed vs. Wind direction

With KMP Camp Station

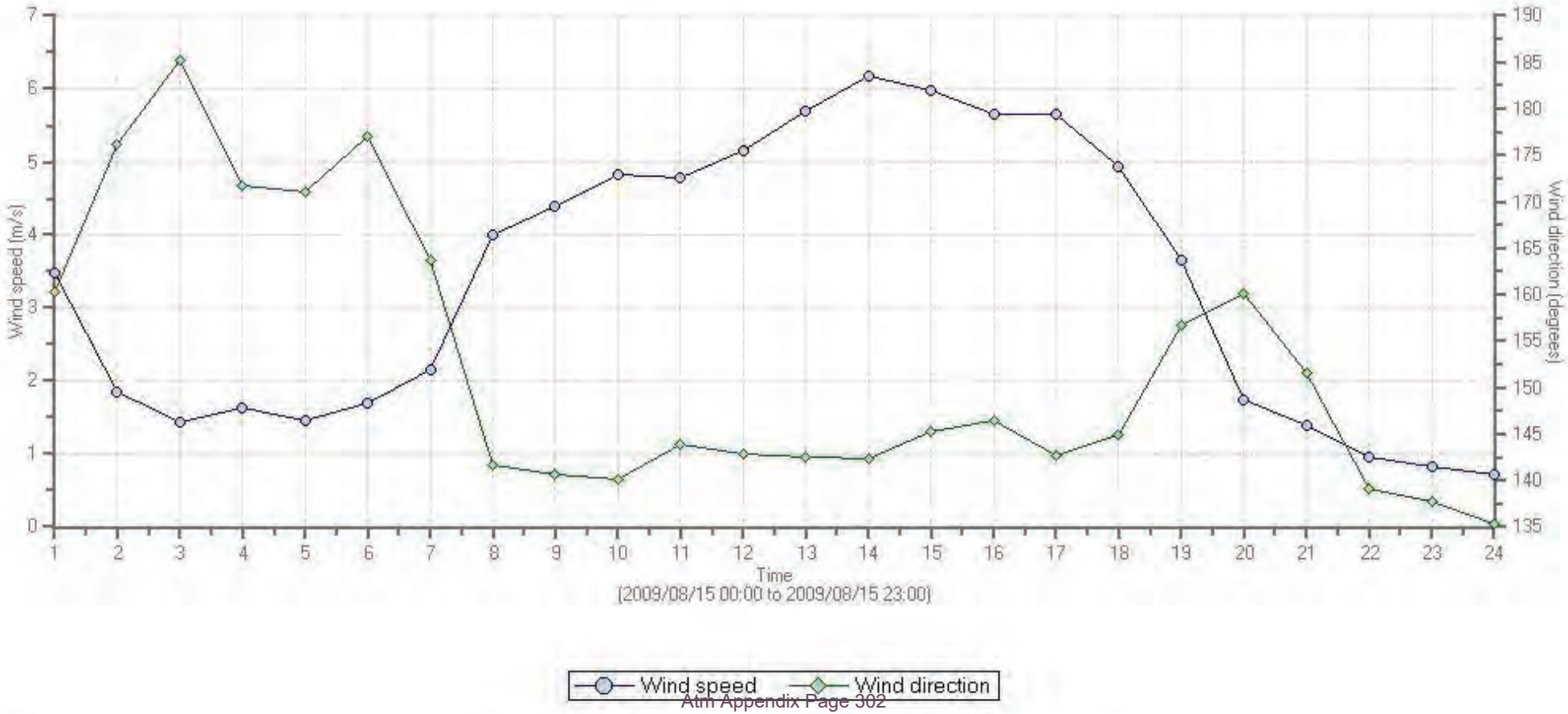
At 519.750, 5985.750, 10 (Near KMP Camp Station)



Wind speed vs. Wind direction

Without KMP Camp Station

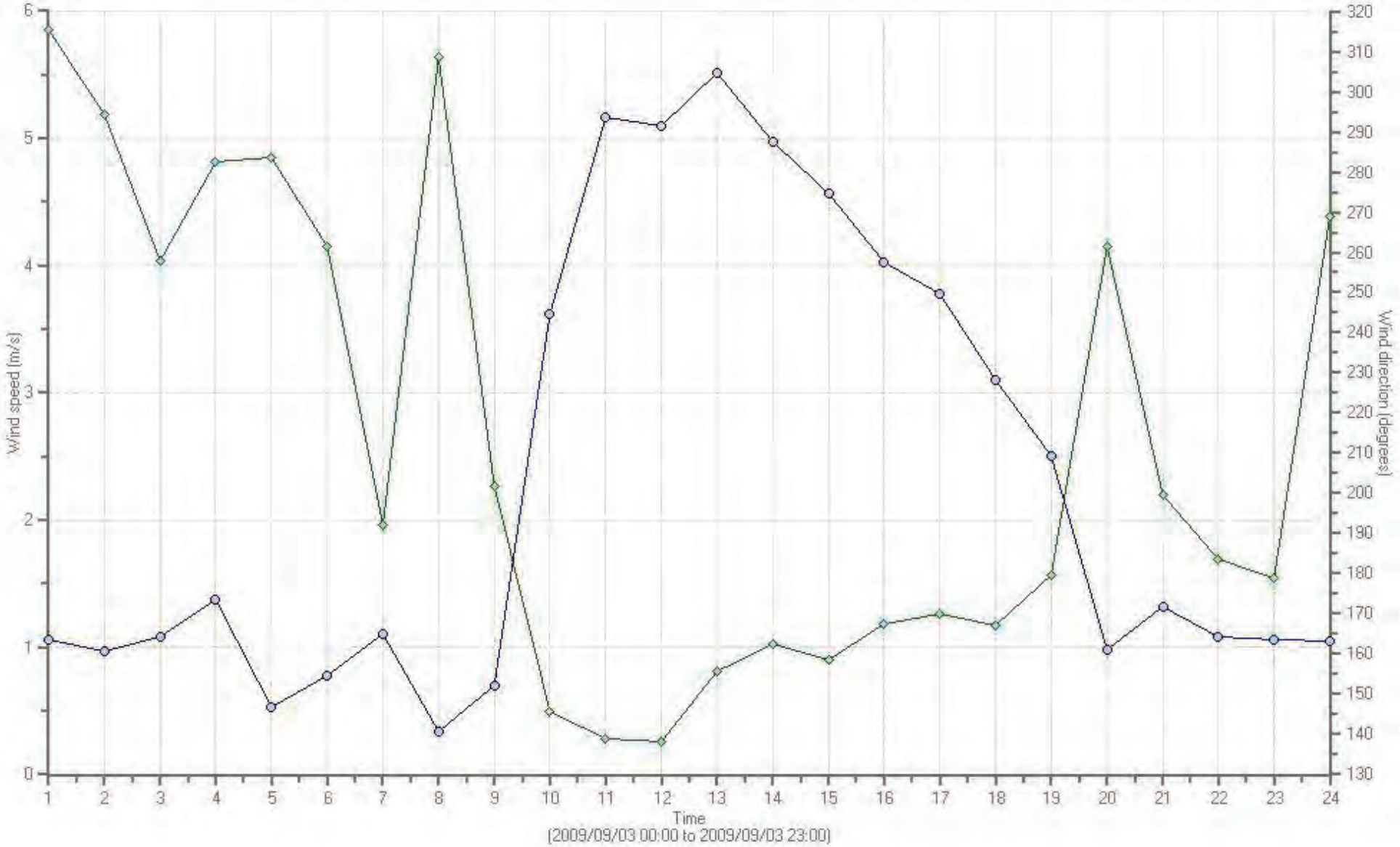
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Wind speed vs. Wind direction

With KMP Camp Station

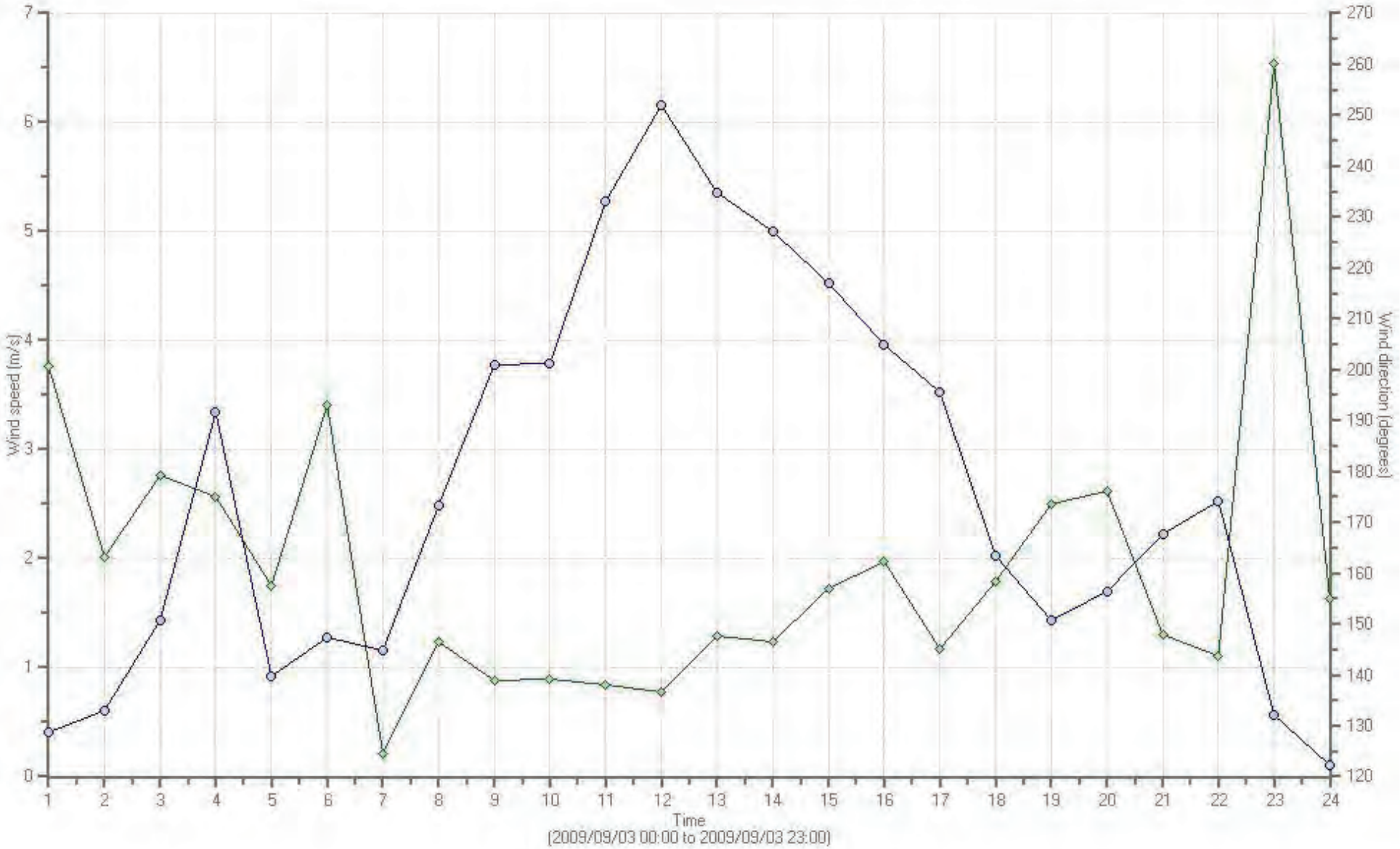
At 519.750, 5985.750, 10 (Near KMP Camp Station)



Wind speed vs. Wind direction

Without KMP Camp Station

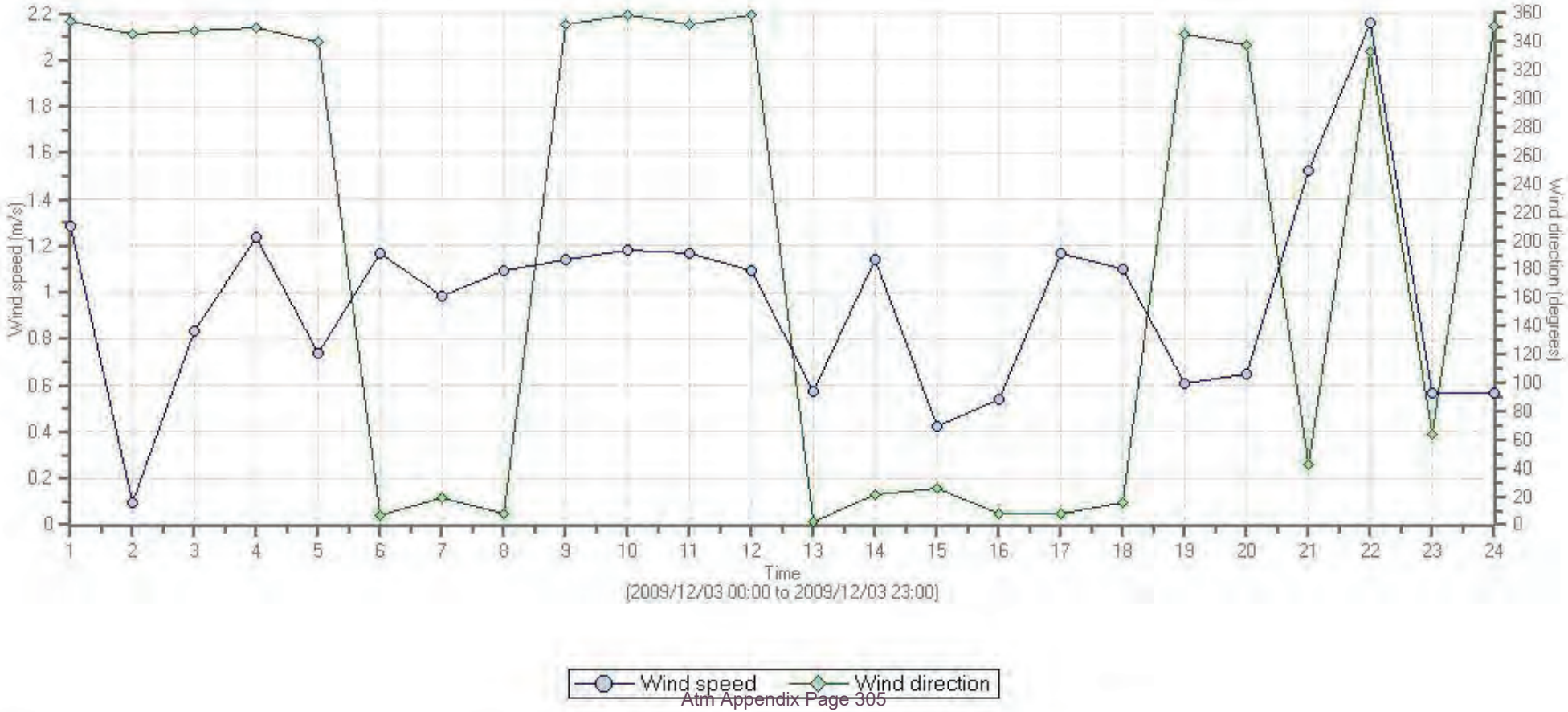
At 519.750, 5985.750, 10 (Near KMP Camp Station)



Wind speed vs. Wind direction

With KMP Camp Station

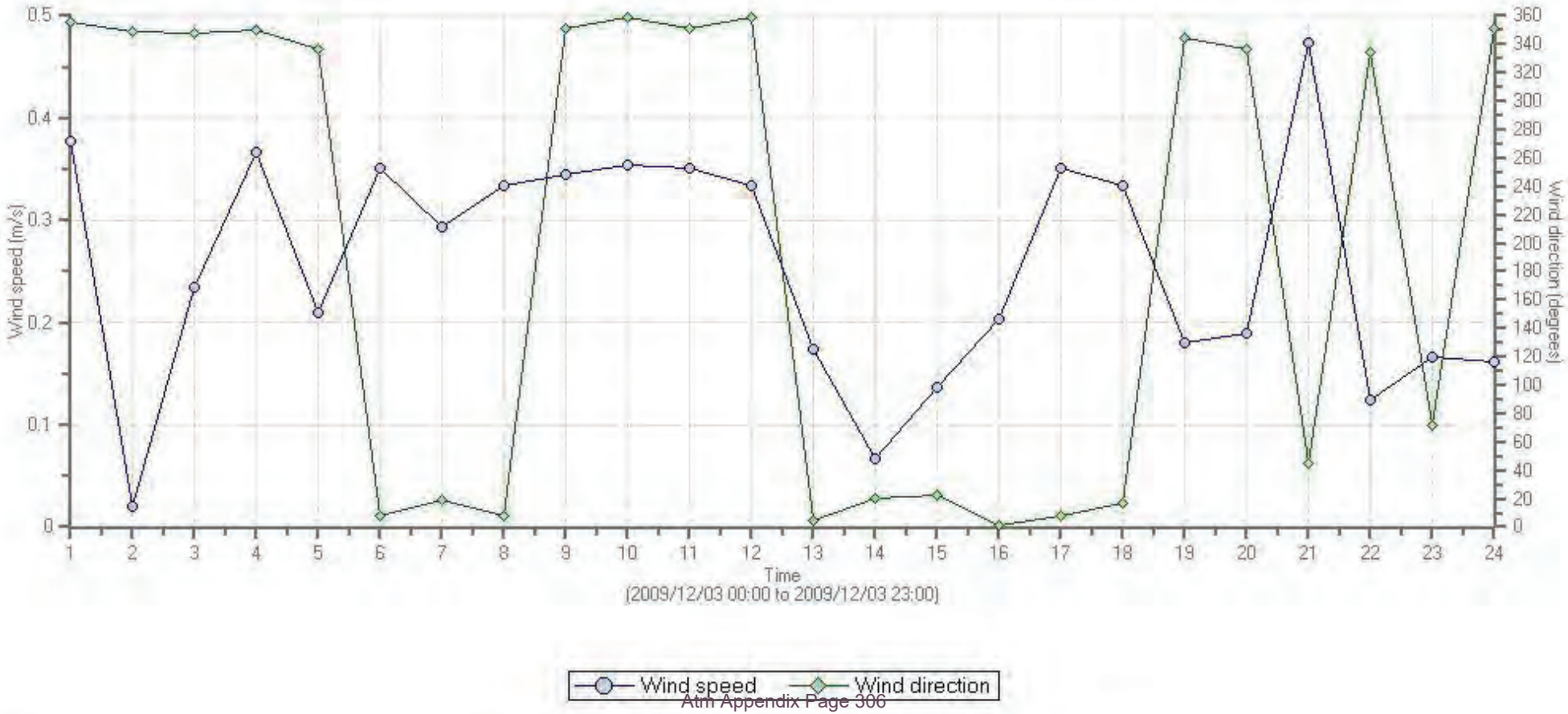
At 519.750, 5985.750, 10 (Near KMP Camp Station)



Wind speed vs. Wind direction

Without KMP Camp Station

At 519.750, 5985.750, 10 (Near KMP Camp Station)



APPENDIX C

Process Flow Diagram
Facility Plot Plan

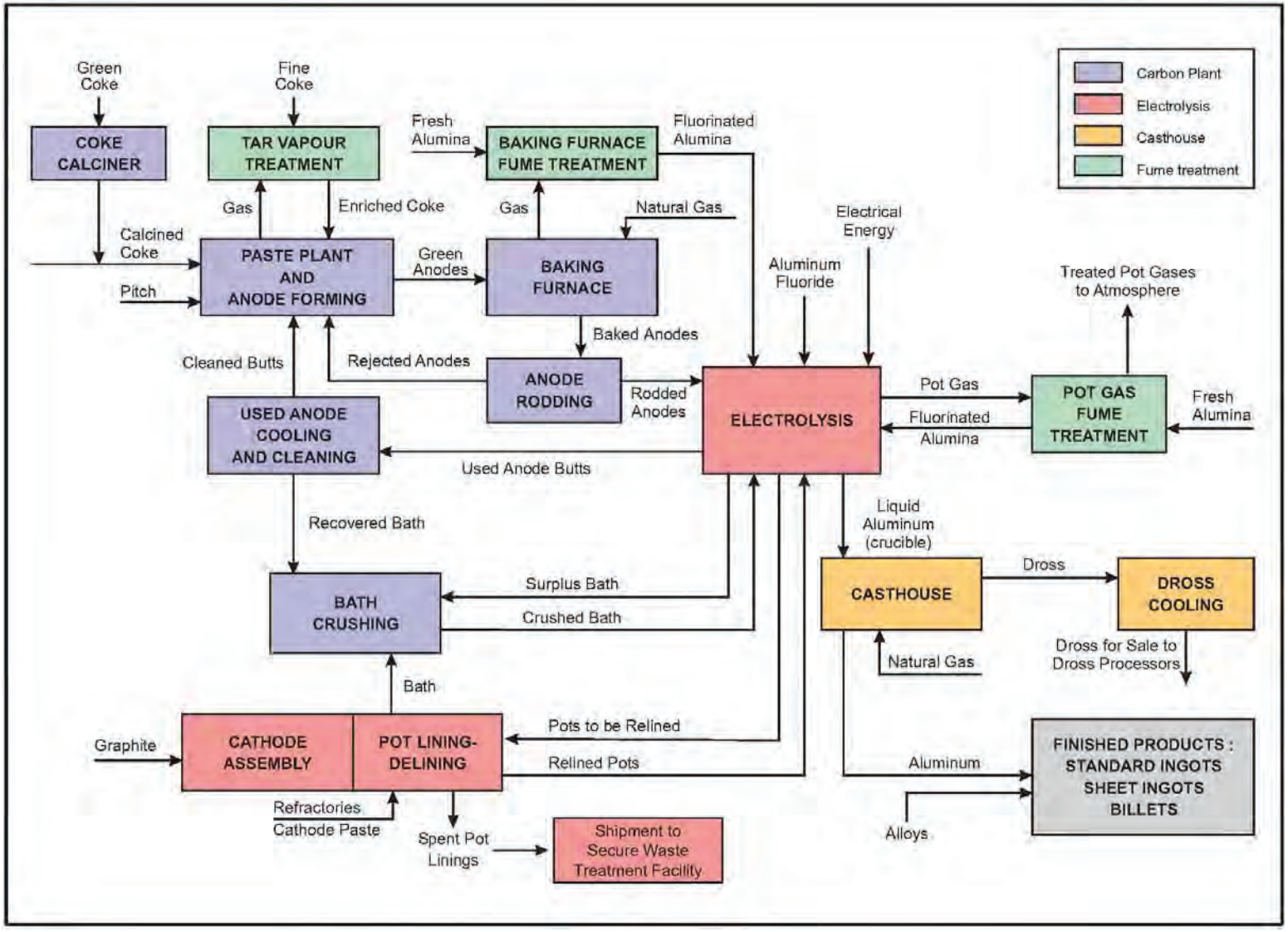


Figure 9: Schematic Diagram of the Operations of an Aluminum Reduction Plant

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C:\DOCUMENTS AND SETTINGS\ADMINISTRATOR\DESKTOP\ATM\ATM_APPENDIX_PAGE_309.DGN 10/09/2009 11:33:21 AM

CUSTOM (841x1559)

NEW FACILITY FOOTPRINTS

| FACILITY | DESCRIPTION | LOCATION - PAD (1000MASTS) | | |

APPENDIX D

CTSG HILL RECEPTOR RESULTS

CTSG Study Results - Jan 2008 - 1-Month SO2 Concentrations

Without CTSG			With CTSG			
X	Y	*Conc*	X	Y	*Conc*	Percent Change
524.5	6000.5	*3.81E+00*	524.5	6000.5	*1.15E+00*	-70%
525	6000.5	*1.52E+00*	525	6000.5	*3.57E-01*	-77%
524	6001	*3.03E+00*	524	6001	*1.36E+00*	-55%
524.5	6001	*4.00E+00*	524.5	6001	*1.20E+00*	-70%
525	6001	*1.47E+00*	525	6001	*1.70E-01*	-88%
524	6001.5	*3.22E+00*	524	6001.5	*1.36E+00*	-58%
524.5	6001.5	*4.01E+00*	524.5	6001.5	*1.24E+00*	-69%
525	6001.5	*1.22E+00*	525	6001.5	*1.75E-01*	-86%
524	6002	*3.78E+00*	524	6002	*1.38E+00*	-64%
524.5	6002	*3.90E+00*	524.5	6002	*1.28E+00*	-67%
522.5	6002.5	*2.67E+00*	522.5	6002.5	*9.98E-01*	-63%
523	6002.5	*2.35E+00*	523	6002.5	*3.99E-01*	-83%
524	6002.5	*4.08E+00*	524	6002.5	*1.38E+00*	-66%
524.5	6002.5	*4.03E+00*	524.5	6002.5	*1.33E+00*	-67%
525	6002.5	*2.79E+00*	525	6002.5	*1.20E+00*	-57%
522	6003	*4.03E+00*	522	6003	*1.47E+00*	-64%
522.5	6003	*3.81E+00*	522.5	6003	*2.20E+00*	-42%
523	6003	*3.85E+00*	523	6003	*1.85E+00*	-52%
523.5	6003	*4.21E+00*	523.5	6003	*1.43E+00*	-66%
524.5	6003	*4.02E+00*	524.5	6003	*1.35E+00*	-67%
525	6003	*3.61E+00*	525	6003	*1.29E+00*	-64%
522	6003.5	*4.28E+00*	522	6003.5	*1.92E+00*	-55%
522.5	6003.5	*3.84E+00*	522.5	6003.5	*2.41E+00*	-37%
523	6003.5	*3.77E+00*	523	6003.5	*2.29E+00*	-39%
523.5	6003.5	*4.22E+00*	523.5	6003.5	*2.22E+00*	-47%
524.5	6003.5	*3.80E+00*	524.5	6003.5	*1.40E+00*	-63%
525	6003.5	*3.64E+00*	525	6003.5	*1.33E+00*	-63%
525.5	6003.5	*3.07E+00*	525.5	6003.5	*1.18E+00*	-62%
521.5	6004	*3.80E+00*	521.5	6004	*1.66E+00*	-56%
522.5	6004	*3.86E+00*	522.5	6004	*2.57E+00*	-33%
523	6004	*3.67E+00*	523	6004	*2.41E+00*	-34%
523.5	6004	*4.06E+00*	523.5	6004	*2.36E+00*	-42%
524	6004	*4.22E+00*	524	6004	*1.79E+00*	-58%
525	6004	*3.54E+00*	525	6004	*1.37E+00*	-61%
525.5	6004	*3.28E+00*	525.5	6004	*1.27E+00*	-61%
526	6004	*1.62E+00*	526	6004	*4.79E-01*	-70%
521.5	6004.5	*3.72E+00*	521.5	6004.5	*2.11E+00*	-43%
522	6004.5	*4.08E+00*	522	6004.5	*2.62E+00*	-36%
522.5	6004.5	*3.88E+00*	522.5	6004.5	*2.70E+00*	-30%
523	6004.5	*3.62E+00*	523	6004.5	*2.54E+00*	-30%
523.5	6004.5	*3.92E+00*	523.5	6004.5	*2.89E+00*	-26%
524	6004.5	*4.14E+00*	524	6004.5	*2.03E+00*	-51%
525.5	6004.5	*3.16E+00*	525.5	6004.5	*1.28E+00*	-59%
526	6004.5	*2.85E+00*	526	6004.5	*1.09E+00*	-62%
521.5	6005	*3.64E+00*	521.5	6005	*2.18E+00*	-40%
522	6005	*3.98E+00*	522	6005	*2.75E+00*	-31%
522.5	6005	*3.91E+00*	522.5	6005	*2.76E+00*	-29%
523	6005	*3.63E+00*	523	6005	*2.82E+00*	-22%
523.5	6005	*3.80E+00*	523.5	6005	*2.73E+00*	-28%

CTSG Study Results - Jan 2008 - 1-Month SO2 Concentrations

Without CTSG			With CTSG			
X	Y	*Conc*	X	Y	*Conc*	Percent Change
524	6005	*3.97E+00*	524	6005	*1.80E+00*	-55%
526	6005	*1.51E+00*	526	6005	*1.78E-01*	-88%
521.5	6005.5	*3.54E+00*	521.5	6005.5	*1.93E+00*	-46%
522	6005.5	*3.89E+00*	522	6005.5	*2.79E+00*	-28%
522.5	6005.5	*3.92E+00*	522.5	6005.5	*2.83E+00*	-28%
523	6005.5	*3.68E+00*	523	6005.5	*2.52E+00*	-32%
523.5	6005.5	*3.65E+00*	523.5	6005.5	*1.95E+00*	-47%
524	6005.5	*3.81E+00*	524	6005.5	*1.69E+00*	-56%
521.5	6006	*3.51E+00*	521.5	6006	*1.94E+00*	-45%
522	6006	*3.81E+00*	522	6006	*2.84E+00*	-25%
522.5	6006	*3.90E+00*	522.5	6006	*2.85E+00*	-27%
523	6006	*3.72E+00*	523	6006	*2.74E+00*	-26%
523.5	6006	*3.63E+00*	523.5	6006	*2.21E+00*	-39%
521.5	6006.5	*3.30E+00*	521.5	6006.5	*1.77E+00*	-46%
522	6006.5	*3.76E+00*	522	6006.5	*2.76E+00*	-27%
522.5	6006.5	*3.87E+00*	522.5	6006.5	*3.07E+00*	-21%
523	6006.5	*3.77E+00*	523	6006.5	*2.77E+00*	-27%
523.5	6006.5	*3.64E+00*	523.5	6006.5	*2.52E+00*	-31%
522	6007	*3.70E+00*	522	6007	*2.41E+00*	-35%
522.5	6007	*3.85E+00*	522.5	6007	*2.81E+00*	-27%
523	6007	*3.82E+00*	523	6007	*5.25E+00*	37%
523.5	6007	*3.68E+00*	523.5	6007	*2.60E+00*	-29%
524	6007	*3.60E+00*	524	6007	*2.07E+00*	-42%
522.5	6007.5	*3.79E+00*	522.5	6007.5	*2.36E+00*	-38%
523	6007.5	*3.84E+00*	523	6007.5	*2.77E+00*	-28%
523.5	6007.5	*3.72E+00*	523.5	6007.5	*2.70E+00*	-27%
524	6007.5	*3.60E+00*	524	6007.5	*2.30E+00*	-36%
522.5	6008	*3.74E+00*	522.5	6008	*2.25E+00*	-40%
523	6008	*3.83E+00*	523	6008	*2.70E+00*	-30%
523.5	6008	*3.75E+00*	523.5	6008	*2.69E+00*	-28%
524	6008	*3.61E+00*	524	6008	*2.12E+00*	-41%
523	6008.5	*3.81E+00*	523	6008.5	*2.34E+00*	-38%
523.5	6008.5	*3.79E+00*	523.5	6008.5	*2.52E+00*	-34%
524	6008.5	*3.65E+00*	524	6008.5	*2.44E+00*	-33%
525	6021	*3.03E+00*	525	6021	*1.48E+00*	-51%
525.5	6021	*2.86E+00*	525.5	6021	*1.56E+00*	-46%
525.5	6021.5	*2.76E+00*	525.5	6021.5	*1.56E+00*	-44%
525.5	6022	*2.68E+00*	525.5	6022	*1.55E+00*	-42%
525.5	6022.5	*2.62E+00*	525.5	6022.5	*1.54E+00*	-41%
525	6027.5	*2.35E+00*	525	6027.5	*1.25E+00*	-47%
525	6028	*2.45E+00*	525	6028	*1.24E+00*	-49%
525.5	6028	*2.55E+00*	525.5	6028	*1.29E+00*	-49%
525	6028.5	*2.43E+00*	525	6028.5	*1.24E+00*	-49%
525.5	6028.5	*2.54E+00*	525.5	6028.5	*1.27E+00*	-50%
526	6028.5	*2.53E+00*	526	6028.5	*1.31E+00*	-48%
525	6029	*2.39E+00*	525	6029	*1.23E+00*	-49%
525.5	6029	*2.49E+00*	525.5	6029	*1.27E+00*	-49%
526	6029	*2.47E+00*	526	6029	*1.30E+00*	-47%
525	6029.5	*2.29E+00*	525	6029.5	*1.24E+00*	-46%
525.5	6029.5	*2.42E+00*	525.5	6029.5	*1.26E+00*	-48%
	MAX	**4.28E+00**			**5.25E+00**	-88%

Ministry of Environment and Climate Change Strategy

MEMORANDUM
P2-00001

May 31, 2019

Rio Tinto
Smeltersite Rd.
P.O. Box 1800
Kitimat, B.C.
V8C 2H2

Attention: Shawn Zettler,

RE: Environmental Effects Monitoring Program Dispersion Modelling Plan
Approval of Revised CALPUFF Model Plan
British Columbia Ministry of Environment P2-00001

Dear Shawn,

I have completed my review of revised material in support of the CALPUFF Modelling Protocol (the "Protocol") submitted by Anna Henolson (Trinity Consultants) on Rio Tinto (RT)'s behalf for work related to the 2019 comprehensive sulphur dioxide (SO_2) Environmental Effects Monitoring plan (EEMP) review. The material I reviewed included:

- the "CALPUFF and CALMET Modeling Protocol_2019-0513.pdf" submitted on May 13th 2019,
- the "CALPUFF Inputs (2016-2018)v4.00.xlsx" spreadsheet submitted on May 13th 2019,
- the email from Anna Henolson with subject heater "Rio Tinto CALPUFF & CALMET Dispersion Modelling Plan_Revised" sent May 31st, and
- the "CALPUFF Inputs (2016-2018)v4.00_TotalCorrected.xlsx" spreadsheet attached to the above email.

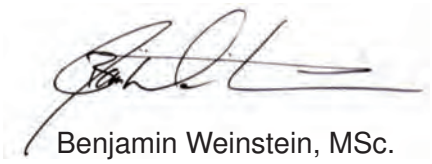
Aspects of the revised Protocol and emissions inventory were discussed with yourself, Anna Henolson, Arvind Saraswat and I on May 14th.

The only missing item from the revised Protocol is a small statement confirming that in addition to all other model output there will be output on timeframes consistent with the passive monitoring conducted over past years. As we have spoken and agreed on this issue there is no need to resubmit another Protocol.

Moving Forward

It is my recommendation to Karen Moores, head of the Authorizations North section, that based on my review of the above material the model Protocol is approved for the purposes of the 2019

comprehensive SO_2 EEMP review and related studies. I look forward to reviewing the results.



Benjamin Weinstein, MSc.
Air Quality Meteorologist
Authorizations North & Monitoring, Assessment and Stewardship
B.C. Ministry of Environment and Climate Change Strategy
250.847.7256

cc: Karen Moores, Head, Authorizations North Section, Environmental Protection, Williams Lake
cc: Frazer McKenzie, Sr. Environmental Protection Officer, Environmental Protection, Smithers
cc: Arvind Saraswat, Head, Air Quality Section (Assessments), Environmental Protection, Surrey
cc: Donna Haga, Air Quality Meteorologist, Environmental Protection, Cranbrook
cc: Anna Henolson, Managing Consultant, Trinity Consultants, Seattle

MEMORANDUM

To: Benjamin Weinstein – Ministry of Environment and Climate Change Strategy
CC: Shawn Zettler, Jonathan Bernier – Rio Tinto
From: Anna Henolson – Trinity Consultants
Date: August 7, 2019
RE: Addendum to CALMET and CALPUFF Model Plan for Hybrid CALMET Approach

Rio Tinto owns and operates an aluminum smelter located in Kitimat, BC (the Kitimat Smelter). In order to support the Environmental Effects Monitoring (EEM) program, Rio Tinto is conducting SO_2 air dispersion modeling using the CALPUFF modelling system, including the CALMET meteorological model.

Rio Tinto submitted a detailed CALMET and CALPUFF modelling plan on May 13, 2019. The plan included a proposal to run CALMET in the no-obs mode using only Weather Research Forecast (WRF) data for the regional-scale CALMET model. Trinity has conducted initial modelling following this no-obs approach. This memorandum provides preliminary no-obs CALPUFF results for the actual emissions scenario, and proposes updates to the CALMET model approach for the regional-scale domain.

PRELIMINARY CALPUFF RESULTS COMPARISONS

Trinity has 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 do 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. Figures 1 and 2 below compare CALPUFF results using the original No-Obs CALMET model compared to using the hybrid CALMET model. The focus of the comparisons for the regional model output is on 3-year average deposition results and annual average SO_2 results because the primary purpose of the regional model is to assess long-term soil and water acidification impacts. Regional SO_2 results are also used to assess vegetation impacts, and annual average SO_2 concentrations are of key importance in the vegetation impact assessment.

Figure 1. Deposition Results Comparison

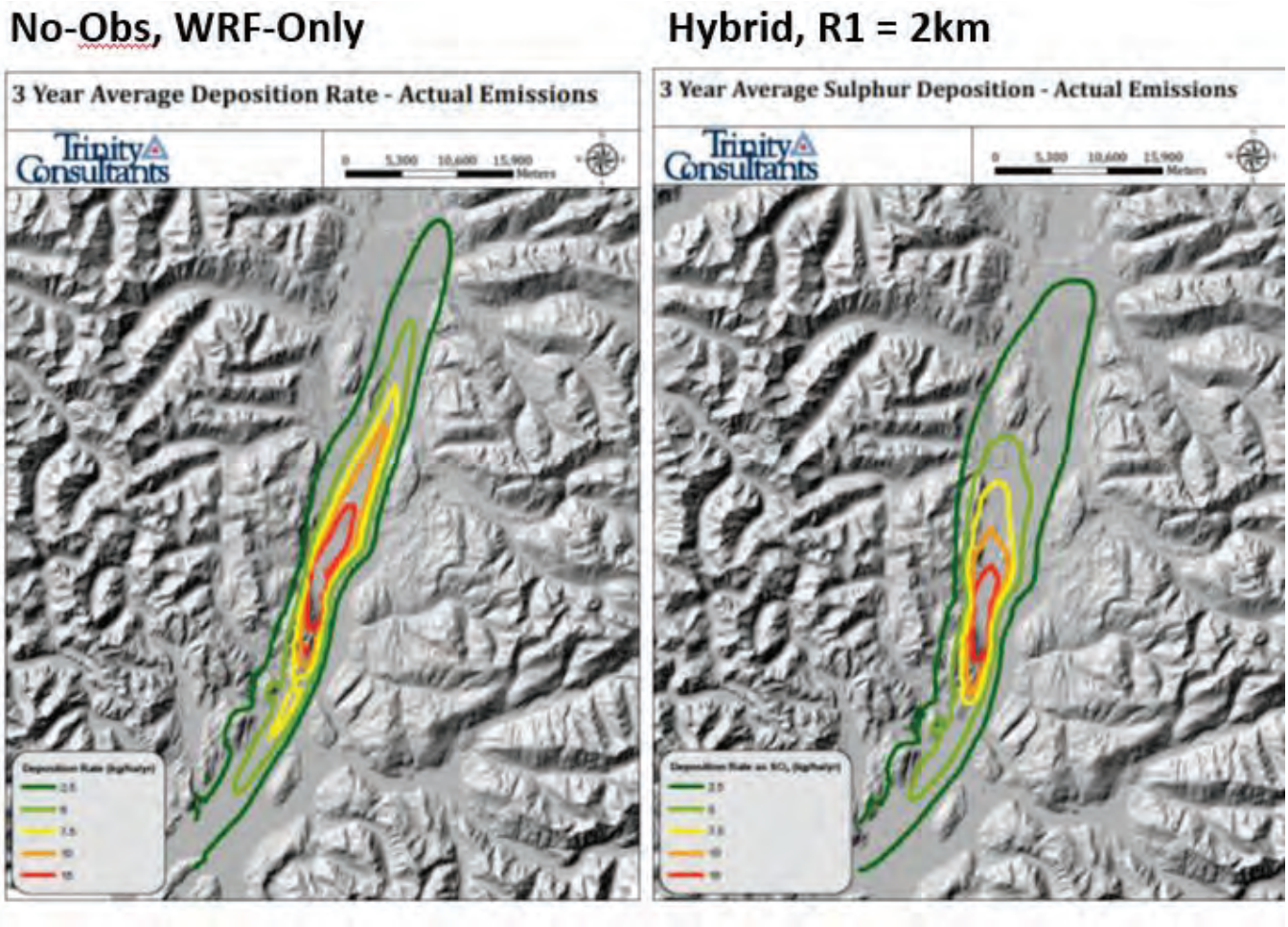
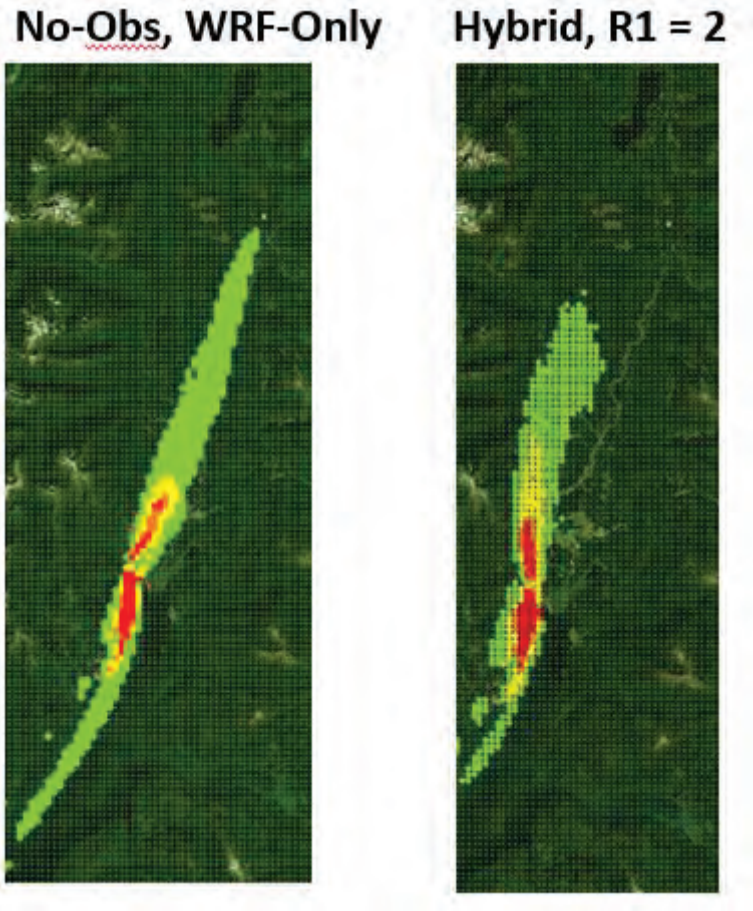


Figure 2. SO_2 Concentration Results Comparison, 2016 Annual Average



As shown in Figures 1 and 2 above, the hybrid model produces the highest results to the north of the smelter as expected based on terrain and monitoring data. In order to further evaluate the accuracy of the two sets of model results, modelled air concentrations were compared against passive sampler data collected in 2016, 2017, and 2018. Figures 3 through 5 below provide side-by-side comparisons of SO_2 model results compared to passive sample observations for each year's passive sampling season.

Figure 3. SO_2 Concentration Results Comparison, 2016 Passive Sampling Period Average (Approx. June - Oct)

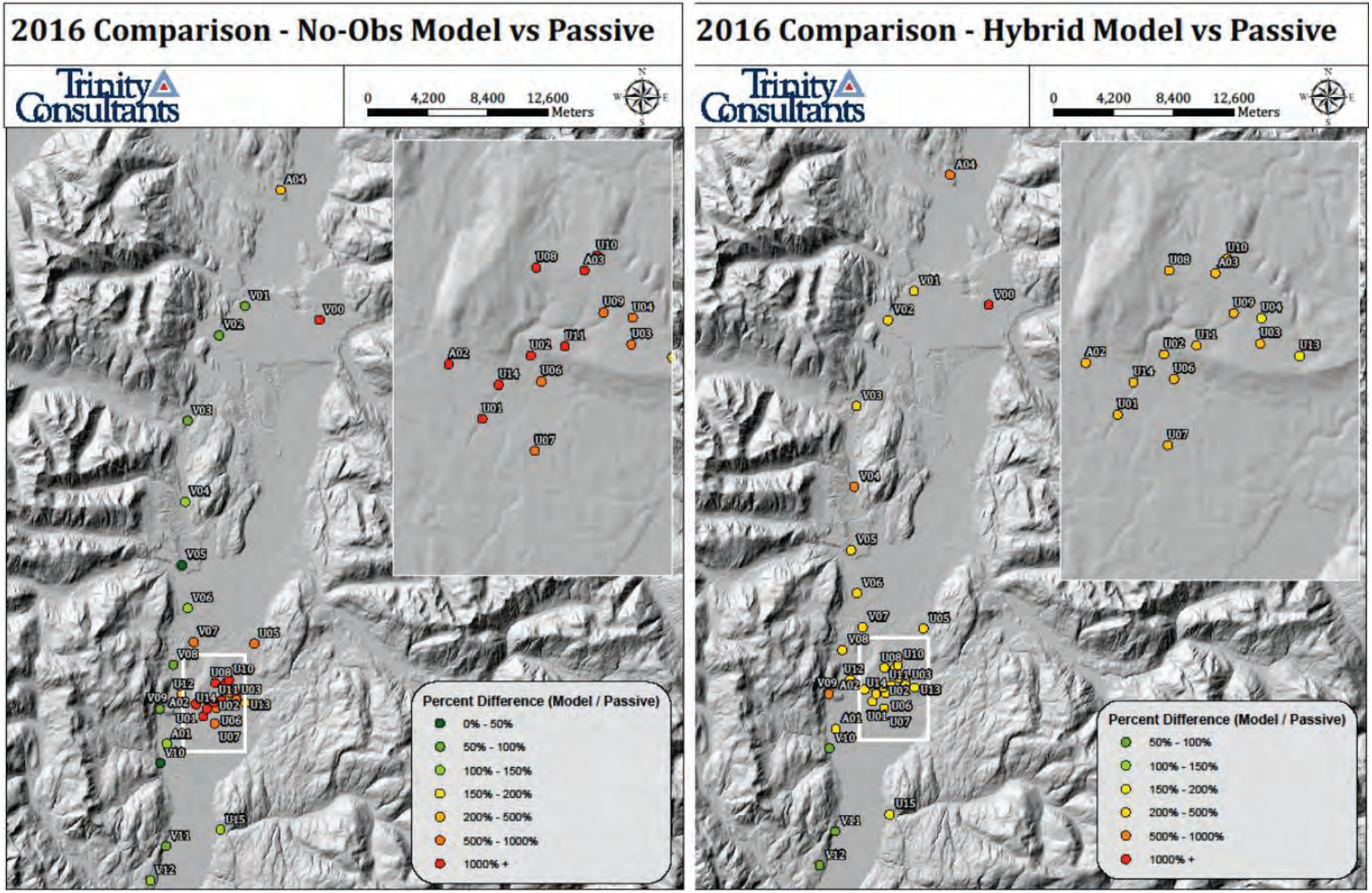


Figure 4. SO_2 Concentration Results Comparison, 2017 Passive Sampling Period Average (Approx. June - Oct)

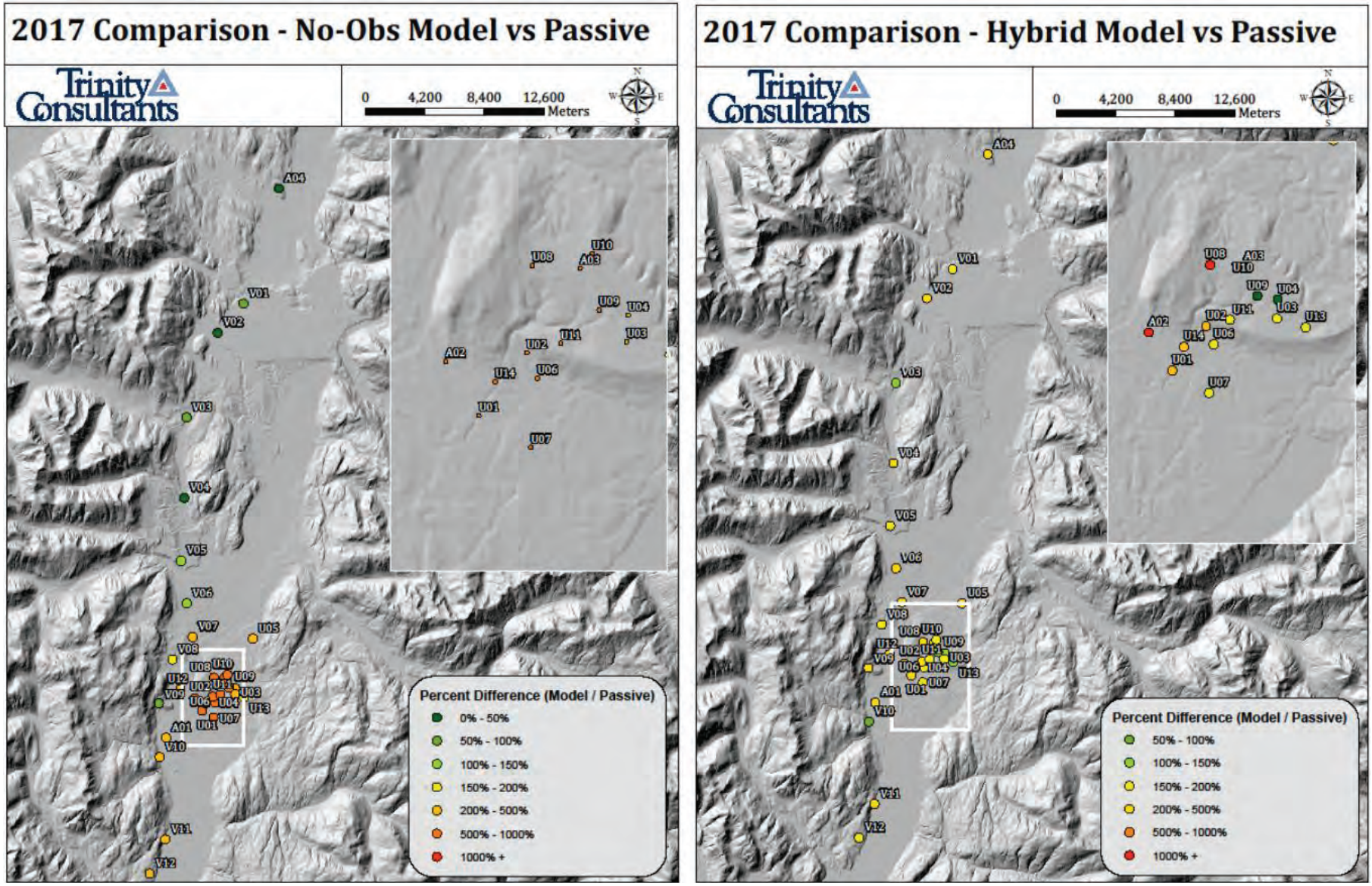
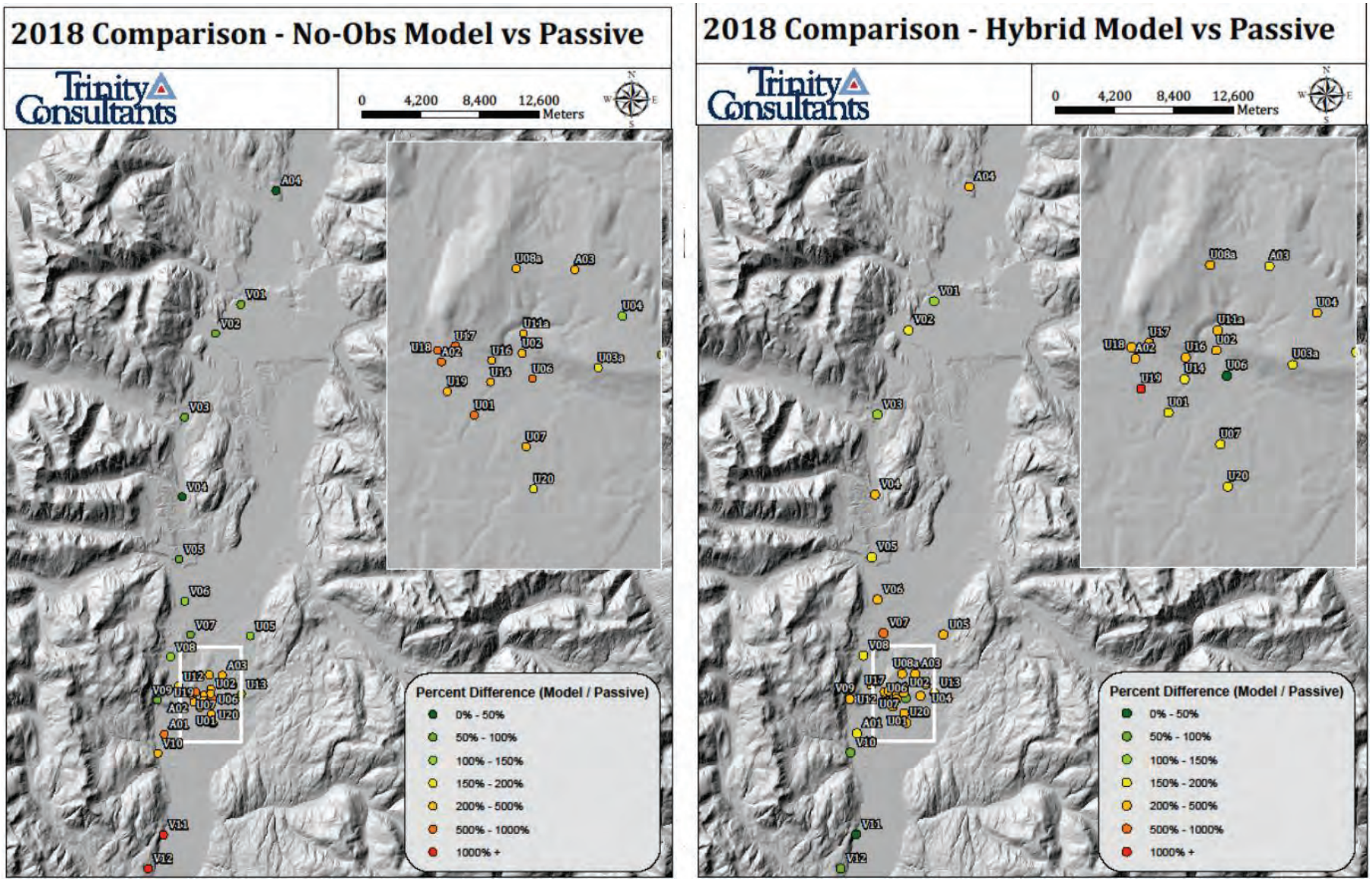


Figure 5. SO_2 Concentration Results Comparison, 2018 Passive Sampling Period Average (Approx. June - Oct)



As illustrated in the passive sampling comparisons shown in Figures 3 through 5 above, the passive sampling observations show better agreement with the hybrid model results, and the no-obs model over-predicts concentration to the northeast and under-predicts concentrations to the north of the smelter.

HYBRID MODEL SENSITIVITY TO R1 (OBSERVATION INFLUENCE RADIUS)

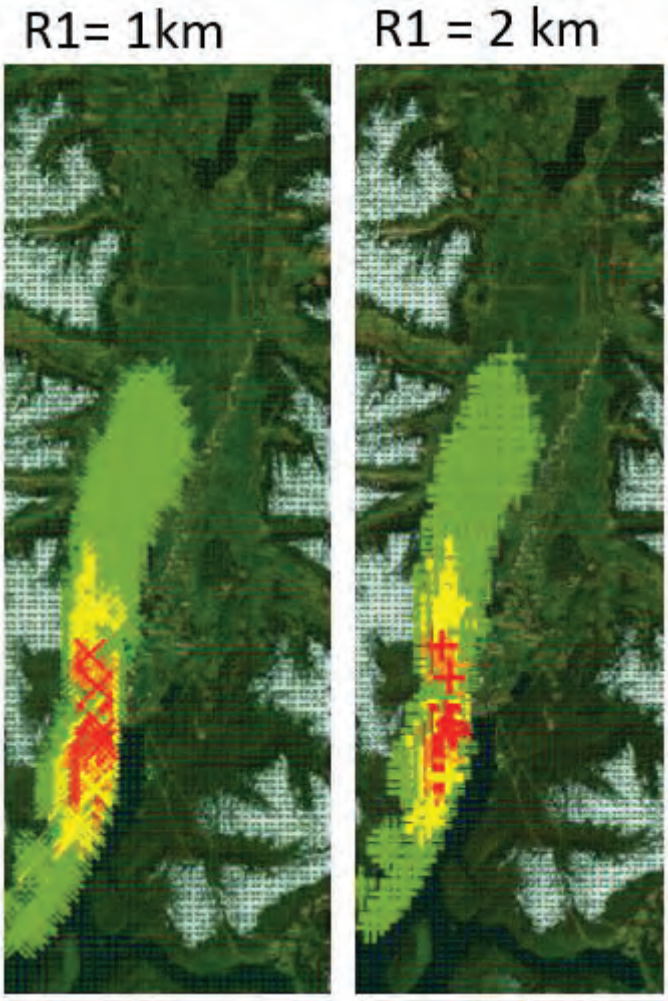
The most influential CALMET input for including observation meteorological data in the hybrid mode is the R1 value, the radius of influence of the surface observations stations. At the distance set by R1, the CALMET model gives equal weight to the local surface observation and the mesoscale WRF data. For the Sulphur Dioxide Technical Assessment Report (STAR) dated April 2013, an R1 value of 2 km was used. As part of testing the performance of the hybrid approach, different R1 values were also tested. Figure 6 below shows the comparison of using R1 = 1 km versus R1 = 2 km. As illustrated in the figure, the two sets of results are nearly identical; therefore, an R1 value of 2 km is proposed. The remaining proposed inputs for the CALMET hybrid option are:

- RMAX1 = 10,
- RMAX2 = 40,
- RMAX3 = 100
- RMIN = 0.1,
- R2 = 5
- Overwater buoy data included (SEA.DAT) from Nakala Shoal buoy station 46181
- ITWPROG = 0
- IEXTRP = -4

The TERRAD value remains the same at 10 km.

Also, in order to run CALMET in hybrid mode without upper air data (because no upper air data are available within the airshed), NOOBS is set to 1, and ITPROG is set to 1.

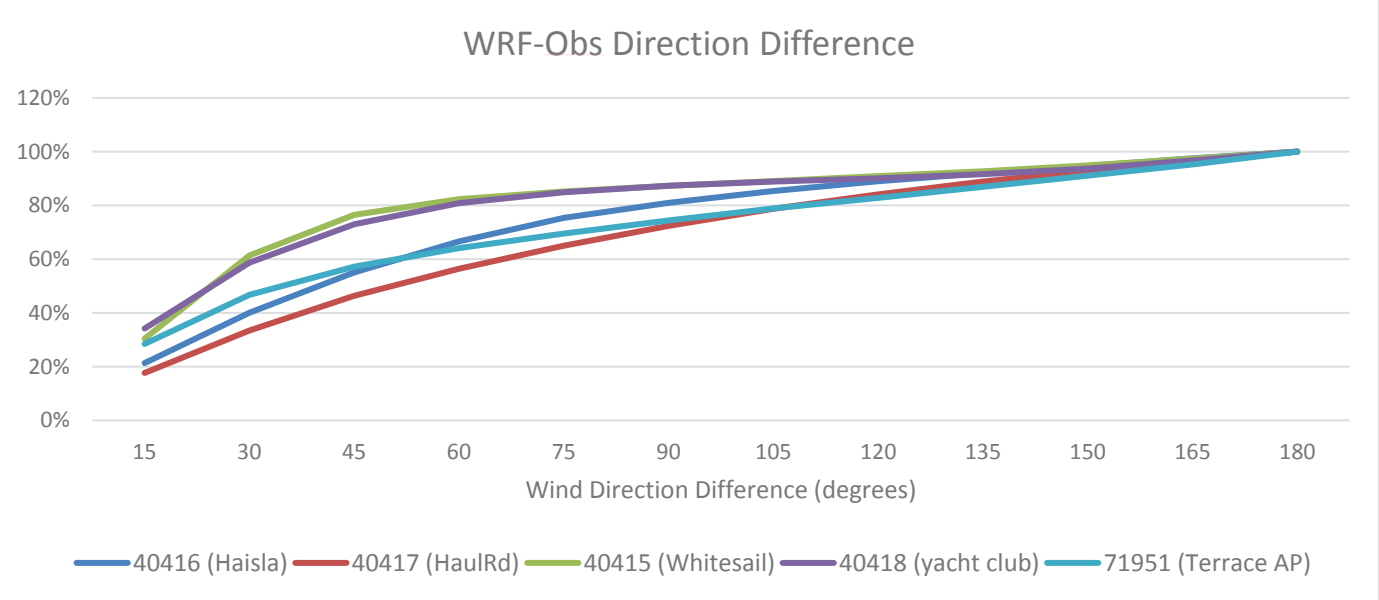
Figure 6. SO_2 Concentration Results Comparison, 2016 Annual Average



WIND DIRECTION REVIEW

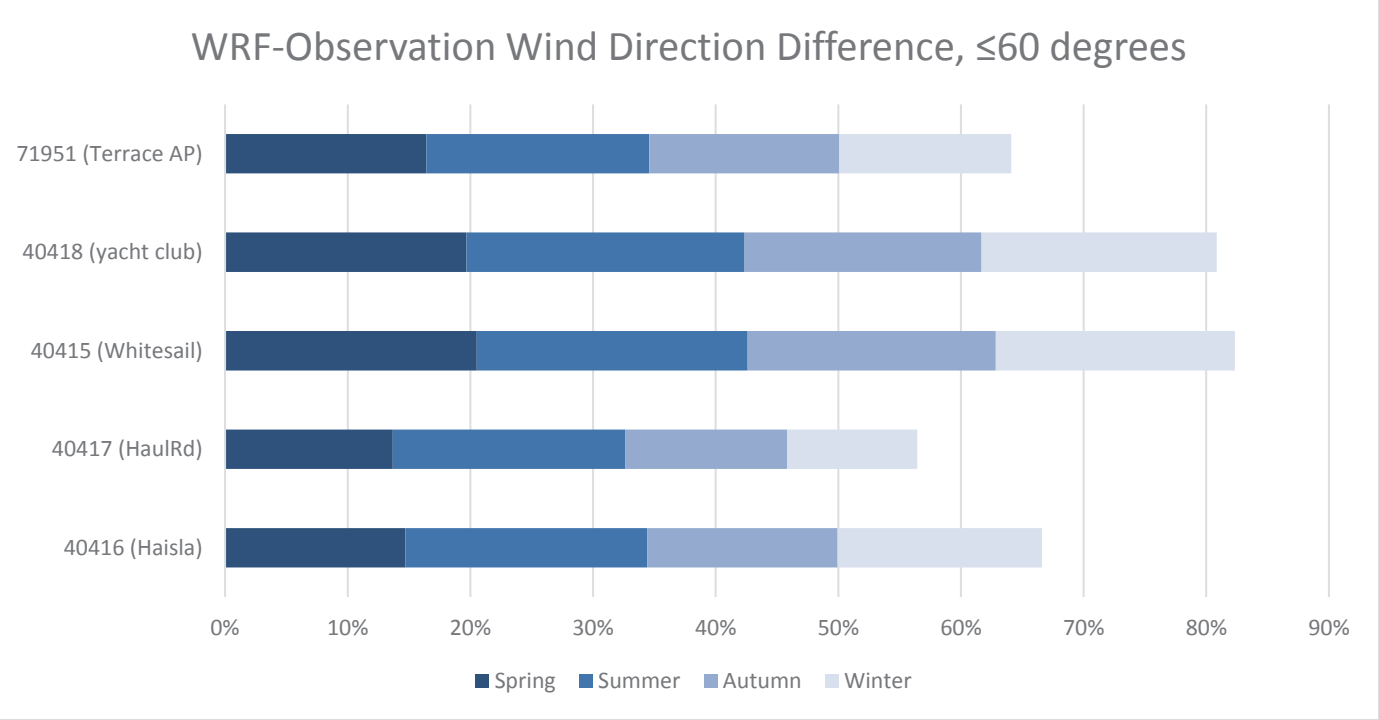
It is possible for the local observation winds to conflict with the mesoscale winds when the local observation data are included in CALMET in the hybrid mode. Therefore, Trinity reviewed wind fields, wind roses, and frequency of wind direction differences between the observation data and the WRF data. Attachment 1 includes several wind roses, wind field plots, and charts, while Figure 7 and 8 below summarize the frequency of how often the WRF and Observation data agree and how often the directions are different, which could lead to conflicting wind fields.

Figure 7. Wind Direction Comparison, 2016-2018



Direction Difference (degrees)	40416 (Haisla)	40417 (HaulRd)	40415 (Whitesail)	40418 (yacht club)	71951 (Terrace AP)
0-15	21%	18%	30%	34%	28%
15-30	40%	33%	61%	59%	47%
30-45	55%	46%	77%	73%	57%
45-60	67%	56%	82%	81%	64%
60-75	75%	65%	85%	85%	70%
75-90	81%	72%	87%	87%	74%
90-105	85%	79%	89%	89%	79%
105-120	89%	84%	91%	90%	83%
120-135	92%	89%	93%	92%	87%
135-150	95%	93%	95%	94%	91%
150-165	98%	97%	97%	97%	95%
165-180	100%	100%	100%	100%	100%

Figure 8. Wind Direction Comparison, 2016-2018, Summarized by Season



As illustrated in Figure 7 above, all stations agree within 60 degrees the majority of hours, within 90 degrees over 70% of hours, and within 120 degrees over 80% of the time. The yacht club and Whitesail stations show the best agreement, with over half the hours agreeing within 30 degrees. The Haul Road station has the lowest frequency of close agreement (approximately one third within 45 degrees), but approaches a similar frequency as the other stations within 90 degrees.

As shown in Figure 8 and in the seasonal cumulative frequency charts in Attachment 1, the wind direction agreement does not vary significantly with season, with the exception of Haul Road agreement being similar to other stations in summer and noticeably lower in the other seasons, particularly winter. The Haul Road may have lower agreement frequency due to the WRF model not fully resolving terrain effects near the edges of valleys, near smaller valleys, and/or in the area where the main valley direction changes from northeast-southwest in the Douglas Channel to north-south in the Kitimat Valley. While the Haul Road station less frequently agrees with the WRF data, this station is necessary to provide the correction to improve alignment with actual conditions.

Because all five stations show relatively good agreement, especially in summer months, all five metrological stations within the domain (and shown above) are proposed to be included in the hybrid mode CALMET model.

CONCLUSION

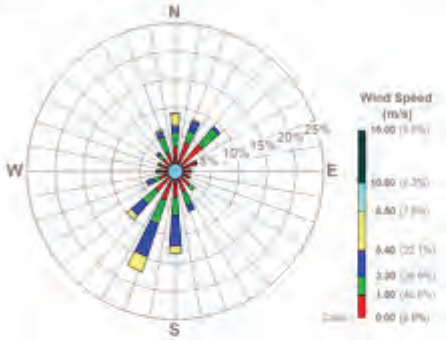
The hybrid CALMET model produces CALPUFF results that are more representative of monitoring data than the no-obs CALMET/CALPUFF results. The frequency of hours when the wind direction from the mesoscale WRF data differs meaningfully from the observation data is relatively small, and influences from these infrequent occurrences of conflicting wind fields are not expected to noticeably influence the 3-year average and

annual average model results. This expected minimal influence is supported by the concentration distribution of annual average SO_2, in that there is an absence of abnormal “hot spot” results in areas where there are the meteorological stations. Additionally, the BC air quality dispersion modelling guideline recommends no-obs mode only for cases when local observation data are not available (or for simpler Level 2 assessments), whereas this situation does have local observation data available and is considered a Level 3 assessment. For all these reasons, Rio Tinto proposes to update the CALMET model plan to use the hybrid CALMET method for the EEM program CALPUFF model analysis.

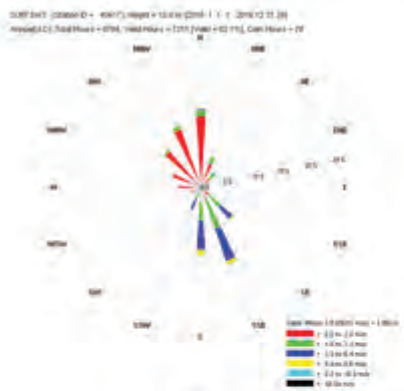
ATTACHMENT 1. WIND DATA ANALYSIS FIGURES

Wind roses at Haul Road and nearest grid center, 2016

WRF



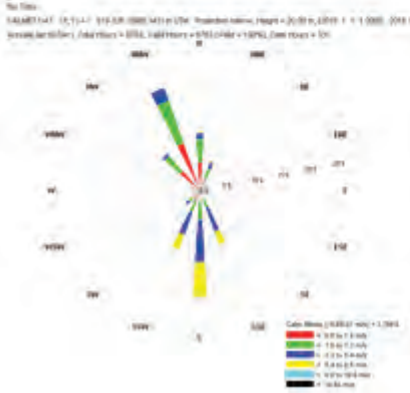
Observation

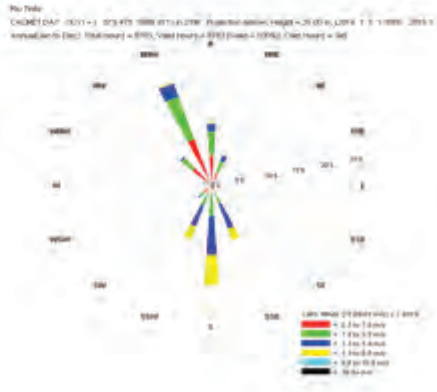


No-Obs, WRF-Only

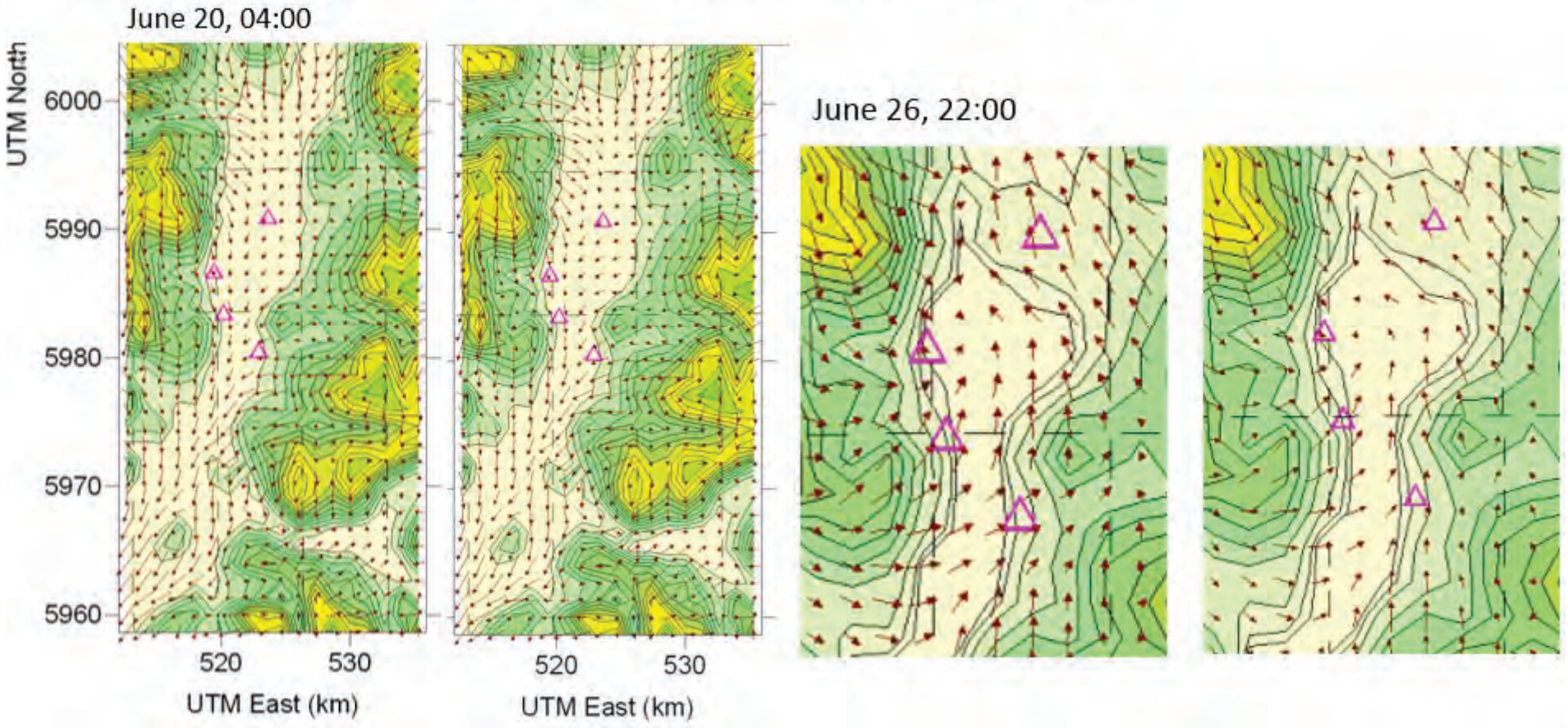


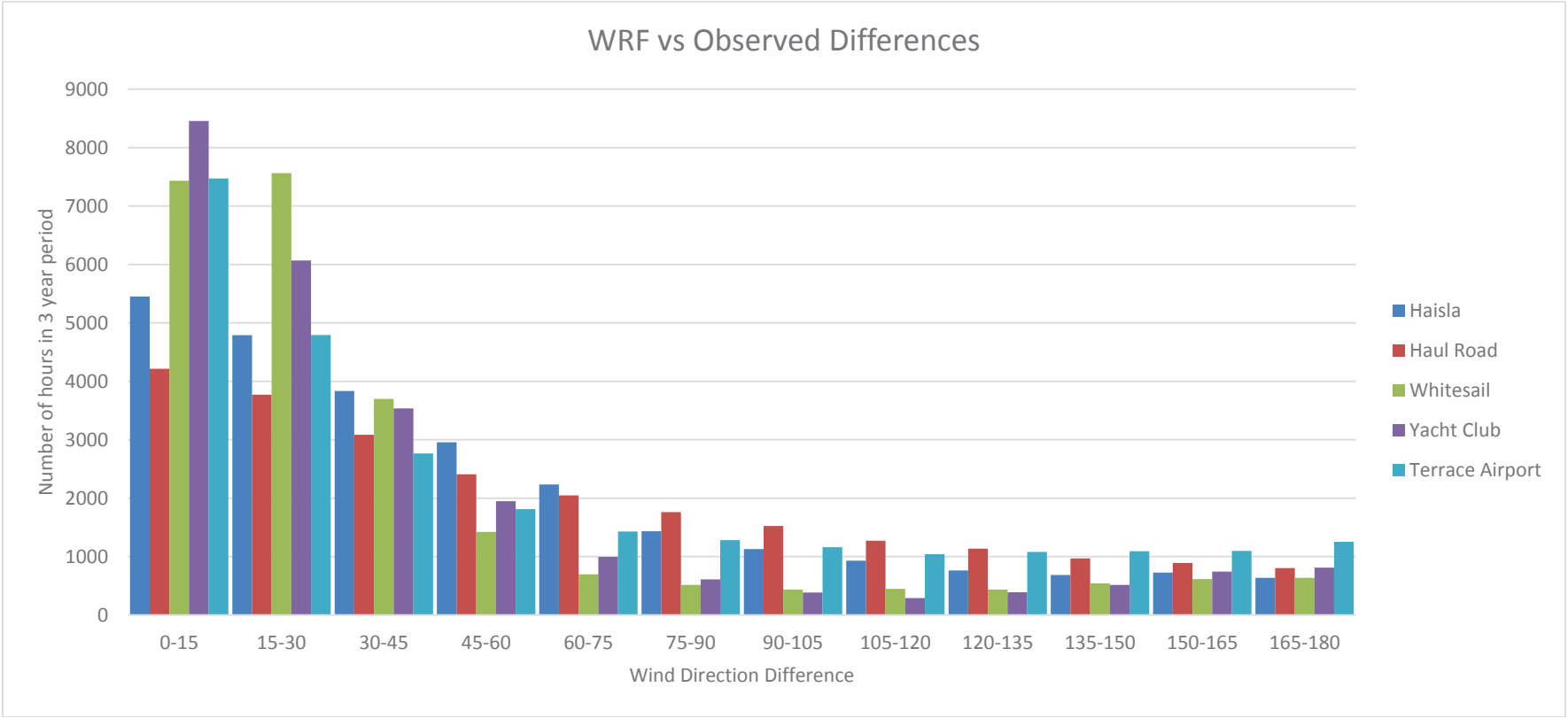
Hybrid, R1=1, R1 = 2 km

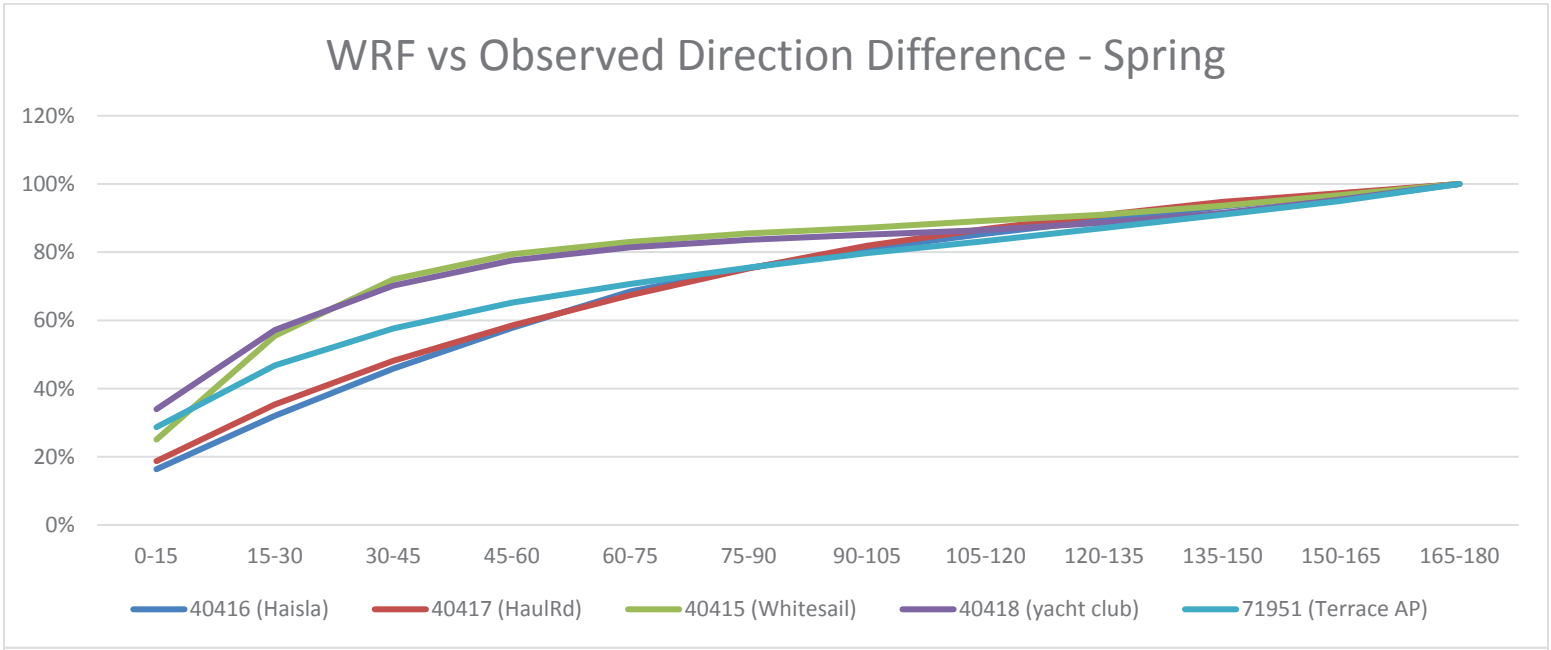


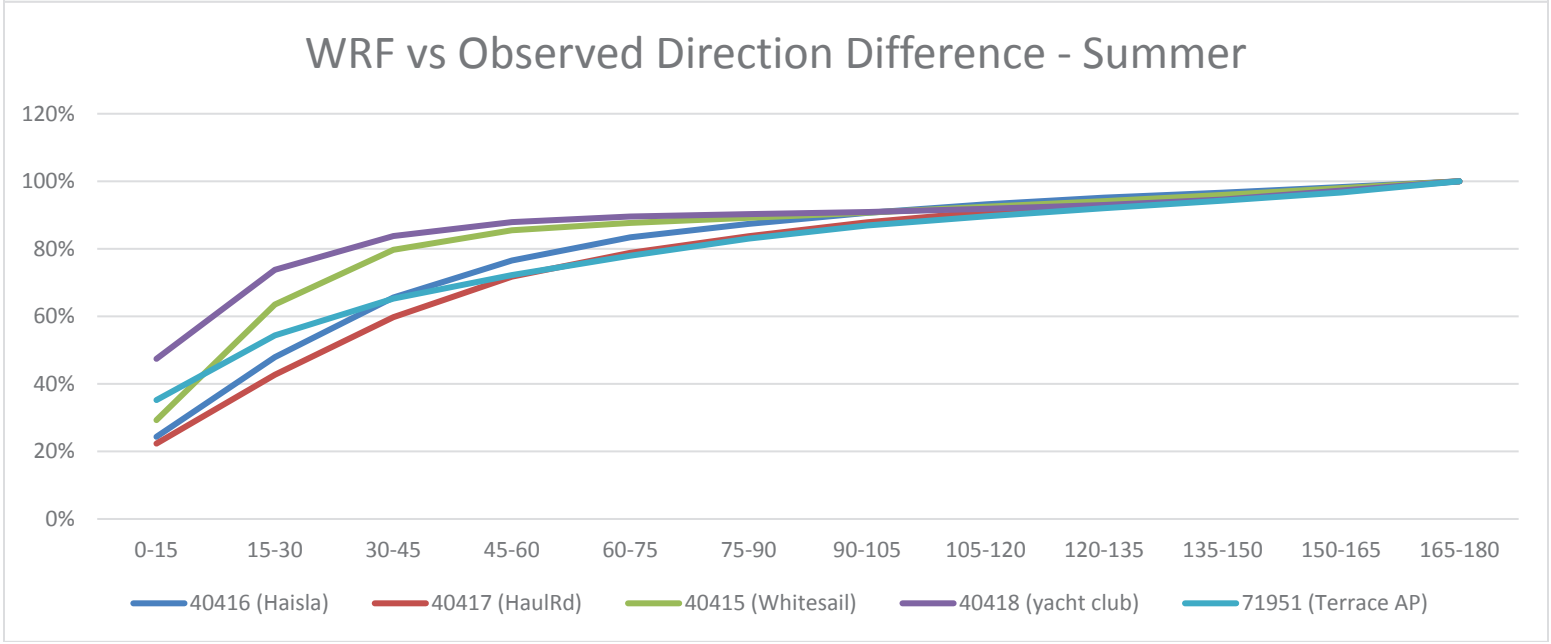


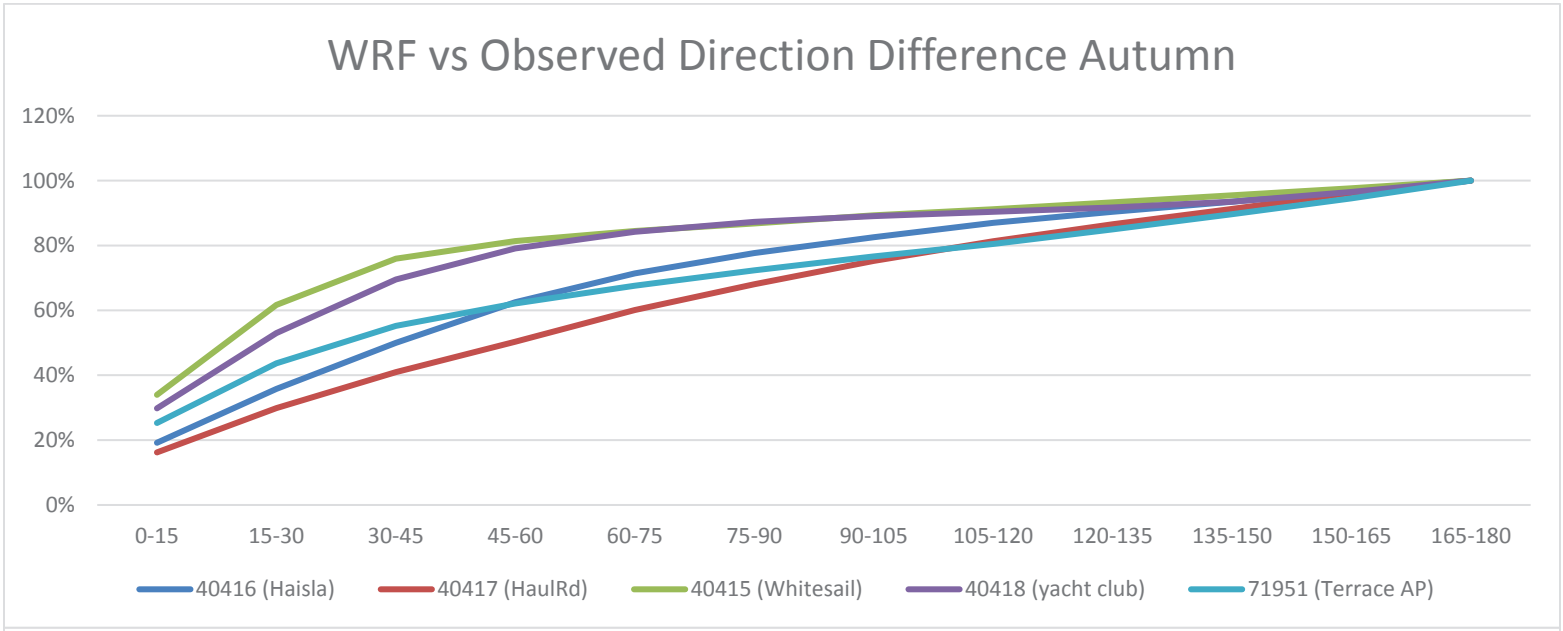
R1= 2km vs. R1 = 1 km – Wind Fields, '16

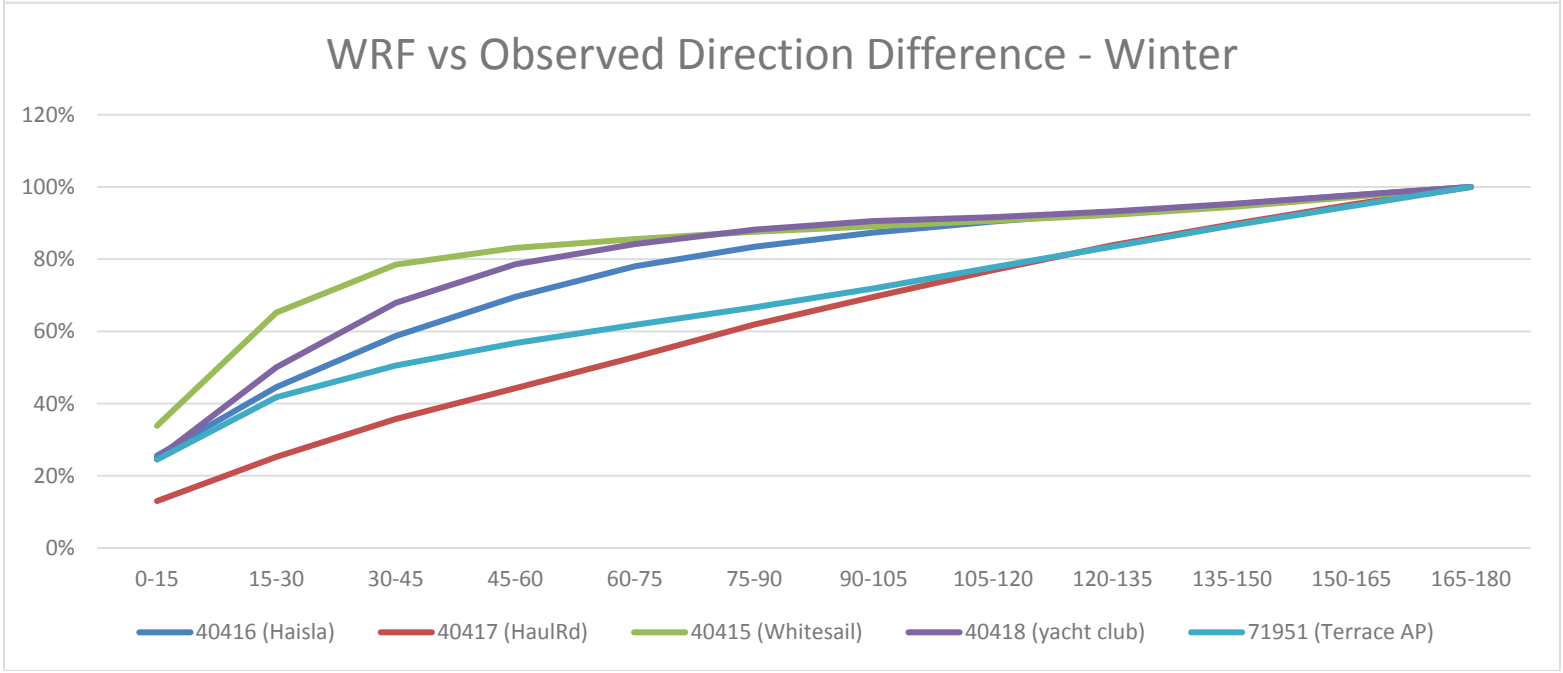



WRF vs Observed Differences
Number of hours in 3 year period
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0-15
15-30
30-45
45-60
60-75
75-90
90-105
105-120
120-135
135-150
150-165
165-180
Wind Direction Difference
Haisla
Haul Road
Whitesail
Yacht Club
Terrace Airport

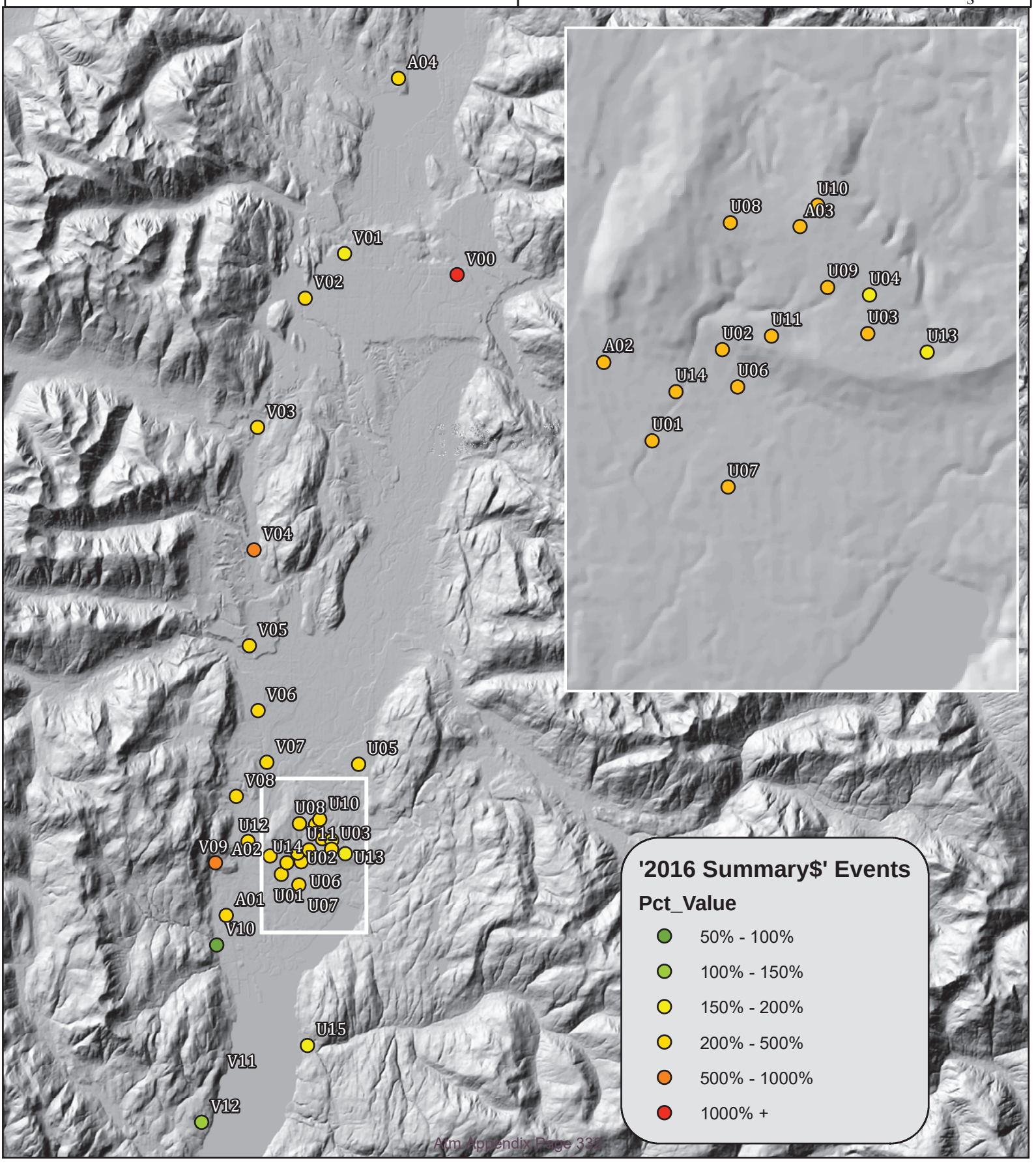

WRF vs Observed Direction Difference - Spring
120%
100%
80%
60%
40%
20%
0%
0-15
15-30
30-45
45-60
60-75
75-90
90-105
105-120
120-135
135-150
150-165
165-180
40416 (Haisla)
40417 (HaulRd)
40415 (Whitesail)
40418 (yacht club)
71951 (Terrace AP)


WRF vs Observed Direction Difference - Summer
120%
100%
80%
60%
40%
20%
0%
0-15
15-30
30-45
45-60
60-75
75-90
90-105
105-120
120-135
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40417 (HaulRd)
40415 (Whitesail)
40418 (yacht club)
71951 (Terrace AP)

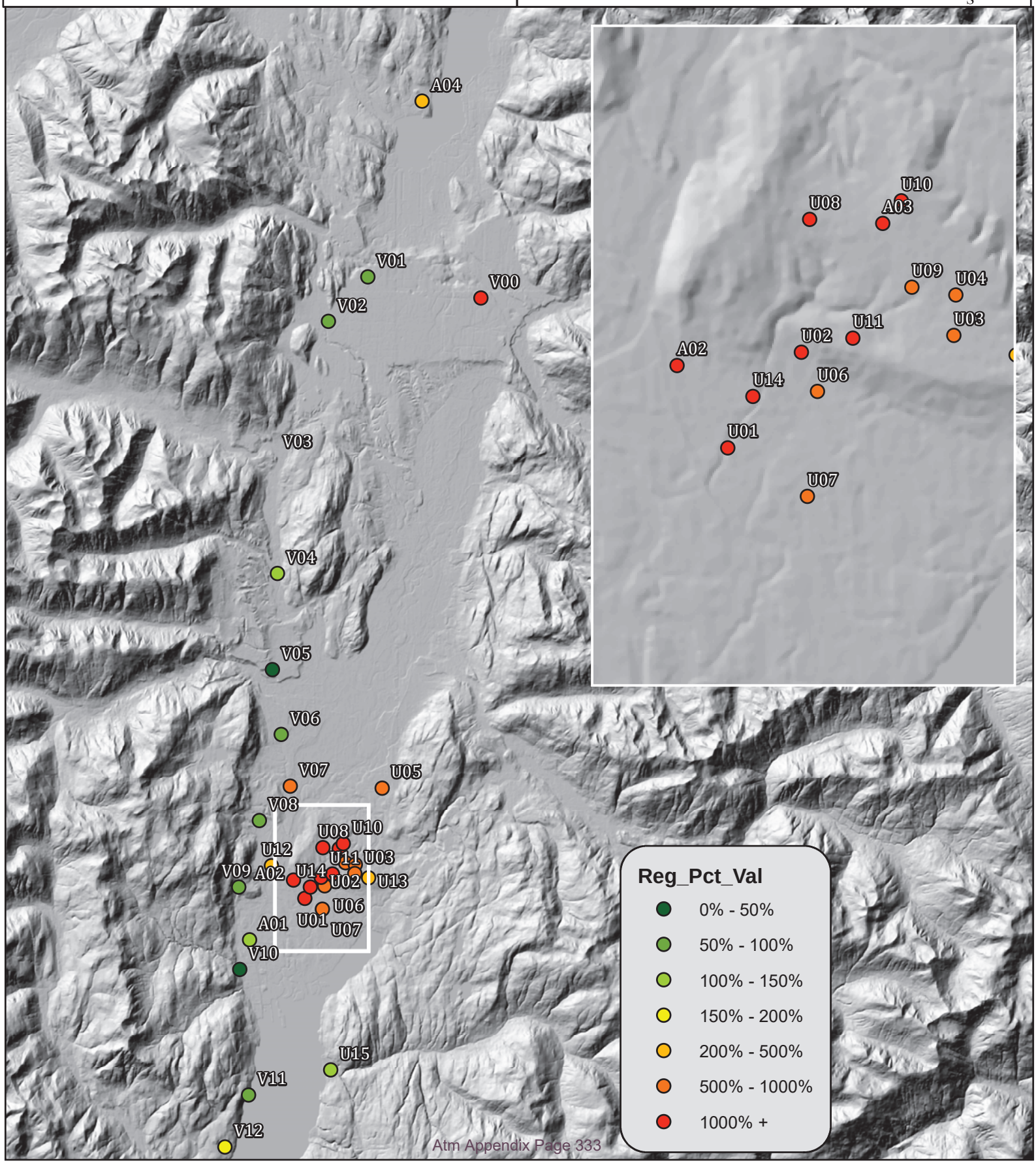

WRF vs Observed Direction Difference Autumn
120%
100%
80%
60%
40%
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0%
0-15
15-30
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60-75
75-90
90-105
105-120
120-135
135-150
150-165
165-180
40416 (Haisla)
40417 (HaulRd)
40415 (Whitesail)
40418 (yacht club)
71951 (Terrace AP)


WRF vs Observed Direction Difference - Winter
120%
100%
80%
60%
40%
20%
0%
0-15
15-30
30-45
45-60
60-75
75-90
90-105
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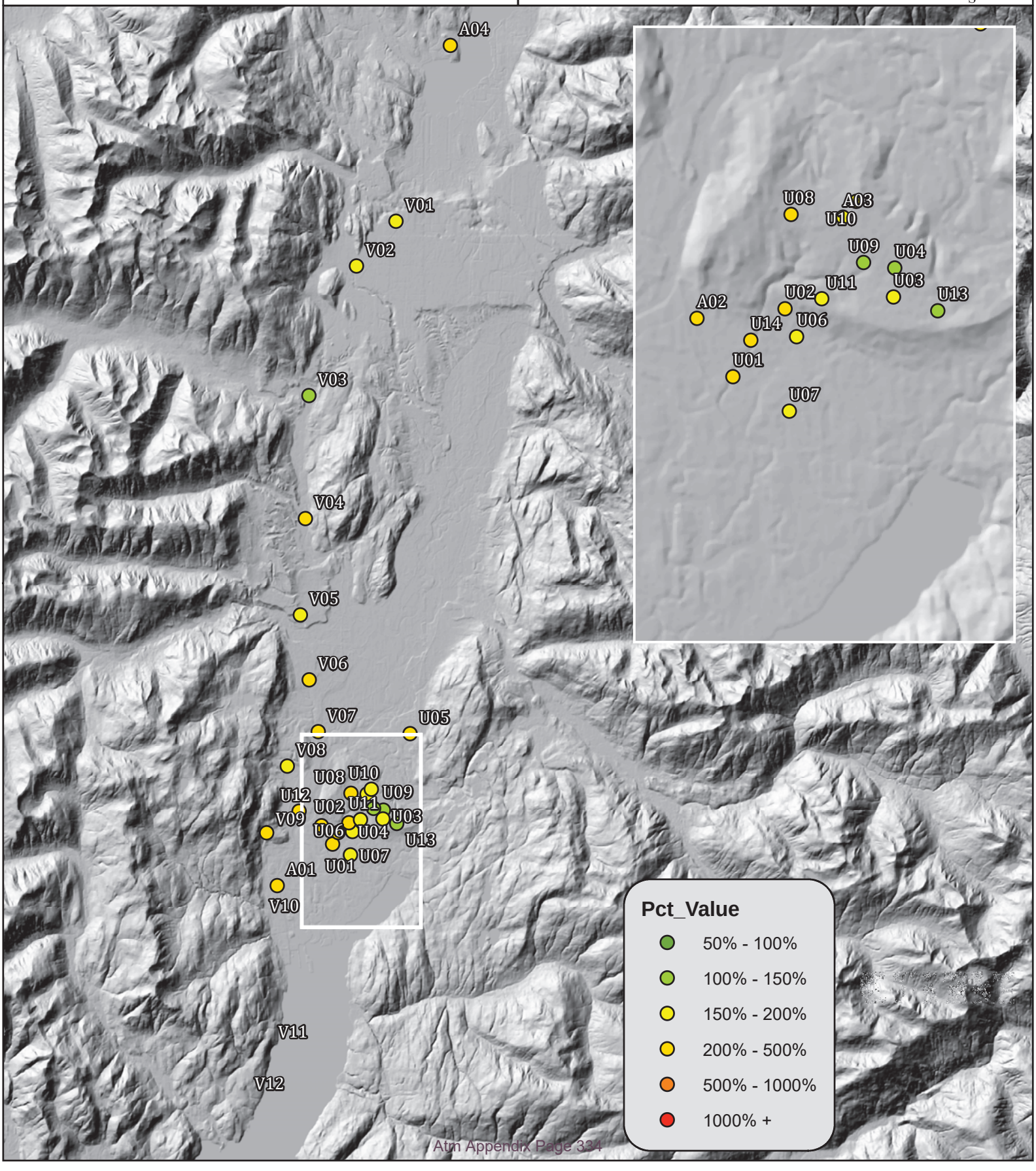
2016 Comparison - Hybrid Model vs Passive



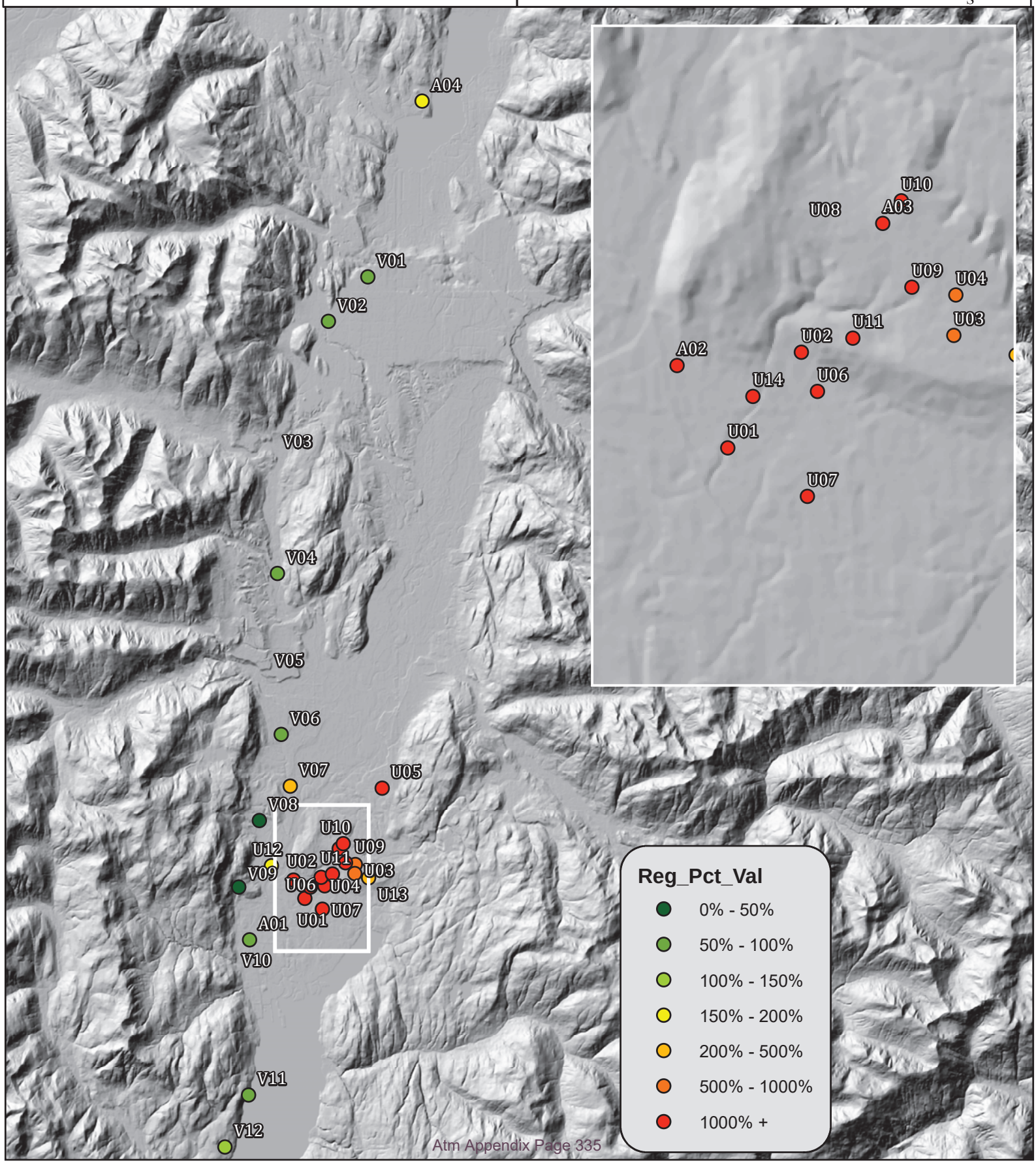
2016 Comparison - No-Obs Model vs Passive



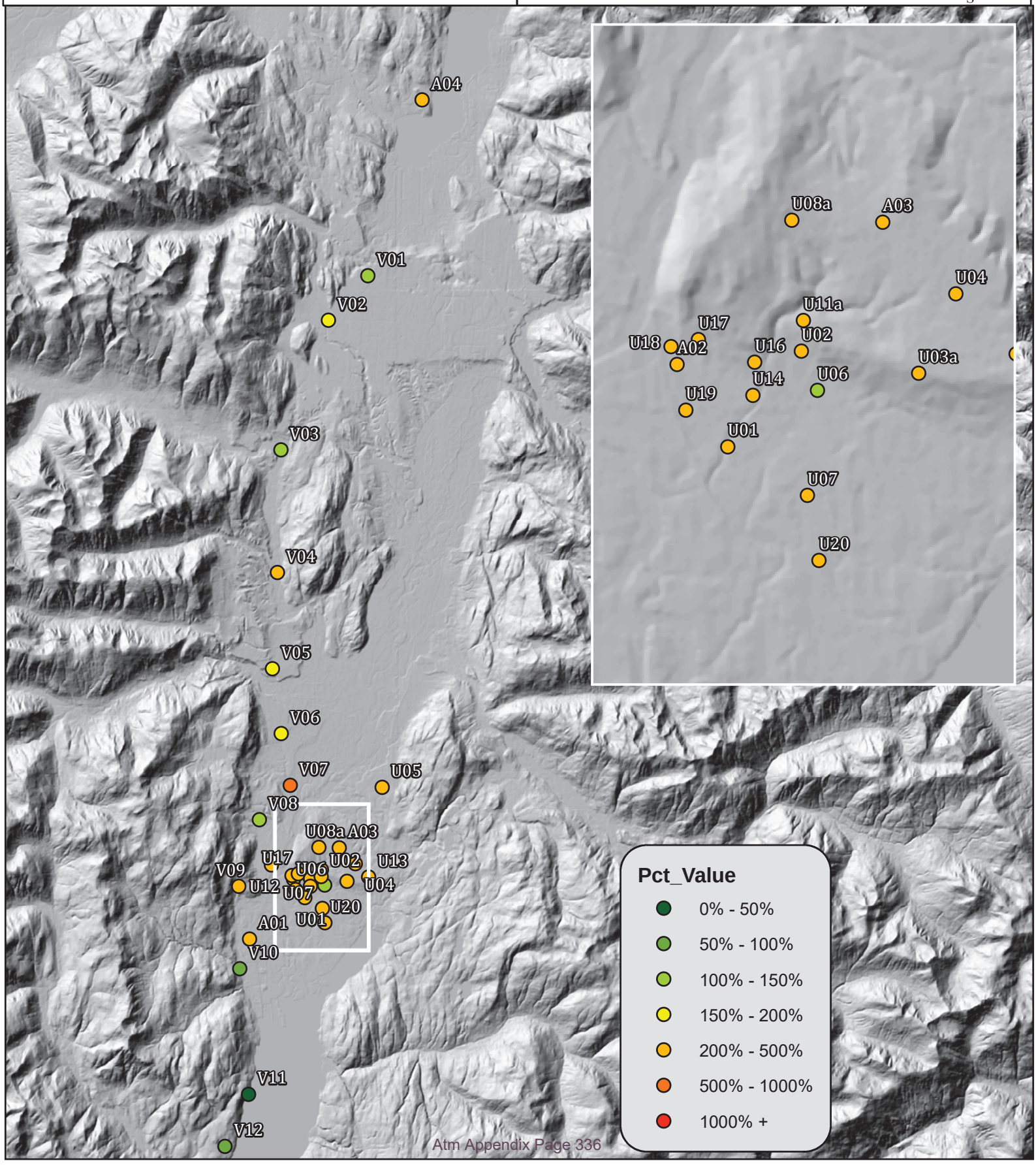
2017 Comparison - Hybrid Model vs Passive



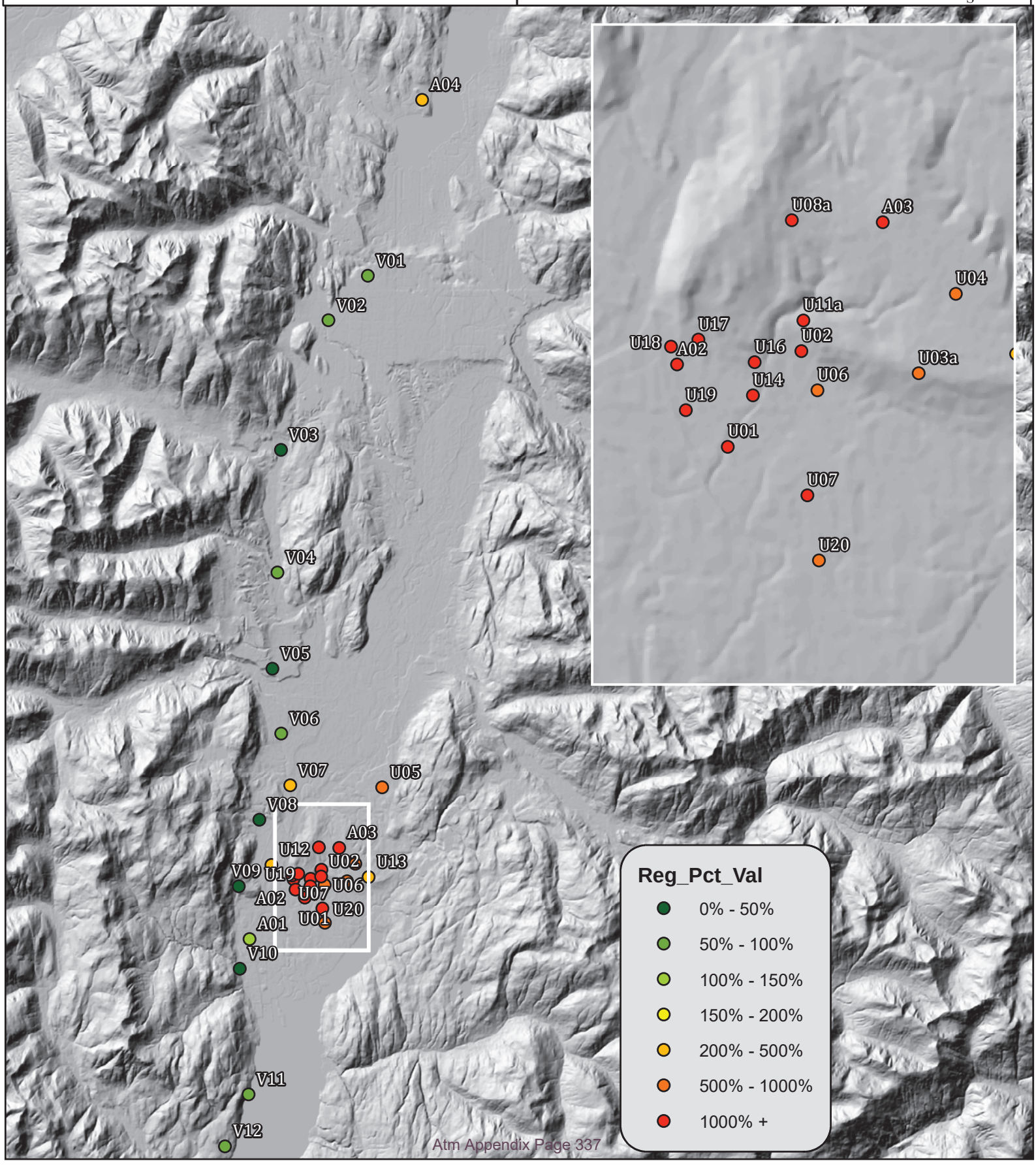
2017 Comparison - No-Obs Model vs Passive



2018 Comparison - Hybrid Model vs Passive



2018 Comparison - No-Obs Model vs Passive



Ministry of Environment and Climate Change Strategy

MEMORANDUM
P2-00001

August 23, 2019

Rio Tinto
Smeltersite Rd.
P.O. Box 1800
Kitimat, B.C.
V8C 2H2

Attention: Shawn Zettler

RE: Environmental Effects Monitoring Program Dispersion Modelling Plan
Approval of Proposed Amendments to the Regional CALPUFF Model Plan
Hybrid as Opposed to NoObs Mode
British Columbia Ministry of Environment P2-00001

Dear Shawn,

I have completed my review of material submitted by Trinity Consultants for the purpose of amending the CALPUFF Modelling Protocol (the "Protocol") to incorporate surface observations into the implementation of CALMET for regional modelling in support of the 2019 sulphur dioxide (SO_2) Environmental Effects Monitoring plan (EEMP) comprehensive review. The material I reviewed included:

- "Memo_CALMET Hybrid_2019-0807_PgNmbs.pdf" submitted on August 15th 2019,
- "Wind_OBSvWRF_2019-0808.xlsx" and "CALPUFF_v_PassiveData_Reg_Act_Values.xlsx" submitted on August 8th and 21st respectively,
- the email from Anna Henolson with subject heater "RE: Addendum to CALMET and CALPUFF Model Plan for Hybrid CALMET Approach" sent August 15th, and
- the "No-Obs_Hybrid_vs_passive_updated maps.pdf" submitted on August 21st.

Aspects of the revised Protocol were discussed with yourself, Anna Henolson, Jonathan Bernier and I on July 12th and August 6th.

My areas of review focussed on:

1. the quantified improvement of mean monthly modelled - observed SO_2 percent difference when CALMET was run in Hybrid mode as opposed to NoObs mode, and
2. the likelihood / prevalence of conflicting windfields resulting from blending surface station observations with Weather Research and Forecast model (WRF) data in Hybrid mode as opposed to WRF-only windfields in NoObs mode.

This memo constitutes written approval of proposed changes to the modelling approach as proposed in "Memo_CALMET Hybrid_2019-0807_PgNmbs.pdf" for the 2019 SO_2 comprehensive EEMP review, regional modelling only. No changes to the nearfied modelling have been considered or approved. For future reference please note that documents submitted without page numbers and/or with illegible figures will not be reviewed.

Addressing Concern 1

Based on Trinity's review of mean monthly modelled / observed SO_2 percent difference I agree that, in this instance (and with the exception of a small number of stations), model results show more favourable agreement with observations when CALMET is run in Hybrid mode as compared to NoObs mode. As such, the use of CALMET in NoObs mode does not pass an operational evaluation, as described by Dennis et al. (2010).

The decision to incorporate surface station data into CALMET is consistent with the methods I described to Sajid Barlas in my memo: "2016-10-03 Qs3-7 BW.pdf", specifically in the section "Answering question 7". The cycle of identifying improvements and rerunning a model to reduce error is an important step in the evaluation process. A conceptual framework for this process is taken from Steyn and Galmarini (2008) and presented as Figure 1.

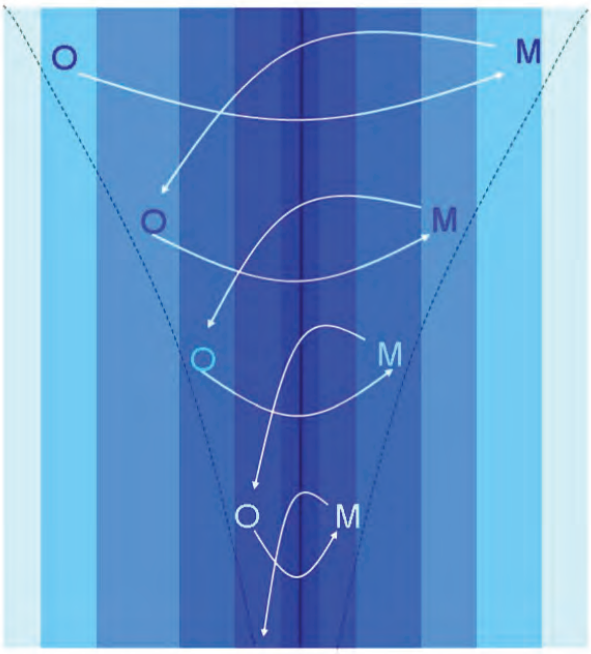


Figure 1: The evaluation of model (M) against observations (O), as presented in Steyn and Galmarini (2008). The dashed line represents the narrowing envelope of M - O variance, and the shaded zones represent various criteria for model success. Darker shades indicate more stringent criteria.

Addressing Concern 2

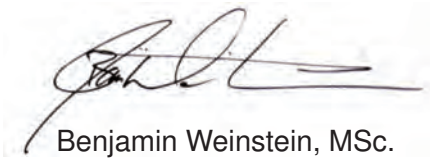
Based on the analysis submitted by Trinity I am satisfied to a reasonable degree that instances of conflicting windfields resulting from blending observation data with WRF windfields in CALMET are not strongly prevalent in the model domain. In my opinion the presence of conflicting windfields created uncertainty in the Sulphur Dioxide Technical Assessment report (STAR) modelling results and my concern is that subsequent modelling studies in this airshed must minimize the potential for artificial hot and cold spots created by conflicting windfields.

Note on the Haul Rd. Met station

As demonstrated by the figures presented in "Memo_CALMET Hybrid_2019-0807_PgNmbs.pdf", paired hourly WRF and observed wind direction data at Haul Rd meteorological monitoring station objectively have the weakest performance of any station in Kitimat. This is possibly because even at 1.333 km, WRF is unable to resolve small-scale meteorological processes along the edge of the Terrace - Kitimat valley (TKV). Were this any other meteorological monitoring station I would hesitate to its inclusion in the regional model, however due to the importance of this station's meteorological data I accept its use in this case. I should note that the previous time I was at Haul Rd I observed trees growing in close proximity to this station. The presence of interfering objects may also explain some of the discrepancy between model and observed data and I request that a plan be immediately implemented to ensure that the citing of this station remain consistent with best practices, including removal of nearby obstructions.

Moving Forward

Please contact me should you have any questions about this memo.



Benjamin Weinstein, MSc.
Air Quality Meteorologist
Authorizations North & Monitoring, Assessment and Stewardship
B.C. Ministry of Environment and Climate Change Strategy
250.847.7256

cc: Karen Moores, Head, Authorizations North Section, Environmental Protection, Williams Lake
cc: Frazer McKenzie, Sr. Environmental Protection Officer, Environmental Protection, Smithers
cc: Arvind Saraswat, Head, Air Quality Section (Assessments), Environmental Protection, Surrey
cc: Anna Henolson, Managing Consultant, Trinity Consultants, Seattle

References

Dennis, R., Fox, T., Fuentes, M., Gilliland, A., Hanna, S., Hogrefe, C., Irwin, J., Rao, S., Scheffe, R., Schere, K., Steyn, D., Venkatram, A. (2010). A framework for evaluating regional-scale numerical photochemical modelling systems. *Environ. Fluid Mech.* 10, 471–489.

Steyn, D., Galmarini, S. (2008). Evaluating the Predictive and Explanatory Value of Atmospheric Numerical Models: Between Relativism and Objectivism. *Open Atmospheric Science Journal*, 2, 38–45.

MEMORANDUM

To: Benjamin Weinstein – Ministry of Environment and Climate Change Strategy
CC: Shawn Zettler, Jonathan Bernier – Rio Tinto
From: Anna Henolson – Trinity Consultants
Date: September 16, 2019
RE: Local-Scale CALMET Model Upper Air Meteorological Data Recommendations

Rio Tinto owns and operates an aluminum smelter located in Kitimat, BC (the Kitimat Smelter). In order to support the Environmental Effects Monitoring (EEM) program, Rio Tinto is conducting SO_2 air dispersion modelling using the CALPUFF modelling system, including the CALMET meteorological model.

Rio Tinto submitted a detailed CALMET and CALPUFF modelling plan on May 13, 2019. The plan included a proposal to run local-scale CALMET using pseudo upper air station meteorological data located near the gas treatment center (GTC) stacks in Kitimat, BC. The initial CALPUFF model using upper air observations at the GTC produced SO_2 air concentration results that differed from expectations and were significantly higher at the Kitimat Riverlodge and Kitimat Whitesail locations than observed concentrations measured using continuous SO_2 analyzers. In order to improve model performance, Rio Tinto has explored the performance of test models using Weather Research Forecast (WRF) pseudo upper air station meteorological data extracted at the Terrace Airport (CYXT) and upper air observations at Annette Island and Port Hardy (Obs Tests). CALMET requires no missing upper air data; therefore, missing data must be filled. Two different filling methods were used:

- Obs 1 method filled all data in all layers.
- Obs 2 method filled data only for the top-most and bottom-most layers.

This memorandum evaluates the model performance data from test CALPUFF runs[1] using the original CALMET and the test CALMET with the three different upper air meteorological datasets for one year (2016).

CALPUFF RESULTS COMPARISON

Trinity has completed initial local-scale CALPUFF models for one test year (2016) using CALMET with original, CYXT, Obs1, and Obs2 upper air meteorological data. Original and test model results from 2016 are compared to the SO_2 observations at four continuous monitoring locations: Kitamaat Village, Haul Road, Whitesail, and Riverlodge. Local-scale model result plots using original and CYXT upper air data are included in Figure 1.

CALPUFF model results over-predicted concentrations at the Riverlodge monitor by an order of 5.2 times observed concentrations using original upper air data. CALPUFF test results using upper air meteorological data extracted at CYXT indicate over-prediction by an order of 2.9, and closer to 2 at highest concentrations. The change indicates a significant improvement in model performance by the CYXT model. Quantile-quantile (Q-Q) plots illustrating performance of the two models at the Riverlodge monitor are provided in Figure 2.

[1] Test CALPUFF runs also omit the potline source because it contributes less than 1% of SO_2 emissions and requires significantly longer model run times.

Figure 1. SO_2 Concentration Results Comparison
(Left: Original Pseudo Upper Air near GTC, Right: Pseudo Upper Air at Terrace Airport)

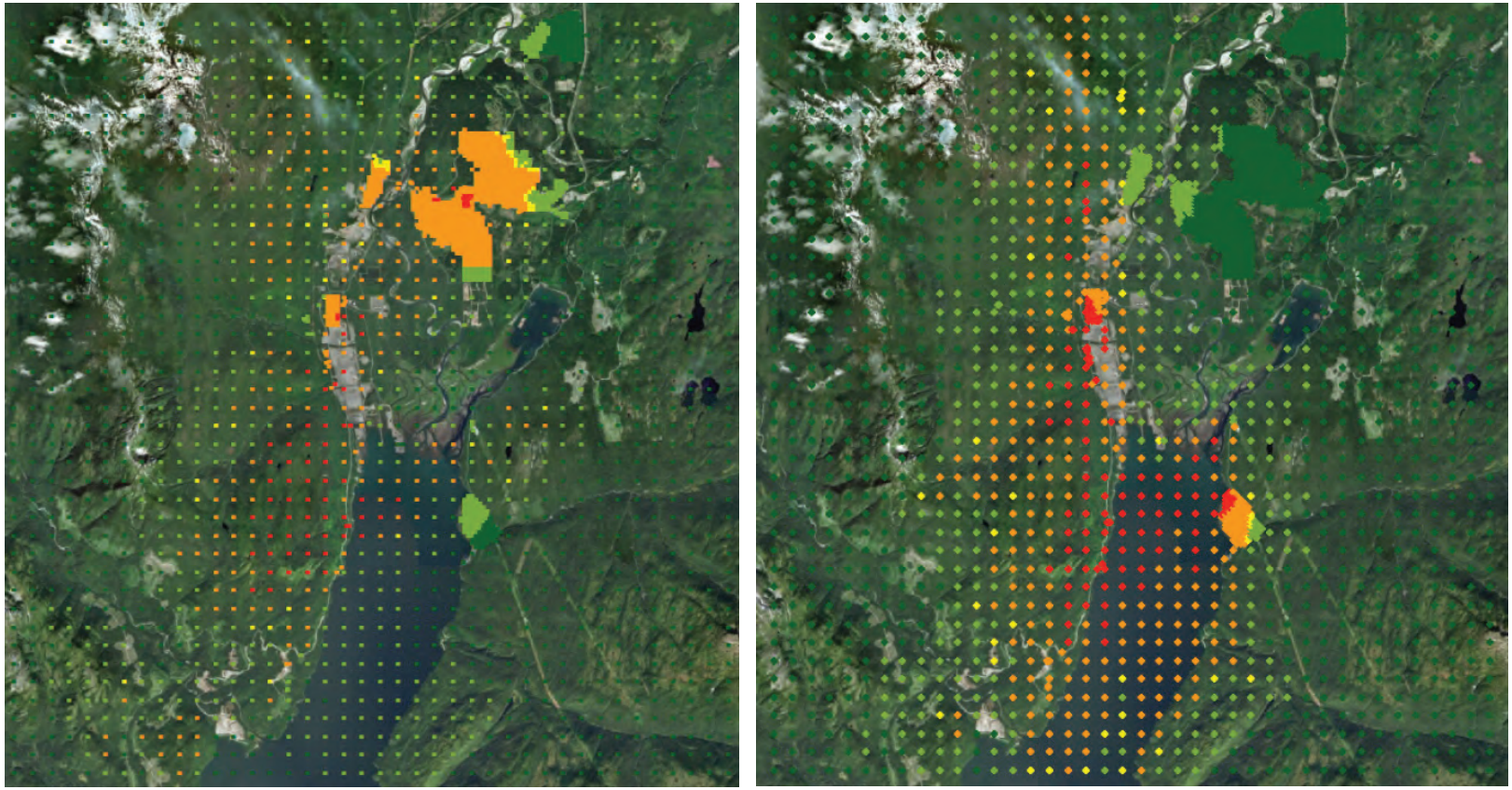
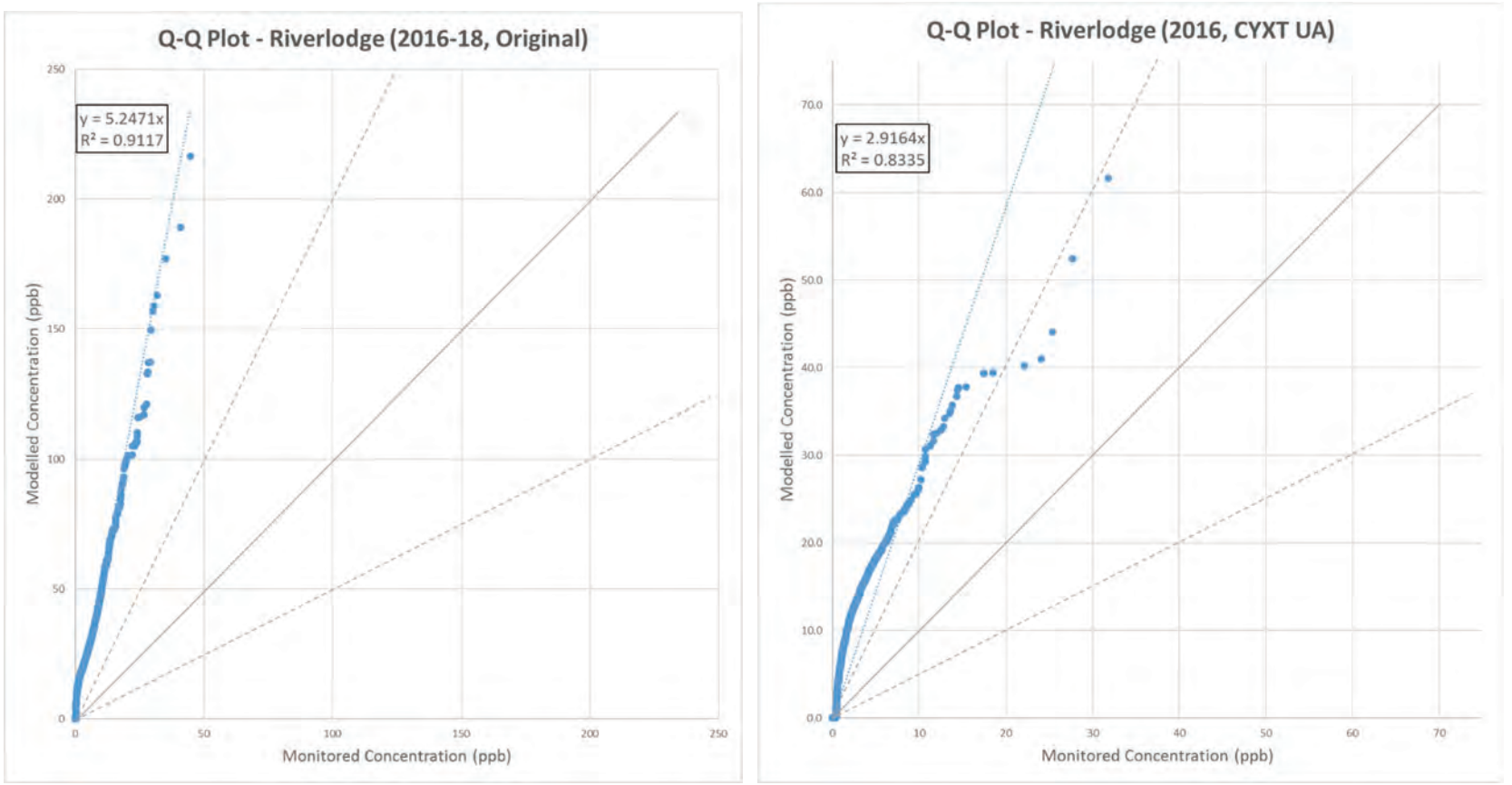


Figure 2. SO_2 Concentration Q-Q Plots Comparison at Riverlodge Station (Left: Original Pseudo Upper Air Near GTC, Right: Pseudo Upper Air at Terrace Airport)



The Obs1 and Obs2 test model runs resulted in CALPUFF concentrations similar to the run using CYXT pseudo upper air data. Results at the Kitamaat Village monitor improved only slightly over CYXT with the use of Obs1 and Obs2 upper air observations. Table 1 compares model results at the continuous monitoring locations for the original and test model runs. Q-Q plots indicating performance of each of the test models at the Riverlodge and Haul Road monitors are provided in Figure 3.

Table 1. Model Concentration Summary

Highest Maximum Daily Concentration (µg/m³)				
Year-Scenario	Kitamaat Village	Haul	Whitesail	Riverlodge
2016-Orig	143	465	300	494
2016-CYX	448	378	107	161
2016-UA Obs1	462	385	100	175
2016-UA Obs2	441	383	103	169
99th Percentile Maximum Daily Concentration (µg/m³)				
Year-Scenario	Kitamaat Village	Haul	Whitesail	Riverlodge
2016-Orig	102	326	206	255
2016-CYX	403	249	43	105
2016-UA Obs1	307	260	43	116
2016-UA Obs2	284	260	45	106
Annual Average Concentration (µg/m³)				
Year-Scenario	Kitamaat Village	Haul	Whitesail	Riverlodge
2016-Orig	1.1	16.0	3.1	7.4
2016-CYX	3.0	19.9	0.9	3.6
2016-UA Obs1	3.3	19.9	1.0	3.7
2016-UA Obs2	3.0	20.0	1.0	3.6

Figure 3. SO_2 Concentration Q-Q Plots Comparison at Riverlodge Station
(Left: Pseudo Upper Air at Terrace Airport, Center: Upper Air Observation Method 1, Right: Upper Air Observation Method 2)

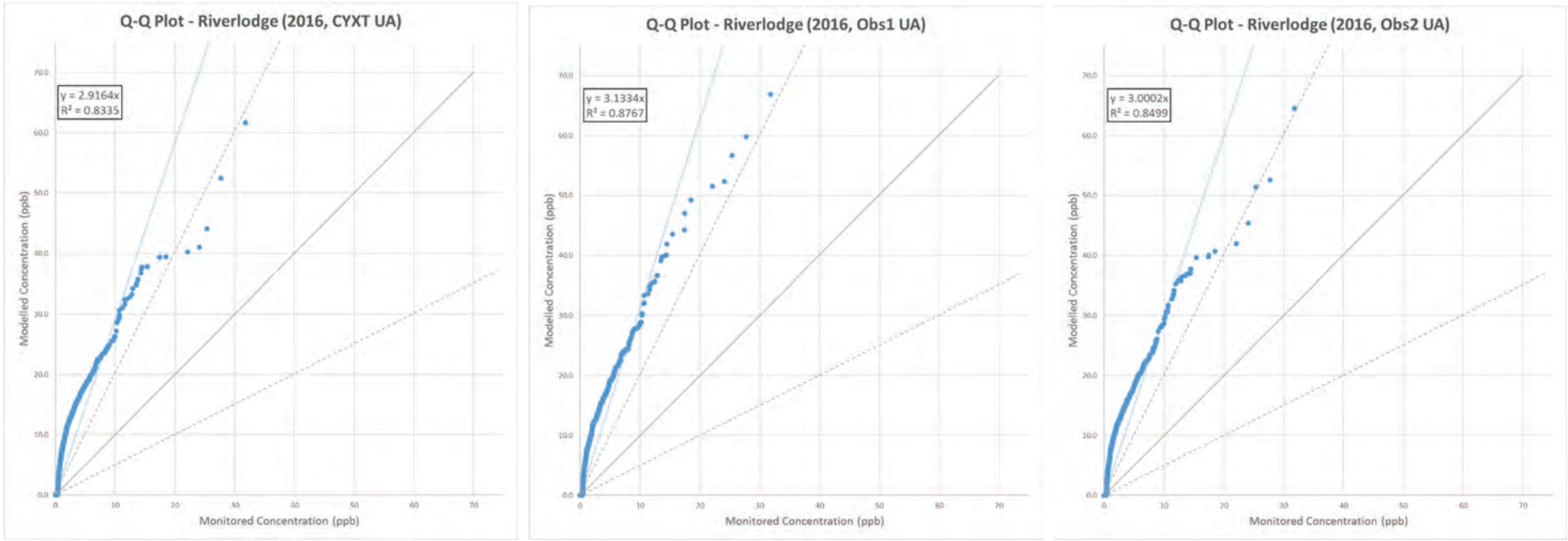
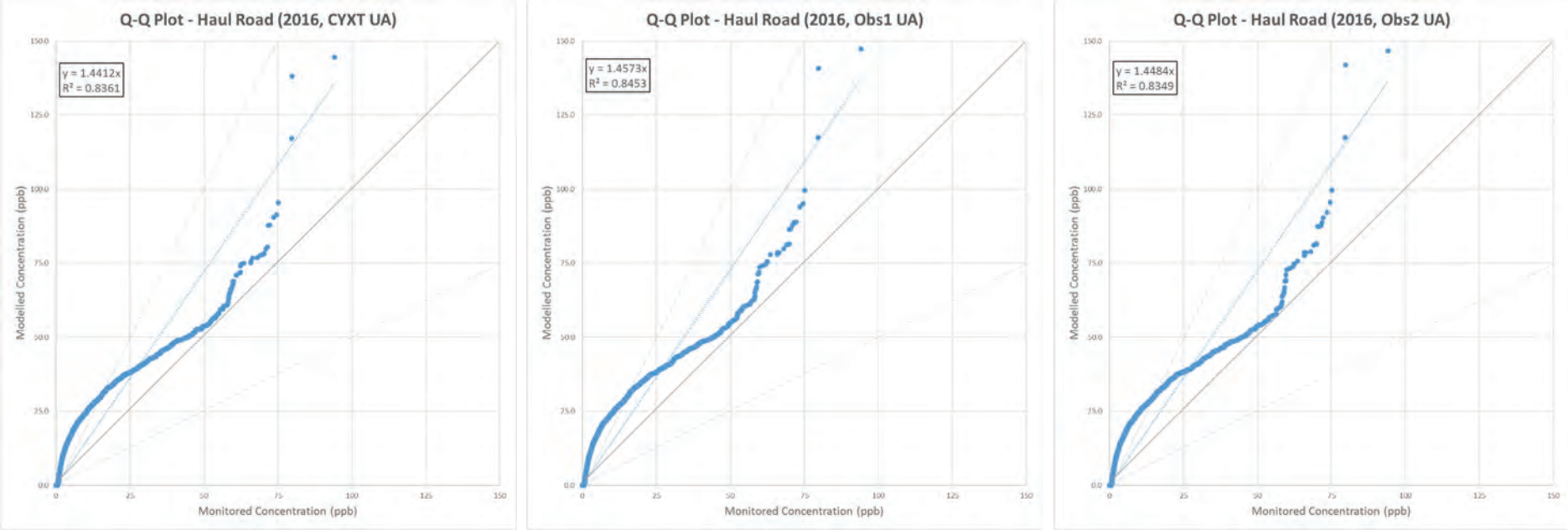


Figure 4. SO_2 Concentration Q-Q Plots Comparison at Haul Road Station
(Left: Pseudo Upper Air at Terrace Airport, Center: Upper Air Observation Method 1, Right: Upper Air Observation Method 2)



MODEL PERFORMANCE EVALUATION STATISTICS

As summarized in Table 2, the model performance of each test model is evaluated using performance statistics including root mean squared error (RMSE), mean bias error (MB), and mean absolute error (MAE) at each continuous monitoring location. The calculated performance statistics for each test model at each monitoring location are displayed in Table 2. All three test models performed noticeably better than the original model. All three test models produce similar performance statistics as each other, with the Obs1 model demonstrating higher error at the Kitamaat Village and Riverlodge monitors. Overall, the CYXT test performed slightly better than the Obs tests at Haul Road and Riverlodge and nearly the same as Obs2 at Whitesail and Kitamaat Village (i.e., CYXT metrics compared to Obs2 are less than 0.6% different for all three metrics at Whitesail and Kitamaat Village versus 1.3% to 2.9% better at Riverlodge).

Table 2. Model Performance Statistics Summary (µg/m³)

Monitor	Model	RMSE	MBE	MAE
Haul Road	Original	39.15	5.88	18.94
	CYXT	36.26	9.68	18.98
	Obs1	36.60	9.76	19.00
	Obs2	36.50	9.80	19.06
Riverlodge	Original	20.19	6.15	7.30
	CYXT	10.61	2.32	3.89
	Obs1	11.17	2.43	3.98
	Obs2	10.82	2.39	3.94
Whitesail	Original	13.70	1.75	3.67
	CYXT	4.12	-0.37	1.74
	Obs1	4.14	-0.32	1.75
	Obs2	4.11	-0.34	1.75
Kitamaat Village	Original	5.17	0.15	1.62
	CYXT	16.04	2.08	3.54
	Obs1	17.61	2.38	3.82
	Obs2	16.02	2.07	3.52

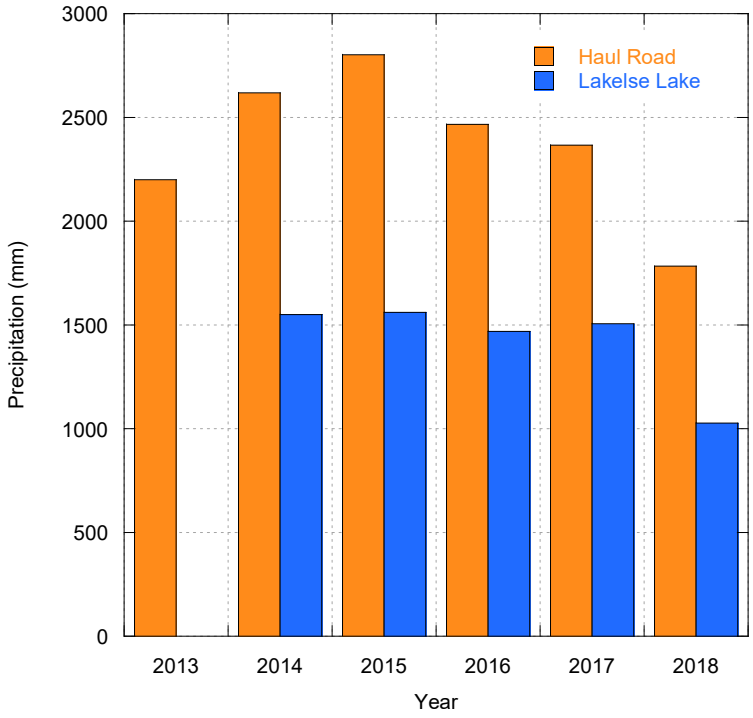
CONCLUSION & RECOMMENDATIONS

CALMET and CALPUFF demonstrated improved performance using pseudo upper air data at Terrace Airport compared to pseudo upper air data near the GTC stacks. The use of pseudo upper air data extracted at CYXT produces CALPUFF results that are more representative of observations at the continuous monitors. Both test model runs using actual upper air observations produced similar results to each other and showed minimal difference compared to the CYXT test run. Overall, the CYXT test performed slightly better than the Obs tests at Haul Road and Riverlodge and on par with Obs2 at Whitesail and Kitamaat Village based on the metrics shown in Table 2. Additionally, the locations of available actual upper air observations are too distant to be representative of actual conditions near the Kitimat Smelter. For both these reasons, Trinity proposes the use of pseudo upper air data extracted from WRF data at Terrace Airport for local CALMET/CALPUFF model runs.

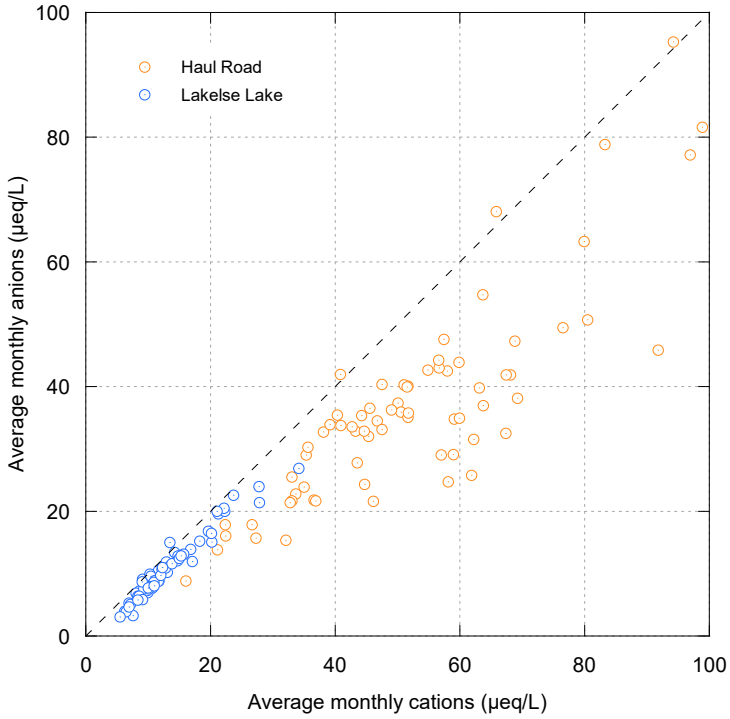
3.2 Atmospheric Deposition

3.2.1 Precipitation chemistry at Haul Road and Lakelse Lake

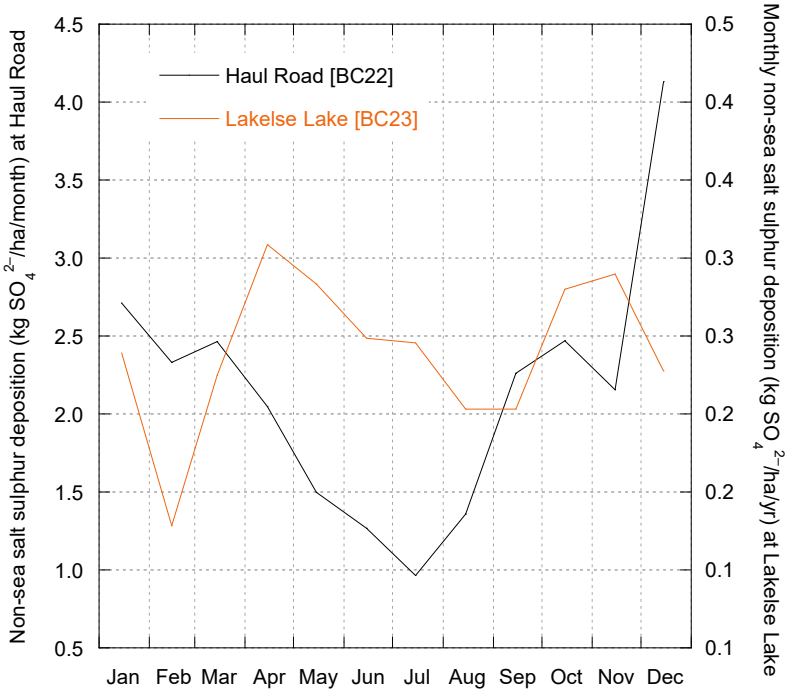
A comparison of precipitation chemistry at Haul Road and Lakelse Lake is presented in Figure 3-16 under Section 3.2.3.1 of the main report. Larger versions (A–F) of each plot is presented below.



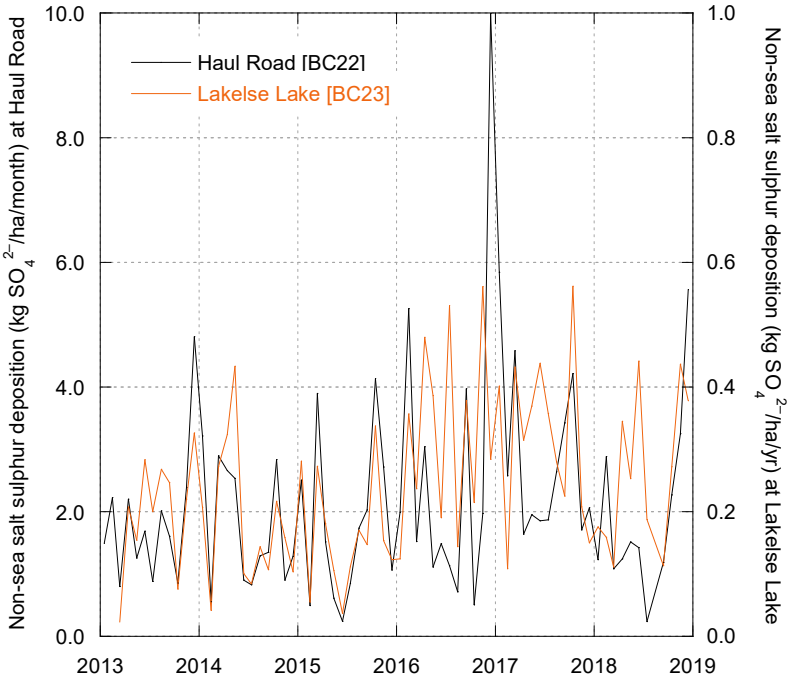
A. Comparison of annual rainfall volume at Haul Road and Lakelse Lake (2013–2018).



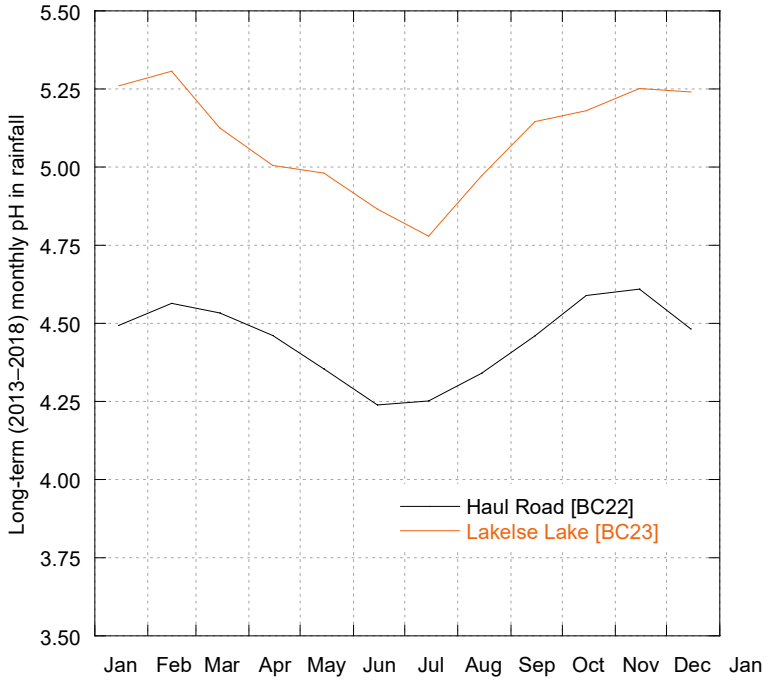
B. Comparison of the monthly ion balance for precipitation chemistry (µeq/L) at Haul Road and Lakelse Lake (2013–2018).



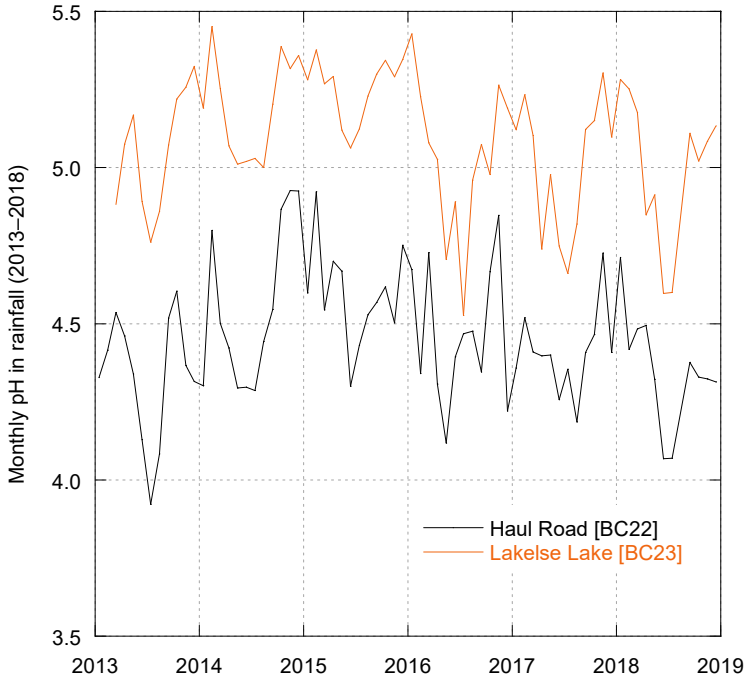
C. Comparison of average monthly (2013–2018) non-sea salt sulphur deposition (kg SO_4^{2-}/ha/yr) at Haul Road and Lakelse Lake; note different axis for Haul Road and Lakelse Lake.



D. Comparison of long-term monthly non-sea salt sulphur deposition (kg SO42–/ha/yr) at Haul Road and Lakelse Lake (2013–2018); note different axis for Haul Road and Lakelse Lake.



E. Comparison of average monthly (2013–2018) pH in rainfall at Haul Road and Lakelse Lake



F. Comparison of long-term monthly pH in rainfall at Haul Road and Lakelse Lake (2013–2018).

Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project

Volume 2: 2019 Comprehensive Review Report Technical Appendices, V.3 Final

[Appendices 4, 5, and 6: Human Health, Vegetation, and Terrestrial Ecosystems (Soils)]

October 15, 2020

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Version Tracking Table

No.	Date	Summary of content /changes
V.1	October 31, 2019	Draft appendix for review by the B.C. Ministry of Environment and Climate Change Strategy
V.2	June 30, 2020	Draft appendix for KPAC review
V.3	October 15, 2020	Final appendix

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Matthew Siegle, ESSA Technologies
Jeremias Szust, Trinity Consultants
Andrew Thompson, ESSA Technologies

Volume 2: Technical Appendices of the 2019 Comprehensive Review of Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project, V.3 Final, is packaged in four parts: Appendix 1; Appendix 3; Appendices 4, 5 and 6; and Appendix 7. Each Technical Appendix is numbered according to the chapter in the Comprehensive Review Report (Volume 1) that it supports. There is no Appendix 2 as there is no appendix material for Section 2 in the Comprehensive Review Report.

Please cite this report as follows:

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4 Appendix to Section 4 of the Comprehensive Review Report: Human Health

4.1 Histograms of Hourly SO_2 Concentrations for 2016 and 2017

The main body of the report contains histograms of hourly SO_2 concentrations for the year 2018 for each of the three residential monitoring stations.

This appendix contains the same type of histograms, but for the years 2016 and 2017.

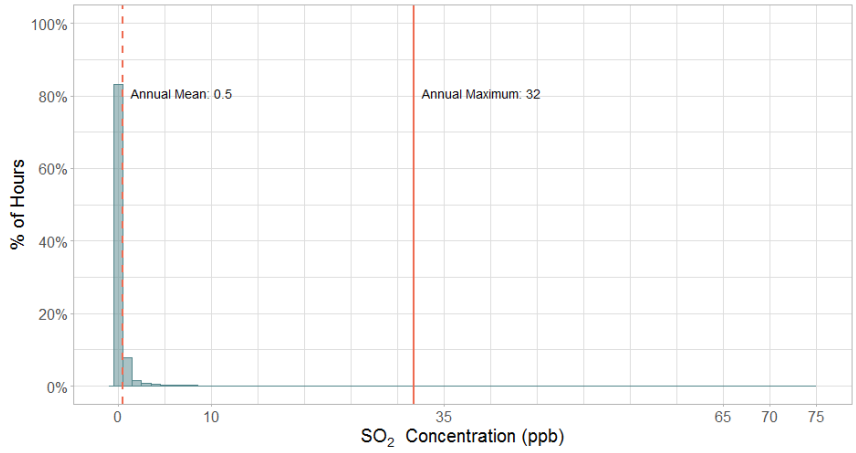


Figure 4.1: Histogram of Hourly Averaged SO_2 Concentrations (Riverlodge, 2016).

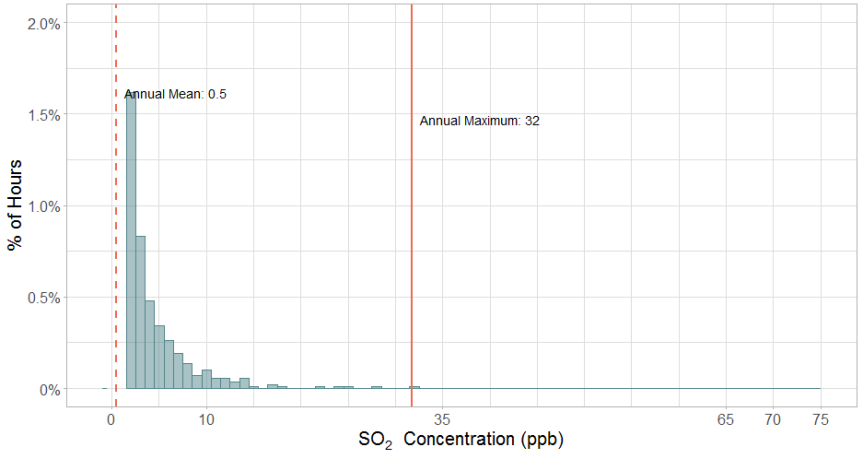


Figure 4.2: Histogram of Hourly SO_2 concentrations with y-axis cut off at 2% (Riverlodge, 2016). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis.

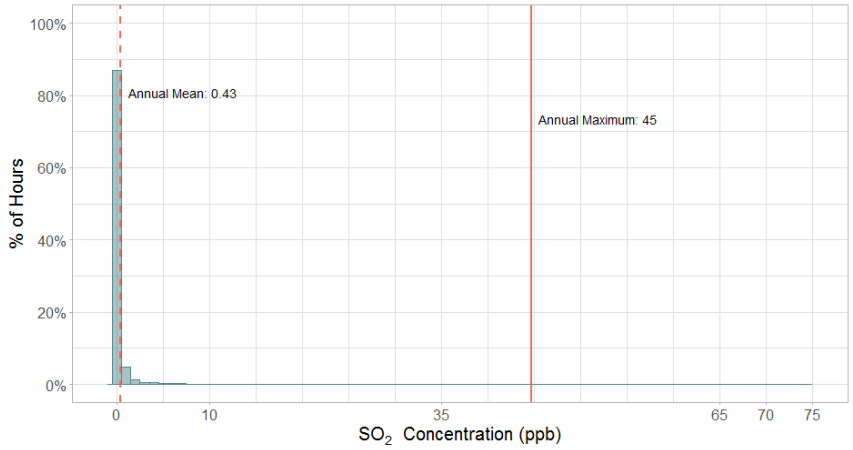


Figure 4.3: Histogram of Hourly Averaged SO_2 Concentrations (Riverlodge, 2017).

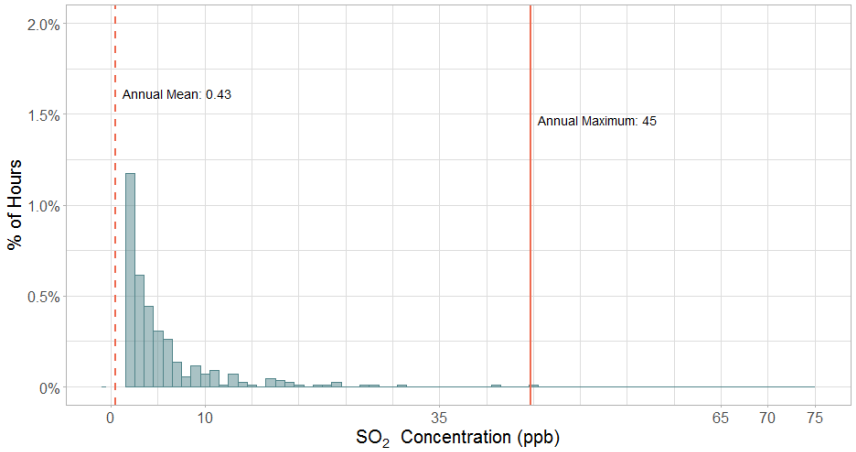


Figure 4.4: Histogram of Hourly SO_2 concentrations with y-axis cut off at 2% (Riverlodge, 2017). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis.

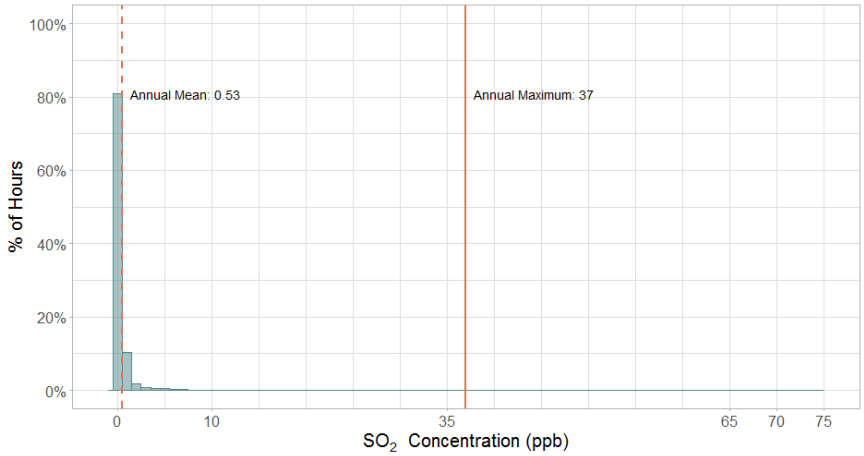


Figure 4.5: Histogram of Hourly Averaged SO_2 Concentrations (Whitesail, 2016).

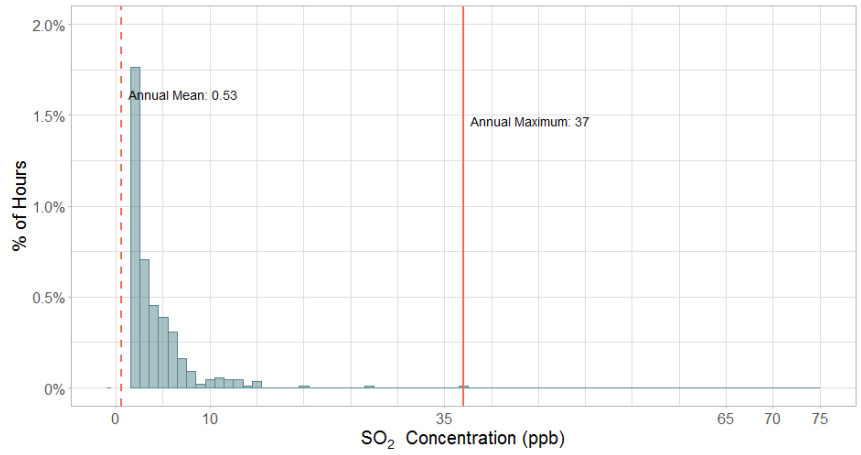


Figure 4.6: Histogram of Hourly SO_2 concentrations with y-axis cut off at 2% (Whitesail, 2016). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis.

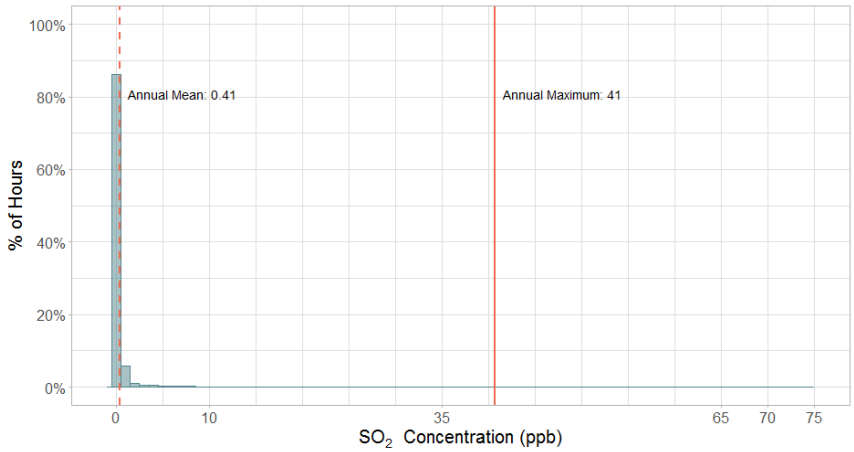


Figure 4.7: Histogram of Hourly Averaged SO_2 Concentrations (Whitesail, 2017).

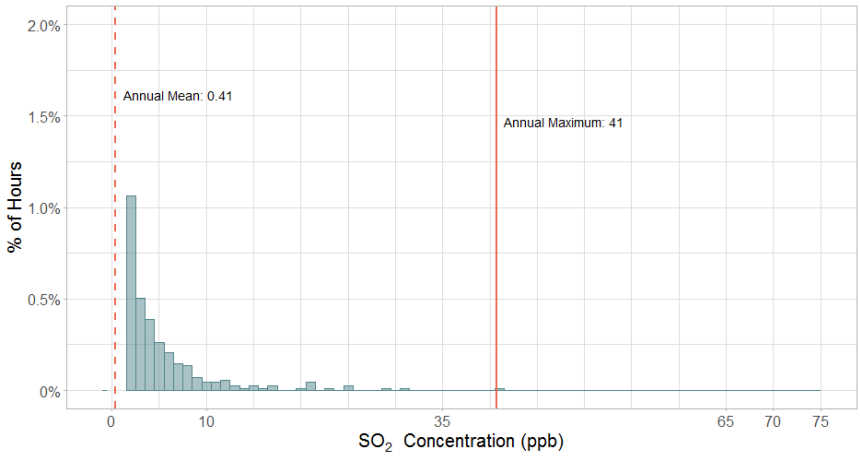


Figure 4.8: Histogram of Hourly SO_2 concentrations with y-axis cut off at 2% (Whitesail, 2017). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis.

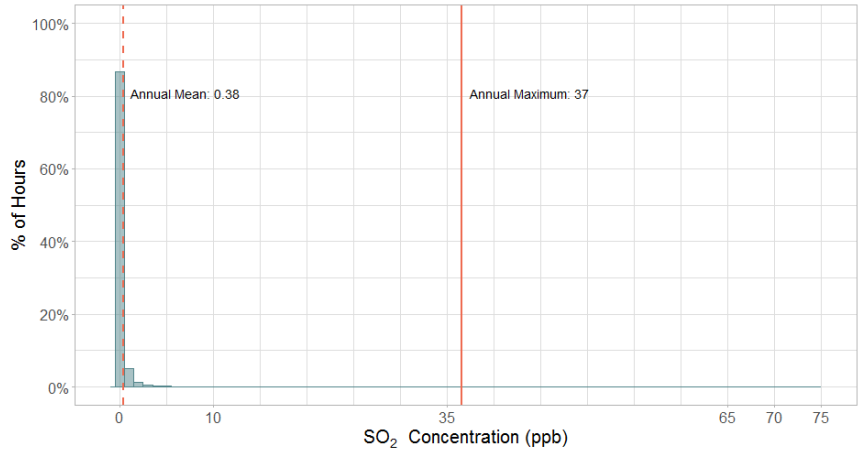


Figure 4.9: Histogram of Hourly Averaged SO_2 Concentrations (Kitamaat Village, 2016).

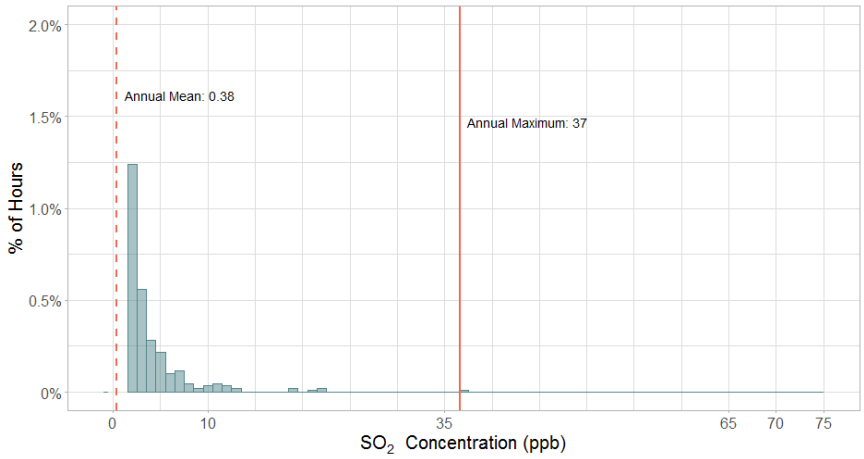


Figure 4.10: Histogram of Hourly SO_2 concentrations with y-axis cut off at 2% (Kitamaat Village, 2016). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis..

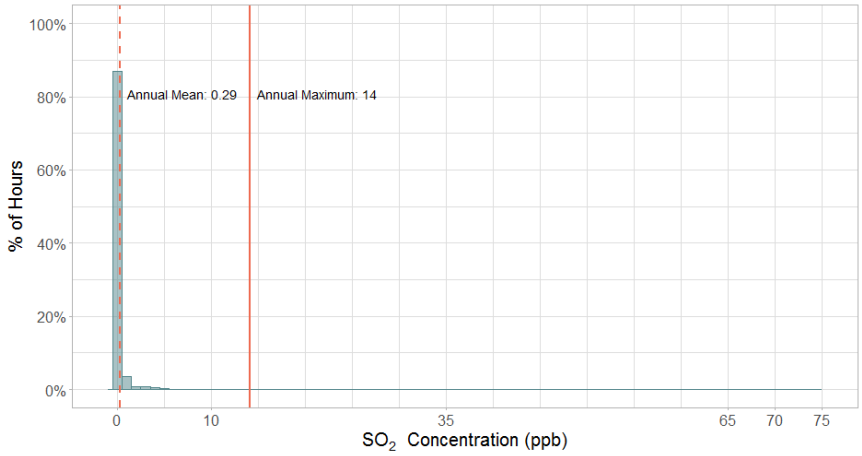


Figure 4.11: Histogram of Hourly Averaged SO_2 Concentrations (Kitamaat Village, 2017).

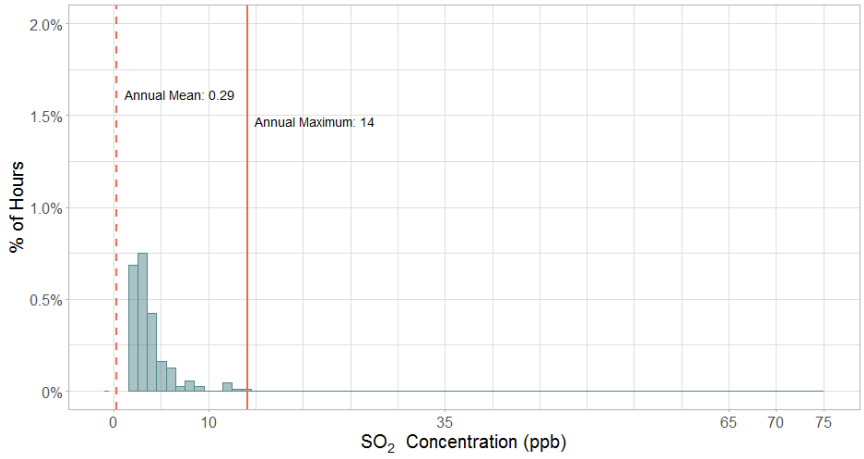


Figure 4.12: Histogram of Hourly SO_2 concentrations with y-axis cut off at 2% (Kitamaat Village, 2017). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis.

4.2 Histograms of Daily 1-Hour Maximum SO_2 Concentrations for 2016 and 2017

The main body of the report contains histograms of the daily 1-hour maximum (D1HM) SO_2 concentrations for the year 2018 for each of the three residential monitoring stations. Note that the 97.5th percentile is shown on each graph, as this is the value that is used in the most recent KPI calculation based on the three-year average of the 97.5th percentile D1HM values over the years 2016-2018. The 97th percentile in each case is slightly lower, and can be found in the main report in Table 4-5 of the main report.

This appendix contains the same type of histograms, but for the years 2016 and 2017. Each histogram is shown twice. The first time the y-axis is shown at full scale (0-100%), while in the second instance, the y-axis is "zoomed in" to the range of 0-2%, in order to show the low frequency occurrences that are not easily discerned on the full scale. For the zoomed-in view, histogram bars that exceed 2% are removed.

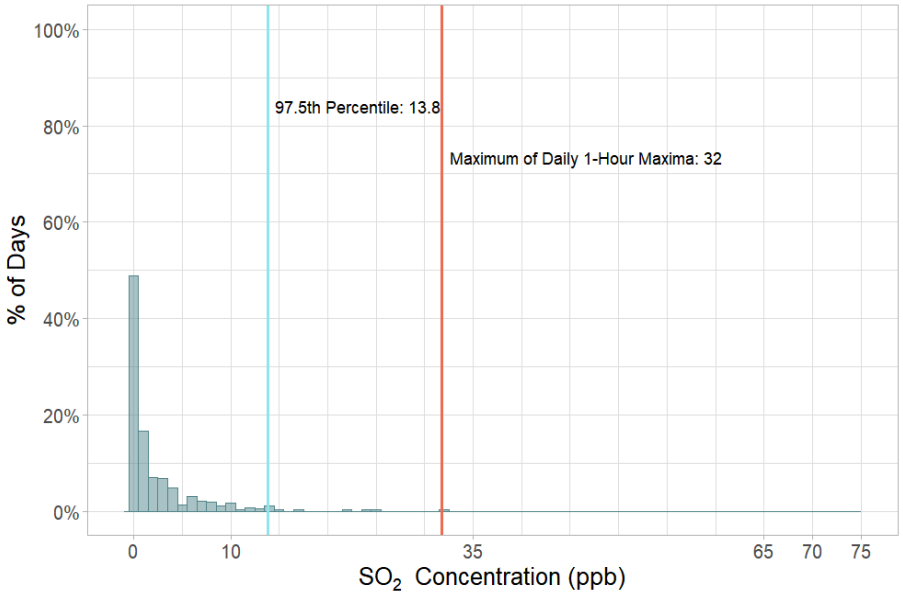


Figure 4.13: Histogram of D1HM SO_2 Concentrations (Riverlodge, 2016).

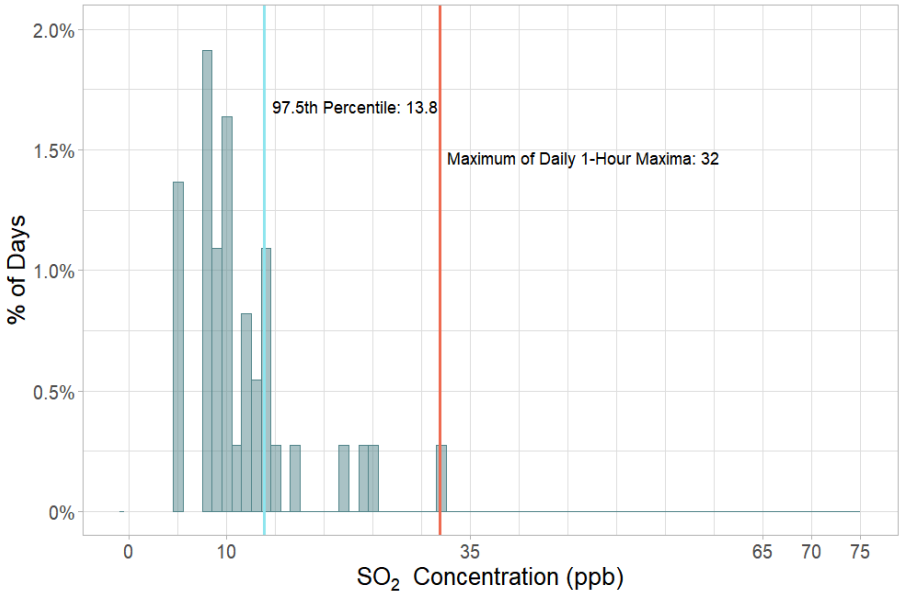


Figure 4.14: Histogram of D1HM SO_2 Concentrations with y-axis cut off at 2% (Riverlodge, 2016). Note: Several of the first histogram bars (0-4 ppb and 6-7ppb) are not shown because they exceed the limit of the y-axis.

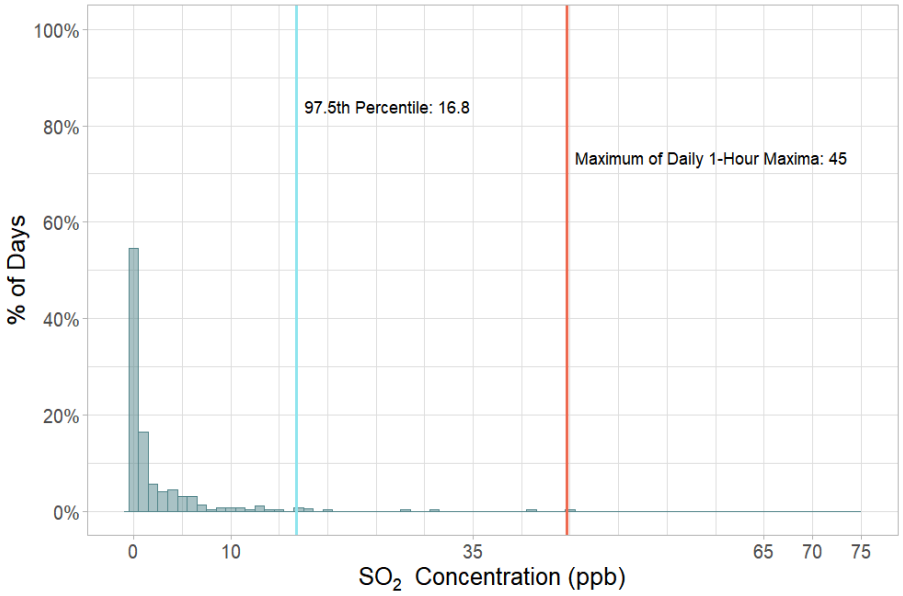


Figure 4.15: Histogram of D1HM SO_2 Concentrations (Riverlodge, 2017).

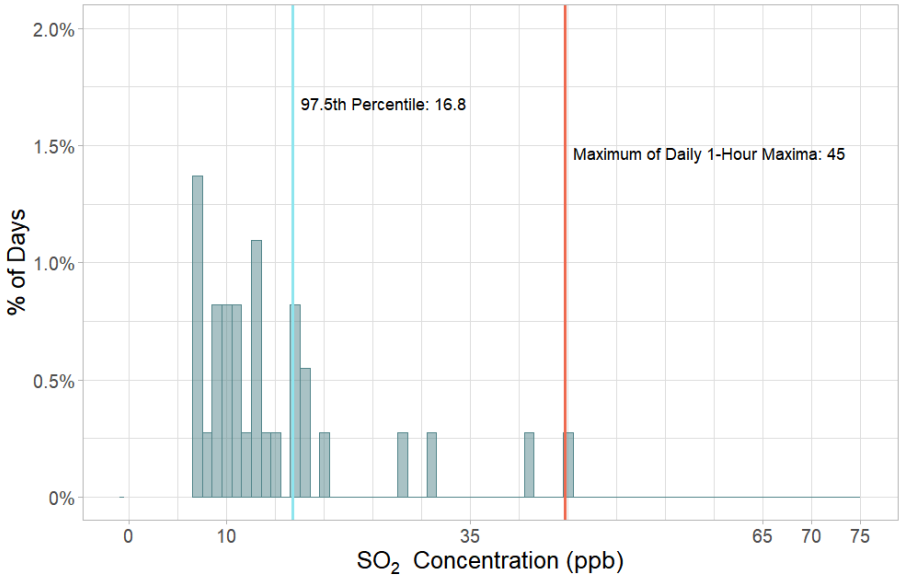


Figure 4.16: Histogram of D1HM SO_2 Concentrations with y-axis cut off at 2% (Riverlodge, 2017). Note: The first seven histogram bars are not shown because they exceed the limit of the y-axis.

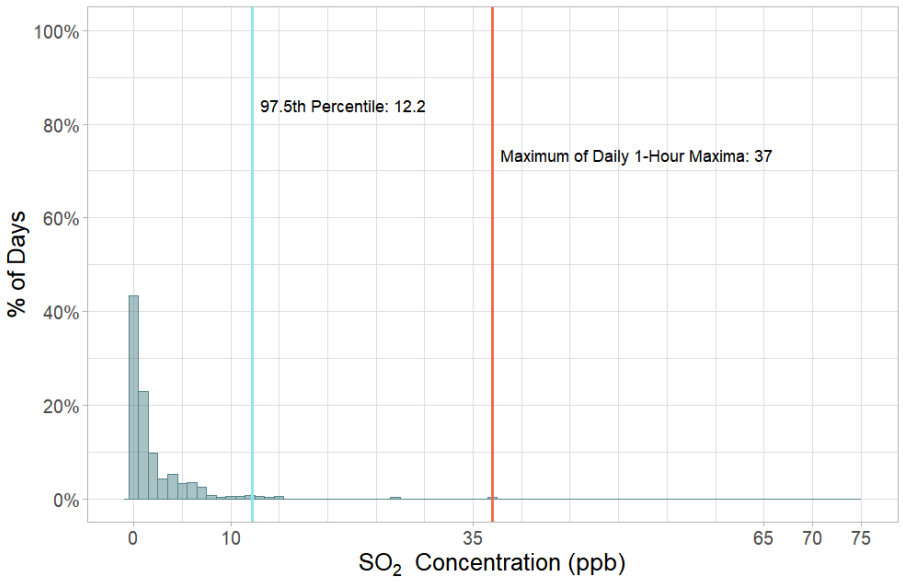


Figure 4.17: Histogram of D1HM SO_2 Concentrations (Whitesail, 2016).

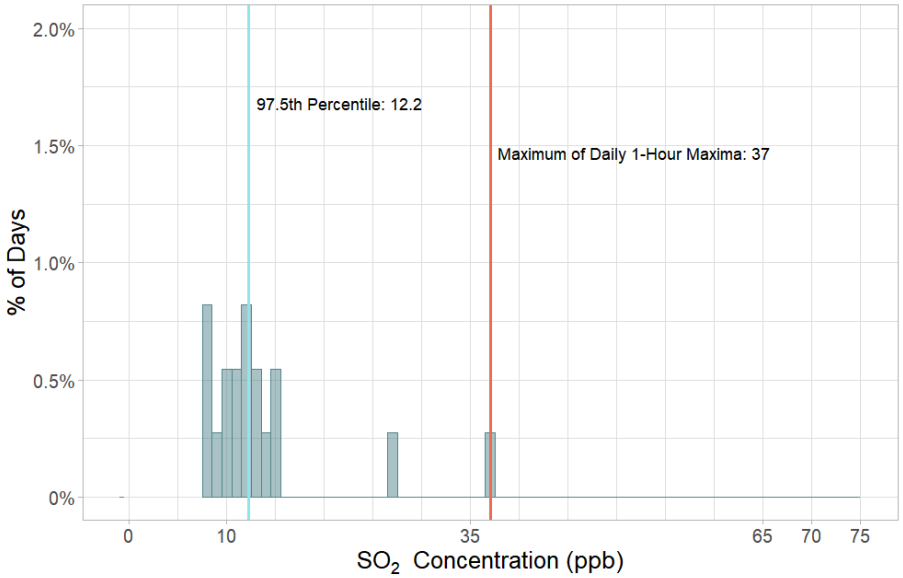


Figure 4.18: Histogram of D1HM SO_2 Concentrations with y-axis cut off at 2% (Whitesail, 2016). Note: The first eight histogram bars are not shown because they exceed the limit of the y-axis.

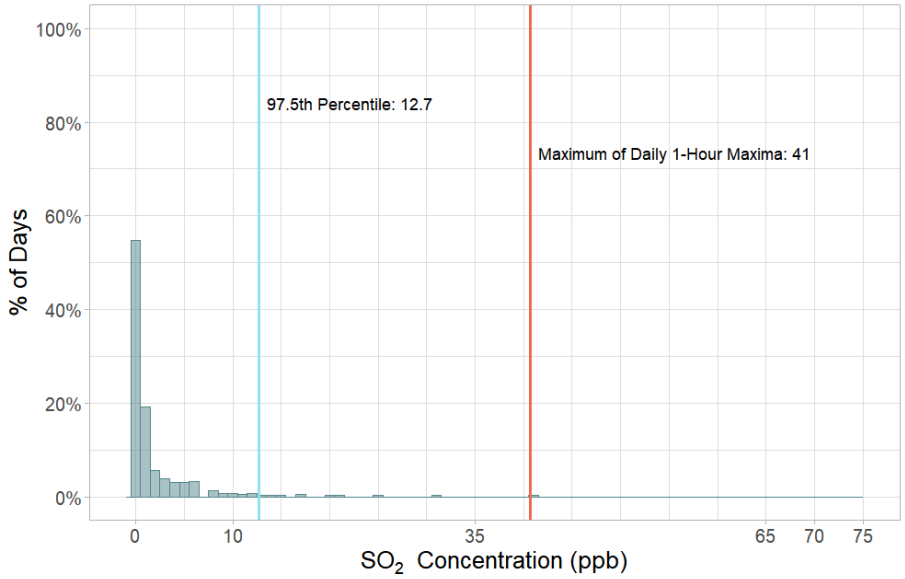


Figure 4.19: Histogram of D1HM SO_2 Concentrations (Whitesail, 2017).

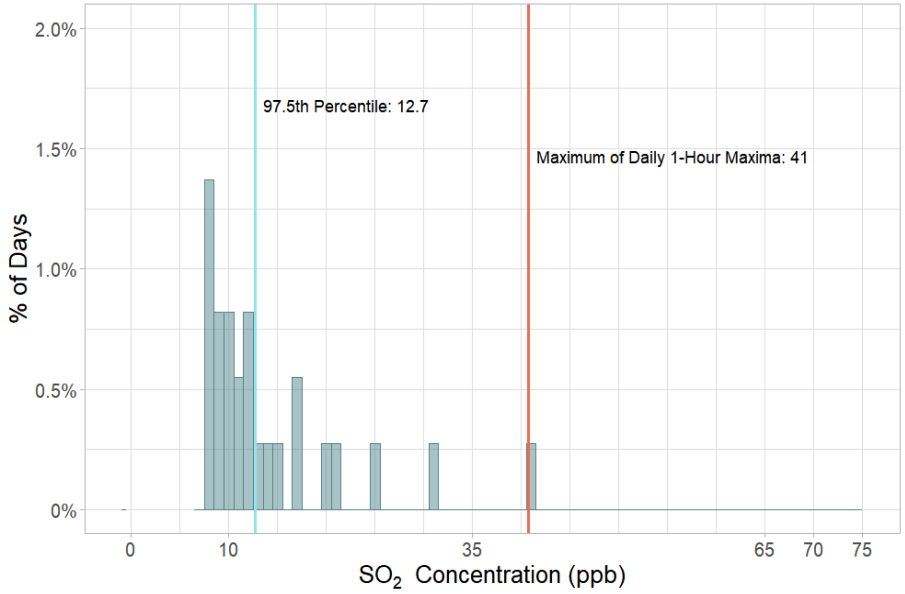


Figure 4.20: Histogram of D1HM SO_2 Concentrations with y-axis cut off at 2% (Whitesail, 2017). Note: The first eight histogram bars are not shown because they exceed the limit of the y-axis.

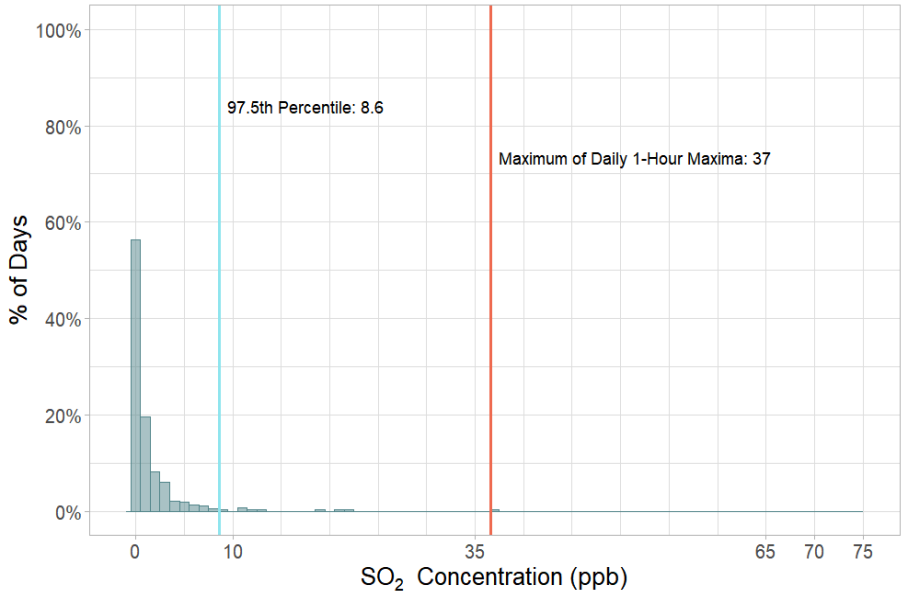


Figure 4.21: Histogram of D1HM SO_2 Concentrations (Kitamaat Village, 2016).

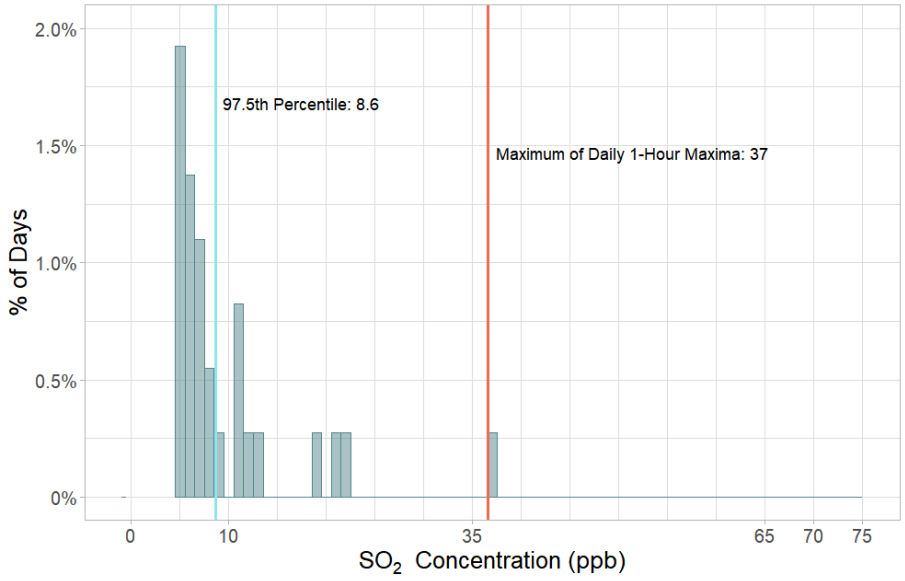


Figure 4.22: Histogram of D1HM SO_2 Concentrations with y-axis cut off at 2% (Kitamaat Village, 2016). Note: The first two histogram bars are not shown because they exceed the limit of the y-axis.

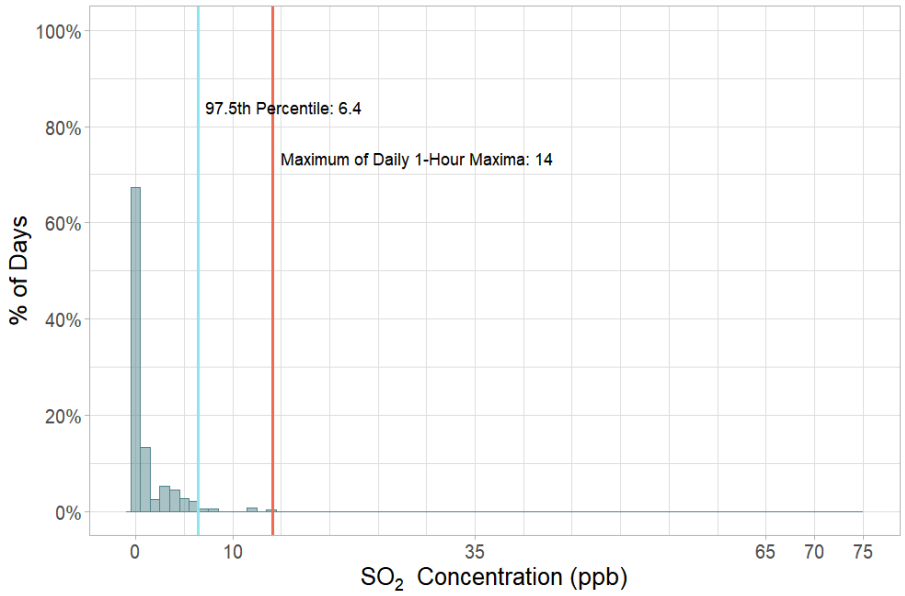


Figure 4.23: Histogram of D1HM SO_2 Concentrations (Kitamaat Village, 2017).

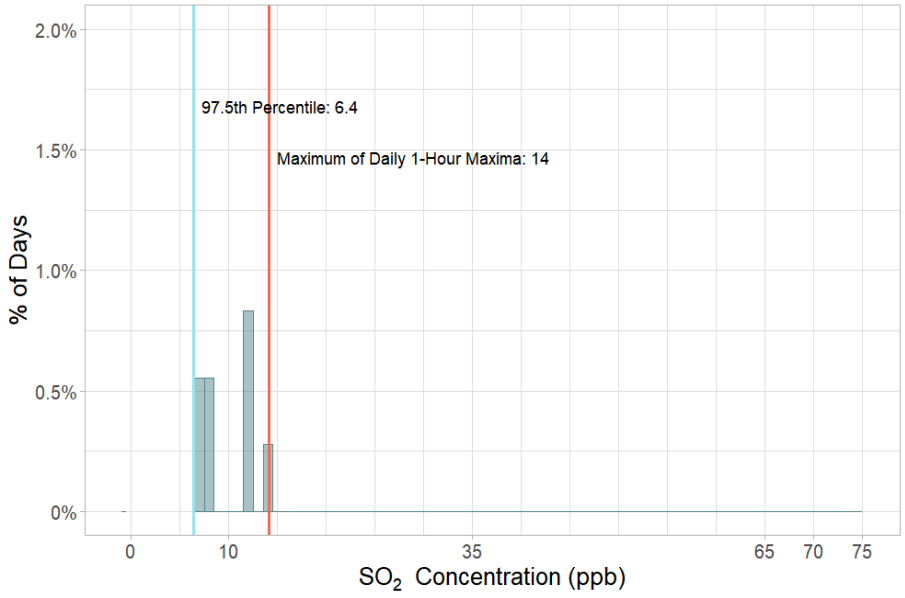


Figure 4.24: Histogram of D1HM SO_2 Concentrations with y-axis cut off at 2% (Kitamaat Village, 2017). Note: The first seven histogram bars are not shown because they exceed the limit of the y-axis.

5 Appendix to Section 5 of the Comprehensive Review Report: Vegetation

5.1 CALPUFF modeled SO_2 concentrations by emissions scenario and by year at vegetation sampling locations

The following pages contain three tables for each of the three years in each of the three scenarios

- Actual emissions, 2016
- Actual emissions, 2017
- Actual emissions, 2018

- 35 tpd scenario, 2016
- 35 tpd scenario, 2017
- 35 tpd scenario, 2018

- 42 tpd scenario, 2016
- 42 tpd scenario, 2017
- 42 tpd scenario, 2018

All concentrations are in ppb.

Table 5.1: Actual emissions, 2016. (All concentrations are in ppb.) Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

	2016															
	1-hour Max				3-hour Max				24-hour Max				Annual Average			
Plots/ year	All Hours	All Daylight	GS	GS Daylight	3-hour	All Daylight	GS	GS Daylight	24-hour	All Daylight	GS	GS Daylight	All Hours	All Daylight	GS	GS Daylight
1	168.0	168.0	168.0	168.0	95.1	71.0	52.0	44.6	38.1	43.3	20.2	15.1	7.1	6.5	2.9	2.1
20	151.8	148.3	148.3	148.3	134.4	112.4	103.1	103.1	59.3	78.4	36.1	55.4	8.6	10.9	5.5	7.8
37	298.9	298.9	298.9	298.9	104.3	101.6	104.3	104.3	20.8	35.2	20.8	35.2	2.1	3.0	2.7	4.0
39	115.1	115.1	115.1	115.1	68.0	71.2	68.0	92.2	19.1	29.7	19.1	29.7	4.4	5.9	7.1	9.8
42	216.1	216.1	141.9	141.9	85.3	95.2	76.4	114.2	25.7	31.4	25.7	31.4	5.4	6.8	4.2	6.0
43A	68.6	68.6	68.6	68.6	52.5	51.2	42.4	54.1	12.7	19.5	12.7	19.5	1.4	1.8	1.8	2.2
43B	111.6	111.6	105.1	72.5	85.9	61.7	85.9	52.8	18.6	22.5	18.6	22.5	1.7	2.1	2.1	2.6
44	178.9	150.5	150.4	137.5	158.6	86.6	88.5	102.8	26.4	42.7	24.9	42.7	3.4	5.0	3.9	6.1
44A	123.0	123.0	123.0	123.0	41.7	62.3	41.7	41.7	9.9	10.4	7.6	9.5	0.7	0.6	0.8	0.6
46	86.9	86.9	76.8	76.8	55.1	54.4	45.9	59.7	13.2	20.4	13.2	20.4	1.6	2.1	2.1	2.7
47B	49.8	49.8	49.8	49.8	34.2	33.9	31.3	44.1	15.0	19.0	15.0	18.6	2.8	3.5	4.3	5.3
52(A)	52.3	52.3	52.3	52.3	32.7	39.5	32.7	45.8	9.8	15.1	9.8	15.1	1.8	2.3	2.6	3.3
54	47.8	47.8	47.8	47.8	26.0	32.5	26.0	36.0	9.9	12.4	8.9	12.4	1.5	1.8	1.9	2.4
55	85.9	85.9	32.0	32.0	55.8	44.2	22.3	15.3	9.2	11.9	4.6	5.7	0.6	0.7	0.7	0.8
56(A)	70.1	33.6	24.3	24.3	40.6	26.0	15.4	13.7	10.7	9.7	3.6	5.5	0.5	0.5	0.5	0.5
57	90.5	90.5	20.2	20.2	70.8	86.8	13.4	13.4	15.0	17.3	3.2	4.9	0.5	0.5	0.4	0.4
68	33.3	32.4	16.1	14.5	18.6	16.5	7.8	9.7	3.6	5.7	1.4	2.2	0.3	0.3	0.3	0.3
69	78.3	65.9	29.8	22.4	45.4	25.6	12.0	12.0	13.4	9.2	1.9	2.7	0.4	0.4	0.3	0.3
70	21.5	14.1	13.6	13.6	14.5	10.2	7.8	7.8	4.2	3.9	1.8	2.7	0.2	0.3	0.2	0.3
78 (A)	39.4	35.2	39.4	29.2	28.1	24.4	28.1	22.3	11.8	16.0	11.8	9.7	2.3	2.5	3.2	3.5
79	72.9	72.9	72.9	72.9	39.6	43.4	39.6	33.7	12.7	14.0	12.7	14.0	3.0	3.4	4.7	5.3
80	50.1	46.5	48.6	46.5	38.5	36.7	38.5	28.5	11.5	12.4	11.5	10.4	2.5	2.7	3.8	3.9
81B	103.9	79.9	103.9	51.7	62.4	64.8	62.4	31.3	12.0	10.4	12.0	10.2	1.3	1.3	1.8	1.8
81C	40.9	40.9	35.6	30.1	31.0	28.9	21.1	26.4	6.4	10.6	6.4	10.6	1.0	1.0	1.3	1.4
82	65.9	34.4	65.9	31.3	50.6	23.1	50.6	21.7	14.2	10.8	14.2	8.7	2.3	2.0	3.7	3.0
84 (A) (B)	6.5	6.5	6.3	6.3	5.0	4.4	3.5	3.4	1.7	2.5	0.9	1.4	0.1	0.2	0.1	0.2
85	11.9	6.6	11.9	6.6	8.3	4.6	8.3	5.6	2.1	1.9	2.1	1.9	0.5	0.4	0.8	0.6
86	10.4	7.2	10.4	7.2	7.4	5.0	7.4	5.6	2.8	3.3	2.8	2.1	0.7	0.6	1.1	0.8
87	163.8	84.6	41.7	40.8	59.2	47.4	30.0	34.6	29.5	28.4	8.6	10.8	4.3	3.7	1.7	1.3
88	52.4	52.4	38.3	38.3	39.7	43.5	26.8	26.8	25.0	30.0	7.1	9.5	3.2	2.8	1.3	1.1
89	52.1	45.6	32.4	31.3	40.3	39.3	21.4	17.1	17.0	16.0	7.6	5.0	2.8	2.2	1.2	0.8
89A	52.5	45.7	33.3	31.5	40.6	39.7	21.5	17.2	17.0	16.1	7.7	5.1	2.9	2.3	1.2	0.8
90	56.4	22.4	56.4	22.4	43.0	18.7	43.0	13.1	9.5	6.0	9.5	6.0	1.2	0.9	2.0	1.4
91(A)	68.3	33.1	68.3	33.1	55.2	24.9	55.2	24.0	14.9	10.0	14.9	8.9	2.3	2.2	3.7	3.3
92	48.6	34.2	46.7	32.1	28.6	28.5	27.7	23.5	12.1	15.5	12.1	9.2	2.2	2.4	3.2	3.3
95	59.2	22.3	35.7	13.5	32.6	10.6	14.4	8.4	4.1	3.8	1.8	2.1	0.3	0.3	0.2	0.3
97	25.0	15.6	11.0	11.0	19.8	11.3	7.9	7.2	4.2	3.9	2.2	2.8	0.4	0.4	0.4	0.5
98A	25.5	16.3	10.8	10.8	21.0	14.6	6.9	6.9	4.7	3.8	2.0	3.0	0.3	0.3	0.3	0.4
490	6.1	2.6	5.5	2.6	3.9	1.7	2.9	2.0	1.0	1.0	1.0	1.0	0.1	0.1	0.2	0.2
492	9.2	5.3	9.2	5.1	7.7	4.1	7.7	3.0	2.2	2.1	1.5	1.5	0.3	0.2	0.4	0.3

Table 5.2: Actual emissions, 2017. (All concentrations are in ppb.) Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

	2017															
	1-hour Max				3-hour Max				24-hour Max				Annual Average			
Plots/ year	All Hours	All Daylight	GS	GS Daylight	3-hour	All Daylight	GS	Day	24-hour	All Daylight	GS	Day	All Hours	All Daylight	GS	GS Daylight
1	168.0	208.7	168.0	168.0	163.6	114.6	68.4	57.4	41.0	57.6	21.8	26.8	7.1	6.6	3.2	2.5
20	309.1	309.1	303.4	120.9	191.5	133.1	121.4	97.6	66.3	85.4	38.5	52.7	9.2	11.6	6.3	8.1
37	548.8	548.8	548.8	548.8	212.2	312.5	212.2	212.2	33.9	57.3	33.9	57.3	2.6	3.5	3.6	4.9
39	70.8	70.8	50.9	50.9	35.8	45.8	35.8	40.2	15.5	21.9	15.5	21.9	4.2	5.7	6.3	8.7
42	281.1	281.1	99.6	98.8	190.0	121.9	50.6	53.1	27.0	45.6	21.3	29.1	5.1	6.4	4.5	6.1
43A	157.2	254.3	73.0	70.4	52.8	128.2	34.7	45.4	10.0	42.4	10.0	11.7	1.6	4.2	2.2	2.7
43B	162.1	149.2	162.1	86.8	63.2	75.7	63.2	56.0	11.6	13.6	11.6	16.3	1.8	2.3	2.6	3.0
44	254.3	47.4	123.2	96.1	171.7	30.4	59.1	56.5	30.9	13.5	18.0	28.9	3.0	2.3	3.8	5.4
44A	89.9	49.9	89.9	89.9	49.4	30.0	49.4	49.4	8.9	11.3	7.5	10.8	0.7	1.8	0.9	0.7
46	149.2	35.3	83.1	83.1	50.4	21.4	46.0	63.4	11.0	7.4	11.0	13.6	1.9	0.6	2.7	3.4
47B	36.3	54.8	32.9	32.9	23.5	30.7	21.3	25.0	9.8	6.2	9.8	12.6	2.8	0.5	3.9	4.9
52(A)	47.4	42.7	47.4	47.4	26.5	26.0	26.5	37.6	9.3	4.8	9.3	13.5	1.8	0.4	2.4	3.1
54	49.9	41.9	49.9	49.9	32.4	21.7	26.6	38.1	9.1	12.9	7.8	10.0	1.5	0.3	1.8	2.3
55	54.9	57.5	30.8	30.8	24.9	34.2	15.4	22.6	6.7	12.2	3.5	5.2	0.6	0.4	0.6	0.6
56(A)	76.6	17.2	34.3	17.5	56.9	10.2	18.1	13.4	11.0	5.7	3.5	4.1	0.6	0.2	0.5	0.4
57	58.2	42.7	24.4	15.0	43.6	34.1	11.9	11.4	8.5	14.6	2.9	3.7	0.5	3.6	0.4	0.4
68	41.9	34.3	11.3	11.3	24.9	21.3	7.6	8.0	8.1	14.5	2.7	3.5	0.3	2.9	0.2	0.3
69	67.8	54.0	14.9	14.9	34.9	48.9	8.7	8.7	7.6	13.1	2.9	3.4	0.3	2.1	0.3	0.3
70	17.2	6.4	10.1	10.1	8.3	4.9	7.9	7.9	3.7	2.7	1.9	2.4	0.2	0.4	0.2	0.2
78 (A)	42.5	6.8	42.5	30.2	23.6	5.2	23.6	18.6	8.5	2.9	7.5	9.1	2.4	0.6	3.1	3.5
79	95.4	73.6	95.4	41.9	39.3	49.8	39.3	28.0	11.7	32.0	11.7	14.6	3.2	3.7	4.6	5.4
80	41.0	56.2	41.0	33.5	31.6	44.5	25.1	18.4	13.9	28.1	8.8	10.8	2.6	3.1	3.4	3.7
81B	70.6	41.2	70.6	31.4	42.6	28.3	42.6	18.5	9.7	14.7	9.7	7.8	1.3	2.3	1.9	1.9
81C	55.1	33.8	55.1	36.8	37.2	26.1	37.2	17.6	8.5	8.4	8.5	6.8	1.1	1.0	1.5	1.6
82	78.0	35.2	78.0	35.5	49.0	26.7	49.0	22.7	13.6	10.4	13.6	9.0	2.3	2.6	3.2	2.9
84 (A) (B)	5.2	22.8	3.2	3.2	3.5	13.1	2.5	2.5	1.2	7.9	0.9	1.1	0.1	0.3	0.2	0.2
85	9.0	14.8	9.0	5.7	5.6	9.4	5.6	4.6	2.3	3.6	2.3	2.7	0.5	0.4	0.7	0.6
86	7.7	3.3	7.2	6.8	6.7	2.1	6.7	4.9	2.8	1.0	2.8	2.9	0.7	0.1	1.0	0.8
87	73.6	5.2	71.4	58.1	57.7	4.2	51.3	41.2	31.0	2.1	11.7	14.7	4.0	0.3	1.7	1.7
88	56.2	157.2	54.7	50.1	50.4	79.1	43.3	37.6	29.8	11.7	8.4	11.8	3.3	1.9	1.4	1.4
89	42.0	121.2	32.6	32.6	34.5	65.5	18.9	20.4	18.1	16.3	7.5	8.0	2.8	2.1	1.2	1.0
89A	42.8	89.9	33.2	33.2	34.4	57.6	18.9	20.8	18.0	10.8	7.5	8.0	2.8	0.6	1.2	1.0
90	41.4	36.3	41.4	17.8	31.0	27.5	31.0	14.4	8.2	14.0	7.0	5.1	1.1	3.5	1.6	1.4
91(A)	45.4	30.3	45.4	37.2	34.3	24.5	26.7	24.2	11.6	10.6	8.8	10.4	2.3	2.7	3.2	3.2
92	55.6	36.6	55.6	35.2	26.1	23.8	26.1	19.7	8.6	7.8	7.7	8.4	2.4	1.3	3.0	3.3
95	24.6	36.8	13.4	13.4	16.0	19.4	9.3	9.5	5.2	6.8	2.5	3.3	0.3	1.0	0.2	0.3
97	19.6	5.2	13.5	13.5	11.6	3.2	9.5	9.5	3.7	1.9	2.5	3.4	0.4	0.1	0.4	0.5
98A	16.6	41.1	12.8	12.8	10.0	28.2	10.0	10.0	2.1	14.8	2.1	3.1	0.3	2.3	0.3	0.4
490	4.7	37.2	3.2	3.2	2.3	23.3	2.2	1.8	0.9	10.4	0.8	1.0	0.1	2.3	0.1	0.2
492	5.9	12.8	5.9	4.1	4.7	9.4	4.7	3.1	2.1	3.2	1.5	1.2	0.3	0.3	0.4	0.3

Table 5.3: Actual emissions, 2018. (All concentrations are in ppb.) Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

	2018															
	1-hour Max				3-hour Max				24-hour Max				Annual Average			
	All Hours	All Daylight	GS	GS Daylight	3-hour	All Daylight	GS	GS Daylight	24-hour	All Daylight	GS	GS Daylight	All Hours	All Daylight	GS	GS Daylight
Plots/ year																
1	168.0	168.0	168.0	168.0	88.1	82.7	57.8	64.1	47.1	43.8	24.7	18.5	7.3	7.1	3.3	3.2
20	289.2	192.5	289.2	167.9	146.4	138.8	140.4	100.9	83.5	73.7	34.6	52.5	9.3	11.5	8.0	10.6
37	528.4	528.4	528.4	528.4	185.1	264.5	185.1	185.1	29.4	50.3	29.4	50.3	2.6	3.6	3.9	5.4
39	82.7	65.7	50.1	50.1	39.2	42.9	35.9	39.4	17.1	23.1	17.1	23.1	4.1	5.6	6.0	8.5
42	250.5	250.5	117.8	98.8	133.8	113.1	59.0	69.4	33.9	57.9	18.9	29.7	5.7	7.2	5.6	7.9
43A	349.0	102.0	120.7	81.8	232.5	54.9	47.7	43.7	30.1	20.5	15.2	20.5	2.1	2.1	2.9	3.2
43B	538.5	165.0	145.2	121.7	325.4	80.7	65.3	52.0	42.1	22.5	16.2	22.5	2.4	2.5	3.3	3.7
44	268.6	268.6	182.1	107.3	136.3	112.9	77.2	77.2	38.0	64.9	23.0	32.9	3.6	5.2	5.0	7.0
44A	70.2	50.5	70.2	50.0	40.2	27.8	40.2	22.3	6.9	9.1	6.9	9.1	0.8	0.7	1.1	0.9
46	335.3	100.9	117.2	89.4	220.1	65.5	46.2	45.7	28.4	22.8	16.3	22.8	2.3	2.5	3.3	3.8
47B	43.1	43.1	32.4	32.4	30.3	36.8	24.2	22.4	13.1	14.6	11.5	14.5	2.8	3.4	3.7	4.7
52(A)	57.7	43.1	43.1	43.1	32.4	35.7	28.6	42.3	13.2	18.4	8.1	11.6	2.0	2.6	2.4	3.3
54	63.8	40.4	40.4	40.4	43.2	31.6	26.2	39.1	9.5	14.9	8.1	13.2	1.7	2.1	1.9	2.5
55	31.7	27.7	23.0	23.0	23.3	19.4	16.0	21.3	8.6	8.3	3.8	5.5	0.7	0.8	0.7	0.8
56(A)	69.6	45.7	16.4	16.4	50.9	34.3	12.9	16.2	11.6	8.2	3.7	5.6	0.6	0.6	0.5	0.6
57	78.6	47.8	20.7	20.7	52.1	27.8	14.5	14.5	14.6	6.3	4.0	6.1	0.5	0.5	0.4	0.5
68	18.6	18.6	17.5	17.5	12.0	12.9	12.0	15.2	3.4	5.6	2.1	2.8	0.3	0.4	0.2	0.4
69	31.0	31.0	31.0	31.0	17.7	18.3	17.7	17.7	4.8	8.0	2.5	4.1	0.3	0.4	0.3	0.4
70	19.0	11.8	11.8	11.8	10.3	9.1	10.3	11.3	2.5	2.7	1.6	2.3	0.2	0.3	0.2	0.3
78 (A)	43.3	39.4	37.4	26.5	28.3	22.2	25.9	19.0	11.8	12.9	8.1	7.7	2.4	2.5	3.0	3.3
79	76.1	76.1	52.7	51.3	49.9	46.1	27.9	26.7	17.0	22.4	12.2	16.3	3.2	3.4	4.8	5.2
80	61.7	47.3	47.3	47.3	27.9	27.6	21.5	21.5	10.8	12.4	9.5	10.1	2.5	2.5	3.5	3.6
81B	119.0	67.2	119.0	25.7	84.8	33.9	84.8	21.0	12.9	17.8	12.9	11.8	1.5	1.1	2.3	1.6
81C	117.7	39.4	117.7	29.6	77.7	33.9	77.7	20.2	11.4	18.3	11.4	13.2	1.3	0.9	1.9	1.4
82	150.8	50.4	150.8	44.0	79.3	41.0	79.3	29.6	13.8	15.9	13.8	9.7	2.3	1.7	3.5	2.5
84 (A) (B)	6.0	6.0	4.0	3.2	4.3	4.2	2.8	2.8	1.8	1.5	0.8	0.9	0.1	0.1	0.1	0.1
85	10.0	9.8	10.0	4.7	7.8	7.2	7.8	4.2	2.2	2.3	2.2	2.0	0.5	0.4	0.7	0.5
86	12.8	9.9	10.2	6.0	10.8	5.9	7.0	5.0	4.0	2.8	3.1	2.8	0.7	0.6	0.9	0.7
87	97.8	97.8	64.8	64.8	56.5	53.3	39.5	53.7	26.6	28.3	9.2	10.2	3.8	3.8	1.7	1.9
88	67.3	67.3	38.4	38.4	56.6	44.5	27.8	37.4	18.6	18.4	6.9	7.6	3.0	3.1	1.3	1.6
89	51.5	51.5	51.5	51.5	30.1	30.3	29.8	38.5	17.8	16.3	5.9	7.9	2.7	2.4	1.2	1.2
89A	51.9	51.9	51.9	51.9	30.5	30.5	30.0	38.7	17.9	16.5	6.1	8.0	2.7	2.4	1.3	1.2
90	49.0	28.8	49.0	28.8	26.9	17.7	26.9	11.9	7.9	6.5	7.9	4.6	1.1	0.8	1.8	1.2
91(A)	94.2	44.6	94.2	44.6	52.7	32.0	52.7	20.6	11.8	16.7	11.8	11.2	2.2	1.9	3.4	2.9
92	39.7	36.8	39.7	22.5	25.6	22.8	25.6	17.1	11.1	12.2	8.2	7.6	2.3	2.4	3.0	3.1
95	13.6	13.6	13.3	13.3	8.4	10.2	8.4	11.5	2.5	4.0	2.1	2.7	0.2	0.3	0.2	0.3
97	28.9	19.7	16.6	16.6	25.3	16.5	9.1	10.6	7.1	5.0	3.2	3.6	0.5	0.5	0.5	0.6
98A	28.8	14.5	14.5	14.5	20.7	9.0	8.4	9.1	4.4	3.4	2.5	3.2	0.3	0.4	0.4	0.5
490	5.6	4.8	3.7	3.3	3.6	2.4	3.0	2.3	1.1	0.9	0.9	0.8	0.1	0.1	0.2	0.2
492	9.1	6.7	9.1	4.6	6.5	5.1	6.5	3.1	2.4	2.5	1.8	1.5	0.4	0.3	0.4	0.3

Table 5.4: 35 tpd scenario, 2016. (All concentrations are in ppb.) Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

	1-hour Max				3-hour Max				24-hour Max				Annual Average			
	All Hours	All Daylight	GS	GS Daylight	3-hour	All Daylight	GS	GS Daylight	24-hour	All Daylight	GS	GS Daylight	All Hours	All Daylight	GS	GS Daylight
Plots/year																
1	169.6	124.4	92.5	66.6	93.2	72.6	61.9	53.5	45.6	55.3	23.6	16.6	7.5	6.8	23.6	2.7
20	266.9	188.1	162.8	162.8	160.1	128.2	112.0	112.0	78.8	93.4	47.2	70.2	9.6	12.8	47.2	11.2
37	217.7	217.7	217.7	217.7	80.1	82.1	80.1	104.7	18.2	30.6	18.2	30.6	2.2	3.1	18.2	4.5
39	125.5	125.5	125.5	125.5	75.6	81.1	75.6	104.7	21.1	34.0	21.1	34.0	4.7	6.5	21.1	11.4
42	151.5	151.5	151.5	151.5	91.5	107.3	91.5	136.9	21.0	27.9	21.0	26.2	4.3	5.5	21.0	6.4
43A	78.5	78.5	78.5	78.5	51.4	49.3	51.4	56.3	15.6	24.2	15.6	24.2	1.4	1.8	15.6	2.5
43B	116.1	115.4	116.1	83.9	67.6	46.7	67.6	55.1	15.7	24.5	15.7	24.5	1.6	2.1	15.7	2.9
44	155.0	155.0	155.0	155.0	84.0	99.6	84.0	125.6	20.4	35.0	20.4	35.0	3.1	4.6	20.4	6.4
44A	109.9	109.9	109.9	109.9	38.1	56.5	38.1	38.1	9.9	11.7	7.6	11.7	0.7	0.6	7.6	0.7
46	85.0	85.0	84.5	84.5	54.9	52.4	54.9	61.0	16.2	25.2	16.2	25.2	1.6	2.2	16.2	3.0
47B	60.6	60.6	60.6	60.6	35.6	39.9	35.6	51.6	13.1	19.2	13.1	19.2	3.0	3.9	13.1	6.4
52(A)	60.9	60.9	60.9	60.9	39.0	48.6	39.0	56.1	12.3	18.9	12.3	18.9	2.0	2.6	12.3	4.1
54	56.7	56.7	56.7	56.7	31.4	40.6	31.4	44.7	10.6	15.7	10.6	15.7	1.6	2.1	10.6	3.0
55	40.7	38.0	40.7	38.0	29.3	18.3	29.3	18.9	5.9	7.1	5.9	7.1	0.7	0.8	5.9	1.0
56(A)	30.8	30.8	30.8	30.8	17.0	19.8	17.0	17.0	4.8	7.0	4.5	7.0	0.5	0.6	4.5	0.7
57	28.8	25.7	25.7	25.7	17.2	17.1	15.5	15.5	4.8	6.6	4.0	6.2	0.5	0.5	4.0	0.6
68	37.0	28.0	18.9	18.0	18.3	13.7	9.1	12.8	3.7	5.9	1.9	3.0	0.3	0.4	1.9	0.4
69	89.1	69.8	40.7	29.9	51.9	27.5	15.3	17.9	14.2	9.7	2.4	3.5	0.4	0.4	2.4	0.4
70	23.0	15.8	14.7	14.7	15.8	11.2	8.8	8.8	4.4	4.4	2.3	3.4	0.3	0.3	2.3	0.3
78 (A)	40.0	40.0	36.7	34.5	31.7	25.5	31.7	27.3	12.6	14.2	12.6	11.0	2.4	2.8	12.6	4.3
79	71.0	71.0	71.0	71.0	46.0	43.0	46.0	35.3	14.2	16.5	14.2	16.5	3.3	3.9	14.2	6.4
80	54.7	50.6	54.7	50.6	33.8	41.2	33.8	32.7	12.0	12.0	12.0	12.0	2.7	3.0	12.0	4.8
81B	147.9	97.3	147.9	37.2	85.8	78.5	85.8	35.3	15.7	13.0	15.7	13.0	1.4	1.4	15.7	2.1
81C	52.0	46.2	52.0	38.5	35.6	28.2	27.0	33.8	8.4	14.1	8.4	14.1	1.1	1.2	8.4	1.6
82	70.7	39.8	70.7	39.8	44.4	26.3	44.4	27.1	15.9	11.4	15.9	11.2	2.5	2.3	15.9	3.6
84 (A) (B)	8.0	8.0	7.7	7.7	5.1	5.9	5.1	4.3	1.6	2.4	1.0	1.6	0.2	0.2	1.0	0.2
85	14.4	8.0	14.4	8.0	10.2	5.5	10.2	6.7	2.6	2.4	2.6	2.3	0.6	0.5	2.6	0.7
86	12.8	7.9	12.8	7.9	8.9	5.8	8.9	5.7	3.5	3.7	3.5	2.7	0.8	0.7	3.5	1.0
87	112.3	112.3	49.5	49.5	54.6	42.2	37.8	44.0	18.9	19.6	12.0	13.8	3.7	3.3	12.0	1.6
88	70.8	70.8	47.6	47.6	37.5	31.9	33.6	33.6	14.7	18.5	10.7	11.9	2.8	2.5	10.7	1.3
89	65.8	65.8	39.8	39.8	35.3	28.8	26.4	21.5	16.0	15.9	9.7	6.4	2.9	2.3	9.7	0.9
89A	66.6	66.6	39.8	39.8	35.5	29.1	26.6	21.5	16.1	16.0	9.8	6.6	2.9	2.3	9.8	0.9
90	52.5	27.9	52.5	27.9	31.9	23.5	31.9	16.4	10.9	8.0	10.9	8.0	1.3	1.1	10.9	1.7
91(A)	72.0	39.5	72.0	39.5	40.8	28.5	40.8	30.1	16.3	11.6	16.3	11.6	2.5	2.5	16.3	4.0
92	46.4	46.4	39.2	39.2	30.8	35.8	30.8	29.7	13.1	14.4	13.1	10.6	2.4	2.7	13.1	4.1
95	47.1	23.6	29.9	18.1	19.0	10.5	12.9	11.1	4.2	4.2	1.8	2.9	0.3	0.3	1.8	0.3
97	17.3	13.5	13.5	13.5	12.7	9.7	9.5	9.4	3.6	4.7	3.0	3.7	0.4	0.5	3.0	0.6
98A	17.9	13.6	13.6	13.6	13.4	9.3	9.1	9.1	2.9	3.9	2.5	3.8	0.3	0.4	2.5	0.5
490	7.6	3.4	6.3	3.4	4.9	2.2	3.8	2.6	1.2	1.3	1.2	1.3	0.1	0.1	1.2	0.2
492	11.2	7.0	11.2	7.0	9.5	5.8	9.5	4.1	2.5	2.3	1.9	1.9	0.3	0.3	1.9	0.4

Table 5.5: 35 tpd scenario, 2017. (All concentrations are in ppb.) Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

	2017															
	1-hour Max				3-hour Max				24-hour Max				Annual Average			
	All Hours	All Daylight	GS	GS Daylight	3-hour	All Daylight	GS	GS Daylight	24-hour	All Daylight	GS	GS Daylight	All Hours	All Daylight	GS	GS Daylight
Plots/year																
1	299.2	299.2	111.8	111.8	222.8	168.0	75.7	61.1	64.8	90.9	27.5	31.8	7.7	7.1	4.1	3.2
20	356.7	356.7	345.0	145.9	258.9	236.5	127.0	109.1	87.5	113.5	43.2	71.3	10.1	13.3	8.3	11.1
37	209.4	209.4	133.4	133.4	133.9	95.8	71.6	82.0	18.5	31.1	17.4	28.6	2.6	3.5	3.8	5.2
39	63.4	63.4	63.4	63.4	37.8	51.6	37.8	54.7	16.8	23.5	16.8	23.5	4.6	6.4	7.4	10.4
42	322.9	322.9	173.7	93.5	213.5	128.5	84.9	56.9	29.9	50.6	16.4	21.9	4.4	5.6	4.8	6.5
43A	69.2	69.2	67.2	67.2	37.3	41.6	35.2	42.3	9.5	14.3	9.5	14.3	1.6	2.0	2.3	2.9
43B	86.0	86.0	82.1	82.1	53.4	52.4	37.6	46.0	11.8	16.4	11.8	15.5	1.8	2.2	2.6	3.3
44	301.8	301.8	225.4	111.3	195.4	121.2	101.2	48.9	27.2	45.9	19.4	32.8	3.0	4.2	4.2	5.9
44A	104.2	97.5	104.2	97.5	65.8	65.6	65.8	57.6	8.7	12.6	8.7	12.6	0.8	0.7	1.0	0.8
46	79.6	79.6	70.7	70.7	43.0	44.9	38.4	45.1	10.3	16.1	10.3	16.1	1.8	2.3	2.8	3.6
47B	39.4	39.4	39.4	39.4	26.0	31.0	23.1	30.8	11.1	15.0	11.1	15.0	3.1	4.0	4.6	5.9
52(A)	56.9	56.9	56.9	56.9	32.5	40.5	32.5	45.9	11.7	16.7	11.7	16.7	2.1	2.7	2.9	3.9
54	60.0	60.0	60.0	60.0	32.5	39.4	32.5	46.4	9.6	13.2	9.2	13.2	1.7	2.1	2.2	2.8
55	38.9	38.9	36.6	36.6	23.1	22.4	18.8	27.6	6.2	6.6	4.2	6.4	0.7	0.7	0.7	0.8
56(A)	64.4	45.2	38.7	23.9	47.1	20.4	19.0	14.4	9.1	6.5	4.2	4.8	0.6	0.5	0.6	0.6
57	51.1	32.5	28.8	20.1	43.7	20.1	14.8	12.4	7.4	6.2	3.6	4.0	0.5	0.5	0.5	0.5
68	51.1	51.1	15.5	15.5	33.7	29.4	9.8	11.0	10.7	17.1	3.6	4.6	0.3	0.4	0.3	0.4
69	96.3	96.3	19.0	19.0	50.4	54.4	11.1	11.1	10.9	17.7	3.9	4.4	0.4	0.4	0.4	0.4
70	26.6	26.6	14.7	14.7	11.4	15.3	9.5	9.5	4.6	7.2	2.6	2.8	0.2	0.3	0.3	0.3
78 (A)	35.6	35.6	34.2	30.6	26.8	23.7	21.7	21.6	8.9	10.9	8.9	9.3	2.6	3.1	3.6	4.3
79	49.7	49.7	49.7	49.7	37.6	30.9	28.5	35.5	11.5	17.2	11.5	17.2	3.4	4.2	5.3	6.6
80	39.2	39.2	35.4	31.5	24.2	23.0	22.3	24.2	10.0	12.5	9.5	12.5	2.8	3.2	4.0	4.5
81B	94.0	39.0	94.0	37.5	54.7	26.8	54.7	22.2	10.5	9.6	10.5	9.6	1.5	1.5	2.2	2.3
81C	69.2	38.3	69.2	38.3	40.0	20.1	40.0	20.7	9.0	8.3	9.0	8.3	1.2	1.2	1.8	1.8
82	117.7	57.8	117.7	57.8	60.6	51.2	60.6	27.4	16.0	16.0	16.0	11.2	2.6	2.4	3.8	3.6
84 (A) (B)	5.4	5.2	4.1	4.1	4.5	3.9	3.4	3.4	1.5	2.4	1.1	1.4	0.2	0.2	0.2	0.2
85	10.7	7.2	10.7	7.2	7.2	5.9	7.2	5.8	2.9	3.4	2.9	3.4	0.6	0.5	0.8	0.7
86	9.1	8.5	9.1	8.5	7.8	6.4	7.8	6.1	3.6	3.5	3.6	3.5	0.9	0.8	1.2	1.0
87	111.4	111.4	80.5	66.4	58.2	61.9	58.2	47.7	20.5	28.1	12.8	17.5	3.5	3.4	2.1	2.1
88	61.9	61.9	60.5	56.9	48.5	42.9	48.5	42.5	18.2	21.1	9.1	14.6	2.9	2.8	1.7	1.8
89	43.0	43.0	41.6	41.6	33.9	32.2	24.6	31.7	17.2	15.7	8.5	10.0	2.9	2.3	1.4	1.3
89A	42.8	42.8	42.3	42.3	33.9	32.2	24.7	31.7	17.2	15.7	8.6	10.0	2.9	2.4	1.4	1.3
90	55.5	36.9	55.5	18.8	37.2	27.6	37.2	15.9	8.5	11.7	7.4	6.4	1.2	1.2	1.8	1.7
91(A)	51.8	41.6	51.8	33.1	32.3	26.0	28.8	26.8	13.2	11.8	9.3	11.3	2.5	2.6	3.7	3.9
92	45.4	35.6	45.4	35.0	25.8	27.0	24.7	21.2	9.1	11.2	9.1	9.5	2.6	3.0	3.5	4.1
95	33.3	28.2	17.5	17.5	21.3	16.3	10.9	12.8	6.7	10.4	3.2	4.3	0.3	0.3	0.3	0.3
97	20.9	18.1	15.7	15.7	14.1	12.6	11.1	11.1	4.2	4.1	3.1	4.1	0.5	0.5	0.5	0.6
98A	17.2	17.2	17.2	17.2	11.8	11.6	11.8	11.8	2.6	3.8	2.6	3.8	0.3	0.4	0.4	0.5
490	6.1	4.4	4.4	4.4	3.2	2.7	2.9	2.4	1.2	1.3	1.0	1.2	0.1	0.1	0.2	0.2
492	8.9	6.5	8.5	5.1	5.6	5.6	5.6	3.7	2.6	2.7	1.8	1.5	0.4	0.3	0.5	0.4

Table 5.6: 35 tpd scenario, 2018. (All concentrations are in ppb.) Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

	2018															
	1-hour Max				3-hour Max				24-hour Max				Annual Average			
	All Hours	All Daylight	GS	GS Daylight	3-hour	All Daylight	GS	GS Daylight	24-hour	All Daylight	GS	GS Daylight	All Hours	All Daylight	GS	GS Daylight
Plots/year																
1	178.3	178.3	131.0	131.0	129.6	113.8	88.1	98.0	47.8	50.9	25.0	25.3	8.1	8.0	4.2	4.2
20	558.6	420.9	323.9	249.9	326.8	201.7	213.7	199.4	90.1	79.1	48.1	66.3	11.1	14.0	10.9	14.6
37	202.2	202.2	186.0	186.0	112.3	88.6	77.6	77.6	24.9	42.4	18.4	31.0	2.6	3.6	4.0	5.6
39	64.5	64.5	58.6	58.6	42.8	45.6	42.8	47.4	18.7	24.9	18.7	24.9	4.4	6.2	7.1	10.2
42	276.4	276.4	109.2	109.2	141.1	112.4	51.8	71.1	30.4	51.5	18.4	31.3	4.9	6.4	5.9	8.3
43A	93.1	93.1	93.1	93.1	47.2	43.5	47.2	47.2	15.7	22.1	15.7	22.1	1.9	2.2	2.9	3.5
43B	146.4	146.4	146.4	146.4	63.0	64.0	63.0	63.0	16.4	24.0	16.4	24.0	2.1	2.5	3.2	3.9
44	258.9	258.9	120.0	120.0	132.8	103.3	60.5	68.1	33.3	56.6	18.2	31.1	3.5	5.0	5.2	7.4
44A	84.0	41.4	84.0	41.4	56.0	23.7	56.0	26.4	9.4	10.7	9.4	10.7	0.9	0.7	1.3	1.0
46	99.0	99.0	99.0	99.0	49.0	48.0	49.0	49.0	16.6	24.1	16.6	24.1	2.1	2.5	3.2	4.1
47B	37.5	37.5	37.5	37.5	27.0	25.2	27.0	26.5	13.1	17.6	13.1	17.6	3.0	3.8	4.4	5.7
52(A)	51.5	51.5	51.5	51.5	34.7	43.1	34.7	51.3	10.4	15.6	10.4	13.9	2.2	2.9	2.9	4.1
54	48.9	48.9	48.9	48.9	32.4	39.0	32.4	48.2	9.6	15.5	9.6	15.5	1.8	2.4	2.3	3.2
55	32.6	32.6	26.6	26.6	19.9	21.8	19.9	25.6	6.4	8.8	4.7	6.5	0.8	1.0	0.8	1.1
56(A)	49.3	27.2	44.9	21.8	37.5	25.0	20.3	21.7	8.7	8.6	4.3	6.4	0.7	0.7	0.6	0.7
57	53.7	25.9	21.3	21.3	39.5	17.5	16.8	20.7	12.1	6.0	4.0	6.0	0.6	0.6	0.5	0.6
68	23.1	23.1	17.8	17.8	15.1	19.7	12.1	15.7	4.8	7.9	2.6	3.6	0.3	0.4	0.3	0.4
69	35.4	35.4	35.4	35.4	21.2	23.5	17.7	19.4	6.1	10.2	3.1	4.7	0.4	0.5	0.4	0.6
70	21.9	16.1	16.1	16.1	14.1	12.3	14.1	14.9	2.2	3.5	2.2	2.9	0.3	0.3	0.3	0.4
78 (A)	42.5	41.5	40.1	33.2	32.0	24.5	32.0	24.2	10.2	10.0	10.1	10.0	2.5	2.8	3.6	4.1
79	61.4	61.4	61.4	61.4	35.2	39.9	35.2	31.0	13.2	18.3	13.2	18.3	3.4	3.8	5.6	6.3
80	47.6	37.1	37.1	37.1	28.1	20.3	24.6	26.9	10.9	12.4	10.5	12.4	2.7	2.9	4.1	4.4
81B	175.3	71.9	175.3	34.4	125.7	31.3	125.7	27.4	18.7	15.1	18.7	15.1	1.7	1.3	2.7	1.9
81C	156.4	36.7	156.4	36.7	94.4	23.3	94.4	24.9	14.3	16.6	14.3	16.6	1.5	1.1	2.3	1.6
82	190.3	48.9	190.3	48.9	100.1	48.8	100.1	35.6	15.4	12.2	15.4	10.8	2.6	2.0	4.2	3.1
84 (A) (B)	7.8	7.8	5.0	4.4	5.9	5.1	3.0	3.1	2.3	1.8	0.8	1.1	0.1	0.2	0.1	0.2
85	11.3	11.3	11.2	5.8	9.5	8.4	9.5	4.9	3.0	3.0	3.0	2.4	0.6	0.5	0.8	0.6
86	17.6	12.1	10.9	7.1	15.1	7.5	9.9	5.9	5.5	3.5	3.8	3.5	0.8	0.7	1.2	0.9
87	107.1	107.1	87.1	87.1	79.2	73.1	53.7	70.9	19.1	31.0	10.0	13.5	3.6	3.8	2.1	2.4
88	73.8	73.8	47.8	47.8	54.7	51.2	33.9	47.6	14.1	22.9	7.6	10.4	2.8	3.0	1.7	2.1
89	58.5	58.5	58.5	58.5	33.6	35.2	33.6	44.3	14.5	14.8	7.9	9.3	2.8	2.5	1.5	1.4
89A	58.9	58.9	58.9	58.9	33.8	35.3	33.8	44.5	14.7	14.9	8.2	9.3	2.9	2.6	1.6	1.5
90	59.5	38.3	59.5	38.3	30.0	22.3	30.0	15.9	8.4	7.3	8.4	6.1	1.3	0.9	2.1	1.5
91(A)	120.0	46.3	120.0	38.8	66.0	36.9	66.0	22.8	13.8	12.9	13.8	12.9	2.4	2.2	3.9	3.5
92	41.8	41.8	37.4	29.3	32.8	28.5	32.8	22.3	10.3	10.7	10.3	9.6	2.5	2.7	3.5	3.9
95	17.9	17.9	13.8	13.8	10.9	15.6	9.9	12.0	3.6	5.8	2.6	3.4	0.3	0.4	0.3	0.3
97	37.1	28.5	19.5	18.6	32.5	23.4	11.0	12.1	9.5	6.9	4.2	4.6	0.6	0.6	0.6	0.8
98A	36.1	16.3	16.3	16.3	27.7	11.8	10.3	11.6	6.3	4.1	3.2	4.1	0.4	0.5	0.4	0.6
490	6.8	6.2	4.8	4.3	3.8	3.9	3.8	2.9	1.2	1.2	1.1	1.1	0.2	0.2	0.2	0.3
492	11.5	8.3	11.5	5.8	7.5	7.6	7.5	3.8	3.3	2.9	2.1	1.9	0.5	0.4	0.5	0.4

Table 5.7: 42 tpd scenario, 2016. (All concentrations are in ppb.) Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

	2016															
	1-hour Max				3-hour Max				24-hour Max				Annual Average			
	All Hours	All Daylight	GS	GS Daylight	3-hour	All Daylight	GS	GS Daylight	24-hour	All Daylight	GS	GS Daylight	All Hours	All Daylight	GS	GS Daylight
Plots/year																
1	203.9	156.2	115.5	80.3	113.4	91.1	77.5	65.0	57.2	69.5	29.2	20.3	9.3	8.4	4.7	3.3
20	334.9	236.2	204.2	204.2	200.7	161.0	139.9	139.9	98.9	117.3	58.9	88.1	11.9	16.0	9.5	14.0
37	260.3	260.3	260.3	260.3	96.1	99.7	96.1	126.6	22.1	37.1	22.1	37.1	2.7	3.8	3.8	5.6
39	150.8	150.8	150.8	150.8	90.7	97.1	90.7	125.5	25.4	40.7	25.4	40.7	5.6	7.9	9.7	13.7
42	179.8	179.8	179.8	179.8	109.0	127.8	109.0	163.1	25.1	33.4	25.1	31.1	5.2	6.7	5.5	7.8
43A	93.7	93.7	93.7	93.7	61.5	59.0	61.5	68.4	18.8	29.0	18.8	29.0	1.7	2.2	2.4	3.1
43B	139.0	137.4	139.0	100.4	81.0	56.4	81.0	67.3	18.9	29.5	18.9	29.5	2.0	2.6	2.7	3.5
44	183.9	183.9	183.9	183.9	100.1	118.6	100.1	149.6	24.3	41.7	24.3	41.7	3.8	5.5	5.1	7.8
44A	130.9	130.9	130.9	130.9	45.5	67.5	45.5	45.5	11.9	14.1	9.1	14.1	0.8	0.7	1.1	0.9
46	101.3	101.3	100.8	100.8	65.7	62.7	65.7	74.2	19.5	30.3	19.5	30.3	1.9	2.6	2.7	3.7
47B	72.5	72.5	72.5	72.5	42.6	47.7	42.6	61.8	15.7	23.0	15.7	23.0	3.6	4.7	5.9	7.7
52(A)	72.8	72.8	72.8	72.8	46.7	58.1	46.7	67.1	14.8	22.7	14.8	22.7	2.5	3.2	3.7	4.9
54	67.6	67.6	67.6	67.6	37.6	48.6	37.6	53.6	12.7	18.8	12.7	18.8	2.0	2.5	2.9	3.6
55	48.4	45.6	48.4	45.6	35.1	22.0	35.1	22.7	7.1	8.6	7.1	8.6	0.8	0.9	1.0	1.2
56(A)	37.1	37.1	37.1	37.1	20.4	23.8	20.4	20.4	5.8	8.4	5.5	8.4	0.6	0.7	0.7	0.8
57	35.9	30.9	30.9	30.9	21.2	20.6	18.6	18.6	5.9	7.9	4.8	7.4	0.6	0.6	0.6	0.7
68	44.8	34.9	22.5	21.5	22.0	16.6	10.9	15.4	4.5	7.1	2.2	3.6	0.4	0.4	0.4	0.4
69	107.2	83.9	49.1	37.2	62.5	33.0	18.5	22.1	17.1	11.7	2.9	4.2	0.5	0.5	0.4	0.5
70	28.1	19.1	17.6	17.6	19.2	13.5	10.6	10.6	5.3	5.3	2.7	4.1	0.3	0.4	0.3	0.4
78 (A)	48.0	48.0	43.9	41.3	38.0	30.4	38.0	32.8	15.1	17.2	15.1	13.1	2.9	3.4	4.6	5.2
79	86.4	86.4	86.4	86.4	55.2	52.3	55.2	43.0	17.2	19.9	17.2	19.9	3.9	4.6	6.6	7.7
80	65.4	60.7	65.4	60.7	40.5	49.8	40.5	39.4	14.6	14.4	14.6	14.4	3.3	3.6	5.3	5.7
81B	175.4	117.2	175.4	44.6	101.8	94.5	101.8	42.3	18.8	15.6	18.8	15.6	1.7	1.7	2.5	2.5
81C	64.8	55.4	64.8	46.5	42.7	34.6	32.7	40.6	10.1	16.9	10.1	16.9	1.4	1.4	1.8	2.0
82	84.7	47.4	84.7	47.4	53.0	32.1	53.0	32.6	19.1	14.0	19.1	13.4	3.0	2.7	5.2	4.3
84 (A) (B)	9.5	9.5	9.2	9.2	6.1	7.1	6.1	5.2	1.9	2.9	1.2	2.0	0.2	0.2	0.2	0.2
85	17.2	9.6	17.2	9.6	12.2	6.6	12.2	8.0	3.1	2.9	3.1	2.7	0.7	0.6	1.1	0.9
86	15.2	9.4	15.2	9.4	10.7	7.0	10.7	6.9	4.2	4.4	4.2	3.2	1.0	0.8	1.6	1.3
87	141.0	141.0	60.8	60.8	68.5	52.9	45.8	53.9	23.1	24.2	14.7	16.8	4.5	4.1	2.4	2.0
88	88.9	88.9	57.5	57.5	47.1	40.0	40.4	40.4	18.1	23.0	13.1	14.4	3.4	3.1	1.9	1.6
89	79.8	79.8	47.7	47.7	42.9	35.4	32.7	25.8	19.7	19.6	11.9	7.9	3.5	2.7	1.8	1.1
89A	80.7	80.7	47.7	47.7	43.1	35.7	32.9	25.7	19.8	19.7	12.0	8.1	3.6	2.8	1.8	1.1
90	62.6	33.4	62.6	33.4	38.2	28.3	38.2	19.7	13.0	9.6	13.0	9.6	1.6	1.3	2.9	2.1
91(A)	86.1	47.3	86.1	47.3	49.0	34.1	49.0	36.2	19.6	13.9	19.6	13.9	3.0	3.0	5.1	4.8
92	55.7	55.7	47.3	47.3	36.9	43.6	36.9	35.5	15.7	17.4	15.7	12.8	2.9	3.3	4.5	5.0
95	58.3	28.9	35.8	21.7	23.2	12.6	15.5	13.4	5.2	5.0	2.2	3.5	0.4	0.4	0.4	0.4
97	21.0	16.2	16.2	16.2	15.5	11.6	11.5	11.2	4.4	5.7	3.6	4.4	0.5	0.6	0.6	0.7
98A	22.2	16.3	16.3	16.3	16.4	11.2	10.9	10.9	3.5	4.6	3.1	4.5	0.4	0.5	0.5	0.6
490	9.0	4.0	7.6	4.0	5.8	2.6	4.5	3.2	1.4	1.6	1.4	1.6	0.2	0.2	0.2	0.3
492	13.3	8.3	13.3	8.3	11.3	6.9	11.3	4.8	3.0	2.8	2.2	2.3	0.4	0.3	0.6	0.4

Table 5.8: 42 tpd scenario, 2017. (All concentrations are in ppb.) Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

	2017															
	1-hour Max				3-hour Max				24-hour Max				Annual Average			
	All Hours	All Daylight	GS	GS Daylight	3-hour	All Daylight	GS	GS Daylight	24-hour	All Daylight	GS	GS Daylight	All Hours	All Daylight	GS	GS Daylight
Plots/year																
1	360.9	360.9	133.8	133.8	267.9	202.5	93.5	73.1	79.1	110.3	34.2	38.7	9.6	8.8	5.1	3.9
20	433.0	422.4	433.0	179.9	310.0	288.8	159.3	137.0	109.9	137.9	53.8	89.4	12.5	16.6	10.3	13.9
37	248.2	248.2	159.8	159.8	158.7	114.6	86.9	99.1	21.9	36.9	21.1	34.7	3.2	4.3	4.7	6.4
39	76.1	76.1	76.1	76.1	45.4	62.1	45.4	65.8	20.3	28.3	20.3	28.3	5.6	7.8	8.9	12.6
42	382.8	382.8	208.1	110.8	253.2	152.5	103.0	68.1	35.5	60.0	19.6	26.2	5.3	6.8	5.9	7.9
43A	83.9	83.9	81.5	81.5	45.4	50.5	42.5	51.3	11.5	17.2	11.5	17.2	1.9	2.4	2.8	3.5
43B	102.1	102.1	100.2	100.2	63.5	62.7	44.9	56.0	14.2	19.6	14.2	18.7	2.2	2.7	3.2	4.0
44	357.8	357.8	269.8	133.2	231.7	144.3	122.3	58.5	32.2	54.5	23.2	39.3	3.7	5.1	5.2	7.3
44A	130.8	117.4	130.8	117.4	81.1	79.0	81.1	69.3	10.4	15.2	10.4	15.2	0.9	0.8	1.2	1.0
46	95.4	95.4	85.8	85.8	52.2	54.5	46.3	54.7	12.4	19.6	12.4	19.6	2.2	2.8	3.4	4.3
47B	47.1	47.1	47.1	47.1	30.9	37.0	27.7	36.7	13.4	18.0	13.4	18.0	3.7	4.8	5.5	7.1
52(A)	67.6	67.6	67.6	67.6	38.7	48.2	38.7	54.6	14.1	20.0	14.1	20.0	2.5	3.3	3.5	4.7
54	71.2	71.2	71.2	71.2	38.7	47.0	38.7	55.2	11.7	15.9	11.1	15.9	2.1	2.6	2.7	3.4
55	46.8	46.8	43.6	43.6	27.9	26.7	22.5	32.9	7.5	7.9	5.1	7.7	0.8	0.9	0.9	1.0
56(A)	76.7	54.3	46.1	28.8	58.4	24.6	22.7	17.2	11.0	7.8	5.1	5.9	0.8	0.7	0.7	0.7
57	62.2	38.6	34.2	24.3	53.5	23.9	17.8	14.9	9.1	7.5	4.3	4.9	0.6	0.6	0.6	0.6
68	60.8	60.8	18.6	18.6	40.4	35.3	11.8	13.2	12.8	20.6	4.3	5.5	0.4	0.5	0.4	0.4
69	117.1	117.1	22.8	22.8	61.1	66.0	13.3	13.3	13.2	21.4	4.7	5.3	0.5	0.5	0.4	0.5
70	32.5	32.5	17.6	17.6	13.9	18.6	11.4	11.4	5.5	8.7	3.1	3.4	0.3	0.4	0.3	0.4
78 (A)	43.0	43.0	41.5	36.6	32.0	28.3	26.3	25.9	10.7	13.1	10.7	11.2	3.1	3.7	4.4	5.1
79	59.6	59.6	59.6	59.6	45.0	37.0	34.4	42.6	13.8	20.7	13.8	20.7	4.2	5.0	6.4	7.9
80	47.1	47.1	42.8	37.7	29.3	28.0	26.9	29.0	12.1	15.0	11.4	15.0	3.4	3.9	4.8	5.4
81B	115.6	46.9	115.6	44.7	66.8	32.2	66.8	26.7	12.8	11.6	12.8	11.6	1.8	1.8	2.7	2.8
81C	85.5	46.3	85.5	46.3	48.5	24.0	48.5	24.9	10.9	10.0	10.9	10.0	1.5	1.4	2.1	2.2
82	140.7	69.2	140.7	69.2	72.4	62.2	72.4	32.7	19.3	19.2	19.3	13.4	3.1	2.9	4.6	4.3
84 (A) (B)	6.4	6.2	5.0	5.0	5.3	4.7	4.0	4.0	1.8	2.8	1.3	1.7	0.2	0.2	0.2	0.3
85	12.7	8.6	12.7	8.6	8.6	7.1	8.6	6.9	3.4	4.0	3.4	4.0	0.7	0.7	1.0	0.9
86	10.9	10.2	10.9	10.2	9.4	7.7	9.4	7.4	4.3	4.2	4.3	4.2	1.0	0.9	1.4	1.2
87	134.8	134.8	98.7	79.5	70.2	74.5	70.2	57.6	25.4	33.9	15.6	21.2	4.3	4.1	2.5	2.5
88	74.5	74.5	72.5	68.4	58.2	51.7	58.2	51.0	22.6	25.5	11.1	17.7	3.5	3.4	2.0	2.2
89	51.6	51.6	50.4	50.4	40.6	38.9	29.9	38.4	20.7	18.9	10.3	12.0	3.5	2.8	1.7	1.6
89A	51.4	51.4	51.2	51.2	40.7	38.8	29.9	38.4	20.7	18.9	10.4	12.0	3.5	2.9	1.8	1.6
90	66.4	44.0	66.4	22.4	44.5	33.2	44.5	19.1	10.2	14.0	8.9	7.7	1.5	1.4	2.2	2.1
91(A)	62.0	50.5	62.0	39.6	39.5	31.6	34.8	32.1	16.0	14.3	11.3	13.6	3.0	3.2	4.5	4.7
92	55.3	42.8	55.3	41.9	30.8	32.3	29.9	25.5	11.0	13.4	11.0	11.4	3.1	3.6	4.3	4.9
95	39.6	33.7	21.0	21.0	25.6	19.5	13.0	15.3	8.1	12.5	3.9	5.1	0.4	0.4	0.3	0.4
97	25.1	21.9	18.9	18.9	17.1	15.0	13.3	13.3	5.1	4.9	3.7	4.9	0.6	0.6	0.6	0.7
98A	20.6	20.6	20.6	20.6	14.2	13.9	14.2	14.2	3.1	4.6	3.1	4.6	0.4	0.4	0.5	0.5
490	7.2	5.2	5.2	5.2	3.8	3.2	3.4	2.9	1.4	1.5	1.2	1.5	0.2	0.2	0.2	0.2
492	10.5	7.8	10.1	6.1	6.7	6.8	6.7	4.4	3.1	3.2	2.2	1.9	0.5	0.4	0.6	0.5

Table 5.9: 42 tpd scenario, 2018. (All concentrations are in ppb.) Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

	2018															
	1-hour Max				3-hour Max				24-hour Max				Annual Average			
	All Hours	All Daylight	GS	GS Daylight	3-hour	All Daylight	GS	GS Daylight	24-hour	All Daylight	GS	GS Daylight	All Hours	All Daylight	GS	GS Daylight
Plots/year																
1	213.6	213.6	163.8	163.0	156.7	140.0	110.0	121.2	59.8	62.0	31.1	31.1	10.1	9.9	5.2	5.1
20	701.5	528.5	406.3	311.6	410.4	248.8	268.0	247.9	111.7	99.0	60.0	82.6	13.8	17.4	13.5	18.2
37	239.5	239.5	221.8	221.8	133.1	105.8	93.5	93.5	29.8	50.6	22.2	37.6	3.2	4.4	4.9	6.9
39	78.0	78.0	70.2	70.2	51.3	54.5	51.3	57.4	22.5	29.9	22.5	29.9	5.4	7.5	8.5	12.3
42	327.3	327.3	131.2	131.2	167.3	133.3	61.5	86.0	36.3	61.6	22.3	38.0	5.9	7.7	7.1	10.1
43A	111.2	111.2	111.2	111.2	56.6	52.4	56.6	56.6	19.0	26.6	19.0	26.6	2.3	2.7	3.5	4.2
43B	174.6	174.6	174.6	174.6	75.2	76.4	75.2	75.2	19.8	28.9	19.8	28.9	2.6	3.1	3.9	4.8
44	306.6	306.6	144.0	144.0	157.5	123.3	72.1	82.3	39.8	67.6	22.1	37.7	4.3	6.1	6.4	9.0
44A	105.3	49.6	105.3	49.6	70.2	28.5	70.2	31.6	11.4	12.8	11.4	12.8	1.1	0.9	1.6	1.2
46	118.2	118.2	118.2	118.2	58.7	57.7	58.7	58.7	20.1	29.0	20.1	29.0	2.5	3.1	3.9	4.9
47B	44.9	44.9	44.9	44.9	33.1	30.3	33.1	31.9	15.7	21.1	15.7	21.1	3.6	4.5	5.3	6.9
52(A)	61.3	61.3	61.3	61.3	41.4	51.5	41.4	61.1	12.5	18.7	12.5	16.7	2.6	3.5	3.6	4.9
54	58.4	58.4	58.4	58.4	38.7	46.6	38.7	57.5	11.6	18.5	11.6	18.5	2.2	2.9	2.8	3.9
55	38.7	38.7	31.5	31.5	24.4	26.2	24.4	30.3	8.0	10.7	5.8	7.8	1.0	1.2	1.0	1.3
56(A)	59.3	33.0	53.7	26.1	45.2	30.4	24.5	26.1	10.6	10.4	5.2	7.7	0.8	0.8	0.7	0.9
57	64.4	31.3	25.4	25.4	47.9	21.1	20.2	24.9	14.6	7.2	4.9	7.2	0.7	0.7	0.6	0.8
68	28.1	28.1	21.7	21.7	18.3	23.9	14.8	18.9	5.8	9.6	3.1	4.3	0.4	0.5	0.4	0.5
69	42.7	42.7	42.7	42.7	25.3	28.1	21.6	23.4	7.3	12.2	3.7	5.6	0.5	0.6	0.5	0.7
70	26.2	19.4	19.4	19.4	17.0	14.9	17.0	17.9	2.6	4.2	2.6	3.5	0.3	0.4	0.3	0.5
78 (A)	51.9	51.9	48.0	39.5	38.3	29.4	38.3	28.9	12.3	11.9	12.1	11.9	3.1	3.4	4.3	4.9
79	73.5	73.5	73.5	73.5	43.3	47.9	43.3	37.2	15.9	22.0	15.9	22.0	4.1	4.6	6.8	7.6
80	57.5	44.4	44.4	44.4	33.9	24.3	30.0	32.2	13.3	14.9	12.6	14.9	3.3	3.5	4.9	5.2
81B	208.6	85.7	208.6	41.2	149.8	37.8	149.8	32.9	22.3	18.1	22.3	18.1	2.1	1.5	3.3	2.3
81C	187.0	44.0	187.0	44.0	112.5	28.0	112.5	29.9	17.2	19.9	17.2	19.9	1.8	1.3	2.7	2.0
82	226.6	58.4	226.6	58.4	119.1	58.4	119.1	42.6	18.5	14.6	18.5	13.0	3.1	2.4	5.0	3.7
84 (A) (B)	9.3	9.3	6.0	5.3	7.0	6.1	3.6	3.7	2.7	2.2	1.0	1.3	0.2	0.2	0.2	0.2
85	13.7	13.7	13.5	7.0	11.4	10.1	11.4	5.9	3.6	3.6	3.6	2.9	0.7	0.6	1.0	0.8
86	21.0	14.5	13.0	8.5	18.0	9.0	11.8	7.1	6.6	4.2	4.5	4.2	1.0	0.8	1.4	1.1
87	129.5	129.5	107.3	107.3	95.5	87.9	66.2	87.3	23.2	37.6	12.2	16.6	4.4	4.6	2.6	3.0
88	89.0	89.0	58.2	58.2	66.1	61.3	41.4	58.1	17.1	27.7	9.2	12.7	3.4	3.7	2.0	2.5
89	71.1	71.1	71.1	71.1	40.9	42.6	40.9	53.7	17.8	17.8	9.8	11.3	3.5	3.1	1.9	1.8
89A	71.5	71.5	71.5	71.5	41.1	42.8	41.1	53.9	18.1	17.9	10.1	11.3	3.5	3.1	1.9	1.8
90	70.9	45.5	70.9	45.5	36.1	26.5	36.1	18.9	10.1	8.7	10.1	7.3	1.5	1.1	2.6	1.8
91(A)	143.7	55.2	143.7	46.1	79.4	44.2	79.4	27.4	16.7	15.5	16.7	15.5	2.9	2.7	4.7	4.2
92	52.2	52.2	44.8	35.0	39.2	34.2	39.2	26.7	12.3	12.9	12.3	11.5	3.0	3.3	4.3	4.7
95	21.5	21.5	16.9	16.9	13.2	18.9	11.9	14.6	4.3	7.0	3.2	4.0	0.3	0.4	0.3	0.4
97	44.8	34.6	23.6	22.3	39.3	28.5	13.2	14.5	11.4	8.4	5.0	5.6	0.7	0.8	0.8	0.9
98A	43.9	19.4	19.4	19.4	33.7	14.0	12.3	13.8	7.7	4.9	3.9	4.9	0.5	0.6	0.5	0.7
490	8.1	7.4	5.7	5.1	4.5	4.6	4.5	3.4	1.4	1.4	1.3	1.3	0.2	0.2	0.3	0.3
492	13.6	9.8	13.6	6.9	8.9	9.0	8.9	4.6	4.0	3.5	2.5	2.3	0.6	0.5	0.6	0.5

5.2 Vegetation Site Evaluation Report, May 9, 2019

Evaluation of Sites for Future Sampling
John Laurence, Consulting Plant Pathologist

NOTE: This report was completed in September 2018 and submitted to Rio Tinto on October 6, 2018. It was subsequently submitted to ENV in May of 2019. Review comments were received from Dr. Adriana Almeida-Rodriguez on July 4, 2019. The purpose of the report was to evaluate sites for use in the 2019 sampling program. Dr. Almeida-Rodriguez's comments were incorporated into the 2019 sampling program and 7 sites proposed for removal (20, 70, 79, 84A, 85, 87, and 90) were retained. The purpose of including this report is to demonstrate the pre-KMP relationship between emissions of F and S from Rio Tinto and the accumulation of F and S in western hemlock needles. The analysis and report were completed in advance of the discussion of the TOR and new atmospheric dispersion modeling.

Background

In 2010, an evaluation of sampling and inspection sites for the Rio Tinto BC Works (RTBCW) vegetation program was conducted[1]. The evaluation used the entire available dataset—1970-2009—for analysis of the relationship of F emissions to F in western hemlock needles. As a result of that analysis, 17 sites were dropped from the program due to either poor correlation with F emissions from the smelter or redundancy due to close proximity. A set of 37 sites were retained. Site 89A was added when a sample tree couldn't be located; the original tree was located the next year, but sampling continued at site 89A. In 2016, at the request of the BC Ministry of Environment and Climate Change Strategy, sites 490 and 492 in the Williams Creek drainage were added as reference sites outside of the projected dispersion from the Kitimat Modernization Project (KMP). Those 40 sites are currently sampled and inspected as part of the vegetation monitoring program and the Environmental Effects Monitoring Plan (EEM) for the BC Works.

Beginning in 2010, the smelter at Kitimat began to reduce operations in preparation for the KMP. There was a substantial decline in emissions in 2010 and again in 2014-2015 when the original VSS operations ceased[2] [3].

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[1] Laurence, J. A. A Review of the Vegetation Monitoring and Assessment Program in the Vicinity of the Rio Tinto Alcan British Columbia Operations at Kitimat, British Columbia. Submitted to Rio Tinto Alcan British Columbia Operations Kitimat, BC. May 16, 2010. 141 p.

[2] Stantec Consulting, Ltd and J. Laurence. 2018. Vegetation Monitoring Report (Annual Report 2017). Submitted to Rio Tinto BC Works, May 4, 2018. 224 p.

[3] Beginning in 2014, results of F analyses conducted by the Rio Tinto laboratory in Jonquière, Québec began to differ substantially from the historical site means. Given the reduction in emissions, the results did not make sense. Over the next few years and many re-analyses, chemists at the laboratory identified a piece of equipment that was failing.
In 2018, RTBCW organized an interlaboratory study to assess variability in analyses at 3 laboratories. Results of that study showed that all 3 laboratories (including the Rio Tinto laboratory) produced similar results[3]. The Rio Tinto laboratory had not yet replaced the failing equipment, so they used an ion-specific electrode to measure F, the same method used by the other laboratories.
In order to clarify the results from 2014-2016, it would be best to have the Rio Tinto laboratory re-analyze the samples using the ion-specific electrode. The analysis of 2015 and 2016 is particularly important since 2015 represents a year with very low emissions (and thus a reasonable "background" level of F and S in vegetation) and 2016 is the first year of operations of KMP. Results from 2014 provide another year in which emissions were quite low compared to historical levels.
These results will be especially important in the comprehensive review of sites for the EEM that is scheduled for 2019. While the EEM covers SO_2 effects, F in vegetation is perhaps a more accurate indicator of dispersion as F is not an essential element for plant growth and it occurs

Given the reduction in F emissions from KMP and the implementation of the EEM for SO_2, it is an appropriate time to review the current array of sampling sites and assess their contribution to our understanding of the deposition of F and S in the Kitimat Valley.

I undertook an analysis to evaluate the efficacy of the sites with regard to their relationship to F emissions from RTBCW. This analysis allowed me to prioritize the sites to be re-analyzed as soon as possible to facilitate the comprehensive review of EEM. The same methodology was used to propose a new array of sampling sites based on the relationship of the sites to both F and S emissions from RTBCW.

Methods

I used the F and S analysis results from the vegetation monitoring program that both Stantec Consulting and I have used in past analyses. Emissions data were used to calculate loadings—tons of F and S released—for both annual and growing season (April 15-September 15) periods. Both annual and growing season loadings were used in the analysis.

Correlation of F and S emissions with F and S in western hemlock needles.

I first examined the correlation between F and S emissions (separately) reported by RTBCW and F and S (separately) in needles of western hemlock. Four time spans were used in the analysis: the full span of results since the beginning of the S dataset in 1998 through 2013 when emissions of F and S dropped substantially; 1998-2011, the range of years used to establish a historical mean in the Sulphur Technical Assessment Report (STAR)[4]; 2000-2009, a 10-year period of VSS smelter operation; and 2000-2010, a period that included reduced operations. The correlations were examined to determine which sites had consistent and high correlations (for this analysis, I used 0.6 as the lower limit for a high correlation). The analysis allows identification of sites that are not highly correlated with F or S emissions.

Correlation among sites for F and S concentrations in western hemlock needles.

In order to identify potential redundancies in what is learned from individual sites, I examined the correlation among sites—that is, is one site a good predictor of what the result at another site will be. The rationale is that if two sites are both correlated with F and/or S emissions, but are also highly correlated with each other, one site may be redundant primarily due to close proximity to the other. For this analysis, a threshold of 0.7 was used to examine correlated sites. Two time spans were used, 1998-2013 and 2000-2009. Additional time spans will be examined for the comprehensive review.

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at very low concentrations in leaves as compared to S which is essential and occurs at high concentrations that vary not only with atmospheric input, but also with soil S availability.

[4] ESSA et al. 2013. 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, B.C. 450 pp.

Results

Correlation of F and S emissions with F and S in western hemlock needles.

Results of the analysis for F in western hemlock needles related to F emissions are shown in Table 5.10. Some sites have consistently high correlations in all four time spans whereas some sites have a high correlation only when 1998-2000 is included or excluded. This is likely due to particularly high loadings in 1998. Seventeen sites (37, 39, 43B, 44, 46, 52, 54, 55, 56, 57, 68, 80, 81C, 86, 91A, 92, 95, and 98A) have consistently high correlations with growing season loadings of F.

Results for the analysis of S in western hemlock needles related to S emissions are shown in Table 5.11. Only 2 sites—78A and 80—have a consistently high correlation across the four time spans. As in past analyses, this is likely due to rather homogenous S concentrations in needles throughout the valley, with a few exceptions where concentrations of S have historically been greater than the mean, but not statistically greater.

Correlation among sites for F and S concentrations in western hemlock needles.

Results of the analysis of the correlations among sites for F in western hemlock needles are shown in Table 5.12 and Table 5.13, and for S in Table 5.14 and Table 5.15. These results, in conjunction with results of the correlations with loadings, may be used to determine whether sites are adding understanding or predictive capacity to the sampling array. For instance, sites 37 and 39 both have consistently high correlations with F loadings, and the results at the 2 sites are highly correlated, indicating that one or the other site could be used without sacrificing understanding of where F deposition is occurring—we may conclude that if site 37 is low, site 39 will be as well and vice-versa.

Recommendations

Based on this analysis and other factors (e.g. reference sites, socially important sites, etc.) the following 20 sites are recommended for continued sampling:

Site	Correlation with F	Correlation with S	Additional Factors
1	Low	Low	Proximity to RTBCW
37	High	Low	
43B	High	Low	
44	High	Low	
44A	Low	Low	High elevation
46	High	Low	
52A	High	Low	
56	High	Low	
68	High	Low	
69	Low	Low	East side of Minette
78A	Low	High	High elevation
80	High	High	
81B	Low	Low	High Elevation

Site	Correlation with F	Correlation with S	Additional Factors
81C	High	Low	
86	High	Low	
89	High	Low	
91A	High	Low	
98A	High	Low	
490	N/A	N/A	Reference site
492	N/A	N/A	Reference site

The following 20 sites are recommended to be discontinued:

Site	Correlation with F	Correlation with S	Additional Factors
20	Low	Low	
39	High	Low	Proximity to and correlation with 39
42	Low	Low	
43A	Low	Low	Proximity to 43B
47B	Low	Low	
54	High	Low	Proximity to and high correlation with 52A
55	High	Low	High correlation with 57
57	High	Low	High correlation with 56
70	Low	Low	
79	Low	Low	
82	Low	Low	
84A	Low	Low	Proximity to 86
85	Low	Low	Proximity to 86
87	Low	Low	
88	Low	Low	Safety consideration
89A		Low	Proximity to 89 (about 20 meters)
90	Low	Low	High correlation with 80 and 81C
92	High	Low	Proximity to and correlation with 80
95	Low	Low	Proximity to and correlation with 68
97	Low	Low	Proximity to 98A

The sites recommended for continued sampling provide geographic coverage that will allow an estimation of the extent of the dispersion from RTBCW as shown below:

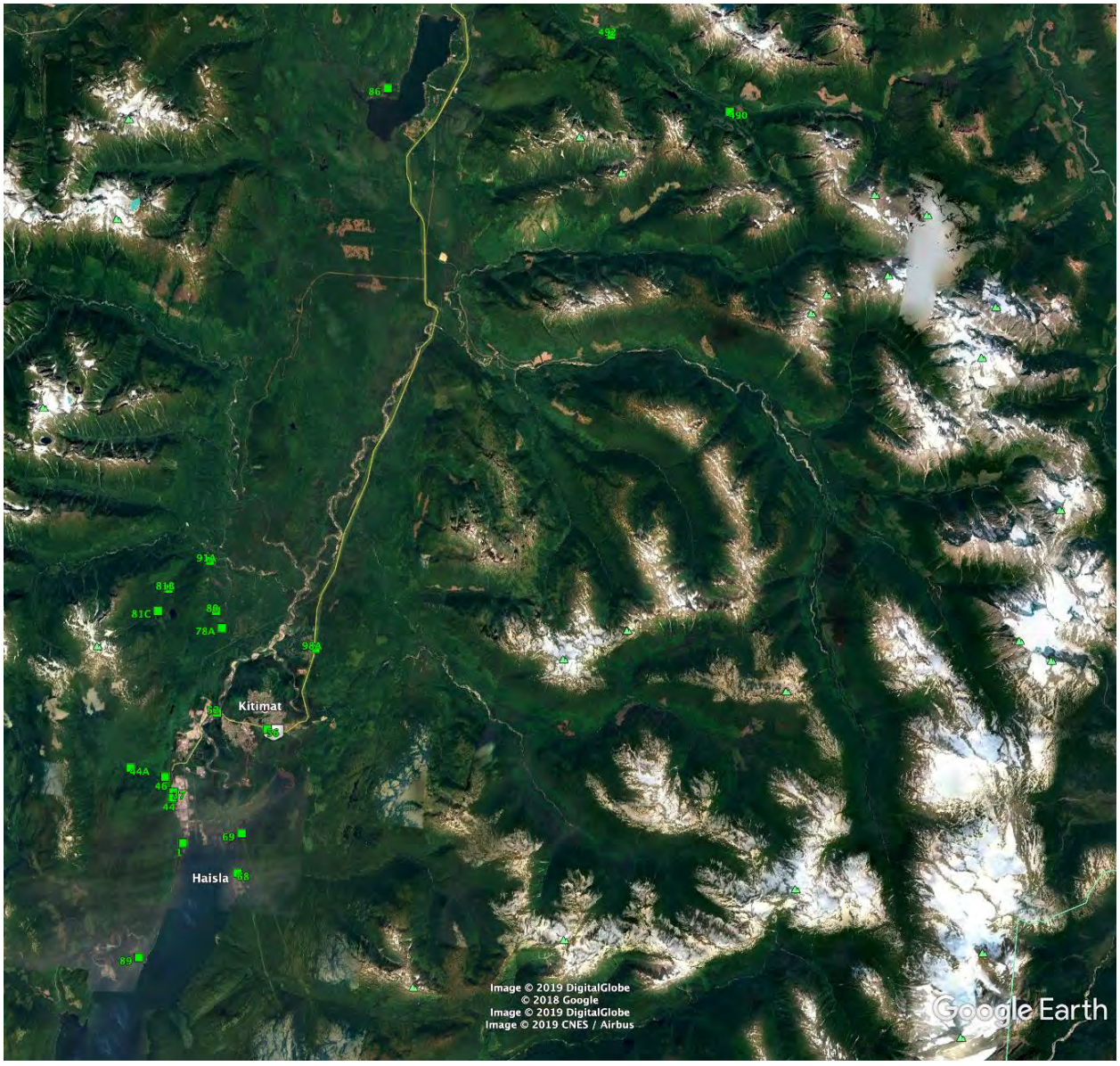


Table 5.10: Correlation between F loadings and F in needles of western hemlock for four time spans. Red shading identifies correlations greater than 0.6.

	Annual Loading				Growing Season Loading			
Site Identifier	FULL SPAN 1998-2013	STAR MEAN 1998-2011	2000-2009	2000-2010	FULL SPAN 1998-2013	STAR MEAN 1998-2011	2000-2009	2000-2010
1	0.741	0.735	-0.110	0.006	0.823	0.818	0.052	0.322
20	0.482	0.466	0.361	0.365	0.603	0.584	0.555	0.566
37	0.612	0.609	0.583	0.534	0.792	0.792	0.831	0.789
39	0.701	0.706	0.736	0.636	0.768	0.772	0.806	0.740
42	0.536	0.544	0.460	0.462	0.592	0.592	0.545	0.549
43A	0.874	0.876	0.390	0.419	0.923	0.927	0.241	0.589
43B	0.583	0.598	0.559	0.466	0.635	0.657	0.657	0.607
44	0.622	0.634	0.552	0.553	0.764	0.781	0.804	0.809
44A	0.574	0.554	0.756	0.688	0.510	0.482	0.694	0.578
46	0.815	0.809	0.681	0.657	0.855	0.850	0.885	0.815
47B	0.359	0.434	0.273	0.272	0.288	0.380	0.237	0.234
52(A)	0.545	0.599	0.768	0.737	0.575	0.645	0.885	0.872
54	0.789	0.799	0.608	0.546	0.829	0.846	0.765	0.723
55	0.349	0.329	0.550	0.516	0.471	0.444	0.681	0.669
56	0.627	0.668	-0.183	0.150	0.766	0.811	-0.022	0.611
57	0.536	0.533	0.505	0.545	0.597	0.606	0.638	0.710
68	0.098	0.126	0.545	0.487	0.238	0.275	0.720	0.680
69	0.474	0.468	0.442	0.349	0.555	0.552	0.639	0.464
70	0.229	0.238	0.350	0.271	0.274	0.282	0.507	0.442
78(A)	0.749	0.765	0.605	0.487	0.793	0.788	0.733	0.570
79	0.794	0.809	0.414	0.402	0.761	0.790	0.529	0.509
80	0.917	0.924	0.923	0.926	0.937	0.944	0.973	0.843
81B	0.463	0.446	-0.080	-0.087	0.549	0.530	0.160	0.137
81C	0.467	0.698	0.669	0.460	0.538	0.817	0.780	0.836
82	0.682	0.695	0.363	0.312	0.692	0.689	0.396	0.301
84 (A) (B)	-0.134	-0.137	0.388	0.362	-0.038	-0.037	0.593	0.533
85	-0.066	-0.052	0.341	0.322	0.011	0.035	0.490	0.443
86	0.284	0.284	0.472	0.472	0.382	0.385	0.611	0.611
87	0.840	0.853	0.653	0.654	0.779	0.781	0.470	0.475
88	0.878	0.884	0.816	0.740	0.834	0.832	0.693	0.544
89/89 (A)	0.566	0.575	0.643	0.607	0.546	0.531	0.633	0.568
90	0.628	0.626	0.588	0.586	0.374	0.355	0.291	0.286
91(A)	0.650	0.713	0.748	0.747	0.695	0.762	0.788	0.780
92	0.548	0.557	0.753	0.753	0.611	0.610	0.768	0.768
95	0.188	0.179	0.385	0.388	0.395	0.397	0.598	0.610
97	0.475	0.566	0.826	0.811	0.328	0.404	0.601	0.571
98A	0.680	0.677	0.774	0.694	0.639	0.642	0.702	0.659
490	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
492	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 5.11: Correlation between S loadings and S in needles of western hemlock for four time spans. Red shading identifies correlations greater than 0.6.

	Annual Loading				Growing Season Loading			
	FULL SPAN 1998-2013	STAR MEAN 1998-2011	2000-2009	2000-2010	FULL SPAN 1998-2013	STAR MEAN 1998-2011	2000-2009	2000-2010
1	0.789	0.715	-0.209	0.303	0.784	0.683	-0.280	0.223
20	0.724	0.641	-0.196	0.336	0.649	0.546	-0.260	0.232
37	0.642	0.517	-0.224	0.152	0.570	0.426	-0.257	0.076
39	0.716	0.577	-0.111	0.283	0.656	0.484	-0.194	0.173
42	0.727	0.620	0.121	0.459	0.702	0.588	0.179	0.452
43A	0.622	0.429	-0.807	-0.365	0.627	0.406	-0.791	-0.390
43B	0.717	0.630	-0.167	0.363	0.655	0.558	-0.149	0.304
44	0.596	0.539	-0.012	0.331	0.495	0.424	-0.118	0.212
44A	0.507	0.407	-0.159	0.020	0.464	0.365	-0.132	0.021
46	0.511	0.326	-0.483	0.007	0.468	0.263	-0.385	-0.004
47B	0.681	0.551	0.044	0.337	0.616	0.463	-0.009	0.260
52(A)	0.532	0.380	-0.338	0.075	0.452	0.271	-0.410	-0.035
54	0.491	0.204	-0.501	-0.206	0.416	0.089	-0.603	-0.339
55	0.303	0.121	0.133	-0.022	0.258	0.051	0.014	-0.097
56	0.729	0.650	-1.000	0.152	0.696	0.598	-0.996	0.096
57	0.568	0.405	0.483	-0.126	0.554	0.375	0.417	-0.123
68	0.806	0.772	0.562	0.601	0.736	0.681	0.409	0.486
69	0.524	0.395	0.117	0.169	0.459	0.299	-0.020	0.051
70	0.618	0.550	0.289	0.265	0.527	0.441	0.124	0.137
78 (A)	0.909	0.922	0.683	0.863	0.860	0.872	0.648	0.806
79	0.661	0.591	0.258	0.403	0.578	0.489	0.121	0.280
80	0.789	0.908	1.000	0.947	0.738	0.889	0.996	0.961
81B	0.739	0.692	0.607	0.581	0.724	0.684	0.573	0.572
81C	0.401	0.338	0.483	-0.432	0.385	0.323	0.417	-0.402
82	0.747	0.646	0.140	0.403	0.680	0.556	0.056	0.308
84 (A) (B)	0.685	0.529	-0.010	0.257	0.609	0.414	-0.136	0.125
85	0.509	0.384	0.414	0.296	0.498	0.362	0.349	0.268
86	0.531	0.497	0.473	0.278	0.526	0.488	0.463	0.308
87	0.670	0.610	0.466	0.485	0.613	0.545	0.378	0.422
88	0.275	0.060	-0.198	-0.109	0.251	0.017	-0.229	-0.148
89/89 (A)	0.753	0.688	0.558	0.624	0.706	0.639	0.480	0.565
90	0.398	0.351	0.091	0.199	0.316	0.270	0.007	0.117
91(A)	0.195	0.178	0.191	0.060	0.155	0.115	0.092	0.000
92	0.203	0.359	0.084	0.084	0.098	0.238	-0.037	-0.037
95	0.727	0.690	0.553	0.581	0.681	0.634	0.477	0.529
97	0.727	0.631	0.541	0.438	0.684	0.573	0.452	0.393
98A	0.394	0.301	0.207	0.186	0.282	0.166	-0.007	0.032
490								
492								

Table 5.12: Correlations for F in western hemlock needles among sampling sites for the period 1998-2013. Yellow identifies sites with a correlation greater than 0.7, blue for sites greater than 0.8, and green for sites with greater than 0.9. Sites listed as 42A and 56A are the same as sites 42 and 56.

SITE	1	20	37	39	42(A)	43A	43B	44	44A	46	47B	52(A)	54	55	(56 A)	57	68	69	70	78(A)	79	80	81B	81C	82	84 (A)	85	86	87	88	89/89 (A)	90	91(A)	92	95	97	98A
1	1	0.624	0.662	0.577	0.076	0.591	0.36	0.628	0.249	0.403	0.42	0.438	0.55	0.293	0.219	0.03	0.271	-0.04	0.364	0.57	0.385	0.234	0.579	0.262	0.415	0.106	0.011	0.253	0.368	0.245	0.579	0.21	0.318	0.129	0.183	0.081	0.186
20		1	0.574	0.39	0.502	0.539	0.17	0.766	0.446	0.388	0.056	0.26	0.18	0.173	-0.04	-0.16	0.234	-0.05	0.158	0.495	0.565	0.34	0.762	0.354	0.572	0.015	-0.07	0.251	0.63	0.623	0.652	0.315	0.124	0.057	-0.01	0.036	0.18
37			1	0.764	0.611	[illegible]	0.783	0.773	0.53	0.749	0.478	[illegible]	0.745	0.482	0.161	-0.12	0.466	0.069	0.674	0.51	0.553	0.532	0.332	0.52	0.166	0.086	-0.06	0.241	0.394	0.345	0.521	0.218	0.569	0.359	0.239	-0.02	0.523
39				1	0.645	0.59	[illegible]	0.589	0.153	0.445	0.378	0.719	[illegible]	0.695	0.529	0.285	0.647	0.2	0.498	0.341	0.447	0.426	0.016	0.447	0.205	0.319	0.169	0.539	0.462	0.297	0.395	0.381	0.741	0.709	0.415	0.432	0.696
42(A)					1	0.459	0.63	0.586	0.318	0.676	0.415	0.587	0.403	0.331	-0.25	-0.56	0.213	0.028	0.227	0.658	0.641	0.211	0.203	-0.35	0.365	-0	-0.19	0.103	0.494	0.464	0.565	0.318	0.639	0.314	-0.02	0.082	0.291
43A						1	0.711	[illegible]	0.673	0.773	0.666	[illegible]	0.611	0.134	-0.04	-0.25	0.177	-0.23	0.774	-0.33	0.477	0.61	0.554	0.476	-0.04	-0.21	-0.29	-0.17	0.457	0.34	0.402	0.419	0.496	-0.24	-0.18	-0.2	0.047
43B							1	0.458	0.371	0.629	0.526	[illegible]	0.74	0.459	0.222	-0.12	0.425	-0.01	0.608	0.267	0.427	0.494	0.023	0.517	-0.02	0.105	0.007	0.127	0.194	0.066	0.236	0.274	0.582	0.357	0.262	0.066	0.579
44								1	0.419	0.608	0.311	0.684	0.596	0.409	0.477	0.155	0.501	0.256	0.416	0.581	0.74	0.771	0.575	0.792	0.328	0.255	0.161	0.402	0.519	0.481	0.569	0.243	0.534	0.344	0.275	0.209	0.377
44A									1	0.709	0.547	0.595	0.01	-0.09	-0.22	-0.34	-0.29	-0.18	0.545	0.676	0.387	0.709	0.768	0.044	0.234	-0.21	-0.33	-0.27	0.57	0.587	0.465	0.496	0.116	-0.28	-0.35	-0.22	0.109
46										1	0.559	0.777	0.387	0.159	-0.27	-0.46	0.012	0.054	0.376	[illegible]	0.535	0.702	0.349	0.101	0.376	-0.07	-0.22	-0.05	0.387	0.508	0.628	0.304	0.609	0.22	-0.01	-0.08	0.097
47B											1	0.69	0.442	0.095	-0.18	-0.22	-0.03	0.1	0.328	0.254	0.651	0.572	0.035	0.381	-0.06	0.046	-0.15	0.092	0.291	0.328	0.285	0.394	0.364	0.077	-0.07	-0.04	0.239
52(A)												1	0.764	0.403	0.216	-0.09	0.398	0.155	0.704	0.35	0.625	[illegible]	0.106	0.535	-0.03	0.143	0.017	0.193	0.396	0.307	0.393	0.323	0.671	0.363	0.186	0.139	0.553
54													1	0.739	0.658	0.443	[illegible]	0.44	0.611	0.168	0.464	0.439	-0.07	0.78	-0.02	0.45	0.365	0.619	0.121	-0.01	0.291	0.104	0.696	0.768	0.615	0.29	0.734
55														1	0.932	[illegible]	[illegible]	0.726	0.498	0.254	0.156	0.362	-0	0.396	0.254	0.791	0.696	[illegible]	0.135	0.111	0.397	0.178	0.55	[illegible]	[illegible]	0.475	[illegible]
(56 A)															1	[illegible]	[illegible]	[illegible]	0.422	-0.01	0.029	0.416	0.03	0.399	0.07	0.932	0.928	0.949	-0.03	-0.1	0.105	0.027	0.473	[illegible]	0.928	0.607	0.914
57																1	0.693	0.905	0.137	0.146	-0.16	0.259	-0.02	0.388	0.203	0.928	0.93	0.95	-0.1	-0.07	0.07	0.112	0.277	0.971	0.9	0.597	0.762
68																	1	0.6	0.486	-0.03	0.335	0.298	-0.01	0.611	0.085	0.696	0.697	[illegible]	0.049	-0.03	0.256	0.008	0.492	[illegible]	[illegible]	0.493	[illegible]
69																		1	0.139	0.283	0.173	0.368	0.006	0.279	0.223	0.911	[illegible]	0.915	-0.09	0.049	0.292	0.042	0.404	[illegible]	[illegible]	0.501	0.572
70																			1	-0.31	0.081	0.724	0.156	0.449	-0.09	0.185	0.141	0.216	0.251	0.102	0.219	0.143	0.25	0.201	0.194	-0.07	0.66
78(A)																				1	0.422	-0.22	0.466	-0.27	0.691	0.152	-0.03	0.177	0.471	0.654	0.677	0.46	0.526	0.378	0.2	0.107	0.082
79																					1	0.492	0.441	0.483	0.293	0.203	0.066	0.36	0.552	0.582	0.508	0.523	0.453	0.228	0.13	0.27	0.22
80																						1	0.628	0.389	0.262	0.388	0.331	0.369	0.506	0.537	0.601	0.535	0.605	0.266	0.185	0.317	0.746
81B																							1	0.409	0.621	0.042	-0	0.097	0.382	0.434	0.511	0.348	-0.15	-0.26	-0.08	-0.21	-0.16
81C																								1	-0.22	0.358	0.406	0.462	-0.11	-0.07	0.054	0.2	0.123	0.257	0.533	0.064	0.527
82																									1	0.193	0.124	0.304	0.547	0.593	0.792	0.494	0.198	0.321	0.079	0.218	-0.02
84 (A) (B)																										1	0.95	0.941	-0.02	0.091	0.249	0.135	0.309	0.714	[illegible]	0.634	0.771
85																											1	[illegible]	-0.12	-0.03	0.147	0.029	0.15	0.652	[illegible]	0.608	0.707
86																												1	0.158	0.231	0.397	0.17	0.372	0.774	[illegible]	0.667	0.9
87																													1	[illegible]	0.693	0.715	0.298	0.153	-0.22	0.389	0.349
88																														1	0.797	0.764	0.293	0.182	-0.14	0.385	0.361
89/89 (A)																															1	0.529	0.389	0.481	0.171	0.255	0.306
90																																1	0.294	0.131	-0.04	0.414	0.474
91(A)																																	1	0.748	0.392	0.519	0.432
92																																		1	0.791	0.696	0.794
95																																			1	0.517	[illegible]
97																																				1	0.759
98A																																					1

Table 5.13: Correlations for F in western hemlock needles among sampling sites for the period 2000-2009. Yellow identifies sites with a correlation greater than 0.7, blue for sites greater than 0.8, and green for sites with greater than 0.9. Sites listed as 42A and 56A are the same as sites 42 and 56.

SITE	1	20	37	39	42(A)	43A	43B	44	44A	46	47B	52(A)	54	55	(56 A)	57	68	69	70	78(A)	79	80	81B	81C	82	84 (A) (B)	85	86	87	88	89/89 (A)	90	91(A)	92	95	97	98A
1	1.000	0.674	0.709	0.542	-0.738	0.871	0.064	0.743	0.792	1.000	0.644	0.567	0.739	0.649	0.729	0.977	0.515	0.469	0.485	1.000	1.000	0.961	0.999	0.618	0.940	0.939	0.811	1.000	0.977	0.872	0.955	0.785	0.905	1.000	0.797	0.911	-1.000
20		1.000	0.582	0.409	0.414	0.696	0.053	0.854	0.505	0.206	0.089	0.361	0.362	0.357	0.997	0.811	0.556	0.256	0.335	0.241	0.729	0.953	0.710	0.997	0.451	0.445	0.302	0.714	0.902	0.704	0.533	0.327	0.210	0.207	0.172	0.350	0.322
37			1.000	0.922	0.594	0.943	0.740	0.774	0.398	0.607	0.483	0.918	0.935	0.791	1.000	0.811	0.553	0.343	0.691	0.370	0.567	0.966	0.030	0.993	0.184	0.552	0.242	0.807	0.733	0.476	0.523	0.513	0.767	0.855	0.768	0.694	0.778
39				1.000	0.674	0.940	0.901	0.580	0.090	0.541	0.543	0.894	0.921	0.893	0.970	0.710	0.794	0.181	0.647	0.311	0.542	0.868	-0.136	0.996	0.117	0.431	0.064	0.684	0.536	0.186	0.334	0.507	0.761	0.821	0.691	0.583	0.791
42(A)					1.000	0.238	0.675	0.561	-0.012	0.620	0.661	0.708	0.587	0.638	-0.076	-0.576	0.474	0.412	0.194	0.663	0.824	-0.304	-0.011	0.074	0.259	0.456	-0.016	0.476	0.511	0.422	0.487	0.496	0.710	0.558	0.329	0.346	0.546
43A						1.000	0.648	0.931	0.064	1.000	0.359	0.942	0.969	0.956	0.994	0.911	0.811	-0.269	0.944	-0.482	0.897	0.993	0.378	0.966	-0.029	0.181	-0.052	0.623	0.914	0.201	0.378	0.995	0.983	0.623	0.772	0.325	1.000
43B							1.000	0.302	-0.119	0.483	0.407	0.855	0.841	0.779	0.730	0.277	0.648	0.002	0.579	0.214	0.278	0.553	-0.363	0.834	-0.060	0.183	0.008	0.282	0.192	-0.218	0.071	0.511	0.705	0.754	0.601	0.424	0.750
44								1.000	0.717	0.584	0.236	0.691	0.601	0.546	1.000	0.870	0.628	0.446	0.394	0.587	0.715	0.978	0.556	0.985	0.418	0.519	0.325	0.661	0.867	0.697	0.595	0.502	0.574	0.478	0.452	0.532	0.404
44A									1.000	0.610	-0.030	0.367	0.193	0.155	0.160	0.643	0.127	0.571	-0.081	0.608	0.188	0.383	0.597	0.011	0.207	0.484	0.430	0.369	0.431	0.742	0.390	0.266	0.503	0.440	0.554	0.726	-0.127
46										1.000	0.674	0.792	0.614	0.589	1.000	1.000	0.396	0.799	0.042	0.901	0.522	1.000	-0.025	1.000	0.470	0.701	0.460	0.579	0.374	0.551	0.626	0.432	0.914	0.872	0.705	0.746	0.302
47B											1.000	0.548	0.557	0.537	-0.055	0.464	0.203	0.448	0.030	0.581	0.587	0.177	-0.265	-0.204	0.220	0.438	-0.230	0.477	0.360	0.285	0.451	0.259	0.612	0.557	0.284	0.239	0.342
52(A)												1.000	0.929	0.893	0.977	0.731	0.749	0.421	0.588	0.530	0.513	0.902	-0.122	0.998	0.162	0.491	0.225	0.577	0.578	0.323	0.511	0.482	0.877	0.852	0.767	0.636	0.729
54													1.000	0.959	1.000	0.867	0.778	0.367	0.765	0.296	0.485	0.976	-0.088	0.986	0.240	0.528	0.275	0.745	0.605	0.279	0.547	0.571	0.788	0.954	0.807	0.593	0.790
55														1.000	0.994	0.798	0.909	0.448	0.748	0.248	0.542	0.942	-0.122	0.999	0.273	0.647	0.366	0.787	0.568	0.414	0.616	0.660	0.874	0.953	0.844	0.665	0.851
(56 A)															1.000	0.911	0.962	-0.263	0.952	-1.000	0.720	0.973	0.704	0.989	0.257	0.449	0.987	1.000	0.973	0.216	0.493	0.996	0.951	1.000	0.994	0.959	1.000
57																1.000	0.687	0.268	0.662	-1.000	0.974	0.954	0.968	0.773	0.715	0.834	0.931	1.000	0.954	0.685	0.838	0.796	0.975	1.000	0.908	0.969	1.000
68																	1.000	0.303	0.858	-0.021	0.482	0.879	0.125	0.992	0.314	0.561	0.526	0.841	0.669	0.433	0.586	0.620	0.585	0.879	0.761	0.602	0.845
69																		1.000	-0.055	0.742	0.574	-0.033	0.199	-0.404	0.714	0.882	0.639	0.868	0.401	0.714	0.861	0.473	0.659	0.914	0.569	0.642	0.063
70																			1.000	-0.411	0.113	0.892	-0.003	0.987	0.022	0.166	0.342	0.632	0.499	0.114	0.311	0.395	0.289	0.741	0.567	0.270	0.645
78(A)																				1.000	0.644	-1.000	0.134	-1.000	0.490	0.607	0.015	0.424	0.319	0.503	0.489	0.342	0.733	0.556	0.311	0.491	0.027
79																					1.000	0.865	0.490	0.608	0.636	0.687	0.178	0.761	0.731	0.699	0.677	0.598	0.582	0.461	0.274	0.414	0.292
80																						1.000	0.945	0.928	0.472	0.643	0.998	1.000	1.000	0.435	0.680	0.989	0.997	1.000	0.992	0.999	1.000
81B																							1.000	0.590	0.660	0.216	0.337	0.314	0.496	0.373	0.309	0.368	-0.127	-0.213	-0.171	-0.045	-0.610
81C																								1.000	0.109	0.311	0.951	1.000	0.928	0.067	0.357	0.972	0.896	1.000	0.967	0.906	1.000
82																									1.000	0.704	0.620	0.711	0.463	0.494	0.729	0.525	0.308	0.409	0.248	0.300	-0.360
84 (A) (B)																										1.000	0.654	0.931	0.512	0.788	0.836	0.619	0.709	0.815	0.719	0.851	0.405
85																											1.000	0.589	0.336	0.495	0.694	0.320	0.264	0.582	0.572	0.555	0.110
86																											1.000	0.830	0.870	0.835	0.502	0.564	0.712	0.623	0.695	0.736
87																												1.000	0.719	0.730	0.330	0.368	0.480	0.325	0.365	0.444
88																													1.000	0.881	0.362	0.450	0.558	0.382	0.637	0.391
89/89 (A)																														1.000	0.450	0.537	0.787	0.533	0.527	0.278
90																															1.000	0.660	0.461	0.581	0.483	0.203
91(A)																																1.000	0.855	0.824	0.783	0.586
92																																	1.000	0.881	0.779	0.854
95																																		1.000	0.774	0.851
97																																			1.000	0.706
98A																																				1.000

Table 5.14: Correlations for S in western hemlock needles among sampling sites for the period 1998-2013. Yellow identifies sites with a correlation greater than 0.7, blue for sites greater than 0.8, and green for sites with greater than 0.9. Sites listed as 42A and 56A are the same as sites 42 and 56.

SITE	1	20	37	39	42(A)	43A	43B	44	44A	46	47B	52(A)	54	55	(56 A)	57	68	69	70	78(A)	79	80	81B	81C	82	84 (A)	85	86	87	88	89/89	90	91(A)	92	95	97	98A
1	1.000			0.945		0.925		0.693	0.730	0.769		0.908	0.907	0.620		0.679	0.756		0.750	0.783	0.779	0.536	0.709	0.481		0.934	0.650	0.647	0.747	0.756	0.750	0.594	0.356	0.319	0.725	0.706	-0.391
20		1.000			0.779	0.782	0.680	0.740	0.745		0.738	0.659	0.275	0.936	0.494	0.698	0.466	0.629	0.908	0.625	0.723	0.488	0.354	0.757	0.714	0.359	0.398	0.637	0.502	0.642	0.481	0.062	0.317	0.564	0.476	0.219
37			1.000		0.783			0.628	0.748		0.740	0.669	0.393	0.960	0.691	0.668	0.610	0.523		0.628	0.711	0.600	0.569	0.787	0.683	0.530	0.526	0.656	0.492	0.666	0.590	0.344	0.402	0.670	0.649	0.401
39				1.000				0.634	0.686				0.558	0.919	0.686	0.738	0.709	0.728		0.774	0.670	0.531	0.413			0.584	0.542	0.642	0.629	0.628	0.671	0.393	0.424	0.662	0.649	0.498
42(A)					1.000	0.784		0.590	0.542		0.675	0.749	0.559	0.178		0.563	0.597	0.465	0.449		0.706	0.652	0.522	0.326	0.783	0.646	0.439	0.455	0.584	0.396	0.700	0.436	0.307	0.299	0.545	0.513	0.305
43A						1.000		0.688	0.699	0.736	0.701	0.759		0.391		0.666	0.539	0.559	0.458		0.629	0.449	0.593	0.516	0.755		0.485	0.451	0.358	0.633	0.679	0.311	-0.053	0.000	0.520	0.570	-0.398
43B							1.000	0.753	0.552	0.761	0.686	0.780	0.698	0.303	0.916	0.608	0.628	0.501	0.560		0.728	0.717	0.507	0.470		0.761	0.365	0.470	0.621	0.296	0.646	0.554	0.335	0.436	0.649	0.620	0.520
44								1.000	0.482	0.593	0.599	0.652	0.600	0.291		0.558	0.584	0.491	0.506		0.673	0.759	0.681	0.561	0.729	0.682	0.390	0.339	0.701	0.204		0.491	0.262	0.570	0.638	0.667	0.652
44A									1.000	0.781		0.672	0.682	0.541		0.646	0.571	0.377	0.669	0.740	0.477	0.683	0.426	0.484	0.673	0.732	0.351	0.594	0.384	0.757	0.321	0.598	-0.034	0.365	0.559	0.527	-0.099
46										1.000	0.775		0.665	0.603	0.786	0.612	0.543	0.515	0.520		0.351	0.536	0.392		0.779	0.690	0.698	0.579	0.657	0.554	0.584	0.511	0.581	0.768	0.706	0.544
47B											1.000	0.682	0.642	0.556	0.928	0.635	0.687	0.481	0.675		0.612	0.684	0.496	0.413	0.746	0.734	0.493	0.593	0.669	0.691	0.566	0.635	0.154	0.368	0.661	0.577	0.180
52(A)												1.000		0.592		0.588	0.682	0.773	0.686	0.705	0.794	0.511	0.397	0.371	0.771		0.504	0.436	0.527	0.537	0.479	0.532	0.508	0.505	0.615	0.602	0.607
54													1.000	0.551		0.715	0.628	0.694	0.703	0.652	0.696	0.579	0.475	0.438	0.792	0.903	0.451	0.361	0.355	0.628	0.432	0.640	0.302	0.423	0.515	0.642	0.662
55														1.000	0.505	0.733	0.568	0.707	0.652	0.119	0.644	0.302	0.354	0.569	0.477	0.702	0.703	0.681	0.414	0.552	0.196	0.524	0.614	0.451	0.704	0.686	0.693
(56 A)															1.000	0.664	0.644	0.573	0.706	0.933	0.511	0.706	0.509	0.508	0.783		0.362	0.490		0.615		0.495	0.010	0.143	0.550	0.554	-0.612
57																1.000	0.745	0.775		0.348	0.644	0.645	0.765		0.772	0.768	0.742		0.763	0.611		0.604	0.630	0.541	0.724		0.526
68																	1.000			0.705		0.794	0.699	0.611		0.793	0.661	0.652	0.600	0.452	0.591	0.611	0.516	0.522			0.746
69																		1.000	0.769	0.399	0.711	0.576	0.495	0.597	0.639	0.778	0.688	0.514	0.476	0.414	0.371	0.540	0.775	0.465	0.679	0.761	0.768
70																			1.000	0.594	0.793		0.500	0.637	0.714		0.503	0.554	0.613	0.527	0.474	0.678	0.506	0.634	0.646	0.710	0.760
78(A)																				1.000	0.674		0.684	0.307		0.725	0.391	0.423	0.756	0.484		0.516	0.034	0.367	0.620	0.569	0.293
79																					1.000	0.438	0.721	0.470			0.767	0.724	0.565	0.534	0.730	0.687	0.589	0.772	0.913		
80																						1.000	0.655	0.562	0.681	0.657	0.303	0.492		0.302		0.640	0.168	0.378	0.550	0.626	-0.167
81B																							1.000	0.692	0.732	0.587		0.720	0.556	0.414	0.781	0.542	0.301	0.509			0.578
81C																							1.000	0.558	0.512	0.606	0.768	0.692	0.291	0.614	0.369	0.576	0.562	0.655	0.761	0.557
82																								1.000		0.629	0.670	0.534	0.597	0.702	0.725	0.411	0.619			0.702
84 (A) (B)																									1.000	0.569	0.517	0.554	0.550	0.565	0.587	0.423	0.467	0.729	0.792	0.737
85																										1.000		0.492	0.554	0.530	0.585	0.662	0.535		0.797	0.585
86																											1.000	0.487	0.578	0.441	0.659	0.576	0.617		0.762	0.396
87																												1.000	0.241		0.419	0.417	0.502	0.581	0.544	0.491
88																													1.000	0.218	0.703	0.188	0.480	0.431	0.409	0.019
89/89 (A)																														1.000	0.417	0.282	0.496	0.619	0.640	0.579
90																															1.000	0.470		0.621	0.597	0.575
91(A)																																1.000	0.653	0.544	0.558	0.732
92																																	1.000	0.572	0.522	0.721
95																																		1.000	0.912	0.725
97																																			1.000	0.799
98A																																				1.000

Table 5.15: Correlations for S in western hemlock needles among sampling sites for the period 2000-2009. Yellow identifies sites with a correlation greater than 0.7, blue for sites greater than 0.8, and green for sites with greater than 0.9. Sites listed as 42A and 56A are the same as sites 42 and 56.

SITE	1	20	37	39	42(A)	43A	43B	44	44A	46	47B	52(A)	54	55	(56 A)	57	68	69	70	78(A)	79	80	81B	81C	82	84 (A) (	85	86	87	88	89/89 (A	90	91(A)	92	95	97	98A
1	1.000	0.189	0.945	0.982	1.000	0.500	0.996	0.945	0.945	1.000	0.982	0.990	0.996	0.189	0.756	0.327	0.577	0.500		1.000	-0.189	0.676	0.756	0.929	0.929			-0.189	0.999	0.500		0.756	0.963	0.756	0.619	
20		1.000	0.305	0.515	0.277	0.000	-0.458	-0.101	0.420	0.349	0.767	0.212	0.020	0.091	1.000	-0.500	0.088	-0.025	0.198	0.463	0.104	-1.000	-0.221	-0.500	-0.081	-0.035	0.129	0.019	0.315	0.450	0.139	0.135	-0.090	0.146	-0.090	-0.359	-0.256
37			1.000	0.451	0.398	0.739	0.178	0.497	-0.223	0.175	0.292	0.317	0.125	0.171	0.500	0.500	0.105	0.418	-0.064	0.358	0.221	-0.500	0.260	0.500	0.214	-0.082	0.505	0.303	0.326	0.423	0.293	0.409	0.488	0.376	0.255	0.160	0.170
39				1.000	0.602	-0.106	0.231	0.060	0.308	0.678	0.605	0.791	0.530	0.750	0.000		0.423	0.602	0.605	0.504	0.651	0.000	-0.010		0.493	0.567	0.531	0.502	0.402	0.610	0.158	0.699	0.706	0.706	0.352	0.181	0.495
42(A)					1.000	0.167	0.474	-0.161	-0.140	0.576	0.190	0.407	-0.145	0.188	0.189	0.756	0.050	0.182	-0.082	0.511	0.396	-0.189	0.109	0.756	0.208	0.010	0.511	0.532	0.256	0.149	0.240	0.226	0.500	0.206	0.345	0.059	-0.022
43A						1.000	0.577	0.786	0.348	1.000	-0.276	0.297	0.408	-0.129	0.945	-0.189	-0.577	-0.414	-0.629	-1.000		-0.945	0.101	-0.189	0.187	0.000	0.087	0.000	-0.782	0.303	-0.375	-0.117	-0.289	0.079	0.000	-0.099	
43B							1.000	0.159	-0.407	0.262	-0.494	0.292	0.235	0.127	0.277	0.693	-0.109	0.163	-0.200	-0.350	0.468	-0.277	0.049	0.693	0.528	0.179	0.275	0.333	-0.254	-0.158	0.084	0.259	0.608	0.340	0.339	0.268	0.522
44								1.000	-0.370	-0.129	-0.131	0.260	0.256	0.324	0.500	0.500	0.185	0.405	0.121	0.244	0.460	-0.500	0.556	0.500	0.280	0.312	0.415	0.112	0.506	-0.093	0.657	0.118	0.418	0.517	0.413	0.489	
44A									1.000	0.631	0.709	0.274	0.510	0.422	0.500	0.500	0.034	-0.163	0.332	0.332	0.111	-0.500	0.053	0.500	0.220	0.364	0.071	0.330	-0.156	0.927	-0.303	0.391	-0.278	0.261	-0.007	-0.050	-0.676
46										1.000	0.310	0.687	0.420	0.520	1.000		-0.296	0.000	-0.089	0.596	0.690	-1.000	-0.070		0.537	0.383	0.533	0.520	-0.198	0.627	-0.150	0.290	0.190	0.582	0.334	-0.258	-0.282
47B											1.000	0.153	0.131	0.373	0.000		0.272	0.057	0.444	0.750	0.220	0.000	0.087		0.211	0.080	0.310	0.413	0.408	0.787	0.165	0.576	0.044	0.444	0.122	-0.085	-0.341
52(A)												1.000	0.758	0.773	0.327	0.655	0.307	0.710	0.502	0.056	0.625	-0.327	-0.040	0.655	0.401	0.794	0.391	0.213	0.165	0.397	-0.002	0.406	0.666	0.584	0.269	0.259	0.599
54													1.000	0.727	0.277	0.693	0.297	0.583	0.561	-0.476	0.527	-0.277	-0.051	0.693	0.571		0.197	0.110	-0.176	0.543	-0.243	0.552	0.426	0.625	0.181	0.293	0.717
55														1.000	-0.277	0.971	0.686	0.768		0.305		0.277	0.384	0.971	0.702	0.908	0.632	0.569	0.376	0.579	0.265	0.733	0.725		0.615	0.641	
(56 A)															1.000	-0.500	-0.866	-0.693	-0.756			-1.000	-0.596	-0.500	-0.189	-0.189	-0.359	-0.327	-1.000	0.240	-0.756	-0.305	-0.500	-0.082	-0.500	-0.655	
57																1.000		0.971	0.945		1.000	0.500	0.993	1.000	0.945	0.945	0.988	0.982	0.500	0.721	0.945	0.977	1.000	0.904	1.000	0.982	
68																	1.000	0.770		0.241			0.526		0.564	0.588	0.650	0.494	0.317	0.268	0.331	0.581	0.589	0.535	0.704	0.761	
69																		1.000	0.700	0.007	0.625	0.693	0.277	0.971	0.484	0.714	0.561	0.306	0.274	0.206	0.159	0.546		0.577	0.520	0.649	0.762
70																			1.000	0.185	0.712	0.756	0.183	0.945	0.475	0.781	0.365	0.317	0.388	0.416	0.165	0.618	0.535	0.645	0.405	0.480	0.794
78(A)																				1.000	0.308		0.527		0.076	-0.078	0.555	0.627		0.629	0.752	0.309	0.202	0.410	0.401	0.168	-0.172
79																					1.000		0.574	1.000		0.760		0.742	0.327	0.428	0.535	0.685	0.736			0.750	
80																						1.000	0.596	0.500	0.189	0.189	0.359	0.327	1.000	-0.240	0.756	0.305	0.500	0.082	0.500	0.655	
81B																							1.000	0.993	0.586	0.244		0.749	0.342	0.225	0.695	0.368	0.311	0.508			0.508
81C																								1.000	0.945	0.945	0.988	0.982	0.500	0.721	0.945	0.977	1.000	0.904	1.000	0.982	
82																									1.000	0.609	0.768	0.791	0.045	0.547	0.308		0.615			0.746	
84 (A) (B)																										1.000	0.414	0.290	0.158	0.372	0.115	0.480	0.598	0.703	0.477	0.570	
85																											1.000		0.409	0.444	0.635	0.654	0.675	0.733	0.943	0.798	0.570
86																												1.000	0.321	0.557	0.495	0.758	0.555	0.706		0.668	0.340
87																													1.000	0.009		0.194	0.441	0.472	0.339	0.231	0.348
88																														1.000	-0.071	0.785	0.138	0.605	0.293	0.172	-0.157
89/89 (A)																															1.000	0.151	0.387	0.505	0.654	0.501	0.503
90																																1.000	0.628		0.590	0.525	0.557
91(A)																																	1.000	0.713	0.637	0.626	0.790
92																																		1.000	0.706	0.626	
95																																			1.000	0.912	0.698
97																																				1.000	0.799
98A																																					1.000

5.3 Off-site Maximums

Table 5.16, Table 5.17 and Table 5.18 provide, for each emissions scenario, the maximum CALPUFF-modelled SO_2 concentrations (and where they occurred) in ppb 1-hour, 3-hour, 24-hour, annual, and growing season averages for all hours of the day and for daylight hours. Although provided, the daylight hours should only be used with the growing season statistics as the hours were not adjusted for short winter days. Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included in the SO_2 concentrations listed in the table. However, these background values are considered when evaluating the risk of impacts to vegetation.

Table 5.16: Maximum CALPUFF-modelled SO_2 concentrations in ppb, and where they occurred, in 1-hour, 3-hour, 24-hour, annual, and growing season averages for all hours of the day and for daylight hours, under the actual emission scenario.

Regional 500m Receptor Grid, Offsite & Fenceline receptors only, Discrete & Onsite receptors omitted.

		all hours, all seasons			all hours, growing season			daylight hours, all seasons			daylight hours, growing season		
Avg. Period	Year	CONC (ppb)	UTM X (km)	UTM Y (km)	CONC (ppb)	UTM X (km)	UTM Y (km)	CONC (ppb)	UTM X (km)	UTM Y (km)	CONC (ppb)	UTM X (km)	UTM Y (km)
1hr	2016	780.0	518.709	5984.689	759.8	518.262	5984.605	584.4	519.163	5983.139	399.8	518.531	5984.693
	2017	890.6	518.500	5985.000	890.6	518.500	5985.000	570.7	518.974	5983.510	413.8	516.000	5987.500
	2018	859.0	518.500	5985.000	859.0	518.500	5985.000	802.3	518.441	5984.695	265.2	518.000	5987.500
3hr	2016	465.3	518.979	5984.883	334.0	518.352	5984.696	380.4	518.978	5985.066	180.9	518.891	5983.842
	2017	373.6	519.000	5982.500	373.6	519.000	5982.500	294.8	518.978	5984.976	190.6	516.000	5987.500
	2018	584.0	518.500	5985.000	316.8	518.000	5985.500	657.3	518.500	5985.000	137.2	518.799	5984.688
24hr	2016	179.8	518.978	5984.976	68.5	518.441	5984.695	270.4	518.978	5984.976	56.5	518.709	5984.689
	2017	176.8	518.978	5985.066	65.2	519.000	5982.500	200.0	518.978	5985.066	47.9	518.620	5984.691
	2018	137.6	518.978	5984.976	67.6	518.000	5985.500	136.1	518.978	5984.976	44.3	518.620	5984.691
All hours	2016	14.5	519.161	5982.368	12.6	519.267	5987.193	11.1	519.161	5982.368	15.5	519.267	5987.193
	2017	14.9	519.149	5981.875	12.4	519.173	5987.193	11.1	519.161	5982.368	15.6	519.173	5987.193
	2018	15.5	519.149	5981.875	12.7	519.173	5987.193	11.7	519.158	5982.270	15.6	519.173	5987.193

Table 5.17. Maximum CALPUFF-modelled SO_2 concentrations in ppb, and where they occurred, in 1-hour, 3-hour, 24-hour, annual, and growing season averages for all hours of the day and for daylight hours, under the 35 tpd emission scenario.

Regional 500m Receptor Grid. Offsite & Fenceline receptors only, Discrete & Onsite receptors omitted

		all hours, all seasons			all hours, growing season			daylight hours, all seasons			daylight hours, growing season		
		aa			ag			da			dg		
Avg. Period	Year	CONC (ppb)	UTM X (km)	UTM Y (km)	CONC (ppb)	UTM X (km)	UTM Y (km)	CONC (ppb)	UTM X (km)	UTM Y (km)	CONC (ppb)	UTM X (km)	UTM Y (km)
1hr	2016	1083.1	518.709	5984.689	943.5	518.352	5984.696	708.6	518.973	5983.429	411.7	518.531	5984.693
	2017	869.7	518.500	5985.000	869.7	518.500	5985.000	632.8	519.000	5983.000	513.7	516.000	5987.500
	2018	995.4	518.500	5985.000	995.4	518.500	5985.000	587.0	518.974	5983.510	294.3	518.352	5984.696
3hr	2016	517.7	518.973	5983.429	414.2	518.352	5984.696	354.3	518.973	5983.429	197.7	518.891	5983.842
	2017	561.3	519.000	5983.000	427.8	519.000	5982.500	603.1	519.000	5983.000	239.1	516.000	5987.500
	2018	477.9	518.973	5983.429	477.9	518.973	5983.429	389.2	518.973	5983.429	182.5	519.163	5983.139
24hr	2016	104.7	518.973	5983.429	84.9	519.158	5982.949	108.2	518.978	5984.976	56.2	518.709	5984.689
	2017	119.9	519.000	5983.000	72.9	519.000	5982.500	127.9	519.000	5983.000	52.8	518.500	5983.500
	2018	112.6	518.978	5984.976	87.7	518.973	5983.429	114.8	518.978	5984.976	51.9	519.000	5987.500
All hours	2016	15.4	519.149	5981.875	13.2	519.267	5987.193	11.3	519.161	5982.368	16.9	519.267	5987.193
	2017	15.7	519.149	5981.875	13.0	519.173	5987.193	11.4	519.158	5982.270	17.0	519.173	5987.193
	2018	16.8	519.149	5981.875	13.4	519.173	5987.193	12.4	519.158	5982.270	17.2	519.173	5987.193

Table 5.18. Maximum CALPUFF-modelled SO2 concentrations in ppb, and where they occurred, in 1-hour, 3-hour, 24-hour, annual, and growing season averages for all hours of the day and for daylight hours, under the 42 tpd emission scenario.

Regional 500m Receptor Grid, Offsite & Fenceline receptors only, Discrete & Onsite receptors omitted

		all hours, all seasons			all hours, growing season			daylight hours, all seasons			daylight hours, growing season		
		aa			ag			da			dg		
Avg. Period	Year	CONC (ppb)	UTM X (km)	UTM Y (km)	CONC (ppb)	UTM X (km)	UTM Y (km)	CONC (ppb)	UTM X (km)	UTM Y (km)	CONC (ppb)	UTM X (km)	UTM Y (km)
1hr	2016	1297.8	518.709	5984.689	1122.1	518.441	5984.695	838.0	518.973	5983.429	494.6	518.500	5983.500
	2017	1028.6	518.500	5985.000	1028.6	518.500	5985.000	749.0	519.000	5983.000	610.7	516.000	5987.500
	2018	1177.0	518.500	5985.000	1177.0	518.500	5985.000	732.5	518.974	5983.510	350.8	518.000	5988.000
3hr	2016	616.9	518.973	5983.429	489.8	518.352	5984.696	419.0	518.973	5983.429	234.0	518.891	5983.842
	2017	664.4	519.000	5983.000	514.3	519.000	5982.500	713.8	519.000	5983.000	284.1	516.000	5987.500
	2018	595.1	518.973	5983.429	595.1	518.973	5983.429	488.1	518.973	5983.429	228.0	519.163	5983.139
24hr	2016	124.6	518.973	5983.429	105.8	519.158	5982.949	129.5	518.978	5984.976	66.5	518.709	5984.689
	2017	142.2	519.000	5983.000	87.6	519.000	5982.500	151.7	519.000	5983.000	63.1	518.500	5983.500
	2018	134.8	518.978	5984.976	108.4	518.973	5983.429	137.4	518.978	5984.976	62.3	519.000	5987.500
All hours	2016	18.6	519.158	5982.270	15.8	519.267	5987.193	13.7	519.161	5982.368	20.4	519.267	5987.193
	2017	19.0	519.149	5981.875	15.6	519.173	5987.193	13.8	519.158	5982.270	20.5	519.173	5987.193
	2018	20.3	519.149	5981.875	16.1	519.173	5987.193	15.0	519.158	5982.270	20.7	519.173	5987.193

5.4 Field Sampling and Inspection Protocols

This report has been inserted in its original format on the subsequent pages, and as such does not have the correct figure and table numbering format that the rest of the appendices have.

Field Manual for Vegetation Sampling and Inspection in the Vicinity of Rio Tinto—BC Works, Kitimat, BC[5]

Introduction

Background

The vegetation sampling and inspection program is composed of two components: annual sampling of vegetation, and a biennial inspection of vegetation. The purpose of the vegetation sampling and inspection program is to 1) document the accumulation of fluoride (F^-, hereafter F) and sulphur (S) in needles of western hemlock as a method of estimating dispersion and potential effects of hydrogen fluoride gas (HF) and sulphur dioxide (SO_2) on the health of vegetation; and 2) assess the health of vegetation as affected by emissions from the smelter as well as other stressors through a biennial inspection by a qualified professional (QP).

Formal sampling and inspection of vegetation to assess the concentration of F in foliage and the effects of F on vegetation near the aluminium smelter in Kitimat, BC began around 1970. Vegetation sampling occurred before that time, but the protocols are not documented. F is measured in the needles of western hemlock (*Tsuga heterophylla*) in part to serve as a biomonitor of F, but also as a method of estimating the dispersion of the plume from the Alcan smelter, now the Rio Tinto BC Works (RTBCW). Analysis of foliage for S began in 1997. Over the years, sampling has been carried out by company personnel as well as consultants, but the recent sampling program has been implemented by contracted consultants, currently Stantec Consulting Ltd.

Western hemlock was chosen as a bioaccumulator because it is ubiquitous in the Kitimat Valley, and it is not particularly sensitive to either pollutant. Since it is not sensitive, it was rarely injured, even when emissions were substantially greater than today, thus it continued to accumulate both F and S over the course of the growing season. As emissions of F were reduced over the years, visible injury no longer occurs. Visible injury of western hemlock due to SO_2 has never been documented in the area.

A biennial inspection of vegetation to assess the effects of pollutants as well as other stressors such as insects, pathogens, and environmental conditions, is conducted by RTBCW's QP.

[5] This manual was compiled by John Laurence, RT Vegetation QP, and Nicole Glover and Meghan O'Neill of Stantec Consulting, Ltd.

The vegetation sampling and inspection program has been reviewed and revised periodically[6,7]. The current methods for the program are documented here.

Vegetation Sampling

Safety

Safety is a critical component of the vegetation sampling program. Sampling takes place under a variety of outdoor conditions, utilizes sharp tools, requires travel on foot over uneven and slippery terrain, may involve wildlife encounters, and requires both truck and aircraft operations. The vegetation sampling contractor operates an independent safety program but is also required to assess and mitigate risk using the RTBCW health and safety program. Requirements are listed under Field Preparation.

Field Preparation

Field preparation for the vegetation sampling program includes submitting necessary safety paperwork to RTBCW, completing contractor inductions, finalizing the field schedule (including having RTBCW book the helicopter), gathering field supplies, and liaising with RTBCW and their QP during preparations and planning. Prior to field work with RTBCW, a Contractor Safe Work Plan must be submitted to RTBCW. RTBCW will schedule a kick-off meeting the morning of the first day of field work to review the field program and safety requirements, and to issue a work permit for the field program.

Site List

The current array of sample sites was chosen to provide a range of locations across the Kitimat Valley, both near and far from RTBCW. Some sites have been in use since 1970, while others have been added to address specific concerns (e.g. reference sites outside the dispersion of the plume, helicopter accessible sites on the valley hillslope, etc.). In each case, one or more western hemlock trees are chosen for sampling. Because of the nature of sampling, new trees are periodically sampled when appropriate branches on sample trees are no longer accessible. A procedure for replacing sample trees and sites is detailed below.

The Site List and Location Descriptions are found in Appendix A. The site list includes the UTM coordinates for each site, as well as a brief site access description.

RTBCW's QP conducts a visual inspection of vegetation every second year. The QP accompanies the vegetation sampling field crew in their fleet vehicle for field site visits. The field work schedule must be coordinated with the QP well before the proposed sampling date.

Field Supplies

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[6] Laurence, J. A. 2010. A Review of the Vegetation Monitoring and Assessment Program in the Vicinity of the Rio Tinto Alcan British Columbia Operations at Kitimat, British Columbia. Submitted to Rio Tinto Alcan British Columbia Operations, May 16, 2010. 92 p. and appendices 49 p.

[7] ESSA Technologies, J. Laurence, Risk Sciences International, Trent University, and Trinity Consultants. 2019. 2019 Comprehensive Review of Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project – Volume 2: Draft Report. Prepared October 31, 2019 for Rio Tinto, B.C. Works, Kitimat, B.C.

Tools required for the field Program include the following:

- Pole Pruners
- Hand Pruning Shears
- Loppers
- Clean Tarp (to be purchased annually)
- 50 Large Sample (lawn waste) Bags
- Heavy Duty Stapler and Staples
- Orange and Red Flagging Tape
- Aluminum Scratch Tags
- Nails and Hammer
- Colored Stickers (5 colors, used to mark bags by date when put into storage)

Pole pruners, hand pruners and loppers should be inspected for damage, debris, and blade sharpness before use. The blades of these tools are to be cleaned and sharpened if required. A new tarp must be purchased for each field season to ensure that it is free from dust, dirt, or other contaminants. Mark the side of the tarp to be in as the ground contact side to keep the sample contact surface of the tarp clean.

Vegetation Sampling Field Work

Safety

The approved safety protocols, including check-in/check-out, tailgate safety sessions, periodic assessments during the day, and an end-of-the-day safety debrief must be followed in the field.

Maintenance

At each vegetation sample site, determine the presence and condition of flagging and tree tags. If missing or damaged, replace flagging and aluminum scratch tree ID tags. Hang orange and red colored flagging from a visible height on the tree. ID tags and flagging should be labelled with the site number. Write the ID of the new location on the tree tag with ballpoint pen and nail it to trunk of the sample tree(s). If a site needs to be moved, remove and dispose of flagging and tree ID tags from the old location.

Sampling Procedures

Generally, one field member will collect the sample while the other takes photographs and fills out the field form. The camera must have the time and date stamp feature turned on with the correct time, and date settings. Photographs are all to be taken in landscape format.

Place the tarp on the ground close to the tree so that it collects the sample clippings as they fall. Make every effort to keep the sample clippings from contacting the ground.

Collect sample material using pruners, shears, or loppers, dropping sample material on the tarp. Good samples tend to be collected using the pole pruners from higher up in the tree on specifically exposed aspects. Select boughs with long leader lengths and vigorous growth. Trim the ends of boughs, not entire branches from the tree so that the tree can be sampled for multiple years. When samples of poor or moderate growth, collect additional material so that

the sample will yield a minimum of 20 g dry weight of processed needles. Figure 1 shows an example of an ideal sample and Figure 2 shows an example of a poor sample.

Once an adequate sample has been collected, transfer the material to a paper sample bag. Label the sample bag in large letters. After the sample is transferred to the sample bag, roll the top of the bag over and staple it shut.



Figure 1: Good quality field sample. Note the long leader lengths and that all clippings are from the ends of the tree boughs



Figure 2: Poor quality field sample. Note the short leader lengths, clippings are large and include the inner boughs and foliage. Note the previously clipped bough.

Photographs

Check that the camera time and date stamp are correct and turned on for all field photographs. The following photos should be taken at each site:

- **Sample Label:** A close photo of the sampling bag with sample site number, date, and crew written in large print
- **Tree Prior to Sampling:** A landscape photo which includes the sampling tree prior to removing and sample
- **Tree During Sampling:** A landscape photo of the sampling personnel clipping sample vegetation from the tree
- **North:** A landscape photo showing the north from the sample location
- **East:** A landscape photo showing the east from the sample location
- **South:** A landscape photo showing the south from the sample location
- **West:** A landscape photograph showing the west from the sample location
- **Sample Prior to Bagging:** A photo from above of the sample on the tarp. Flip a representative bough upside down on the top of the sample for this photo.
- **Sample Close Up:** A close up of a few boughs of the sample. Flip a representative bough upside down on the top of the sample for this photo and include the leader of that bough included in the photo.
- **Other Photos:** Photograph damage, evidence of insect infestation, symptoms of disease, discolored foliage, or other interesting findings.

Field Forms

The Field Form documents conditions of the site and the sample tree at the time of sampling and includes checklists and direction on data to be recorded. At the end of each day all completed field forms should be removed from the field clipboard, scanned and saved, and left at the office. The current Field Form can be found in Appendix B.

Record any defoliation, insects, foliar pests (e.g., woolly adelgid, looper larvae), dwarf mistletoe, porcupine scarring, rubs/scars, decay/fungi, root diseases, or abiotic signs such as drought. Record and photograph the location of pests/damage on the tree. If there are no signs of pests or disease, record the general health and condition of the trees and justify why you are assessing something as healthy or not healthy. Estimate the percent of the branch and tree that is affected. Note if neighboring trees display similar symptoms or signs of insect, disease, and other stresses.

When a Site is Lost or Needs to be Moved

When a sample tree is no longer adequate for sampling or is lost to unforeseen circumstances such as brushing and clearing, blowdown, or industry. The following three scenarios describe how to assign sample site numbers to a site when the coordinates change.

- When a new site is selected and is within 100 meters of the previous tree or coordinate (if the tree is lost), a new tree(s) should be selected, and the coordinates updated on the field form. The site number will not change in this scenario.
- When a new site is selected and is greater than 100 meters away from the previous tree or coordinate (if the tree is lost), but less than 300 meters away, a new tree(s) should be selected, and the coordinates updated on the field form. The site number will have a letter added to it. If the sample site number already has a letter, then you will select the next sequential letter. Check the sample site list to be certain that a site name is not duplicated.
- When a new site is located that is greater than 300 meters away, or a new site is added to the Program, a new sample site number is selected, and the coordinates recorded on the field form. The sample site number should be greater than 100 in order to avoid duplicating sample sites from historical data sets that have been dropped.

Select only healthy trees for sampling. The RTBCW QP should be consulted in new site selection if they are present at the site. All new sample trees should each be marked with orange and red flagging tape and have an aluminum scratch tag attached to the trunk. The following factors should be considered when selecting new sample tree(s) (Laurence, 2010):

- Two to five trees should be selected for each site and the crown height of these trees should be greater than 6 meters
- Sample trees should be located away from rock faces or other features that may affect wind dispersion patterns
- Sample trees should be in an open canopy area and exposed to ambient air flows
- Sample trees should have accessible foliage, and ideally have one aspect of the tree that is fully exposed to ambient air and light
- Avoid trees with damaged boughs, defoliation, insect infestations, damaged terminal leaders/apical stems

Sample Storage and Daily Post Field

Samples are to be transported to a refrigerated cooler for storage the same day that they are collected. If sample bags are dirty or wet, transfer the sample into a fresh bag for storage in the cooler. Mark the sample bags with a colored sticker (with a unique color assigned for each sample day) to assist in retrieving samples in the same order that they are stored in. Samples will be processed in the order that they are collected, first-in-first-out.

Back up photos and return and scan completed field forms to the office. Fill out the Chain of Custody form at the end of each day.

Lab Procedures

Preparation consists of clipping the current years' growth, drying the vegetation samples, grinding the samples, measuring and packaging sample units, and shipping to a lab for further analysis. Laboratory methods and quality control measures are consistent with the Standard

Operating Procedure for Processing of Vegetation Samples Prior to Analysis[8]. This standard procedure is intended to provide consistency and uniformity of drying and grinding preparations among samples.

Lab Set Up

The lab is to be set up in a secure room, free of wind, dust, and contamination. The room must be kept locked overnight. The work bench in this room should be equipped with scales, metal mixing bowls, Pyrex baking dishes, small hand clippers, tweezer, bags and labels.

A second area should be set up with a drying oven and wash station. The work bench in this area must be in a well-ventilated area and was equipped with the drying oven, Alconox powdered soap, paper towels and sponge, dust masks, beaker, grinder and sink with wash basin.

Prior to starting the sampling clipping, the drying oven, Pyrex baking dishes, metal mixing bowls, tweezers, hand clippers, and the work bench should be cleaned with a solution of Alconox and water. Equipment should be left to air dry or was dried in the drying oven.

Sample Clipping

Samples are to be collected from the storage cooler on the same day that they are to be prepared in the lab and processed in in the same order in which they are collected in the field. The sample clipping will follow the steps outlined below. Refer to Figure 5.1 which shows how to determine the current annual growth from previous year's growth.

Sample clipping must be done according to the following steps:

- Clean the work bench and wash hands before starting each new sample
- Complete the sample clipping fields for date and crew on the Chain of Custody
- Attach a piece of masking tape to the outside of each metal bowl and weigh. Mark the weight of the bowl on the masking tape and tare the scale.
- Remove the current year's growth from the stems (Figure 5.1) and place into the metal mixing bowl. Collect between 100 and 125 grams of needles for each sample so there is enough sample for a duplicate analysis. Samples with more woody stems (i.e., those with abundant growth and long leaders) will have a higher stem to needle ratio and will require closer to 125 grams.
- Weigh and record clipped sample weight on the Chain of Custody form. Transfer the clippings to a Pyrex baking dish and label the dish using masking tape and marker with the sample site number and weight.

During the clipping process, record on the Chain of Custody form any relevant observations of the sample condition such as wooly adelgid infestations, looper larvae, fungus etc.

[8] Ontario Ministry of Environment, Environmental Monitoring, and Reporting Branch. 2015. Standard Operating Procedure for Processing of Vegetation Samples Prior to Analysis.



Figure 5.1 Growth leaders, showing the annual growth to be clipped off in the lab (marked in red)

Sample Dehydrating

Dehydrate samples in the drying oven for 24 hours at 38ºC (100ºF) in the labeled Pyrex dishes. Drying time was recorded on the COC form. The needles should be crispy, and brownish green. If needles still have a waxy texture, are deep green, or do not easily come off the stem, they need more time in the oven.

Sample Cleaning and Grinding

To clean the samples, pour the sample into a clean Pyrex dish and use a clean pair of tweezers to remove stems or other debris, leaving only the dried foliage. When the sample is clean, weigh it and record the clean sample weight on the Chain of Custody.

To grind the sample:

- Pour the sample into the clean lid of the grinder.
- Continue grinding until all the sample is ground into a powder9.
- Place a clean 50 mL beaker on the scale and tare it. Slowly add small amounts of the sample to the beaker using a clean spoon until 10 g is reached. Transfer the sample into a small plastic sample bag.
- Label the 10 g sample bag as part of Sample Set A for shipment to the lab
- Repeat the above steps, adding the remainder of the sample into a beaker, then weighing and transferring the sample to a small plastic sample bag.

[9] This is a rough preparation. Starting in 2018, an additional processing step has been added by the RT lab – fine grinding of the sample to a maximum particle size of 0.1 to 0.15mm, using a Wiley mill.

- Label the bag of remaining sample as part of Sample Set B (for sample duplicates and sample retention).
- Complete the Chain of Custody form for both Sample Set A and Sample Set B.
- Clean the work bench, scale, grinder, grinder lid, spoon and beaker using the Alconox solution before moving to the next sample.
- Package duplicates of 3 samples to send with Sample Set A and sent to the lab for quality control purposes.

Sample Shipping and Retention

Sample set A is to be shipped to the lab. Prior to shipping, confirm with RTBCW that the RT lab in Québec ready to receive the samples.

Sample set B is to be provided to RTBCW for indefinite retention. These samples should be stored in a cool dark place, out of direct sunlight in an area where they cannot be tampered with or contaminated.

Reporting

The sampling contractor works with the QP and RTBCW Primary Project Contact to report the results of the sampling and analysis. The QP has the lead for integrating the results of the sampling, site and tree condition data collected by the sampling team, and the results of the inspection. In years when the inspection is not conducted, the QP works with the sampling team to help interpret the condition data that was recorded.

Vegetation Inspection

Safety

Safety is a critical component of the vegetation inspection program. The QP works with the Primary Project Contact from RTBCW to complete a separate HSE risk assessment since, although most of the hazards are the same as for the sampling team, some differ. The QP does not remain at the sampling site and so may encounter different field travel conditions, wildlife encounters, traffic hazards, overhead hazards, and so on.

In addition to the separate HSE risk assessment, the QP follows the contractor's safety plan since they travel together and work in the same general environment. Following the contractor's safety plan also allows common check-in/check-out procedures, tailgate sessions, mid-day assessments, etc.

Field Preparation

The QP must be prepared for variable, and sometimes very uncomfortable field conditions including heavy rain, cold, slippery, and boggy conditions. Field data sheets (shown in Appendix C) should be printed on water resistant paper. Camera equipment should be waterproof or protected from the elements.

The QP should be knowledgeable about the ecology and plant taxonomy of the area, as well as the signs and symptoms of plant pathogens, pollution injury and insect pests. In addition, it is helpful to review previous reports to understand the conditions observed during the last few

sampling and inspection visits. This is particularly important since the QP visits on a biennial frequency, thus it will likely have been 2 years since the last inspection.

The QP should communicate with both the RTBCW Program Project Manager and the contractor's field lead well in advance (at least 3 months) of the inspection. Adequate lead time allows development of a workable schedule by all involved.

Site Location

The inspection sites are the same as the sampling sites with a few additions. Historically, observations have been made in Kitamaat Village, at the Minette Bay overlook on the east side of the bay, at the RTBCW administration building, at Moore Creek Falls overlook, and in neighborhoods of Kitimat. Samples are not taken at those locations.

The purpose of the observations in Kitamaat Village and in Kitimat is to document conditions of both ornamental and native vegetation in the area. The focus of the observations is to identify any significant problems with vegetation (particularly insect infestation, disease, or drought) that may be confused or associated symptoms that might be caused by smelter operations.

Visual Assessment Field Work

General Site Conditions At each site an assessment of general conditions should be made. This assessment includes the general appearance of the site (e.g. green, healthy vegetation; droughty conditions; insect infestation; dusty; industrial activity such as logging, transmission line maintenance, construction, etc.). A general site photo is taken to support the description.

Survey of Signs and Symptoms A survey of vegetation in the area of the sample site is made. This survey notes the presence of symptoms or signs of pests, pathogens, and other stressors on any vegetation at the site. If the site is along a road, the survey usually covers 100-200 meters in either direction from the sample tree. The survey should extend as far into the surrounding terrain as is practicable and necessary to examine the variety of species at the site. Symptoms are noted on the field data sheet. If symptoms of F or S injury are present, the affected area of individual leaves and the percentage of the plant that is affected should be estimated for calculation of an injury index[10]. The intensity of other symptoms such as insect feeding, fungal leaf spots, etc. are qualitatively assessed—slight, moderate, or severe. The QP should define those categories. In the case of an insect outbreak or disease epidemic, the injury index can be calculated using incidence and severity to provide a more quantitative assessment.

While the inspection and survey should be thorough, it does not require documenting every species present at the site. Particular attention should be paid to species that are common to a large number of sites (e.g. western hemlock, western redcedar, Sitka spruce, elderberry, red-osier dogwood, balsam poplar, thimble berry, salmon berry, and others). Other species that are known to be sensitive to HF and SO_2 such as lodgepole pine, *Rubus sp.*, white pine, and *Salix sp.* should be noted if present.

Observations of Sample Tree and Samples The sampling team makes detailed observations of the sample tree and records that data on their field data form. It is important for the QP to

[10] Laurence, J. A. 2010. A Review of the Vegetation Monitoring and Assessment Program in the Vicinity of the Rio Tinto Alcan British Columbia Operations at Kitimat, British Columbia. Submitted to Rio Tinto Alcan British Columbia Operations, May 16, 2010. 92 p. and appendices 49 p.

observe the sample tree and note any signs or symptoms to confirm the sample team observations and provide a consistent assessment of the sample tree.

Presence/Absence of Species of Interest A list of species that have been reported to be sensitive to SO_2 can be found in Appendix D. This list was compiled from a source reference[11] by the BC Ministry of the Environment and, at their request, the QP notes the presence of the species at a site. While presence is noted, the lack of a notation does not mean the species wasn't present, just that it wasn't observed during the inspection.

Digital Images

Digital images are used to document the general conditions and any signs or symptoms of stressors such as insects, pathogens, air pollutants, physical injury, or other environmental stressors. Digital images should be geo-referenced, and date/time stamped to assure accurate site location information. Data sheets should be photographed in the field when the site inspection is completed. At the end of the day, all digital images should be backed up to an appropriate device for safe keeping.

A digital image archive is maintained along with the report of the inspection by RTBCW.

Reporting

The QP provides a stand-alone report of the vegetation inspection to the Primary Project Contact and the Senior Environmental Advisor. The QP also works with the sampling team to interpret the results of the sampling and inspection for the overall annual report of the vegetation sampling and inspection program. Examples of both reports are on file with RTBCW.

In addition to the reports of the vegetation sampling and inspection reports, the QP works with the Environmental Effects Monitoring (EEM) team to address the vegetation aspects of the EEM.

[11] The list is derived from "Sulfur Dioxide" by A. H. Legge, H-J Jager, and S. V. Krupa in Recognition of Air Pollution Injury to Vegetation: A Pictorial Atlas, Second Addition, edited by R. B. Flagler and published by the Air and Waste Management Association in 1998. The reference does quantify the response of plants reported to be sensitive nor the exposure concentration and duration that caused the observed response.

Appendices

Appendix A - Sample Site Locations and Example Field Sampling Schedule

Site #	zone	Easting (mE)	Northing (mN)	Elevation (m)	Access Description
Close to Smelter Site					
44	9U	519031	5985223	66	Gravel access road south of Anderson Creek (gated), walk or drive up steep road to water tower; site is on the south-east side of the water tower overlooking steep drop.
1	9U	519811	5982791	6	Smelter site road to Hospital Beach. Across from Hospital Beach entrance.
20A	9U	519718	5983429	20	Smeltersite road to ~250m south of RTA contractor gate. Moved site in 2017 as previous site was lost due to brushing. Site is located on east side of road.
37	9U	518423	5986410	31	Up Anderson Creek intake road (south of Anderson Creek), turn left; site is on north margin of large clearing (old rifle range).
39	9U	519822	5987826	15	Turn onto Eurocan road, take an immediate left before the rail tracks; ~500 m south on the east side of the access road which parallels the rail tracks to the west and the Smelter Site Road to the east.
42	9U	519033	5985220	34	West side of Smelter site road, ~200m north of KMP gate.
43A	9U	518422	5986420	140	Turn west off Smelter Site road ~500m north of the KMP camp; turn left on steep, overgrown access road across from the Minette substation; ~800m up access road
43B	9U	518621	5986006	118	Left up overgrown access road across from Minette substation, drive for ~1km, turn right on access road just before powerline
46	9U	518509	5986364	126	Left ~80 m up overgrown access road across from Minette substation, drive for ~800m up road, quad trail flagged on the left
47B	9U	520329	5990897	13	Through industrial park toward Wedeene FSR; before FSR entrance, turn right at PNG compound; left along small access road up on PNG ROW
Helicopter Access					
44A	9U	520330	5990896	192	Helicopter access to subalpine wetland; site on the north margin of the wetland.
78A	9U	520856	5994845	26	Helicopter access to a wetland located west of Claque Trail road. Site is on the edge of a smaller wetland (~80 m X 25 m) in second growth stand.
81B	9U	517867	5996764	344	Helicopter access; land in creek bed of Bowbye Creek downhill from Bowbye trail
81C	9U	517377	5995487	394	Helicopter access to wetland clearing near base of old ski hill; located west of Bowbye Lake and east of Minifie Creek bridge on Bowbye road

Site #	zone	Easting (mE)	Northing (mN)	Elevation (m)	Access Description
	Bish FSR				
87	9U	519591	5980745	42	3 km on Bish FSR, walk ~30m up an overgrown branch road (BR100)
88	9U	519312	5979512	45	4.5 km up Bish FSR; site is on west side of road behind old Skeena Sawmills sign
89	9U	517963	5976266	93	Bish Cove access road at km 7 turn left (KBR area H) to North Cove trail; walk south east on trail for ~300m
89A	9U	517954	5976290	84	Bish Cove access road at km 7 turn left (KBR area H) to North Cove trail; walk south east on trail for ~300m; Site 89A is ~30 up-trail (northwest) of Site 89
	Cable Car				
97	9U	526234	5996927	41	Right on North Hirsch FSR; ~100m down on the right
98A	9U	526151	5994156	39	Turn east off Highway 37 onto access road opposite Cablecar entrance; turn right just past PNG compound; ~50m on the left
	Minette Bay / Kitimaat Village				
68	9U	522993	5981428	10	Kitimat Village road to MK Bay marina; site is on the east side of the village road across from the MK Bay Marina and approximately 30 m north of "Welcome to Kitimaat Village" sign
69	9U	523008	5983628	46	Kitimaat Village road to transmission line crossing over road; ~50m north of access road on the east side of Kitimaat Village road
70	9U	525773	5986706	9	Kitimaat Village road to Minette Bay; ~50m north of Minette Creek bridge on east side of Kitimaat Village road
95	9U	523640	5980346	87	Through Kitimaat Village, uphill, left on Raven Road, right on small access road (before white house on the right); up to a small gravel pit on the left
	Wedeene FSR				
79	9U	519318	5992584	86	Take Wedeene FSR to Clauge Mountain road (turn off Wedeene at ~36km); ~1.5 km up Clauge Mountain road. Turn right just before trailhead and site is on margin of clearing
80	9U	520481	5995782	57	Wedeene FSR to km 33; pull off at Site 92; walk ~550m down a deactivated spur road (cross small creek at start)
82	9U	519788	5999711	164	Wedeene FSR to 28.5 km at crest of hill on curve; turn left (west) onto narrow branch road and drive up ~500m to fork; site is on spur forking north (right) on east side of the spur.

Site #	zone	Easting (mE)	Northing (mN)	Elevation (m)	Access Description
90	9U	520068	6006716	124	Wedeene FSR at ~20.5 km; site is located on west shoulder of road
91A	9U	519891	5998473	96	Wedeene FSR to Bowbyes Lake access road at ~31 km; go ~1.5 km up Bowbyes road; site is on left before big dip in the road
92	9U	520922	5995706	38	Wedeene FSR at ~32.8 km, turn west onto branch road; ~20m from entrance on right
	Williams Creek FSR				
490	9U	546187	6025665	466	Follow Williams Creek FSR approximately 14.5 km, keep right when you encounter a fork in the road, park approx. 25 m north (small pullout) before the bridge crossing, sample tree will be on the west side of the road.
492	9U	539294	6029344	329	Follow Williams Creek FSR approximately 7 km, keep left when you encounter a fork in the road. A pullout is located on the south side of the road approximately 50 m east of the sample site location. The sample trees are on the south side of the road.
	Kitimat				
52	9U	520979	5990124	18	Drive through Radley Park to boat launch; site is west side of the parking lot on the edge of a cleared area
54	9U	521347	5990154	27	Turn right into Rod and Gun Club (before the Kitimat River bridge); site is immediately on the right at entrance to parking lot
55	9U	522924	5989734	60	Park on Albatross Cres. at top of park; walk down paved footpath. Site is ~50m from pedestrian overpass up a dirt path.
56	9U	523871	5989511	102	Across the street from the firehall, walk ~50m downslope along the powerline
57	9U	524285	5989347	93	West side of Lookout Park in Kitimat; walk down the west side of the cleared area; site is at the south side (downslope) of clearing
	Beam Station Road				
84A	9U	516906	6033624	62	Whitebottom FSR to 3km; left on spur road; site is on northwest corner of quarry
85	9U	526774	6032743	189	North of powerlines, just east of Beam station road on northeast side of clearing
86	9U	527263	6025385	77	Take Beam Station road to Beam Station FSR; site is located at a pull-out right before the pavement ends

Appendix B - Vegetation Sampling Field Form developed by Stantec Consulting Ltd.

Page 2 - Rio Tinto, Kitimat BC Works **2018 Vegetation Inspection, Monitoring and Assessment Program**	Site No:

Tree Factors

Tree ID Tag Replaced? ❑ Yes ❑ No	Tree in exposed location? ❑ ❑
Height of Sample Tree(s): m	If not, distance to nearest tree (m):
Height to Base of Live Crown: m	

Damage:

Frost Crack	Broken Top	Scar	Root Disruption	Other
☐	☐	☐	☐	☐

Comments on condition of sample tree(s)

Pests/Pathogens:

Wooly Adelgid	Budworm	H. Looper	Mistletoe	Other
☐	☐	☐	☐	☐

Estimate percentage of individual branch and tree affected, as well as percentage of neighbouring trees affected

Signs and Symptoms:

Shedding Needles	Discolouration	Dying Branches	Top Dieback	Other
☐	☐	☐	☐	☐

Estimate percentage of individual branch and tree affected, as well as percentage of neighbouring trees affected

Sample

Longest terminal growth: cm	Growth Rating: *Circle rating and estimate average* *Poor = little terminal growth, all < 4cm* *Moderate = terminal growth > 4cm and < 10cm* *Good = terminal growth >= 10cm*
Colour of Current Year Growth *Green (normal)* *Off-colour (abnormal)*	Bare Twigs ☐ *Estimate percentage of sample that is bare twigs*
Deposits (sap, road dust, soot, etc):	

Comments on sample observations

Photos	
Sample Label	
Tree Prior to Sampling	
Tree During Sampling	
North	
East	
South	
West	
Sample Prior to Bagging	
Sample Close Up	

Did the sample come into contact with the ground? y
Was the sample dry when bagged? y
How many trees were sampled? _____
What is the sample height range? ____to____

Additional Notes: *Site moved and rationale, etc.*

Page 2 of 2

Appendix C - Field Data Sheets for Vegetation Inspection

Site #	Date	Site Photo					
Species	Symptom	% of Leaf Affected	% of Plant Affected	Cause	Comments	F rating	Photo (Y/N)

Presence or absence:

Species	P/A	Species	P/A
Amelanchier alnifolia		*Abies amabilis*	
Aralia nudicaulis		*Abies lasiocarpa*	
Cornus stolonifera		*Acer glabrum*	
Disporum hookeri		*Alnus crispa*	
Dryopteris expansa		*Alnus tenuifolia*	
Epilobium angustifolium		*Betula papyrifera*	
Lycopodium clavatum		*Crataegus douglasii*	
Menziesia ferruginea		*Pinus contorta*	
Pteridium aquilinum		*Populus tremuloides*	
Rosa acicularis		*Populus trichocarpa*	
Rubus parviflorus		*Prunus pennsylvanica*	
Rubus spectabilis		*Prunus virginiana*	
Senecio triangularis		*Sorbus scopulina*	
Symphoricarpos albus		*Sorbus sitchensis*	
Vaccinium alaskaense		*Tsuga heterophylla*	
Vaccinium membranaceum			
Vaccinium ovalifolium			
Vicia americana			

Lichen presence:

Species	Present or Absent	Host
L. oregana		
L. pulmonaria		

Appendix D - Presence of Species Reported to be Sensitive to SO_2

Presence of species reported to be sensitive to SO_2 in scientific or anecdotal literature at vegetation inspection and collection sites in 2018. Presence is indicated by an x. Absence does not mean that the species is not present in the area of the site, only that it was not observed during the inspection. NV=not visited

Species\Site	1	20A	37	39	42	43A	43B	44	44A	46	47B	52	54	55	56	57	68	69	70	78A	79	80	81B	81C	82	84A	85	86	87	88	89A	90	91A	92	95	97	98A	490	492
Shrubs and small stature plants																																							
Amelanchier alnifolia			X								X						X	X																					
Aralia nudicaulis																																							
Cornus stolonifera	X	X		X	X		X	X			X	X	X				X		X							X		X					X		X	X	X		X
Disporum hookeri																																							
Dryopteris expansa										X																					X								
Epilobium angustifolium	X	X	X	X	X			X			X	X	X				X	X	X							X		X			X	X	X	X	X	X	X	X	X
Lycopodium clavatum																																							
Menziesia ferruginea										X						X						X		X	X	X	X		X		X	X		X		X		X	
Pteridium aquilinum																		X		X	X	X				X					X		X	X		X			
Rosa acicularis																																							
Rubus parviflorus	X	X		X	X	X	X	X		X	X	X	X		X	X	X	X	X				X			X		X	X	X		X	X	X	X	X	X		X
Rubus spectabilis	X	X		X	X	X	X			X		X			X		X	X	X		X	X	X	X	X				X	X	X	X	X	X	X	X		X
Senecio triangularis																																							
Symphoricarpos albus																																							
Vaccinium alaskaense																X							X	X	X		X				X								
Vaccinium membranaceum																X							X	X			X												
Vaccinium ovalifolium																X							X	X			X				X								
Vicia americana																												X											

	Trees																																						
Species\Site	1	20A	37	39	42	43A	43B	44	44A	46	47B	52	54	55	56	57	68	69	70	78A	79	80	81B	81C	82	84A	85	86	87	88	89A	90	91A	92	95	97	98A	490	492
Abies amabilis																															X								X
Abies lasiocarpa																																							
Acer glabrum												X	X																									X	
Alnus crispa	X	X		X	X														X		X		X	X			X		X	X	X	X		X			X	X	X
Alnus tenuifolia																																							
Betula papyrifera															X			X																					
Crataegus douglasii																																							
Pinus contorta								X						X		X		X		X					X		X												X
Populus tremuloides															X		X	X									X	X											X
Populus trichocarpa	X	X	X	X			X	X			X	X	X						X		X		X					X		X		X			X			X	
Prunus pennsylvanica								X																															
Prunus virginiana								X																															
Sorbus scopulina																																							
Sorbus sitchensis	X	X	X	X	X	X	X	X		X	X			X	X	X		X			X			X		X					X			X	X		X		
Tsuga heterophylla	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

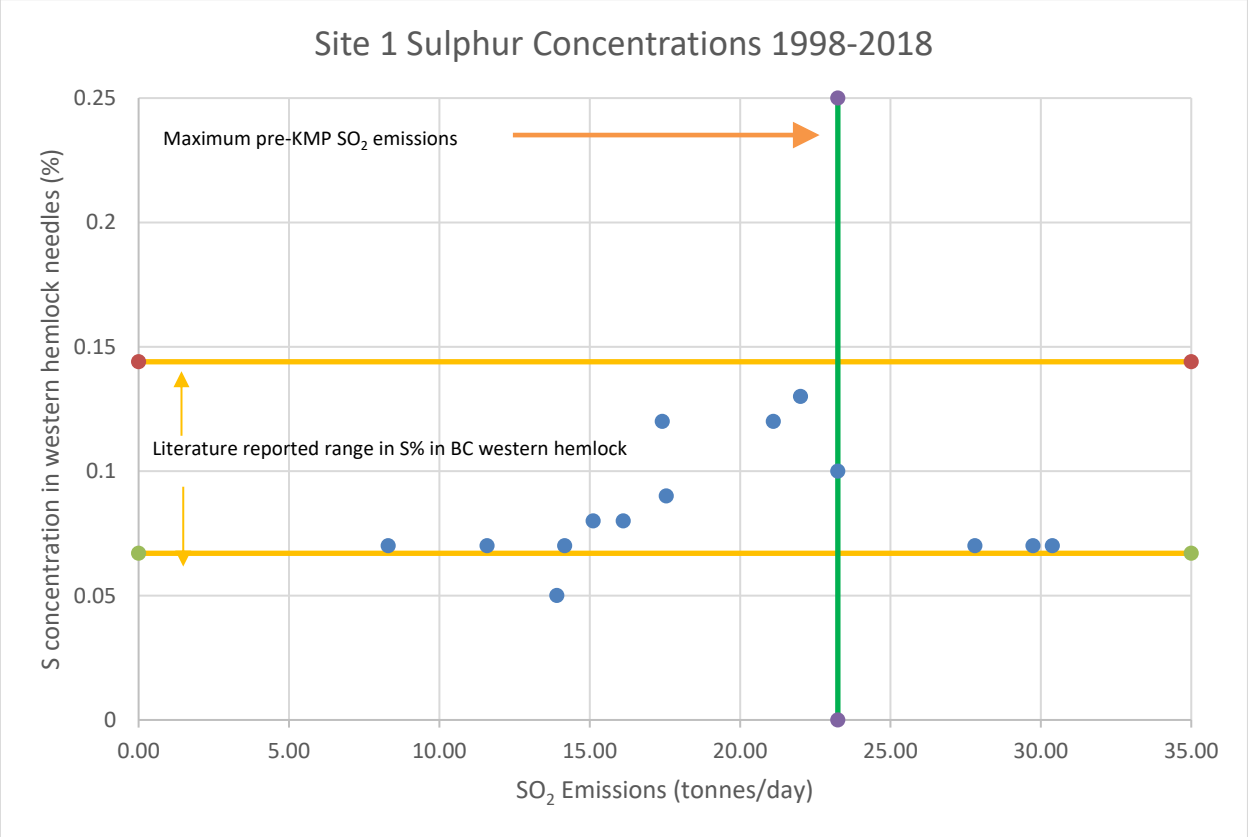
5.5 Sulfur in Western Hemlock Data, Site Graphs, and Box and Whisker Diagrams

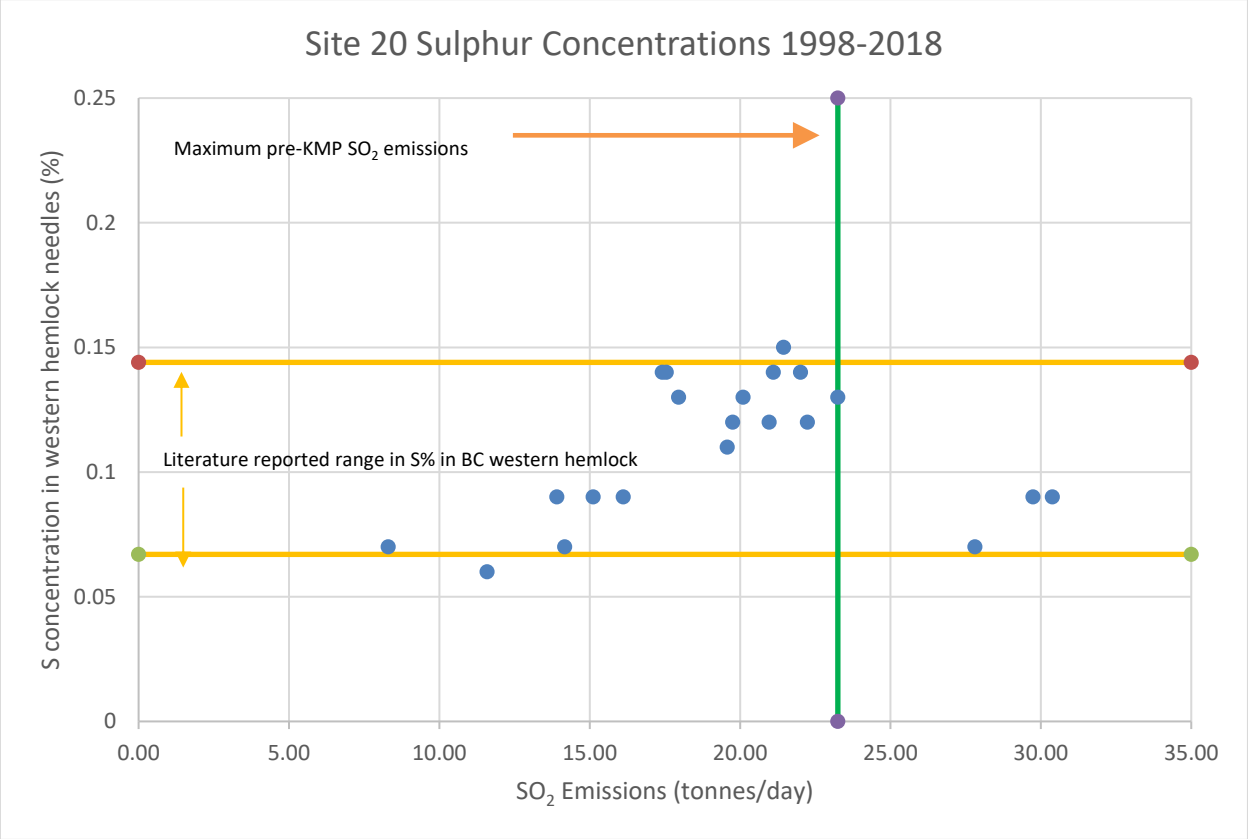
This appendix includes all %S in western hemlock needle data from 1998 to 2018, graphs of the %S in western hemlock needles versus smelter emissions of SO_2 for the 40 sampling sites, and Box and Whisker plots of %S data for each site for the pre-KMP baseline (1998-2011), all years (1998-2018), and post-KMP (2016-2018). The graphs of %S in western hemlock needles versus smelter emissions of SO_2 are not in chronological order—the order depends on the emissions. However, on every graph, the minimum emission level is from 2015 when the smelter operations were vastly curtailed. The maximum pre-KMP emissions of 23.25 tonnes per day of SO_2 occurred in 2000.

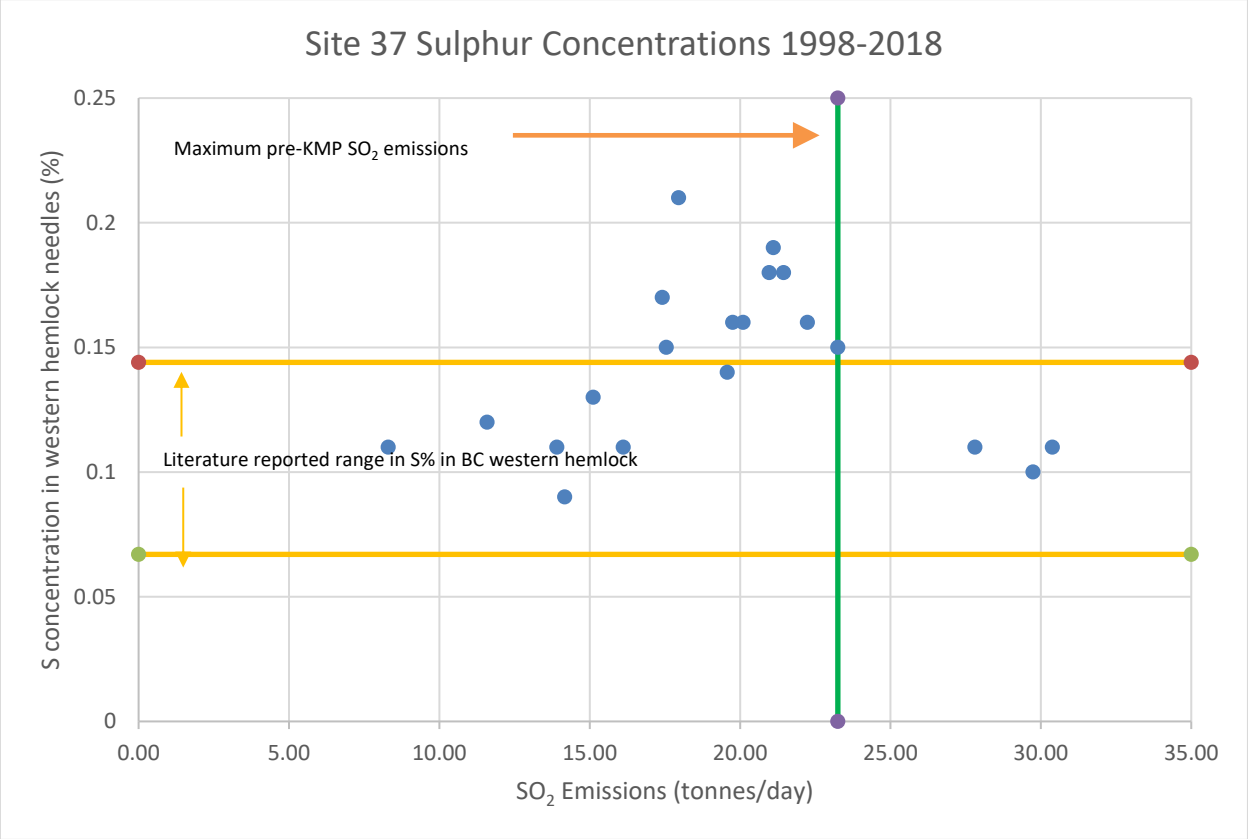
Table 5.19: Concentrations of sulfur in western hemlock in the Kitimat Valley from 1998 to 2018. No entry is a cell indicates a sample was not taken that year. Measurement in in %S.

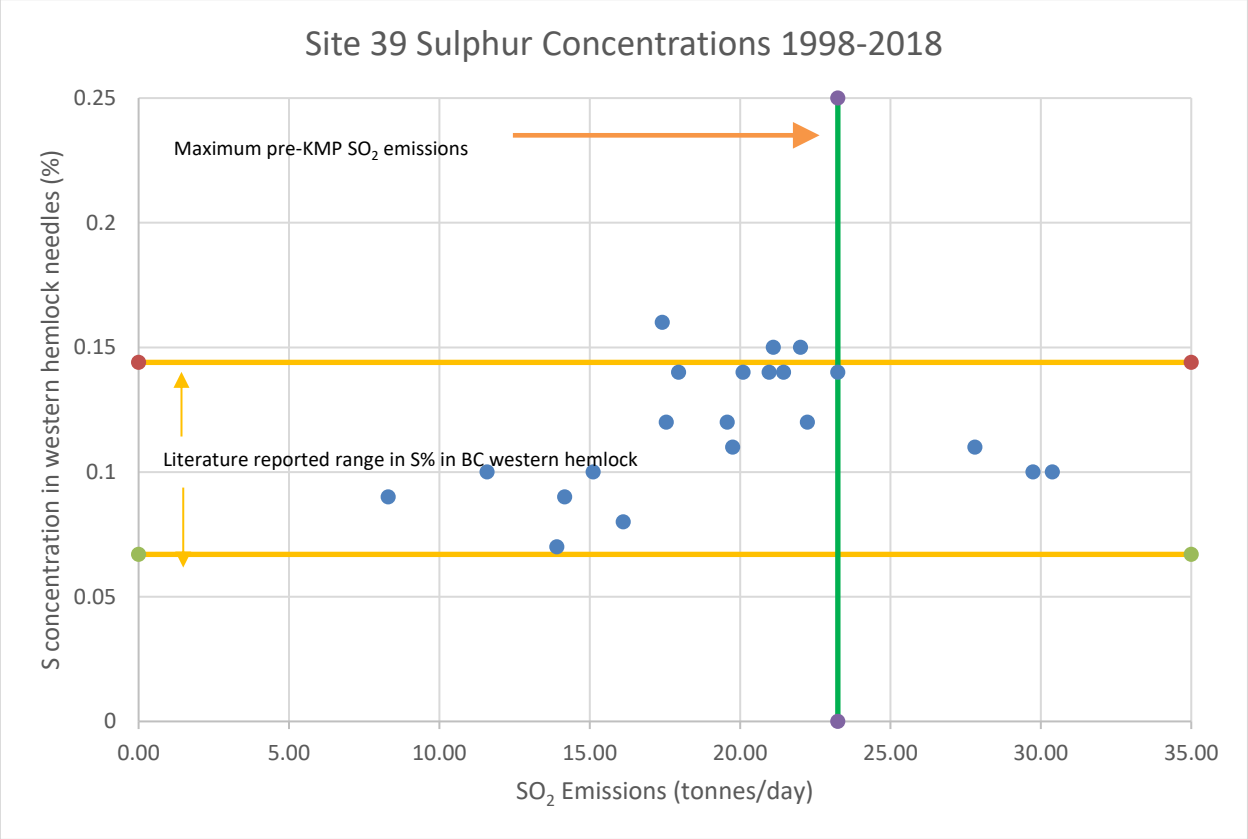
Plots/year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	0.13	0.12	0.1	0.12	0.09								0.08	0.07	0.08	0.05	0.07	0.07	0.07	0.07	0.07
20	0.14	0.14	0.13	0.14	0.14	0.12	0.15	0.12	0.12	0.11	0.13	0.13	0.09	0.07	0.09	0.09	0.06	0.07	0.07	0.09	0.09
37		0.19	0.15	0.17	0.15	0.16	0.18	0.18	0.16	0.14	0.16	0.21	0.13	0.09	0.11	0.11	0.12	0.11	0.11	0.1	0.11
39	0.15	0.15	0.14	0.16	0.12	0.11	0.14	0.14	0.12	0.12	0.14	0.14	0.1	0.09	0.08	0.07	0.1	0.09	0.11	0.1	0.1
42	0.17	0.15	0.17	0.19	0.16	0.16	0.17	0.2	0.18	0.13	0.2	0.17	0.12	0.09	0.12	0.1	0.09	0.12	0.1	0.08	0.1
43A	0.17	0.16	0.13	0.16	0.15	0.16							0.14	0.12	0.12	0.1	0.11	0.11	0.1	0.12	0.13
43B	0.17	0.18	0.15	0.18	0.14		0.14		0.18	0.17	0.2	0.18	0.1	0.07	0.1	0.1	0.14	0.07	0.09	0.1	0.12
44	0.15	0.18	0.13	0.15	0.13	0.16	0.21	0.18	0.16	0.2	0.17	0.2	0.11	0.08	0.09	0.13	0.11	0.09	0.13	0.12	0.12
44A	0.16	0.22	0.18	0.23	0.18	0.17	0.18				0.12	0.14	0.15	0.09	0.11	0.13	0.12	0.11	0.13	0.09	0.11
46	0.14	0.18	0.14	0.22			0.17	0.19	0.16	0.15	0.17	0.15	0.13	0.1	0.13	0.1	0.08	0.13	0.11	0.11	0.11
47B	0.12	0.16	0.14	0.15	0.13	0.11	0.15	0.12	0.13	0.11	0.11	0.13	0.1	0.08	0.09	0.08	0.09	0.09	0.1	0.1	0.11
52A	0.11	0.12	0.1	0.14	0.09	0.09	0.11	0.13	0.07	0.11	0.12	0.11	0.07	0.06	0.06	0.08	0.05	0.08	0.08	0.1	0.1
54	0.12	0.11	0.1	0.13	0.09	0.1	0.1	0.1	0.08	0.12	0.1	0.11	0.09	0.08	0.08	0.06	0.05	0.06	0.05	0.05	0.07
55	0.09	0.13	0.1	0.11	0.07	0.08	0.1	0.1	0.08	0.1	0.09	0.09	0.1	0.09	0.09	0.09	0.06	0.07	0.07	0.07	0.08
56	0.1	0.11	0.09	0.1	0.1								0.08	0.06	0.06	0.06	0.07	0.06	0.06	0.08	0.06
57	0.1	0.11	0.1	0.1	0.06								0.12	0.05	0.05	0.06	0.05	0.05	0.05	0.07	0.06
68	0.1	0.1	0.11	0.09	0.07	0.09	0.1	0.09	0.08	0.09	0.09	0.09	0.08	0.06	0.06	0.08	0.06	0.07	0.06	0.09	0.08
69	0.1	0.1	0.1	0.09	0.06	0.08	0.09	0.1	0.06	0.09	0.09	0.1	0.08	0.07	0.07	0.08	0.05	0.06	0.07	0.08	0.08
70	0.1	0.1	0.11	0.1	0.08	0.08	0.1	0.09	0.08	0.1	0.09	0.09	0.09	0.07	0.07	0.08	0.06	0.06	0.07	0.08	0.08

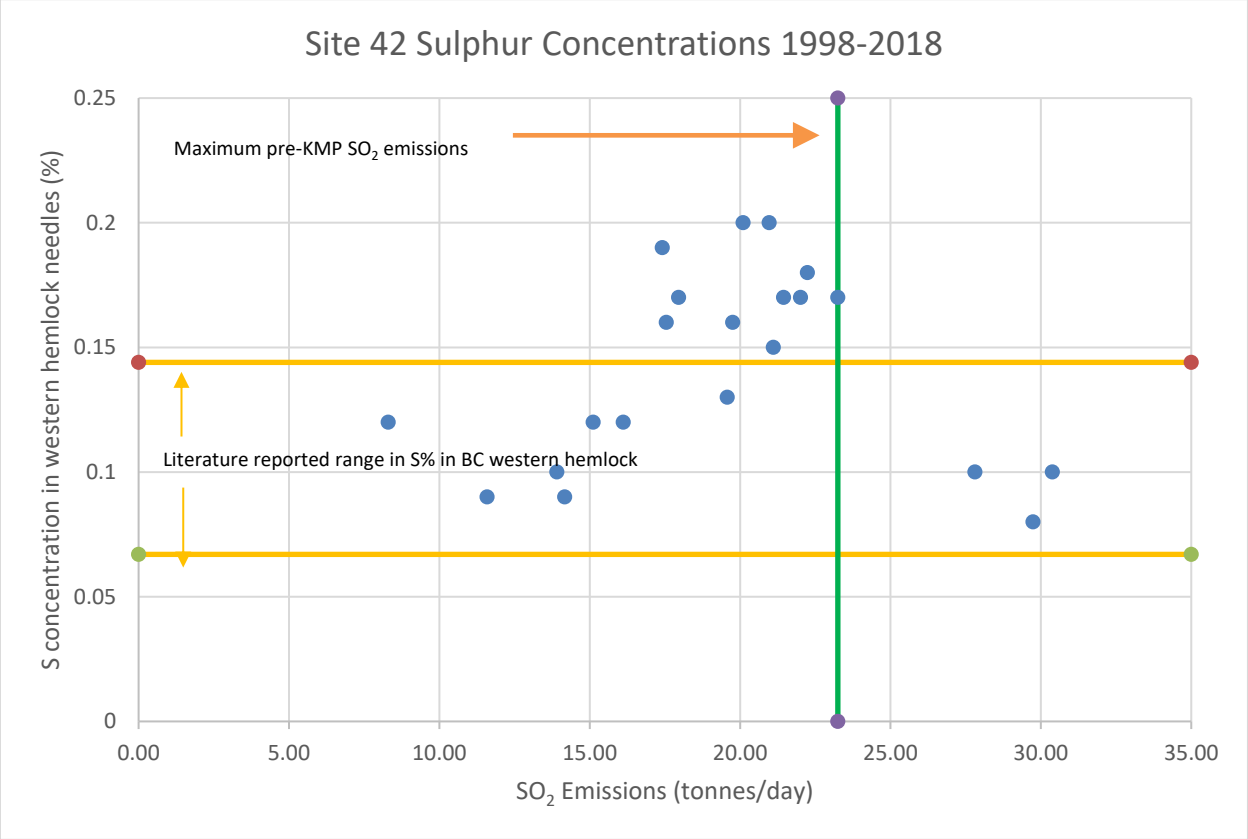
Plots/year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
78A	0.16				0.14	0.13	0.17	0.16	0.16	0.13	0.14	0.14	0.09	0.07	0.07	0.07	0.09	0.06	0.09	0.12	0.09
79	0.14			0.16	0.07	0.12	0.15	0.13	0.12	0.13	0.15	0.12	0.1	0.08	0.08	0.1	0.08	0.1	0.1	0.11	0.12
80	0.12	0.12	0.13	0.11	0.11								0.11	0.09	0.09	0.09	0.1	0.07	0.09	0.12	0.08
81B	0.17	0.15	0.14	0.13	0.06	0.17	0.19	0.16	0.17		0.12	0.13	0.12	0.09	0.09	0.09	0.07	0.06	0.08	0.1	0.1
81C	0.13	0.14	0.11	0.11	0.09								0.15	0.07	0.07	0.1	0.09	0.09	0.12	0.09	0.12
82	0.12	0.12	0.12	0.14	0.08	0.12	0.12	0.11	0.12	0.12	0.12	0.12	0.09	0.06	0.06	0.08	0.08	0.07	0.1	0.1	0.1
84AB	0.09	0.1	0.09	0.1	0.07	0.08	0.09	0.09	0.07	0.1	0.09	0.08	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07
85	0.09	0.1	0.08	0.09	0.03	0.08	0.1	0.09	0.08	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.05	0.05	0.06	0.06	0.07
86	0.09	0.11	0.09	0.1	0.05	0.08	0.09	0.09	0.1	0.07	0.08	0.08	0.09	0.06	0.06	0.08	0.06	0.08	0.07	0.07	0.07
87	0.14	0.16	0.15	0.12	0.12	0.07	0.21	0.17	0.16	0.14	0.15	0.15	0.12	0.08	0.08	0.1	0.09	0.12	0.12	0.14	0.11
88	0.14	0.14	0.14	0.19	0.12	0.13	0.15	0.13	0.13	0.12	0.1		0.13	0.12	0.12	0.12	0.12	0.09	0.09	0.11	0.1
89		0.13	0.14	0.13	0.11	0.13	0.21	0.16	0.18	0.15	0.17	0.15	0.12	0.09	0.09	0.09	0.11	0.1	0.1	0.11	0.12
89A													0.12	0.09	0.09	0.09	0.11	0.1	0.11	0.11	0.12
90		0.12	0.13	0.15	0.06	0.09	0.11	0.1	0.11	0.1	0.09	0.13	0.09	0.08	0.08	0.06	0.06	0.08	0.08	0.09	0.11
91A		0.11	0.11	0.11	0.06	0.08	0.1	0.12	0.09	0.1	0.12	0.12	0.11	0.09	0.09	0.11	0.08	0.14	0.1	0.1	0.09
92		0.1	0.1	0.13	0.06	0.08	0.12	0.1	0.1	0.11	0.1	0.11		0.07	0.07		0.11	0.09	0.09	0.09	0.08
95		0.12	0.09	0.09	0.04	0.09	0.1	0.09	0.09	0.08	0.09	0.08	0.07	0.05	0.05	0.07	0.07	0.07	0.08	0.06	0.08
97		0.11	0.1	0.09	0.05	0.1	0.1	0.1	0.09	0.1	0.09	0.09	0.09	0.06	0.06	0.07	0.06	0.09	0.07	0.08	0.08
98A					0.05		0.09	0.08	0.07	0.1	0.1	0.09	0.08	0.07	0.07	0.07	0.07	0.08	0.07	0.06	0.07
490																			0.07	0.06	0.07
492																			0.06	0.06	0.08

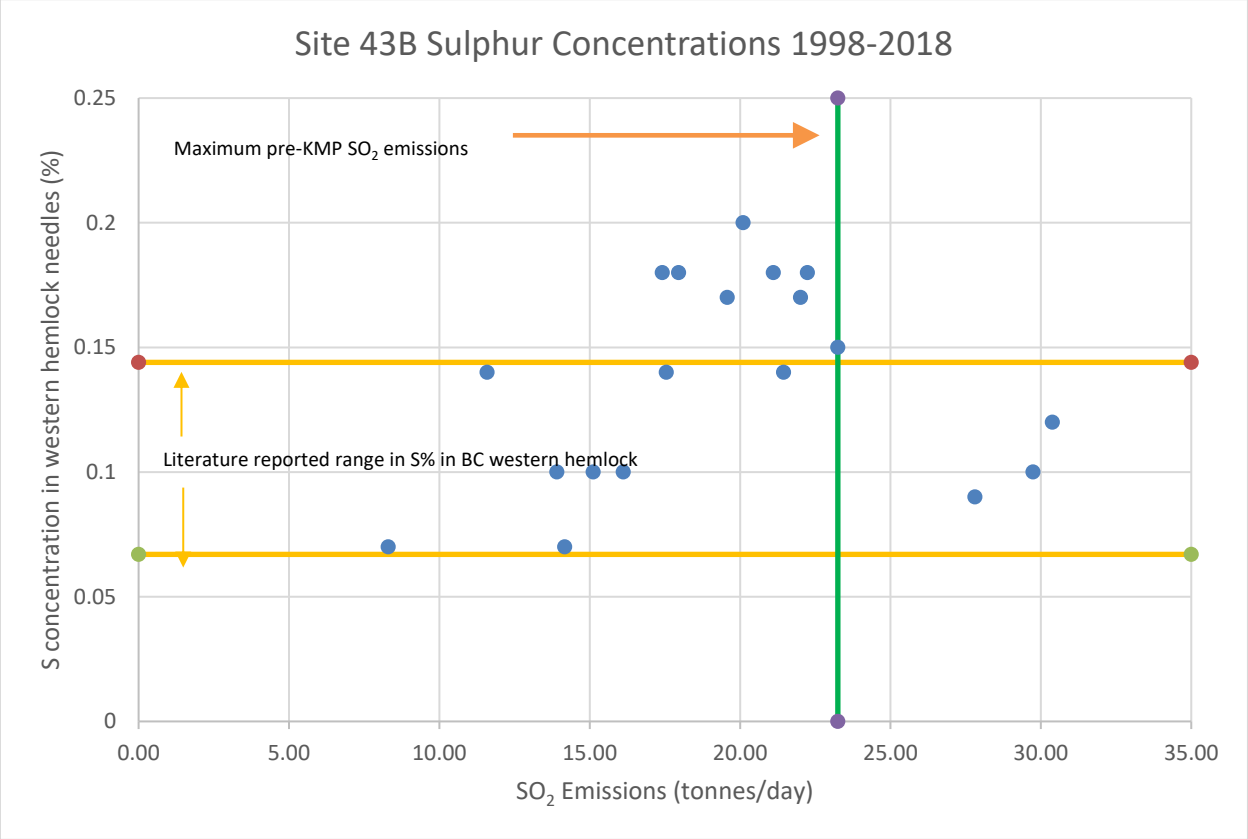

Site 1 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

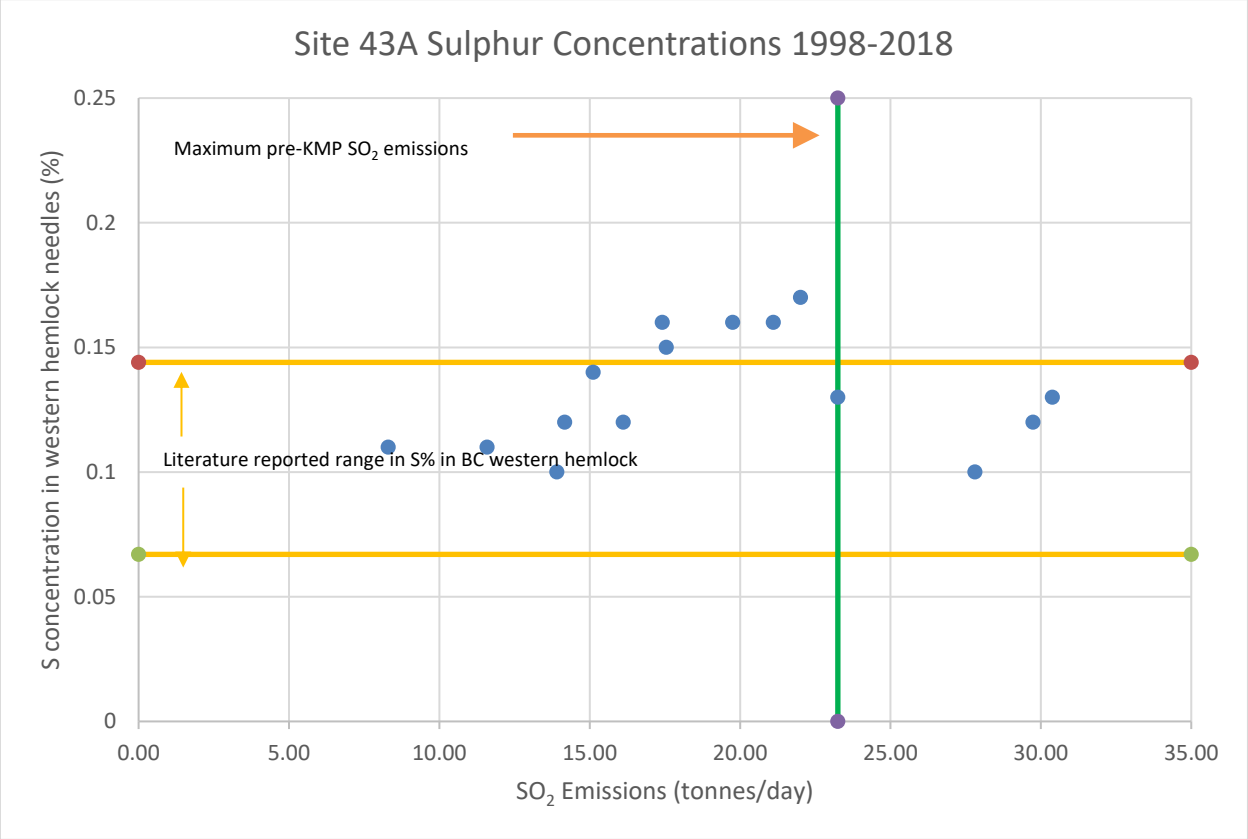

Site 20 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

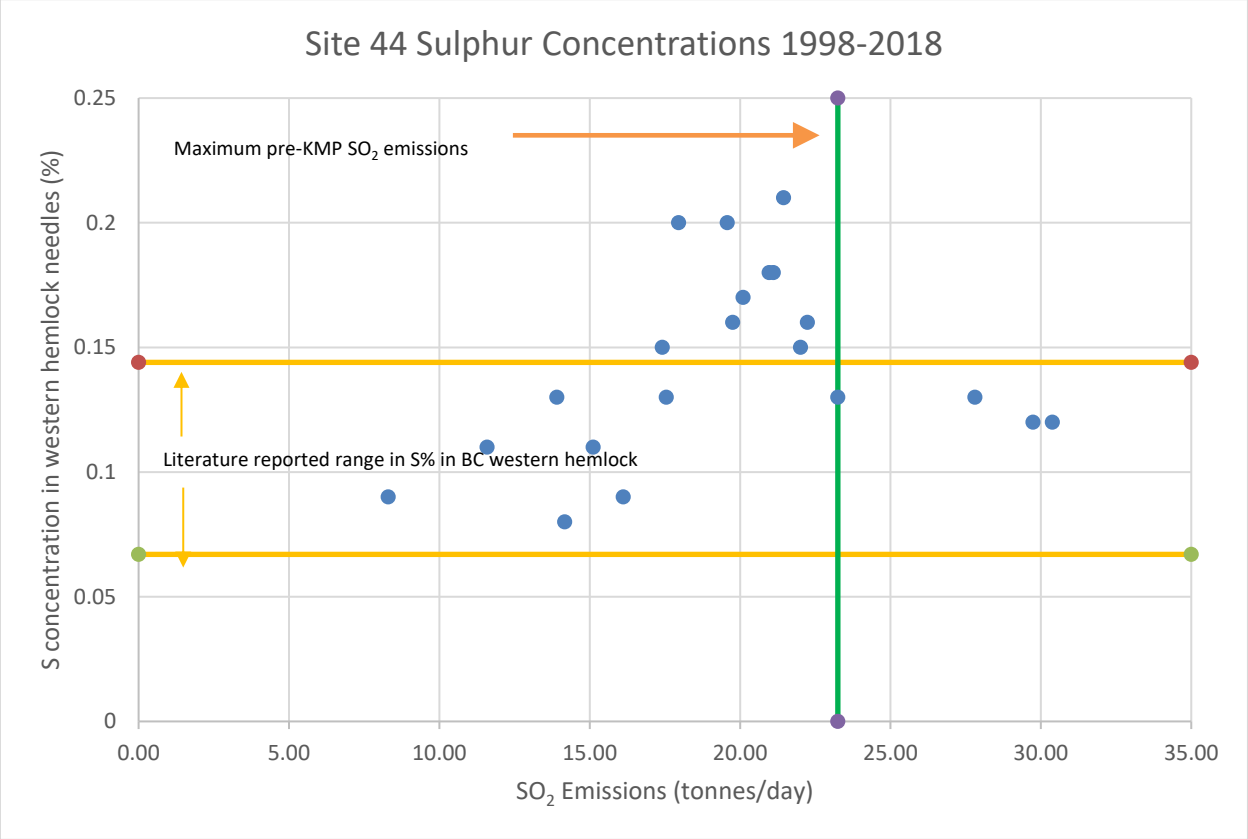

Site 37 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

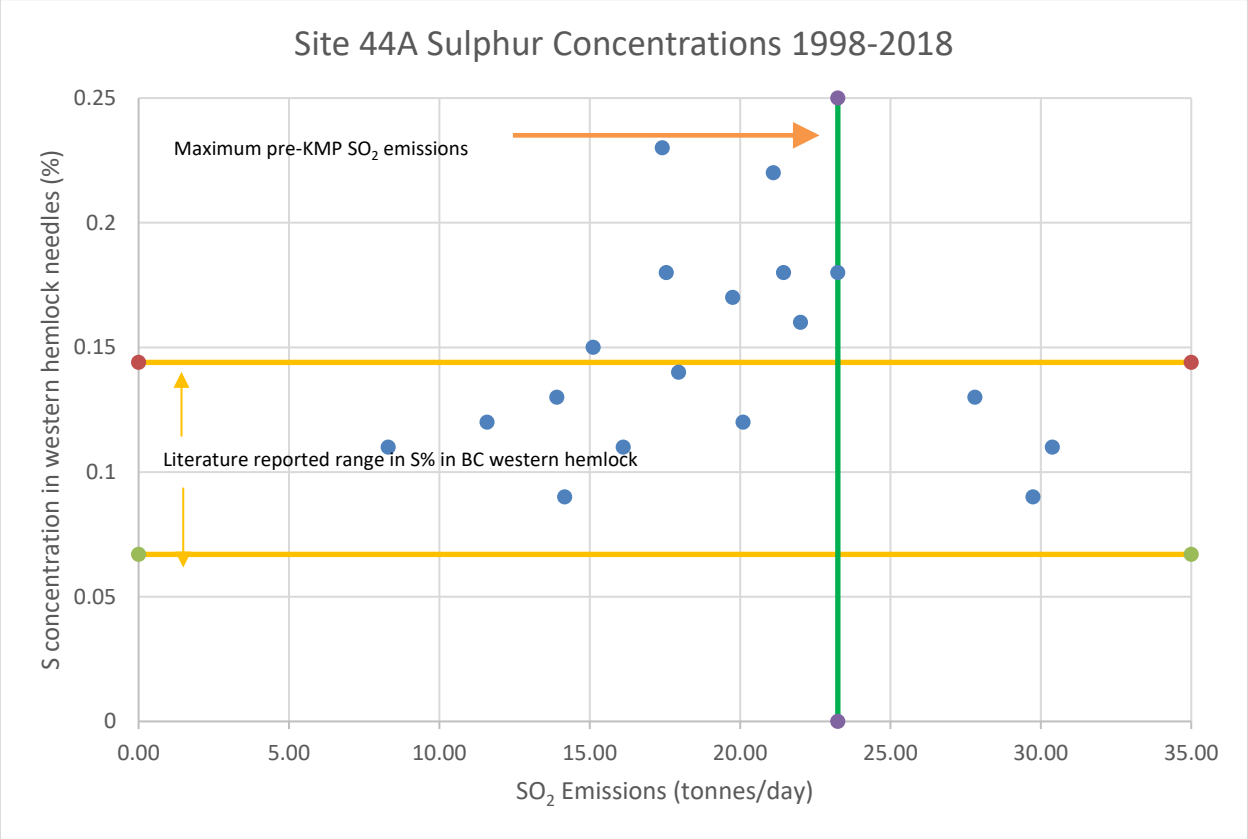

Site 39 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

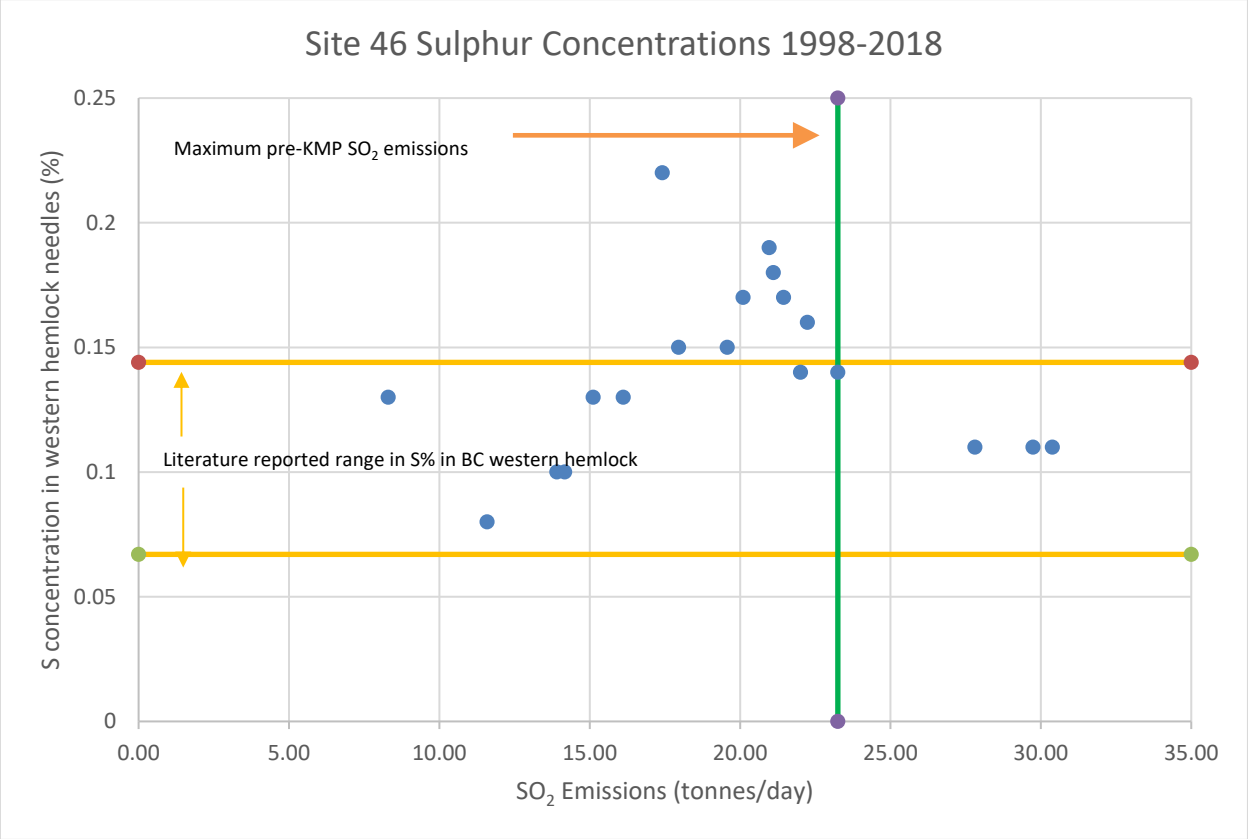

Site 42 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

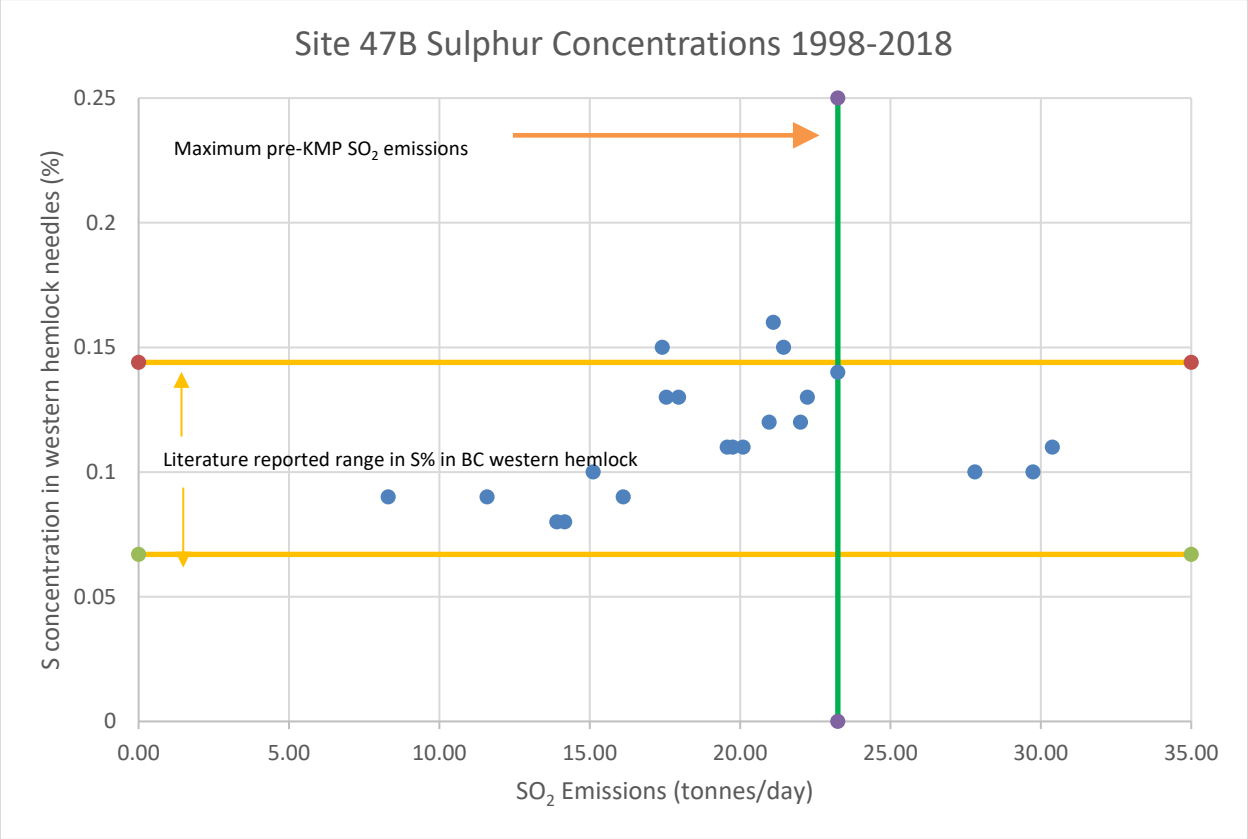

Site 43B Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

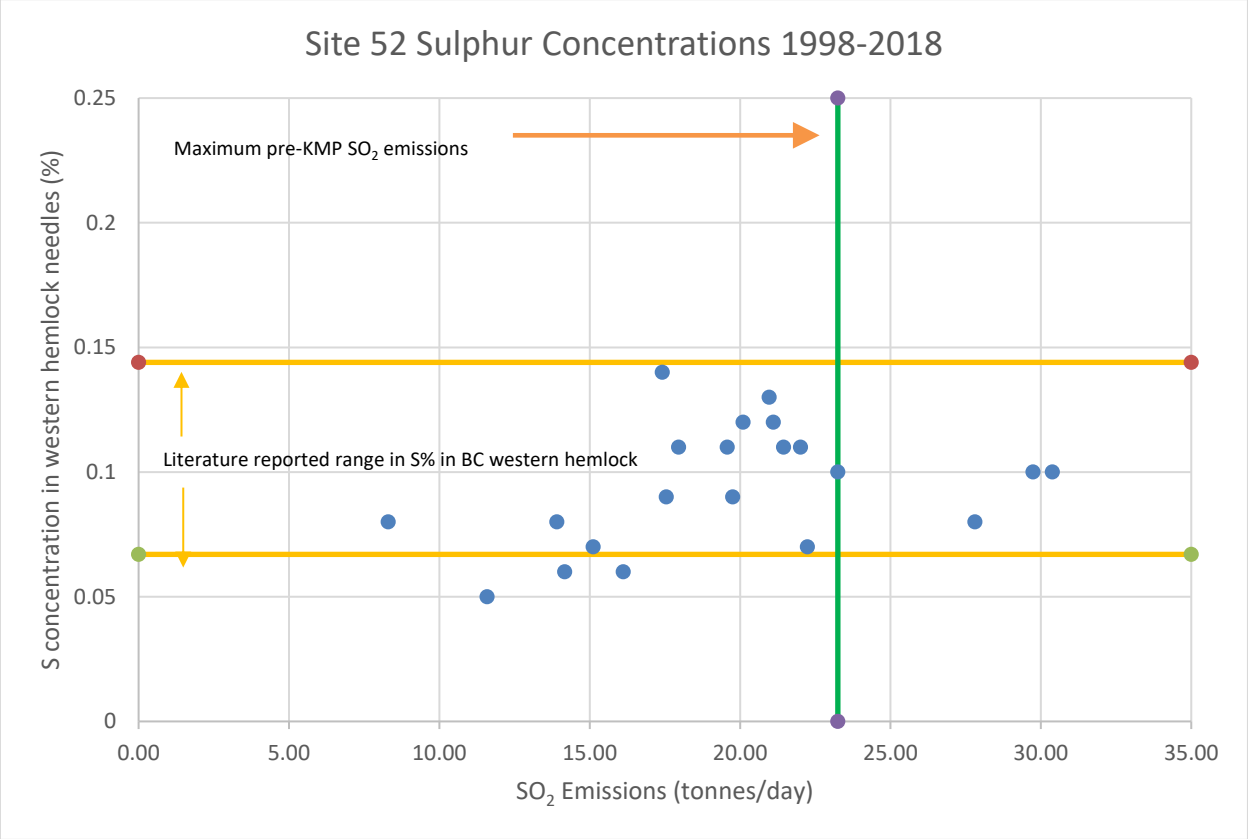

Site 43A Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

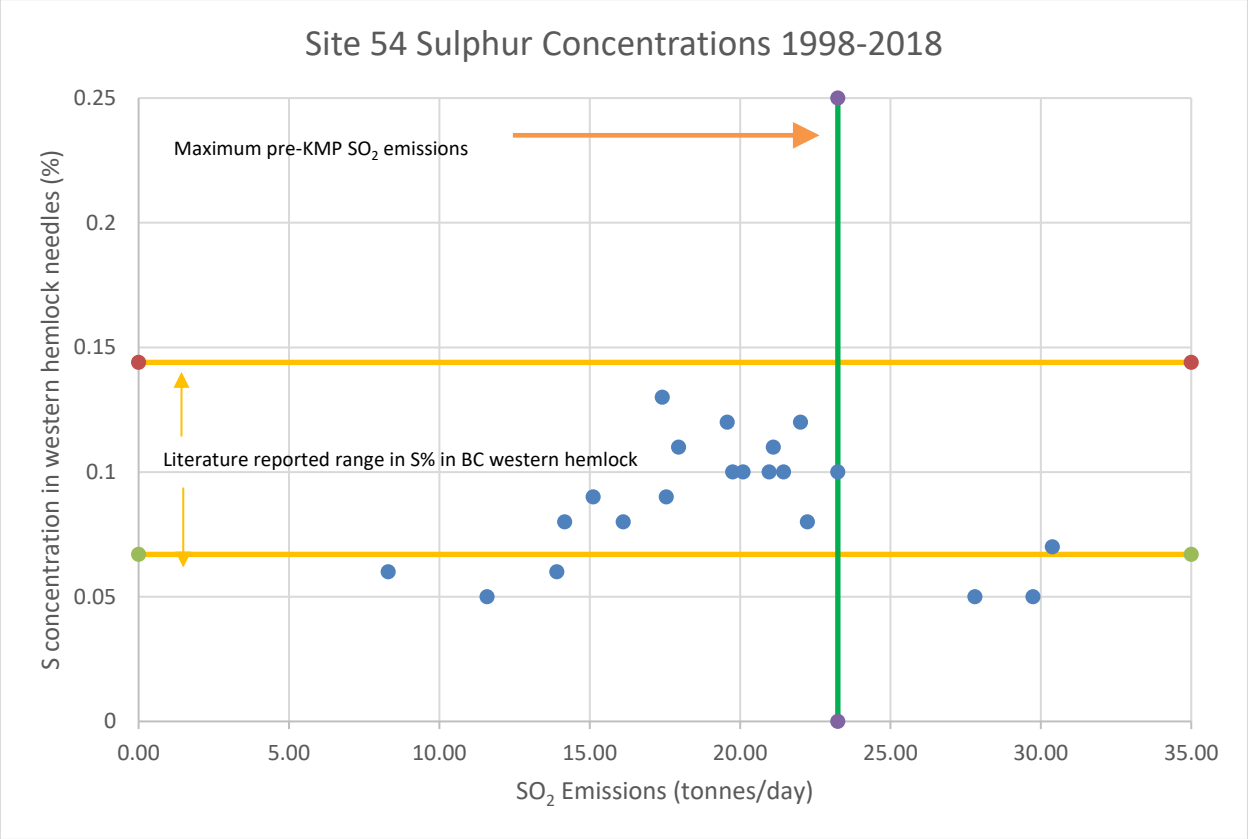

Site 44 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

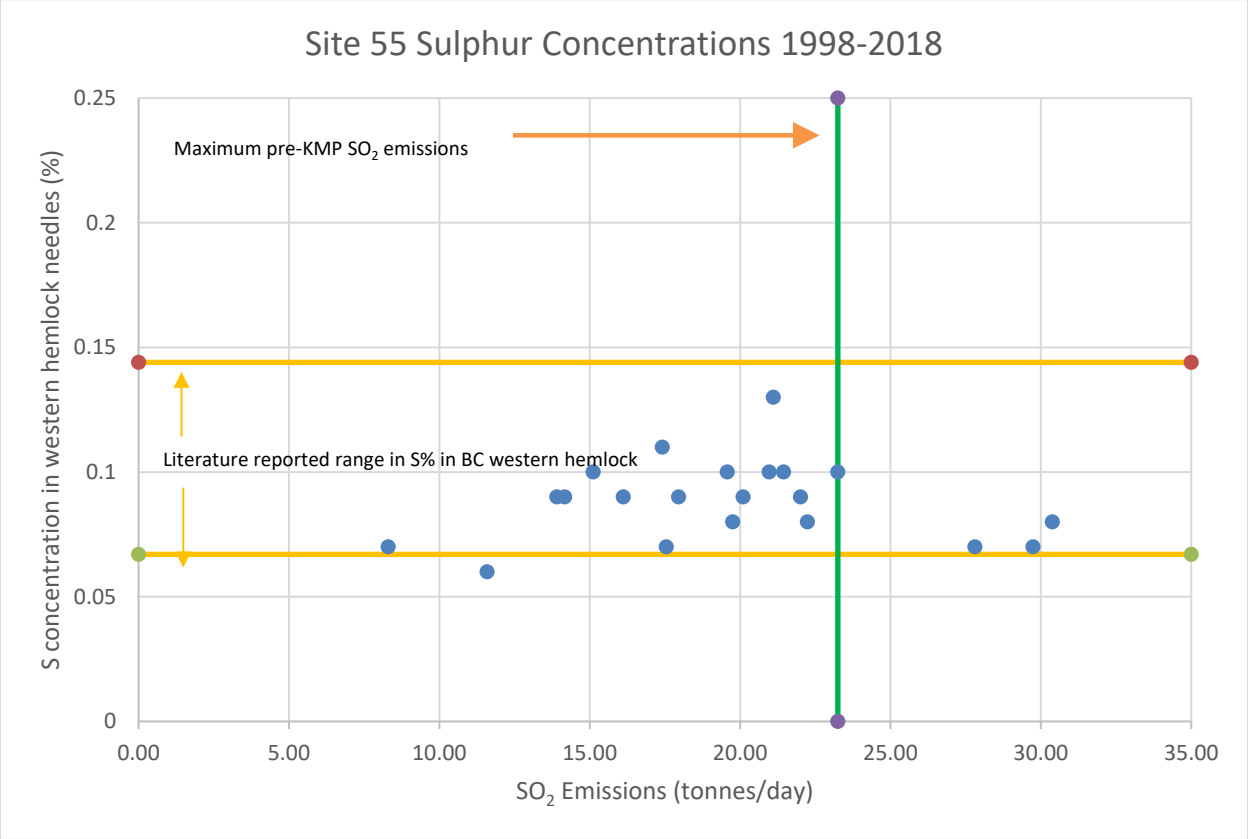

Site 44A Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

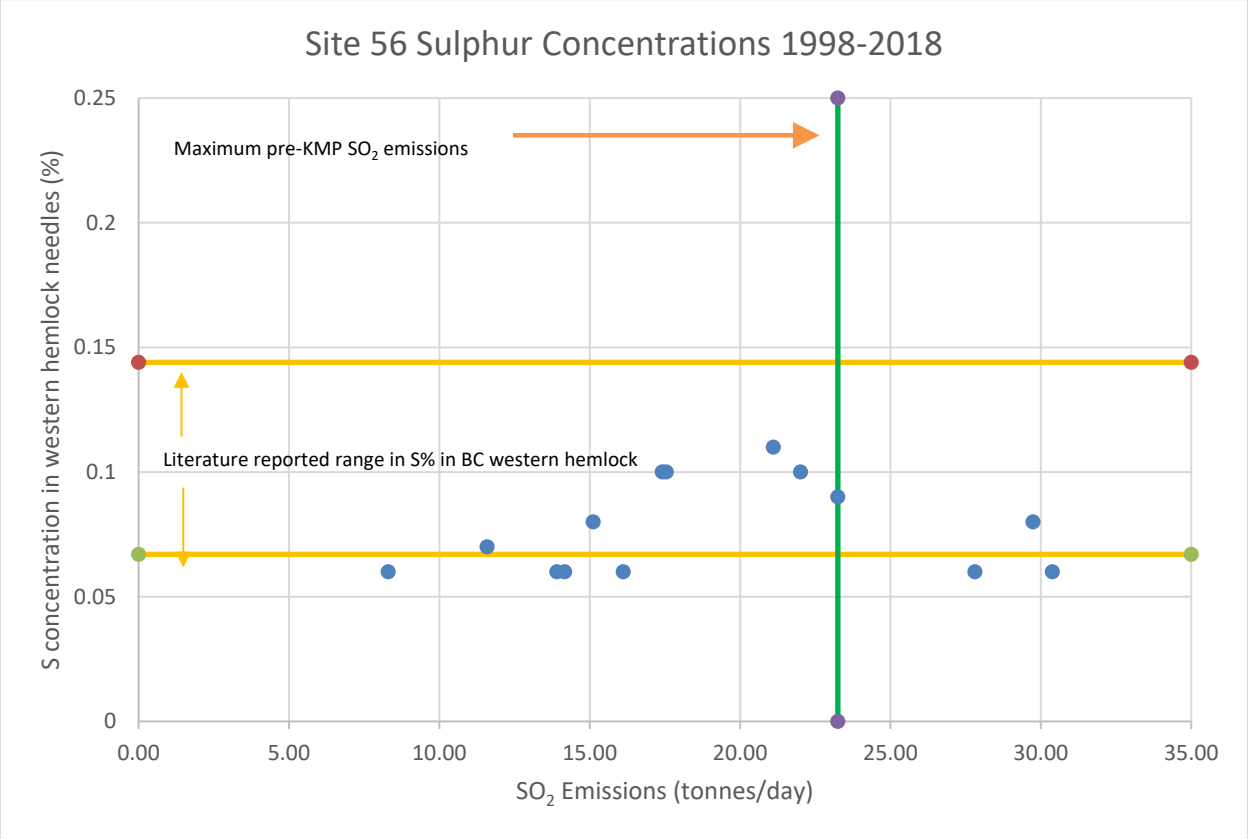

Site 46 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

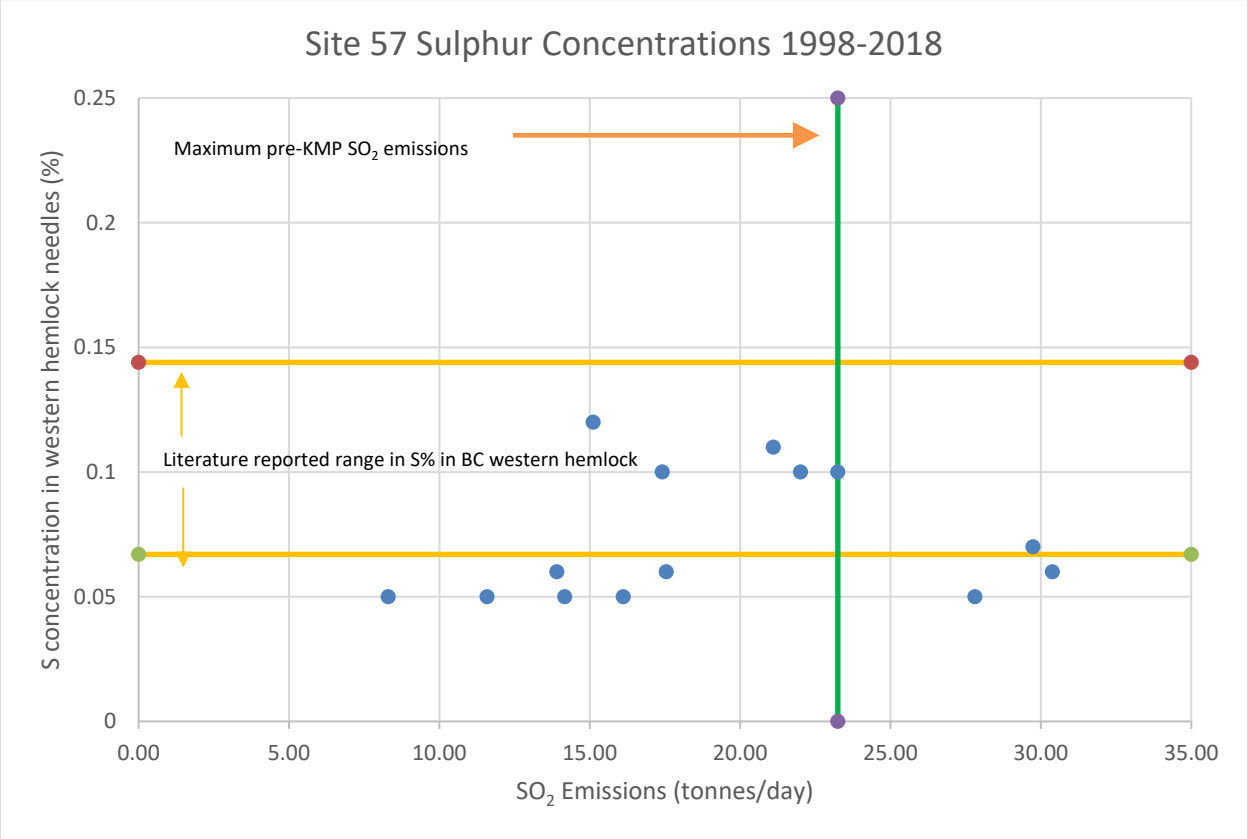

Site 47B Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

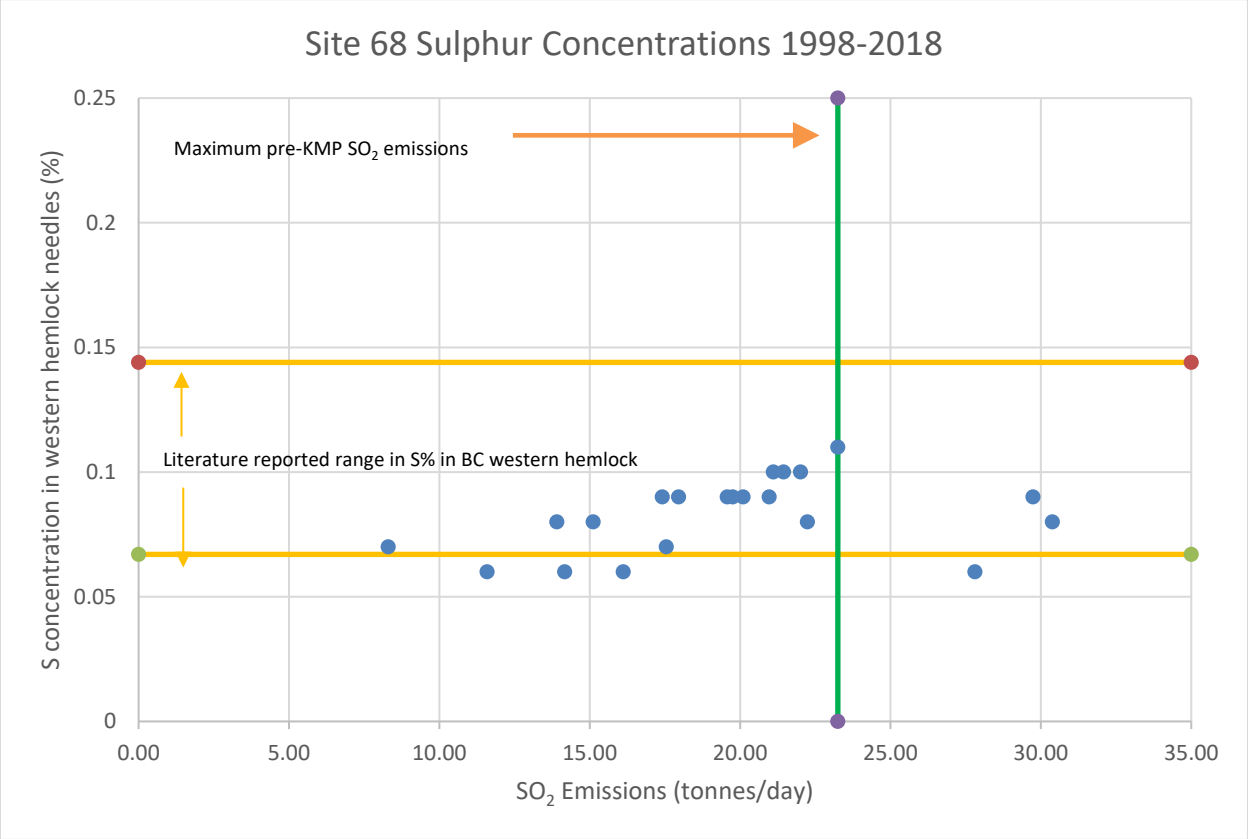

Site 52 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

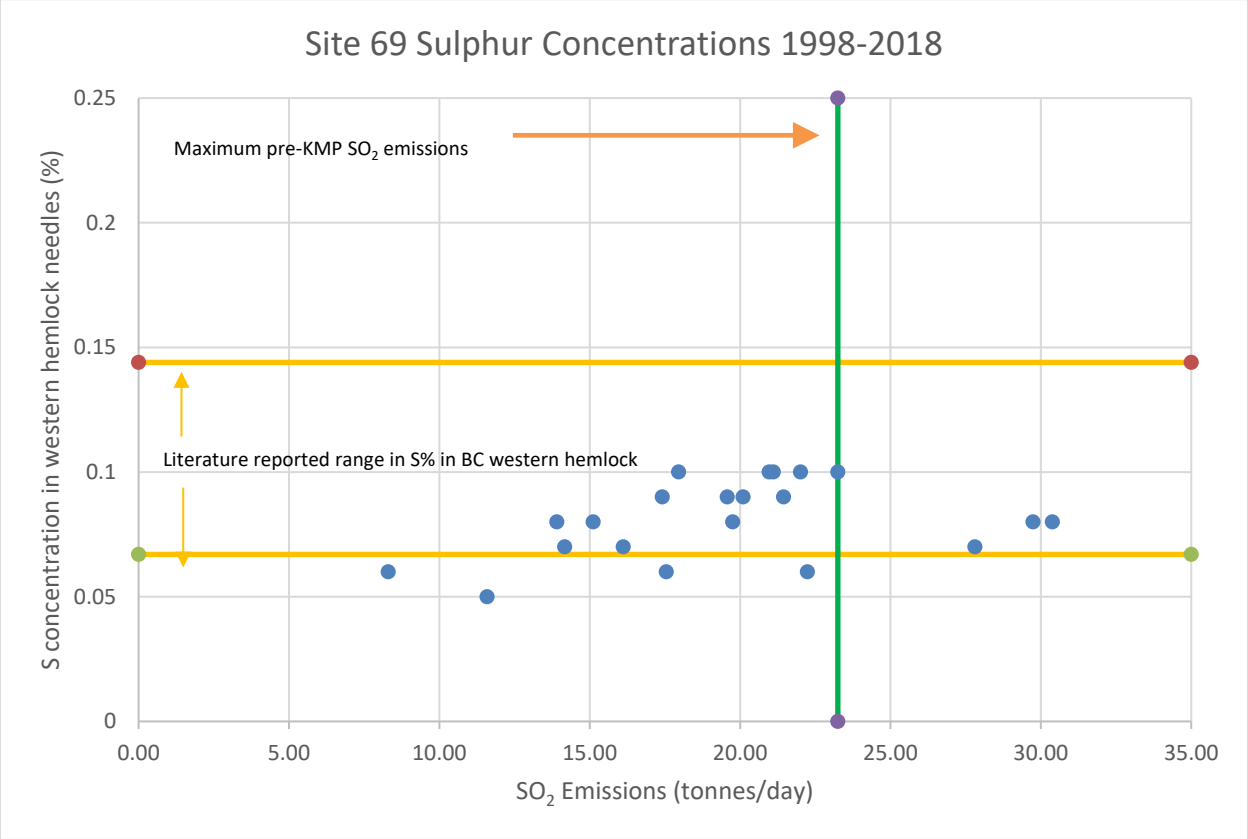

Site 54 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

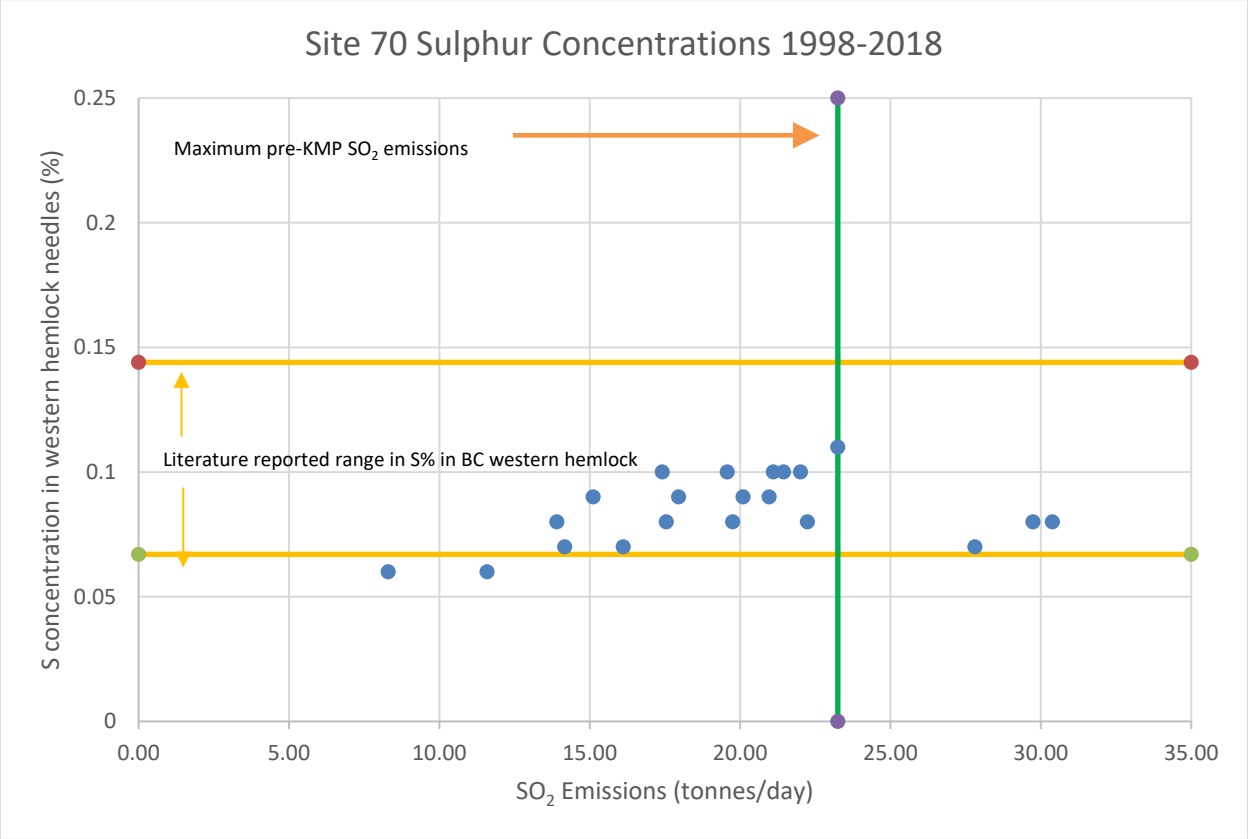

Site 55 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

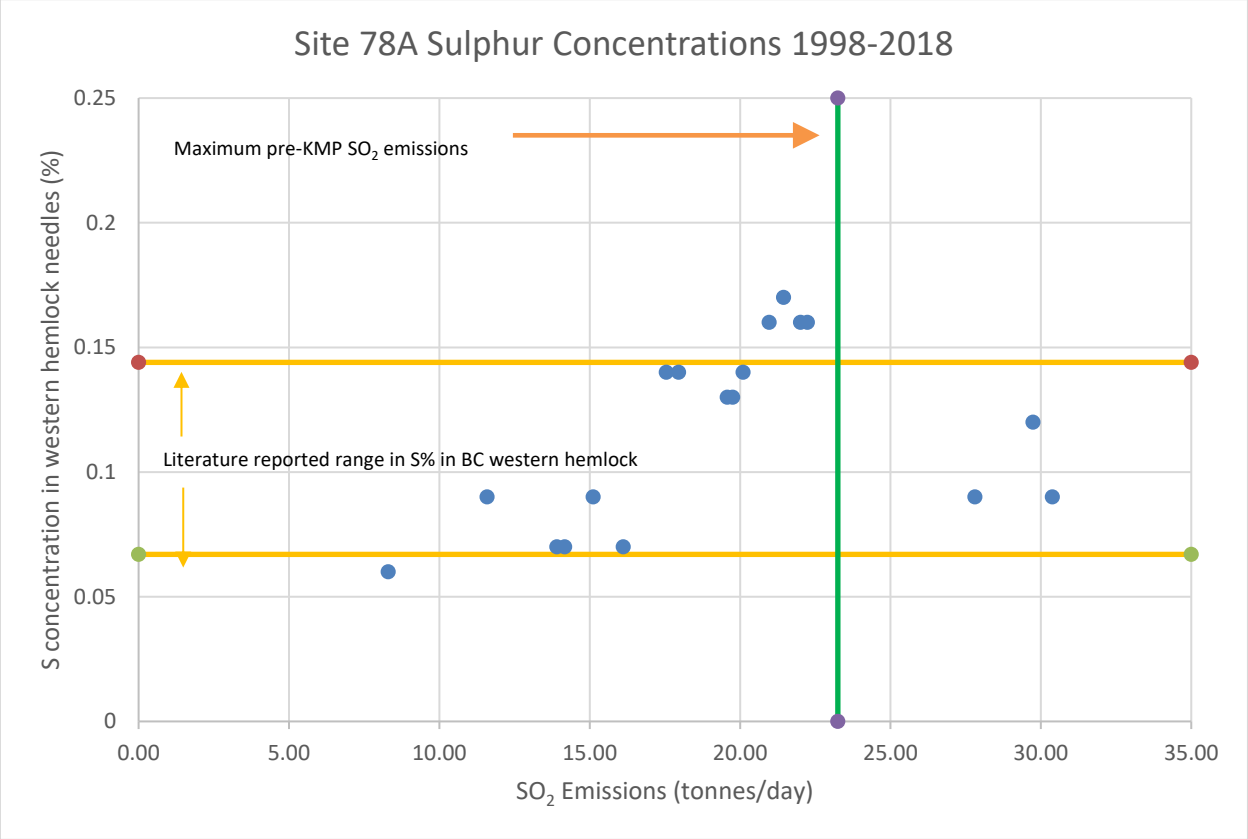

Site 56 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

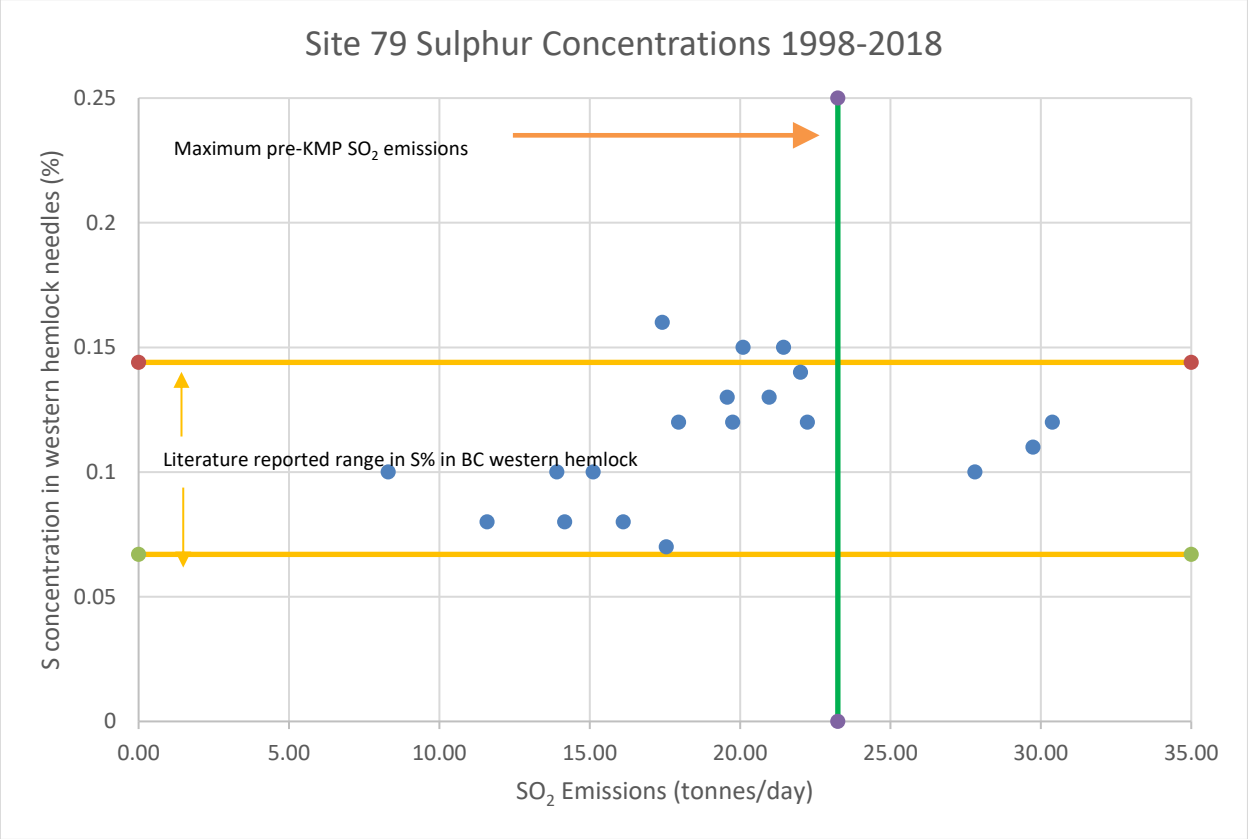

Site 57 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

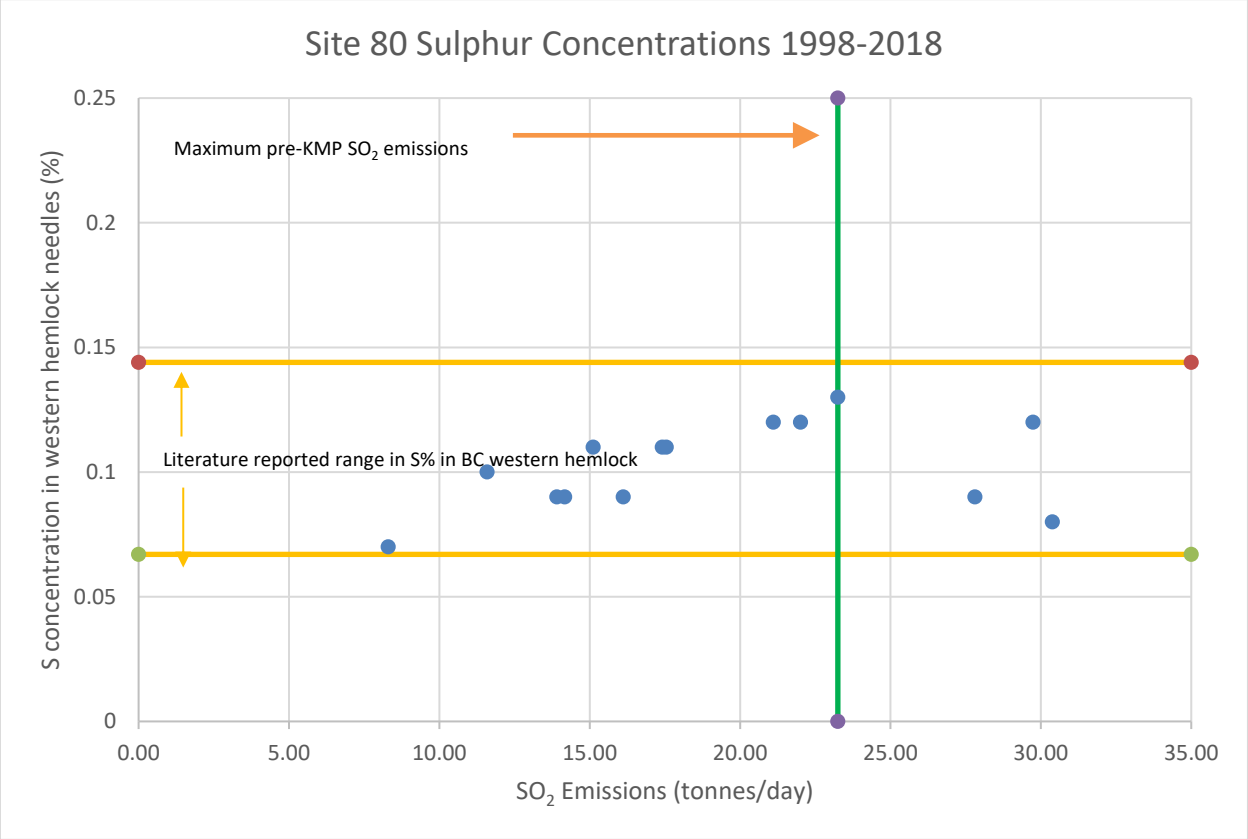

Site 68 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

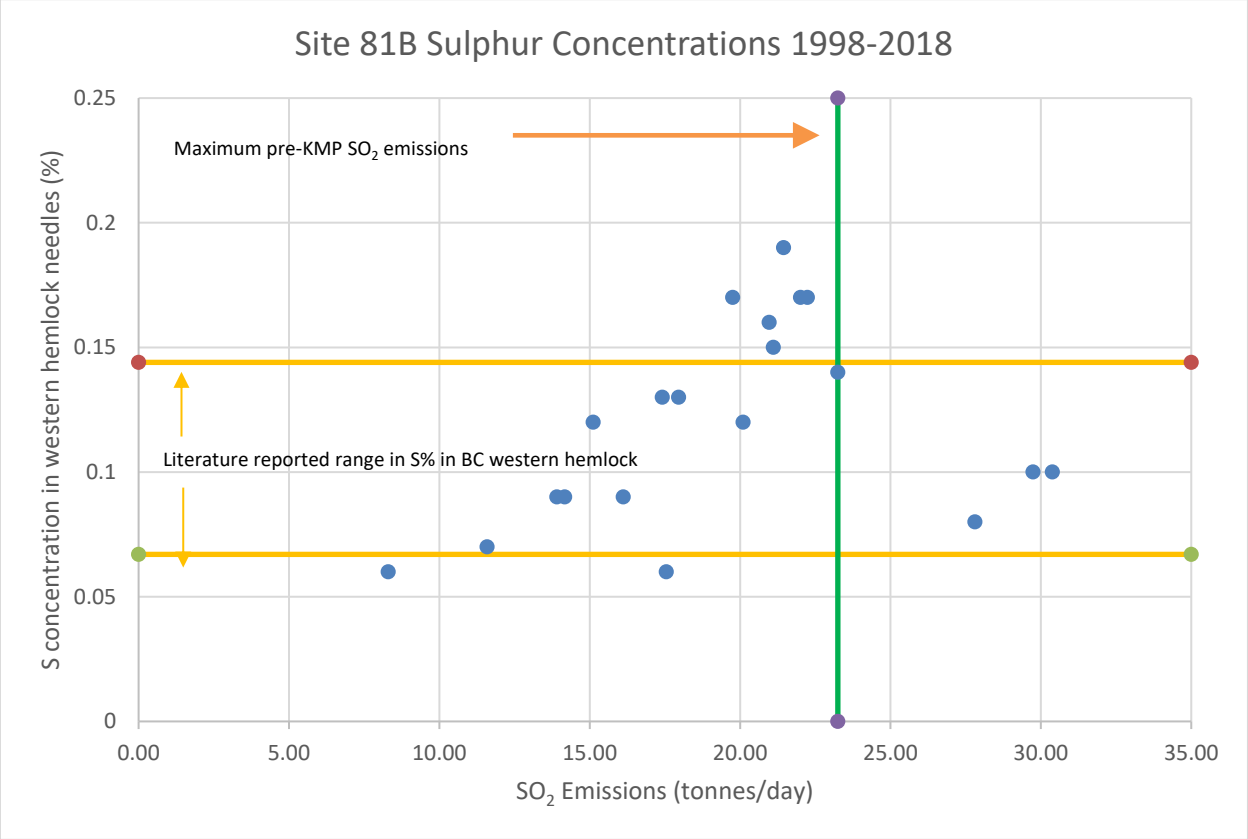

Site 69 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

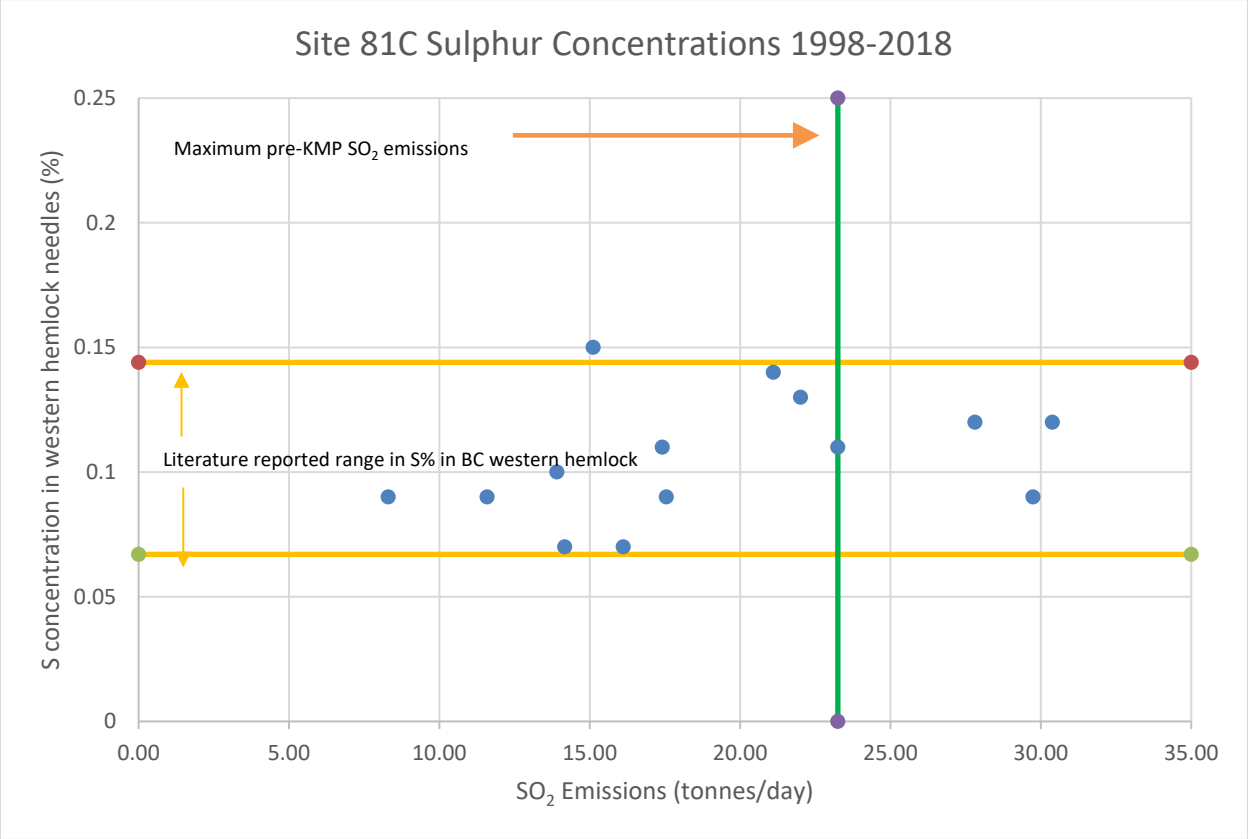

Site 70 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

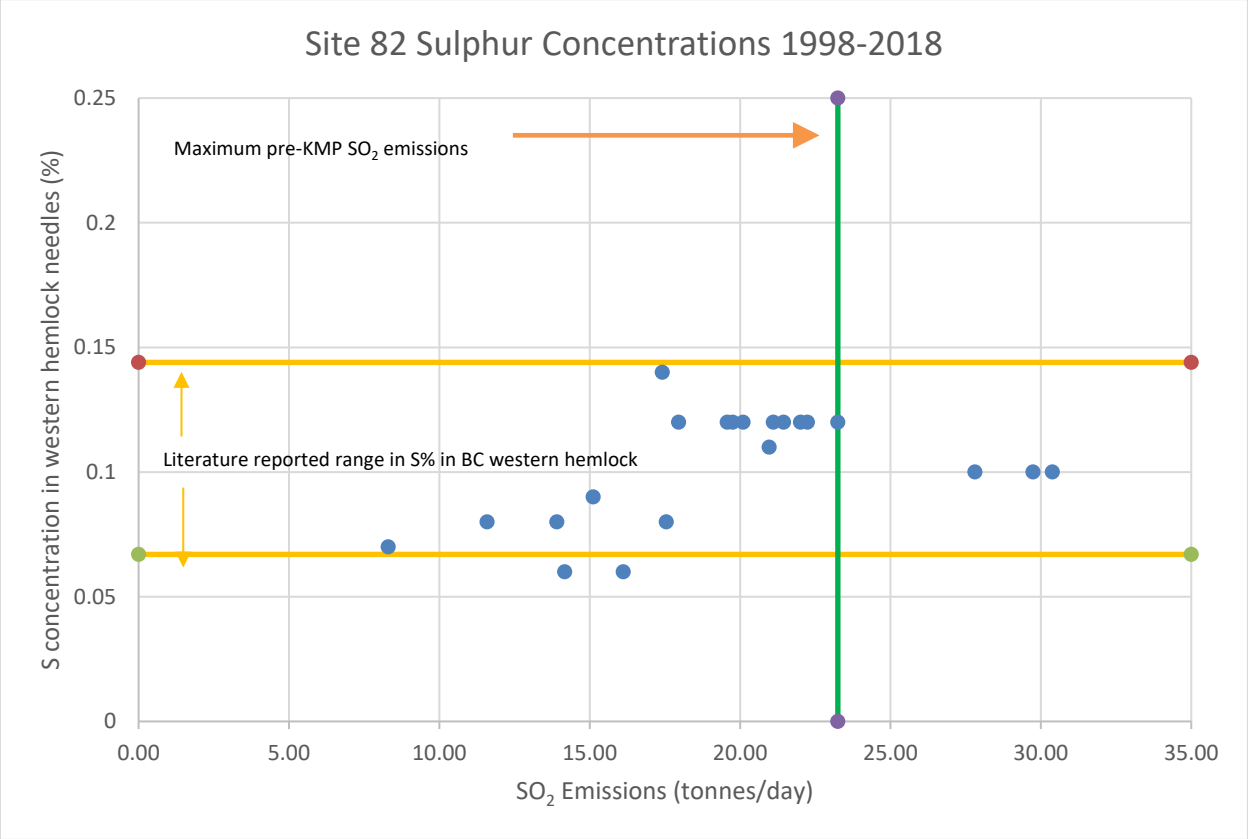

Site 78A Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

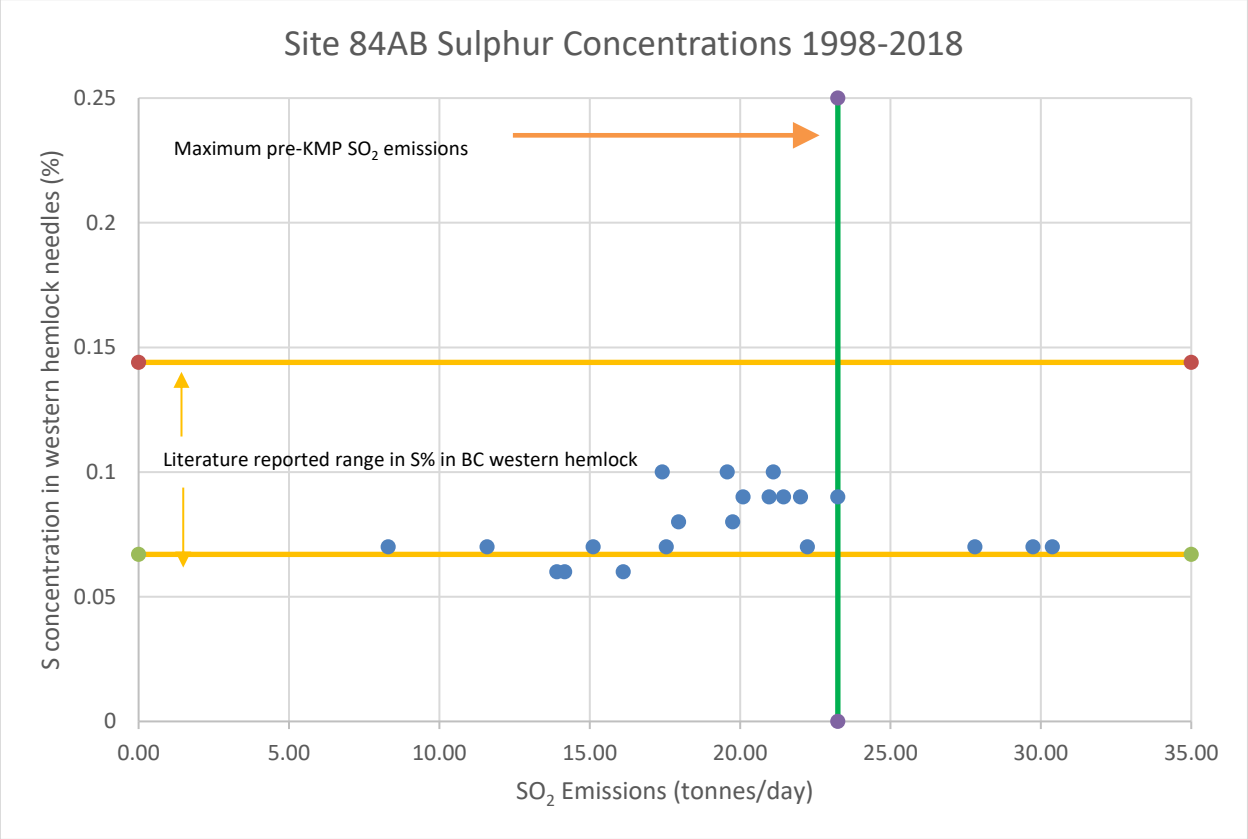

Site 79 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

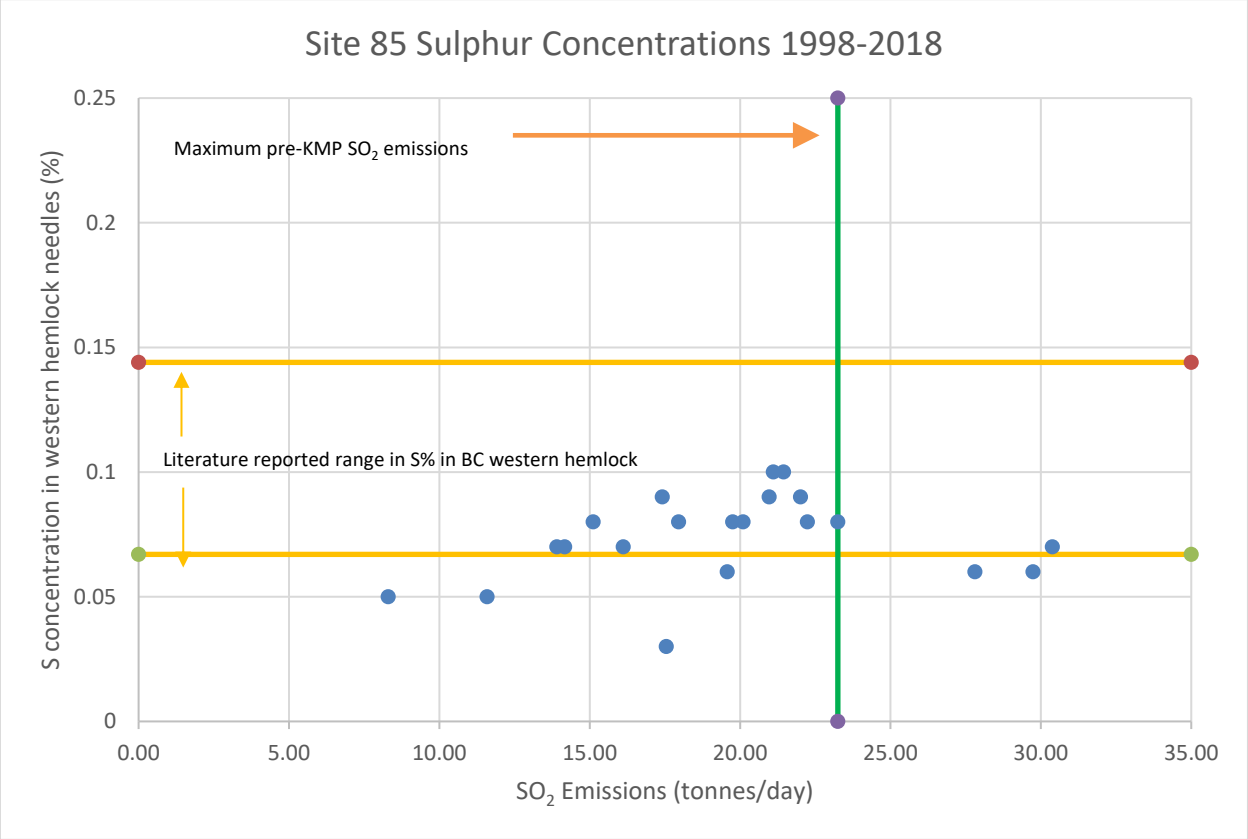

Site 80 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

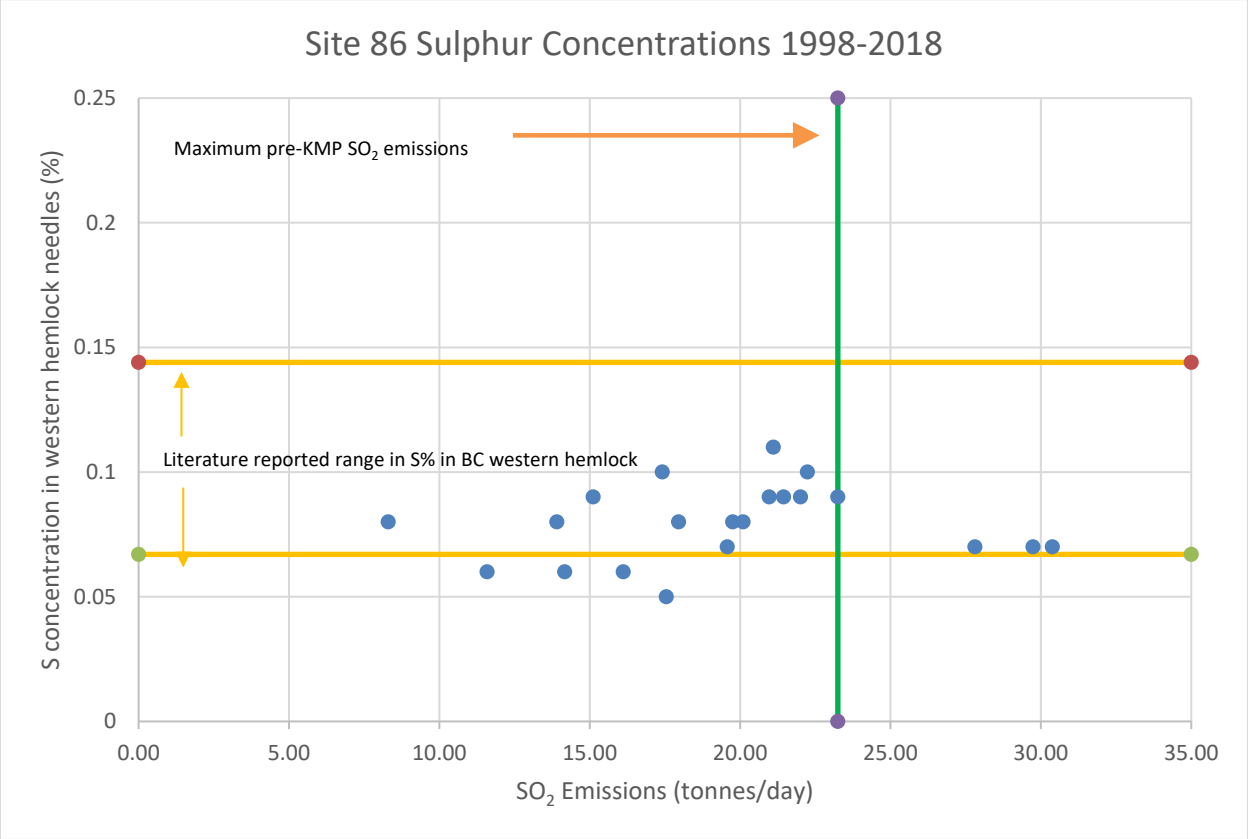

Site 81B Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

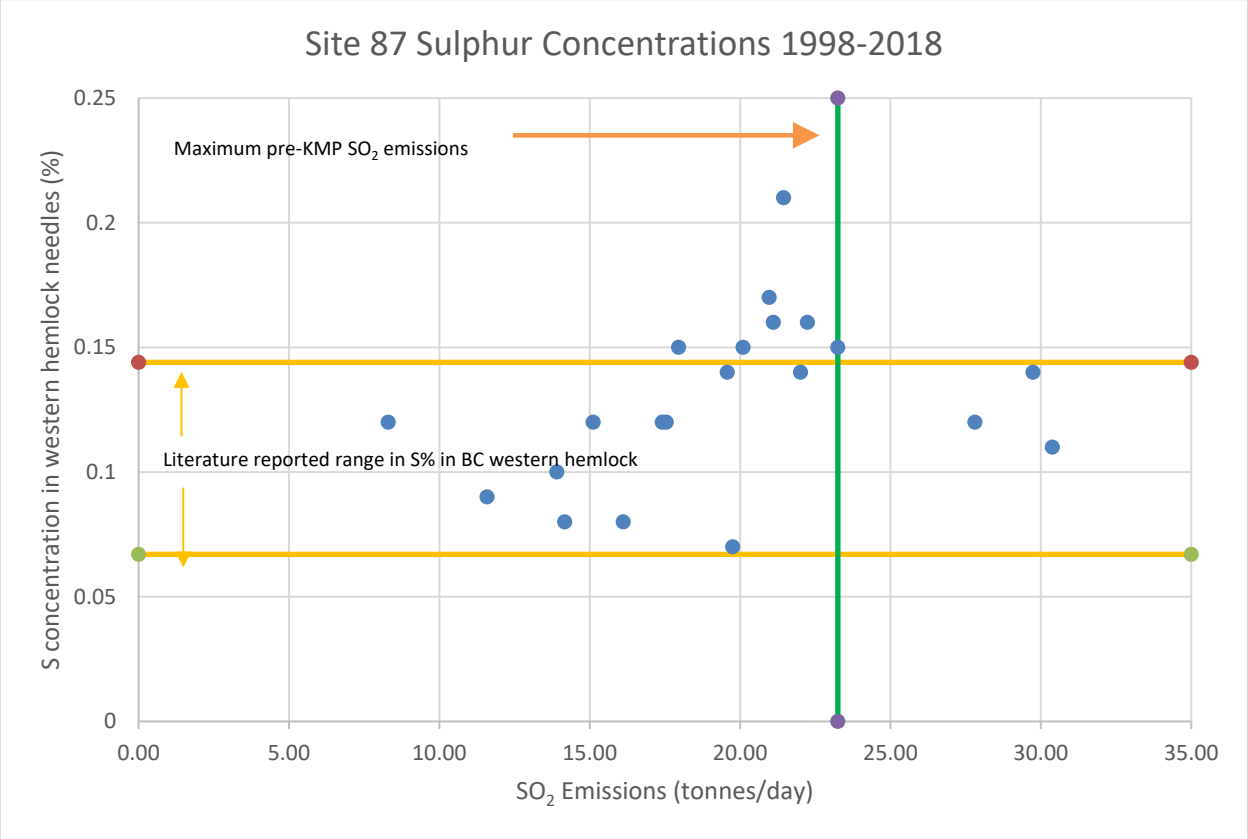

Site 81C Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

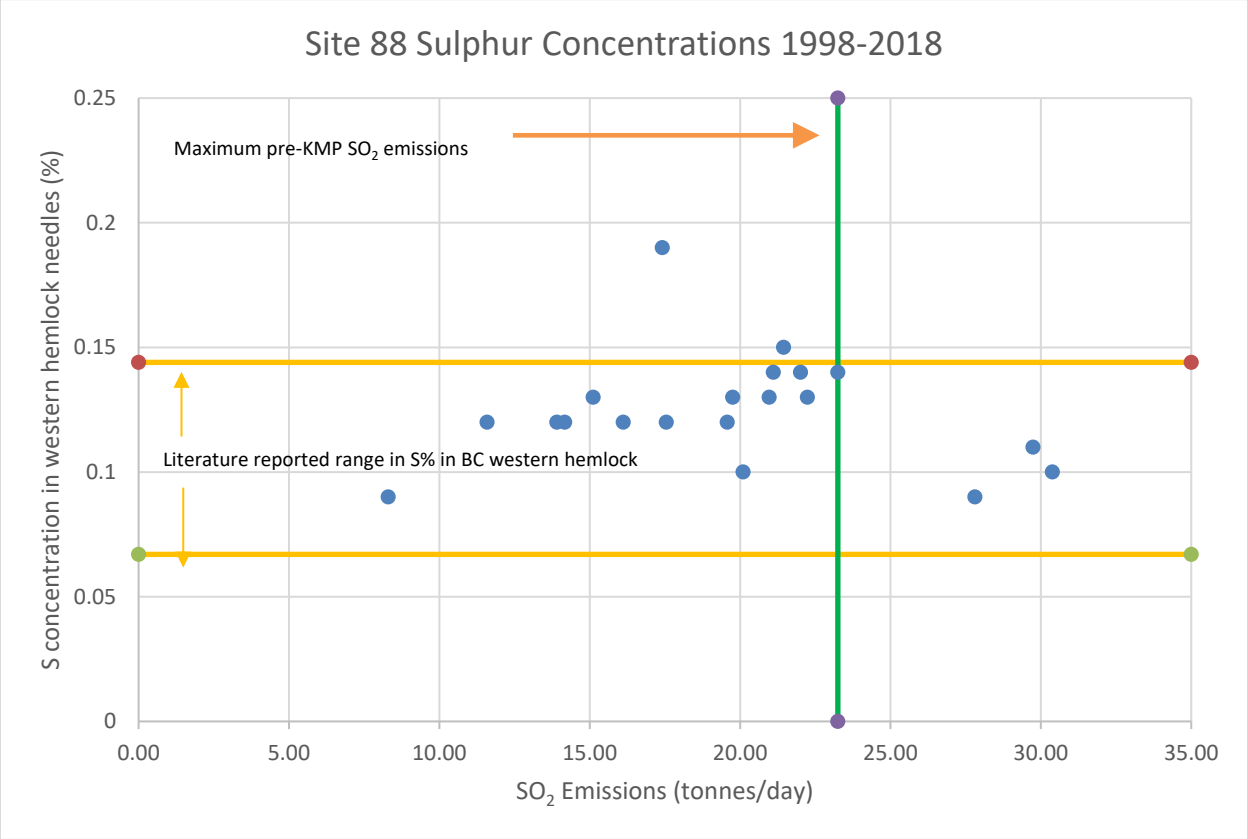

Site 82 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

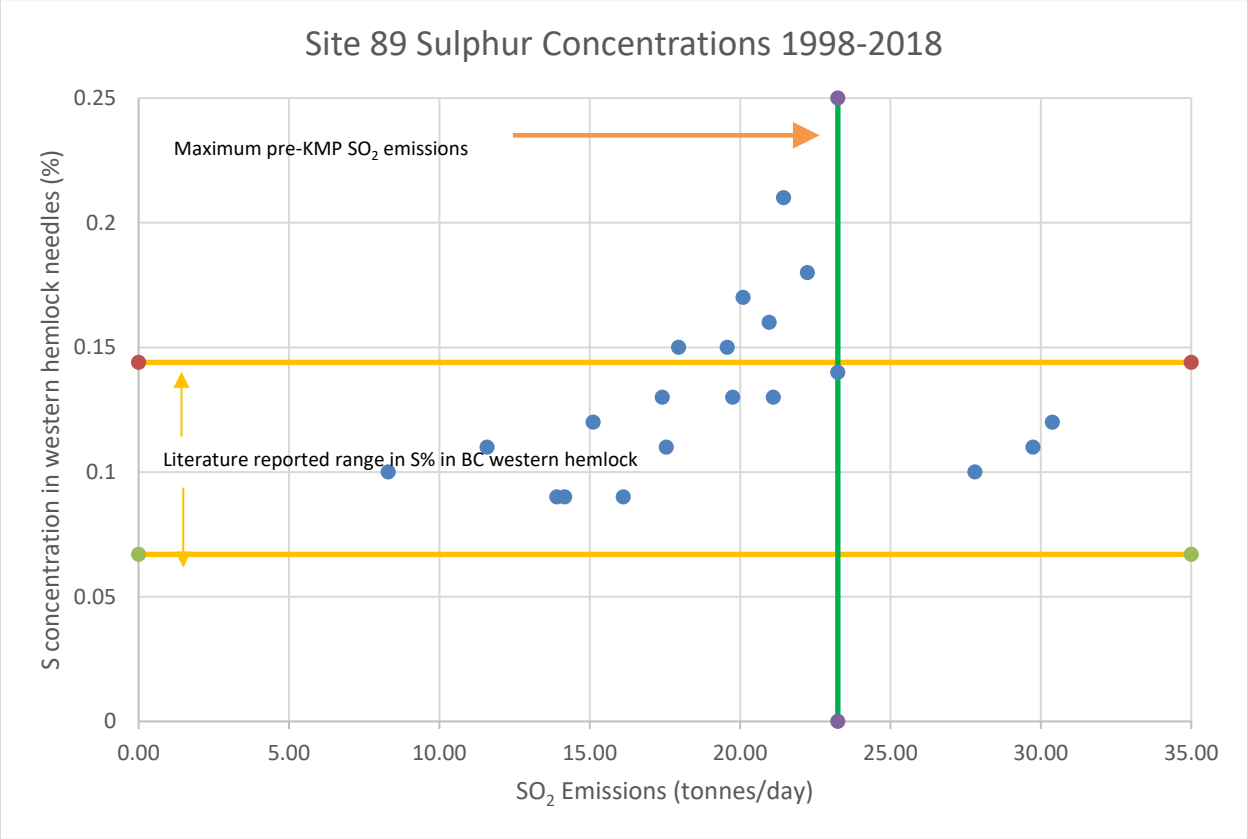

Site 84AB Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

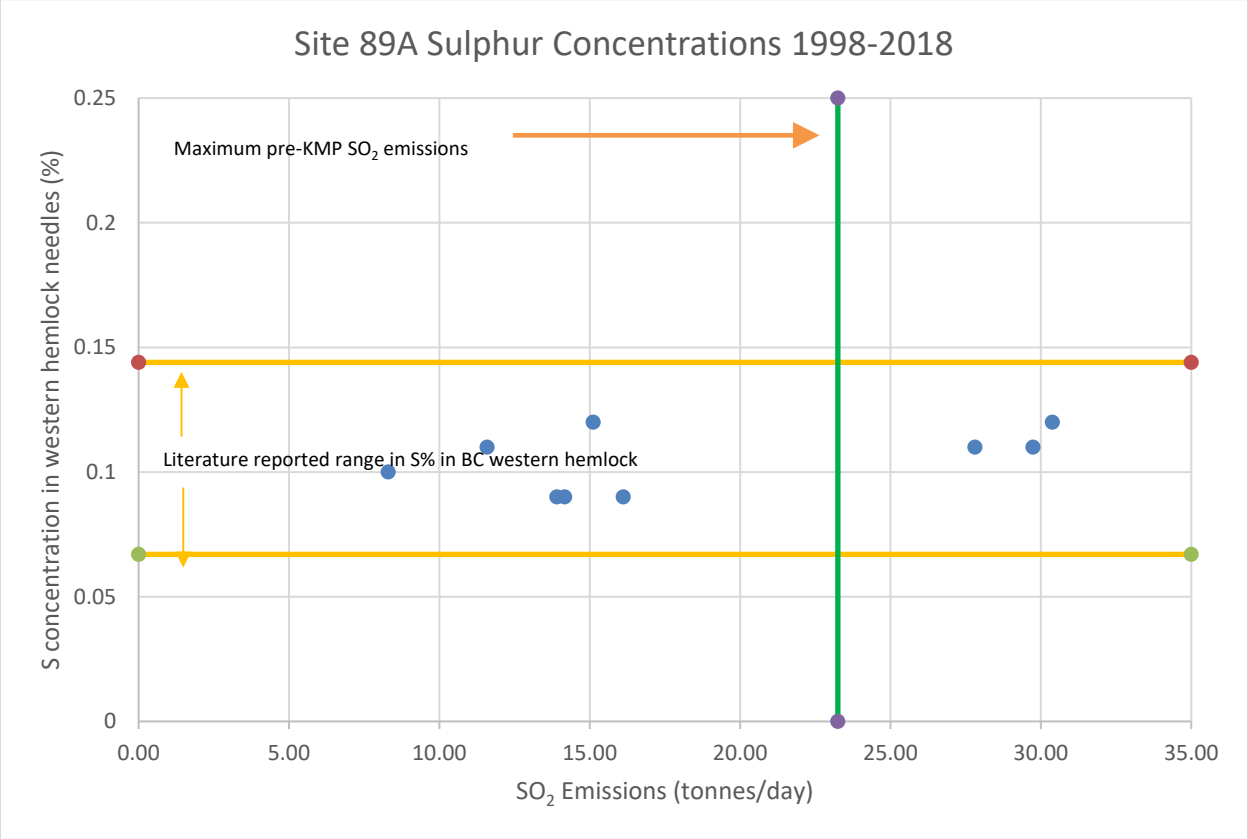

Site 85 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

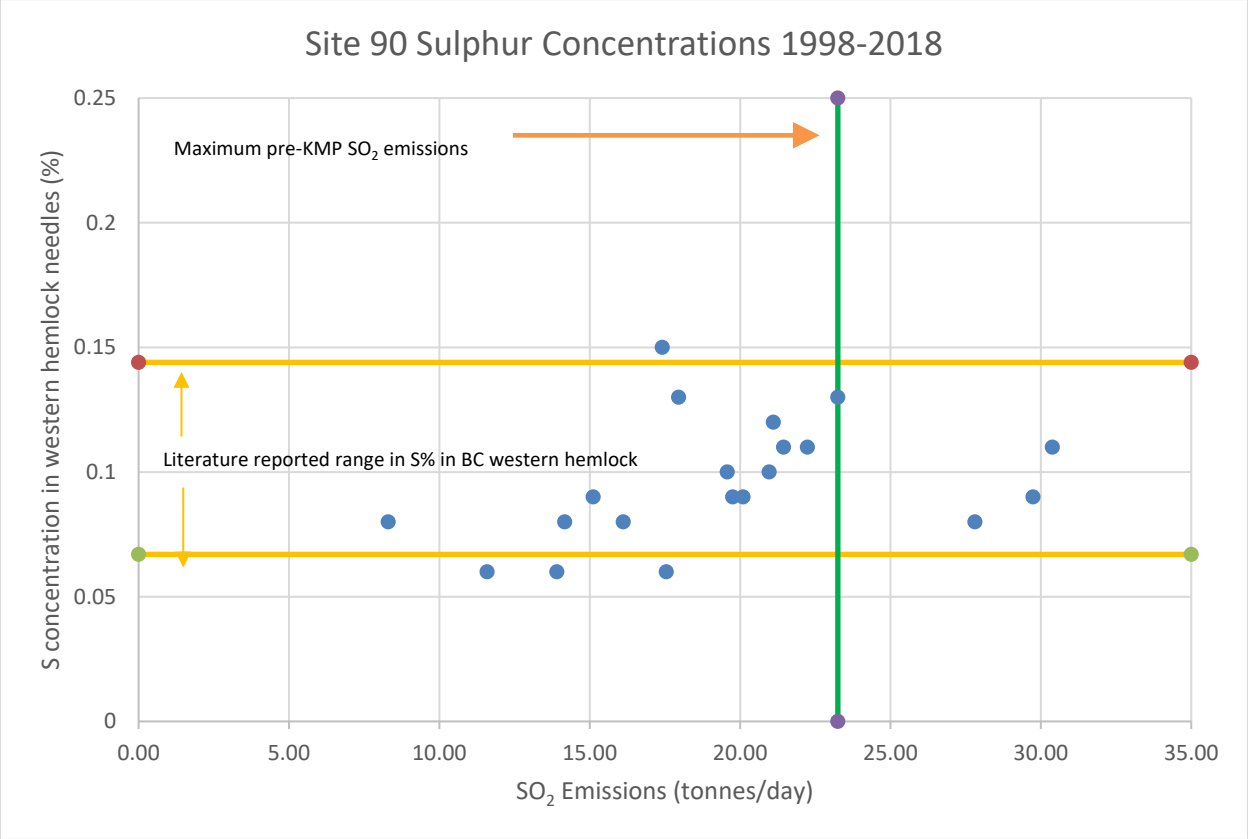

Site 86 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

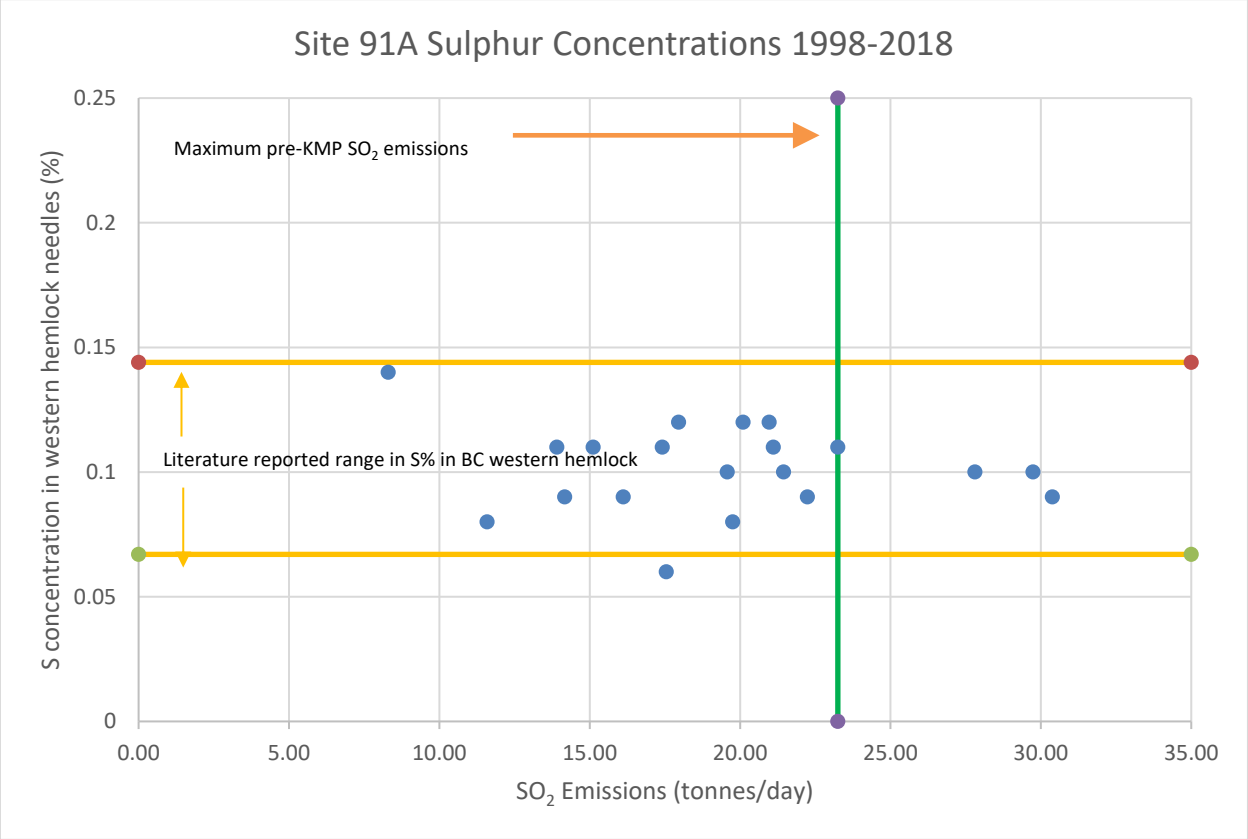

Site 87 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

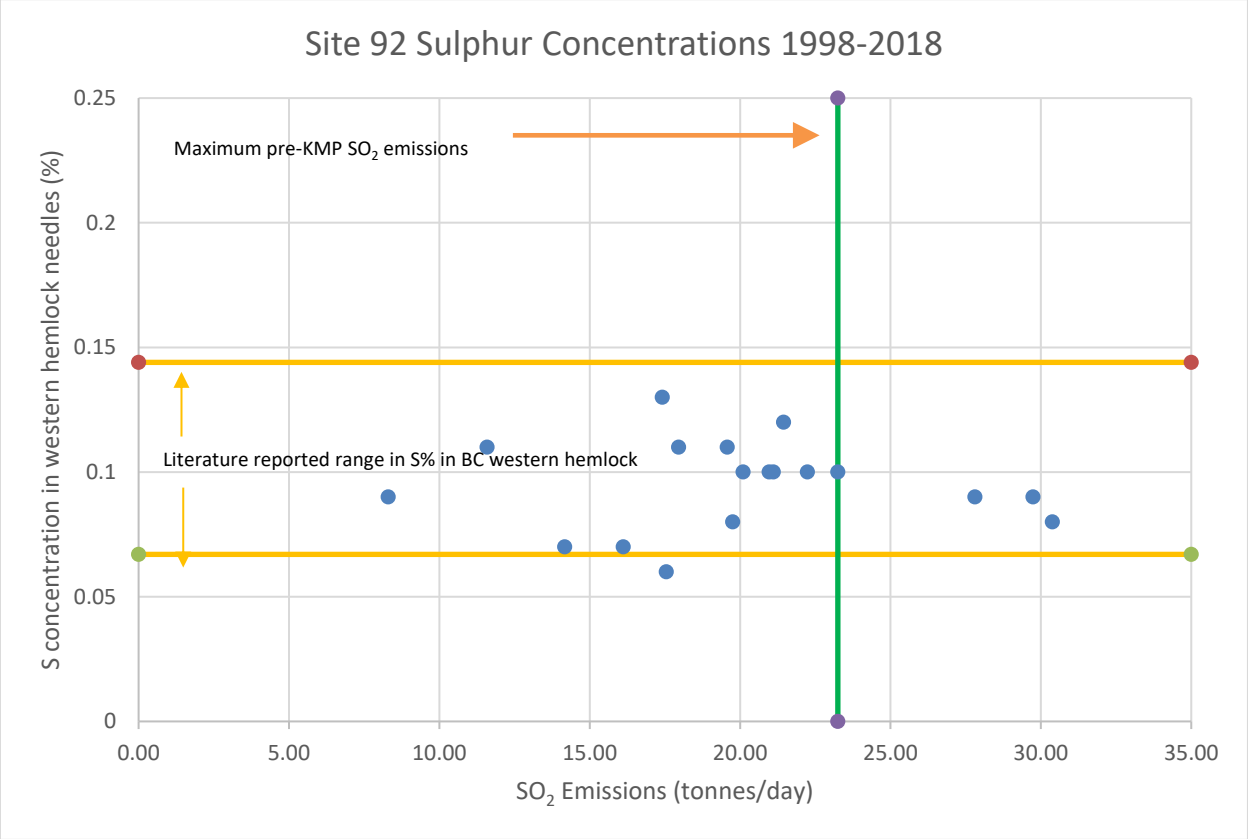

Site 88 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

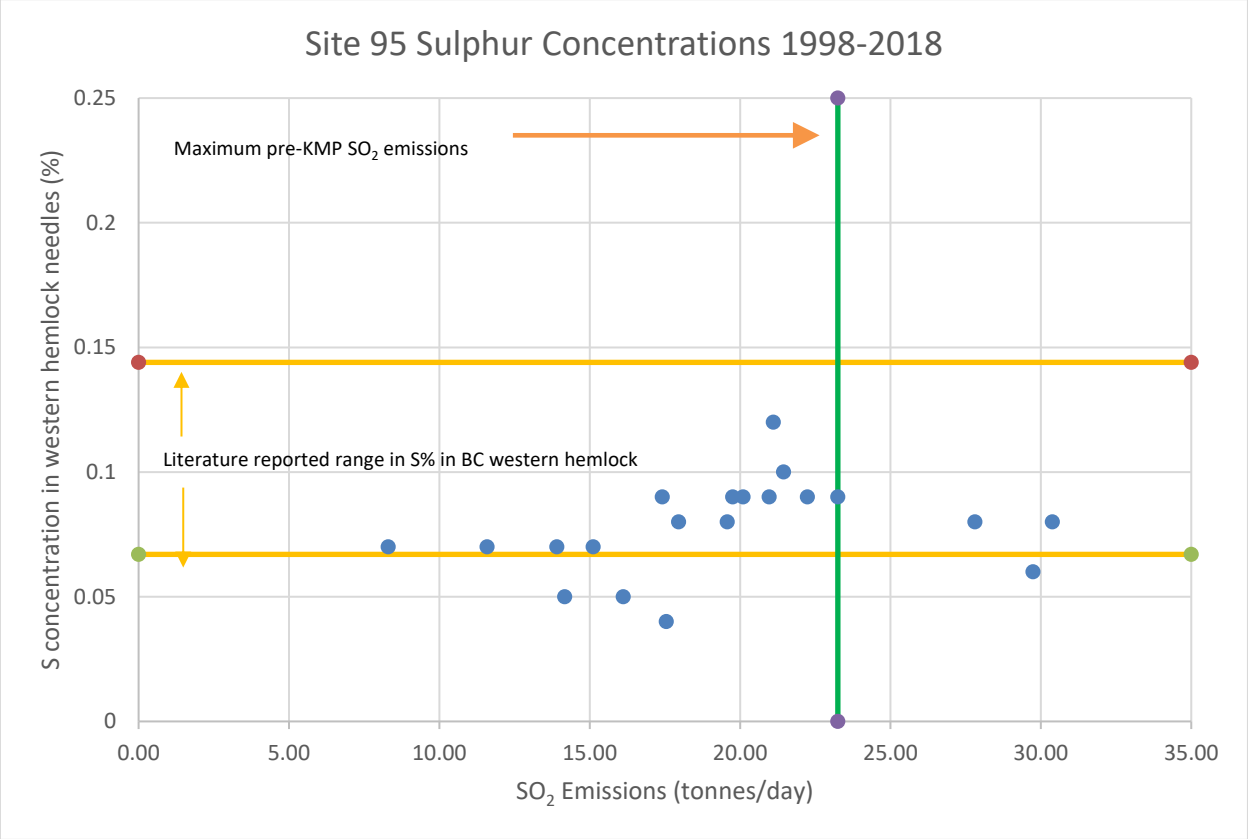

Site 89 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

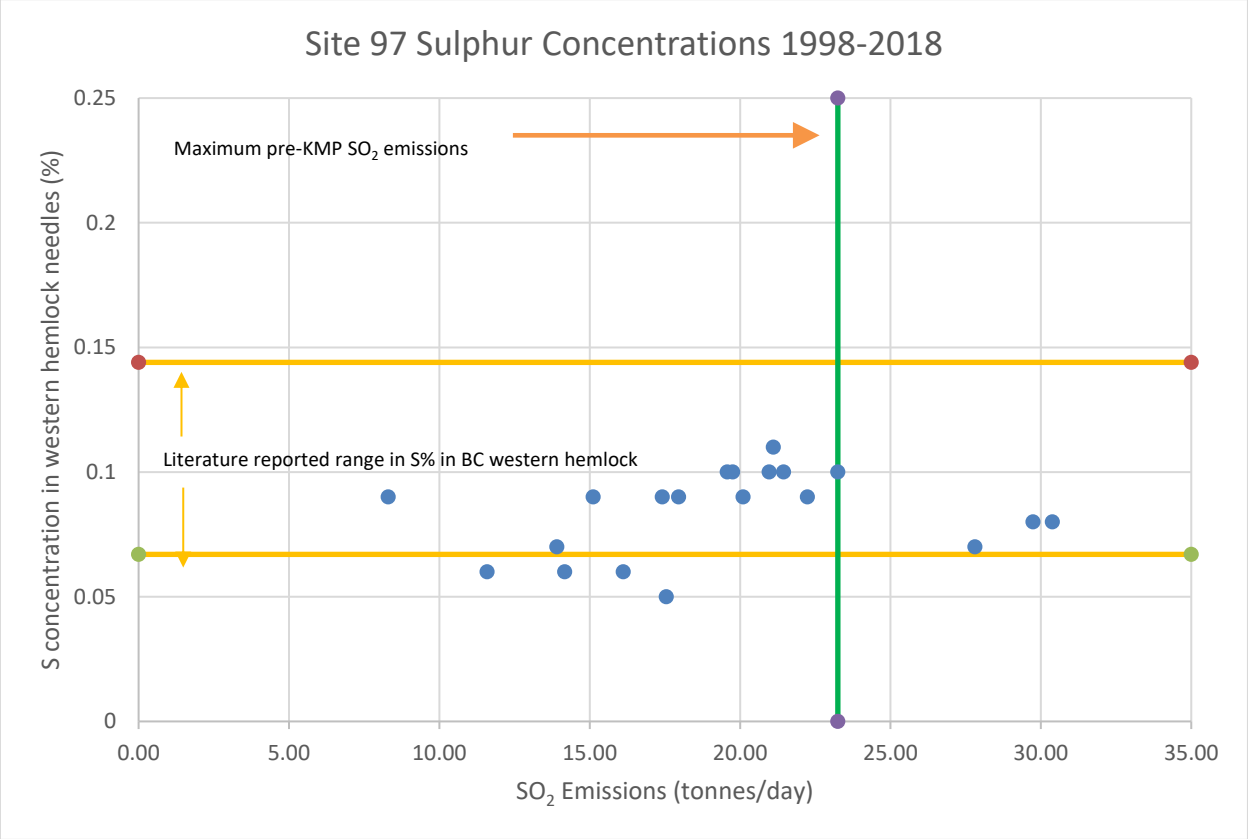

Site 89A Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

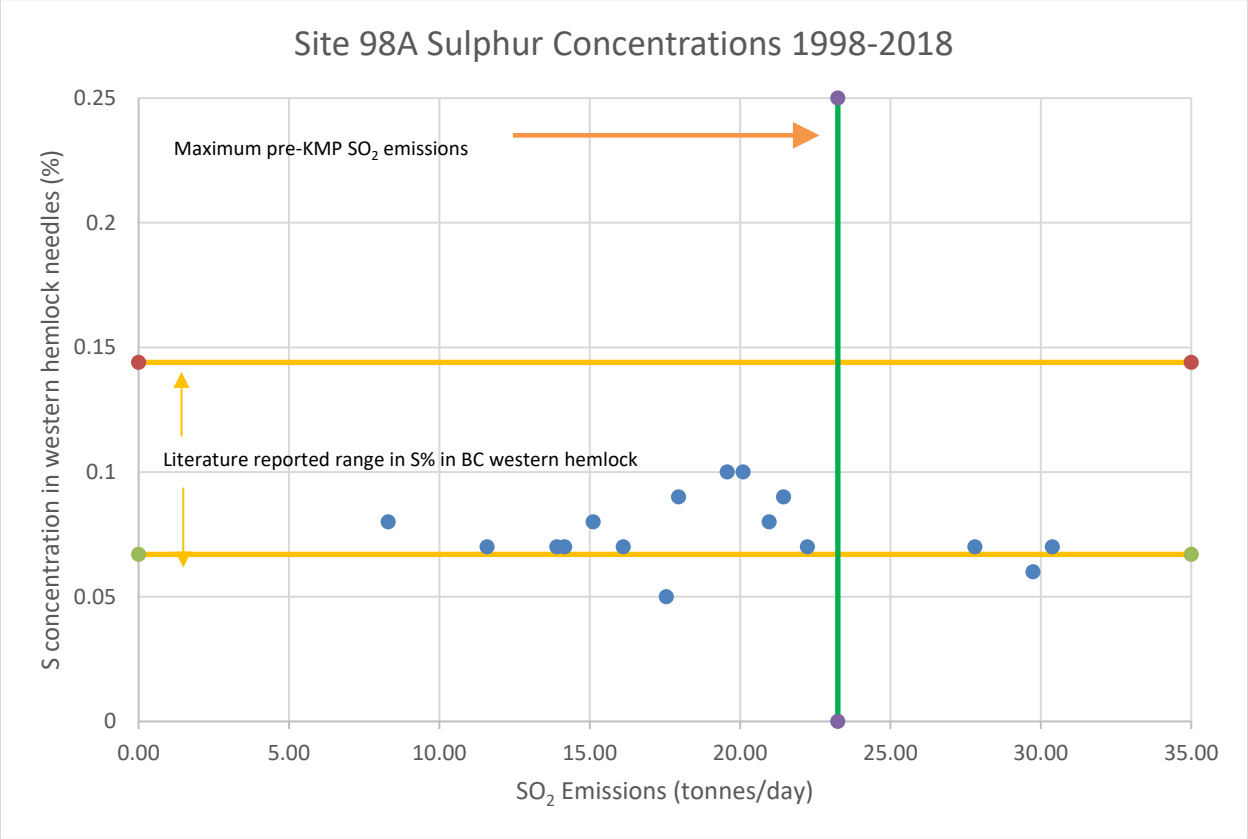

Site 90 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

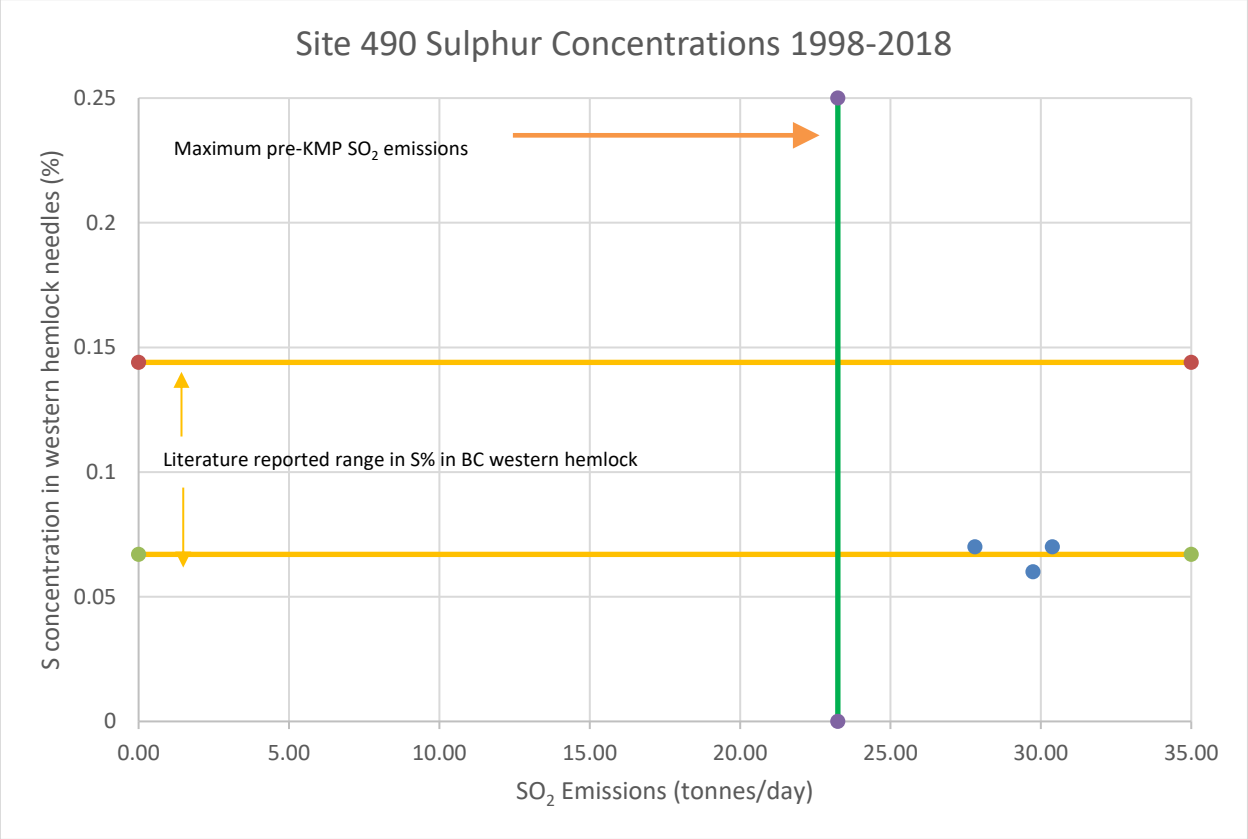

Site 91A Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

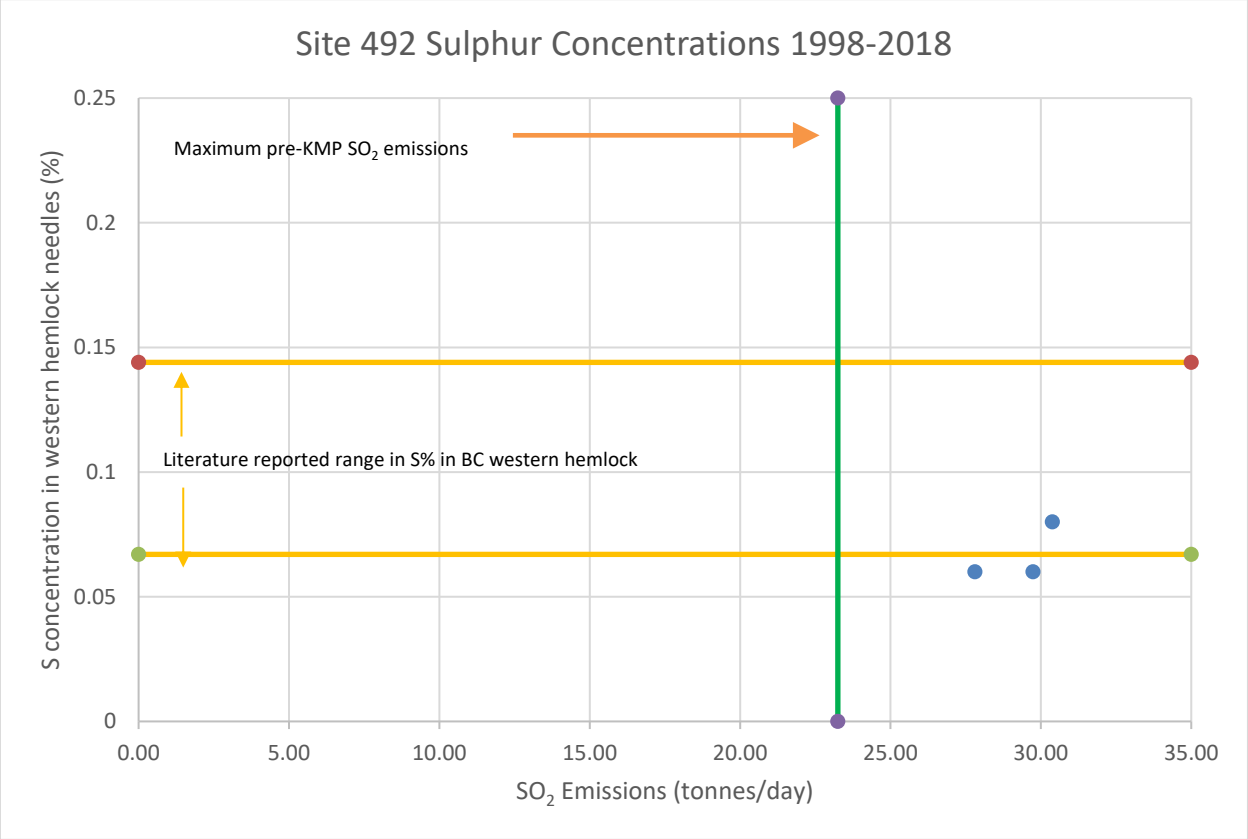

Site 92 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

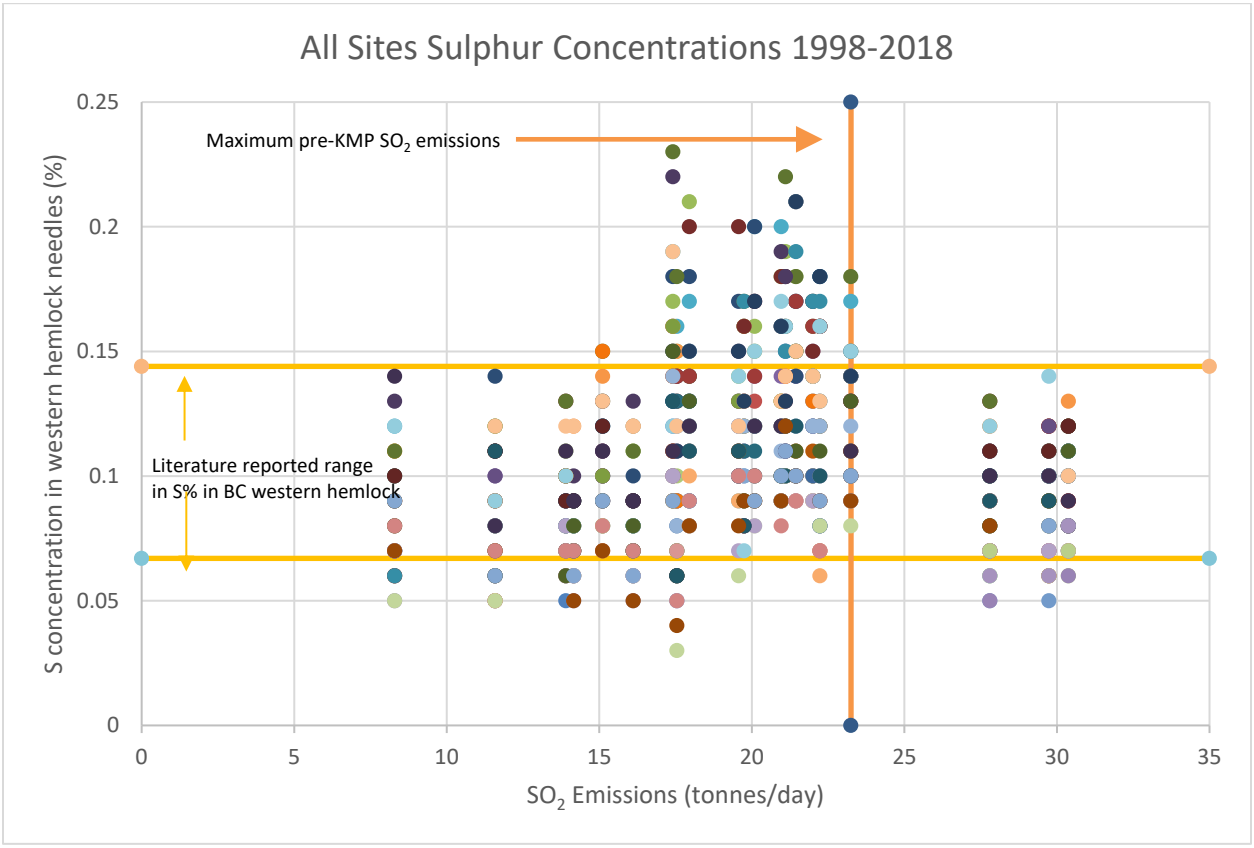

Site 95 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

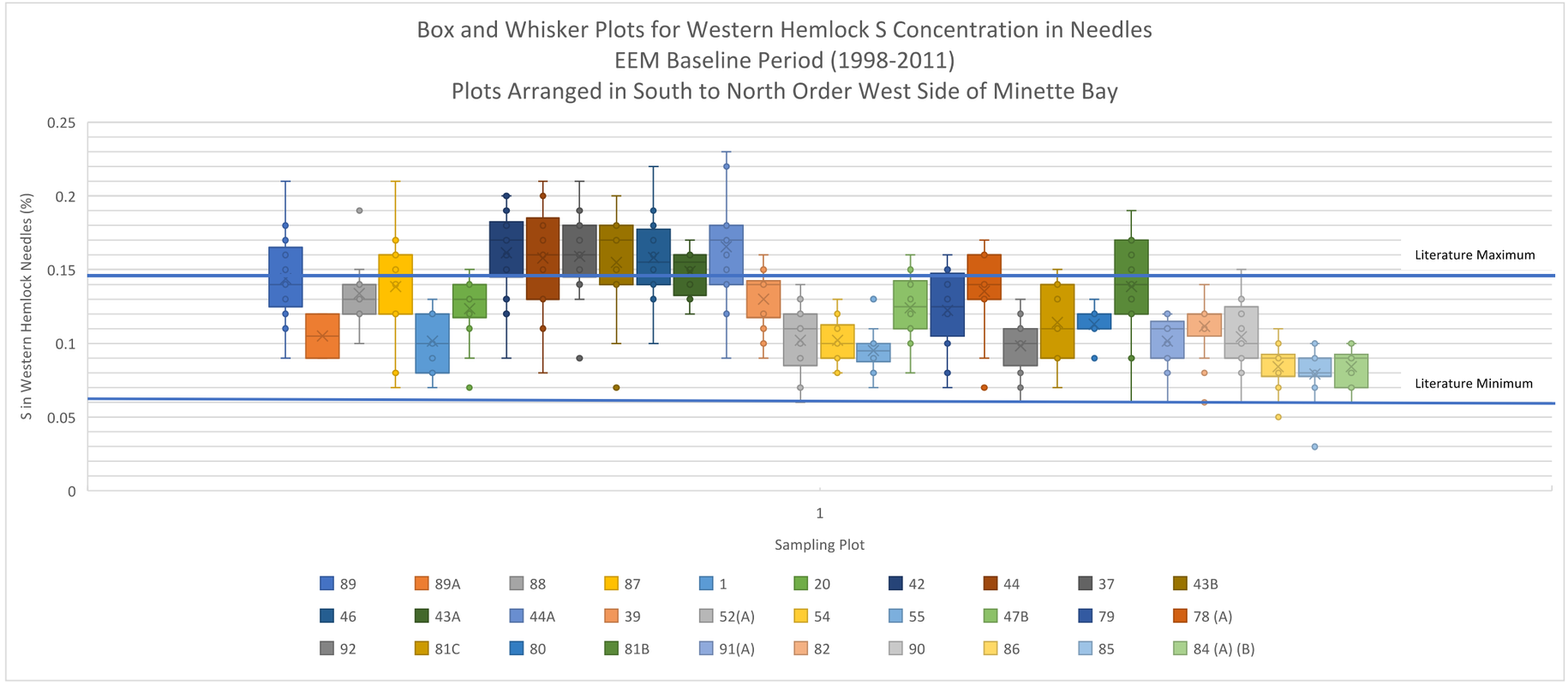

Site 97 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

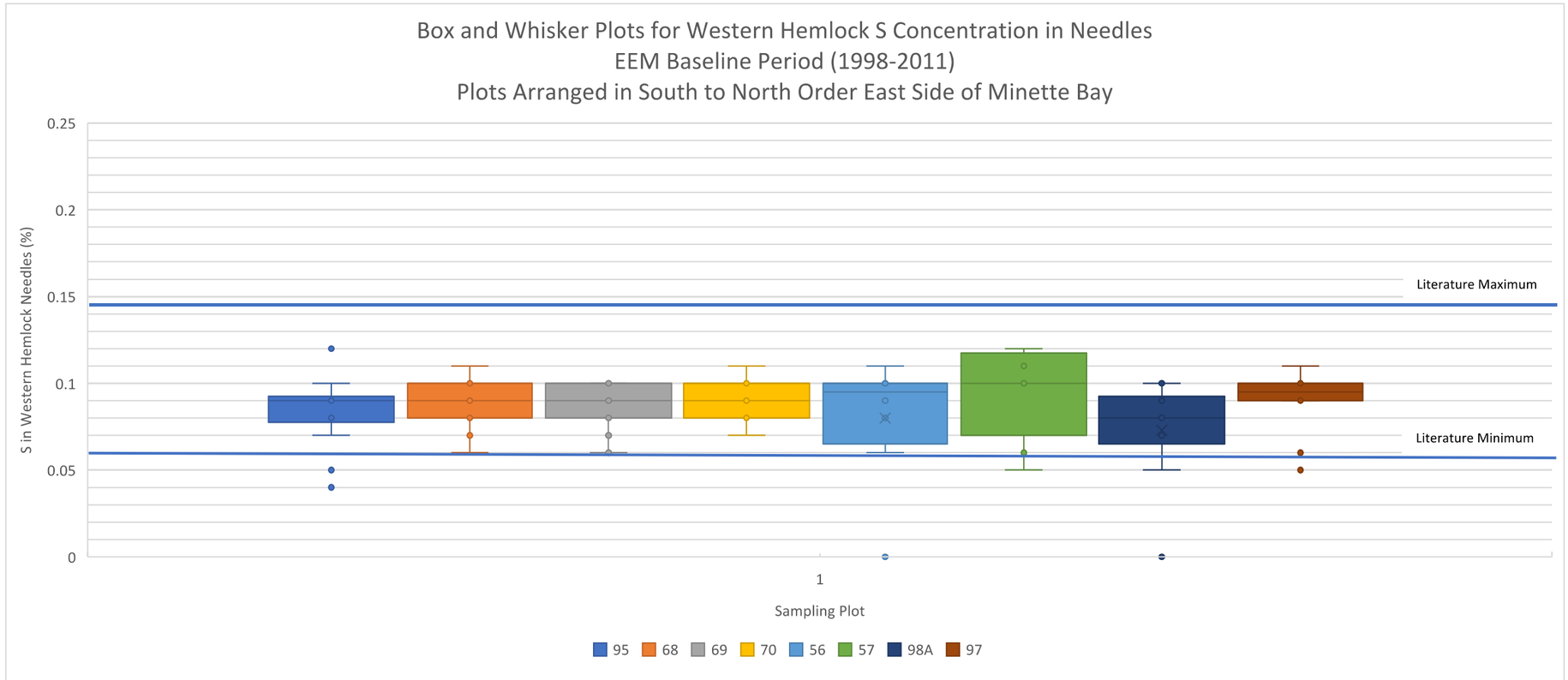

Site 98A Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

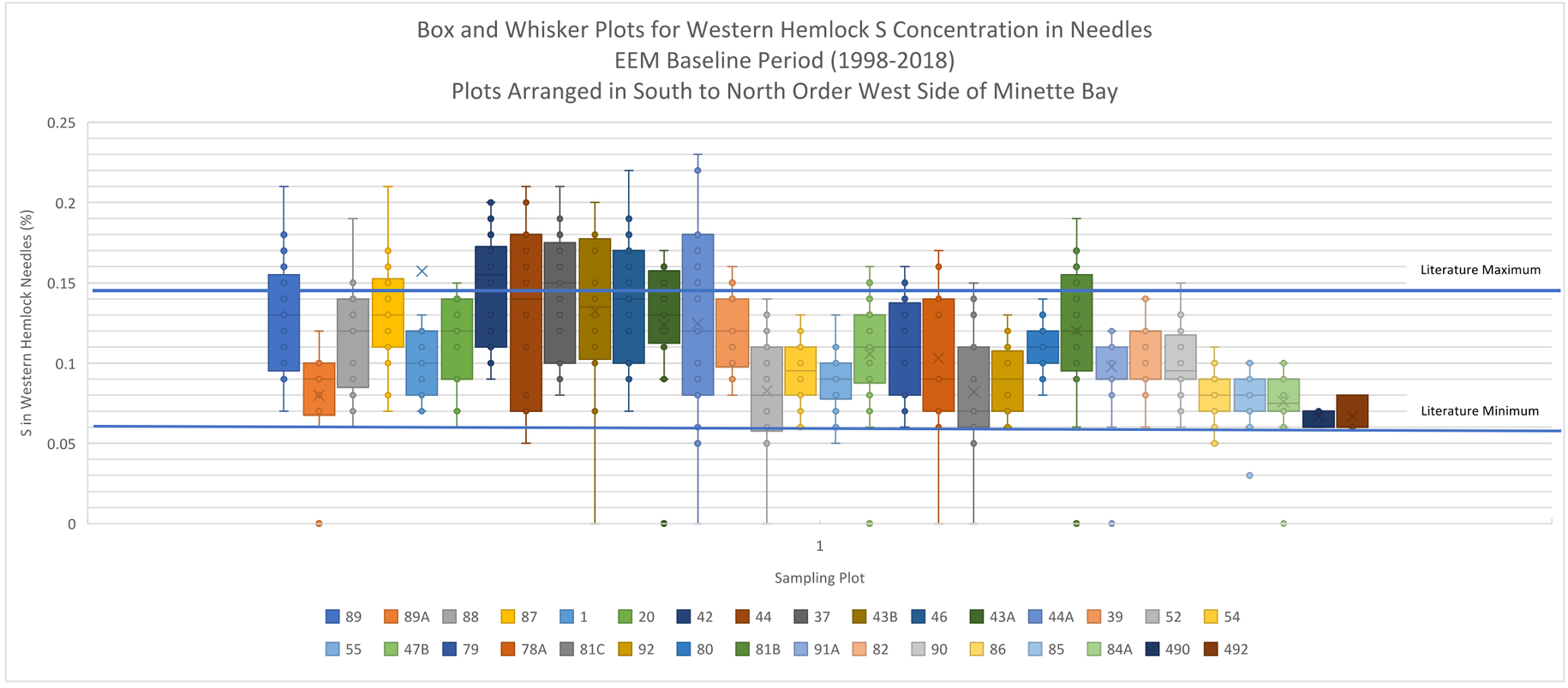

Site 490 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO2 Emissions (tonnes/day)

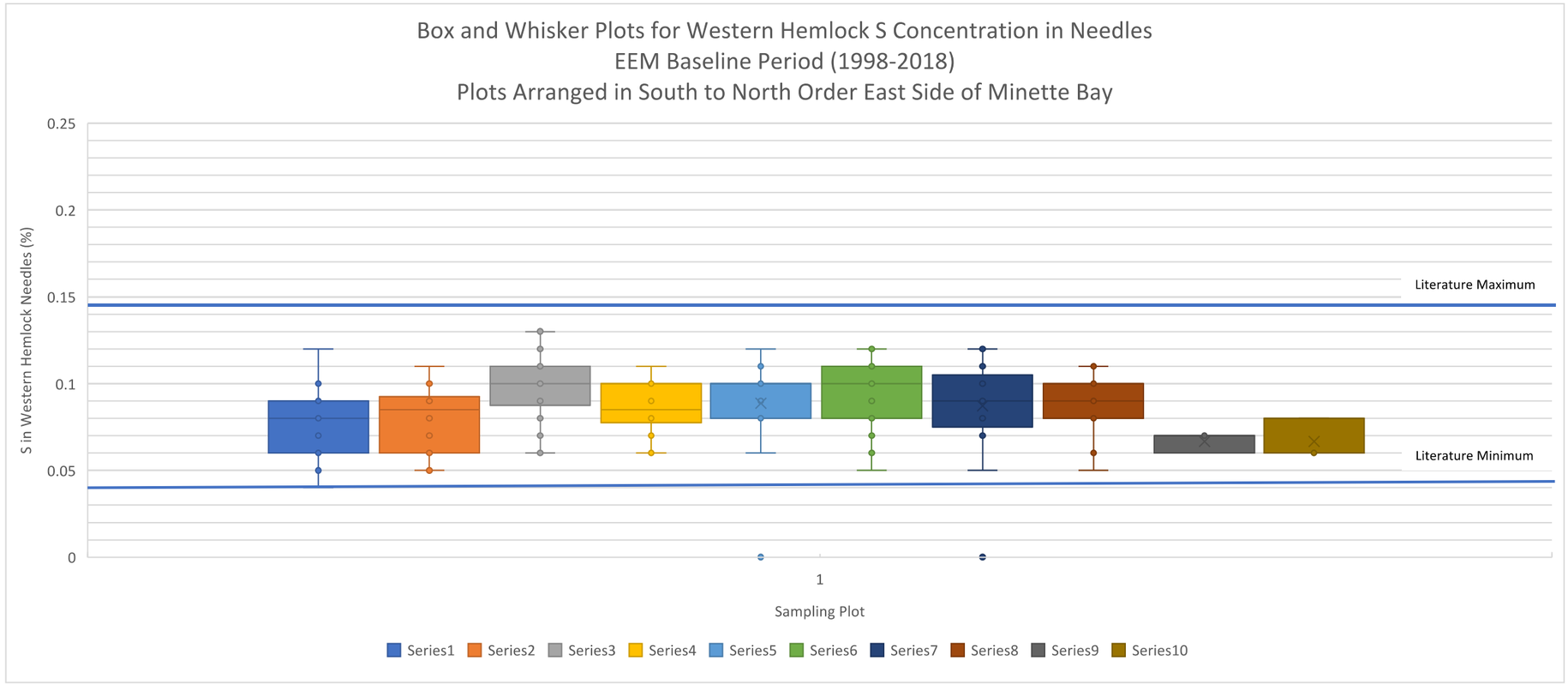

Site 492 Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO_2 emissions
Literature reported range in S% in BC western hemlock
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
SO_2 Emissions (tonnes/day)

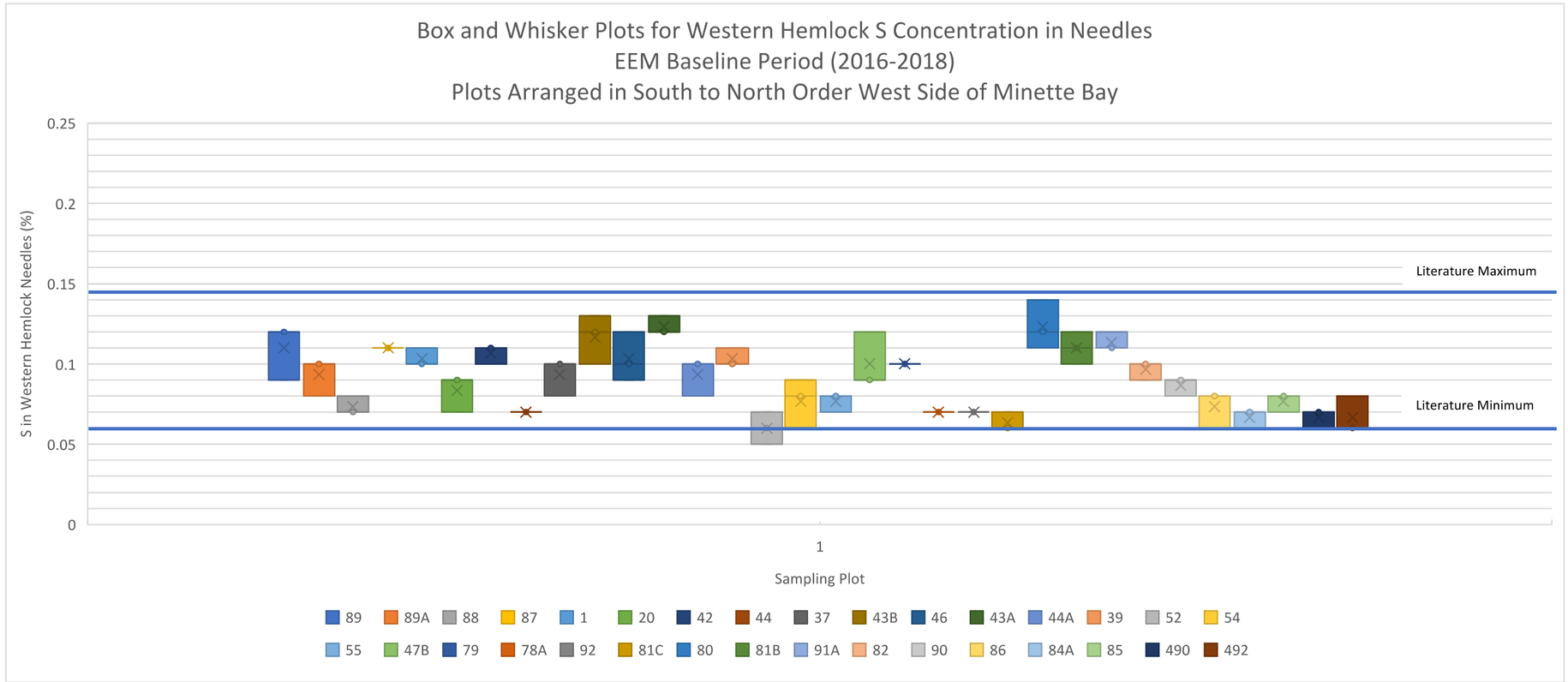

All Sites Sulphur Concentrations 1998-2018
S concentration in western hemlock needles (%)
0.25
0.2
0.15
0.1
0.05
0
Maximum pre-KMP SO2 emissions
Literature reported range
in S% in BC western hemlock
0
5
10
15
20
25
30
35
SO2 Emissions (tonnes/day)

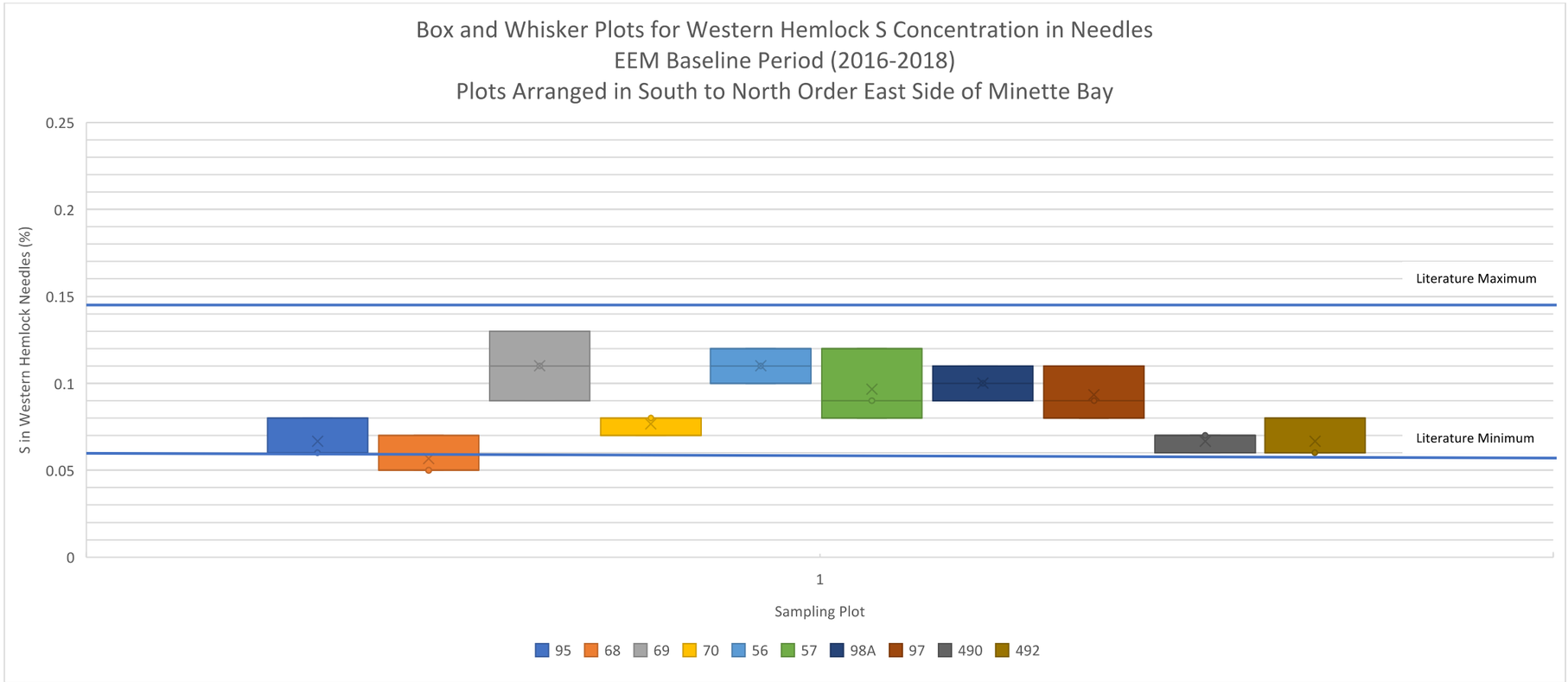

Box and Whisker Plots for Western Hemlock S Concentration in Needles
EEM Baseline Period (1998-2011)
Plots Arranged in South to North Order West Side of Minette Bay
S in Western Hemlock Needles (%)
0.25
0.2
0.15
0.1
0.05
0
Literature Maximum
Literature Minimum
1
Sampling Plot
89
89A
88
87
1
20
42
44
37
43B
46
43A
44A
39
52(A)
54
55
47B
79
78 (A)
92
81C
80
81B
91(A)
82
90
86
85
84 (A) (B)


Box and Whisker Plots for Western Hemlock S Concentration in Needles
EEM Baseline Period (1998-2011)
Plots Arranged in South to North Order East Side of Minette Bay
S in Western Hemlock Needles (%)
0.25
0.2
0.15
0.1
0.05
0
Literature Maximum
Literature Minimum
1
Sampling Plot
95
68
69
70
56
57
98A
97


Box and Whisker Plots for Western Hemlock S Concentration in Needles
EEM Baseline Period (1998-2018)
Plots Arranged in South to North Order West Side of Minette Bay
S in Western Hemlock Needles (%)
0.25
0.2
0.15
0.1
0.05
0
Literature Maximum
Literature Minimum
1
Sampling Plot
89 89A 88 87 1 20 42 44 37 43B 46 43A 44A 39 52 54
55 47B 79 78A 81C 92 80 81B 91A 82 90 86 85 84A 490 492


Box and Whisker Plots for Western Hemlock S Concentration in Needles
EEM Baseline Period (1998-2018)
Plots Arranged in South to North Order East Side of Minette Bay
S in Western Hemlock Needles (%)
0.25
0.2
0.15
0.1
0.05
0
Literature Maximum
Literature Minimum
1
Sampling Plot
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10


Box and Whisker Plots for Western Hemlock S Concentration in Needles
EEM Baseline Period (2016-2018)
Plots Arranged in South to North Order West Side of Minette Bay
S in Western Hemlock Needles (%)
0.25
0.2
0.15
0.1
0.05
0
Literature Maximum
Literature Minimum
1
Sampling Plot
89 89A 88 87 1 20 42 44 37 43B 46 43A 44A 39 52 54
55 47B 79 78A 92 81C 80 81B 91A 82 90 86 84A 85 490 492


Box and Whisker Plots for Western Hemlock S Concentration in Needles
EEM Baseline Period (2016-2018)
Plots Arranged in South to North Order East Side of Minette Bay
S in Western Hemlock Needles (%)
0.25
0.2
0.15
0.1
0.05
0
Literature Maximum
Literature Minimum
1
Sampling Plot
95
68
69
70
56
57
98A
97
490
492

5.6 Information from the BC Conservation Data Centre

The species and ecological communities that potentially occur in the study area are shown in Table 5.20 and Table 5.21.

Table 5.20: Red-listed species and ecological communities that occur or potentially occur in the study area.

Scientific Name(s)	Common Name(s)
Acroscyphus sphaerophoroides	mountain crab-eye
Arctopoa eminens	eminent bluegrass
Leymus mollis ssp. *mollis - Lathyrus japonicus*	dune wildrye - beach pea
Picea sitchensis / Rubus spectabilis	Sitka spruce / salmonberry Very Wet Maritime
Picea sitchensis / Rubus spectabilis	Sitka spruce / salmonberry Wet Submaritime 1
Pinus contorta / Arctostaphylos uva-ursi	lodgepole pine / kinnikinnick
Sclerophora peronella	frosted glass-whiskers

Source: BC Species and Ecosystem Explorer (http://a100.gov.bc.ca/pub/eswp/) accessed January 17, 2020.

Table 5.21: Blue-listed species and communities that occur or potentially occur in the study area.

Scientific Name(s)	Common Name(s)
Abies amabilis - Picea sitchensis / Oplopanax horridus	amabilis fir - Sitka spruce / devil's club
Abies amabilis - Thuja plicata / Gymnocarpium dryopteris	amabilis fir - western redcedar / oak fern
Abies amabilis - Thuja plicata / Oplopanax horridus	amabilis fir - western redcedar / devil's club Moist Submaritime
Abies amabilis - Thuja plicata / Rubus spectabilis	amabilis fir - western redcedar / salmonberry Very Wet Maritime
Lobaria retigera	smoker's lung
Nephroma occultum	cryptic paw
Picea sitchensis / Rubus spectabilis	Sitka spruce / salmonberry Wet Submaritime 2
Populus trichocarpa - Alnus rubra / Rubus spectabilis	black cottonwood - red alder / salmonberry
Pseudocyphellaria rainierensis	oldgrowth specklebelly
Thuja plicata - Picea sitchensis / Lysichiton americanus	western redcedar - Sitka spruce / skunk cabbage
Thuja plicata - Picea sitchensis / Polystichum munitum	western redcedar - Sitka spruce / sword fern
Thuja plicata - Tsuga heterophylla / Polystichum munitum	western redcedar - western hemlock / sword fern
Tsuga heterophylla - Abies amabilis / Struthiopteris spicant	western hemlock - amabilis fir / deer fern
Tsuga heterophylla - Pinus contorta / Pleurozium schreberi	western hemlock - lodgepole pine / red-stemmed feathermoss
Tsuga heterophylla - Thuja plicata / Gaultheria shallon	western hemlock - western redcedar / salal Very Wet Maritime

Source: BC Species and Ecosystem Explorer (http://a100.gov.bc.ca/pub/eswp/)

The following report is from the British Columbia Conservation Data Centre with occurrence and approximate locations of Red- and Blue-listed species and ecological communities in the study area. This report has been inserted in its original format as a PDF file on the subsequent pages, and as such has different headers and footers from this main appendix file.

BC Conservation Data Centre: Ecosystem Occurrence Report
Shape ID: 70480

Scientific Name: *Populus trichocarpa - Alnus rubra / Rubus spectabilis*

English Name: black cottonwood - red alder / salmonberry

Identifiers

Occurrence ID: 9663

Shape ID: 70480

Element Group: Ecological Community

Status

Provincial Rank: S3

BC List: Blue

Global Rank: GNR

Locators

Survey Site: SKEENA RIVER, AT ZYMAGOTITZ RIVER

Directions:

Biogeoclimatic Unit: CWH ws 1

Ecosection: NAM

Occurrence Information

First Observation Date: 1994 **Last Observation Date:** 2004

Occurrence Data:

This deciduous riparian forest occurrence is based on Terrestrial Ecosystem Mapping (TEM). It is mapped as young to mature black cottonwood dominated forests on a middle bench floodplain that have mostly regenerated after harvesting. This ecological community occupies approximately 20 ha or 57% of the area shown.

General Description:

This occurrence is on the north bank of the Skeena River at New Remo. It is bisected by Highway 16 and the CN rail line. It is associated with with high bench floodplain ecosystems and gravel bars; and is surrounded by the Skeena River to the south and the Zymagotiz River to the north.

Environmental Summary:

The terrain is a fluvial plain.

Occurrence Rank and Occurrence Rank Factors

Rank*: E : Verified extant (viability not assessed)

Note: in the case of Ecological Communities, "viability" should read as "ecological integrity".

Rank Date:

Rank Comments:

Condition of Occurrence:

Size of Occurrence:

19.5 ha

Landscape Context:

Version

Version Date: 2012-03-23

Version Author: de Groot, A.

Mapping Information

Estimated Representation Accuracy:	Medium
Estimated Representation Accuracy Comments:	The ecological community occupies 56.78% (19.5 ha) of the mapped occurrence.
Confident that full extent is represented by Occurrence:	?
Confidence extent Definition:	Uncertain whether full extent of EO is known
Additional Inventory Needed:	Y
Inventory Comments:	This element occurrence is based on available ecosystem mapping. Many factors influence the reliability of an ecosystem map. Depending on the scale of aerial images used to capture the ecosystems, very small ecosystems and some types of disturbance may not be visible and will not be mapped. If the air photos are not current, new disturbance may have occurred since the time of mapping and the inventory may not accurately represent the current state of the landscape. Other factors, such as the skill and experience of the mapper within the study area, and the field survey intensity level will also influence the reliability of the map.

Documentation

References:

de Groot, A,, S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics Mapping, and Conservation Ranking, of the Skeena River Floodplain Forests. 1:20,000 spatial data.

de Groot, A. 2005. Review of the Hydrology, Geomorphology and Ecology of the Skeena River Floodplain Downstream of Terrace. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

de Groot, A., S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics, and Conservation Ranking, of the Skeena River Floodplain Forests. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

Please visit the website http://www.env.gov.bc.ca/cdc/gis/eo_data_fields_06.htm for definitions of the data fields used in this occurrence report.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 70480, black cottonwood - red alder / salmonberry. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Ecosystem Occurrence Report
Shape ID: 70598

Scientific Name: *Picea sitchensis / Rubus spectabilis* Wet Submaritime 1

English Name: Sitka spruce / salmonberry Wet Submaritime 1

Identifiers

Occurrence ID: 9674

Shape ID: 70598

Element Group: Ecological Community

Status

Provincial Rank: S2

BC List: Red

Global Rank: G3

Locators

Survey Site: SKEENA RIVER, DOWNSTREAM OF TERRACE TO SHAMES RIVER

Directions:

Biogeoclimatic Unit: CWH ws 1

Ecosection: NAM

Occurrence Information

First Observation Date: 1993 **Last Observation Date:** 2004-09-02

Occurrence Data:

This coniferous riparian forest occurrence is based on Terrestrial Ecosystem Mapping (TEM) and has been confirmed by several ecosystem plots. It is comprised of pole-sapling, young, mature and old Sitka spruce dominated forests. These forests are either primary stands or secondary stands that have regenerated after clear-cut or partial-cut forest harvesting. Other tree species include black cottonwood, western redcedar and red alder. This ecological community occupies approximately 363 ha or 82% of the area shown.

General Description:

This occurrence is located along the Skeena River downstream of Terrace. It is associated with middle and low bench floodplain ecosystems. There is an urban area just upstream, and some nearby areas of forest harvesting and agriculture.

Environmental Summary:

This occurrence is located on a fluvial plain. Soil materials are silty.

Occurrence Rank and Occurrence Rank Factors

Rank*: E : Verified extant (viability not assessed)

Note: in the case of Ecological Communities, "viability" should read as "ecological integrity".

Rank Date:

Rank Comments:

Condition of Occurrence:

Size of Occurrence:

1200.6 ha

Landscape Context:

Version

Version Date: 2012-03-26

Version Author: de Groot, A.

Mapping Information

Estimated Representation Accuracy: Medium

Estimated Representation Accuracy Comments: The ecological community occupies 76.08% (1200.6 ha) of the mapped occurrence.

Confident that full extent is represented by Occurrence: ?

Confidence extent Definition: Uncertain whether full extent of EO is known

Additional Inventory Needed: Y

Inventory Comments: Project name - Landscape and stand scale structure and dynamics, and conservation ranking of Skeena River floodplain forests

This element occurrence is based on available ecosystem mapping. Many factors influence the reliability of an ecosystem map. Depending on the scale of aerial images used to capture the ecosystems, very small ecosystems and some types of disturbance may not be visible and will not be mapped. If the air photos are not current, new disturbance may have occurred since the time of mapping and the inventory may not accurately represent the current state of the landscape. Other factors, such as the skill and experience of the mapper within the study area, and the field survey intensity level will also influence the reliability of the map.

Documentation

References:

de Groot, A,, S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics Mapping, and Conservation Ranking, of the Skeena River Floodplain Forests. 1:20,000 spatial data.

de Groot, A. 2005. Review of the Hydrology, Geomorphology and Ecology of the Skeena River Floodplain Downstream of Terrace. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

de Groot, A., S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics, and Conservation Ranking, of the Skeena River Floodplain Forests. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

de Groot, A., and C.M. Cadrin. 2012b. Element occurrence and element occurrence rank specifications for coniferous floodplain forests of coastal British Columbia. Unpublished document. Version October, 2012. B.C. Minist. Environ., Conservation Data Centre, Victoria, B.C. 5 pp.

Please visit the website http://www.env.gov.bc.ca/cdc/gis/eo_data_fields_06.htm for definitions of the data fields used in this occurrence report.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 70598, Sitka spruce / salmonberry Wet Submaritime 1. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Ecosystem Occurrence Report
Shape ID: 70497

Scientific Name: *Populus trichocarpa - Alnus rubra / Rubus spectabilis*

English Name: black cottonwood - red alder / salmonberry

Identifiers

Occurrence ID: 9665

Shape ID: 70497

Element Group: Ecological Community

Status

Provincial Rank: S3

BC List: Blue

Global Rank: GNR

Locators

Survey Site: SKEENA RIVER, AT TERRACE

Directions:

Biogeoclimatic Unit: CWH ws 1

Ecosection: NAM

Occurrence Information

First Observation Date: 2003 **Last Observation Date:** 2004-08-31

Occurrence Data:

This deciduous riparian forest occurrence is based on Terrestrial Ecosystem Mapping (TEM) and has been confirmed by several ecosystem plots. It is comprised of young to mature black cottonwood dominated forests on a middle bench floodplain that is a mixture of primary stands and stands that have regenerated after harvesting. Red alder, Sitka spruce and western hemlock may be present in the understory. Soils are generally silty. This ecological community occupies approximately 20 ha or 57% of the area shown.

General Description:

This occurrence is located in the Skeena River immediately downstream of Terrace. It is associated with high bench and low bench floodplain ecosystems. Erosion and deposition is ongoing, shifting the ecosystem types. Adjacent areas are partly urban, but other areas have little or no disturbance evident.

Environmental Summary:

The occurrence is located on a fluvial plain with silty soils.

Occurrence Rank and Occurrence Rank Factors

Rank*: E : Verified extant (viability not assessed)

Note: in the case of Ecological Communities, "viability" should read as "ecological integrity".

Rank Date:

Rank Comments:

Condition of Occurrence:

Size of Occurrence:

288.94 ha

Landscape Context:

Version

Version Date: 2012-03-26

Version Author: de Groot, A.

Mapping Information

Estimated Representation Accuracy: Medium

Estimated Representation Accuracy Comments: The ecological community occupies 75.32% (288.94 ha) of the mapped occurrence.

Confident that full extent is represented by Occurrence: ?

Confidence extent Definition: Uncertain whether full extent of EO is known

Additional Inventory Needed: Y

Inventory Comments: Project name - Landscape and stand scale structure and dynamics, and conservation ranking of Skeena River floodplain forests

This element occurrence is based on available ecosystem mapping. Many factors influence the reliability of an ecosystem map. Depending on the scale of aerial images used to capture the ecosystems, very small ecosystems and some types of disturbance may not be visible and will not be mapped. If the air photos are not current, new disturbance may have occurred since the time of mapping and the inventory may not accurately represent the current state of the landscape. Other factors, such as the skill and experience of the mapper within the study area, and the field survey intensity level will also influence the reliability of the map.

Documentation

References:

de Groot, A,, S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics Mapping, and Conservation Ranking, of the Skeena River Floodplain Forests. 1:20,000 spatial data.

de Groot, A. 2005. Review of the Hydrology, Geomorphology and Ecology of the Skeena River Floodplain Downstream of Terrace. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

de Groot, A., S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics, and Conservation Ranking, of the Skeena River Floodplain Forests. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

Please visit the website http://www.env.gov.bc.ca/cdc/gis/eo_data_fields_06.htm for definitions of the data fields used in this occurrence report.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 70497, black cottonwood - red alder / salmonberry. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Ecosystem Occurrence Report
Shape ID: 70597

Scientific Name: *Populus trichocarpa - Alnus rubra / Rubus spectabilis*

English Name: black cottonwood - red alder / salmonberry

Identifiers

Occurrence ID: 9673

Shape ID: 70597

Element Group: Ecological Community

Status

Provincial Rank: S3

BC List: Blue

Global Rank: GNR

Locators

Survey Site: SKEENA RIVER, DOWNSTREAM OF TERRACE

Directions:

Biogeoclimatic Unit: CWH vm 1;CWH ws 1

Ecosection: KIR;NAM

Occurrence Information

First Observation Date: 1994 **Last Observation Date:** 2004-09-01

Occurrence Data:

This deciduous riparian forest occurrence is based on Terrestrial Ecosystem Mapping (TEM) and has been confirmed by numerous ecosystem plots. It is comprised of young to mature black cottonwood dominated forests on a middle bench floodplain, which are a mixture of primary stands and secondary stands that have regenerated after harvesting. Red alder, Sitka spruce and western redcedar may be present in the understory. Soils maybe sandy loam or silty. This ecological community occupies approximately 3,276 ha or 68% of the area shown.

General Description:

This occurrence is located on the floodplain of the Skeena River downstream of Terrace, from Zymagotitz River to Kwinitsa Creek. It is approximately 60 km long. It is associated with and surrounded by high and low bench floodplain ecosystems. These ecosystems are subject to erosional and depositional processes, and are shifting over time.

Environmental Summary:

The occurrence is mapped on a fluvial plain, with silty to sandy soils.

Occurrence Rank and Occurrence Rank Factors

Rank*: E : Verified extant (viability not assessed)

Note: in the case of Ecological Communities, "viability" should read as "ecological integrity".

Rank Date:

Rank Comments:

Condition of Occurrence:

Size of Occurrence:

3,275.8 ha

Landscape Context:

Version

Version Date: 2012-03-26

Version Author: de Groot, A.

Mapping Information

Estimated Representation Accuracy: Medium

Estimated Representation Accuracy Comments: The ecological community occupies 67.9% (3275.8 ha) of the mapped occurrence.

Confident that full extent is represented by Occurrence: ?

Confidence extent Definition: Uncertain whether full extent of EO is known

Additional Inventory Needed: Y

Inventory Comments: Project name - Landscape and stand scale structure and dynamics, and conservation ranking of Skeena River floodplain forests

This element occurrence is based on available ecosystem mapping. Many factors influence the reliability of an ecosystem map. Depending on the scale of aerial images used to capture the ecosystems, very small ecosystems and some types of disturbance may not be visible and will not be mapped. If the air photos are not current, new disturbance may have occurred since the time of mapping and the inventory may not accurately represent the current state of the landscape. Other factors, such as the skill and experience of the mapper within the study area, and the field survey intensity level will also influence the reliability of the map.

Documentation

References:

de Groot, A,, S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics Mapping, and Conservation Ranking, of the Skeena River Floodplain Forests. 1:20,000 spatial data.

de Groot, A. 2005. Review of the Hydrology, Geomorphology and Ecology of the Skeena River Floodplain Downstream of Terrace. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

de Groot, A., S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics, and Conservation Ranking, of the Skeena River Floodplain Forests. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

Please visit the website http://www.env.gov.bc.ca/cdc/gis/eo_data_fields_06.htm for definitions of the data fields used in this occurrence report.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 70597, black cottonwood - red alder / salmonberry. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Ecosystem Occurrence Report
Shape ID: 70489

Scientific Name: *Picea sitchensis / Rubus spectabilis* Wet Submaritime 1

English Name: Sitka spruce / salmonberry Wet Submaritime 1

Identifiers

Occurrence ID: 9664

Shape ID: 70489

Element Group: Ecological Community

Status

Provincial Rank: S2

BC List: Red

Global Rank: G3

Locators

Survey Site: SKEENA RIVER, AT REMO

Directions:

Biogeoclimatic Unit: CWH ws 1

Ecosection: NAM

Occurrence Information

First Observation Date: 1994 **Last Observation Date:** 2004

Occurrence Data:

This coniferous riparian forest occurrence is based on Terrestrial Ecosystem Mapping (TEM). It is comprised of pole-sapling, mature and old forests. This ecological community occupies approximately 18 ha or 42% of the area shown.

General Description:

This occurrrence is located on the north bank of the Skeena River at Remo. It is associated with middle bench floodplain and backchannels of the Skeena River. It is surrounded by residential development, railway and fields.

Environmental Summary:

This occurrence is located on a fluvial plain.

Occurrence Rank and Occurrence Rank Factors

Rank*: E : Verified extant (viability not assessed)

Note: in the case of Ecological Communities, "viability" should read as "ecological integrity".

Rank Date:

Rank Comments:

Condition of Occurrence:

Size of Occurrence:

17.79 ha

Landscape Context:

Version

Version Date: 2012-03-26

Version Author: de Groot, A.

Mapping Information

Estimated Representation Accuracy:	Medium
Estimated Representation Accuracy Comments:	The ecological community occupies 41.53% (17.79 ha) of the mapped occurrence.
Confident that full extent is represented by Occurrence:	?
Confidence extent Definition:	Uncertain whether full extent of EO is known
Additional Inventory Needed:	Y
Inventory Comments:	This element occurrence is based on available ecosystem mapping. Many factors influence the reliability of an ecosystem map. Depending on the scale of aerial images used to capture the ecosystems, very small ecosystems and some types of disturbance may not be visible and will not be mapped. If the air photos are not current, new disturbance may have occurred since the time of mapping and the inventory may not accurately represent the current state of the landscape. Other factors, such as the skill and experience of the mapper within the study area, and the field survey intensity level will also influence the reliability of the map.

Documentation

References:

de Groot, A,, S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics Mapping, and Conservation Ranking, of the Skeena River Floodplain Forests. 1:20,000 spatial data.

de Groot, A. 2005. Review of the Hydrology, Geomorphology and Ecology of the Skeena River Floodplain Downstream of Terrace. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

de Groot, A., S. Haussler and D. Yole. 2005. Landscape and Stand Scale Structure and Dynamics, and Conservation Ranking, of the Skeena River Floodplain Forests. Bulkley Valley Centre for Natural Resource Research and Management, Smithers, B.C.

Please visit the website http://www.env.gov.bc.ca/cdc/gis/eo_data_fields_06.htm for definitions of the data fields used in this occurrence report.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 70489, Sitka spruce / salmonberry Wet Submaritime 1. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Species Occurrence Report
Shape ID: 3716

Scientific Name: *Arctopoa eminens*
English Name: eminent bluegrass

Identifiers

Occurrence ID: 4150
Shape ID: 3716
Taxonomic Class: monocots
Element Group: Vascular Plant

Status

Provincial Rank: S1S2
BC List: Red
Global Rank: G5
COSEWIC:
SARA Schedule:

Locators

Survey Site: BISH CREEK, MOUTH OF
Directions:
Biogeoclimatic Zone:
Ecosection: NCF;KIR

Area Description

General Description:

Vegetation Zone: Lowland
Min. Elevation (m):
Max. Elevation (m):
Habitat: ESTUARINE; TIDAL FLAT

Occurrence Information

First Observation Date: 1977-06-12

Last Observation Date: 1977-06-12

Occurrence Data:

Tide water predominant.

Occurrence Rank and Occurrence Rank Factors

Rank: H : Historical

Rank Date: 1977-06-12

Rank Comments:

There is insufficient data to assign a viability rank.

Condition of Occurrence:

Size of Occurrence:

Landscape Context:

Version

Version Date: 1994-12-17

Version Author: DOUGLAS, G.D.

Mapping Information

Estimated Representation Accuracy:

Estimated Representation Accuracy Comments:

Confident that full extent is represented by Occurrence:

Confidence Extent Definition:

Additional Inventory Needed: N

Inventory Comments:

Documentation

References:

Royal British Columbia Museum. 675 Belleville Street, Victoria, BC. V8V 1X4.

Specimen: Mendel, G.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 3716, eminent bluegrass. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Species Occurrence Report
Shape ID: 33798

Scientific Name: *Nephroma occultum*
English Name: cryptic paw

Identifiers

Occurrence ID: 7233
Shape ID: 33798
Taxonomic Class:
Element Group: Fungus

Status

Provincial Rank: S3
BC List: Blue
Global Rank: G4
COSEWIC: T (MAY 2019)
SARA Schedule: 1

Locators

Survey Site: KITIMAT VILLAGE
Directions: South of Terrace, at the head of Kitimat Arm.
Biogeoclimatic Zone:
Ecosection: NCF;KIR

Area Description

General Description:

Epiphytic in humid, old growth forests (COSEWIC 2006g).

Vegetation Zone: Lowland
Min. Elevation (m): 0 **Max. Elevation (m):** 10
Habitat: TERRESTRIAL: Epiphytic; Old Forest

Occurrence Information

First Observation Date: 1991-08-28 **Last Observation Date:** 1991-08-28

Occurrence Data:

1991-08-28: Collected (University of British Columbia herbarium)

Occurrence Rank and Occurrence Rank Factors

Rank: B? : Possibly good estimated viability

Rank Date: 1991-08-28

Rank Comments:

Appears to be successfully regenerating, but is not abundant and is potentially threatened by forest harvest.

Condition of Occurrence:

Seems to show good vigour with many young thalli having been noted (Goward 1995).

Size of Occurrence:

Not abundant (Goward 1995).

Landscape Context:

The continued logging of oldgrowth forests in B.C. is leading to a steady decline of this species throughout most of its range (Goward 1995).

Version

Version Date: 2007-03-08

Version Author: Varrin, G.

Mapping Information

Estimated Representation Accuracy: Low

Estimated Representation Accuracy Comments:

Confident that full extent is represented by Occurrence: ?

Confidence Extent Definition: Uncertain whether full extent of EO is known

Additional Inventory Needed: Y

Inventory Comments: To determine full extent and viability of population.

Documentation

References:

COSEWIC. 2006g. COSEWIC assessment and update status report on the cryptic paw Nephroma occultum in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 28 pp.

Goward, T. 1995. Status report on the Cryptic Paw Lichen, Nephroma occultum Wetm. in Canada. Rep. submitted to the Comm. on the Status of Endangered Wildl. in Can. (COSEWIC). Ottawa. 32pp.

University of British Columbia. Dep. Bot., Dep. Zool., Biol. Sci. Bldg., 6270 Univ. Blvd., Vancouver, BC.

Specimen: Goward, T. (91-1240). 1991. UBC.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 33798, cryptic paw. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Species Occurrence Report
Shape ID: 74212

Scientific Name: *Arctopoa eminens*
English Name: eminent bluegrass

Identifiers

Occurrence ID: 10155
Shape ID: 74212
Taxonomic Class: monocots
Element Group: Vascular Plant

Status

Provincial Rank: S1S2
BC List: Red
Global Rank: G5
COSEWIC:
SARA Schedule:

Locators

Survey Site: DALA-KILDALA ESTUARY PARK
Directions: Kildala River estuary; near Kitimat.
Biogeoclimatic Zone:
Ecosection: NCF;KIR

Area Description

General Description:

Vegetation Zone: Lowland
Min. Elevation (m):
Max. Elevation (m):
Habitat: ESTUARINE: Tidal Flat

Occurrence Information

First Observation Date: 1985-07-31 **Last Observation Date:** 1985-07-31

Occurrence Data:

1985-07-31: Collected (Royal British Columbia Museum).

Occurrence Rank and Occurrence Rank Factors

Rank: E : Verified extant (viability not assessed)

Rank Date: 1985-07-31

Rank Comments:

There is not enough information to rank this occurrence.

Condition of Occurrence:

[No data provided.]

Size of Occurrence:

[No data provided.]

Landscape Context:

[No data provided.]

Version

Version Date: 2012-10-30

Version Author: Sinclair, L.

Mapping Information

Estimated Representation Accuracy: Low

Estimated Representation Accuracy Comments:

Confident that full extent is represented by Occurrence: ?

Confidence Extent Definition: Uncertain whether full extent of EO is known

Additional Inventory Needed: Y

Inventory Comments:

Documentation

References:

Royal British Columbia Museum. 675 Belleville Street, Victoria, BC. V8V 1X4.

Specimen: Cambell, A. (A). 1985. V133566A. V. ; Cambell. A. (B). 1985. V133566B. V. ; Cambell, A. (C). 1985. V133566C. V.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 74212, eminent bluegrass. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Species Occurrence Report
Shape ID: 96973

Scientific Name: *Pseudocyphellaria rainierensis*

English Name: oldgrowth specklebelly

Identifiers

Occurrence ID: 12220

Shape ID: 96973

Taxonomic Class:

Element Group: Fungus

Status

Provincial Rank: S2S3

BC List: Blue

Global Rank: G4

COSEWIC: SC (APR 2010)

SARA Schedule: 1

Locators

Survey Site: MINETTE BAY CREEK, KITIMAT

Directions: On trail to Robinson Lake above Kitamat Village, at north end of boardwalk on yellow cedar at edge of wetland.

Biogeoclimatic Zone:

Ecosection: KIR

Area Description

General Description:

Vegetation Zone: Lowland

Min. Elevation (m): 367 **Max. Elevation (m):**

Habitat: TERRESTRIAL: Forest Needleleaf

Occurrence Information

First Observation Date: 2013-06-25 **Last Observation Date:** 2013-06-25

Occurrence Data:

2013-06-25: On 5 or 6 small stunted yellow cedar trees growing in association with Lobaria oregana (University of British Columbia Herbarium).

Occurrence Rank and Occurrence Rank Factors

Rank: E : Verified extant (viability not assessed)

Rank Date: 2013-06-25

Rank Comments:

Condition of Occurrence:

[No data provided.]

Size of Occurrence:

2013: On 5 or 6 small stunted yellow cedar trees (University of British Columbia Herbarium).

Landscape Context:

[No data provided.]

Version

Version Date: 2014-10-24

Version Author: Chytyk, P.

Mapping Information

Estimated Representation Accuracy: High

Estimated Representation Accuracy Comments:

Confident that full extent is represented by Occurrence: ?

Confidence Extent Definition: Uncertain whether full extent of EO is known

Additional Inventory Needed: Y

Inventory Comments: To determine full extent and viability of population.

Documentation

References:

University of British Columbia. Dep. Bot., Dep. Zool., Biol. Sci. Bldg., 6270 Univ. Blvd., Vancouver, BC.

Specimen: Williston, P. (8621). 2013. UBC.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 96973, oldgrowth specklebelly. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Species Occurrence Report
Shape ID: 97189

Scientific Name: *Lobaria retigera*
English Name: smoker's lung

Identifiers

Occurrence ID: 12250
Shape ID: 97189
Taxonomic Class:
Element Group: Fungus

Status

Provincial Rank: S3
BC List: Blue
Global Rank: GNR
COSEWIC: T (MAY 2018)
SARA Schedule:

Locators

Survey Site: FURLONG BAY, LAKELSE LAKE
Directions: Terrace area: 18 km south of Terrace at Lakelse Provincial Park (Furlong Bay).
Biogeoclimatic Zone:
Ecosection: NAM

Area Description

General Description:

Located in open, old growth coniferous dominant stand.

Vegetation Zone: Lowland
Min. Elevation (m): 61 **Max. Elevation (m):** 90
Habitat: TERRESTRIAL: Forest Needleleaf, Old Forest, Epiphytic

Occurrence Information

First Observation Date: 1970-07-24 **Last Observation Date:** 2015-10-08

Occurrence Data:

2015-10-08: One, old thallus over 1 square m (1 m x 1 m) on an Acer twig in oldgrowth (or selectively logged) Thuja-dominated rain forest. Associates include: Porella navicularis and Lobaria oregana. On a level slope position with a slope of 0%. Filtered crown closure and very moist moisture regime (Bjork 2016a,b,c). 1991-08-27: Branch of Tsuga sp. in open old growth Picea-Tsuga forest (University of British Columbia Herbarium). 1970-07-24: Forest primarily of cedars and firs (University of British Columbia Herbarium).

Occurrence Rank and Occurrence Rank Factors

Rank: D : Poor estimated viability

Rank Date: 2015-10-08

Rank Comments:

Small population within provincial park, with no evidence of successful reproduction.

Condition of Occurrence:

2015: Old thallus, no juveniles present. Overall quality of the occurrence is poor (Bjork 2016a,b,c).

Size of Occurrence:

2015: One thallus over 1 square m (1 m x 1 m) (Bjork 2016a,b,c).

Landscape Context:

2015: Air pollution may be a threat or may become a threat (Bjork 2016a,b,c).

Version

Version Date: 2017-09-12

Version Author: Chytyk, P.

Mapping Information

Estimated Representation Accuracy: High

Estimated Representation Accuracy Comments:

Confident that full extent is represented by Occurrence: N

Confidence Extent Definition: Confident full extent of EO is NOT known

Additional Inventory Needed: Y

Inventory Comments: To determine precise location, full extent and viability of population.

Documentation

References:

Bjork, C. 2016. Report on surveys for Lobaria retigera in the Skeen-Nass-Kispiox Basins, British Columbia. Unpubl. Rep. prepared for the B.C. CDC by Enlichened Consulting Ltd., Clearwater, B.C. 6 pp.

Bjork, C. 2016b. 'Appendix A' for: Report on surveys for Lobaria retigera in the Skeen-Nass-Kispiox Basins, British Columbia. Unpubl. Rep. prepared for the B.C. CDC by Enlichened Consulting Ltd., Clearwater, B.C. 32 pp.

Bjork, C. 2016c. EXCEL spreadsheet of Lobaria retigera and other rare lichens for the Skeen-Nass-Kispiox Basins, British Columbia.

Canadian Museum of Nature. P.O. Box 3443, Stn. "D", Ottawa. K1P 6P4.

Michigan State University Herbarium. Plant Biology Laboratories, Michigan State University, 612 Wilson Road, Room 166, East Lansing, Michigan 48824.

University of British Columbia. Dep. Bot., Dep. Zool., Biol. Sci. Bldg., 6270 Univ. Blvd., Vancouver, BC.

Specimen: Goward, T. and H. Knight. (91-1182). 1991. #L25315. UBC.; Ohlsson, K.E. (2579). 1991. #L32053. CAN.; Ohlsson, K.E. (2579). 1991. #L5090. UBC.; Ohlsson, K.E. (2579). 1991. #59927.

Suggested Citation:

B.C. Conservation Data Centre. 2014. Occurrence Report Summary, Shape ID: 97189, smoker's lung. B.C. Ministry of Environment. Available: http://maps.gov.bc.ca/ess/hm/cdc, (accessed Jul 29, 2019).

BC Conservation Data Centre: Species Occurrence Report
Shape ID: 43828

Scientific Name: *Pseudocyphellaria rainierensis*
English Name: oldgrowth specklebelly

Identifiers

Occurrence ID: 7851
Shape ID: 43828
Taxonomic Class:
Element Group: Fungus

Status

Provincial Rank: S2S3
BC List: Blue
Global Rank: G4
COSEWIC: SC (APR 2010)
SARA Schedule: 1

Locators

Survey Site: KITIMAT, EAST OF
Directions: On the trail to Robinson Lake, leading from the road between Kitimat and Kitimat Mission. Robinson Lake trail, near Volunteer Creek.
Biogeoclimatic Zone:
Ecosection: KIR

Area Description

General Description:

Vegetation Zone: Lowland
Min. Elevation (m): 183
Max. Elevation (m):
Habitat: PALUSTRINE: Herbaceous Wetland

5.7 Species Presence Recorded During Vegetation Sampling and Inspection

This table shows the presence of selected species at vegetation sampling sites during inspections in 2014, 2015, 2016, and 2018. Absence of a species means that it was not observed, not that it didn't exist in a defined area during the inspection. Sampling and inspection methodology did not use a pre-determined defined area that was revisited, but rather an inspection of the general area near the sampled western hemlock.

Table 5.22: Presence of species reported to be sensitive to SO_2 in scientific or anecdotal literature at vegetation inspection and collection sites in 2018. Presence is indicated by an x. Absence does not mean that the species is not present in the area of the site, only that it was not observed during the survey. NV=not visited.

Year	Species\Site	1	20A	37	39	42	43A	43B	44	44A	46	47B	52	54	55	56	57	68	69	70	78A	79	80	81B	81C	82	84A	85	86	87	88	89A	90	91A	92	95	97	98A	490	492
	Shrubs and small stature plants																																							
2014	*Amelanchier alnifolia*			X						N/A			X		X						N/A			N/A	N/A											X			
2015				X											X																						X		
2016			X							N/A					X																						X		
2018				X								X						X	X																				
2014	*Aralia nudicaulis*									N/A											N/A			N/A	N/A															
2015																																								
2016										N/A																														
2018																																								
2014	*Cornus stolonifera*				X					N/A		X	X		X	X	X	X		X	N/A			N/A	N/A			X								X	X	X		
2015			X		X								X	X	X	X		X	X	X						X		X				X	X		X		X		
2016			X		X	X			X	N/A		X		X	X			X				X				X		X							X		X		
2018		X	X		X	X		X	X			X	X	X				X		X						X		X					X		X	X	X		X
2014	*Disporum hookeri*									N/A											N/A			N/A	N/A			X												
2015																																								
2016										N/A																														
2018																																								
2014	*Dryopteris epansa*									N/A											N/A			N/A	N/A															
2015																																								
2016										N/A																														
2018											X																					X								
2014	*Epilobium angustifolium*									N/A											N/A			N/A	N/A															
2015			X	X	X	X		X	X			X		X				X	X	X						X	X	X	X	X	X	X		X		X	X		

Year	Species\Site	1	20A	37	39	42	43A	43B	44	44A	46	47B	52	54	55	56	57	68	69	70	78A	79	80	81B	81C	82	84A	85	86	87	88	89A	90	91A	92	95	97	98A	490	492
2016		X	X	X	X	X			X	N/A	X	X		X		X	X	X	X								X		X		X	X	X		X	X	X	X	X
2018		X	X	X	X	X			X			X	X	X				X	X	X							X		X			X	X	X	X	X	X	X	X	X
2014	*Lycopodium clavatum*									N/A											N/A			N/A	N/A																
2015							X																			X															
2016										N/A																X						X								
2018																																								
2014	*Menziesia ferruginea*						X			N/A											N/A			N/A	N/A		X							X							
2015																									X	X	X			X		X		X	X					
2016										N/A									X						X	X	X	X		X		X							X	
2018											X						X						X		X	X	X	X		X		X	X		X		X		X	
2014	*Pteridium aquilinum*						X		X	N/A	X									X	N/A	X	X	N/A	N/A		X	X					X	X	X					
2015							X	X	X		X			X						X	X	X	X	X	X		X	X		X	X	X	X	X	X		X			
2016						X	X			N/A	X			X							X	X	X				X	X		X		X	X	X	X		X	X		X
2018																			X		X	X	X				X					X		X	X		X			
2014	*Rosa acicularis*									N/A											N/A			N/A	N/A																
2015																X																								
2016										N/A																			X											
2018																																								
2014	*Rubus parviflorus*	X	X	X	X	X	X	X	X	N/A		X	X	X	X	X		X	X	X	N/A	X	X	N/A	N/A	X	X		X				X	X	X	X	X	X		
2015		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X				X	X	X	X	X		X	X	X	X	X		
2016		X	X	X	X	X	X		X	N/A	X	X	X	X		X	X	X	X	X		X	X				X	X	X	X	X		X	X		X	X	X	X
2018		X	X		X	X	X	X	X		X	X	X	X		X	X	X	X	X				X			X		X	X	X		X	X	X	X	X		X
2014	*Rubus spectabilis*	X	X		X	X	X	X	X	N/A	X		X		X	X			X	X	N/A	X	X	N/A	N/A	X			X				X	X	X	X	X	X		
2015		X	X		X	X	X	X	X		X			X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X		X	X		
2016		X	X		X	X	X	X	X	N/A	X		X	X	X	X	X	X	X	X		X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
2018		X	X		X	X	X	X			X		X			X		X	X	X		X	X	X	X	X			X	X	X	X	X	X	X	X	X		X
2014	*Senecio triangularis*									N/A											N/A			N/A	N/A																
2015																																								
2016										N/A																														
2018																																								

Year	Species\Site	1	20A	37	39	42	43A	43B	44	44A	46	47B	52	54	55	56	57	68	69	70	78A	79	80	81B	81C	82	84A	85	86	87	88	89A	90	91A	92	95	97	98A	490	492
2014	*Symphoricarpos albus*									N/A											N/A			N/A	N/A														
2015																																								
2016										N/A																														
2018																																							
2014	*Vaccinium alaskaense*									N/A											N/A			N/A	N/A		X	X												
2015																											X				X								
2016							X			N/A					X	X	X				X	X		X	X	X	X	X				X				X			
2018																	X							X	X	X		X				X							
2014	*Vaccinium membranaceum*									N/A											N/A	X		N/A	N/A	X													
2015																						X																	
2016							X			N/A					X	X	X				X	X		X	X	X	X	X				X				X			
2018																	X							X	X			X											
2014	*Vaccinium ovalifolium*				X		X	X		N/A	X						X				N/A			N/A	N/A										X			X		
2015					X		X	X			X					X	X				X			X	X	X		X											
2016										N/A																														
2018							X								X	X	X				X	X		X	X	X	X	X				X				X			
2014	*Vicia americana*									N/A											N/A			N/A	N/A														
2015																			X									X											
2016										N/A																														
2018																												X											

	Trees																																							
	Species\Site	**1**	**20A**	**37**	**39**	**42**	**43A**	**43B**	**44**	**44A**	**46**	**47B**	**52**	**54**	**55**	**56**	**57**	**68**	**69**	**70**	**78A**	**79**	**80**	**81B**	**81C**	**82**	**84A**	**85**	**86**	**87**	**88**	**89A**	**90**	**91A**	**92**	**95**	**97**	**98A**	**490**	**492**
2014	*Abies amabilis*									N/A							X				N/A		X	N/A	N/A														
2015																								X	X														
2016										N/A																					X						X		
2018																															X							X	
2014	*Abies lasiocarpa*									N/A											N/A			N/A	N/A														
2015																																							
2016										N/A																														
2018																																							

Year	Species\Site	1	20A	37	39	42	43A	43B	44	44A	46	47B	52	54	55	56	57	68	69	70	78A	79	80	81B	81C	82	84A	85	86	87	88	89A	90	91A	92	95	97	98A	490	492
2014	*Acer glabrum*									N/A											N/A		X	N/A	N/A		X													
2015														X													X													
2016										N/A			X	X																								X	
2018													X	X																								X	
2014	*Alnus crispa*	X						X		N/A	X		X		X		X				N/A			N/A	N/A		X	X	X				X	X			X	X		
2015		X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	X		X		X	X	X	X	X	X	X	X	X		X		X	X	X		
2016				X		X	X		X	N/A	X		X					X	X	X		X		X	X	X	X	X		X	X	X	X		X		X	X	X	X
2018		X	X		X	X														X		X		X	X			X		X	X	X	X		X			X	X	X
2014	*Alnus tenuifolia*	X	X	X	X	X	X	X	X	N/A	X	X	X	X		X	X		X	X	N/A	X		N/A	N/A	X	X	X	X				X	X	X	X	X			
2015		X	X			X	X	X			X	X	X		X			X	X	X	X	X	X	X		X	X	X	X	X		X	X	X	X	X	X		
2016										N/A																														
2018																																							
2014	*Betula papyrifera*									N/A							X		X		N/A			N/A	N/A															
2015																	X		X																					
2016										N/A							X		X		X						X	X										X		
2018																X			X																					
2014	*Crataegus douglasii*									N/A											N/A			N/A	N/A															
2015																					X																		
2016										N/A																														
2018																																							
2014	*Pinus contorta*								X	N/A							X	X			N/A			N/A	N/A	X		X	X								X			
2015									X								X	X	X		X					X		X			X					X			
2016									X	N/A							X	X	X		X					X		X			X								
2018									X						X		X		X		X					X		X											X
2014	*Populus tremuloides*									N/A						X	X				N/A			N/A	N/A			X	X											
2015																X	X	X	X									X	X										
2016				X						N/A						X												X	X										X
2018																X		X	X									X	X										X
2014	*Populus trichocarpa*	X		X	X				X	N/A		X		X				X	X		N/A			N/A	N/A		X						X		X		X		
2015		X		X			X	X				X	X						X	X				X		X			X		X		X						

Year	Species\Site	1	20A	37	39	42	43A	43B	44	44A	46	47B	52	54	55	56	57	68	69	70	78A	79	80	81B	81C	82	84A	85	86	87	88	89A	90	91A	92	95	97	98A	490	492
2016		X	X	X	X			X	X	N/A			X						X	X				X			X			X						X			X	X
2018		X	X	X	X			X	X			X	X	X						X		X		X					X						X			X	
2014	*Prunus pennsylvanica*									N/A											N/A			N/A	N/A															
2015																																								
2016										N/A																														
2018									X																														
2014	*Prunus virginiana*				X					N/A											N/A			N/A	N/A															
2015															X																									
2016																																								
2018									X	N/A																														
2014	*Sorbus scopulina*	X	X	X		X	X	X	X	N/A											N/A			N/A	N/A			X							X	X		X		
2015		X	X	X		X	X	X	X		X				X	X	X					X			X								X	X			X		
2016										N/A															X															
2018																					N/A			N/A	N/A															
2014	*Sorbus sitchensis*							X		N/A						X	X																							
2015							X	X			X																													
2016		X	X	X		X		X	X	N/A	X	X			X	X	X					X					X								X		X		
2018		X	X	X	X	X	X	X	X		X	X			X	X	X		X			X			X		X					X			X		X		
2014	*Tsuga heterophylla*	X	X	X	X	X	X	X	X	N/A	X	X	X	X	X	X	X	X	X	X	N/A	X		N/A	N/A	X	X	X	X				X	X	X	X	X	X		
2015		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
2016		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2018		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

5.8 Supplementary Versions of Vegetation Maps

This section includes supplementary versions of maps used in Section 5 of the main report. These additional figures provide larger versions of the maps used in multi-panel figures in the main report for improved legibility, and include site labels for vegetation monitoring sites on all the maps.

For the full-page versions of individual map panels from the multi-panel figures, the original multi-panel figures are also included for figures that have more than two map panels in the main report, to help orient readers.

The maps are presented in the same order as they appear in Section 5 of the main report. Each map caption includes a reference to the relevant figure number in the main report (e.g., **main report Figure 5-2**).

Note: **Main report Figure 5-16** is the same map as the left panel of **main report Figure 5-7.** Therefore a large version of only main report Figure 5-7 is provided in this appendix.

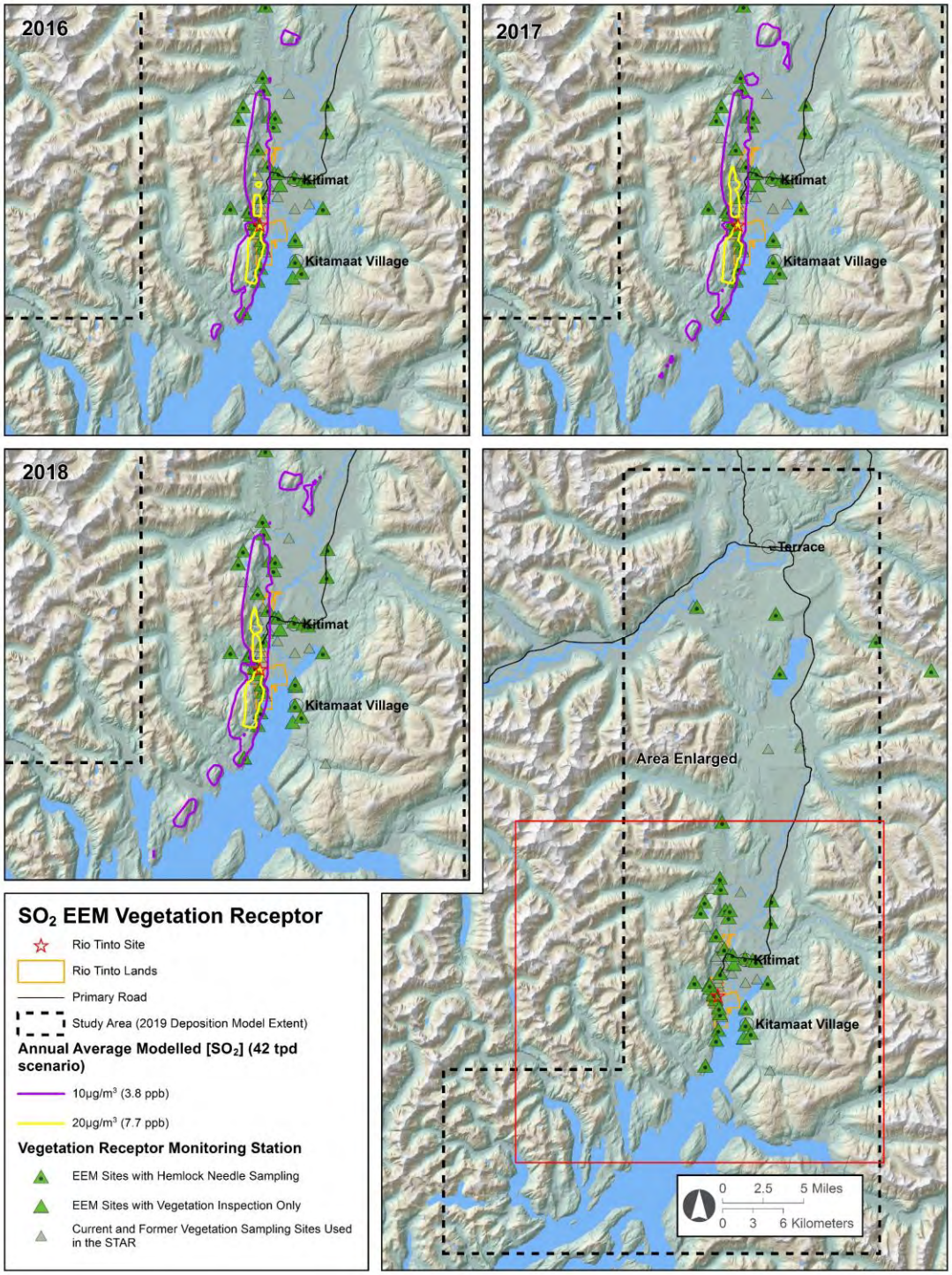


Figure 5.2: Main report Figure 5-2. Location of sampling and inspection sites with respect to the CALPUFF-modelled annual average air concentration isopleths of 10 and 20 µg/m³ (3.8 and 7.6 ppb), the threshold values used in Europe to protect sensitive lichens and natural ecosystems. The 10 µg/m³ isopleth corresponds approximately to the 2025 CAAQS. The modelling scenario is 42 tpd (the maximum permitted level). The isopleths include background SO_2 concentrations of 0.47 ppb.

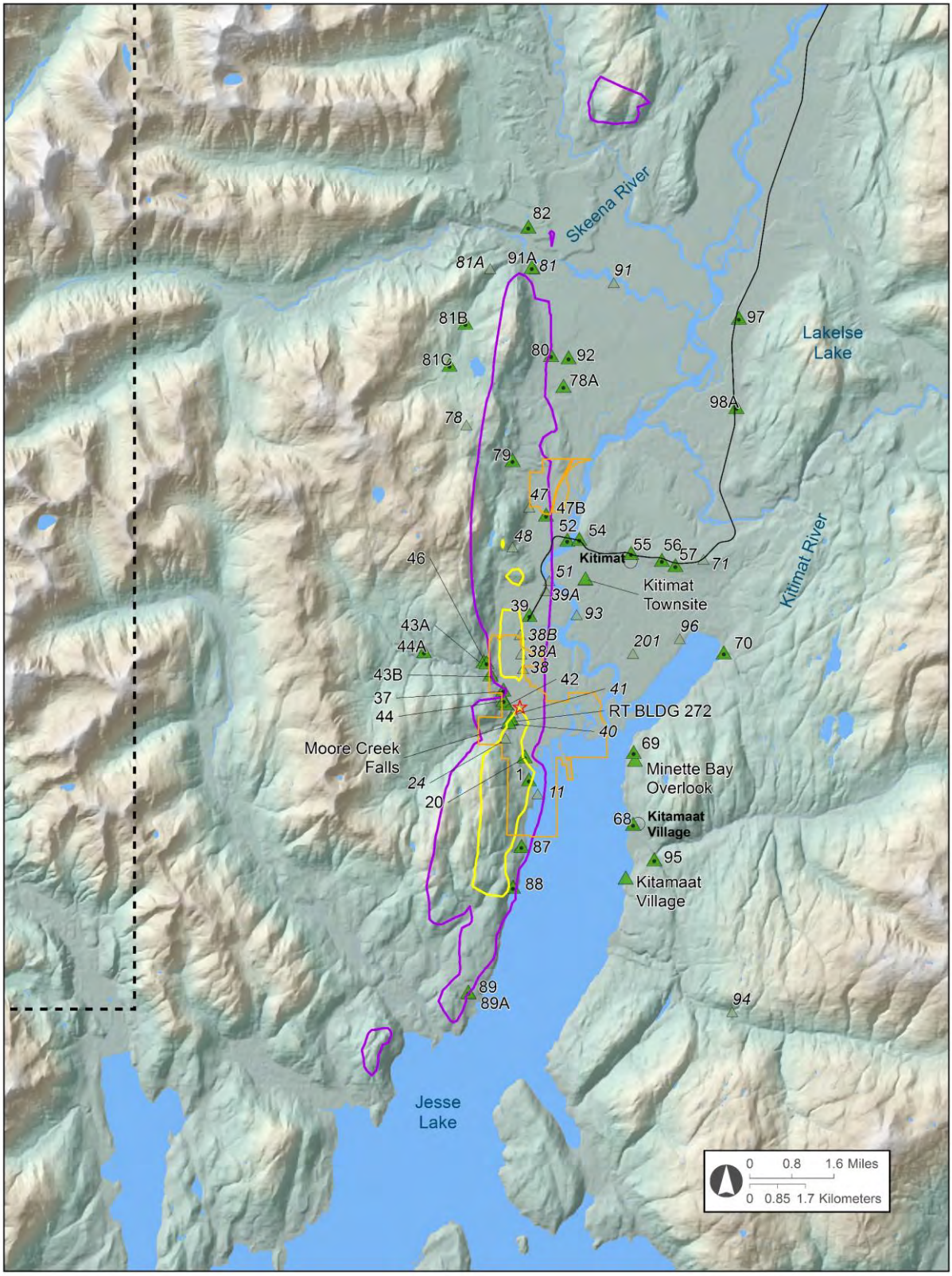


Figure 5.3: Upper left panel of main report Figure 5-2 – 2016 results.

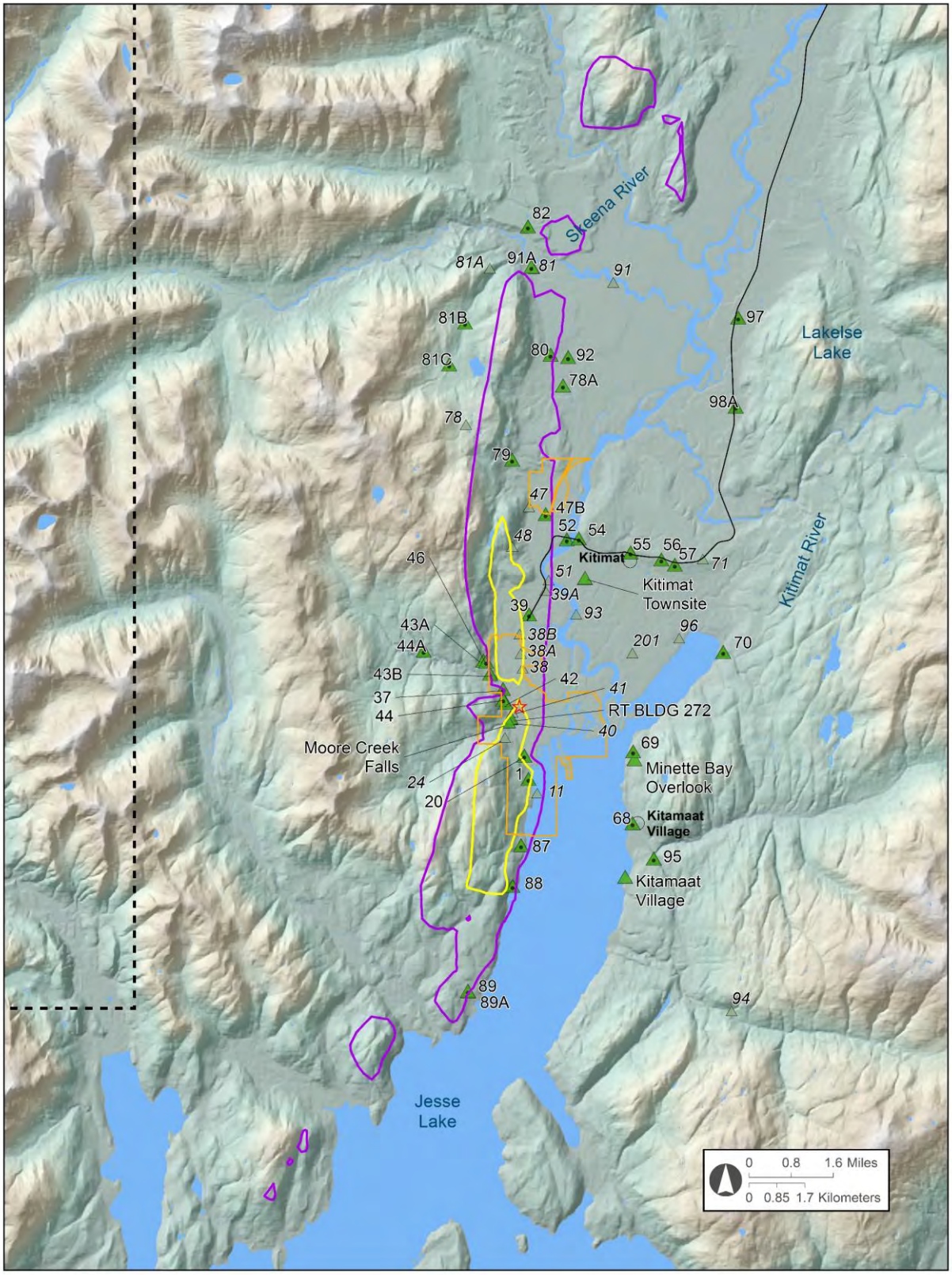


Figure 5.4: Upper right panel of main report Figure 5-2 – 2017 results.

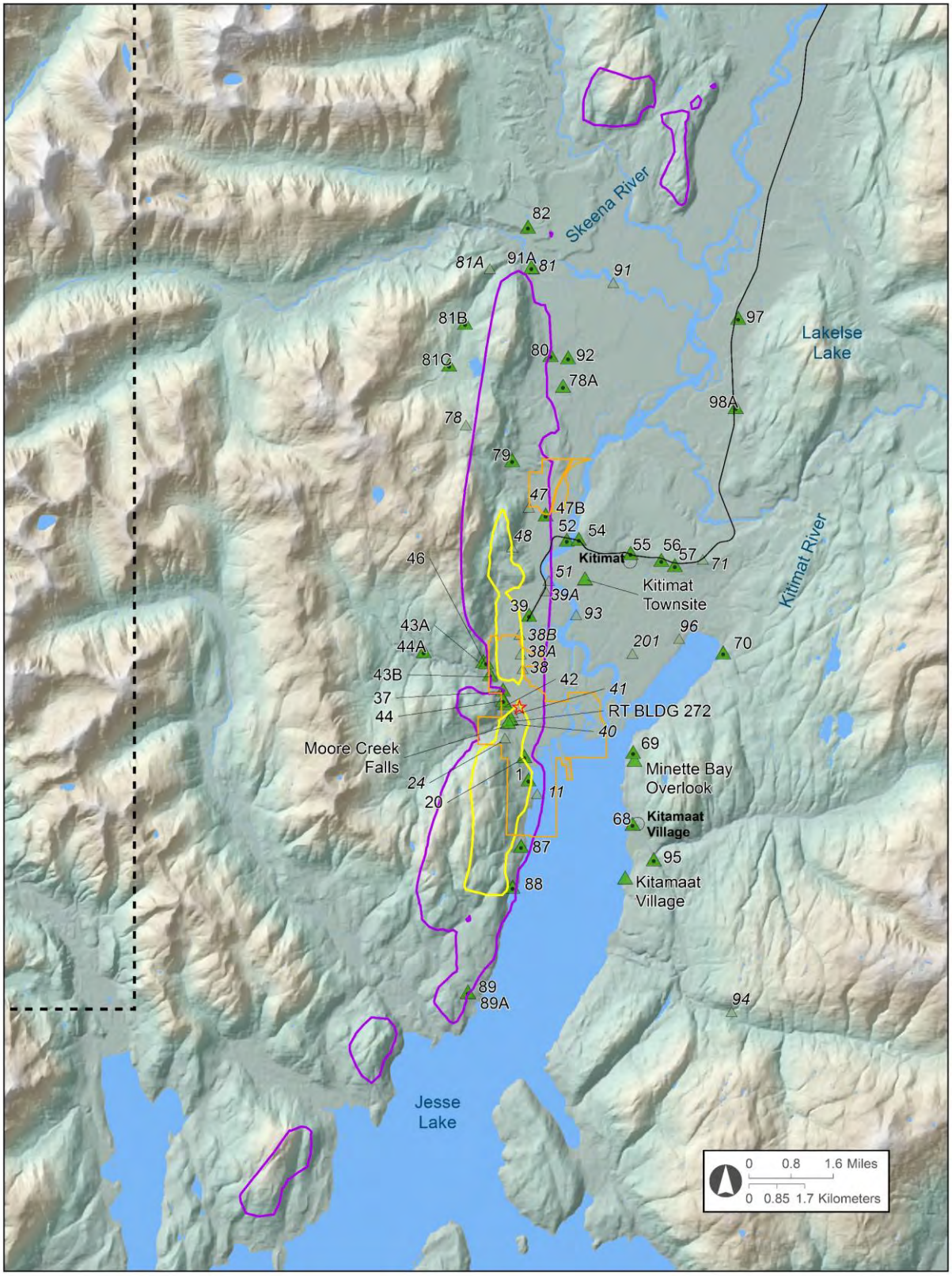


Figure 5.5: Middle left panel of main report Figure 5-2 – 2018 results.

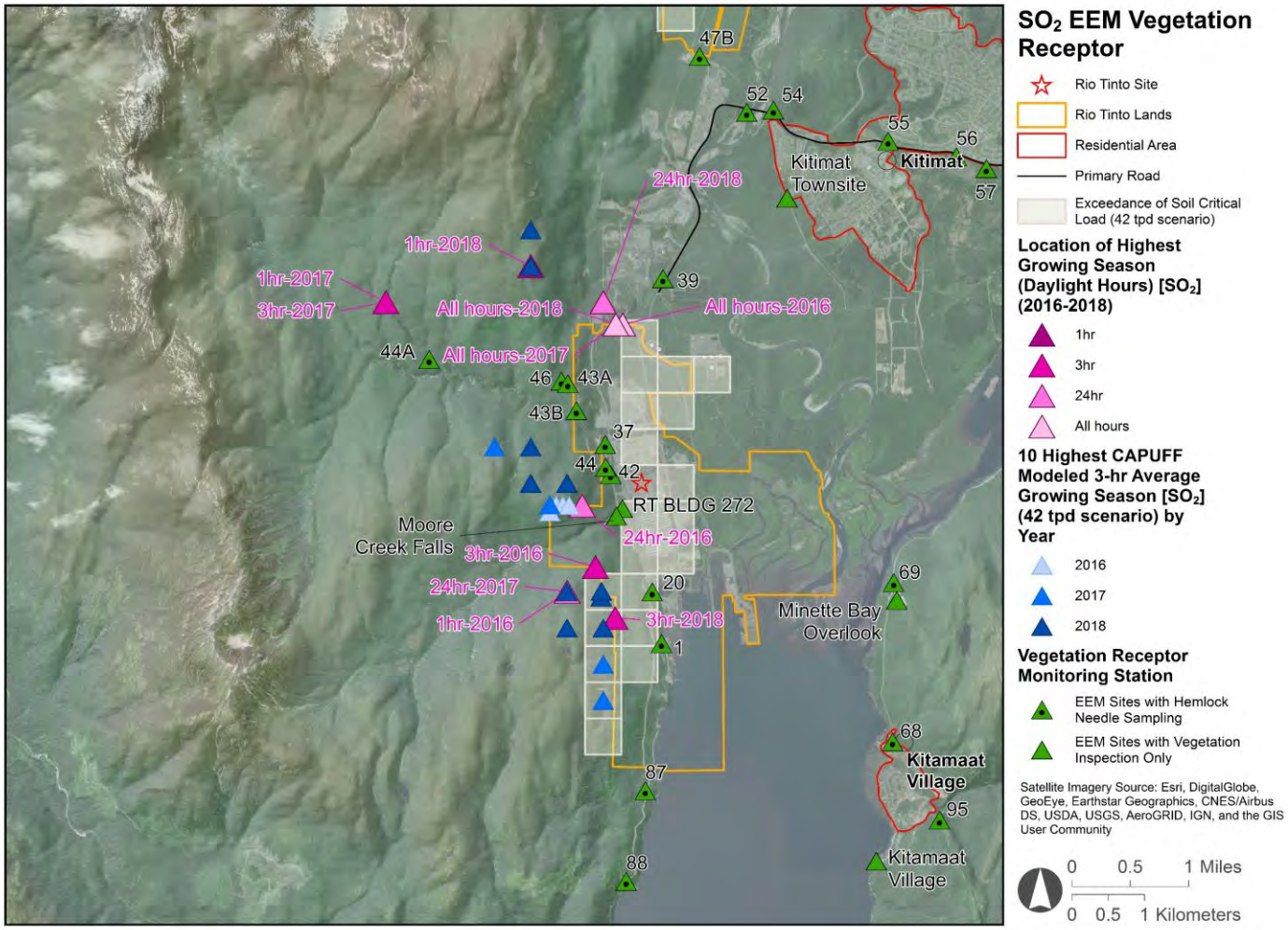


Figure 5.6: Main report Figure 5-4. Location of the 10 highest CAPUFF modelled 3-hour average Growing Season SO_2 concentrations under the 42 tpd scenario (maximum permitted level case) for 2016-2018 (blue symbols) and the highest locations for growing season daylight hours 1-hour, 3-hour, 24-hour, and annual averages for each year (pink symbols). Background SO_2 concentrations of 5.53, 2.80, 1.74, and 0.47 ppb for 1-hour, 3-hour, 24-hour, and annual (and growing season) average, respectively, are not included but do not affect the locations.

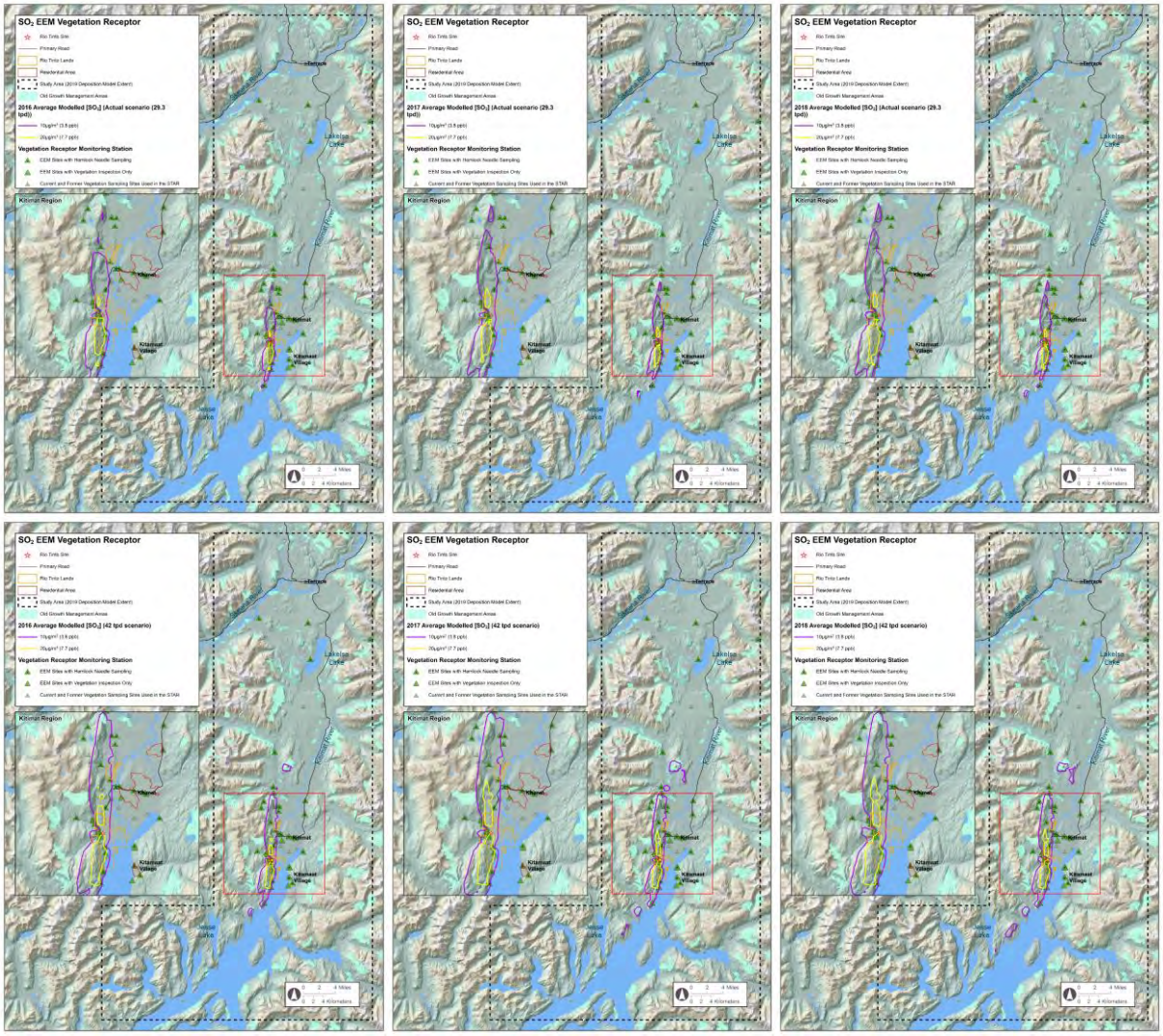


Figure 5.7: Main report Figure 5-5. CALPUFF-modelled annual average SO2 concentration isopleths (yellow=20 µg/m³ (7.6 ppb) and purple=10µg/m3 (3.8 ppb) for 2016-2018 under the actual emission scenario (top) and the 42 tpd scenario (bottom). Teal-coloured areas are Old Growth Management Areas. Background SO2 concentrations are included to allow comparison to European thresholds of 10 and 20 µg/m³.

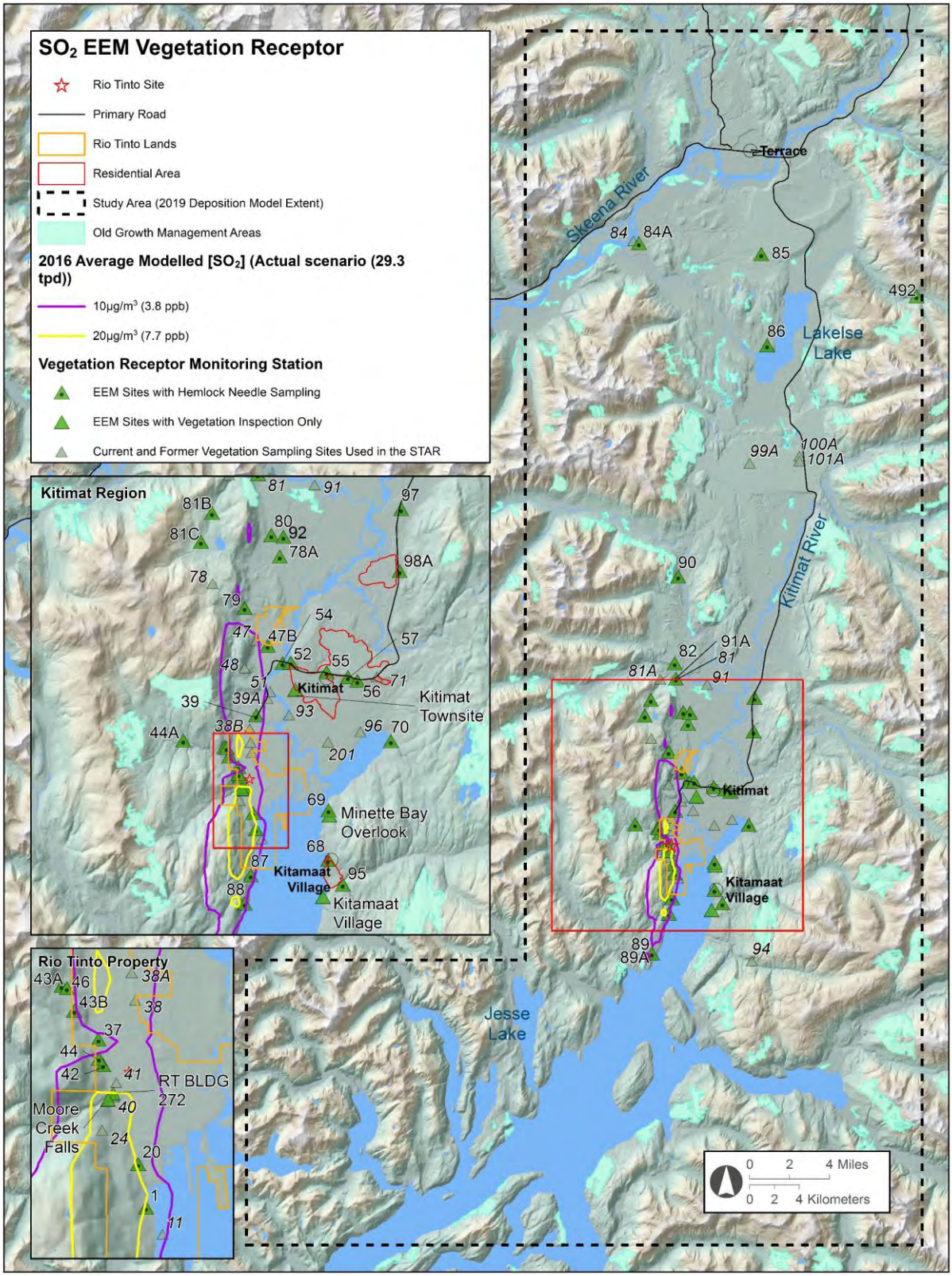


Figure 5.8: Upper left panel of Main report Figure 5-5 – Actual scenario; 2016 results.

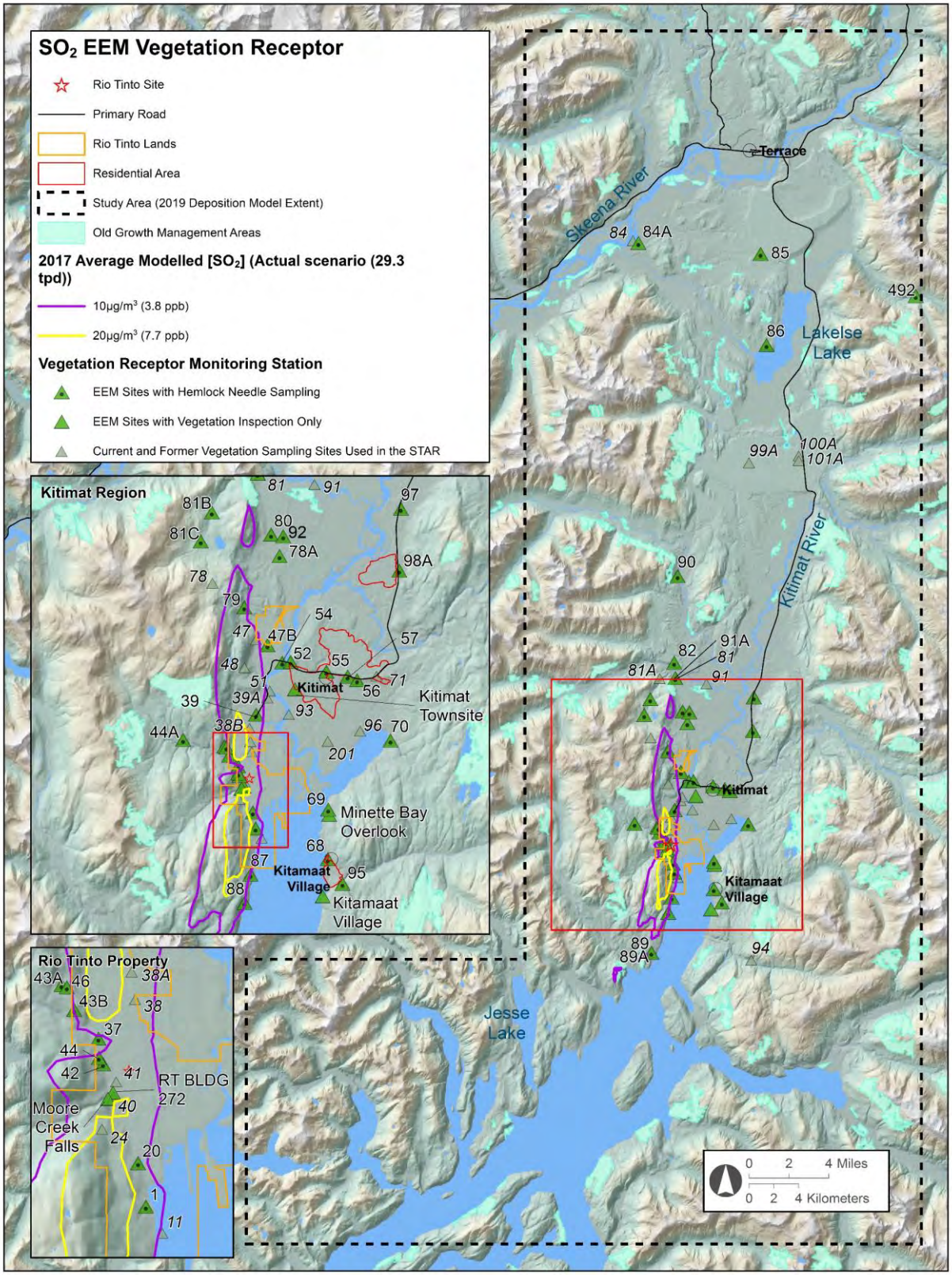


Figure 5.9: Upper middle panel of main report Figure 5-5 – Actual scenario; 2017 results.

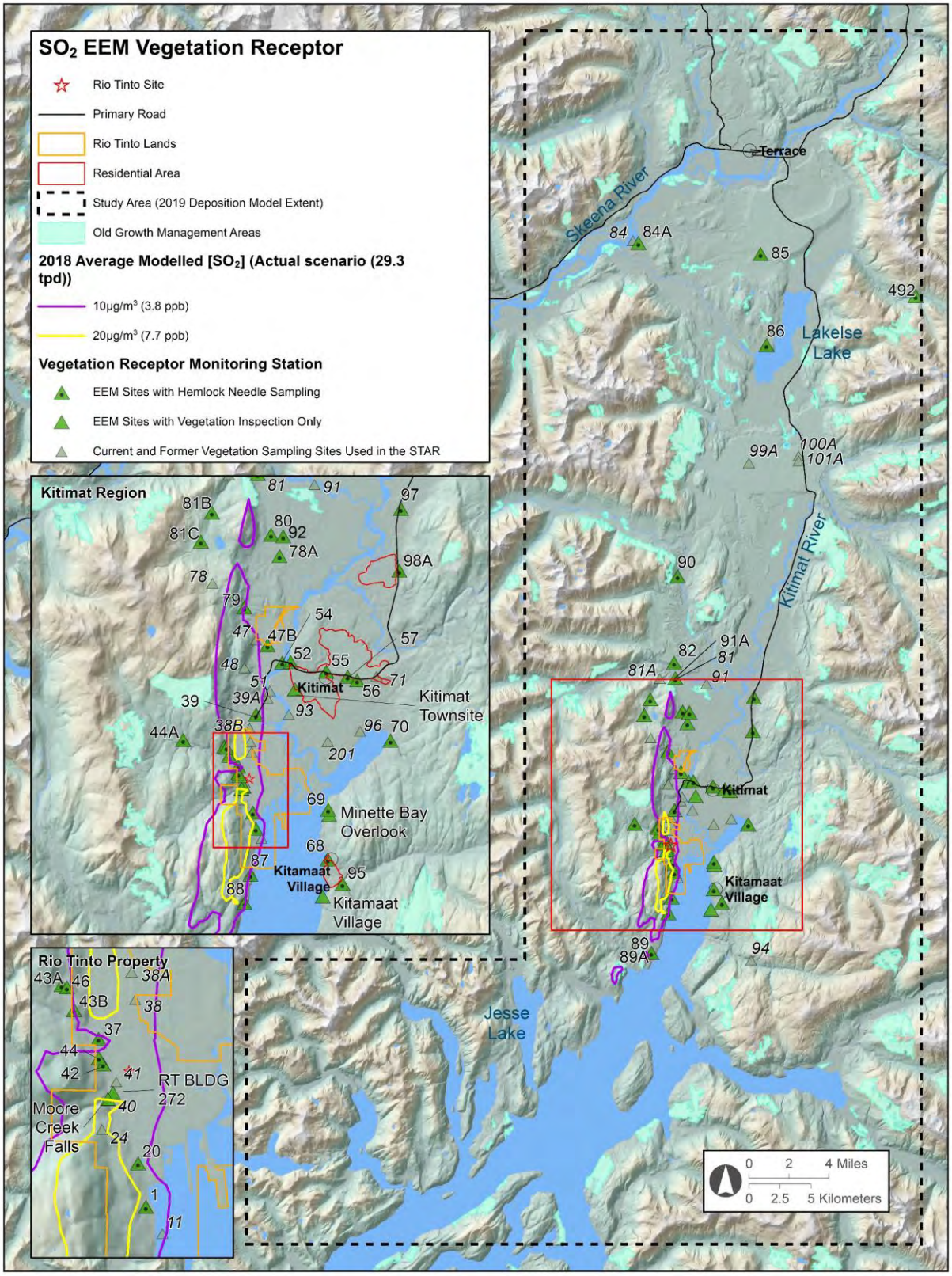


Figure 5.10: Upper right panel of main report Figure 5-5 – Actual scenario; 2018 results.

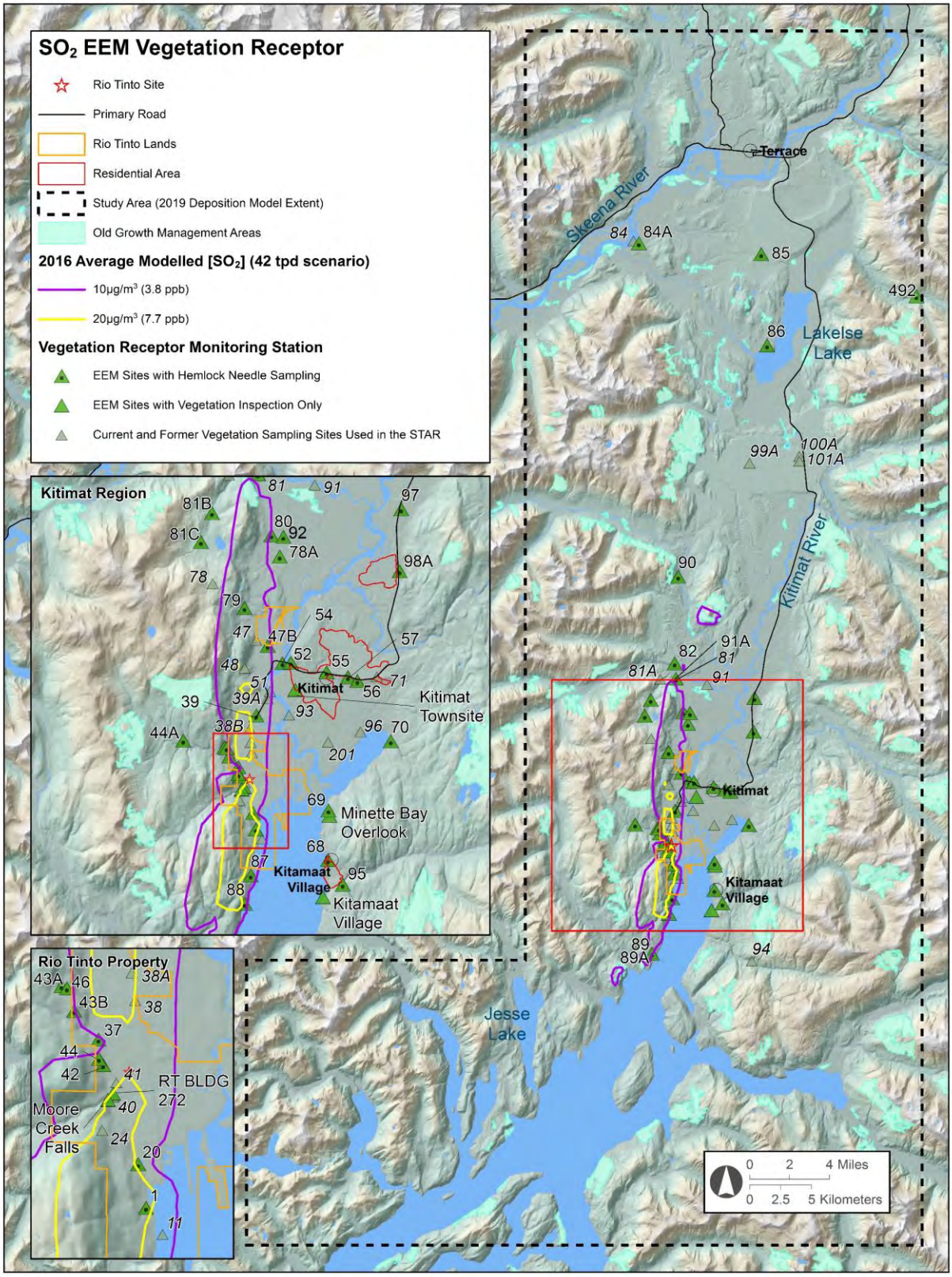


Figure 5.11: Lower left panel of main report Figure 5-5 – 42 tpd scenario; 2016 results.

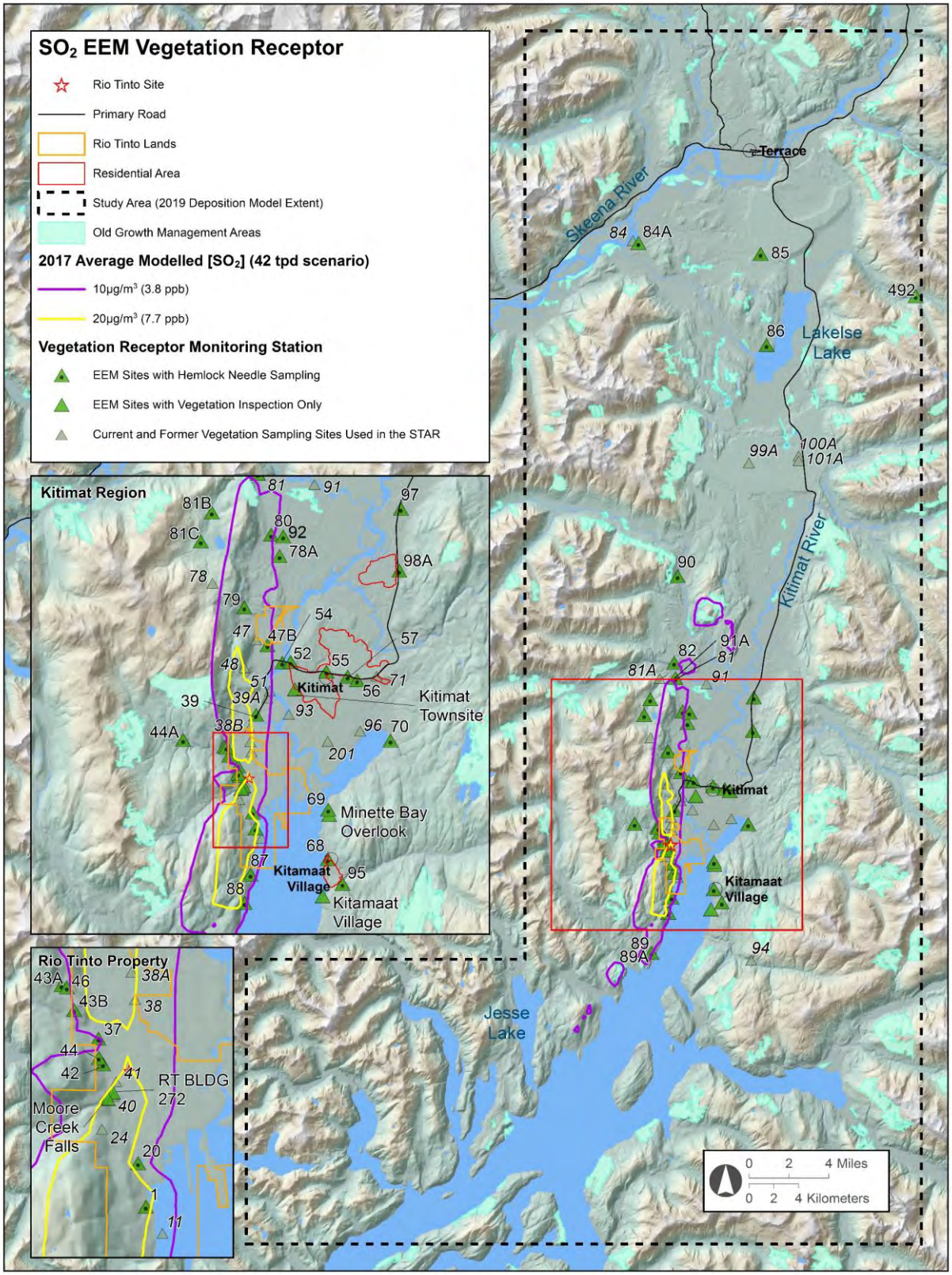


Figure 5.12: Lower middle panel of main report Figure 5-5 – 42 tpd scenario; 2017 results.

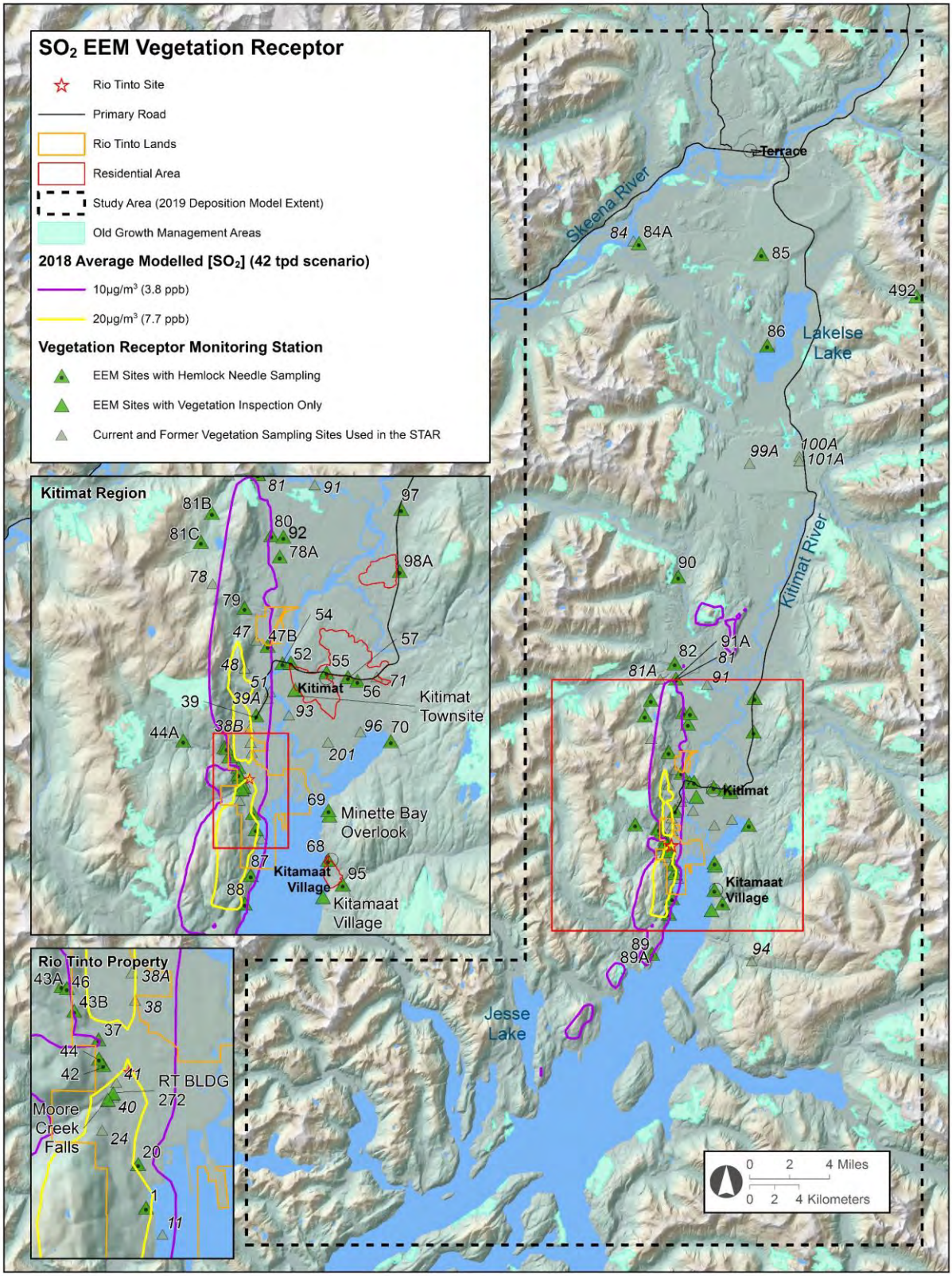


Figure 5.13: Lower right panel of main report Figure 5-5 – 42 tpd scenario; 2018 results.

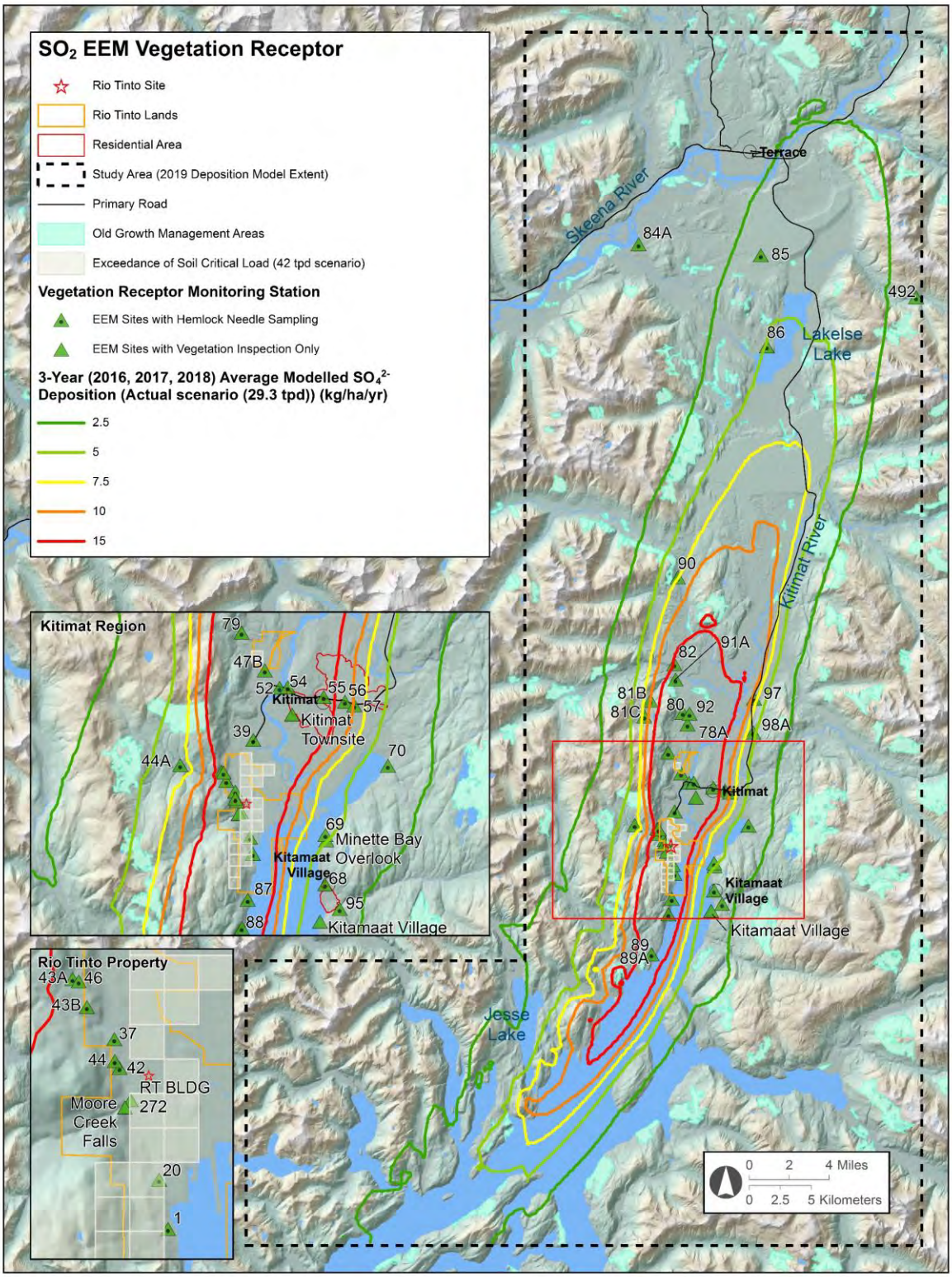


Figure 5.14: Left panel of main report Figure 5-7. Three-year average deposition of SO_4^{2-} as modelled by CALPUFF under the actual deposition scenario. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleths.

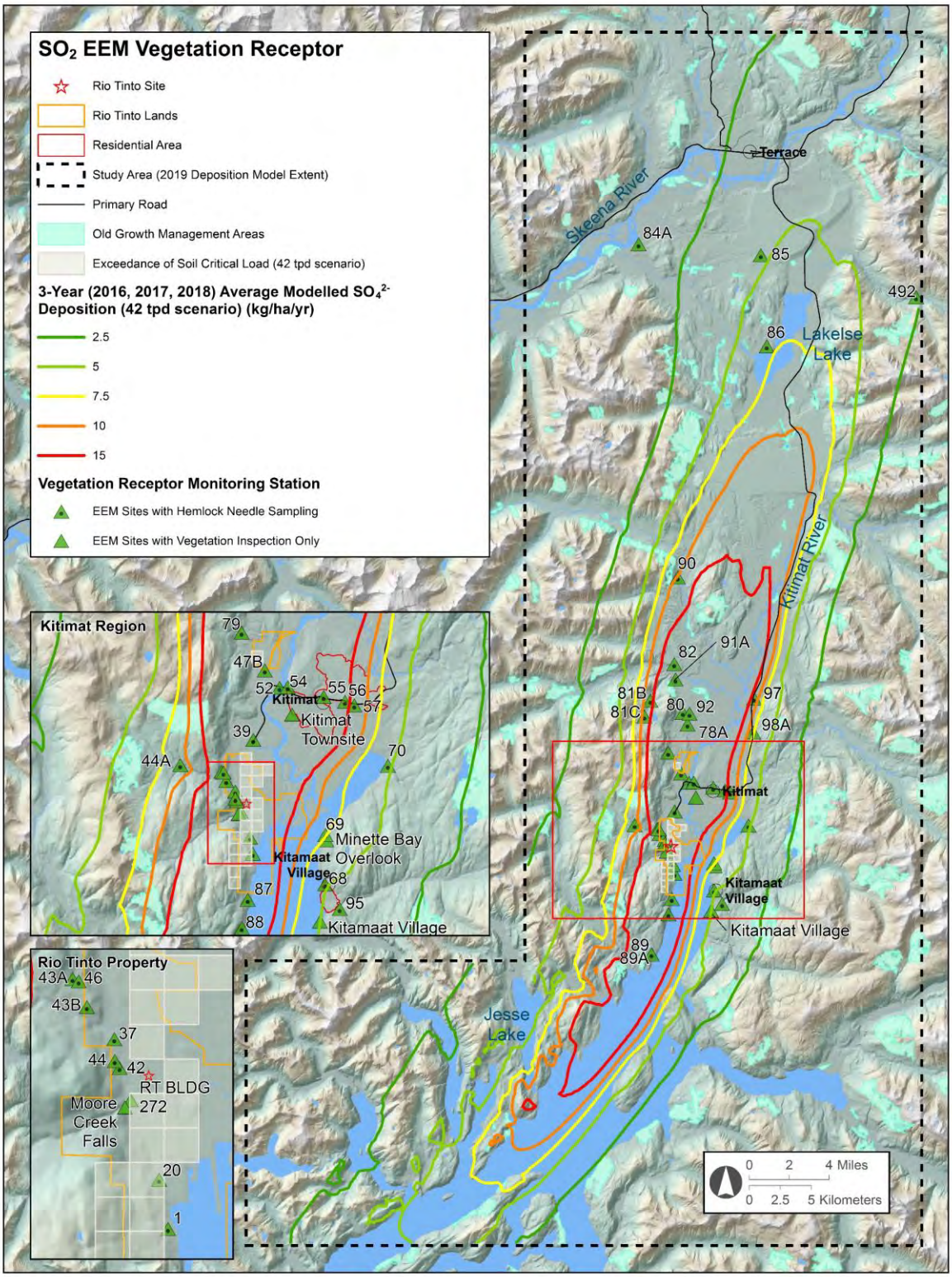


Figure 5.15: Right panel of main report Figure 5-7. Three-year average deposition of SO_4^{2-} as modelled by CALPUFF under the 42 tpd scenario. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleths.

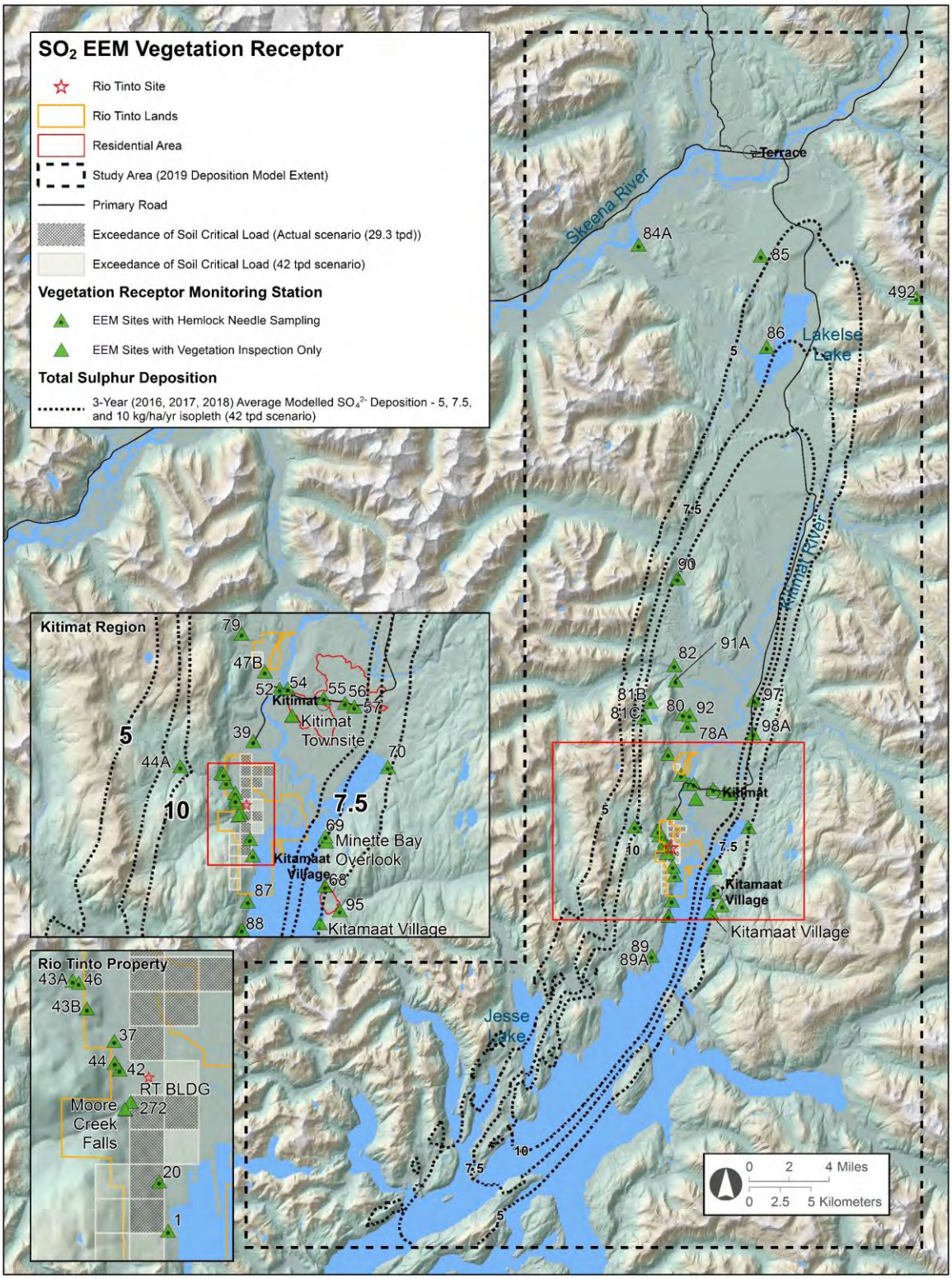


Figure 5.16: Main report Figure 5-8. Location of vegetation sampling and inspection sites, as well as isopleths of SO_4^{2-} deposition. Background deposition of 3.6 kg SO_4^{2-}/yr is not included in the isopleths.

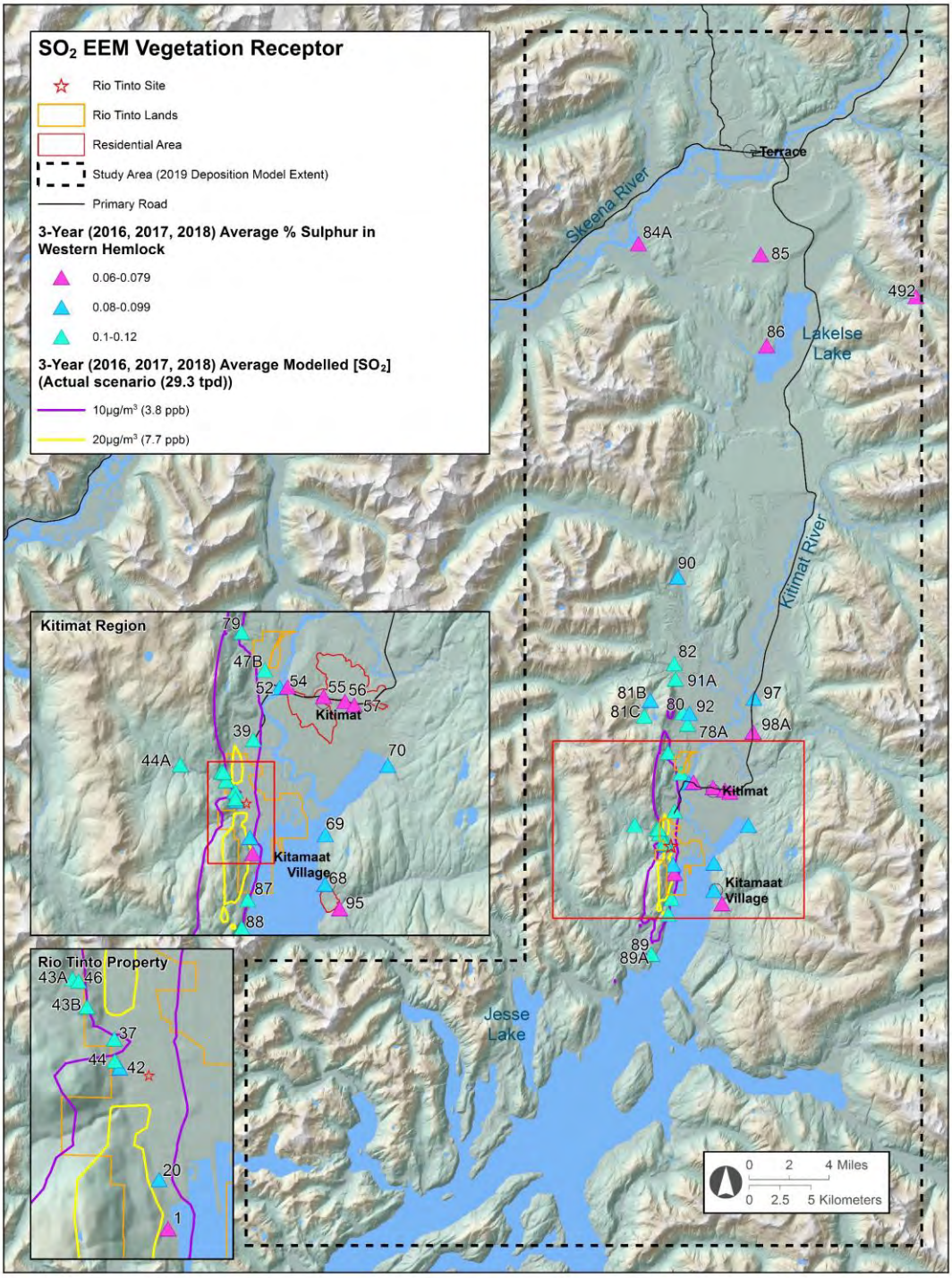


Figure 5.17: Main report Figure 5-10. The spatial distribution of %S in western hemlock needles in relation to SO_2 concentrations as modelled by CALPUFF. Purple symbols are at sites that have a post-KMP average %S between 0.06 and 0.08; blue symbols %S between 0.08 and 0.10; cyan symbols %S between 0.10 and 0.12. Isopleths represent growing season means of 10 and 20 µg/m³, threshold concentrations established in Europe for the protection of sensitive lichens and natural forest ecosystems respectively. Background air concentrations of SO_2 have been added.

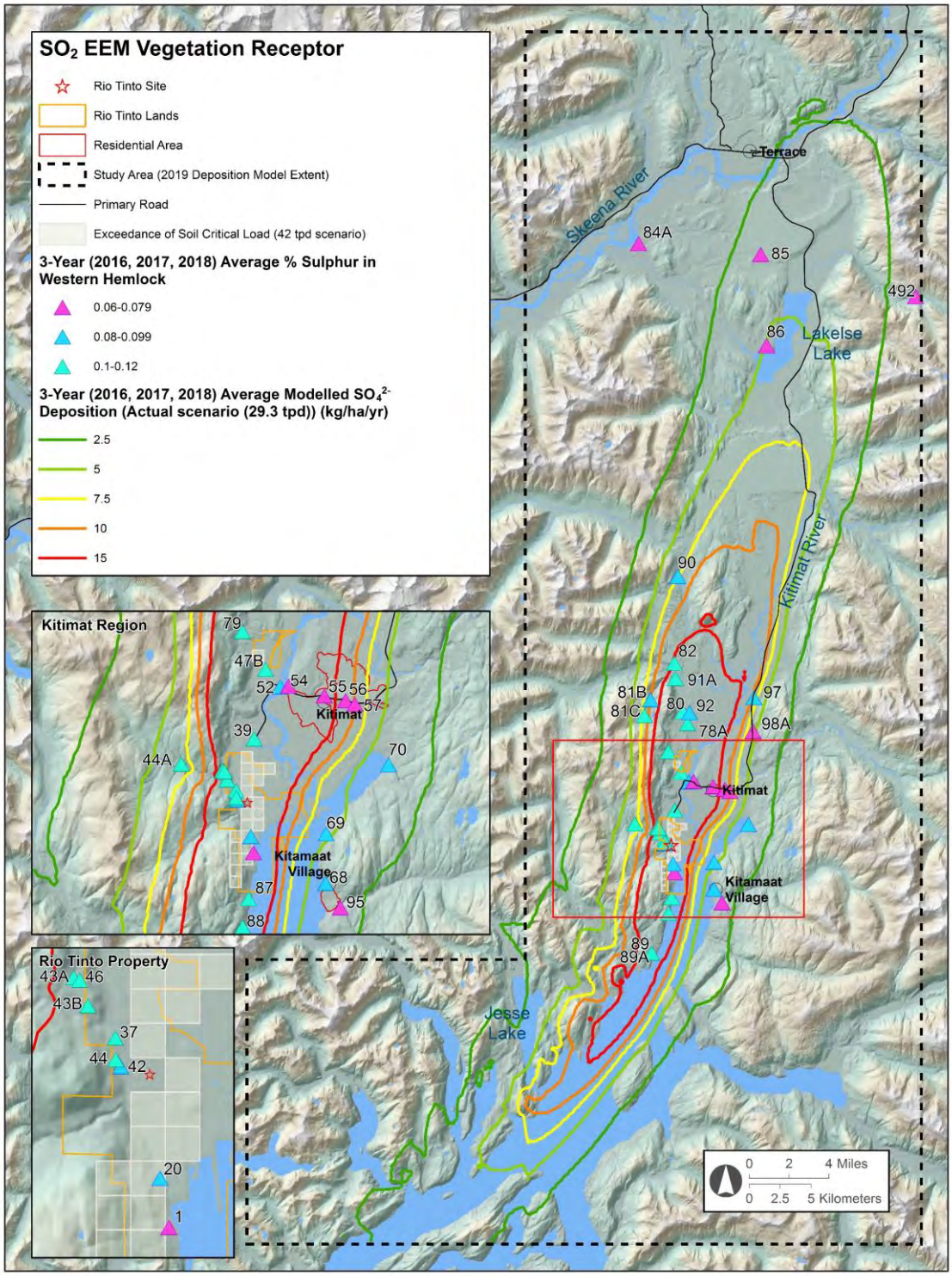


Figure 5.18: Main report Figure 5-12. The spatial distribution of %S in western hemlock needles in relation to SO_4^{2-} deposition as modelled by CALPUFF. Purple symbols are at sites that have a post-KMP average % S between 0.06 and 0.08; blue symbols % S between 0.08 and 0.10; cyan symbols % S between 0.10 and 0.12. Isopleths represent 2.5, 5, 7.5, and 10 kg SO_4^{2-}/ha/yr. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included.

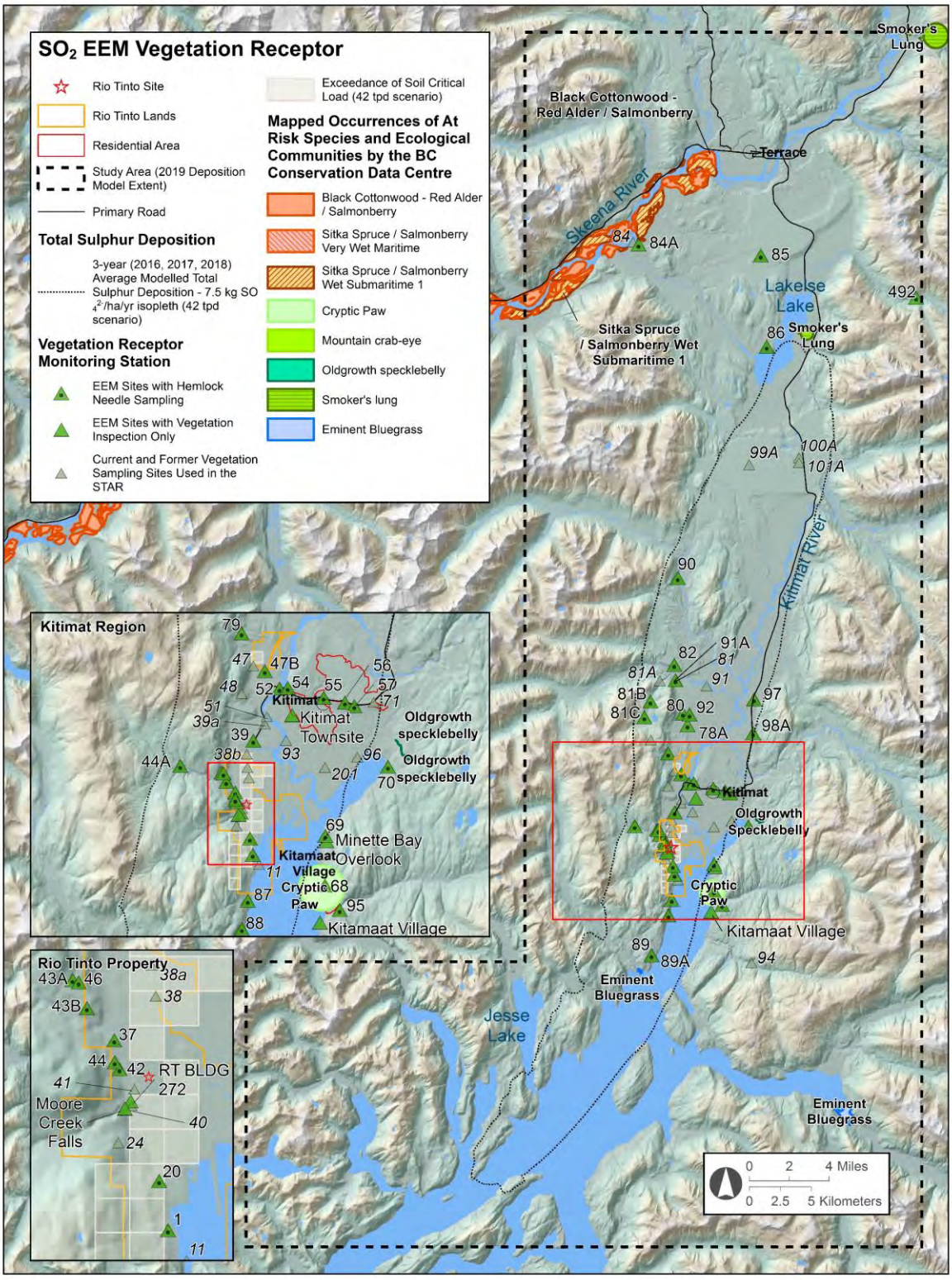


Figure 5.19: Main report Figure 5-15. Approximate locations of listed ecological communities, plants, and lichens at risk in the study domain. The data are from the British Columbia Conservation Data Centre, accessed on February 14th, 2020.

6 Appendix to Section 6 of the Comprehensive Review Report: Terrestrial Ecosystems (Soils)

6.1 Regional Soil Data

Table 6.1: Soil physicochemical characteristics for sites sampled for soils during the SO_2 EEM program (n = 31); site ID, sampling location (UTM Zone 09N), elevation (ALT), and profile average estimates of coarse fragment (CFG) by volume, bulk density (Db), loss-on-ignition (LOI), particle size (sand, silt and clay) and soil pH (H2O) averaged (weighted by depth and bulk density) over 0–50 cm depth.

Site ID	Easting m	Northing m	ALT m	CFG %v	Db g/cm³	LOI %	pH H_2O	Sand %	Silt %	Clay %
L02	523594	6020539	191	0.26	0.954	7.23	5.49	70.0	27.6	2.4
S02	517413	5977553	171	1.34	0.600	9.15	5.66	64.3	32.4	2.7
L03	524232	6020376	130	1.36	1.323	5.26	5.78	72.3	24.9	2.8
S03	517940	5976248	115	1.02	0.546	11.19	4.93	52.4	43.0	4.2
EP712 312 Ss	523045	6010822	208	10.80	0.825	11.20	4.75	64.9	32.0	3.2
EP712 132 Hw	526493	6015024	202	7.59	0.727	11.58	4.46	68.2	28.6	3.1
SS1	519445	5986513	12	39.72	0.834	6.96	5.45	64.7	33.4	1.9
L01	522859	6018576	216	5.79	0.652	9.02	5.65	76.1	22.1	1.6
E02	518413	5986415	159	11.95	0.560	9.72	5.24	58.4	37.6	3.8
E01	518998	5985172	76	4.40	0.535	7.31	5.81	65.6	31.5	2.7
A05	516558	6007946	792	0.48	0.415	19.60	5.77	40.1	57.3	2.6
A04	519704	6018724	1128	11.87	0.758	12.61	5.93	55.7	41.4	2.8
A03	519367	6016713	1128	13.96	0.834	13.77	5.62	72.3	24.7	0.9
A01	517056	6007036	1097	2.35	0.814	12.61	5.95	55.0	42.2	2.6
A02	517912	6013609	1250	2.56	0.861	16.18	5.55	47.5	48.4	4.1
P01	528159	6036327	220	0.00	1.027	4.64	6.82	41.0	53.0	5.5
L28	519336	5992515	107	0.63	0.820	7.33	5.38	57.5	38.3	4.2
S01	513680	5974041	137	1.93	0.589	8.26	5.70	71.8	25.4	2.8
EP712 S1 Ss	526559	6015028	202							
EP712 S1 Hw	526291	6015021	202							
EP712 S3 Hw	523288	6010181	242							
EP712 S3 Ss	523040	6010872	208							
V-81A	518748	5998651	250							
V-39	519812	5987827	15							
V-69	523009	5983626	51							
V-47B	520331	5990894	20							
V-56	523898	5989507	99							
V-68	522990	5981427	26							
CF-P	522823	5992101	73	5.01	0.335	5.68	.	21.6	68.2	10.3
LE-P	527286	6025691	87	5.94	0.863	4.87	.	20.8	67.1	12.1
L28-S2	519229	5993269	222	.	.	15.86	3.58	16.2	72.6	11.2

Note: In total, 115 regional soil sites (see Section 6 Figure 6-1 in the main report) are used for mapping and modelling soil properties. These include 51 soil pits from the STAR (ESSA et al. 2013), 11 from the KAEEA (ESSA et al. 2014) and 22 from the LNG Canada Project [URL: lngcanada.ca; n =]. The physicochemical soil properties for 'new' sites sampled under the SO_2 EEM program (n = 31) are only shown here; please see related technical reports for soil data for the other sites.

Table 6.2: Major oxide content and loss-on-ignition (LOI) per soil profile (n = 31) used for the determination of soil mineralogy and base cation weathering rate. See Table 6.1 above for further details on sampling location.

Site ID	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	K2O	Na2O	P2O5	LOI
	%	%	%	%	%	%	%	%	%	%	%
L02	58.57	0.70	14.48	5.04	0.07	1.01	2.05	1.68	3.01	0.19	13.23
S02	49.40	0.63	11.88	5.57	0.06	1.03	1.45	1.16	1.73	0.07	26.96
L03	60.17	0.71	15.11	6.41	0.07	1.22	1.21	1.44	2.72	0.19	10.63
S03	49.48	0.76	12.54	5.56	0.05	0.96	1.45	1.09	1.72	0.06	26.31
EP712 312 Ss	59.47	0.68	13.24	5.55	0.07	0.88	1.70	1.43	2.69	0.11	13.87
EP712 132 Hw	57.15	0.86	13.07	7.02	0.06	0.85	1.15	1.16	2.29	0.17	15.97
SS1	58.28	0.48	14.67	5.31	0.11	2.28	4.16	0.71	3.01	0.12	10.80
L01	58.30	0.68	14.34	5.90	0.08	1.16	1.49	1.59	2.71	0.20	13.41
E02	52.76	0.72	14.97	6.96	0.11	1.46	1.57	1.25	2.20	0.12	17.87
E01	56.26	0.71	13.99	6.84	0.09	1.41	2.73	1.16	2.68	0.14	14.00
A05	31.94	0.42	11.41	5.16	0.07	2.89	2.79	0.75	1.16	0.15	43.04
A04	42.22	0.82	14.21	7.05	0.06	1.58	2.20	1.86	2.78	0.20	26.99
A03	42.21	0.78	14.98	7.05	0.09	2.49	4.20	1.02	2.32	0.31	24.54
A01	48.11	0.52	12.81	6.32	0.07	1.20	1.84	1.96	2.46	0.19	24.36
A02	39.81	0.77	13.89	8.27	0.08	1.19	1.86	2.03	2.85	0.29	29.05
P01	62.11	0.88	15.23	6.92	0.07	1.20	1.07	1.28	2.64	0.27	8.20
L28	50.70	0.81	15.63	6.87	0.09	1.35	1.07	1.42	1.76	0.14	20.07
S01	59.55	0.48	13.33	4.42	0.06	0.73	2.85	1.24	2.73	0.05	14.32
EP712 S1 Ss	59.03	0.80	13.41	5.68	0.07	0.99	2.05	1.31	2.66	0.15	13.71
EP712 S1 Hw	62.01	0.68	13.41	4.81	0.07	1.00	2.04	1.36	2.83	0.13	11.37
EP712 S3 Hw	58.12	0.81	14.30	6.84	0.07	1.22	1.09	1.25	2.51	0.18	12.81
EP712 S3 Ss	55.90	0.95	13.90	7.20	0.07	1.03	1.09	1.11	2.20	0.18	16.28
V-81A	59.01	0.80	10.62	4.10	0.06	1.03	2.40	1.21	2.08	0.11	18.25
V-39	61.27	0.72	14.81	6.03	0.12	2.41	3.94	1.53	3.26	0.22	5.51
V-69	70.39	0.31	12.01	1.83	0.06	0.28	0.91	3.16	3.91	0.06	7.13
V-47B	53.66	0.78	13.69	6.16	0.11	2.30	3.29	1.24	2.63	0.23	15.67
V-56	44.92	0.63	11.44	4.90	0.05	0.55	1.34	0.96	2.00	0.14	32.79
V-68	54.83	0.43	12.52	4.14	0.11	0.88	2.44	1.29	2.74	0.11	20.45
CF-P	46.80	0.80	14.20	7.46	0.07	1.28	1.65	1.22	2.43	0.11	23.50
LE-P	61.80	0.82	15.70	6.75	0.11	1.60	1.22	1.42	2.69	0.09	8.12
L28-S2	52.90	0.93	12.10	9.42	0.08	1.40	2.58	0.71	2.22	0.07	17.30

Note: In total, 115 regional soil sites (see Section 6 Figure 6-1 in the main report) are used for mapping and modelling soil properties. These include 51 soil pits from the STAR (ESSA et al. 2013), 11 from the KAEEA (ESSA et al. 2014) and 22 from the LNG Canada Project [URL: lngcanada.ca; n =]. The major oxide contents for 'new' sites sampled under the SO_2 EEM program (n = 31) are only shown here; please see related technical reports for soil oxide data for the other sites.

6.2 Soil Laboratory Analysis

The soils from the regional surveys and long-term soils plots were analysed for a suite of soil physicochemical properties. The laboratory analysis including sample preparation is described below. Prior to analysis all mineral soil samples were air dried and sieved to 2 mm, i.e., here after known as the 'fine' fraction.

Soil bulk density core samples were oven dried at 105°C for 24 hours and weighed. The dried soil was sieved to < 2 mm (fine fraction), the volume of the coarse fragment (>2 mm) was measured by displacement. Bulk density was estimated using the dry weight of the fine fraction (<2 mm) and the volume of the core (adjusted for coarse fragment volume).

The soils (fine fraction) from the regional surveys and long-term plots were analysed for organic matter content by loss on ignition (LOI); 5 g of soil was placed into a muffle furnace at 400°C for 10 hours and then reweighed to determine percent loss. Soil pH was measured by mixing 5 g of soil with 20 mL of water and analysed using a pH probe.

Soils from the primary plots at Coho Flats and Lakelse Lake (2015 and 2018) were analysed for exchangeable base cations and exchangeable acidity. Exchangeable base cations were measured using an ammonium acetate (NH_4OAc) extraction, 5 g of mineral soil was mixed with 25 mL of NH_4OAc, the solution was extracted via vacuum filtration. The sample then received two addition washes of 10 mL NH_4OAc, the extractant was analyzed by ICP–OES for exchangeable base cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+).

Exchangeable acidity was measured using a potassium chloride (KCl) extraction; 5 g of soil was mixed with 25 mL of KCl, the solution was extracted via vacuum filtration. The sample then received five addition washes of 25 mL KCl. The extractant (135 mL) was titrated with sodium hydroxide (NaOH) to determine exchange acidity ($H^+ + Al^{3+}$).

The regional soil samples were pulverized to ~ 100 µm for analysis of oxide and qualitative mineralogy. Total oxide analysis was carried out by the Analytical Sciences Laboratory, Western University, Ontario on a PANalytical PW-2400 X-ray Fluorescence Spectrometer. Qualitative mineralogy analysis was carried out by the Department of Earth, Oceans and Atmospheric Sciences, University of British Columbia by X-ray Diffraction on a Siemens (Bruker) D5000 Bragg-Brentano diffractometer.

6.3 Modelling and Mapping of Soil Properties

The modelling and mapping of critical loads of acidity (sulphur) for terrestrial ecosystems (soils) required the development of regional maps for soil properties (see Figure 6.1 in this appendix). The spatial prediction or regionalisation of soil input parameters, e.g., base cation weathering rates and soil organic matter, was carried out using established geostatistical mapping techniques (McBrantley et al. 2003), i.e., regression-kriging following Hengl et al. (2004).

In brief, site-specific estimates of base cation weathering rates were estimated at each location (n = 115; Section 6 Figure 6-1 in the main report) from measurements of soil major oxide content (Appendix 6.1 Table 6.2) using the Analysis to Mineralogy (A2M) solver (Posch and Kurz 2007) and the PROFILE model (Sverdrup and Warfvinge 1988; Warfvinge and Sverdrup 1992), following the same approach as the STAR (ESSA et al. 2013; see Figure 6.1 in this appendix). Base cation weathering was determined for the top 50 cm of the mineral soil (using bulked soil observation data; see Appendix 6.1 Table 6.2), which was assumed to represent tree rooting depth. The soil rooting depth of 50 cm was modified by coarse fragment (%) to reflect the amount of fine earth (soil < 2 mm) in the top 50 cm of soil.

Base cation weathering rates (Bc_{we} = Ca^{2+} + Mg^{2+} + K^{+} and BC_{we} = Ca^{2+} + Mg^{2+} + K^{+}+ Na^{+}), sand and clay fractions, coarse fragment (CF_v), bulk density (Db and organic matter (LOI) content (estimated as loss-on-ignition) at each point location was regionalised using regression-kriging (Hengl et al. 2004). Geostatistical methods are optimal when data are normally distributed and stationary. Predictor variables with continuous coverage (n = 70) assumed to represent soil forming processes (i.e., scorpan factors: McBratney et al. 2003) were assembled for each point location. All predictor (explanatory or auxiliary) variables were transformed into principal components and their predictive capacity evaluated against the dependent variables using linear regression. The components with the greatest predictive capacity were selected for each dependent variable; a semi-variogram model was fitted to the residuals of each dependent variable to characterise their spatial correlation and interpolated (on a 0.25 km × 0.25 km grid) across the study domain using kriging. Continuous coverage maps for each dependent variable (base cation weathering rates, sand fraction, coarse fragment, and organic matter content) were produced by combining the linear regression model and interpolated residuals. Continuous coverage maps were used to derive input parameters (see main report Section 6 Table 6-3) and estimate critical loads (see main report Section 6 Table 6-2) for terrestrial ecosystems in each 0.25 km × 0.25 km grid square (see main report Section 6 Figure 6-3).

Logistic regression kriging was chosen as a mapping method because it provides better results than regression or universal kriging alone (Hengl et al., 2007). Regression kriging is an approach that combines a regression of a dependent variable on covariate map layers (such as soil or forest maps) kriging on the residuals (see Figure 6.2 in this appendix).

Covariates were obtained from global soil maps, forest cover maps, geological surveys, and land use (see Section 6 Table 6-1 in the main report). All maps were projected to EPSG:26909 and resampled using cubic spline interpolation to align them to the modelled sulphur deposition grid (250 m by 250 m). Covariates were transformed to principal components (PC) for inclusion in each model; this has the advantage of reducing collinearity, at the expense of some obfuscation of contributing covariates. The first 12 PCs were included in the covariate selection process for each model (see Figure 6.3 in this appendix); the rest had eigenvalues below 1 (below Kaiser's criterion) and were discarded. Variables of interest were logistic transformed to provide log transformation (and enable back-transformation of the final predictions, not possible with log transformation alone) and bounding of realistic values. Generalized linear models (GLM) were then built using the GSIF package (Hengl, 2019) using R software (R Core Team, 2019) to help select the optimal spatial and regression models (Table 6.3 in this appendix). Five-fold validation was performed on each model (Figure 6.4 in this appendix) before prediction and back-transformation for the final maps.

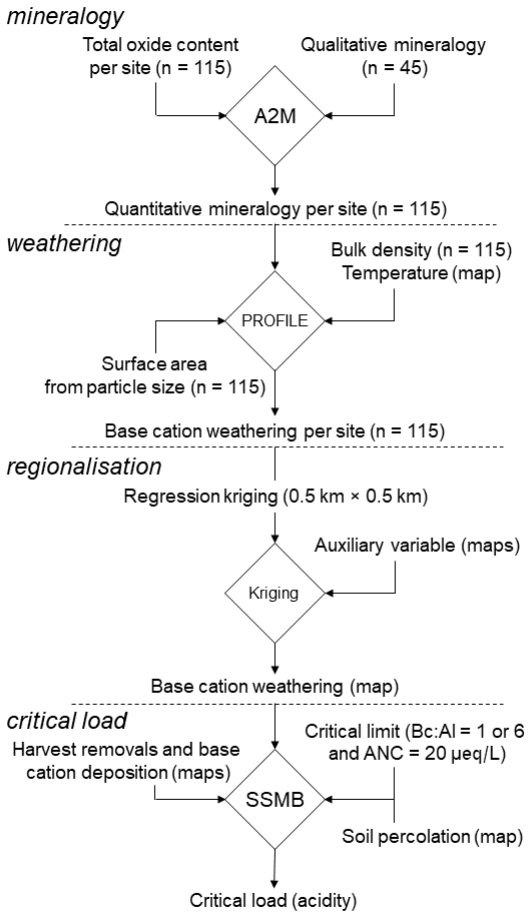


Figure 6.1: Overview of the modelling process for the regional determination of critical loads for soils. The approach used site specific estimates of total oxide (element) content to predict soil mineralogy (via A2M), these data were used to model site-specific estimates of soil weathering rate (via PROFILE model). The point estimates (n = 115) were regionalised using regression kriging, i.e., the were mapped at a 250 m by 250 m grid resolution and used in the determination of critical loads of acidity for soils via the Steady-State Mass Balance (SSMB) model.

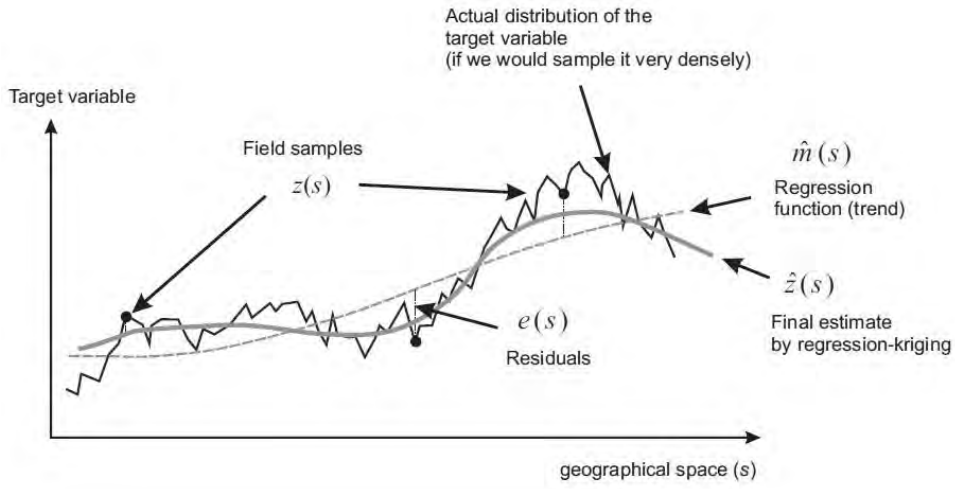


Figure 6.2: A representation of regression kriging with three main components, the observations or field samples, residuals, and the regression function (source: Hengl, 2012).

Table 6.3: Logistic regression models with total variation explained as well as the significance of each covariate used for the predicted soil properties. See Figure 6.3 in this appendix for a description of the loadings in each principal component (PC).

Predicted variable	Variation explained	Significance of Covariates 0.0001	0.001	0.01	0.1–1.0
Bulk density (Db)	25.7	PC3, PC12	PC6, PC7	PC4	PC11
Organic matter (LOI)	54.5	Db		PC8	PC2, PC9
Sand	17.2	Clay, LOI	PC1, PC6	PC2	PC4, PC11, PC12
Clay	12.8		Db	PC2, PC11, PC12	PC1, PC6
Coarse fragment (CFv)	12.4		PC8, PC9	PC12	PC2, PC5, LOI, Db
Weathering (Bcwe)	22.0	PC3, PC4, PC12	PC 7		PC1, PC5
Weathering (BCwe)	14.0	PC4	PC3, PC12	PC7	PC5

Bcwe = (Ca + Mg + K) and BCwe (Ca + Mg + K + Na)

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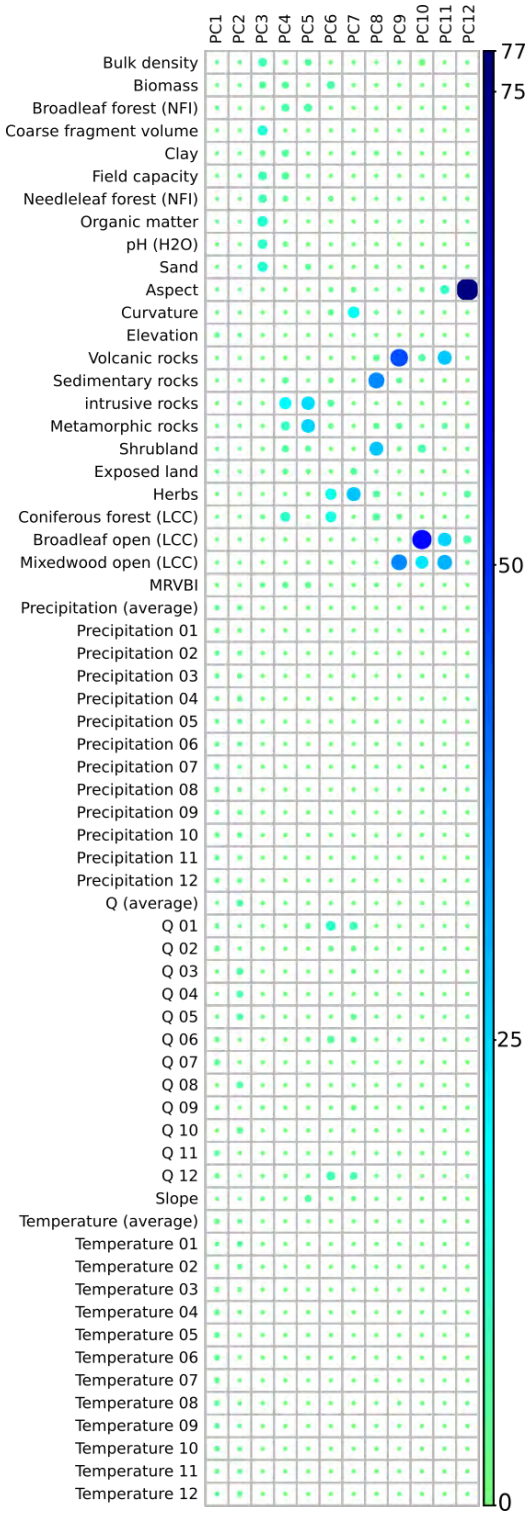


Figure 6.3: Correlation plot of the principal component's analysis matrix showing contributions of individual covariates to the first 12 dimensions. Note that two different sources of forest cover were used, one from the National Forest Inventory (NFI) and another from the Canadian Land Cover circa 2000 (LCC); see Section 6 Table 6-1 in the main report.

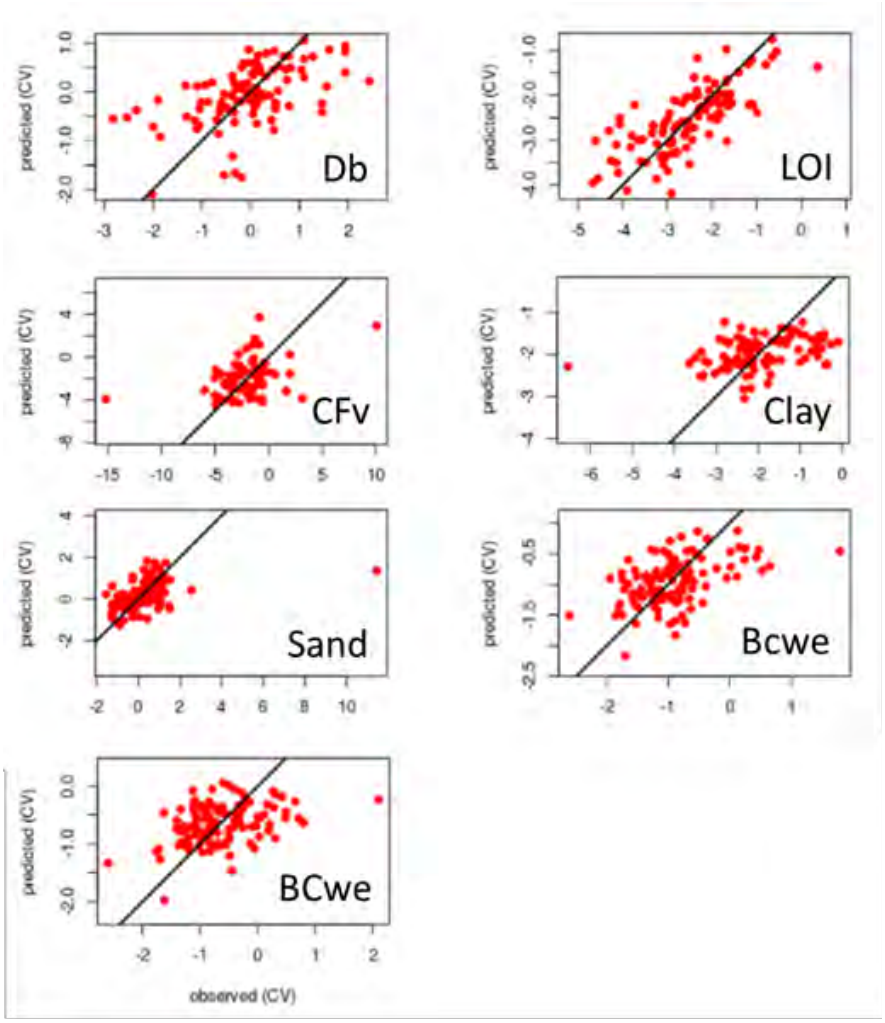


Figure 6.4: Goodness of fit for five-fold cross validated datasets for bulk density (Db), loss on ignition (LOI), coarse fragment by volume (CF_v), clay, sand, base cation weathering (Bcwe = Ca^{2+} + Mg^{2+} + K^+) and base cation weathering (BCwe = Ca^{2+} + Mg^{2+} + K^+ + Na^+). Note that units in these graphs are transformed.

6.4 Predictive Maps of Soil Properties

Predictive maps of soil organic matter content (as loss-on-ignition [LOI]) and base cation weathering (Bcwe = Ca^{2+} + Mg^{2+} + K^+) are displayed below. For details on the mapping procedure see Appendix 6.3.

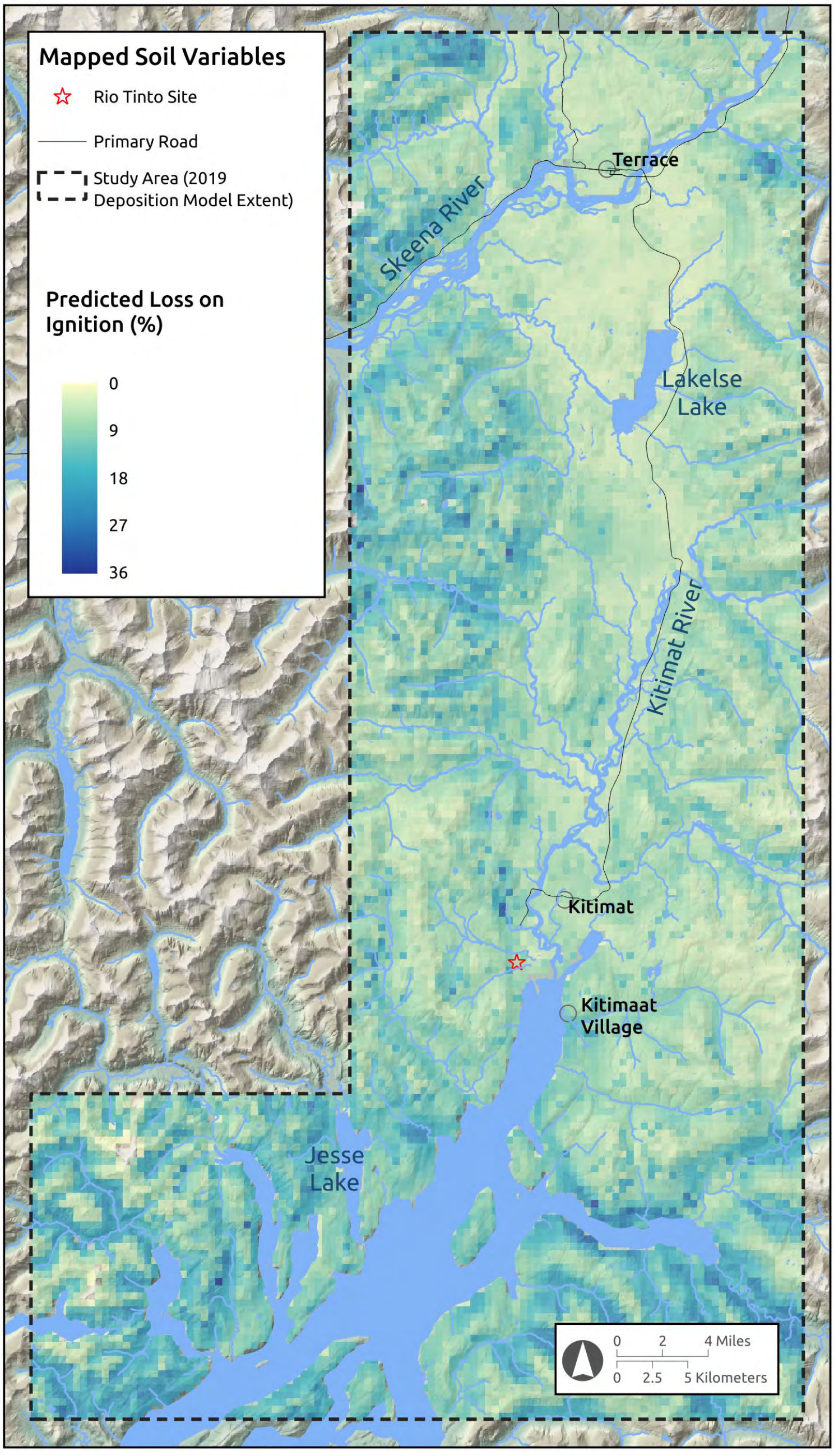


Figure 6.5: Predicted average soil percent loss-on-ignition (organic matter content) in the top 0–50 cm of mineral soil.

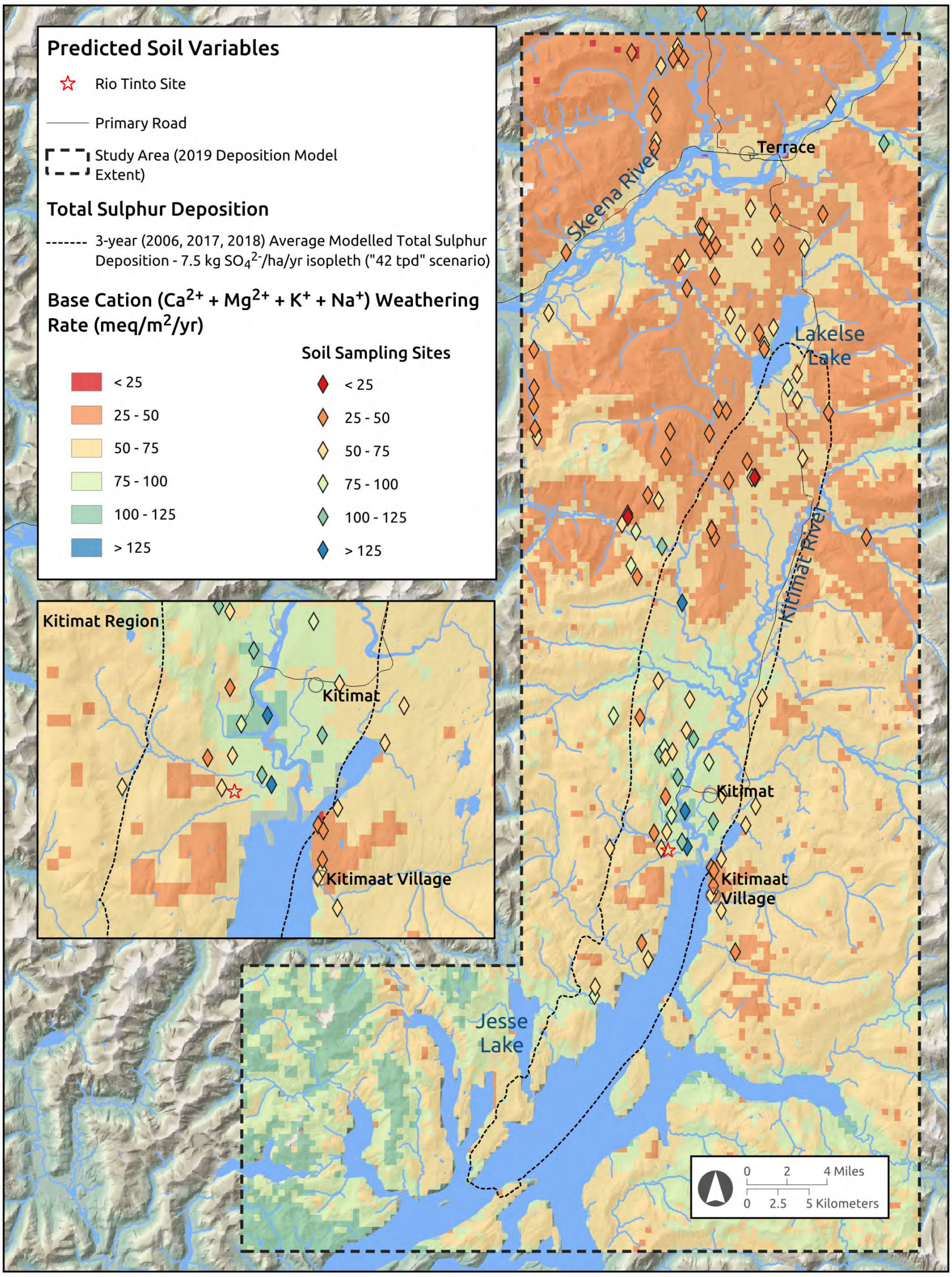


Figure 6.6: Predicted average soil base cation (Ca^{2+} + Mg^{2+} + K^+) weathering rates excluding sodium (meq/m^2/yr) in the top 0–50 cm of mineral soil. Diamonds represent site-specific estimates of weathering rates used to develop the predictive map (using regression kriging, see Appendix 6.3). The dotted line indicates the isoline for modelled total sulphur deposition > 7.5 kg SO_4^{2-}/ha/yr based on permitted emissions of 42 tonnes of sulphur dioxide per day.

6.5 Modelling and Mapping of Terrestrial Critical Loads

The mapping and modelling of critical loads of acidity (sulphur) for terrestrial ecosystems (soil) under the SO_2 EEM Program primarily followed the methodology described in the STAR (ESSA et al., 2013) with the inclusion of seven revisions (labelled A to G).

A. All new soil data will be captured and incorporated into the STAR soils database. Base cation weathering rates will be estimated for all soil sampling pits with total element content data following the methodology used in the STAR. See Appendix 6.1.
B. Spatial prediction or regionalisation of soil input parameters for the determination of critical loads, e.g., weathering rates and soil organic matter will be carried out using regression-kriging. The approach will incorporate all available soil data in the study area (see revision A). See Appendix 6.3.
C. Base cation deposition will be mapped across the study domain and incorporated into the determination of critical loads of acidity for (upland) forest soils. See Appendix 6.6.
D. Incorporation of background sulphur deposition in the determination of exceedance of critical loads following the KAEEA (ESSA et al. 2014). See Appendix 6.7.
E. Spatial delineation of unique vegetation types within the study domain and assignment of vegetation-specific Bc:Al ratios. Incorporation of vegetation-specific Bc:Al ratios into the determination of critical loads of acidity.
F. Determination of exceedance of critical load under multiple chemical criteria to assess the influence of the chosen criterion on predicted exceedance following the KAEEA (ESSA et al. 2014).
G. Determination of proportional areal exceedance using the original domain and an effects domain defined by the area under the 7.5 kg SO_4^{2-}/ha/yr deposition plume.

6.6 Base Cation Deposition

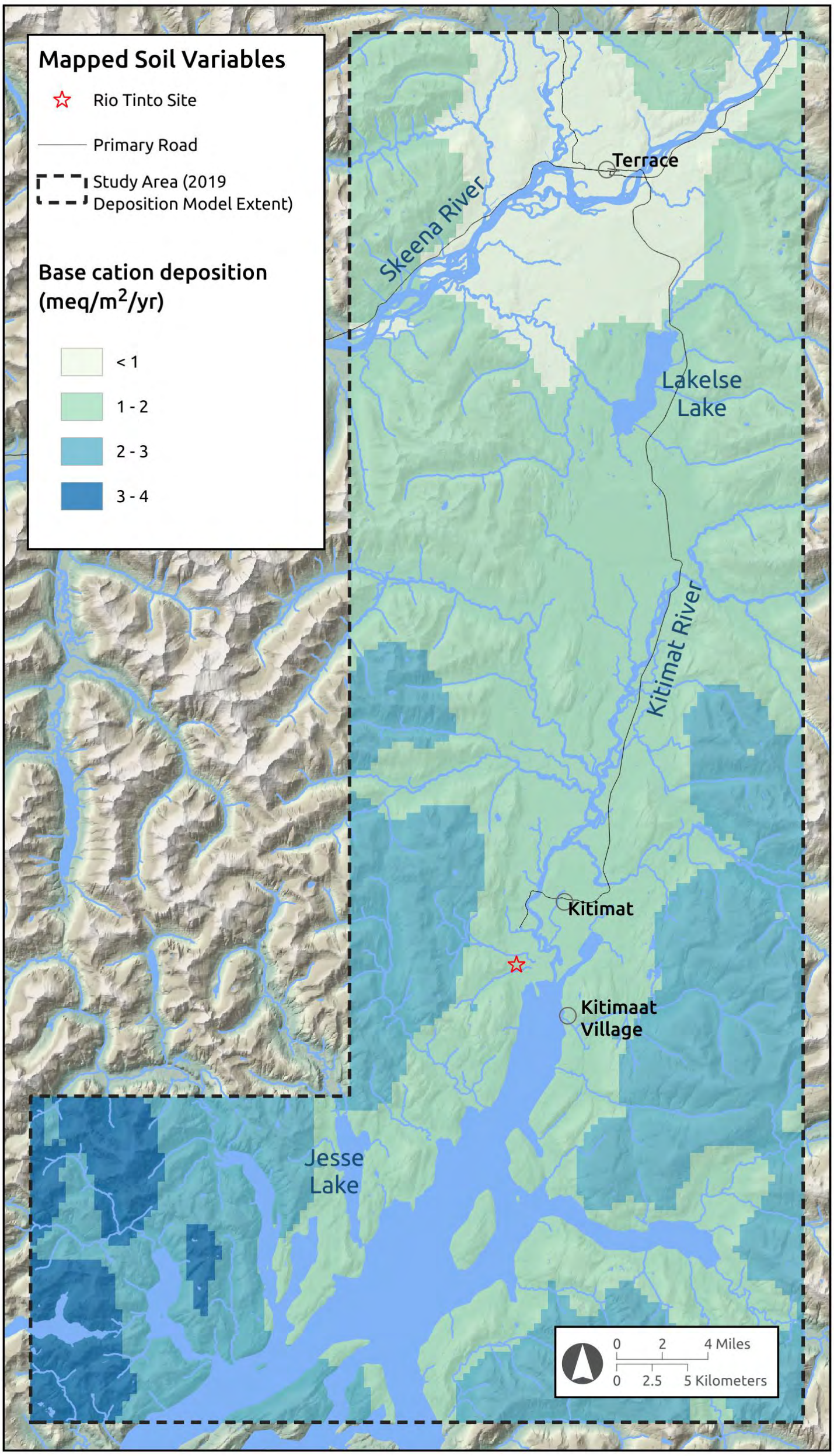


Figure 6.7: Predicted non-marine base cation wet deposition derived from a constant precipitation concentration across the study area combined with mapped rainfall volume. Base cation concentration in precipitation was set to 0.71 µeq/L based on annual average observations during 2014–2018 at two National Atmospheric Deposition Program (NADP) precipitation chemistry monitoring stations (Port Edward [BC24] and Lakelse Lake [BC23]).

6.7 Background Sulphur Deposition

Modelled sulphur deposition estimates under the comprehensive review do not include background transboundary deposition estimates, i.e., modelled deposition only represents the contribution of all stationary and mobile emissions sources in the study domain. However, transboundary atmospheric sources contribute a significant amount of anthropogenic sulphur deposition, as observed by monitoring stations in background regions (see CAPMoN and NADP).

There have been large changes in global sulphur dioxide (SO_2) emissions during the last four decades. Between ~1980 and 2000, there was a global decrease in SO_2 emissions followed by an increased until ~2006, owing to a sharp rise in emissions from China; since then there has been a declining global trend (Aas et al., 2019). Global anthropogenic sulphur emissions during 2010 were approximately 100 Tg SO_2, with China responsible for approximately one third of all global emissions (Klimont et al. 2013). Modelled global predictions of sulphur deposition indicate that shipping and emissions from China are sources of transboundary anthropogenic deposition to northwestern British Columbia (Lamarque et al. 2013).

Observations of wet deposition from the National Atmospheric Deposition Program (NADP) monitoring station at Port Edward (BC24) indicated that non-sea salt sulphate deposition decreased by 23% between the three-year periods 2013–2015 and 2016–2018. A similar decrease was observed at NADP monitoring stations in Washington state (WA19: 26% decrease) and Alaska (AK02: 25% decrease). This is consistent with the annual average trend of –2.78% in sulphate wet deposition observed at monitoring stations (n = 217) across North America (Aas et al., 2019).

Current observations at background wet deposition monitoring stations in Alaska and Washington (NADP AK02, AK03, AK96, WA14 and WA19) show that the concentration of sulphate in precipitation is 0.10 mg/L. This suggests that background total deposition of non-sea salt sulphur (owing to transboundary sources) in the Kitimat Valley ranges from 5–10 meq/m2/yr based on recent (2016–2018) annual rainfall volume at Lakelse Lake and Haul Road, and the contribution of wet deposition to total deposition at both stations. Wet deposition in general represents 40–60% of total deposition in the Kitimat Valley. Based on wider monitoring networks, and recent reductions in atmospheric sulphur, we chose a constant sulphur deposition of 7.5 meq/m2/yr to represent background deposition, compared with 10 meq/m2/yr used in the Kitimat Airshed Emissions Effects Assessment (ESSA et al., 2014). It is recognised that actual background deposition will vary across the region, and that the selected value represents a precautionary estimate of background deposition.

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Aas, W., A. Mortier, V. Bowersox, R. Cherian, G. Faluvegi, H. Fagerli, J. Hand, Z. Klimont, C. Galy-Lacaux, C.M.B. Lehmann, C.L. Myhre, G. Myhre, D. Olivié, K. Sato, J. Quaas, P.S.P. Rao, M. Schulz, D. Shindell, R.B. Skeie, A. Stein, T. Takemura, S. Tsyro, R. Vet, and X. Xu, 2019. Global and regional trends of atmospheric sulfur. Scientific Reports, 9:1, 953.

ESSA Technologies, J. Laurence, Risk Sciences International, Trent University, and Trinity Consultants. 2014. Kitimat Airshed Emissions Effects Assessment. Report prepared for BC Ministry of Environment, Smithers, BC. 205 pp. + appendices.

Klimont, Z., S.J. Smith, and J. Cofala. 2013. The last decade of global anthropogenic sulfur dioxide: 2000–2011 emissions. Environmental Research Letters 8: 014003.

Lamarque, J.-F., F. Dentener, J. McConnell, C.-U. Ro, M. Shaw, R. Vet, and 20 others. 2013. Multi-model mean nitrogen and sulfur deposition from the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP): evaluation of historical and projected future changes. Atmospheric Chemistry and Physics 13: 7997-8018.

6.8 Close-up of Exceedance of Critical Loads of Acidity



Figure 6.8: Predicted exceedance of critical loads of acidity for forest and wetland soils (grids cells with white outline; n = 21) under modelled total sulphur deposition based on permitted emissions of 42 tonnes of sulphur dioxide per day. The Rio Tinto fence line (red outline) is also shown.

6.9 Exceedance of Critical Loads of Acidity

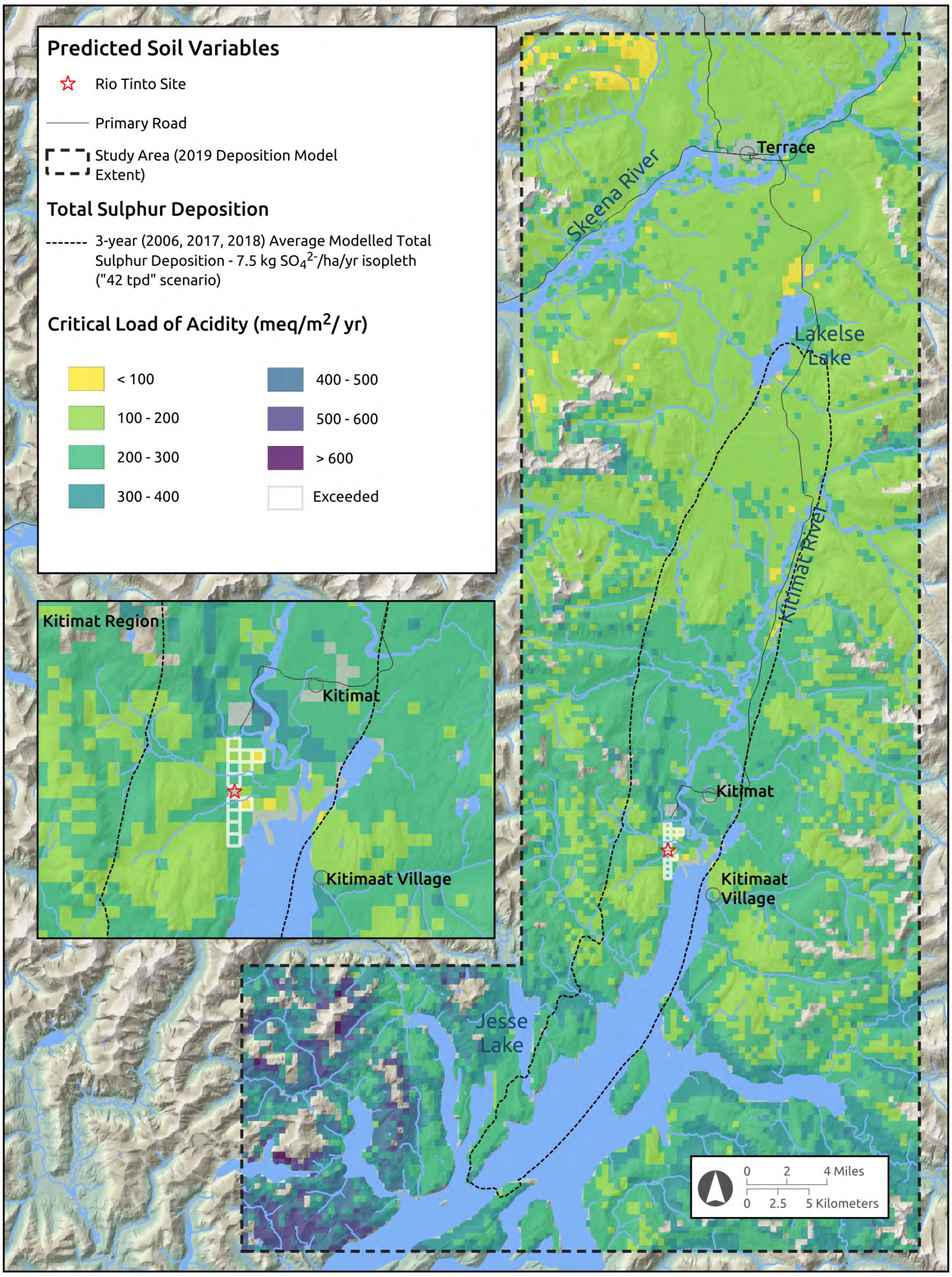


Figure 6.9: Predicted critical loads of acidity for forest and wetland soils (meq/m^2/yr), and their exceedance (grids cells with white outline; n = 12) under modelled total sulphur deposition based on actual emissions of sulphur dioxide (during 2016–2018). The dotted line indicates the isoline for modelled total sulphur deposition > 7.5 kg SO_4^{2-}/ha/yr based on permitted emissions of 42 tonnes of sulphur dioxide per day.

6.10 Uncertainty of Exceedance of Critical Loads of Acidity

The influence of critical load (critical limit) model parameters and uncertainty in modelled deposition on the determination of exceedance was examined through a simple one-at-a-time sensitivity analysis. The 'base' exceedance under 42 tpd was compared with exceedance under extreme ranges for K_{gibb}, Bc:Al and double deposition. In addition, following the Kitimat Airshed Emissions Effects Assessment (ESSA et al., 2014b), exceedance was estimated for multiple critical chemical criteria. Three criteria were selected following UNECE (2004) and evaluated under 42 tpd. The soil pH criterion was set at pH= 4.5 based on an approximate 0.5 pH unit shift from the average soil pH in the Kitimat valley. The other critical limits were taken from UNECE (2004), e.g., aluminium mobilisation (p) was set to 2. A calcium to aluminium (Ca:Al) ratio was not used as this criterion requires mapped calcium weathering rates. The three criteria show no exceedance under 42 tpd, as each criterion is less sensitive than the Bc:Al criterion. Similar results were observed in the Kitimat Airshed Emissions Effects Assessment (ESSA et al., 2014b).

Table 6.4: Exceedance of critical loads of acidity for forest soils and wetlands. See main report Section 6 Tables 6-2 and 6-3 for details on model parameters used to estimate critical load and exceedance.

Exceedance	Base	K_{gibb}	K_{gibb}	Bc:Al	Bc:Al	pH	Al	p	Base × 2
	42 tpd	7.5	9.0	1	10	4.2	0.2	1	42 tpd × 2
Average exceedance (meq/m²/yr)	149.6	178.9	137.6	149.6	99.4	0	0	0	213.6
Exceeded area (km²)	2.33	1.10	2.84	2.33	7.30	0	0	0	7.30
Exceeded area (%) *	0.58	0.28	0.71	0.58	1.83	0	0	0	1.25
Exceeded grids (n)	23	17	26	23	66	0	0	0	62
Mapped receptor area (km²)	398.4	398.4	398.4	398.4	398.4	398.4	398.4	398.4	583.4

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

6.11 Long-term Soil Plots

During October–December 2015, near-field and far-field long-term soil plots were established at Coho and Lakelse Lake, respectively, to reflect the gradient in atmospheric deposition, and during 2016 a reference (or background) plot was established at Kemano. At each location, primary and secondary (backup) plots were established within forest stands dominated by western Hemlock; secondary plots (located generally within 500 m of the primary plot) provide a backup or replacement to the primary plot if disturbed or destroyed within the lifetime of the monitoring program. For further details, see Technical Memo S04 (2016), Technical Memo S06 (2017) and Technical Memo S07 (2018).

This appendix provides detailed data for the long-term soil plots including dates of establishment, initial field observations, and chemical analysis:

Table 6.5. Dates of establishment of the primary and secondary long-term soil plots.

Table 6.6. List of sub-grids sampled during establishment (2015–2016) and re-sampling (2018).

Table 6.7. Physicochemical soil properties at Coho Flats during establishment in 2015.

Table 6.8. Physicochemical soil properties at Lakelse Lake during establishment in 2015.

Table 6.9. Physicochemical soil properties at Kemano during establishment in 2016.

Table 6.10. Basal area (m2/ha) and stem density (stems per ha) at the long-term soil plots.

Table 6.11. Average soil pools by depth during 2015 and 2018 and minimum detectable difference.

Table 6.12. Soil chemistry by sampling layer at Coho Flats primary plot for 2015 and 2018.

Table 6.13. Soil chemistry by sampling layer at Lakelse Lake primary plot for 2015 and 2018.

Figure 6.10. Plot layout showing the lettered grid (A–T) and number sub-grids (1–12).

Figure 6.11. Tree species at the primary long-term soil monitoring plots.

Figure 6.12. Loss-on-ignition (%), pH and exchangeable base cations by depth during 2015 and 2018 at Coho Flats and Lakelse Lake long-term soil plots.

Table 6.5: Dates of establishment of the primary and secondary long-term soil plots and their location (latitude, longitude and elevation).

Long-term Soil Plots	Established	Latitude	Longitude	Elevation (m)
Coho Flats Primary (CFP)	02–03/12/2015	54.07660	–128.65117	73.1
Coho Flats Secondary (CFS)	29/10/2015	54.07458	–128.65025	128.8
Lakelse Lake Primary (LEP)	28/10/2015	54.37827	–128.57991	87.3
Lakelse Lake Secondary (LES)	30/10/2015	54.37814	–128.57593	199.5
Kemano Primary (KMP)	25/06/2016	53.53032	–127.97384	53.0
Kemano Secondary (KMS)	25/06/2016	53.55259	–127.95502	57.0

Re-sampled on Sunday 24/06/2018

Table 6.6: List of (numbered) sub-grids from each lettered grid sampled during establishment (2015–2016) and re-sampling (2018) at the primary and secondary long-term soil plots are Coho Flats, Lakelse Lake and Kemano. See Figure 6.10 in this appendix for plot layout.

#	Coho Flats (CF)			Lakelse Lake (LE)			Kemano (KM)	
	Primary 2015	Primary 2018	Secondary 2015	Primary 2015	Primary 2018	Secondary 2015	Primary 2016	Secondary 2016
1	A12	A07	A10	A10	A04	A10	A09	A08
2	B08	B04	B06	B11	B02	B06	B02	B12
3	C05	C07	C03	C02	C11	C10	C10	C03
4	D04	D01	D07	D05	D12	D02	D09	D12
5	E11	E10	E07	E04	E11	E06	E03	E04
6	F03	F02	F01	F02	F01	F02	F04	F07
7	G06	G02	G05	G09	G01	G02	G12	G06
8	H06	H07	H01	H07	H05	H04	H03	H11
9	I11	I06	I04	I06	I07	I08	I12	I09
10	J05	J07	J12	J01	J05	J09	J06	J01
11	K12	K10	K05	K04	K12	K10	K09	K09
12	L02	L03	L06	L12	L05	L11	L08	L06
13	M03	M01	M01	M04	M03	M12	M08	M02
14	N12	N01	N02	N05	N06	N04	N09	N04
15	O07	O10	O03	O06	O09	O11	O04	O11
16	P11	P10	P06	P09	P05	P09	P03	P07
17	Q03	Q06	Q06	Q12	Q06	Q01	Q12	Q02
18	R02	R06	R02	R07	R02	R03	R07	R04
19	S03	S04	S07	S06	S01	S09	S06	S10
20	T02	T08	T05	T09	T02	T03	T09	T04

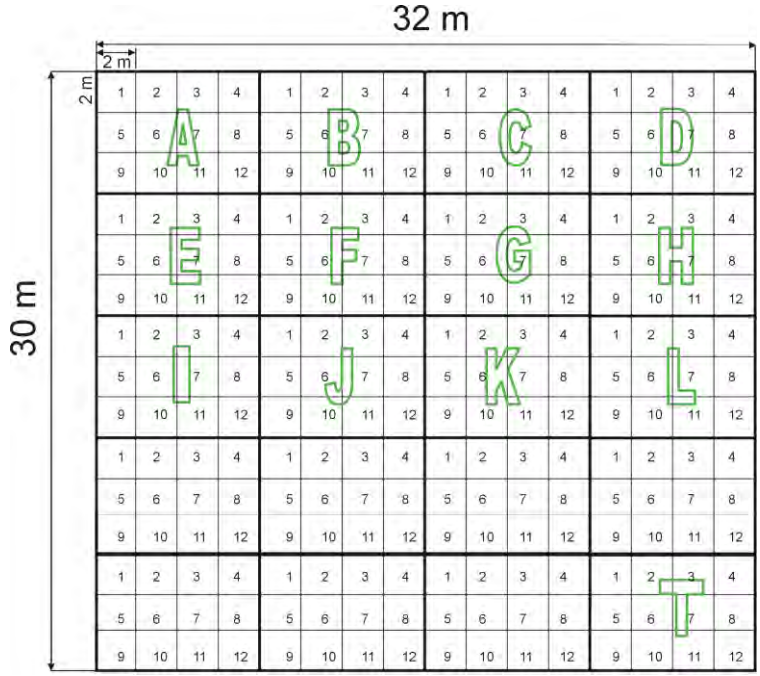


Figure 6.10: Plot layout showing the lettered grid (A–T) and number sub-grids (1–12). The plots are oriented so that the A grid is at North West corner. During each sampling campaign, one numbered sub-grid is randomly sampled (without replacement) from each lettered grid. A total of 20 sub-grids are sampled at three depths in the mineral soil 0–5 cm, 5–15 cm and 15–30 cm. See Table 6.6 in this appendix for a list of sub-grids sampled at the primary and second plots at Coho Flats, Lakelse Lake and Kemano during establishment (2015–2016) and during the first re-sampling (2018) at the Coho Flats and Lakelse Lake primary plots.

Table 6.7: Physicochemical soil properties (organic matter [LOI], pH and bulk density [Db]) at the primary (P) and secondary (S) plots at Coho Flats (CF) during establishment in 2015.

Depth	CFP	LOI	pH	Db	CFS	LOI	pH	Db
cm	ID	%		g cm^{-3}	ID	%		g cm^{-3}
0–5	A12	16.84	4.38	0.307	A10	21.7	4.45	.
5–15	A12	25.59	4.45	0.496	A10	21.5	4.71	.
15–30	A12	4.00	4.49	1.124	A10	13.3	4.84	.
0–5	B08	17.00	3.77	0.389	B06	16.6	4.63	0.480
5–15	B08	16.40	4.25	0.459	B06	16.3	4.94	0.596
15–30	B08	12.74	4.49	0.364	B06	10.6	5.02	0.600
0–5	C05	21.05	3.89	0.348	C03	25.1	4.45	0.787
5–15	C05	22.04	4.41	0.346	C03	15.9	4.88	0.713
15–30	C05	14.26	4.53	0.589	C03	9.9	5.27	0.685
0–5	D04	19.56	4.51	0.432	D07	17.4	4.47	0.438
5–15	D04	19.29	4.57	0.351	D07	9.2	5.09	0.536
15–30	D04	19.45	4.66	0.302	D07	6.4	5.07	0.459
0–5	E11	.	.	0.468	E07	27.8	4.80	0.295
5–15	E11	.	.	0.440	E07	26.2	5.04	0.364
15–30	E11	.	.	0.538	E07	16.3	5.25	0.600
0–5	F03	16.18	4.14	0.455	F01	14.1	4.82	0.529
5–15	F03	18.41	4.52	0.467	F01	15.7	4.90	0.547
15–30	F03	11.02	4.63	0.624	F01	14.2	5.16	0.555
0–5	G06	22.97	4.17	0.267	G05	20.2	4.16	.
5–15	G06	21.00	4.37	0.663	G05	15.4	4.63	.
15–30	G06	17.62	4.54	0.500	G05	21.3	4.75	.
0–5	H06	20.24	4.16	0.248	H01	11.3	5.20	0.392
5–15	H06	18.47	4.40	0.200	H01	.	.	0.410
15–30	H06	22.40	4.41	0.399	H01	.	.	0.367
0–5	I11	20.18	4.00	0.443	I04	21.2	4.77	0.497
5–15	I11	23.41	4.24	0.381	I04	18.5	4.66	0.323
15–30	I11	.	.	0.538	I04	15.7	4.86	0.324
0–5	J05	20.64	3.86	0.471	J12	23.9	4.73	0.598
5–15	J05	19.67	4.13	0.417	J12	21.3	4.87	0.502
15–30	J05	22.11	4.90	0.366	J12	14.2	5.12	0.454
0–5	K12	14.31	4.14	0.733	K05	25.4	4.87	.
5–15	K12	9.52	4.63	0.525	K05	24.3	4.39	.
15–30	K12	8.20	4.43	0.716	K05	19.4	5.08	.
0–5	L02	14.85	4.14	0.486	L06	16.5	4.66	0.864
5–15	L02	35.43	4.19	0.527	L06	.	.	0.581
15–30	L02	17.71	4.85	0.451	L06	.	.	0.570
0–5	M03	11.94	4.03	0.524	M01	16.8	4.76	0.658
5–15	M03	22.04	4.24	0.389	M01	16.1	4.66	0.474
15–30	M03	18.79	4.44	0.616	M01	15.5	4.82	0.350
0–5	N12	14.45	3.65	0.459	N02	16.2	5.21	0.773
5–15	N12	23.36	4.36	0.345	N02	16.7	4.96	0.402
15–30	N12	15.89	4.75	0.243	N02	21.6	5.01	0.315
0–5	O07	19.47	4.10	0.214	O03	17.7	4.60	0.492
5–15	O07	20.61	4.55	0.238	O03	23.5	4.48	0.635
15–30	O07	12.54	4.49	0.644	O03	12.9	4.88	0.483
0–5	P11	38.86	4.44	0.299	P06	19.8	4.91	0.614
5–15	P11	23.10	4.43	0.221	P06	.	.	0.444
15–30	P11	20.43	4.70	0.438	P06	.	.	0.433
0–5	Q03	8.70	4.37	0.684	Q06	15.8	4.51	0.264
5–15	Q03	10.31	4.07	0.560	Q06	15.8	4.82	0.253
15–30	Q03	.	.	0.260	Q06	11.8	4.95	0.216
0–5	R02	16.16	4.23	0.350	R02	36.9	4.34	0.359
5–15	R02	17.67	4.06	0.471	R02	23.5	4.78	0.386
15–30	R02	.	.	0.653	R02	20.6	4.91	0.382
0–5	S03	17.97	3.85	0.321	S07	26.4	4.48	0.671
5–15	S03	23.90	4.52	0.401	S07	24.9	4.39	0.467
15–30	S03	17.64	5.03	0.405	S07	16.2	4.74	0.694
0–5	T02	30.36	5.06	0.790	T05	16.3	5.27	0.413
5–15	T02	15.95	4.78	0.437	T05	11.9	5.30	0.474
15–30	T02	22.82	5.25	0.472	T05	11.8	5.46	0.540

Table 6.8: Physicochemical soil properties (organic matter [LOI], pH and bulk density [Db]) at the primary (P) and secondary (S) plots at Lakelse Lake (LE) during establishment in 2015.

Depth	LEP	LOI	pH	Db	LES	LOI	pH	Db
cm	ID	%		g cm^{-3}	ID	%		g cm^{-3}
0–5	A10	11.36	4.79	0.517	A10	7.6	5.17	1.096
5–15	A10	5.10	5.09	0.830	A10	8.0	5.48	0.818
15–30	A10	4.57	5.33	0.987	A10	5.4	5.50	1.139
0–5	B11	5.48	4.24	0.567	B06	8.1	4.77	0.668
5–15	B11	5.15	5.21	0.569	B06	6.2	5.09	0.719
15–30	B11	2.11	5.48	0.884	B06	4.2	5.67	0.654
0–5	C02	9.57	4.71	0.690	C10	13.5	5.23	0.667
5–15	C02	6.67	5.03	1.119	C10	5.4	5.31	0.976
15–30	C02	4.46	5.02	1.174	C10	4.9	5.37	0.867
0–5	D05	15.09	5.53	0.617	D02	10.1	5.19	0.789
5–15	D05	10.27	5.29	0.719	D02	6.6	5.63	0.967
15–30	D05	5.94	5.30	0.902	D02	8.0	5.52	0.950
0–5	E04	15.00	4.75	0.483	E06	8.0	5.29	1.058
5–15	E04	5.56	5.23	0.550	E06	2.8	5.57	1.028
15–30	E04	5.08	5.15	0.849	E06	2.0	6.00	1.138
0–5	F02	6.63	5.08	0.782	F02	8.3	5.20	0.941
5–15	F02	7.11	5.08	0.693	F02	6.9	5.15	1.109
15–30	F02	4.75	5.34	0.878	F02	7.7	5.21	0.983
0–5	G02	6.61	5.28	0.548	G02	13.5	5.11	0.615
5–15	G02	5.21	5.26	0.745	G02	4.9	5.58	0.828
15–30	G02	4.89	5.30	0.903	G02	2.8	5.79	1.043
0–5	H07	6.23	5.33	0.874	H04	9.7	4.80	0.525
5–15	H07	4.90	5.42	1.013	H04	4.5	5.42	0.809
15–30	H07	4.67	5.31	0.969	H04	4.3	5.47	1.060
0–5	I06	14.20	5.03	0.467	I08	8.7	5.14	0.672
5–15	I06	7.03	5.24	1.081	I08	5.6	5.27	0.861
15–30	I06	4.19	5.19	1.129	I08	3.3	5.57	0.724
0–5	J01	11.58	4.92	0.639	J09	10.2	4.73	0.539
5–15	J01	5.43	5.31	0.643	J09	5.7	5.40	0.675
15–30	J01	5.14	5.11	0.544	J09	5.5	5.31	0.849
0–5	K04	8.00	5.22	0.850	K10	12.5	4.90	0.656
5–15	K04	4.36	5.26	0.731	K10	9.1	5.41	0.563
15–30	K04	1.05	5.42	1.123	K10	8.5	5.51	0.521
0–5	L12	8.96	4.89	0.597	L11	9.5	5.01	0.634
5–15	L12	8.05	4.91	1.214	L11	6.5	5.16	0.689
15–30	L12	2.89	5.11	0.926	L11	4.8	5.39	0.993
0–5	M04	12.02	4.52	0.728	M12	16.4	5.15	0.766
5–15	M04	11.21	5.05	0.827	M12	7.2	5.62	0.643
15–30	M04	4.27	5.33	0.765	M12	6.4	5.56	0.955
0–5	N05	9.18	5.02	0.476	N04	9.8	5.07	1.178
5–15	N05	4.69	5.17	0.836	N04	10.2	5.25	1.116
15–30	N05	4.57	5.08	1.149	N04	7.4	5.44	0.498
0–5	O06	9.09	4.79	1.285	O11	13.1	5.28	0.768
5–15	O06	4.70	5.38	1.051	O11	5.3	5.35	0.851
15–30	O06	2.47	5.25	1.224	O11	3.7	5.26	0.930
0–5	P09	8.69	4.85	0.567	P09	7.7	4.62	1.205
5–15	P09	3.23	5.15	1.010	P09	5.6	5.51	1.254
15–30	P09	3.86	5.13	1.255	P09	3.8	6.01	1.272
0–5	Q12	12.87	5.00	0.804	Q01	7.1	5.44	1.186
5–15	Q12	9.28	5.08	1.012	Q01	5.5	5.28	1.177
15–30	Q12	4.74	5.11	0.882	Q01	5.9	5.38	1.137
0–5	R07	9.15	4.98	1.055	R03	8.6	5.28	0.605
5–15	R07	6.26	5.02	0.756	R03	6.1	5.55	0.717
15–30	R07	4.63	5.08	0.977	R03	4.9	5.60	0.586
0–5	S06	6.64	4.90	0.663	S09	9.1	4.84	1.087
5–15	S06	5.64	5.06	0.944	S09	5.2	5.55	1.087
15–30	S06	2.52	5.19	1.082	S09	4.9	5.52	0.848
0–5	T09	10.61	4.80	0.472	T03	10.0	4.60	0.894
5–15	T09	5.37	4.97	0.769	T03	4.7	5.60	1.112
15–30	T09	4.20	4.97	1.039	T03	3.2	5.58	1.015

Table 6.9: Physicochemical soil properties (organic matter [LOI], pH and bulk density [Db]) at the primary (P) and secondary (S) plots at Kemano (KM) during establishment in 2016.

Depth	KMP	LOI	pH	Db	KMS	LOI	pH	Db
cm	ID	%		g cm^{-3}	ID	%		g cm^{-3}
0–5	A09	15.0	5.10	1.106	A08	2.6	5.46	1.193
5–15	A09	6.2	5.04	0.883	A08	1.7	5.65	.
15–30	A09	8.7	5.20	.	A08	1.77	5.72	.
0–5	B02	9.6	4.91	1.135	B12	5.8	5.82	1.033
5–15	B02	8.3	4.97	.	B12	9.4	5.90	.
15–30	B02	14.4	4.96	.	B12	1.97	5.72	.
0–5	C10	10.2	5.14	0.778	C03	2.5	5.71	1.127
5–15	C10	10.2	5.02	0.860	C03	1.3	5.81	.
15–30	C10	10.9	5.07	0.797	C03	1.47	5.66	.
0–5	D09	16.9	4.90	1.146	D12	3.5	5.87	0.948
5–15	D09	10.0	4.94	0.910	D12	2.3	5.79	.
15–30	D09	9.5	4.97	0.801	D12	1.11	5.78	.
0–5	E03	4.0	4.55	0.938	E04	0.9	5.60	1.258
5–15	E03	19.5	4.65	0.605	E04	2.3	5.62	.
15–30	E03	9.7	5.20	0.336	E04	2.33	5.70	.
0–5	F04	10.3	5.16	0.714	F07	2.6	5.78	1.013
5–15	F04	9.5	5.02	0.919	F07	1.7	5.71	.
15–30	F04	10.4	5.12	.	F07	2.08	5.72	.
0–5	G12	11.8	5.20	1.094	G06	3.0	6.04	1.246
5–15	G12	7.4	5.14	0.942	G06	2.1	5.97	.
15–30	G12	12.2	5.22	.	G06	2.16	6.14	.
0–5	H03	19.4	4.97	0.826	H11	4.6	5.56	1.128
5–15	H03	9.7	5.05	0.813	H11	2.5	5.75	.
15–30	H03	12.0	4.99	.	H11	2.59	5.79	.
0–5	I12	9.3	4.99	1.090	I09	3.1	5.63	1.249
5–15	I12	9.2	5.07	1.032	I09	2.1	5.79	.
15–30	I12	8.8	5.14	.	I09	2.15	5.81	.
0–5	J06	12.0	4.95	1.061	J01	3.3	5.82	1.249
5–15	J06	9.7	5.10	1.025	J01	3.5	5.87	.
15–30	J06	11.0	5.09	.	J01	2.04	5.82	.
0–5	K09	6.9	4.98	0.980	K09	4.5	5.54	1.048
5–15	K09	10.5	5.00	.	K09	3.5	5.61	.
15–30	K09	8.0	5.05	.	K09	1.85	5.78	.
0–5	L08	14.9	5.10	0.641	L06	4.6	5.62	1.151
5–15	L08	30.7	5.00	0.678	L06	3.0	5.73	.
15–30	L08	12.1	5.07	.	L06	1.81	5.70	.
0–5	M08	11.6	5.02	0.604	M02	4.1	5.84	1.233
5–15	M08	11.2	5.08	0.838	M02	2.2	5.87	.
15–30	M08	13.8	5.12	0.700	M02	2.26	5.78	.
0–5	N09	13.8	4.99	1.023	N04	3.3	5.93	1.152
5–15	N09	9.5	5.19	.	N04	2.3	5.75	.
15–30	N09	11.2	4.97	.	N04	1.77	5.85	.
0–5	O04	11.2	5.24	0.788	O11	3.7	5.80	1.161
5–15	O04	10.4	5.09	0.836	O11	2.5	5.41	.
15–30	O04	12.4	5.08	0.899	O11	1.77	5.84	.
0–5	P03	28.1	4.96	.	P07	3.3	5.62	1.100
5–15	P03	15.1	5.14	0.885	P07	3.1	5.56	.
15–30	P03	14.0	5.10	0.941	P07	3.32	5.65	.
0–5	Q12	5.9	4.55	0.799	Q02	3.2	5.81	1.023
5–15	Q12	6.3	4.95	0.720	Q02	1.9	5.70	.
15–30	Q12	8.1	5.03	0.791	Q02	1.02	5.84	.
0–5	R07	10.9	4.92	0.917	R04	2.6	5.75	1.215
5–15	R07	8.8	5.14	.	R04	1.8	5.87	.
15–30	R07	8.5	5.21	.	R04	1.85	5.82	.
0–5	S06	11.9	5.06	0.681	S10	3.2	5.53	1.149
5–15	S06	16.1	5.06	0.865	S10	3.2	5.73	.
15–30	S06	9.0	5.22	0.883	S10	2.08	5.72	.
0–5	T09	7.3	4.64	0.963	T04	3.6	5.77	1.210
5–15	T09	8.5	4.71	0.792	T04	2.6	5.79	.
15–30	T09	12.7	5.15	0.831	T04	2.17	5.54	.

Table 6.10: Basal area (m^2/ha), stem density (stems per ha) and the percentage Western hemlock and Sitka spruce as a proportion of total trees observed at the primary and secondary plots at Cho Flats, Lakelse Lake and Kemano. See Figure 6.11 in this appendix for layout of trees at the primary plots.

Long-term Soil Plots	Basal Area	Density	Western hemlock	Sitka spruce
	m^2/ha	stems/ha	% of stems	% of stems
Coho Flats Primary (CFP)	70.1	489.6	59.5	
Coho Flats Secondary (CFS)	68.3	416.7	100.0	
Lakelse Lake Primary (LEP)	55.6	1125.0	50.5	23.6
Lakelse Lake Secondary (LES)	54.2	2365.0	34.9	16.7
Kemano Primary (KMP)	79.6	718.8	51.1	24.0
Kemano Secondary (KMS)	76.3	510.4	19.2	66.8

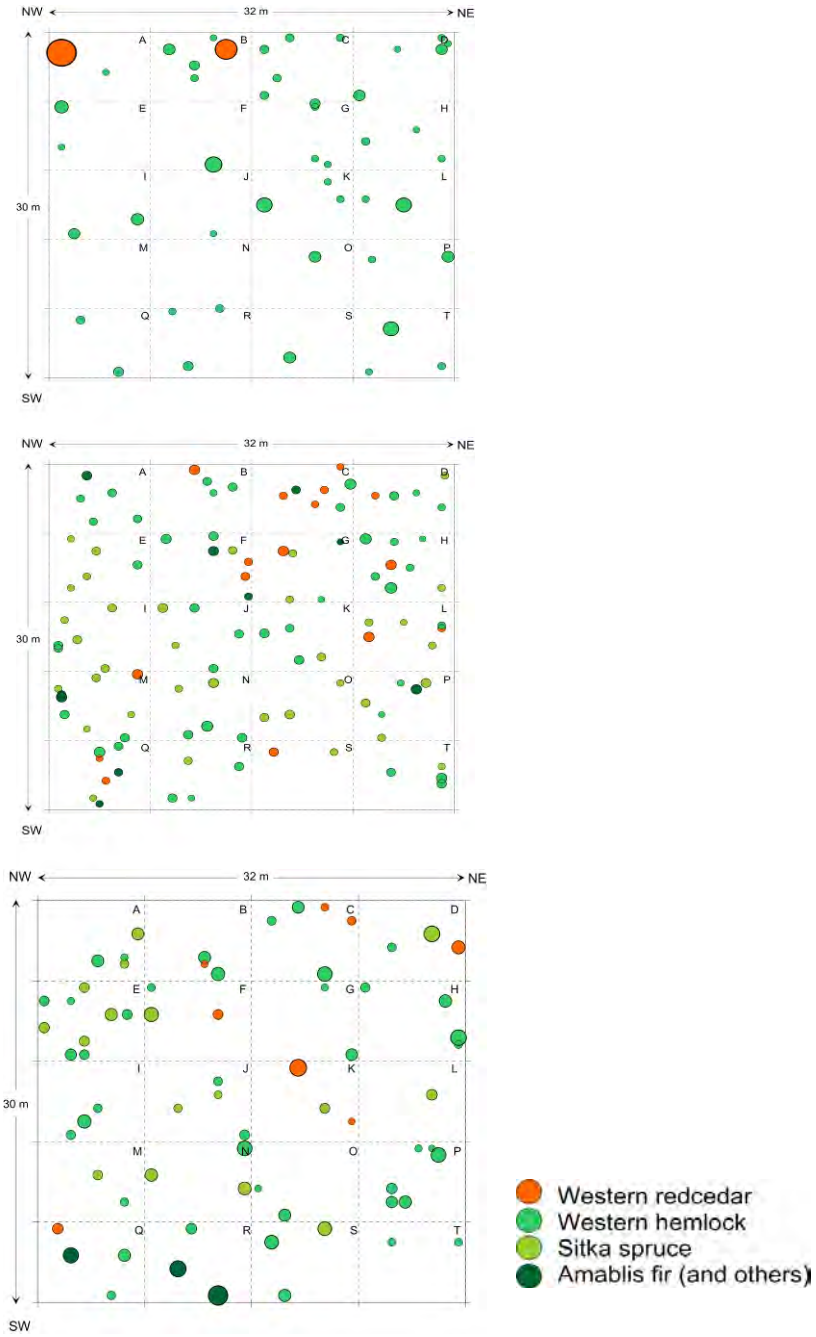


Figure 6.11: Layout of the primary long-term soil monitoring plots at Coho Flats (upper), Lakelse Lake (middle), and Kemano (lower) showing the location and relative size of each tree species.

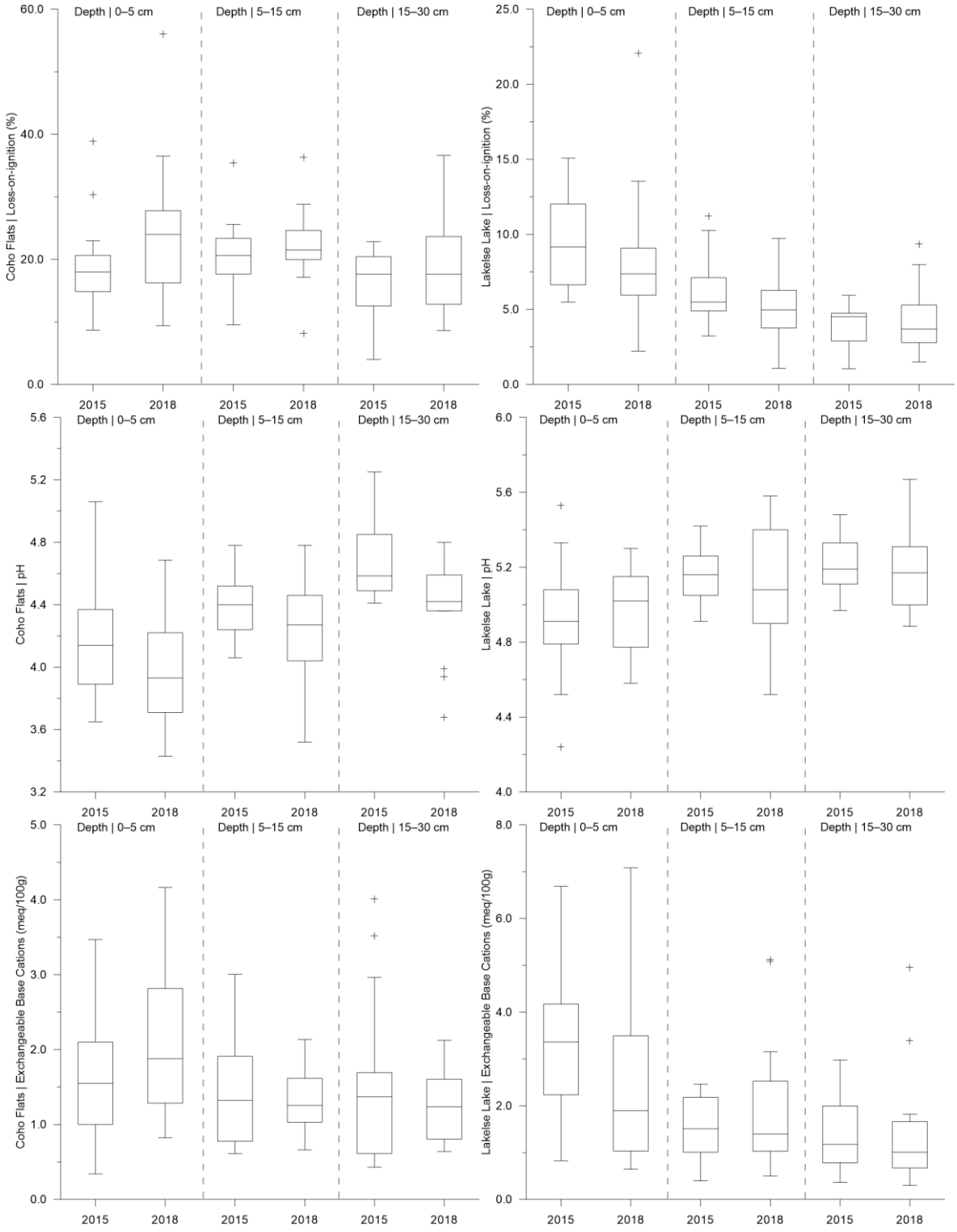


Figure 6.12: Boxplots showing loss-on-ignition (%), pH and exchangeable base cations (meq/100g) by depth during 2015 and 2018 at Coho Flats and Lakelse Lake long-term soil plots. There up to 20 observations per depth.

Table 6.11: Average soil pools by depth during 2015 and 2018, probability of decrease between 2015 and 2018, magnitude of difference (MOD) and minimum detectable difference (MDD) based on the variability during 2015 and pooled variability during 2015 and 2018 at Coho Flats Primary (CFP) and Lakelse Lake Primary (LEP) plots.

Plot	Depth	Param	Units	Test[a]	n 2015	Trans[b]	MCT 2015	MCT 2018	p-value	MOD[d] %	MDD 2015	MDD pSD
CFP	0–5	Ca^{2+}	meq/m²	tequal	19	Log10	177	205	0.737	16	-51	-53
		Mg^{2+}	meq/m²	tunequal	19	None	66	138	1.000	109	-37	-81
		BC	meq/m²	tequal	19	None	333	446	0.953	34	-47	-57
		EA	meq/m²	tequal	18	Log10	1,584	1,181	0.026	-25	-26	-34
		CEC_e	meq/m²	tequal	18	None	1,989	1,796	0.215	-10	-29	-35
		BS_e	%	tequal	18	Log10	15	24	0.999	62	-38	-43
LEP	0–5	Ca^{2+}	meq/m²	tequal	20	Log10	719	386	0.015	-46	-49	-56
		Mg^{2+}	meq/m²	tequal	20	Log10	205	120	0.024	-42	-45	-54
		BC	meq/m²	tequal	20	Log10	998	565	0.016	-43	-45	-53
		EA	meq/m²	tequal	20	None	1,252	997	0.066	-20	-34	-39
		CEC_e	meq/m²	tequal	20	Log10	2,279	1,476	0.013	-35	-31	-43
		BS_e	%	tequal	20	None	47	41	0.150	-11	-31	-32
CFP	0–15	Ca^{2+}	meq/m²	tunequal	19	Log10	485	453	0.363	-6.6	-48	-58
		Mg^{2+}	meq/m²	tunequal	19	None	188	301	0.994	60	-39	-62
		BC	meq/m²	tequal	19	None	938	927	0.468	-1.3	-49	-59
		EA	meq/m²	tequal	18	None	4,445	3,525	0.034	-21	-29	-31
		CEC_e	meq/m²	tequal	18	None	5,377	4,452	0.060	-17	-29	-30
		BS_e	%	tequal	18	None	17	22	0.988	28	-34	-35
LEP	0–15	Ca^{2+}	meq/m²	tequal	20	Log10	1,578	1,156	0.097	-27	-44	-50
		Mg^{2+}	meq/m²	tequal	20	Log10	466	339	0.083	-27	-40	-49
		BC	meq/m²	tequal	20	Log10	2,228	1,691	0.108	-24	-40	-48
		EA	meq/m²	tequal	20	None	3,632	3,046	0.113	-16	-38	-39
		CEC_e	meq/m²	tequal	20	Log10	5,722	4,565	0.088	-20	-32	-39
		BS_e	%	tequal	20	None	41	39	0.389	-3.0	-28	-31
CFP	0–30	Ca^{2+}	meq/m²	tequal	18	Log10	1,012	899	0.295	-11	-47	-57
		Mg^{2+}	meq/m²	tunequal	18	Log10	324	435	0.895	34	-36	-44
		BC	meq/m²	tequal	18	Log10	1,708	1,651	0.426	-3.3	-39	-41
		EA	meq/m²	tequal	18	Log10	8,447	5,598	0.008	-34	-24	-36
		CEC_e	meq/m²	tequal	18	Log10	10,297	7,293	0.017	-29	-24	-35
		BS_e	%	tequal	18	None	18	23	0.992	31	-35	-44
LEP	0–30	Ca^{2+}	meq/m²	tequal	20	Log10	2,714	2,279	0.223	-16	-44	-49
		Mg^{2+}	meq/m²	tequal	20	Log10	794	679	0.236	-14	-42	-47
		BC	meq/m²	tequal	20	Log10	4,041	3,367	0.189	-17	-38	-45
		EA	meq/m²	tequal	20	None	6,938	6,245	0.221	-10	-32	-38
		CEC_e	meq/m²	tequal	20	Log10	10,742	9,205	0.164	-14	-31	-37
		BS_e	%	tequal	20	None	39	39	0.504	0.11	-23	-29

† Soil parameters (Param) included exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), base cations (BC), exchangeable acidity (EA), effective cation exchange capacity (CEC_e) and effective base saturation (BS_e). [a] One-sided t-test assuming equal variances (tequal) or not (tunequal) according to a Levene's test for equal variances ($\alpha = 0.05$) and testing for a decrease in values for 2018. [b] Statistical comparisons were conducted using untransformed (None) or log10 transformed (Log10) data depending on the normality of the residuals determined from a Shapiro-Wilk's test ($\alpha = 0.05$). [c] The measure of central tendency (MCT) was calculated as a mean or geometric mean with untransformed or log10 transformed data, respectively. [d] The magnitude of difference was calculated as 2018 – 2015/ 2015 × 100% using the MCT. [e] The Minimum Detectable Difference (MDD) was conducted using a t-test power analysis (α=0.05, $\beta = 0.1$) using the standard deviation in 2015 and the pooled standard deviation (2015 and 2018) and accounting for unequal variances where appropriate. MDD was expressed as a percent decrease from 2015 (–MDD/MCT2015). For transformed data, power analysis was conducted with log transform data, but back-transformed to raw scale for % MDD relative to 2015.

Table 6.12: Soil chemistry (organic matter [LOI], pH, exchangeable cations [Ca^{2+}, K^{+}, Mg^{2+} and Na^{+}] and exchangeable acidity [EA]) by sampling layer at Coho Flats primary plot for 2015 and 2018.

Year	2015	2015	2015	2015	2015	2015	2015	2015	2018	2018	2018	2018	2018	2018	2018	2018
Depth	Plot	LOI	pH	Ca^{2+}	K^{+}	Mg^{2+}	Na^{+}	EA	Plot	LOI	pH	Ca^{2+}	K^{+}	Mg^{2+}	Na^{+}	EA
Unit		%		meq / 100 g						%		meq / 100 g				
0–5	A12	16.8	4.38	0.83	0.24	0.44	0.04	8.5	A07	9.4	3.43	1.39	0.04	0.57	0.02	7.67
5–15	A12	25.6	4.45	0.33	0.12	0.31	0.08	5.7	A07	8.2	3.52	0.82	0.02	0.35	0.06	8.79
15–30	A12	4.0	4.49	0.35	0.06	0.07	.	6.5	A07	11.4	3.68	0.89	0.04	0.39	0.05	9.53
0–5	B08	17.0	3.77	2.81	0.14	0.44	0.03	8.5	B04	27.7	4.32	1.54	0.10	0.34	0.06	5.43
5–15	B08	16.4	4.25	1.90	0.10	0.33	0.21	7.1	B04	21.5	3.73	0.30	0.22	0.58	0.05	9.59
15–30	B08	12.7	4.49	3.25	0.12	0.43	0.20	5.7	B04	.	.					
0–5	C05	21.1	3.89	1.03	0.13	0.33	0.16	8.5	C07	22.9	3.60	2.06	0.31	0.93	0.16	2.38
5–15	C05	22.0	4.41	1.19	0.06	0.19	0.04	5.9	C07	22.9	4.31	0.96	0.18	0.42	0.09	5.41
15–30	C05	14.3	4.53	1.05	0.10	0.30	.	.	C07	23.7	4.38	0.46	0.19	0.21	0.06	4.45
0–5	D04	19.6	4.51	0.55	0.07	0.14	0.11	5.7	D01	18.0	4.18	0.35	0.17	0.27	0.04	5.17
5–15	D04	19.3	4.57	0.47	0.07	0.11	0.21	5.3	D01	21.0	4.36	0.32	0.13	0.17	0.04	3.63
15–30	D04	19.4	4.66	0.35	0.05	0.05	0.17	3.5	D01	21.9	4.59	0.46	0.13	0.15	0.06	2.73
0–5	E11	.	.	.	.	.	.	.	E10	18.6	4.06	0.69	0.20	0.66	0.08	6.63
5–15	E11	.	.	.	.	.	.	.	E10	21.4	3.89	0.46	0.17	0.72	0.01	7.43
15–30	E11	.	.	.	.	.	.	.	E10	.	.					
0–5	F03	16.2	4.14	0.31	0.07	0.23	0.18	9.5	F02	36.5	4.06	1.05	0.26	0.64	0.07	5.13
5–15	F03	18.4	4.52	0.38	0.05	0.13	0.20	4.5	F02	21.7	4.43	0.58	0.17	0.29	0.19	3.79
15–30	F03	11.0	4.63	0.18	0.03	0.05	0.25	2.7	F02	8.6	4.46	0.45	0.11	0.08	0.05	1.75
0–5	G06	23.0	4.17	2.70	0.15	0.51	0.10	9.7	G02	27.7	4.22	0.56	0.14	0.28	0.06	5.67
5–15	G06	21.0	4.37	0.65	0.06	0.27	0.19	8.9	G02	20.0	4.46	0.52	0.10	0.24	0.02	3.09
15–30	G06	17.6	4.54	0.16	0.05	0.09	0.19	4.9	G02	12.8	4.36	0.78	0.13	0.20	0.23	2.57
0–5	H06	20.2	4.16	0.29	0.08	0.18	.	7.9	H07	24.1	4.68	0.59	0.16	0.17	0.06	3.35
5–15	H06	18.5	4.40	0.43	0.09	0.18	0.07	6.9	H07	24.6	4.78	0.56	0.13	0.12	0.09	2.83
15–30	H06	22.4	4.41	0.37	0.10	0.21	0.06	7.7	H07	17.5	4.80	0.44	0.05	0.10	0.05	2.13
0–5	I11	20.2	4.00	0.17	0.05	0.11	0.01	7.9	I06	25.5	3.76	0.37	0.17	0.87	0.05	5.91
5–15	I11	23.4	4.24	0.29	0.15	0.26	0.09	11.3	I06	28.8	3.89	0.53	0.22	0.74	0.05	6.79
15–30	I11	.	.	.	.	.	.	.	I06	32.1	3.99	0.48	0.12	0.58	0.05	4.63
0–5	J05	20.6	3.86	1.50	0.11	0.35	.	6.3	J07	23.9	3.82	0.93	0.18	0.51	0.07	8.19
5–15	J05	19.7	4.13	1.92	0.13	0.63	0.05	8.3	J07	25.8	4.11	0.89	0.17	0.40	0.05	6.93
15–30	J05	22.1	4.90	1.00	0.08	0.32	.	5.3	J07	21.0	4.42	1.23	0.18	0.48	0.24	5.75
0–5	K12	14.3	4.14	0.66	0.06	0.29	0.05	5.9	K10	11.2	3.57	0.79	0.16	0.61	0.10	7.85
5–15	K12	9.5	4.63	0.42	0.04	0.18	0.02	3.9	K10	18.0	4.04	0.65	0.17	0.69	0.09	6.13
15–30	K12	8.2	4.43	0.28	0.05	0.12	0.17	3.1	K10	17.9	3.94	0.63	0.11	0.85	0.16	6.37
0–5	L02	14.8	4.14	1.04	0.07	0.25	0.03	6.7	L03	56.0	4.43	0.63	0.25	0.34	0.06	3.63
5–15	L02	35.4	4.19	1.14	0.21	0.46	0.10	7.7	L03	36.3	4.40	0.49	0.13	0.22	0.05	3.21
15–30	L02	17.7	4.85	1.08	0.15	0.32	0.14	8.3	L03	36.6	4.52	0.78	0.19	0.42	0.09	2.73
0–5	M03	11.9	4.03	0.84	0.15	0.27	0.04	10.3	M01	24.9	3.70	0.44	0.21	0.92	0.17	10.55
5–15	M03	22.0	4.24	0.17	0.08	0.21	0.15	7.3	M01	.	.					
15–30	M03	18.8	4.44	0.17	0.08	0.19	0.10	5.3	M01	.	.					
0–5	N12	14.4	3.65	1.24	0.10	0.52	0.11	8.5	N01	27.9	3.93	1.15	0.09	1.04	0.13	7.31
5–15	N12	23.4	4.36	0.22	0.12	0.08	0.18	3.1	N01	21.1	4.27	0.83	0.10	0.57	0.11	5.23
15–30	N12	15.9	4.75	1.19	0.11	0.49	0.17	8.3	N01	17.6	4.42	0.90	0.14	0.45	0.12	4.33
0–5	O07	19.5	4.10	1.28	0.14	0.44	0.24	8.7	O10	27.8	3.84	2.86	0.14	1.06	0.11	9.63
5–15	O07	20.6	4.55	1.04	0.21	0.40	0.23	7.3	O10	17.1	4.20	0.65	0.06	0.37	0.05	7.77
15–30	O07	12.5	4.49	0.17	0.05	0.05	0.15	4.3	O10	.	.					
0–5	P11	38.9	4.44	1.23	0.30	0.39	0.21	7.9	P10	13.3	3.94	1.89	0.04	0.83	0.06	6.70
5–15	P11	23.1	4.43	1.95	0.36	0.51	0.19	8.5	P10	22.1	4.57	1.30	0.09	0.49	0.05	3.45
15–30	P11	20.4	4.70	0.84	0.14	0.22	0.16	6.3	P10	14.3	4.60	0.45	0.07	0.13	0.06	2.23
0–5	Q03	8.7	4.37	1.28	0.08	0.29	0.20	5.7	Q06	29.2	.	2.19	0.09	0.61	0.10	2.29
5–15	Q03	10.3	4.07	1.93	0.10	0.29	0.14	6.5	Q06	.	.					
15–30	Q03	.	.	2.91	0.09	0.35	0.16	6.7	Q06	.	.					
0–5	R02	16.2	4.23	1.73	0.09	0.49	0.19	.	R06	16.2	3.79	2.83	0.14	0.89	0.14	9.35
5–15	R02	17.7	4.06	0.90	0.08	0.23	0.12	.	R06	.	.					
15–30	R02	.	.	2.18	0.13	0.46	0.20	7.9	R06	.	.					
0–5	S03	18.0	3.85	0.65	0.09	0.30	0.10	7.9	S04	12.9	4.25	0.76	0.13	0.30	0.07	5.11
5–15	S03	23.9	4.52	1.04	0.13	0.57	0.12	6.9	S04	22.1	4.51	0.72	0.06	0.20	0.05	3.05
15–30	S03	17.6	5.03	0.79	0.10	0.37	0.11	6.5	S04	12.0	4.57	0.67	0.09	0.21	0.06	3.09
0–5	T02	30.4	5.06	0.57	0.16	0.16	0.11	7.1	T08	16.3	3.71	1.31	0.11	0.72	0.11	6.71
5–15	T02	16.0	4.78	1.03	0.10	0.27	0.19	6.7	T08	17.8	4.05	1.28	0.13	0.62	0.11	5.75
15–30	T02	22.8	5.25	1.02	0.13	0.25	.	5.9	T08	.	.					

Table 6.13: Soil chemistry (organic matter [LOI], pH, exchangeable cations [Ca^{2+}, K^+, Mg^{2+} and Na^+] and exchangeable acidity [EA]) by sampling layer at Lakelse Lake primary plot for 2015 and 2018.

Year	2015	2015	2015	2015	2015	2015	2015	2015	2018	2018	2018	2018	2018	2018	2018	2018
Depth	Plot	LOI	pH	Ca^{2+}	K^+	Mg^{2+}	Na^+	EA	Plot	LOI	pH	Ca^{2+}	K^+	Mg^{2+}	Na^+	EA
Unit		%		meq / 100 g						%		meq / 100 g				
0–5	A10	11.4	4.79	2.02	.	0.44	0.07	4.70	A04	8.5	5.02	0.65	0.13	0.10	.	1.82
5–15	A10	5.1	5.09	1.49	0.02	0.29	0.07	2.70	A04	3.6	5.35	0.43	0.04	0.08	.	1.03
15–30	A10	4.6	5.33	0.48	0.11	0.10	0.09	1.70	A04	3.3	5.30	0.22	0.03	0.05	.	0.67
0–5	B11	5.5	4.24	1.19	0.04	0.40	0.07	2.70	B02	9.1	5.14	0.42	0.07	0.13	0.01	1.07
5–15	B11	5.1	5.21	0.94	0.03	0.27	0.07	1.70	B02	4.8	5.53	0.80	0.07	0.21	0.00	2.19
15–30	B11	2.1	5.48	1.41	0.10	0.36	0.12	1.50	B02	1.5	5.67	0.56	0.04	0.09	0.01	0.91
0–5	C02	9.6	4.71	0.32	0.06	0.29	0.05	4.50	C11	5.9	5.14	0.39	0.03	0.11	.	2.01
5–15	C02	6.7	5.03	0.18	0.05	0.11	0.04	0.70	C11	3.2	5.08	0.51	0.06	0.13	0.00	1.57
15–30	C02	4.5	5.02	0.11	0.07	0.04	0.15	0.70	C11	3.4	5.00	0.48	0.08	0.16	0.02	1.47
0–5	D05	15.1	5.53	2.65	0.19	0.57	0.03	5.50	D12	2.2	5.27	0.37	0.04	0.13	0.15	1.50
5–15	D05	10.3	5.29	1.00	0.05	0.36	0.04	2.70	D12	1.1	5.52	0.59	0.08	0.17	0.08	1.71
15–30	D05	5.9	5.30	0.68	0.16	0.22	0.14	1.10	D12	.	.					
0–5	E04	15.0	4.75	1.82	0.16	0.41	0.04	4.70	E11	22.1	5.30	0.54	0.04	0.11	0.06	1.47
5–15	E04	5.6	5.23	0.46	0.08	0.18	0.03	1.20	E11	3.8	5.40	0.29	0.03	0.07	0.03	1.25
15–30	E04	5.1	5.15	0.33	0.08	0.10	0.04	0.90	E11	2.1	5.50	1.68	0.08	0.67	0.05	0.84
0–5	F02	6.6	5.08	2.84	0.12	0.68	0.03	1.20	F01	10.4	.	1.37	0.07	0.55	0.05	4.79
5–15	F02	7.1	5.08	0.71	0.04	0.21	0.05	1.20	F01	6.5	5.08	0.56	0.05	0.18	0.09	2.07
15–30	F02	4.8	5.34	1.19	0.15	0.26	0.03	4.10	F01	8.0	5.27	0.36	0.10	0.12	0.11	1.57
0–5	G02	6.6	5.28	2.22	0.05	0.31	0.05	2.89	G01	3.7	5.22	0.38	0.06	0.15	0.08	0.53
5–15	G02	5.2	5.26	1.64	0.05	0.33	0.03	1.70	G01	3.4	5.28	0.83	0.44	0.25	.	1.41
15–30	G02	4.9	5.30	1.73	0.18	0.29	0.19	1.70	G01	2.3	5.35	0.30	0.06	0.09	0.13	0.97
0–5	H07	6.2	5.33	1.11	0.13	0.27	0.04	2.70	H05	10.3	5.23	5.82	0.46	1.03	.	1.49
5–15	H07	4.9	5.42	0.86	0.04	0.20	0.04	3.70	H05	9.7	5.44	4.00	0.18	0.63	0.10	2.09
15–30	H07	4.7	5.31	0.71	.	0.15	0.13	2.50	H05	9.3	5.31	4.16	0.13	0.53	0.06	2.03
0–5	I06	14.2	5.03	2.60	0.15	0.52	0.04	2.50	I07	7.9	4.89	0.95	0.05	0.33	0.01	4.15
5–15	I06	7.0	5.24	0.75	0.02	0.18	0.05	3.69	I07	8.5	4.97	0.68	0.06	0.22	0.02	4.05
15–30	I06	4.2	5.19	0.22	0.05	0.07	0.09	1.50	I07	1.9	5.28	0.21	0.02	0.07	0.01	1.27
0–5	J01	11.6	4.92	5.19	0.17	0.86	0.03	3.10	J05	5.9	4.61	0.67	0.04	0.38	0.08	4.43
5–15	J01	5.4	5.31	1.22	0.05	0.17	0.03	1.80	J05	4.9	4.52	0.33	0.04	0.12	0.06	2.51
15–30	J01	5.1	5.11	0.60	0.11	0.20	0.11	2.10	J05	3.8	4.88	0.35	0.03	0.13	0.07	2.49
0–5	K04	8.0	5.22	1.29	0.15	0.48	0.05	5.10	K12	7.0	5.03	1.96	0.06	0.57	0.08	3.05
5–15	K04	4.4	5.26	1.09	0.08	0.35	0.04	4.30	K12	5.8	5.07	1.60	0.07	0.40	0.07	2.85
15–30	K04	1.0	5.42	0.59	0.08	0.16	0.04	1.50	K12	3.7	5.00	1.02	0.05	0.32	0.06	2.83
0–5	L12	9.0	4.89	4.42	0.10	1.02	0.05	4.20	L05	8.2	4.87	3.52	0.13	0.77	0.10	3.87
5–15	L12	8.1	4.91	1.35	0.10	0.64	0.07	4.29	L05	5.6	4.98	1.29	0.08	0.42	0.06	3.23
15–30	L12	2.9	5.11	1.16	0.09	0.42	0.07	2.30	L05	3.9	5.24	1.10	0.09	0.26	0.12	2.11
0–5	M04	12.0	4.52	2.19	0.15	1.07	0.07	4.19	M03	7.7	5.14	0.67	0.07	0.35	0.05	1.99
5–15	M04	11.2	5.05	1.84	0.04	0.54	0.04	3.19	M03	4.0	5.58	0.40	0.04	0.12	0.09	0.99
15–30	M04	4.3	5.33	0.62	0.07	0.16	0.08	2.09	M03	2.8	5.46	0.27	0.01	0.10	0.09	1.03
0–5	N05	9.2	5.02	1.61	0.10	0.49	0.05	4.29	N06	6.0	4.58	0.78	0.06	0.35	0.07	4.19
5–15	N05	4.7	5.17	0.39	0.00	0.17	0.05	2.90	N06	5.1	5.10	0.75	0.11	0.25	0.04	2.01
15–30	N05	4.6	5.08	0.37	0.08	0.15	0.11	2.70	N06	4.1	5.16	0.74	0.11	0.21	0.03	1.74
0–5	O06	9.1	4.79	5.19	0.09	1.33	0.06	2.89	O09	6.7	4.77	2.91	0.25	1.07	0.06	3.59
5–15	O06	4.7	5.38	1.40	0.05	0.41	0.06	3.70	O09	7.5	4.85	1.88	0.33	0.68	0.11	3.53
15–30	O06	2.5	5.25	2.03	0.10	0.71	0.13	2.90	O09	5.3	4.89	0.72	0.07	0.23	.	3.09
0–5	P09	8.7	4.85	3.54	0.14	1.16	0.06	3.19	P05	6.0	5.00	2.79	0.20	0.91	0.05	3.21
5–15	P09	3.2	5.15	1.50	0.09	0.54	0.09	1.70	P05	6.3	4.80	2.45	0.13	0.78	0.06	3.41
15–30	P09	3.9	5.13	1.49	0.08	0.50	0.17	2.49	P05	3.5	5.09	1.66	0.19	0.56	0.08	4.91
0–5	Q12	12.9	5.00	2.19	0.14	0.65	0.04	3.90	Q06	6.9	4.94	1.25	0.08	0.39	0.03	3.55
5–15	Q12	9.3	5.08	0.97	0.07	0.26	0.06	2.50	Q06	4.7	4.52	0.53	0.09	0.21	0.02	3.31
15–30	Q12	4.7	5.11	0.73	0.08	0.25	0.09	3.30	Q06	5.3	4.96	0.40	0.04	0.16	0.04	3.13
0–5	R07	9.1	4.98	2.98	0.15	0.92	0.08	3.70	R02	8.2	4.77	1.49	0.10	0.38	0.01	3.83
5–15	R07	6.3	5.02	1.68	0.13	0.51	0.05	1.70	R02	6.1	4.90	0.96	0.10	0.15	0.03	3.21
15–30	R07	4.6	5.08	1.15	0.09	0.38	0.06	3.50	R02	5.4	5.11	0.49	0.08	0.14	0.03	2.33
0–5	S06	6.6	4.90	2.63	0.08	1.04	0.04	3.90	S01	6.9	5.15	4.04	0.17	0.90	0.04	2.53
5–15	S06	5.6	5.06	1.45	0.15	0.54	0.05	4.10	S01	5.9	5.20	2.93	0.10	0.72	0.04	2.67
15–30	S06	2.5	5.19	1.28	0.09	0.49	0.18	3.10	S01	4.8	5.17	1.51	0.10	0.46	0.05	2.65
0–5	T09	10.6	4.80	2.77	0.19	1.17	0.04	4.79	T02	13.5	4.67	2.83	0.17	1.14	0.06	4.03
5–15	T09	5.4	4.97	0.97	0.15	0.30	0.11	4.30	T02	4.4	5.07	1.12	0.09	0.45	0.11	0.82
15–30	T09	4.2	4.97	0.88	0.11	0.25	0.13	3.10	T02	3.1	4.98	1.40	0.08	0.55	0.10	2.83

Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project

Volume 2: 2019 Comprehensive Review Report Technical Appendices V.3 Final

[Appendix 7: Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)]

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7 APPENDIX TO SECTION 7 OF THE COMPREHENSIVE REVIEW REPORT: AQUATIC ECOSYSTEMS (LAKES, STREAMS AND AQUATIC BIOTA)

7.1 Aquatic Appendix A: Review Results for Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)

NOTE: The structural and organization in Aquatic Appendix A are intended to align directly with the detailed Terms of Reference (TOR). Due to the nested nature of the appendices, the absolute numbering does not align but the higher level headings *within Section 7.1* correspond, in content, with the higher level headings *within Section 7 of the TOR*. That is, Section 7.1.x aligns with Section 7.x of the TOR and Section 7.1.x.y aligns with Section 7.x.y of the TOR. Certain sections of the TOR are covered exclusively in the main chapter and not further replicated here, although the associated headings have been retained in order to facilitate comparison among the TOR, the main report chapter, and this appendix. This is explicitly noted in these sections. However, the numbering of some of the sub-headings has changed due to either the addition of new sections that were not part of the original TOR or reordering of certain topics for a more logical flow.

The subsequent appendices (Appendix B through Appendix H) provide additional information on some topics in Appendix A. For these topics, Appendix A maintains the original headings of the TOR as an organizational placeholder and directs readers to the appropriate subsequent appendix.

Text in this format provides comments intended to help readers understand where certain topics or sections as defined in the Terms of the Reference have been shifted to another location, addressed exclusively in the main report chapter, or moved to a supplementary appendix.

7.1.1 What Did We Set Out to Learn?

NOTE: The content of this section exists solely in the Aquatic Ecosystems chapter of the main report.

7.1.2 What Methods Did We Use?

This section provides details on the methods used in the data preparation and analyses applied in the Comprehensive Review. These methods are referenced but not described in any detail in the main chapter. For the comprehensive statistical analyses of changes in water chemistry and for the updated modeling of critical loads, exceedances and future pH, the methods are described in their respective appendices and not repeated here.

7.1.2.1 Data we collected

Data collection and monitoring within the Aquatic Ecosystems component of the EEM Program are summarized in Table 7.2 and mapped in Figure 7.2 and Figure 7.3. Figure 7.2 shows the location of all of the lake and stream sites within the study area, as sampled during the STAR, KAA and/or EEM programs. Figure 7.3 focuses on the locations, frequency and types of sampling implemented as part of the EEM Program specifically.

The bulk of data collection efforts have focused on the annual monitoring of water chemistry for the 14 lakes selected for the EEM Program. Additionally, we have collected data on water chemistry of non-EEM sites, including a few streams of interest, data on fish presence in accessible lakes, intensive monitoring of pH in sensitive lakes, and other data (e.g., lake bathymetry, surface water levels) needed to answer the questions and uncertainties that provided the foundation for the EEM Program and/or emerged during its implementation. The water chemistry metrics that were measured as part of the EEM sampling program align with the sampling in the STAR (which included 41 lakes and 20 stream sites). Table 7.2 provides a chronological summary of data collected for the aquatic receptor in STAR/EEM programs in the period 2012-2018.

The STAR Lakes

The KMP sulphur deposition technical assessment (ESSA et al. 2013a) initially identified 57 candidate lakes (with a surface greater than 1 ha) in the area potentially affected by the prospective increase in deposition following the implementation KMP, including the following sampling groups based on their location relative to the modeled SO_4 deposition plume:

- 31 lakes situated within the three-year average 10 kg SO_4/ha/yr isopleth of total sulphur deposition;
- 9 lakes north of the isopleth that would be potentially exposed to total sulphur deposition of more than 7.5 kg SO_4/ha/yr based on meteorological conditions in 2008;
- 5 lakes south of the smelter that potentially receive SO_4 deposition during wind outflows; and
- 12 lakes within bedrock acid sensitivity class (ASC) 1 or 2 that could potentially receive acid deposition from the smelter.

The sampling strategy focused on lakes rather than streams because they are less influenced by episodic storm and snowmelt events, which makes their water chemistry more temporally stable and thus better suited for estimating critical loads for surface water (ESSA et al. 2013a). However, the STAR sampling program nonetheless still included streams to be precautionary.

After field reconnaissance to confirm accessibility conditions and ground-truthing the spatial information from the BC Watershed Atlas, 16 lakes were excluded from the sample set resulting in a final sampling population of 41 lakes. These 41 lakes represent 30.6 % of the lakes greater than 1 ha in size and 88.4 % of the area of lakes in the study area. The sampling design included 20 stream sites on 14 streams. Water sampling and measurements on these lakes and streams were completed during August 14-20, 2012.

The EEM Lakes

The current composition of lakes that comprise the lake chemistry sampling program within the EEM Program are outlined in Table 7.1.

Table 7.1. Summary of EEM Lakes.

Lake	Initial Sampling	Added to EEM Program	Rationale
EEM Sensitive Lakes			
LAK006	2012	2013	Sensitive lake chemistry
LAK012			
LAK022			
LAK023			
LAK028			
LAK042			
LAK044			
EEM Less Sensitive Lakes			
LAK007	2012	2013	Insensitive
LAK016		2013	Moderately sensitive
LAK024		2014	High public value
LAK034		2013	Moderately sensitive
EEM Control Lakes			
DCAS014A	2013 (KAA)	2015	Control site
NC184			
NC194			

The critical loads analysis (e.g., SSWC model) and risk acidification assessment was applied to these 41 lakes and 20 streams sites. Based on the results of the technical assessment (ESSA et al. 2013_a), we recommended careful monitoring of the chemistry of 7-10 lakes potentially vulnerable to acidification under KMP, baseline studies of their fish populations, and further biological studies if any of these lakes show biologically significant changes in pH (i.e., 0.30 pH units or more). The 7 sensitive lake chosen for the EEM program included all of lakes for which the STAR predicted pH changes greater than 0.1 pH units, including 5 lakes with predicted exceedances of their critical loads (Figure 7.1). These sensitive lakes were complemented by the inclusion of 3 additional lakes predicted to be moderately sensitive to extremely insensitive to increased acidic deposition – i.e., the "less sensitive EEM lakes" were not predicted to show any change in pH under increased levels of sulphur deposition. Lakelse Lake (LAK024) was not initially included in the EEM Program due to being highly insensitive; however, it was added as a fourth "less sensitive EEM lake" in 2014 because of its great importance to local communities and First Nations. Lakelse Lake is the largest lake in the study area (1,374 ha) and is accessible to fish populations.

These 11 lakes were grouped in two categories according to their sensitivity to acidification; there are seven lakes considered sensitive to acidification (i.e., predicted pH changes greater than 0.1 units) and three are considered less sensitive (i.e., predicted pH changes less than 0.1 units):

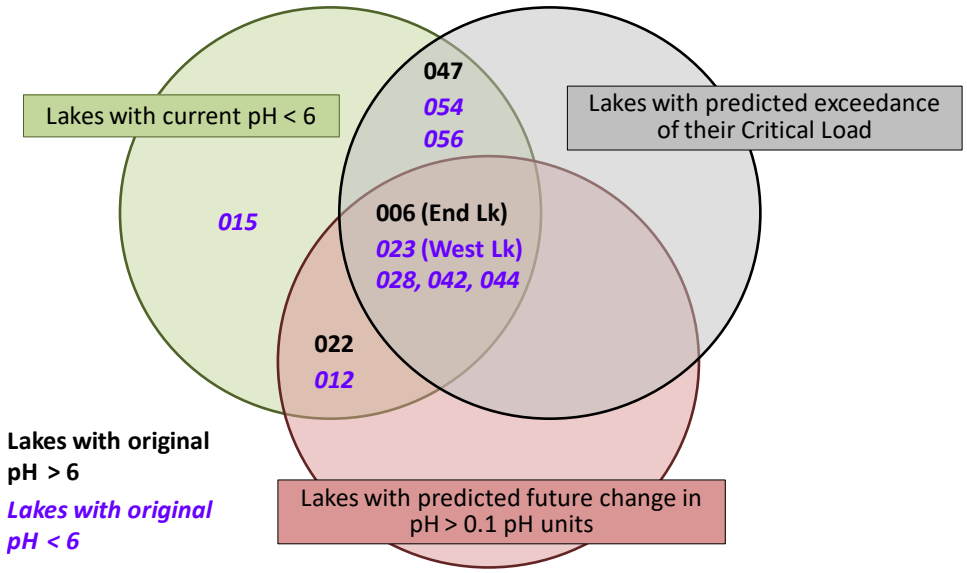


Figure 7.1. Conceptual diagram of criteria for lake vulnerability (ESSA et al. 2013a)

In 2015 three control lakes were added to the EEM Program. These lakes are similar to the sensitive EEM lakes in terms of their low ANC and relatively comparable annual runoff but they are located well outside the KMP deposition zone and therefore predicted to receive only background levels of acidic deposition. The inclusion of control sites addresses multiple objectives: improving the estimates of natural variability; improving the understanding of regional trends independent of KMP effects; and improving our ability to detect potential KMP effects in the sensitive lakes.

Table 7.2. Overview of data collection efforts for the aquatic receptor through the 2012-2018 period.

Year	Annual water chemistry monitoring	Intensive sampling and continuous pH monitoring	Fish sampling	Water chemistry at non-EEM sites	Other data collected[1]
Pre-KMP baseline period					
2012	41 lakes 20 streams as part of STAR (including 11 EEM lakes)				
Transition period					
2013	7 EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044) 3 EEM less sensitive lakes (LAK007, LAK016, LAK034)		Conducted in four acid-sensitive lakes: LAK006, LAK012, LAK023, and LAK044	Cecil Creek (receives drainage from LAK023) sampled in three locations	
2014	7 EEM sensitive lakes 4 EEM less sensitive lakes[2]	Intensive sampling and continuous pH monitoring added to LAK006, LAK012, LAK023		Lake MOE6 and six sites within the Goose Creek watershed	Reconnaissance of habitat and water chemistry in Goose Creek
2015	7 EEM sensitive lakes 4 EEM less sensitive lakes 3 EEM control lakes	Continuation of existing program. Continuous pH monitoring in Anderson Creek	Completed in the three less sensitive lakes: LAK007, LAK016, and LAK034	Additional sampling in Goose Creek watershed to assess sensitivity	Bathymetric surveys of LAK006, LAK012, LAK023
Post-KMP period					
2016	14 EEM lakes (sensitive, less sensitive, and controls)	Continuation of existing program Continuous monitoring of Anderson Creek was unsuccessful			Lake levels monitoring in LAK006, LAK012, LAK023
2017	14 EEM lakes (sensitive, less sensitive, and controls)	Continuation of existing program	Fish sampling was done in LAK028		Lake levels monitoring continued Amphibian literature review
2018	14 EEM lakes (sensitive, less sensitive, and controls)	Continuation of existing program LAK028 was added		7 stream sites within the Goose Creek network	Lake levels monitoring continued Bathymetric survey of LAK028

[1] Other data further discussed in Section 7.1.2.8
[2] LAK024 re-added in 2015

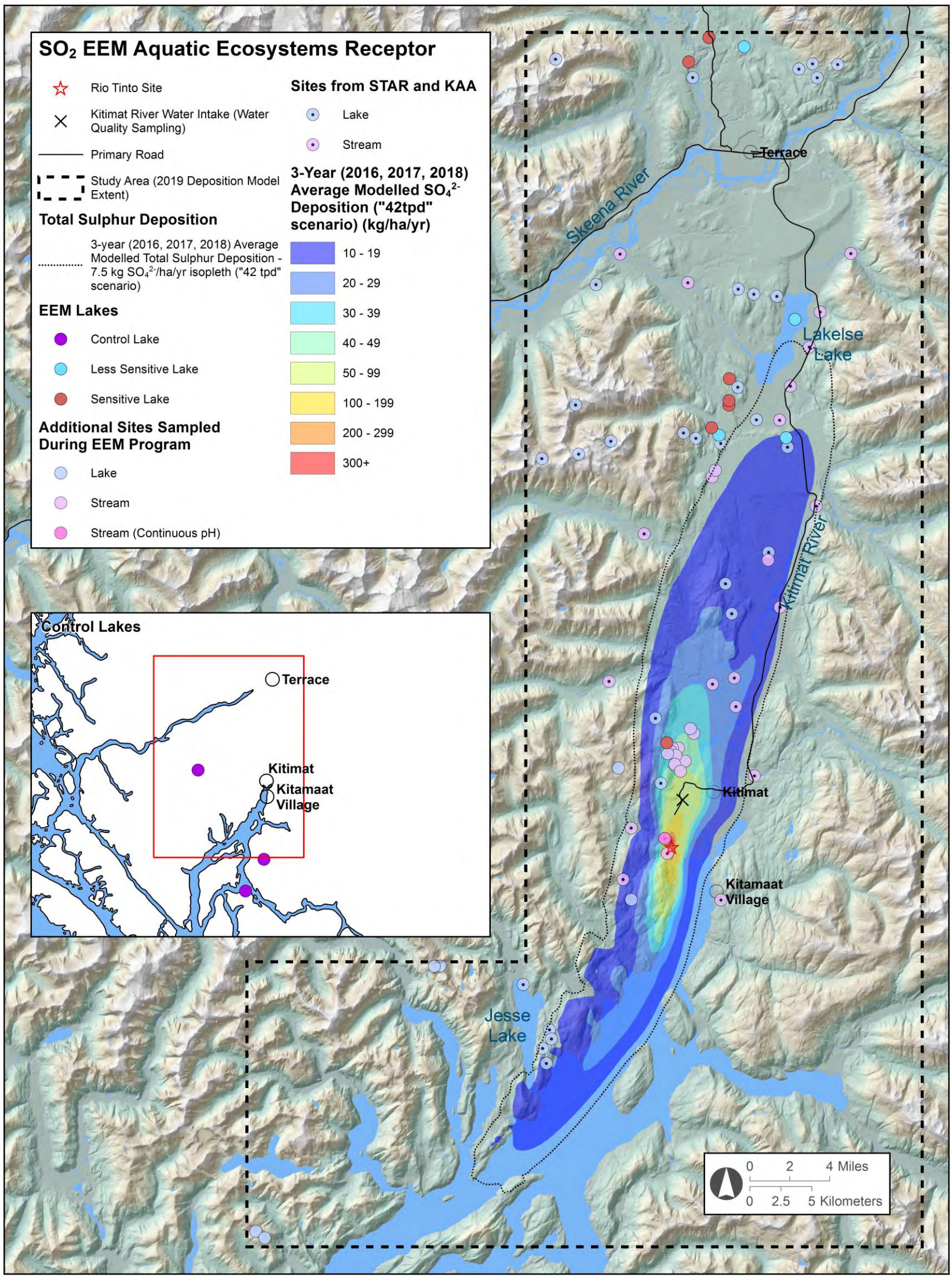


Figure 7.2. Locations of ongoing and existing monitoring and sampling for the aquatic receptor of the EEM Program.

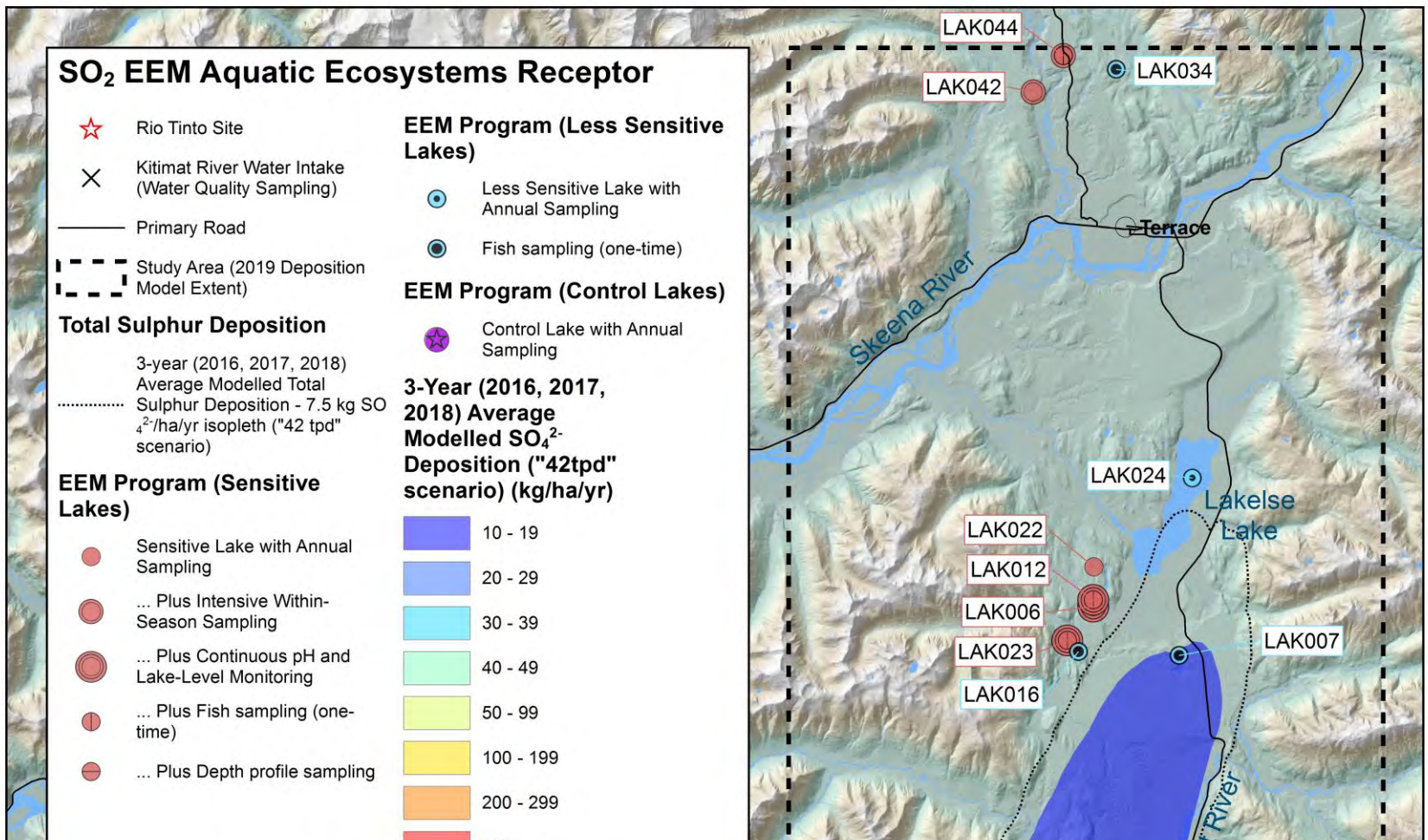


Figure 7.3. Locations of the study lakes of the EEM Program. Lakes are grouped by their classification as sensitive lakes, less sensitive lakes and control lakes. The map also shows the frequency and type of monitoring conducted at each of the lakes.

Water Chemistry Sampling

The annual water chemistry sampling program provides the data foundation for the assessment of inter-annual changes and long-term trends in water chemistry within the EEM lakes. Water chemistry samples are taken annually from all 14 EEM lakes and more intensively for 6 of the sensitive lakes (i.e., three additional samples within the fall index period). The frequency of sampling for each of the lakes over time is summarized in (Table 7.3).

The field and laboratory methods associated with the water sampling are documented in detail each year in Limnotek's technical report (e.g., Bennett and Perrin 2017, 2018; Limnotek 2016, 2019; Perrin et al. 2013; Perrin and Bennett 2015). Please refer to those documents for comprehensive technical details as these methods are only briefly summarized here.

Because most of the lakes in the EEM Program are only accessible by helicopter, annual water sampling was completed from a helicopter in hover position, approximately 4 m above the water surface. In more recent years, some of the lakes have been accessed by foot for the additional within-season sampling and "calibration visits" for the continuous pH monitors. Sampling included field measurements of temperature, dissolved oxygen and total dissolved solids. Laboratory analyses involved the measurement of major ions, dissolved organic carbon (DOC), total alkalinity and Gran ANC, obtained by titration.

The collection, handling, transport, and analyses of water quality samples were conducted with numerous quality checks, to ensure the highest quality data possible. Details on the methods for quality control and quality assurance for the water samples are described in the Limnotek technical reports from each of the years of annual sampling.

In addition to the data quality control and assurance procedures applied during the sampling and subsequent laboratory analyses, we applied two additional methods to confirm the quality of the data input prior to their use for the analyses and modeling described in this technical memo. First, we assessed the charge balance for each sample, and then examined the average charge balance across all samples within a particular data set (i.e., the EEM lakes were considered separately from non-EEM sites). Second, we compared the estimated conductivity based on ion concentrations for each sample to the measured conductivity for that site, then examined average relative differences across all samples. These two tests integrate the cumulative errors in any of the measured parameters, therefore giving an indication of the overall quality of the entire data set.

Table 7.3. Frequency of water chemistry sampling for EEM lakes, 2012-2018.

		Pre-KMP			Transition									Post-KMP								
		2012			2013			2014			2015			2016			2017			2018		
	Lake	Annual	Multiple	Continuous (pH only)	Annual	Multiple	Continuous (pH only)	Annual	Multiple (n=5)	Continuous (pH only)	Annual	Multiple (n=4)	Continuous (pH only)	Annual	Multiple (n=4)	Continuous (pH only)	Annual	Multiple (n=4)	Continuous (pH only)	Annual	Multiple (n=4)	Continuous (pH only)
EEM Sensitive Lakes	LAK006	✓			✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	LAK012	✓			✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	LAK022	✓			✓			✓			✓			✓			✓			✓		
	LAK023	✓			✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	LAK028	✓			✓			✓			✓			✓	✓		✓	✓		✓	✓	✓
	LAK042	✓			✓			✓			✓			✓	✓		✓	✓		✓	✓	
	LAK044	✓			✓			✓			✓			✓	✓		✓	✓		✓	✓	
EEM Less Sensitive Lakes	LAK007	✓			✓			✓			✓			✓			✓			✓		
	LAK016	✓			✓			✓			✓			✓			✓			✓		
	LAK024	✓						✓			✓			✓			✓			✓		
	LAK034	✓			✓			✓			✓			✓			✓			✓		
Control Lakes	NC184				✓						✓			✓			✓			✓		
	NC194				✓						✓			✓			✓			✓		
	DCAS14A				✓						✓			✓			✓			✓		

Continuous and bi-weekly pH monitoring

Starting in 2014, continuous pH monitors were installed each year in three of the acid-sensitive lakes – West Lake (LAK023), End Lake (LAK006) and Little End Lake (LAK012). A similar monitor was installed in LAK028 in 2018. The objective of intensive pH monitoring was to document natural variability in pH and related chemistry in acid-sensitive lakes over the fall season in order to assess the potential for episodic acidification.

The implementation of continuous pH monitoring facilitated an opportunity for an additional time series of pH data for these lakes. The pH monitors that were installed required calibration approximately every two weeks during their period of installation each year, which necessitated a field visit. On each visit, a field measurement of pH was taken[3] and recorded. This "calibration data" thus comprises a data set of bi-weekly field pH for each lake for 2014-2018 (during the ice-free period of the year). In 2017 and 2018, the calibration visit also included taking a water sample and sending it to Trent University to measure laboratory pH and Gran ANC.

A continuous pH monitor was also operated in Anderson Creek for multiple years but experienced significant issues with operating consistently.

7.1.2.2 Quality of Water Chemistry Data

Sampling and laboratory quality control and quality assurance

The collection, handling, transport, and analyses of water quality samples were conducted with numerous quality checks, to ensure the highest quality data possible. Details on the methods for quality control and quality assurance for the water samples are described in the annual technical reports from Limnotek, who are responsible for the implementation of the water chemistry sampling program.

Analyses of Charge Balance and Estimated vs. Measured Conductivity

In addition to the data quality control and assurance procedures applied during the sampling and subsequent laboratory analyses, we applied two additional methods to confirm the quality of the data input prior to their use for the analyses and modeling described in this technical memo. First, we assessed the charge balance for each site, and then examined the average charge balance across all sites. Second, we compared the estimated conductivity based on ion concentrations for each site to the measured conductivity for that site, then examined average relative differences across all sites. These two tests integrate the cumulative errors in any of the measured parameters, therefore giving an indication of the overall quality of the entire data set.

Further details on the methods and rationale are described in greater detail in the STAR (ESSA et al. 2013, Section 8.6.3.2) and the KAA (ESSA et al. 2014a, Section 6.1.1.1).

pH measurements

Water chemistry samples taken have multiple measures of pH, including a field measurement and two lab measurements (Trent University and ALS). As described in Section 7.1.2.1, several lakes also have additional measurements of pH from continuous meters. As described in the

[3] Usually three separate field measurements were taken.

STAR, lab measurements of pH, rather than field measurements, have been used for the analyses of lake chemistry; lab pH measurements have lower variability, and therefore are more relevant to the detection of long term trends.

The 2012 data collected during the STAR included laboratory measurements of pH only from Trent University. Inter-annual comparisons of trends in pH have therefore been conducted using the pH measurements from Trent University. Limnotek has analyzed differences among the different methods of measuring pH for quality assurance purposes, repeating similar comparisons over multiple years.

7.1.2.3 Analyses we conducted with these data

7.1.2.3.1 Variable organic charge density

In the STAR, KAA, and EEM programs, we have calculated the charge concentration of organic anions using the method of Oliver et al. (1983). This method (as with others) requires specification of the average organic charge density (µeq/mg C) in the organic content of the water (as measured by DOC in mg/L). We assumed a charge density of 7.5 µeq/mg C for the STAR, KAA, and EEM. However, the actual organic charge density may vary significantly by lake, depending on the specific composition of organic compounds present and their relative concentrations. Therefore, the difference between the estimated charge concentration of anion and cations for a particular sample may partly be explained by having over or underestimated the contribution of organic acid anions to the charge balance.

As part of the present Comprehensive Review we have explored whether changing the assumed organic charge density would improve the overall charge balance across all lakes (i.e., all samples of all STAR lakes, EEM lakes, and additional lakes sampled during the EEM Program). First, we explored changes in a single, regional value for the organic charge density applied across all lakes (as done in the STAR, KAA, and EEM). Second, we allowed the assumed organic charge density to vary by lake (but keeping the value for each lake constant across years).

The effects on the average charge balance of changing the assumed value for a single, regional organic charge density are shown in Table 7.4. The best overall charge balance is achieved when applying an organic charge density of approximately 4.5-5.5 µeq/mg C, depending on the specific metric used to characterize the average charge balance.

Next we estimated the lake-specific value of organic charge density that produced the best charge balance for each lake – that is, we allowed each lake to be represented by a different value but assumed that value to be a constant property of the lake over time. To facilitate this exploration, we evaluated the average charge balance for each lake across all samples and all years using organic charge density values of 0.5 to 10.0 µeq/mg C (in increments of 0.5 µeq/mg C). The organic charge density value that produced the best charge balance (i.e., closest to zero) was identified as the "best" value for that lake. For this evaluation we focused on two metrics, the *average of the relative difference (%)* and the *average of the absolute differences (µeq/L)*[4] – if

[4] Note that both these metrics are indicators of the effect *on measures of charge balance* of changing the assumed values for *organic charge density* and therefore the correct units are i.e., *µeq/L.*

these two metrics led to different answers we prioritized the latter. Table 7.5 shows the overall charge balance when applying the lake-specific estimates of organic charge density developed through this approach. Table 7.7 shows the lake-specific estimates that we applied.

By applying the results of either of the approaches described above for modifying the organic charge density assumption – i.e., revising the regional organic charge density value or developing lake-specific estimates – produces a much better average charge balance across all the lakes across all four charge balance metrics in most years (Figure 7.4).

These adjustments significantly improve the charge balance reported in previous annual reports, but changing the organic charge density does not affect the water chemistry statistical analyses in Appendix F or the modelling of critical loads, exceedances and future pH because those analyses do not use the charge concentration of organic anions as an input.

Table 7.4. Average charge balance under alternative assumptions for the average regional organic charge density across all samples for all samples from all STAR/EEM lakes from all years.

		Overall Charge Balance across all Lakes and Years			
Organic Charge Density (µeq/mg C)	Number of Samples	Average Percent Difference (%)	Average of the Absolute Value of the Percent Differences (%)	Average Difference (µeq/L)	Average of the Absolute Value of the Differences (µeq/L)
0.5	**199**	**12.6%**	**13.9%**	**17.7**	**25.9**
2.5	**199**	**7.0%**	**9.0%**	**9.3**	**20.0**
4.0	**199**	**3.3%**	**6.1%**	**3.0**	**16.0**
4.5	**199**	**2.1%**	**5.4%**	**0.9**	**14.8**
5.0	**199**	**1.0%**	**4.8%**	**-1.2**	**13.9**
5.5	**199**	**-0.1%**	**4.3%**	**-3.3**	**13.2**
6.0	**199**	**-1.1%**	**4.0%**	**-5.4**	**12.8**
7.5	**199**	**-4.1%**	**5.1%**	**-11.7**	**14.8**
10.0	**199**	**-8.5%**	**8.9%**	**-22.1**	**23.9**

Table 7.5. Overall average charge balance (four different metrics) using the lake-specific estimates of organic charge density that produce the best charge balance for each lake.

		Overall Charge Balance across all Lakes and Years			
Organic Charge Density (µeq/mg C)	Number of Samples	Average Percent Difference (%)	Average of the Absolute Value of the Percent Differences (%)	Average Difference (µeq/L)	Average of the Absolute Value of the Differences (µeq/L)
Lake-specific	**199**	**-0.3%**	**3.0%**	**-2.9**	**9.2**

Table 7.6. Lake-specific estimates of organic charge density by lake. The sensitive, less sensitive, and control lakes of the EEM Program are bolded and with blue fill. Orange fill indicates lakes that were assigned either the maximum or minimum values of the range tested (see description in text).

Lake	Estimated Organic Charge Density
LAK001	0.50
LAK002	7.75
LAK003	2.00
LAK004	5.75
LAK005	6.75
LAK006	**6.00**
LAK007	0.50
LAK008	0.50
LAK011	5.25
LAK012	**6.50**
LAK013	3.75
LAK014	9.75
LAK015	7.25
LAK016	**6.00**
LAK017	4.25
LAK018	0.50

Lake	Estimated Organic Charge Density
LAK022	**6.00**
LAK023	**5.75**
LAK024	**1.75**
LAK027	6.50
LAK028	**0.50**
LAK030	0.50
LAK032	0.50
LAK034	**6.75**
LAK035	4.25
LAK037	3.25
LAK038	8.50
LAK039	7.00
LAK041	10.00
LAK042	**6.00**
LAK044	**4.00**
LAK045	10.00

Lake	Estimated Organic Charge Density
LAK047	10.00
LAK049	10.00
LAK050	10.00
LAK051	8.50
LAK053	1.00
LAK054	7.50
LAK055	5.75
LAK056	7.25
LAK057	6.00
DCAS14A	**4.75**
NC184	**6.75**
NC194	**10.00**
MOE3	0.50
MOE6	9.50

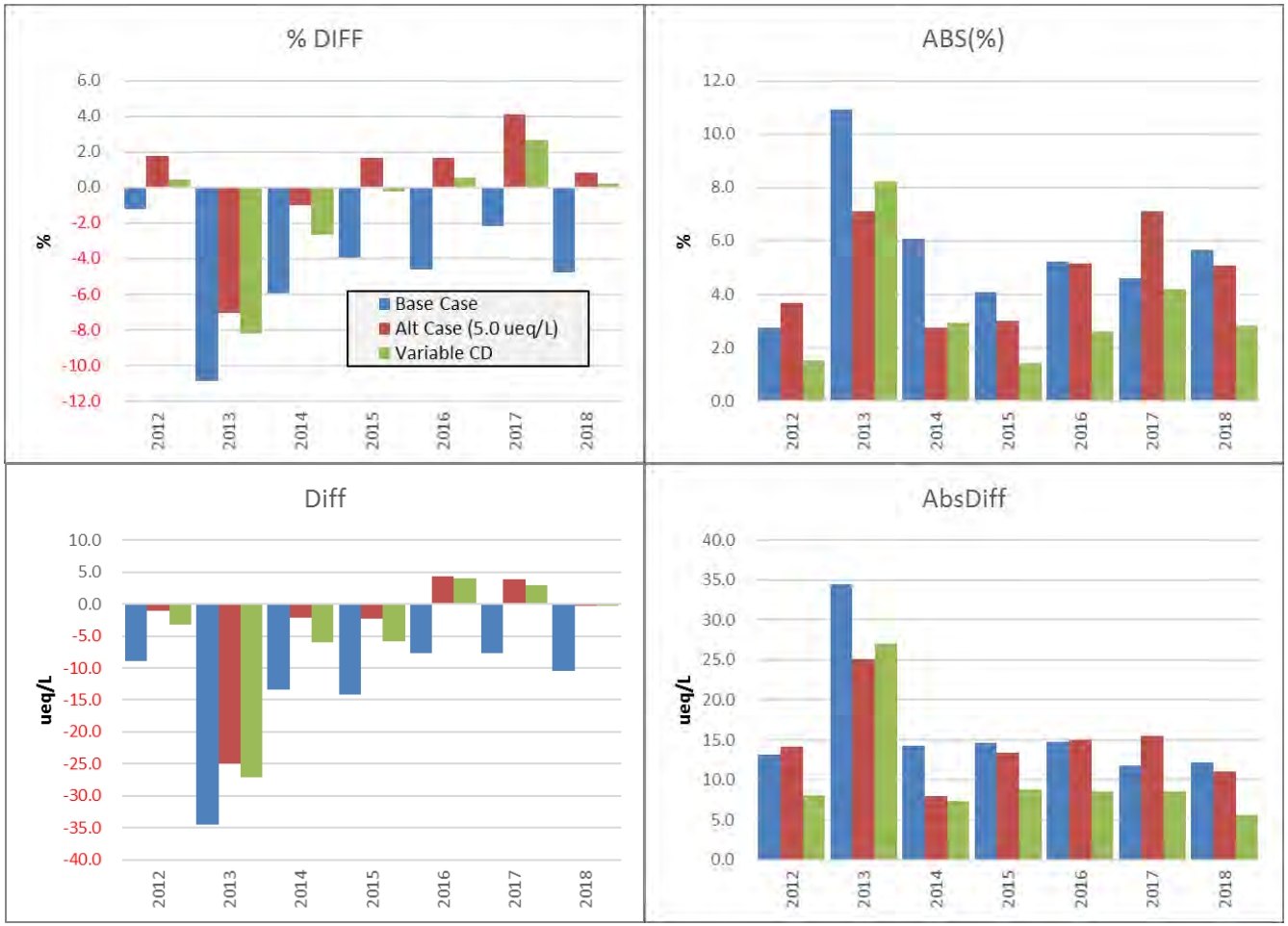


Figure 7.4. Charge balance by year across all lakes under three different assumptions for the organic charge density. "Base Case" applies a value of 7.5 µeq/mg C (as per the STAR, KAA and EEM). "Alt Case" applies a value of 5.0 µeq/mg C (as per the sensitivity analyses described in the text). "Variable CD" applies the lake-specific estimate of organic charge density that produces the best charge balance (as described in the text; values between 0.5-10.0 µeq/mg C). The four metrics of charge balance are: %DIFF = average of the relative difference (%); ABS(%) = average of the absolute value of the relative differences (%); Diff = average of the absolute differences (µeq/L); AbsDiff = average of the absolute value of the absolute differences (µeq/L).

7.1.2.3.2 Exploration of ANC Values and Metrics

Acid neutralizing capacity (ANC) is the buffering capacity of a solution to neutralize strong acids and therefore mitigate acidification[5]. Gran ANC has been the primary measure of ANC for all the analyses in the STAR and EEM. It is determined by titration to the inflection point of the pH-alkalinity titration curve. Gran ANC includes the buffering effect of organic anions. Based on recommendations from other QPs, ENV, and external experts prior to the Comprehensive Review, we have explored alternative measures of ANC, including charge balance ANC (CBANC), Base Cation Surplus (BCS), and organic anion adjusted ANC (ANC_{OAA}). Figure 7.5 shows an idealized comparison of Gran ANC, CBANC and BCS based on hypothetical data.

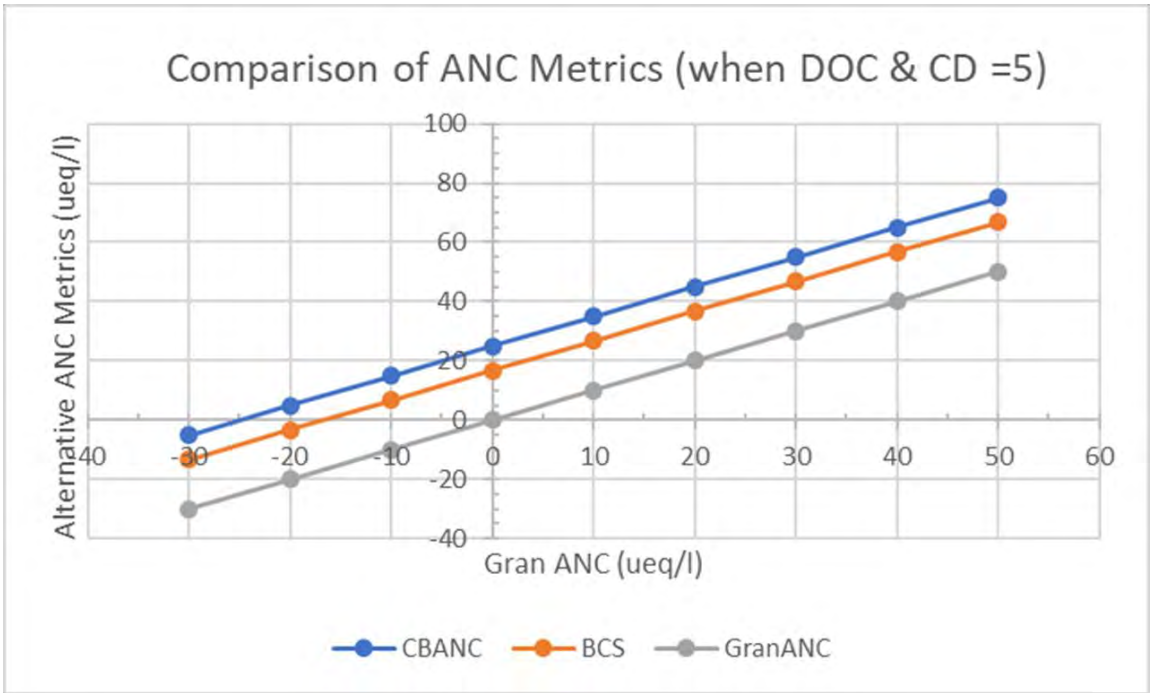


Figure 7.5. Comparison of three alternative measures of ANC – charge balance ANC (CBANC), base cation surplus (BCS), and Gran ANC. The contribution of organic acid anions is based on assumed values of a DOC of 5.0 mg/L and an organic charge density of 5.0 µeq/mg C.

<u>Exploring Relationship between Gran ANC and CBANC</u>

CBANC is generally calculated as the equivalent sum of base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) minus the equivalent sum of strong acid anions (SO_4^{2-}, NO_3^{-}, Cl^{-}). CBANC has the benefits that it has been used in many studies of long term trends (e.g., Stoddard et al. 1998, 2003), and it can be analyzed in commercial labs without specialized equipment for Gran ANC titrations. However, the usual formulation of CBANC has the detriments that it does not take into account buffering by organic anions (which are very important in some of the EEM lakes) and that it is calculated

[5] As defined in the STAR: acid neutralizing is the equivalent capacity of a solution to neutralize strong acids; ANC and alkalinity are often used interchangeably; ANC includes alkalinity plus additional buffering from dissociated organic acids and other compounds.

from the sum of seven different measurements and therefore can potentially accumulate measurement errors (Evans et al. 2001).

Estimating CBANC from Gran ANC

Although CBANC is a calculated measurement (based on the laboratory measurement of major ions) and Gran ANC is measured through an independent laboratory analysis, the two metrics are empirically related as described by the following equation:

CBANC = Gran ANC + CD * DOC,

where CD is an estimate of charge density, generally in the range of 4-6 μeq per mg DOC, but can be from 2-10 μeq per mg DOC (Hemond 1990, Marmorek et al. 1996). As discussed above in Section 7.1.2.3.1, the best overall estimate of CD for the EEM lakes is about 5.0 μeq/mg C, in the middle of the range observed in other studies.

Based on the recommendations from ENV's external expert during the development of the terms of reference for the Comprehensive Review, we calculated a lake-specific charge density (CD) to achieve the best possible charge balance (Section 7.1.2.3.1), and then applied that value to the above equation to compare CBANC vs Gran ANC, for the purposes of understanding the relationship between these two indicators. Figure 7.6 shows the results for all the samples taken during the STAR and EEM programs. The results show a very strong relationship between the estimated and calculated values for CBANC – i.e., CBANC and Gran ANC are very strongly correlated once CBANC is adjusted for the influence or organic anion, as expected. Of the 244 samples included, the only ones with notable deviations from the regression are the five deep-water samples from LAK028 taken in 2018 (which have substantially different water chemistry than the surface water samples) and one Goose Creek site. Figure 7.7 shows how the relationship between estimated and calculated CBANC changes with different assumptions about the organic charge density, which reaffirms the earlier conclusions from Section 7.1.2.3.1 regarding the merits of using lake-specific estimates of organic charge density.

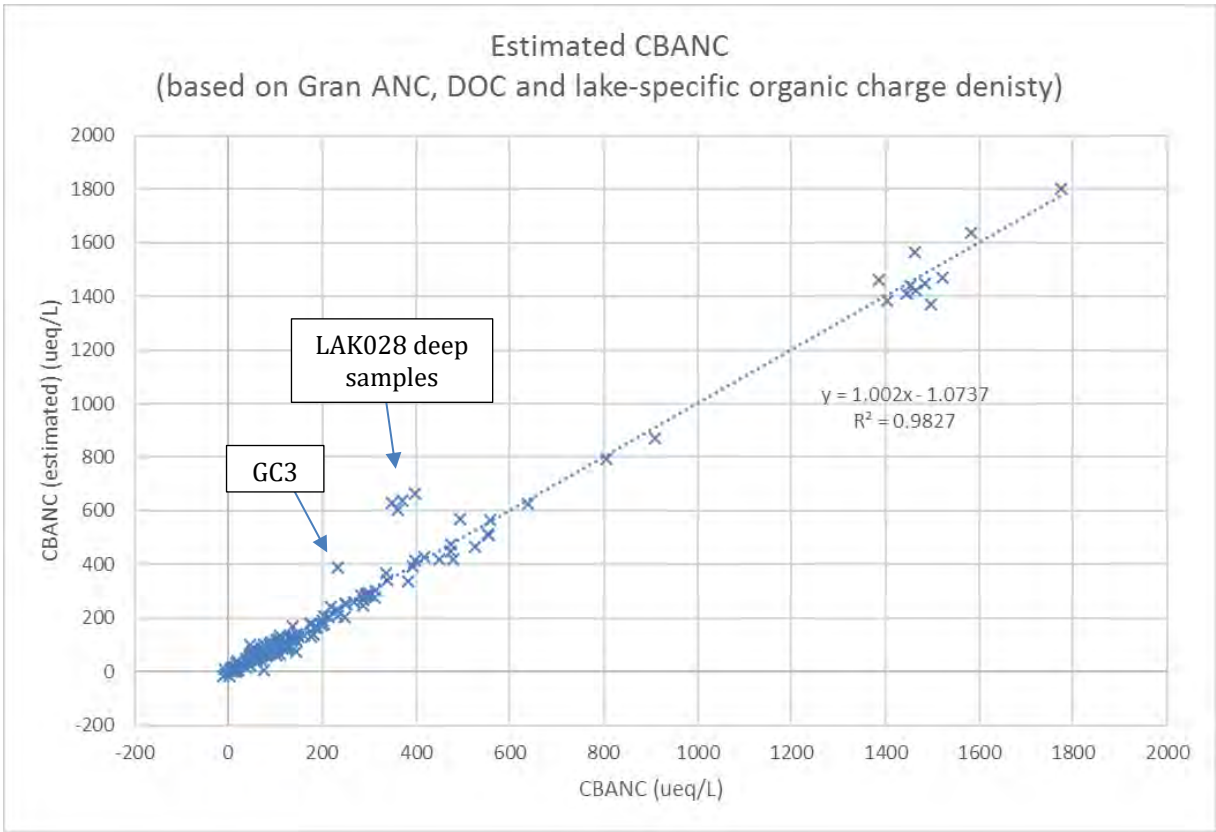


Figure 7.6. Estimated CBANC versus calculated CBANC for all lake and stream site samples from the STAR and EEM programs (n=244). Estimated CBANC is based on the empirical relationship with Gran ANC – i.e., CBANC = Gran ANC + CD * DOC (where CD = organic charge density, using lake-specific values in this implementation).

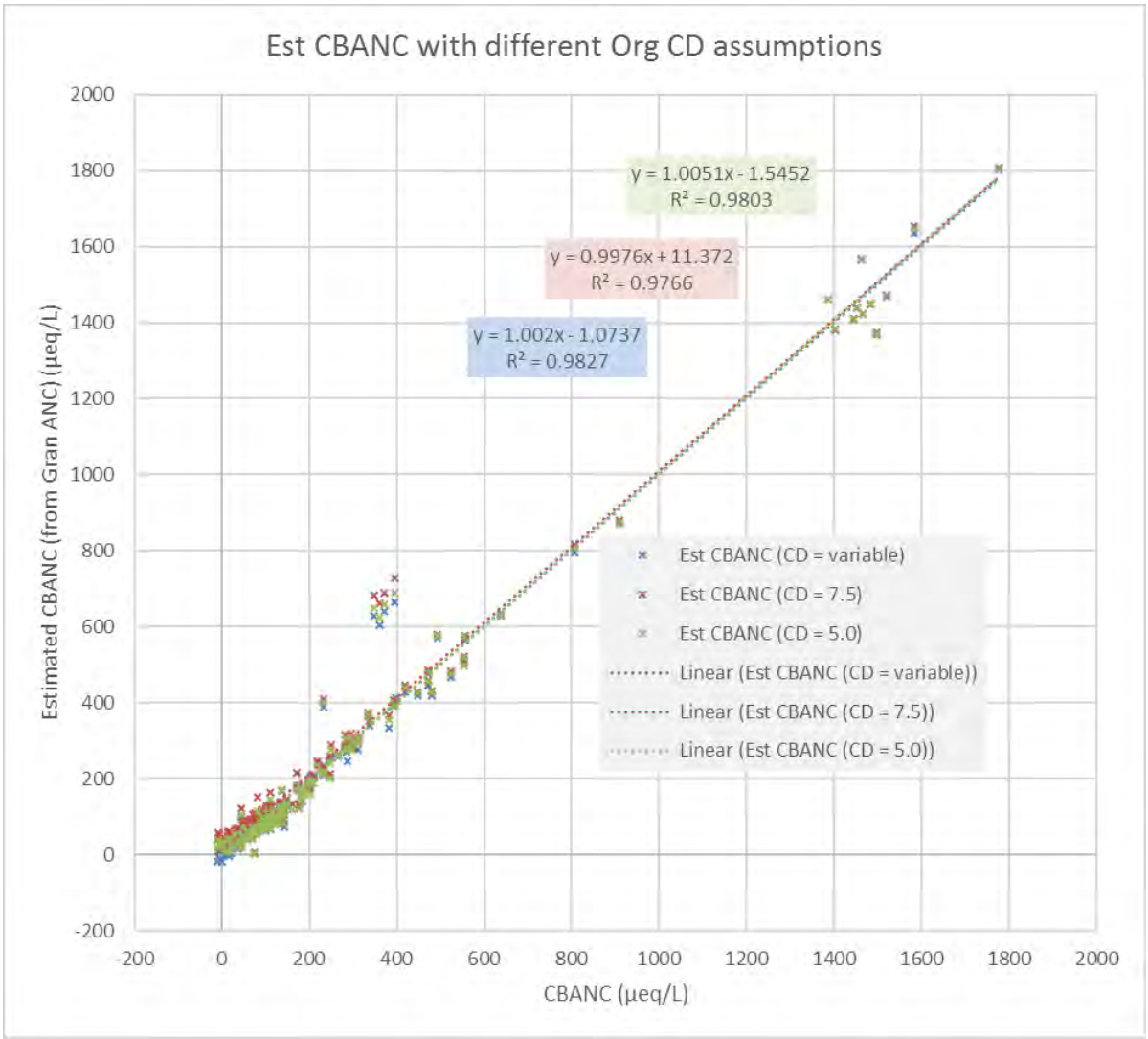


Figure 7.7. Comparison of estimated CBANC (based on varying values for organic charge density (CD)) versus calculated CBANC.

Gran ANC estimated from CBANC

In the Terms of Reference, the empirical relationship between CBANC and Gran ANC was framed as estimating CBANC from adjusted Gran ANC (as presented above). However, ultimately the more pragmatic need is to understand if we can use CBANC instead of Gran ANC, because Gran ANC is difficult to measure and only relatively few laboratories have the ability to do so. Thus we should also look at how closely we can estimate Gran ANC from CBANC. Figure 7.8 shows the relationship between estimated and measured Gran ANC, where *Gran ANC = CBANC – CD * DOC.* The structure of this equation is analogous to the calculation of BCS and ANC_{OAA} (as detailed later), which similarly start with CBANC and apply a reduction to account for the influence of strong organic acid anions. Figure 7.8 shows that when applied across the full set of all samples, both CBANC and estimated Gran ANC have very strong relationships with measured Gran ANC that do not appear markedly different. However, the

figure also suggests that these relationships could be strongly influenced by the largest values, which are an order of magnitude larger than the bulk of the samples.

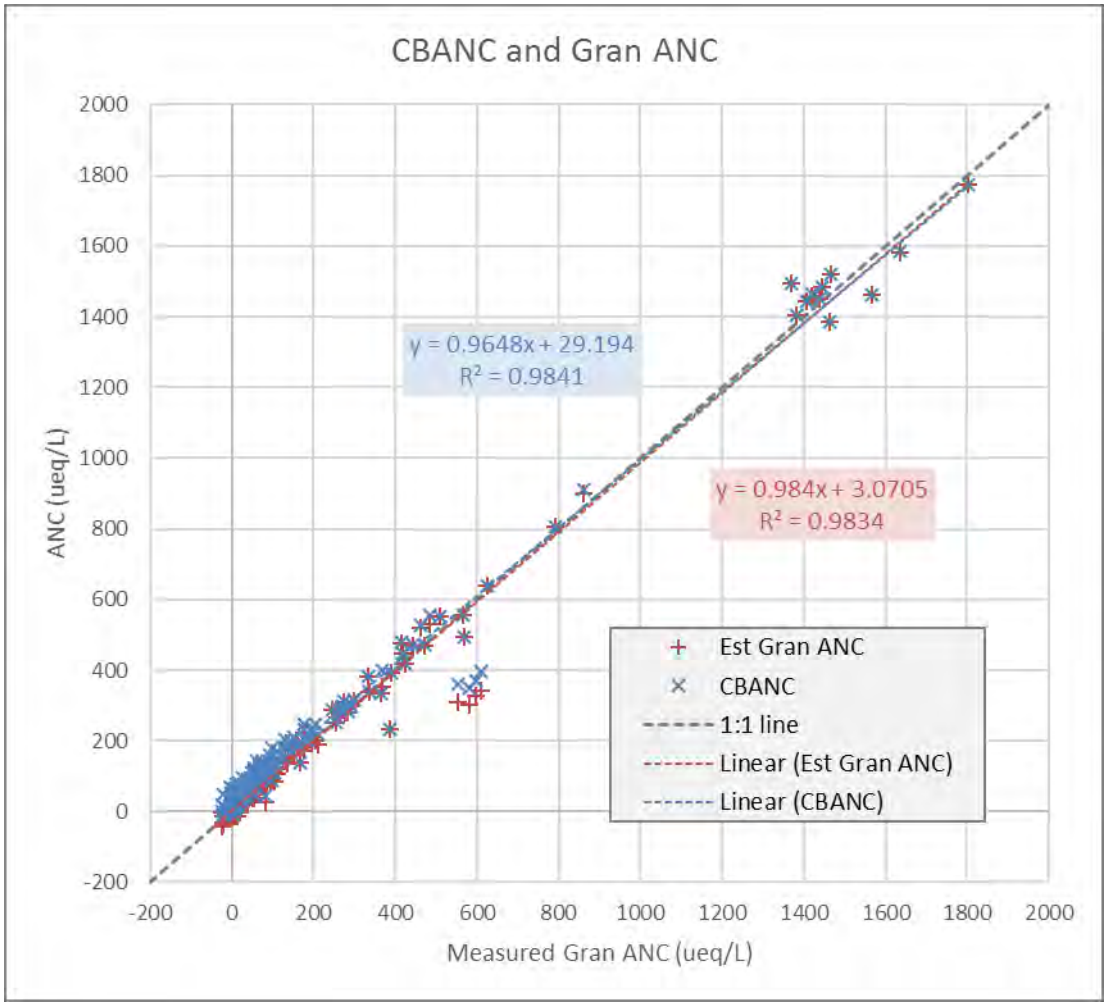


Figure 7.8. CBANC and estimated Gran ANC (based on CBANC) versus measured Gran ANC for all samples. Estimated Gran ANC = CBANC – CD * DOC, where CD is the lake-specific estimate of organic charge density.

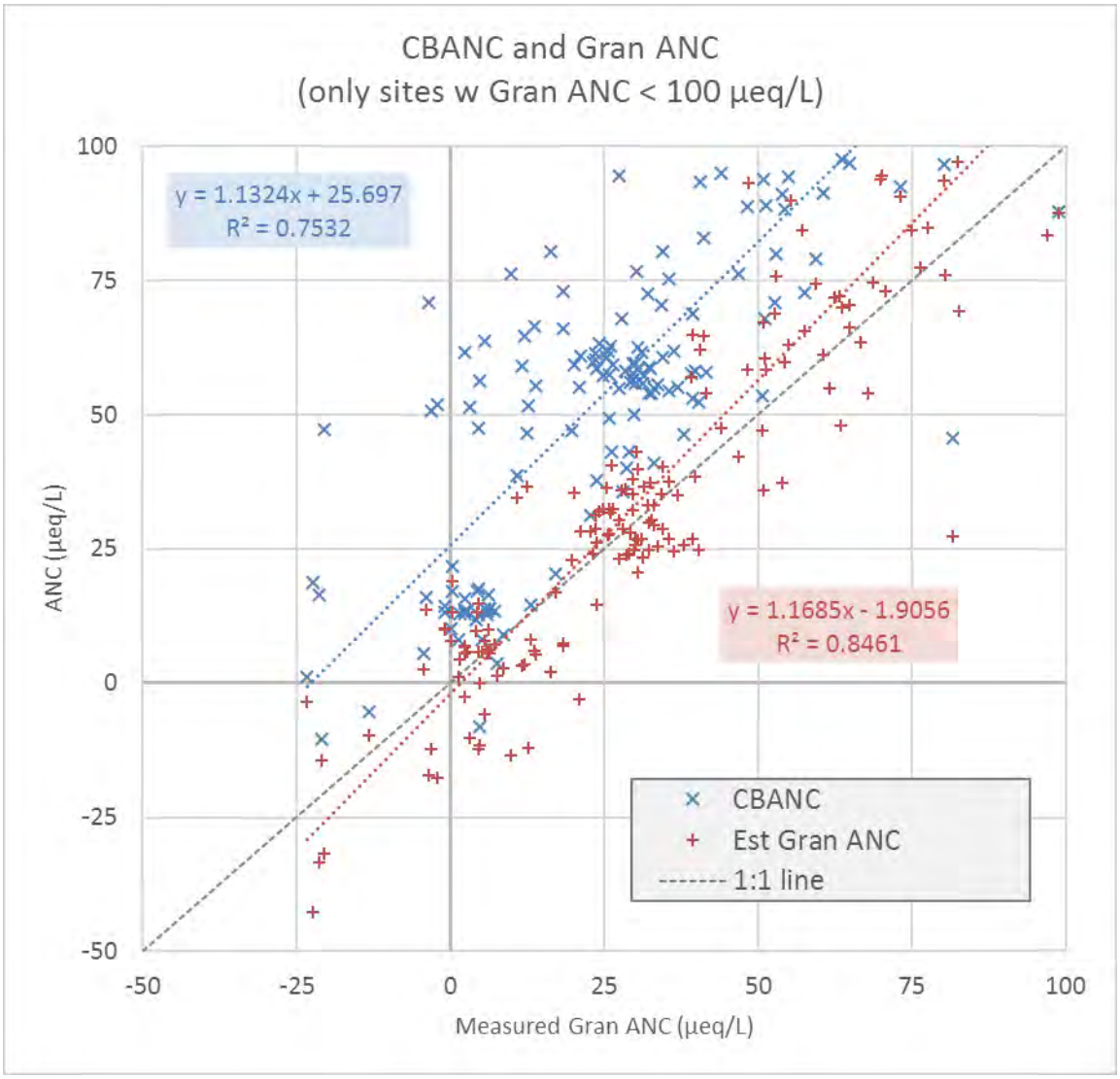


Figure 7.9. CBANC and estimated Gran ANC (based on CBANC) versus measured Gran ANC for all samples with Gran ANC < 100 µeq/L. Estimated Gran ANC = CBANC – CD * DOC, where CD is the lake-specific estimate of organic charge density.

Figure 7.9 shows the same data and relationships but constrained to only those samples with Gran ANC values less than 100 µeq/L) since it is the sites with low to moderate ANC that are of the greatest interest. The results show that when only considering samples with Gran ANC < 100 µeq/L, there are notable differences both from the relationship defined across the full data set and between the metrics. Comparing Figure 7.8 and Figure 7.9 shows that when focusing on sites of lower ANC, the strength of the relationship between estimated and measured Gran ANC is not as strong (but still strong), further from the 1:1 line, and that there is a clear improvement in adjusting CBANC based on organic anions (i.e., estimated Gran ANC) that is not readily apparent when looking at all samples across the full range of ANC values. For the next few years, it would be prudent to use Gran ANC, ANC_{OAA} and BCS (discussed below) as metrics of ANC, and compare their patterns, as implied by Recommendation 11 in the main report.

Alternative Estimates of ANC that Account for Organic Anions

BCS is equal to CBANC minus strongly acidic organic anions (called $RCOO_s^-$), which Lawrence et al. (2007, 2013) estimate from a linear regression of anion deficits vs. DOC for samples with a pH between pH 4 and 4.5 (33 stream samples in their 2007 paper, 200 lake samples in their 2013 paper). $RCOO^-_s$ is set equal to the anion deficit from this linear regression, for all water samples (i.e., both those with pH ≤ 4.5, and those with pH > 4.5), since the strong acid fraction of DOC is not likely to change with pH. The advantage of BCS as a measure of lake condition is that inorganic aluminum (which is associated with acidification and is toxic to fish and other organisms) consistently increases as BCS declines below zero (i.e., BCS < 0 is a concern).

In the EEM data set we do not have any samples with a pH < 4.5, so we proposed three alternative potential approaches in the Terms of Reference:

A. directly apply the regression lines from Lawrence et al. 2013 (derived from lakes in Adirondacks NY);
B. derive similar linear regressions using EEM and other regional data for lakes within a pH range from 4.5 to 5.1; or
C. assume a triprotic model for organic acids as per Lydersen et al. 2004, Hruska et al. 2001, or Driscoll et al. 1994 (i.e., ANC_{OAA}).

Method A has the advantage of relying on data in a pH range where it can be assumed that the anion deficit is entirely due to strong organic acids (weaker organic anions will be protonated), but has the weakness that those data and the resulting relationship defined by Lawrence et al. (2013) are for lakes in the Adirondacks and the acid-base properties of DOC and organic anions in the EEM lakes could be different. Thus in order to apply Method A, we must assume that the properties of the organic acid anion component of the water chemistry of the EEM lakes is on average comparable to the lakes in the Adirondacks and, similar to Lawrence et al. (2013), we must also assume that the acid-base properties of DOC are relatively similar across the lakes in the study area.

BCS is calculated as:

$BCS = (Ca^{2+} + Mg^{2+} + Na^+ + K^+) - (SO_4^{2-} + NO_3^- + Cl^- + RCOO_S^-)$, or

$BCS = CBANC - RCOO_S^-$

Where $RCOO_S^-$ represents the strongly acidic organic anions, as defined above.

Method B theoretically has the advantage of using local data but ultimately we do not have sufficient data required to derive the relationships similar to Lawrence et al. (2007, 2013). First, we do not have any lake samples with pH values <4.5, although we could potentially use data from a higher pH than recommended (e.g., 4.5-5.1). Second, we have an extremely limited sample size – we have 14 samples with pH values in the range from 4.5 to 5.1 but 11 of them are from the same lake. By comparison Lawrence et al. (2007) used samples from 195 streams and Lawrence et al. (2013) had 200 samples from 13 lakes with pH values less than 4.5. Third, we cannot apply the method of Lawrence et al. (2013) to our lakes because we do not have data for either inorganic monomeric aluminum or organic monomeric aluminum, both of which are required to estimate the anion deficit.

Therefore, in order to estimate BCS for the EEM lakes, we have estimated $RCOO_S^-$ based directly on the results of Lawrence et al. (2013) – i.e., based on the relationship between anion deficits and DOC for 200 samples with pH < 4.5 from 13 Adirondack lakes.

For Method C, we have applied the Lydersen et al. (2004) method to estimate ANC_{OAA}, which uses a triprotic model of organic acids to characterize the organic anions. Lydersen et al. (2004) state that "using a model with a 3-protic acid, the first pKa-value is low, and hence 1/3 of the CD of organics will always be negatively charged in most natural waters". The formulation of their recommended method for estimating ANC_{OAA} is described as follows (Lydersen et al. 2004):

> *We have used these data from Hruska et al. (2001a) and Kohler et al. (1999), both data sets from Swedish humic lakes. We have used a charge density of 10.2 µeq/mg C in our calculation, according to Hruska et al. (2001a). This is also close to the value presented by Kohler et al. (1999) (i.e. 8.6 ± 1.6 µeq/mg C). The amount of permanent organic anions, to be incorporated in the ANC_{OAA}, is, therefore 1/3 of the charge density. Hence, we suggest the following expression:*
> *$ANC_{OAA} = ANC – (10.2/3) * TOC$*
> *[where ANC = CBANC, and TOC = total organic carbon]*

Lydersen et al. (2004) cite earlier research from a study of Norwegian lakes that found that particulate carbon is usually <10% of total carbon and therefore TOC ≈ DOC (Lydersen 1998 in Lydersen et al. 2004). Therefore, we have used the following equation:

$ANC_{OAA} = ANC – (CD/3) * DOC,$

However, we use the lake-specific values for organic charge density rather than an average value from the literature (i.e., 10.2 µeq/mg C as applied in Lydersen et al. (2004).

Comparison of BCS and ANC_{oaa} values for the full STAR / EEM data set

For all the samples across sites and years, we calculated BCS using the method Lawrence et al. (2013; "method A" above) and ANC_{OAA} using the method of Lydersen et al. (2004; "method C" above). Figure 7.10 shows the relationship between these two metrics across all samples. These two metrics demonstrate a very strong relationship and the only sites with notable deviation from the regression are the deep-water samples from LAK028 and a couple individual stream sites.

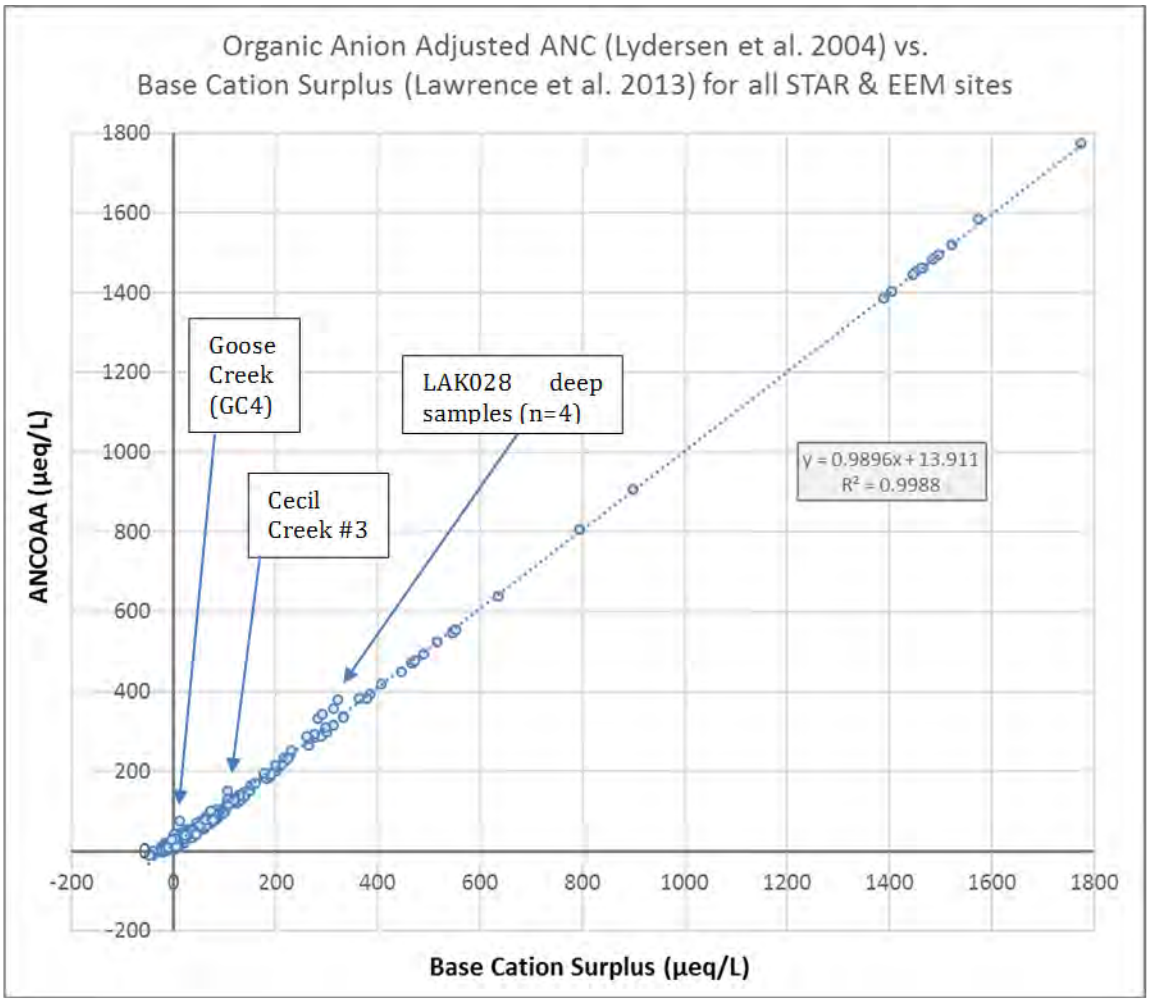


Figure 7.10. ANC_{oaa} versus base cation surplus for the entire data set of all samples within the study area, 2012-2018. Sites with a visible deviation from the trendline at this scale are identified.

Figure 7.11 also shows ANC_{OAA} and BCS values but only for samples with values <100 µeq/L (for either metric) and highlights any lakes with one or more samples below levels identified in the literature as potentially relevant thresholds for the protection of aquatic ecosystems (i.e., ANC_{OAA} < 20 µeq/L or BCS < 0 µeq/L; see Aquatic Appendix B for a literature review of potential ANC thresholds). The lakes highlighted on Figure 7.11 include:

- **LAK042:** only two samples are below the BCS threshold but not below the ANC_{OAA} threshold. However, these two samples are not temporally consistent as one is from 2012 and the other from 2018.
- **LAK044:** all samples are below the ANC_{OAA} only.
- **LAK028:** Most of the samples are below both thresholds; however, the only two of the samples that are above the thresholds occurred in 2014 and 2015, which were the years in which smelter emissions were lowest. LAK028 has four samples that have the lowest BCS values observed and ANC_{OAA} < 0 µeq/L, which is below the threshold for acute toxicity. However, these four samples represent only some but not all of the samples

from the post-KMP period of increased emissions (i.e., 2 of 4 samples from 2016, 1 of 4 samples from 2017, and 0 of 6 samples from 2018), plus one pre-KMP sample (2013).

- **LAK047, LAK054, LAK056:** These lakes were only sampled during the STAR. LAK047 is slightly below the ANC_{OAA} threshold but well above the BCS threshold and the other two are well below both. However, these three lakes were all identified in the STAR as being naturally acidic lakes that were not expected to change in pH (and thus not included in the EEM).

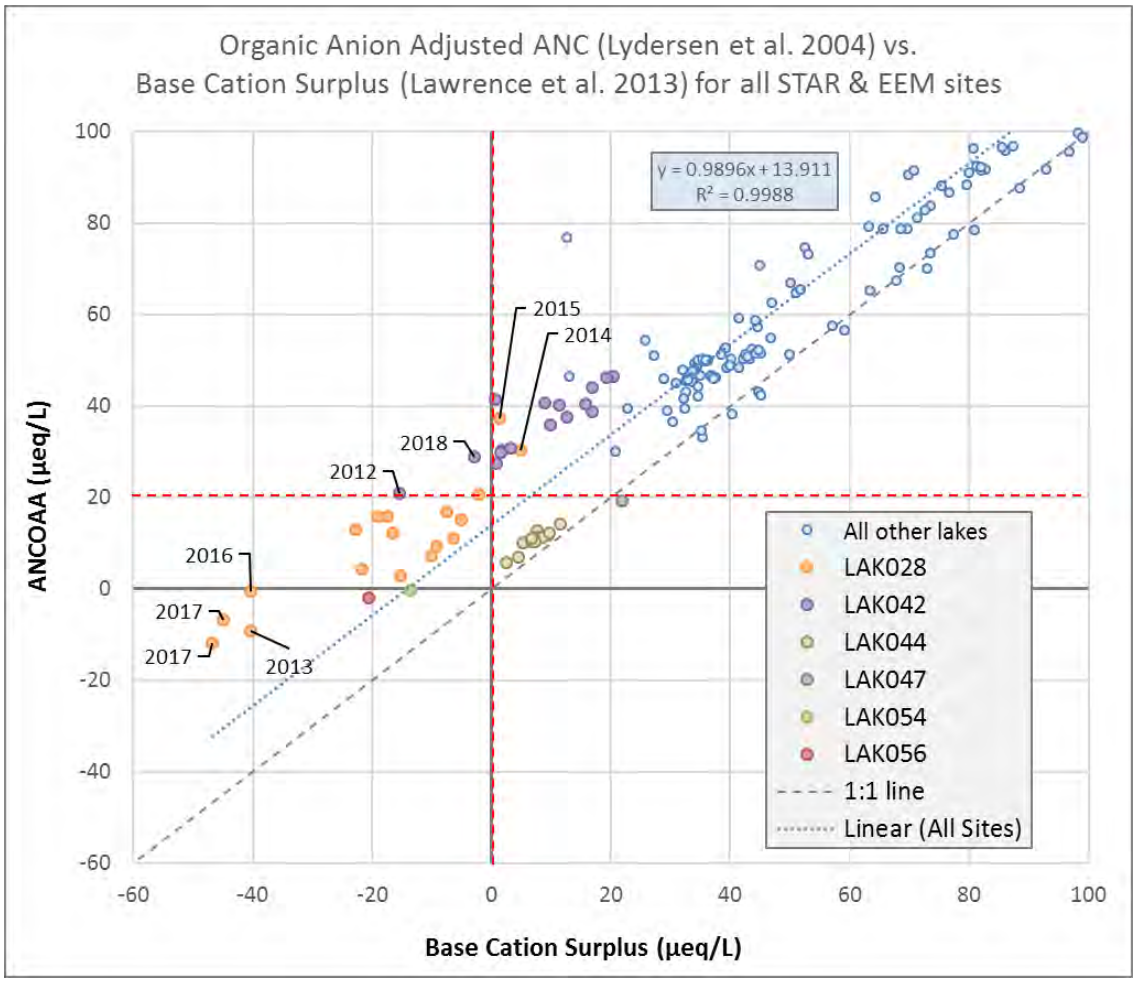


Figure 7.11. Organic anion adjusted ANC (ANC_{oaa}) and base cation surplus (BCS) values for all individual samples within the full data set with values <100 µeq/L. For any lakes with at least *some* samples with BCS<0 or ANC_{oaa}<20 µeq/L (dashed red lines), the full set of samples from the lake are identified. For LAK028 and LAK042, samples that appear to be anomalous within that lake are identified by year of sampling.

Figure 7.10 and Figure 7.11 are based on individual samples across all sites. For the EEM sensitive lakes and less sensitive lakes, we calculated the average BCS by year (Table 7.7). The results show that LAK028 is the only EEM lake with consistent values of BCS < 0 µeq/L. BCS values less than zero are indicative of water chemistry conditions potentially harmful to biota (Lawrence et al. 2007, 2013, Baldigo et al. 2019), especially via chronic toxic levels of aluminum (Baldigo et al. 2009; see Appendix B). For LAK028, BCS has been below this threshold for 5 of

the 7 years of the EEM program, including periods both before and after the increase in emissions. The two years that BCS was greater than zero were the two years with lowest emissions. However, the only year with BCS < -35 µeq/L (identified in the literature review as a threshold for "acute Al toxicity"; see Appendix B) was 2013, which was also a year of low emissions. LAK042 had a negative value for BCS in 2012 (under pre-KMP emissions) but values remained positive from 2013 through 2018.

Table 7.7. Average base cation surplus (BCS) values by lake and year for the EEM lakes. Red cells indicate BCS<0µeq/L.

LAKE	2012	2013	2014	2015	2016	2017	2018
LAK006	34.6	30.3	37.2	38.7	38.9	42.1	43.6
LAK012	94.5	79.5	71.8	71.8	81.0	78.2	70.5
LAK022	44.5	33.9	51.0	47.0	50.1	44.2	51.8
LAK023	29.3	20.7	34.3	34.4	33.6	36.0	36.3
LAK028	-5.1	-40.2	4.8	1.5	-24.9	-32.5	-8.4
LAK042	-15.4	10.0	1.8	16.9	18.0	8.4	0.7
LAK044	2.5	4.5	6.8	11.6	7.0	9.1	7.0
LAK007	1452.5	1388.3	1484.5	1463.9	1495.2	1404.3	1445.7
LAK016	112.0	90.9	115.6	128.8	118.3	107.8	118.4
LAK024	311.7		468.1	465.0	514.8	472.3	548.8
LAK034	158.1	199.4	217.2	198.5	177.6	150.7	161.0

Inorganic Aluminum

Aluminum is of interest because of the concern for toxic effects on aquatic ecosystems.

As described in the STAR (see Section 9.4.1.2.4; based on the 2012 sampling data):

> *Levels of both dissolved aluminum and dissolved organic carbon (DOC) increased as pH decreased, consistent with other studies (Baker et al. 1991). This pattern is expected due to greater solubility of aluminum at low pH, and increased acidity (lower pH) with higher contributions of organic anions. It is likely that most of the aluminum in lower pH sites was complexed with organic anions, which renders it less toxic to fish (Baker et al. 1990). Lakes in the study area have higher levels of both aluminum and DOC than streams for a given pH.*

Inorganic monomeric aluminum (Al_{im}) is strongly linked with toxicity to fish and other aquatic organisms and is therefore frequently interpreted to represent the bioavailable fraction of aqueous aluminum. Differing levels of particulate matter and aluminum complexation in natural surface waters mean that total aluminum and dissolved aluminum do not always correlate well with aquatic toxicity. As part of the EEM Program, Al_{im} was measured in 2013 for 12 of the 14 water chemistry samples taken[6]. Al_{im} is more difficult to measure and therefore

[6] Sites sampled in 2013 included 7 sensitive EEM lakes, 3 less sensitive EEM lakes (LAK024 was only added in 2014), lake MOE6, and 3 sites in Cecil Creek. The three control lakes, which were added to the EEM Program in 2015, have data from 2013 but these data were collected under other water chemistry monitoring programs. LAK044 does not have a measurement for Al_{im}; however, its total Al is among the very lowest (i.e., ~0.01 mg/L). MOE3 does not have a measurement for Al_{im} because its total Al was below the detection limit.

was only a one-time addition only to the water chemistry analyses. It was also added again in 2019. However, total aluminum and dissolved aluminum have been measured ever year. This subsection includes some basic exploration of the one year of data on Al_{im}. The following graphs show the relationship between Al_{im} and total Al (Figure 7.12), pH (Figure 7.13), and (Figure 7.14).

Figure 7.12 shows that there is a positive, potentially non-linear relationship between Al_{im} and total Al and that that only those sites with total Al values greater than 0.1 mg/L have appreciable levels of Al_{im}. LAK028 has the highest levels of Aluminum, then Cecil3, then LAK042. However, although Cecil3 has greater total Al than LAK042, its level of Al_{im} is approximately half.

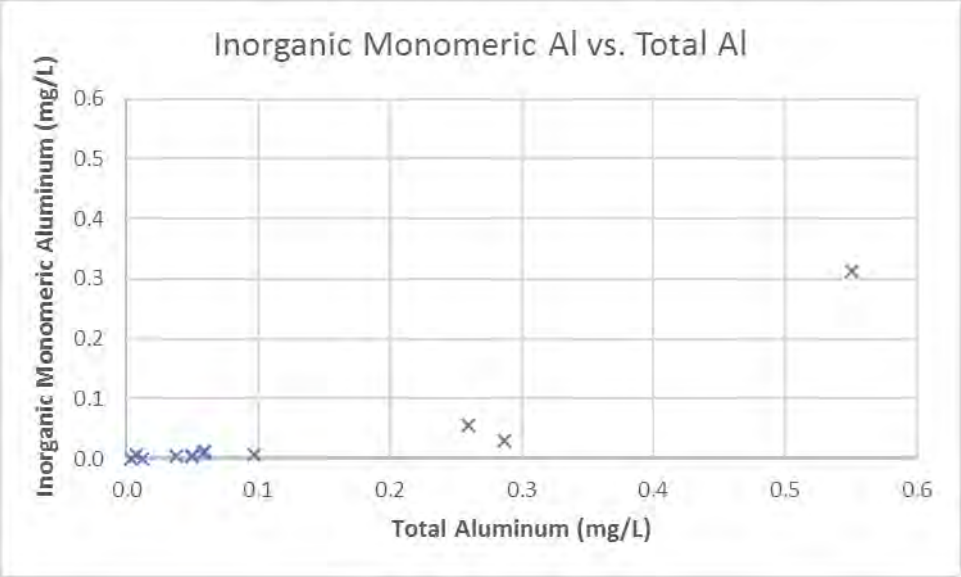


Figure 7.12. Inorganic monomeric aluminum versus total aluminum for the 12 water chemistry samples with Al_{im} values taken in 2013. These data include the non-EEM sites lake MOE3 and three stream sites in Cecil Creek.

As expected, Al_{im} increases with decreasing pH and is most apparent in lakes with pH<5.5 (Figure 7.13). The lakes with low pH and higher Al_{im} are also among the sites with the highest DOC levels. Also as expected, Al_{im} is highest for sites where BCS < 0 µeq/L and relatively negligible for sites where BCS is appreciably greater than zero (Figure 7.14). As discussed previously, one of the strengths of the BCS metric is that Al_{im} consistently increases as BCS declines below zero. LAK028 was the only lake with BCS < 0 µeq/L in 2013 and correspondingly has the highest Al_{im} value. LAK042, which has the second highest Al_{im} value is the only other lake with BCS < 20 µeq/L.

Based on these simple exploratory analyses of Al_{im} from 2013, LAK028 would be the only lake for which concerns regarding potential aluminum toxicity are strongly indicated but LAK042 might also be flagged for further observation based on these results. It appears from this preliminary analysis that BCS provides sufficient information on the potential for toxic conditions without the additional measurement of Al_{im}, but we can check on this preliminary conclusion with the data on Al_{im} collected in the fall of 2019.

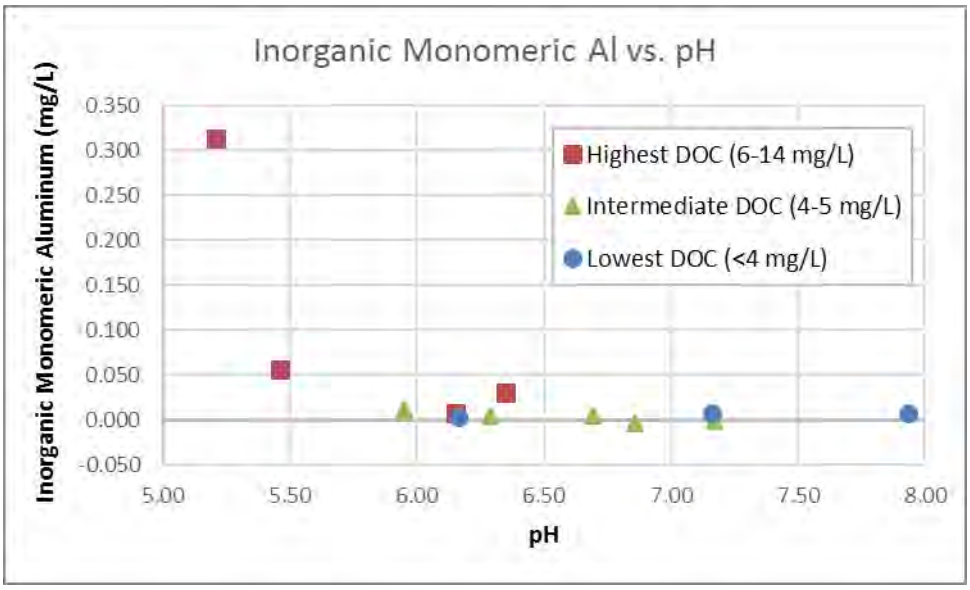


Figure 7.13. Inorganic monomeric aluminum versus pH for the 12 water chemistry samples with Al_{im} values taken in 2013. The sites are stratified into three classes of DOC based on natural breaks in the data. These data include the non-EEM sites lake MOE3 and three stream sites in Cecil Creek.

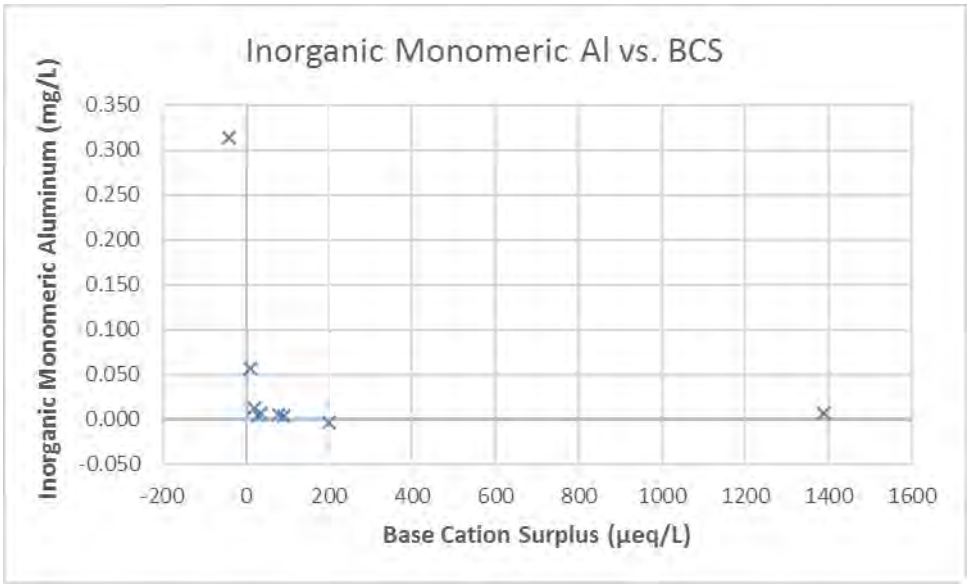


Figure 7.14. Inorganic monomeric aluminum versus Base Cation Surplus (BCS) for EEM lakes. These data include the 9 EEM lakes with Al_{im} values taken in 2013. BCS values were not calculated for the non-EEM sites.

7.1.2.3.3 Temporal patterns in water chemistry

Comparison of August vs. October water chemistry

We used the laboratory pH and Gran ANC measurements for samples taken during the calibration visits to LAK006, LAK012 and LAK023 in 2017 and 2018, and LAK028 in 2018 only,

to test for differences between August and October water chemistry values. We tested for differences between the two months using a t-test.

Temporal Patterns in the Empirical Observations

We examined changes in the empirical data for major water chemistry metrics between the pre-KMP baseline (2012) and the post-KMP period (average of 2016-2018). These basic observational results are presented in the same format as used for EEM Annual Report each year. The time series graphs that are included in the Annual Reports have been updated to include the 2018 data (see Appendix C).

Statistical Analyses of Temporal Patterns

The detailed methods and results of the extensive statistical analyses of the water chemistry data are documented in Appendix F.

7.1.2.3.4 Assessing observed changes in water chemistry relative to STAR predictions

The STAR included predictive analyses of future changes in water chemistry under increased deposition at maximum emissions levels (i.e., the permit level of 42 tpd SO_2). In the STAR (as again in the Comprehensive Review, see Appendix G), we used the Steady-State Water Chemistry model (SSWC) to estimate critical loads and exceedances and the modified ESSA-DFO model to estimate future changes in ANC and pH and the eventual steady state water chemistry. As part of the current review, we compared the changes observed thus far to those predicted changes, after accounting for the fact that average post-KMP emissions have been much lower than the maximum permit level (i.e., 29.3 tpd SO_2). We therefore adjusted the STAR predictions based on current emissions to facilitate an equivalent comparison[7].

Post-KMP emissions have been much lower than the maximum allowable emissions under the permit as modelled in the STAR. Over 2016 to 2018, emissions have been an average of 29.3 tpd SO_2 compared to the permit level of 42 tpd. We explored two different methods for adjusting the STAR predictions based on this difference in emissions levels. In the STAR, the simulated changes in emissions were based on the increase from 20.6 tpd (average of 2006, 2008 and 2009, as per the CALPUFF "pre-KMP" scenario) to 42.0 tpd.

In Method A, we assumed that post-KMP deposition was 70% of what was modelled in the STAR and was proportional to emissions (i.e., (29.4[8] tpd for 2016-2018) / (42.0 tpd in STAR) = 0.70). We kept pre-KMP deposition at the values used in the STAR (average of 2006, 2008 and 2009 simulated deposition).

In Method B, we assumed that the observed change in sulphate deposition since 2012 was proportional to the change in emissions over the period from 2012 (16.1 tpd) to the average of

[7] Note: The underlying analyses described here were conducted based on "actual" emissions of 29.4 tpd rather than the correct 29.3 tpd. The difference was due to minor differences in 2016 data resulting from use of preliminary data that was later revised. However, the analyses have been retained as is because this difference would have a negligible impact on the results and therefore not affect the conclusions of these comparisons.

[8] See previous footnote

2016-2018 (29.4[9] tpd), for a net change in emissions of 13.3 tpd over 2012-2018. Comparing this 13.3 tpd change in emissions with what we simulated in the STAR (i.e., 21.4 tpd = 42.0 tpd permitted emissions – 20.6 average emissions in 2006, 2008 and 2009), we obtain a ratio of 0.621, and applied that ratio to the change in deposition we had simulated in the STAR.

We then compared the results of both sets of adjusted predictions to the changes actually observed through the monitoring program.

7.1.2.4 Weight-of-Evidence approach for assessing causality

The evidentiary framework developed for the EEM Plan applies a weight-of-evidence approach for identifying patterns in the empirical lake chemistry data that are consistent with smelter-driven acidification. It is described in full in the EEM Plan[10] The definition of the KPI for aquatic ecosystems comprises two components: 1) an observed change in pH of greater than a specified threshold *and* 2) that the observed change to be causally linked to the smelter. Lake chemistry is naturally dynamic and there are additional mechanisms or natural variability that could lead to observed changes in pH that are not driven by increases in smelter emissions. The purpose of the evidentiary framework is to consider the patterns of change in the empirical observations of multiple lake chemistry metrics (i.e., different lines of evidence) in an integrated manner to determine whether the observed changes are or are not consistent with smelter-driven acidification.

We have applied the evidentiary framework as outlined in the EEM Plan, as well as a simplified version that maintains the most critical components of the full implementation. Because of its central importance as an integrated framework for assess evidence of the causal linkage between empirical observations of lake chemistry and KMP, the application of the evidentiary framework is presented in full in the main report (Section 7.3.4.5).

7.1.2.5 Episodic acidification studies

As discussed in EEM Annual Reports, there were two sources of information intended[11] to provide the inputs for exploring this topic. The first source is the continuous pH monitoring data from multiple lakes. Continuous pH monitoring has occurred since 2015 in three lakes: LAK006 (End Lake), LAK012 (Little End Lake) and LAK023 (West Lake). From 2015 to 2018, a Manta2 model 2.5 multiprobe was used to take pH measurements every half hour and was recalibrated every two weeks against known buffer solutions (Limnotek 2019).

The second source is the independent, parallel research project being conducted by Dr. Paul Weidman to determine (among other research objectives) the extent of episodic acidification within the Kitimat watershed – "*Impacts of Industrial Sulfur and Nitrogen Deposition and Climate Change on Salmon Stream Habitat in the Kitimat Watershed*"

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[9] See previous footnote

[10] In particular refer to Table 17, pg. 43 in EEM Plan

[11] As described in the "learnings" in Section 7.1.3.2.7, it has not been possible to use either of these sources for exploration of potential patterns of episodic acidification in the Comprehensive Review.

7.1.2.6 Critical loads, exceedances and predicted changes in pH

The modeling, analyses and sensitivity analyses associated with critical loads, exceedances and predicted change in pH are documented in Appendix G.

7.1.2.7 Kitimat River water quality

Rio Tinto conducts water quality monitoring at their intake on the Kitimat River.

7.1.2.8 Other data and/or analyses previously reported

In addition to the core water chemistry sampling program for the 14 EEM lakes (as described above), the we also conducted other data collections and analyses over the course of 2013-2018 in support of the Aquatic Ecosystems component of the Program. These other initiatives and analyses have been documented elsewhere (especially in the Annual Reports) during the program and are only briefly summarized here.

Fish sampling

In order to measure the presence/absence of fish in the acid-sensitive lakes, Limnotek conducted fish sampling in 2013 (LAK006, LAK012, LAK023, and LAK044), 2015 (LAK007, LAK016 and LAK034), and 2017 (LAK028). The EEM Plan established that fish populations in these lakes could potentially be resampled if it were determined that a lake's pH had declined by more than 0.3 pH units.

Fish sampling was done using standard gill netting techniques. Gill nets were left overnight, and each captured fish was identified with lake number, date, unique set code, mesh size where the capture occurred, unique fish code, species code, and scale number (Perrin et al. 2013).

DNA analysis of tissue was done in 2013 to confirm the presence of resident Coho salmon (i.e., non-anadromous, not going to sea) in West Lake (LAK023). More information on sampling methods and results can be found in the detailed sampling results report (Perrin et al. 2013).

Bathymetric surveys

In 2015, bathymetric surveys were done by Limnotek (2016) on the three lakes with continuous monitoring (LAK006, LAK012, LAK023) in order to be able to generate a precise estimate of lake volume and therefore a more accurate estimate of the water residence time for each lake. In 2017, a similar survey was done for LAK028.

Water residence time

Water residence time is relevant to understanding one of the possible factors contributing to variability (especially intra-annual variability) within individual lakes; i.e., lakes with shorter water residence times would be expected to demonstrate higher variability in water chemistry.

An estimate of water residence time of all the lakes in the EEM Program was estimated based on a coarse approximation of lake volume.

Water residence time (or retention time) is calculated as:

$$Residence\ time\ (years) = \frac{Lake\ volume\ (m^3)}{Annual\ outflow\ (\frac{m^3}{year})}$$

where annual outflow is estimated as: watershed area (m^2) * mean annual runoff (m/yr), with mean annual runoff for the period from 1960 to 1990, as described in the STAR.

Regional amphibians and potential risks of aquatic acidification

Acidification effects on amphibian species were not explicitly addressed in the 2013 sulphur dioxide technical assessment report - STAR (ESSA et al. 2013_a and 2013_b) - and were n0t including for monitoring in the aquatic ecosystems' component of the EEM Program.

However, in response to the interest expressed by the Kitimat Public Advisory Committee in learning about the risks KMP might pose to amphibians, ESSA conducted a literature review (ESSA 2017) and compiled regional data on amphibians in order to understand potential acidification risks.

The literature review focused on answering three questions addressing the current uncertainty about acidification risks for amphibians in the Kitimat area:

- Which effects/impact pathways are most relevant (e.g., life stage, habitat, mechanism)?
- What is the level of risk of acidification under KMP for local amphibian species? Are any local amphibian species at significant risk under KMP?
- What are the most critical knowledge gaps/uncertainties? What are the implications?

To answer these questions, we compiled relevant peer-reviewed research, government research and grey literature to understand the occurrence of amphibian species in the Kitimat Valley, their sensitivity to acidification, and the spatial distribution of potential habitats.

We defined a study area (Figure 7.15) encompassing the original STAR study area but with broader boundaries which account for the habitat patterns of amphibian species common to the region (i.e., (e.g., Western Toads, *Anaxyrus boreas*, are known to cover distances greater than 10 km) and also to include control areas which are not affected by KMP deposition.

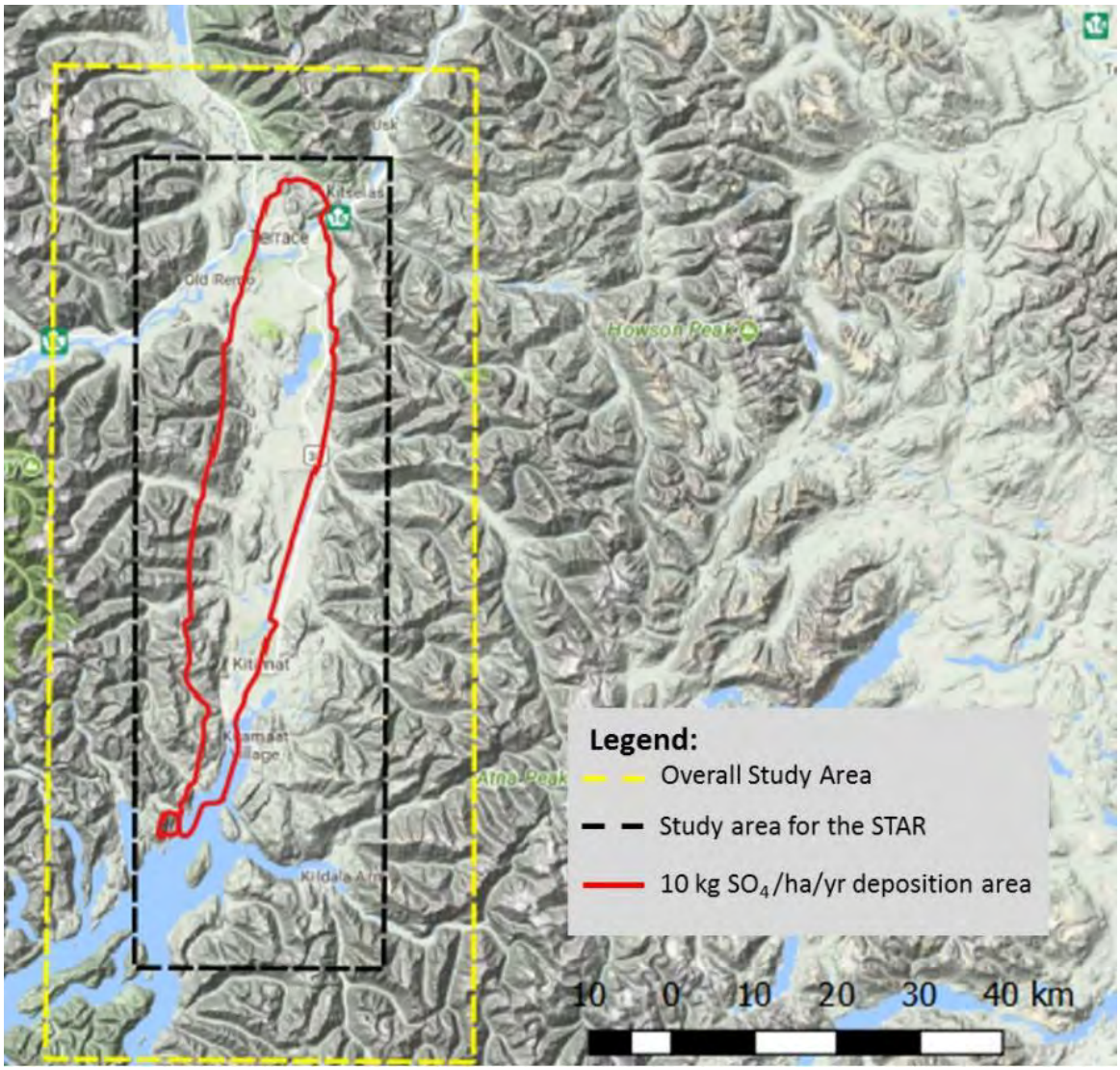


Figure 7.15. Overall study area for the amphibian literature review (hatched yellow line), and the two subareas: the study area for the STAR (hatched black line), and the 10 kg SO_4/ha/yr deposition isopleth as projected from KMP (solid red line). Source: ESSA 2017.

To study amphibian species occurrence and their distribution, we mapped amphibian observations assembled from government spatial databases, specifically the Species Inventory Database, the Conservation Data Centre (CDC), and Frogwatch BC. Additionally, and in order to identify potential amphibian habitat types within the overall study area, we mapped the occurrence of potential aquatic habitats within the overall study area, including lakes, wetlands, streams and rivers.

Lake level monitoring

Surface water level monitoring was done by installing a staff gauge near the lake's border. The staff gauge was attached to an 8-foot-long piece of angle iron and a one-inch wood post that were hammered into the lake bottom.

During the bi-monthly visits to each lake to calibrate the Mantas and collect water samples in June to November, the depth on the staff gauge was recorded on the field notes and the logger installations were checked for signs of tampering or vandalism.

In 2016, lake levels were monitored in End Lake, Little End Lake, and West Lake to provide an accurate, local measure of the timing of storm events, so as to better explain observed variation in pH (monitored continuously) and other water quality parameters of interest monitored during October (particularly sulphate, nitrate, DOC, ANC, and base cations).

Flow data

For some Annual Reports, we looked at regional stream flow data to supplement interpretation of observed patterns in lake chemistry (especially with respect to examining late-season decreases in pH and/or apparent dilution effects in the intensively monitored lakes). For this purpose we downloaded available stream flow data from Environment Canada's Water Survey of Canada (https://wateroffice.ec.gc.ca/) for the available stations within the study area. The three stations in the study area are: Kitimat River below Hirsch Creek (08FF001), Hirsch Creek near the mouth (08FF002), and Little Wedeene River below Bowbyes Creek (08FF003).

Depth profile, water column chemistry, and deep water sampling for LAK028

In 2017, a profile of the water chemistry was conducted at a deep location near the centre of lake LAK028 to gain a more comprehensive understanding of the lake's chemistry. Samples were taken every 1 m for temperature, pH, conductivity, total dissolved solids concentration, turbidity, dissolved oxygen concentration.

Water column sampling from LAK028 strongly suggests the presence of meromixis (i.e., surface and bottom waters do not mix), which was also implied by the small surface area relative to lake depth. The results of the water column sampling (see Bennett and Perrin 2018) show that thermal and chemical conditions change significantly at depths >9 m.

The surface mixed layer (<9 m) had water temperature typical of north coast lakes in the fall, high dissolved oxygen that could support fish, conductivity and inorganic nitrogen concentrations typical of nutrient deficient lakes, and a surface pH (~ 5) at the low end of tolerances for aquatic organisms. The bottom water layer was anoxic and would not support fish, with higher pH, higher conductivity, a warming thermocline, an odour of H2S, and other evidence of sulphur-reducing green and/or purple bacteria.

In 2018, deep water samples were taken from near the bottom of LAK028, in addition to the standard surface water sampling program, to examine chemical differences between surface and bottom mixed layers that were first described in 2017.

Non-EEM sites

In addition to the lakes sampled annually within the EEM Program, multiple other "non-EEM" (i.e., outside the core program) lake and stream sites were identified for exploratory water chemistry sampling in particular years over the course of the EEM Program. These sites were either requested by BC Ministry of Environment (MOE, now ENV) or selected by Rio Tinto to determine their sensitivity to acidic deposition. Table 7.2 provides a summary of the "non-EEM" sites sampled during the course of the EEM Program to date, including: Cecil Creek, lakes MOE3 and MOE6, and multiple sites within the Goose Creek drainage. Most of these sites were only sampled once but some of the Goose Creek sites have been sampled twice.

7.1.2.9 Assessment of acceptable or unacceptable impacts to aquatic receptor

The assessment of the impacts to the aquatic receptor as "acceptable" or "unacceptable"[12] is directly linked to the KPI. If the KPI threshold associated with facility-based mitigation in the EEM is exceeded, this is identified as an "unacceptable" impact for the aquatic receptor. Impacts to the aquatic receptor that do not exceed the KPI threshold associated with facility-mitigation in the EEM are identified as "acceptable".

7.1.3 What did we learn, and did we make any adjustments to the EEM Program?

7.1.3.1 Empirical Data from Lake Chemistry Monitoring Program

7.1.3.1.1 Quality of Water Chemistry Data

Sampling and laboratory quality control and quality assurance

The results of the sampling and laboratory quality control and quality assurance methods are presented in the annual technical reports from Limnotek. The laboratory data show high precision and accuracy, with no apparent problems. Measurements of pH from ALS have common shown a statistically significantly different from pH measurements in the field, and from pH measurements in the laboratory at Trent University, but these differences were still within the specified limits of ± 0.3 pH units for the equipment used by ALS.

Charge Balance Check

The charge balance has been examined for each year of sampling, based on the data from each water chemistry sample. Table 7.8 shows four diagnostics metrics of the charge balance (i.e., the average value and the average of the absolute values, for both percent difference and difference in µeq/L). The charge balance in 2013, although acceptable, was worse than the other years in the series. In all cases, the average charge balance represents an excess of anions relative to cations. In order to be consistent with the results presented throughout the EEM, including those reported in the EEM 2018 Annual Report, the charge balances reported here are calculated using an assumed organic charge density of 7.5 µeq/mg C, rather than the revised and/or lake-specific estimates of organic charge density that we discussed in Section 7.1.2.3.1.

[12] Section 4.2.6 of the P2-00001 permit, dated March 15, 2016, states "If any unacceptable impacts are determined through the use of the impact threshold criteria pertaining to emission reduction, then the maximum SO_2 daily discharge limit shall revert back to 27 Mg/d, unless the Director amends the discharge limit."

Table 7.8. Measures of the charge balance check for all lake samples from 2012 to 2018. Negative (red) values for the two "Average Difference" values indicate less total charge from cations than from anions. See text for explanation of the assumed values for the organic charge density.

Year	Number of samples	Average Percent Difference (%)	Average of the Absolute Value of the Percent Differences (%)	Average Difference (µeq/L)	Average of the Absolute Value of the Differences (µeq/L)
2012	41	0.8	3.9	-6.3	14.4
2013	14	-10.3	10.3	-33.1	33.1
2014	24	-5.3	5.4	-12.2	12.9
2015	22	-3.2	3.3	-12.8	13.2
2016	32	-3.1	3.8	-4.8	12.0
2017	32	-0.3	3.5	-3.7	8.7
2018	34	-3.1	4.1	-7.7	9.6

Measured versus Estimated Conductivity

Measured and estimated conductivity were compared for each year of sampling, based on the data from each water chemistry sample. Table 7.9 shows two diagnostic metrics of the conductivity check for the water chemistry samples for all the lakes from 2012 to 2018. The average difference was highest in 2013. Overall the data demonstrate an acceptable relationship between measured and estimated conductivity. Although most years show an average negative results (i.e., estimated conductivity is lower than measured conductivity), the number of individual samples with negative values cross the entire data series reported shows only slightly more lake samples with negative values than positive values – 53% versus 47%, respectively.

Table 7.9. Measures of the conductivity check for all lake samples from 2012 to 2018. Positive values of "Average %Diff" indicate that the estimated conductivity was higher than the measured conductivity. Negative values (shown in red) indicate that the estimated conductivity was lower than the measured conductivity. The annual range of measured conductivity values is provided for context.

Year	Number of Samples	Average Difference (%)	Average of the Absolute Value of the Differences (%)	Measured Conductivity Values (µS/cm)*		
				Minimum sample value	Mean sample value	Maximum sample value
2012	41	6.6	7.4	2.5	35.4	184.3
2013	14	10.8	13.3	3.3	23.3	147.0
2014	24	-2.9	5.6	3.6	21.0	154.2
2015	22	-2.3	5.9	3.5	18.1	151.2
2016	32	-5.1	10.5	3.8	17.9	153.7
2017	32	-6.0	9.9	3.5	17.7	149.0
2018	34	-1.0	6.8	3.5	17.0	147.4
2018	34	-1.0	6.8	3.5	17.0	147.4

*The minimum, mean and maximum values are based on the total data set of all lake samples from a particular year, therefore the mean value is weighted toward lakes sampled more frequently and should be interpreted accordingly.

pH measurements

Lab measurements of pH were made at two different labs in 2013 to 2018. Limnotek has examined the differences in pH measurements among the two labs and the field measurement each year and concluded that the differences were within the expected ranges (i.e., factory/lab specified measurement error associated with each instrument). The values measured at ALS have generally been higher than those measured by Trent University or those measured in the field. Both labs apply substantial quality control, quality assurance and equipment calibration procedures. However, we know that in lake water with low ionic strength it is very important to allow lots of time for pH measurements to stabilize. This appears to have occurred at Trent University, but possibly not at ALS, where most of the samples they process are from waters with much higher ionic strength (Limnotek 2019). However, throughout the EEM Program, we have used the Trent University measurements for analyses of temporal patterns in pH to be consistent with the data from the STAR – the 2012 samples were only analyzed by Trent University and not ALS.

7.1.3.1.2 Water Chemistry Sampling Results

Appendix D reports the results of the annual water chemistry sampling for the EEM lakes and control lakes from the sampling conducted from 2012 to 2018, for major water chemistry metrics (pH, DOC, Gran ANC, base cations, and major anions).

Changes in pH, Gran ANC, SO_4^{2-}, DOC, sum of base cations, and chloride over the period of the EEM Program are shown in terms of absolute change in Table 7.10 and Table 7.11. The time period of comparison is from the baseline year (2012) to the post-KMP period (the average of 2016-2018). The sensitive EEM lakes and less sensitive EEM lakes are presented separately within each of the tables. The values presented use the mean annual values whenever multiple within-season samples were taken for a given lake in a given year.

Figure 7.16 and Figure 7.17 show the changes in the same water chemistry parameters graphically. These figures allow better visualization of the distribution and variability in the observed changes between the 2012 baseline and the post-KMP period.

Appendix C provides a detailed set of figures showing the inter-annual changes in major water chemistry metrics (Gran ANC, base cations, SO_4^{2-}, chloride, pH and DOC) for each of the EEM lakes across the seven years of monitoring data (2012-2018). Similar figures are also included for the three control lakes based on their five years of annual monitoring (2013, 2015-2018).

However, annual changes should be interpreted with substantial caution due to the combination of large natural variation (both within and between years) and limitations on measurement precision. The power analyses conducted and reported in the 2015 EEM Annual Report (see Section 7.1.3.2.2) illustrated that at least five years of post-KMP of observations are required to reliably detect changes in mean pH, Gran ANC and SO_4.

Given these caveats and the rigid schedule for the Comprehensive Review to occur in 2019 (with only three years of post-KMP observations), we have performed an extensive set of rigorous statistical analyses on the empirical data to ensure that any conclusions are as robust and scientifically defensible as possible given the limited number of post-KMP observations thus far (see Aquatic Appendix F).

These results are examined, analyzed and discussed in detail in Section 7.1.3.2.

Table 7.10. Changes in pH, Gran ANC and SO_4^{2-} from baseline conditions (2012) to the post-KMP period (2016-2018). Green cells indicate increases and red cells indicate decreases.

	pH			Gran ANC (µeq/L)			SO_4^{2-} (µeq/L)		
EEM sensitive lakes	2012	Post-KMP	**ΔpH**	2012	Post-KMP	**ΔANC**	2012	Post-KMP	**ΔSO_4^{2-}**
LAK006	5.8	6.0	0.24	25.7	27.7	2.0	11.4	14.0	2.5
LAK012	5.6	6.2	0.52	57.0	58.3	1.3	6.1	12.9	6.8
LAK022	5.9	6.1	0.15	27.8	33.0	5.1	30.2	38.8	8.6
LAK023	5.7	5.9	0.22	19.8	26.4	6.7	19.0	12.3	-6.7
LAK028	5.0	5.0	0.02	-4.0	-3.5	0.5	56.9	128.4	71.5
LAK042	4.7	5.2	0.54	-20.4	5.6	26.1	6.2	5.4	-0.8
LAK044	5.4	5.6	0.15	1.3	5.0	3.7	6.2	4.4	-1.9
Total lakes with increase			7			7			4
Total lakes with decrease			0			0			3

EEM less sensitive lakes	2012	Post-KMP	**ΔpH**	2012	Post-KMP	**ΔANC**	2012	Post-KMP	**ΔSO_4^{2-}**
LAK007	8.0	8.0	0.03	1437.6	1385.9	-51.6	51.4	47.0	-4.4
LAK016	6.3	6.7	0.34	68.7	89.8	21.1	39.0	44.5	5.4
LAK024	7.1	7.5	0.36	299.5	463.2	163.7	24.8	38.9	14.1
LAK034	6.7	6.4	-0.29	99.4	139.6	40.2	24.1	0.1	-24.0
Total lakes with increase			3			3			2
Total lakes with decrease			1			1			2

Control lakes	2013	Post-KMP	**ΔpH**	2013	Post-KMP	**ΔANC**	2013	Post-KMP	**Δ SO_4^{2-}**
DCAS14A	6.5	6.6	0.2	50.6	55.9	5.4	33.4	36.4	3.0
NC184	5.7	5.8	0.1	16.2	27.0	10.8	5.7	6.2	0.5
NC194	6.6	6.4	-0.2	28.0	22.4	-5.6	3.6	2.5	-1.1
Total lakes with increase			2			2			2
Total lakes with decrease			1			1			1

Table 7.11. Changes in dissolved organic carbon (DOC), total base cations (∑BC), and chloride (Cl) from baseline conditions (2012) to the post-KMP period (2016-2018). Green cells indicate increases and red cells indicate decreases.

	DOC (mg/L)			∑ BC (µeq/L)			Cl (µeq/L)		
EEM sensitive lakes	2012	Post-KMP	ΔDOC	2012	Post-KMP	ΔBC*	2012	Post-KMP	ΔCl
LAK006	3.6	3.9	0.4	60.6	72.1	11.5	5.8	5.7	-0.1
LAK012	4.6	5.0	0.3	120.6	111.5	-9.1	4.2	6.3	2.1
LAK022	5.3	6.1	0.7	98.1	114.7	16.5	6.9	7.4	0.5
LAK023	4.2	5.6	1.5	65.9	72.8	6.9	4.5	4.7	0.2
LAK028	4.9	6.6	1.7	72.9	136.7	63.8	6.1	8.4	2.4
LAK042	13.2	10.7	-2.5	53.4	64.8	11.4	6.1	6.7	0.5
LAK044	1.7	1.8	0.1	14.2	18.1	3.9	5.6	6.2	0.6
Total Lakes with Increase			6			6			6
Total Lakes with Decrease			1			1			1

EEM less sensitive lakes	2012	Post-KMP	ΔDOC	2012	Post-KMP	ΔBC	2012	Post-KMP	ΔCl
LAK007	0.6	0.4	-0.2	1503.9	1494.3	-9.6	24.6	26.4	1.8
LAK016	3.7	4.6	0.9	166.3	179.5	13.2	6.3	7.7	1.4
LAK024	1.4	2.1	0.7	340.0	558.5	218.4	27.3	68.3	41.0
LAK034	4.5	6.2	1.7	201.7	191.2	-10.5	5.8	4.5	-1.3
Total Lakes with Increase			3			2			3
Total Lakes with Decrease			1			2			1

Control lakes	2013	Post-KMP	ΔDOC	2013	Post-KMP	ΔBC	2013	Post-KMP	ΔCl
DCAS14A	1.4	1.3	-0.0	90.6	109.7	19.1	9.2	7.1	-2.0
NC184	11.6	10.3	-1.3	86.2	94.8	8.6	24.0	17.5	-6.5
NC194	0.7	1.0	0.3	39.2	45.8	6.6	7.6	5.9	-1.7
Total Lakes with Increase			1			3			0
Total Lakes with Decrease			2			0			3

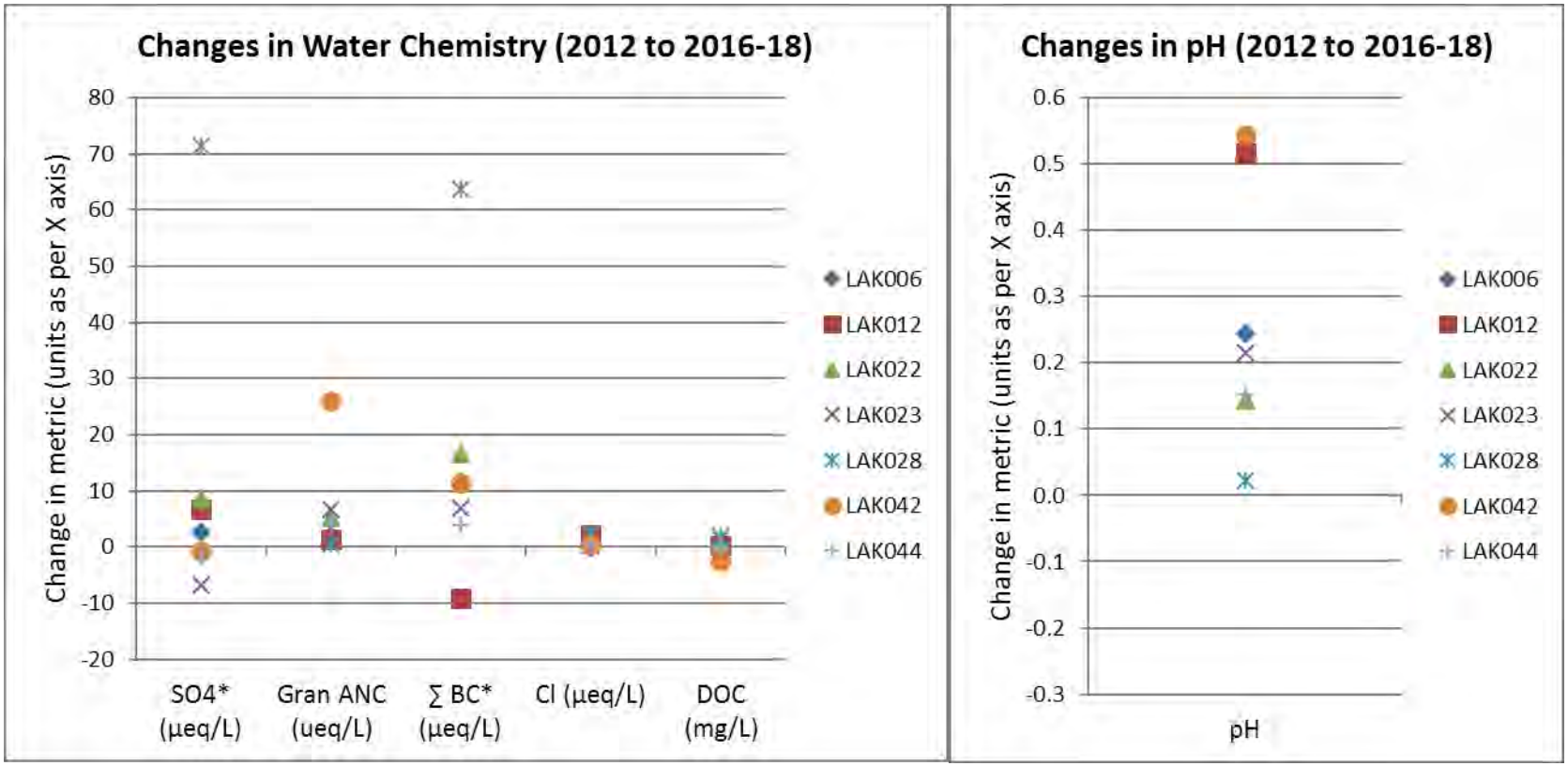


Figure 7.16. Changes in water chemistry metrics (left panel) and pH (right panel) across all of the sensitive EEM lakes, from the baseline (2012) to the average of post-KMP conditions (2016-2018). Values shown are the post-KMP value minus the baseline value.

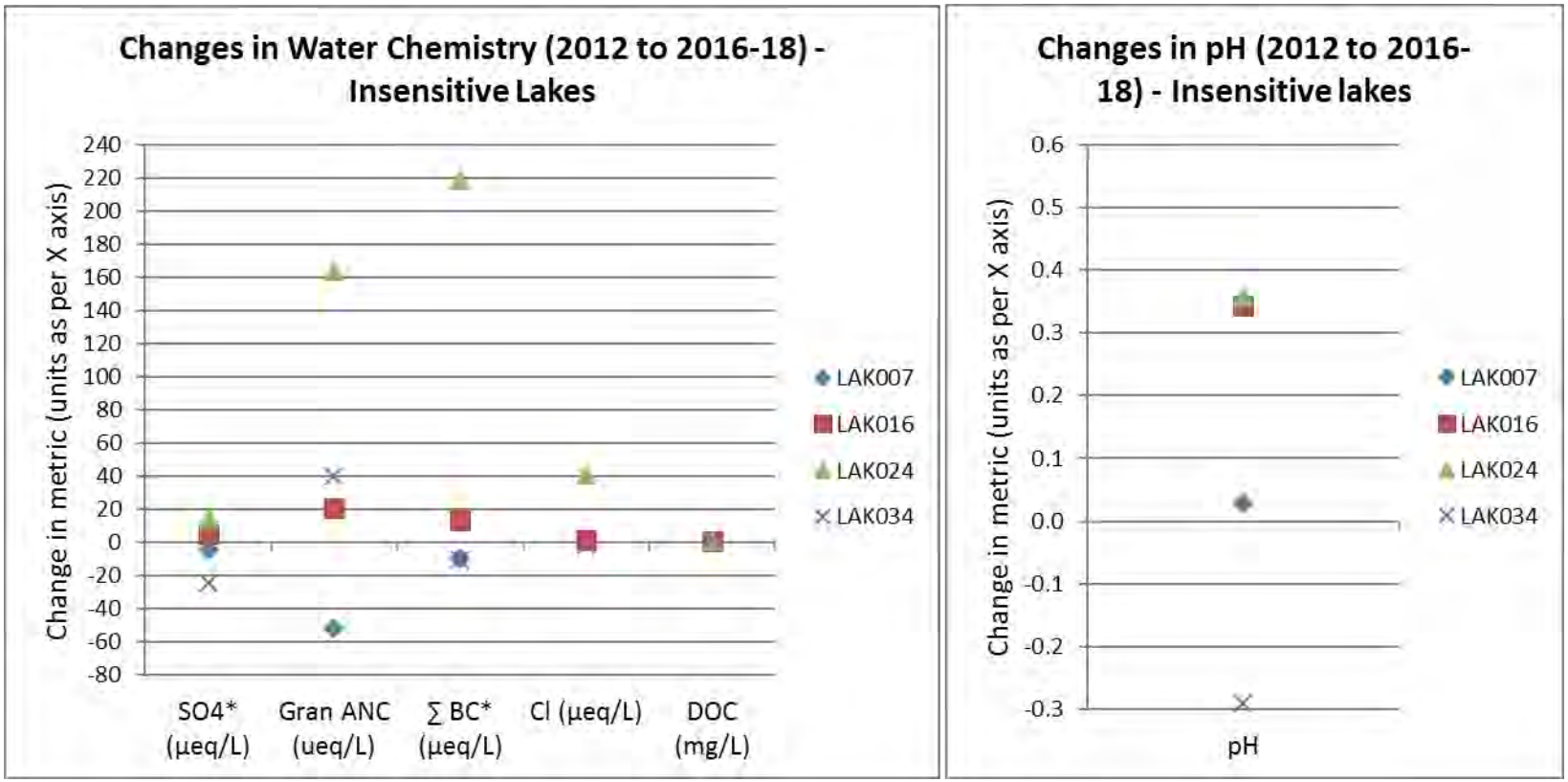


Figure 7.17. Changes in water chemistry metrics (left panel) and pH (right panel) across all of the less sensitive EEM lakes, from the baseline (2012) to the average of post-KMP conditions (2016-2018). Values shown are the post-KMP value minus the baseline value.

7.1.3.2 Knowledge gained

7.1.3.2.1 Measuring pH

Measuring pH accurately, especially in waters with low ionic strength (as is the case for the EEM lakes), is difficult. Skjelkvale et al. (2005) report that *"pH is among the most difficult variables to measure well in the laboratory and variability in measurements makes it more difficult to detect trends".* The details on what we have learned with respect to measuring pH during the course of the EEM program are predominantly reported in the annual technical reports from Limnotek on the water chemistry sampling program. However, some of the major insights are repeated here.

The pH data from the EEM lakes show a high degree of variability. The power analyses study in 2015 showed that the variability in the 2012-2014 pH data from the EEM lakes was much higher than similar pH data collected from a set of lakes studied by Environment Canada in southwestern BC. The data from the continuous pH monitors showed that pH can be highly variable on a seasonal or monthly basis and even over a period of only a few hours. This observed variability has been much greater than anticipated during the design of the EEM Program.

Starting in 2013, water samples were also sent to a commercial laboratory in addition to the laboratory at Trent University for analysis of certain parameters, including pH. The pH values measured by the commercial laboratory have consistently been higher than those measured by the Trent University laboratory, as well as showing greater deviation between values for field duplicates (i.e., two identical samples from the same lake). Work by Limnotek has shown that a critical factor for achieving consistent, reliable measures of pH in these waters of low ionic strength is allowing a long stabilization period (i.e., up to 10 minutes or longer) for each measurement. The lack of time for stabilization is one of the major factors behind Limnotek's recommendations with respect to use of the existing continuous pH monitors (see Section 7.1.3.2.7) and is suspected to be the underlying cause of the consistently higher pH values measured by the commercial laboratory.

Within the program, pH has been measured with multiple field and laboratory instruments. Every year Limnotek conducts analyses of potential instrument effects. Overall, their general conclusions have been that the laboratory analyses conducted at Trent University and the WTW field monitor generate the most reliable measures of pH in the Program, and therefore we have relied on those pH data for our analyses.

7.1.3.2.2 Ability to detect changes in water chemistry

The ability of the EEM Program to detect changes in water chemistry has been significantly informed by the power analyses conducted in 2014-15. The results and implications of this work are summarized in the 2015 EEM Annual Report and reiterated in Appendix F (Section 7.6.3). However, some of the most critical conclusions are repeated here:

1. The power to detect changes in pH, Gran ANC and SO_4^{2-} is highly variable among lakes and metrics
2. On average, the power to detect changes in pH in the EEM lakes is quite low
3. The power for Gran ANC or SO_4^{2-} is higher than for pH

4. Increased sampling frequency increases the power, especially for pH
5. For 4 lakes the power for Gran ANC or SO_4^{2-} is actually relatively high
6. Across most of the lakes, metrics and scenarios, power was low or very low in the first few years after KMP.
7. The EEM Program should not make any strong conclusions about the changes in lake chemistry that have occurred until there have been at least five years of post-KMP data collected.

7.1.3.2.3 Spatial and temporal patterns in water chemistry

NOTE: The following two topics for this subsection (as per the Terms of Reference) are addressed elsewhere (i.e., integrated into other sections as appropriate for improved logical flow and organization). Implementation of the original TOR exposed some areas of overlap and redundancy among sections and we have endeavoured to avoid repeating the same material unnecessarily.

- *"Application of multiple lines of evidence"*
  - *e.g., addressed in Sections 7.2.4, 7.3.2.3, and 7.3.4 in the main report*
- *"Results of Sensitivity Analyses"*
  - *e.g. addressed in Aquatic Appendices F, G and I*

August vs. October Sampling

The seasonal timing of the water chemistry sampling changed from August in 2012 to October from 2013 onwards. In the 2013 EEM Annual Report, the critical loads and exceedances were re-estimated using the October 2013 data to evaluate whether the shift in seasonal timing resulted in substantially different estimates. In more recent annual reports we conducted additional comparisons between August and October sampling values using the data from the continuous pH monitors. However, we have not found any consistent differences between August and October through these previous comparisons. In the present work, we have expanded upon these comparisons using two additional sets of data that allow comparison between August and October lake chemistry values. First, we have field pH data from each of the bi-weekly "calibration visits" to the lakes with continuous pH monitors for 2015-2018 and in 2017 and 2018 samples were also collected for laboratory analysis of pH and Gran ANC. These lakes include LAK006, LAK012, LAK023 and LAK028 (2018 only). Second, in 2018 for LAK028 only, two additional samples prior to the fall index period were collected and sent for full water chemistry analysis. These two samples were collected in early August and early September.

Using the data from the calibration visits, we tested for differences between August and October samples using a t-test. Table 7.12 shows the number of samples available in August and October for each of the metrics, lakes and years for which appropriate data were available. The results are shown below for field pH, lab pH and Gran ANC (Table 7.13, Table 7.14, and Table 7.15, respectively). The results show that we could not detect any differences between the sample values for August and October for these three metrics – i.e., there were no significant results.

Table 7.12. Number of samples available for comparisons of August vs. October sampling.

Metric	Lakes	Year	August samples	October samples
Field pH	LAK006, LAK012, LAK023	2015	2	4
		2016	3	4
		2017	2	5
		2018	3	3
	LAK028	2018	1	4
Lab pH, Gran ANC	LAK006, LAK012, LAK023	2017	2	4
		2018	3	3
	LAK028	2018	1	4

Table 7.13. T-test results for differences between August and October for field pH.

site	year	pval	lwr	upp
Lak006	2015	0.322	-0.57	0.935
Lak012	2015	0.012	-0.026	0.796
Lak023	2015	0.782	-1.066	1.186
Lak006	2016	0.036	-0.117	0.656
Lak012	2016	0.74	-0.746	0.671
Lak023	2016	0.638	-0.226	0.288
Lak006	2017	0.106	-1.041	1.641
Lak012	2017	0.811	-1.346	1.274
Lak023	2017	0.658	-1.26	1.424
Lak006	2018	0.348	-0.477	0.75
Lak012	2018	0.072	-1.195	0.502
Lak023	2018	0.241	-0.291	0.498

Table 7.14. T-test results for differences between August and October for lab pH.

year	lake	pval	lwr	upp
2017	Lak006	0.0395	-0.116	0.536
2018	Lak006	0.263	-0.209	0.337
2017	Lak012	0.572	-2.118	2.408
2018	Lak012	0.052	-0.985	0.342
2017	Lak023	0.179	-0.648	0.448
2018	Lak023	0.389	-0.51	0.338
2018	Lak028	0.0381	-0.496	0.121

Table 7.15. T-test results for differences between August and October for Gran ANC.

site	year	pval	lwr	upp
Lak006	2017	0.398	-20.076	28.056
Lak012	2017	0.245	-27.746	48.111
Lak023	2017	0.052	-22.509	6.474
Lak006	2018	0.146	-6.474	14.781
Lak012	2018	0.088	-56.734	124.854
Lak023	2018	0.066	-19.775	7.415

Figure 7.18 shows the ion composition for the six samples for LAK028 in 2018 that were collected and analyzed for full water chemistry. Figure 7.19 compares the ion composition between the August sample and the average of the four samples taken during the fall index period (i.e., Sept 30th through October). Based on qualitative, visual assessment, there does not appear to be any dominant change in ion composition between the August sample and later samples. However, we did not conduct any quantitative analyses on any of the constituent ions.

The results of both of these comparisons (i.e., the t-tests with the data from the calibration visits and the visual assessment of the ion composition for LAK028 in 2018) continue to indicate that we cannot identify a dominant difference between August and October water chemistry sampling results.

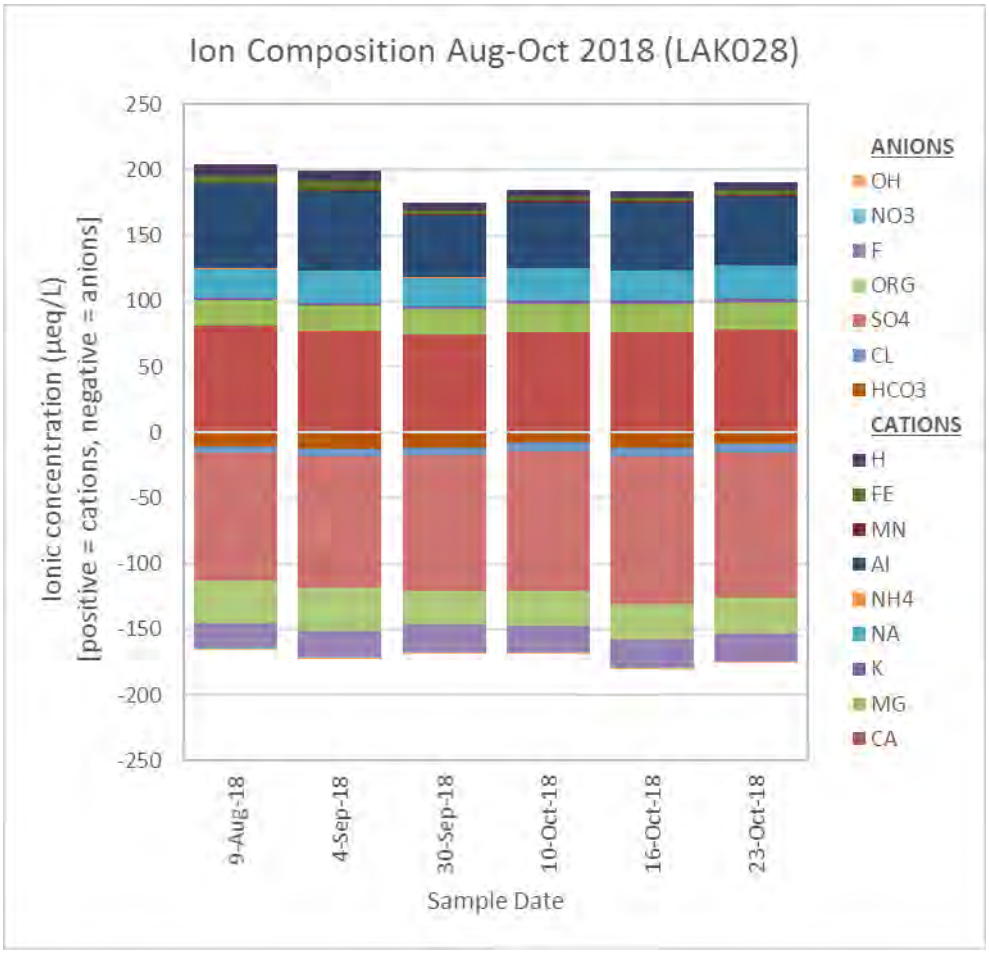


Figure 7.18. Ion composition over six water chemistry samples from LAK028 from August to October 2018. Cation concentrations are displayed as positive values and anion concentrations are displayed as negative values.

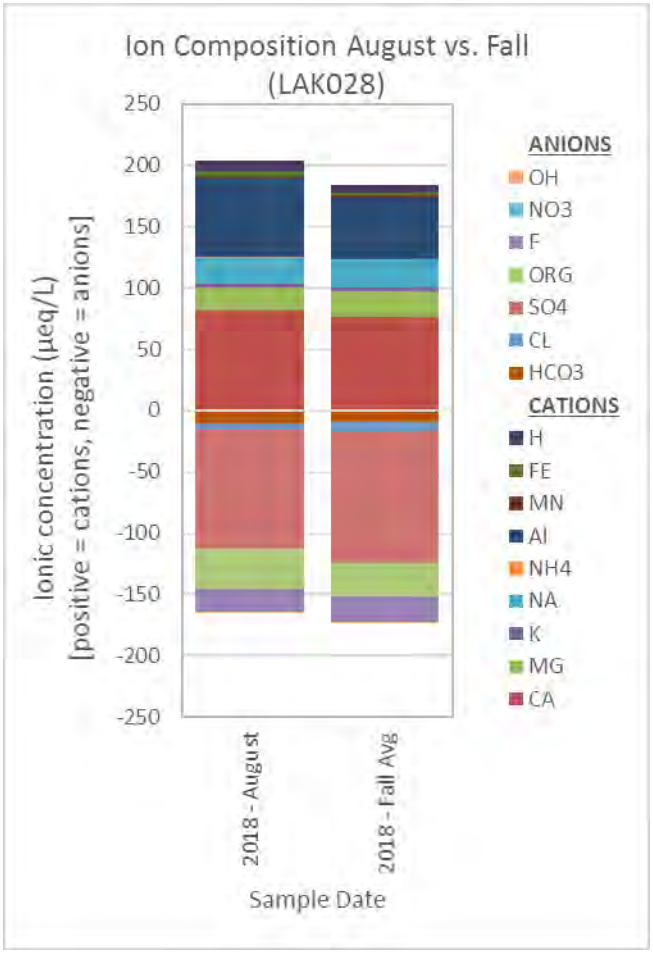


Figure 7.19. Ion composition for LAK028 for the sample taken in August 2018 (n=1) compared to the average of samples taken during the fall index period (i.e., September 30 plus 3 samples in October; n=4). Cation concentrations are displayed as positive values and anion concentrations are displayed as negative values.

Observed Changes in Water Chemistry

NOTE: The following two topics for this subsection (as per the Terms of Reference) are addressed in Section 7.1.3.1.2 and Appendix F:

- *"Observed Changes and Variability"*
- *"Observed Changes Relative to KPI Thresholds"*

The following subsections are addition sub-topics not explicitly included in the Terms of Reference that still fall under this topic.

Relative Changes in Base Cations versus SO_4^{2-}

We compared the changes in base cations versus changes in sulphate for all of the lakes to understand whether changes in base cations tracked changes in sulphate. For lakes with a non-zero F-factors, we would expect to see increases base cations that are correlated (but proportionally smaller, depending on the value of the F-factor) with increases in sulphate. The results are shown below only for LAK028 because it has shown the largest changes in base

cations and sulphate, having increased substantially in both. shows that For LAK028, changes in base cations have tracked changes in sulphate as expected (Figure 7.20) and there is a strong relationship between the two metrics (Figure 7.21). The empirical relationship between base cations and sulphates could theoretically provide another estimate of the F-factor, by using the slope of the regression. For LAK028, the changes in base cations and sulphate appear to have been sufficiently large to produce a seemingly valid estimate of the F-factor (i.e., a positive slope, strong fit). However, this was not the case for any of the other lakes. Seven of the lakes did not even have positive slopes, potentially indicating that for lakes with small changes in sulphate, the magnitude of natural variability in lake chemistry greatly exceeds the magnitude of this pattern.

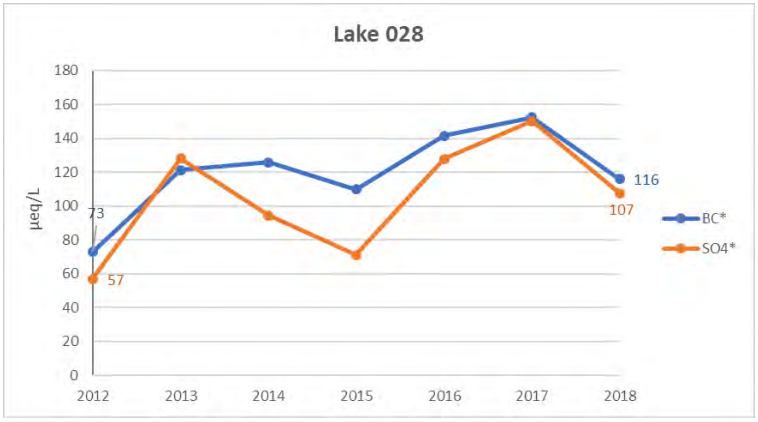


Figure 7.20. Average sulphate and total base cation concentrations over time, 2012-2018.

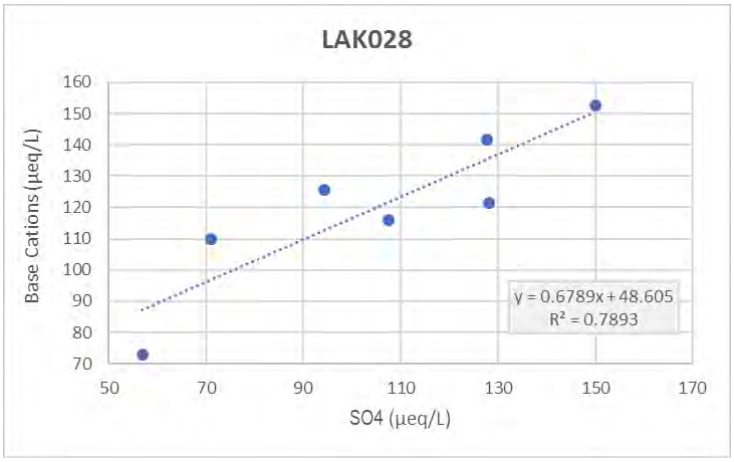


Figure 7.21. Total base cation concentration versus sulphate concentration (average values for each year). The slope of the trend line could be used as an estimate of the F-factor (i.e., how much of an increase in total base cations is, on average, associated with a given increase in sulphate.

Changes in Ion Composition Over Time

We have included figures presenting the change in anion composition on an annual basis in Appendix E and an example of the changes in the full suite of measured anions and cations

composition for LAK028 below (Figure 7.22). These figures are included in these Appendices for exploratory purposes only but are not analyzed or interpreted in detail.

Based on visual inspection, Figure 7.22 indicates that there can be significant variation in the total ionic strength of an individual lake between years and that the variability in ionic composition and strength can sometimes be greater within a single year than across multiple years.

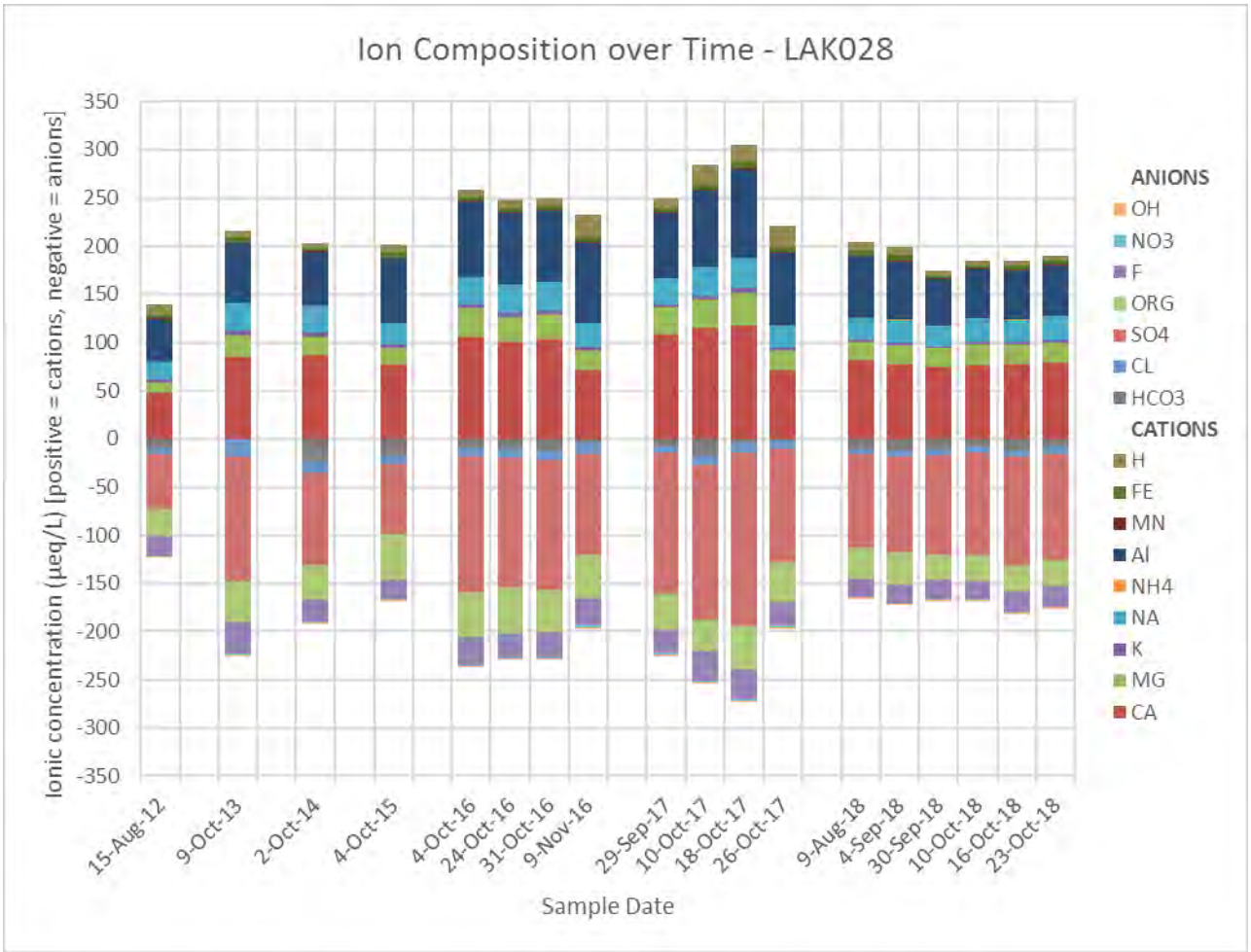


Figure 7.22. Changes in ion composition over time for LAK028. All of the sample events with full water chemistry analyses are shown. Samples from the same year are grouped together.

Magnitude of Changes in Nitrate

In the STAR, nitrate was excluded from analyses of potential acidification as it was assumed to represent a negligible contribution. To validate this assumption, we explored the magnitude of changes in NO_3 relative to changes in SO_4 (Figure 7.23, Figure 7.24), which confirmed that the changes in NO_3 have been negligible.

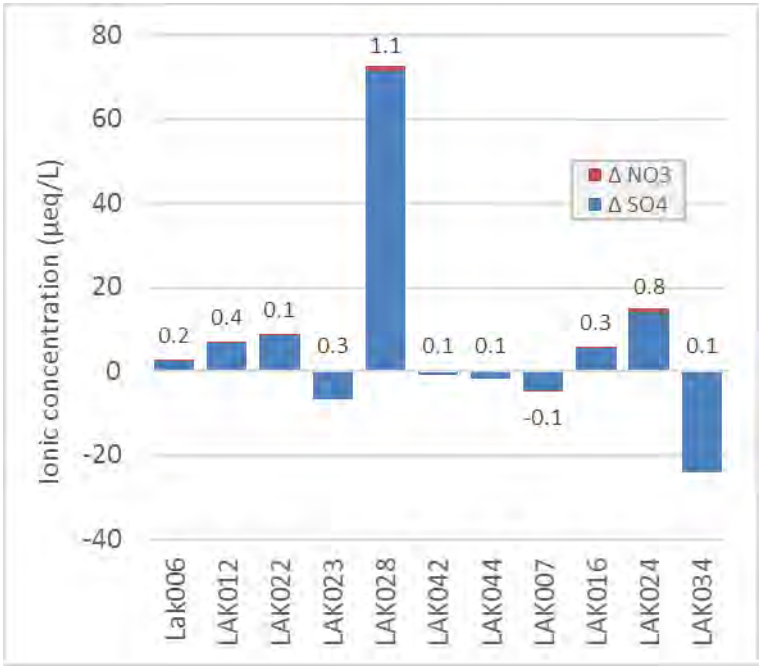


Figure 7.23. Changes in SO_4 and NO_3 from baseline (2012) to post-KMP (2016-2018). The blue bars show ΔSO_4 and the labels display ΔNO_3 because the red bars are barely visible.

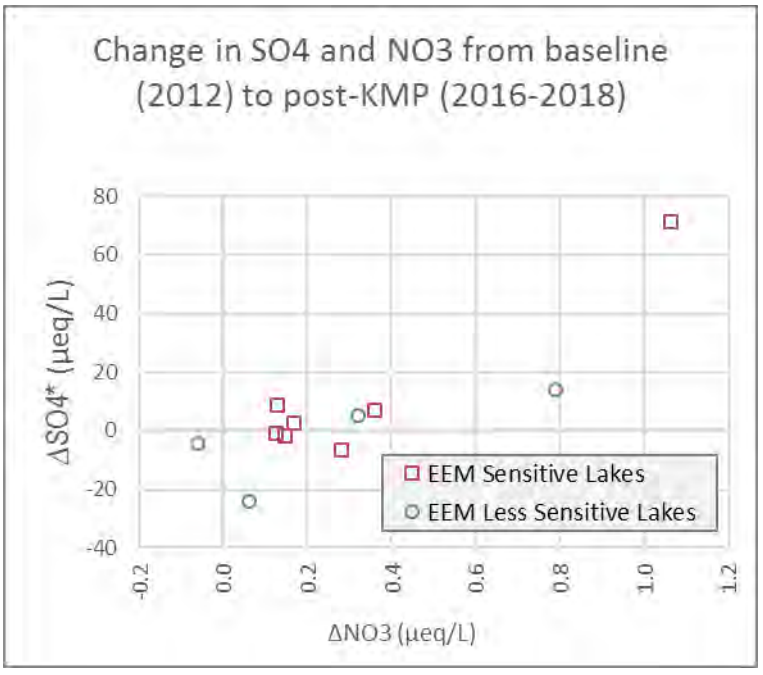


Figure 7.24. Changes in SO_4 relative to changes in NO_3 for the EEM lakes, from 2012 to the post-KMP period (2016-2018).

Statistical Analyses of Trends and Temporal Patterns

NOTE: The following two topics from the Terms of Reference for this section are addressed in depth in Appendix F (Statistical Analyses of Water Chemistry Data)

- *"Statistical Analyses of Trends and Temporal Patterns"*
- *"Statistical Evaluation of Observed Changes Relative to KPI Thresholds"*

7.1.3.2.4 Observed changes in water chemistry relative to STAR predictions

Observed Changes vs. Unadjusted STAR Predictions

The first six columns of Table 7.16 compare predictions from the modified ESSA-DFO model with observed changes. In general, all of the 7 sensitive lakes were predicted to show decreases in both ANC and pH, but none of them have. The main pattern that stands out is much less of a deposition effect (i.e., increased [SO_4^{2-}], decreased ANC and pH) than predicted in the sensitive lakes except that LAK028 had an observed increase in lake [SO_4^{2-}] which was 3.5 times that predicted (pink cell in Table 7.16) but with no decrease in ANC and pH. LAK023 (West Lake) is notable in that [SO_4^{2-}] has declined by 6.7 µeq/l over 2012-2018.

In the rightmost two columns of Table 7.16, we compare the SSWC prediction for critical load exceedances with observed changes in ANC over 2012-18. In the STAR we predicted that under 42 tpd of SO_2 emissions, five of the seven sensitive lakes would receive deposition in exceedance of their CL (LAK006, LAK023, LAK28, LAK042, LAK044, yellow shaded cells in Table 7.16). Of these 5 lakes, none of them showed a decline in ANC. Therefore, all five sensitive lakes showed less of a deposition effect than predicted (and hence are coloured green in Table 7.16). LAK007, an alkaline lake with an ANC > 1350 µeq/l (ESSA 2018b, Tech Memo W07) showed a 3.6% decrease in ANC, but no change in pH (remained constant at 8.0); this ANC change is of no concern.

Table 7.16. Predicted changes in lake chemistry in STAR vs. observed changes from 2012-2018. Green cells and red cells indicate observations less than or greater than, respectively, the predicted deposition effect. SO_4^* is the marine-adjusted sulphate concentration.

Predicted Changes in STAR vs Observed Changes (2012 to 2016-18)

	Predictions from Modified ESSA-DFO model						SSWC model	
	Δ[SO4*]		ΔANC		ΔpH			
	Predicted in STAR	Observed 2012 to 16-18 µeq/l	Predicted in STAR	Observed 2012 to 16-18 µeq/l	Predicted in STAR	Observed 2012 to 16-18	Predicted Critical Load Exceedance meq/m²/yr	Observed ΔANC 2012 to 16-18 µeq/l
Sensitive Lakes								
LAK006	24.8	2.5	-19.6	2.0	-0.5	0.2	14.3	2.0
LAK012	25.1	6.8	-15.2	1.3	-0.1	0.5	-37.5	1.3
LAK022	26.4	8.6	-18.1	5.1	-0.4	0.1	-12.3	5.1
LAK023	22.8	-6.7	-17.6	6.7	-0.5	0.2	9.1	6.7
LAK028	21.2	71.5	-11.8	0.5	-0.4	0.0	49.8	0.5
LAK042	15.0	-0.8	-13.2	26.1	-0.2	0.5	0.2	26.1
LAK044	14.9	-1.9	-14.3	3.7	-0.5	0.2	16.7	3.7
Less Sensitive Lakes								
LAK007	19.3	-4.4	0.0	-51.6	0.0	0.0	-1358.4	-51.6
LAK016	24.6	5.4	-10.8	21.1	-0.1	0.3	-71.0	21.1
LAK024	10.1	14.1	0.0	163.7	0.0	0.4	-347.6	163.7
LAK034	14.9	-24.0	-6.7	40.2	0.0	-0.3	-105.5	40.2

Observed Changes vs. STAR Predictions Adjusted using Method A

With Method A assumptions, LAK028 now shows a 23-fold greater increase in [SO_4^{2-}] than predicted (i.e., 71.5 µeq/l / 3.6 µeq/l; Table 7.17). LAK024 (Lakelse Lake) also shows a greater observed change in [SO_4^{2-}] than would be predicted. However, emissions in 2012 were less than in 2006, 2008 and 2009, so Method A underestimates the actual change in deposition since 2012. Method B (below) is a more accurate approach to testing the predictions of the ESSA-DFO model.

Predictions of exceedance in the SSWC model are driven just by the difference between long term deposition and the critical load, not by the change in deposition. So Method A is defensible for application of SSWC. As shown on the right side of Table 7.17, under Method A, only three lakes show an exceedance of their critical load (LAK006, LAK028, and LAK044). However, none of these lakes have shown a decrease in ANC over 2012-2018.

Table 7.17. Predicted changes in lake chemistry vs. observed changes from 2012 to 2018, assuming that sulphate deposition is 70% of what was modelled in the STAR, and using STAR estimate of pre-KMP deposition from 2006, 2008 and 2009 (Method A, as described in Section 7.1.3.2.4). SO_4^* is the marine-adjusted sulphate concentration.

Predicted Changes with 29.4 tpd emissions (avg of 2016-2018) vs Observed Changes (2012 to 2016-2018)

	Predictions from Modified ESSA-DFO model						SSWC model	
	Δ[SO4*]		ΔANC		ΔpH			
	Predicted w 29.4 tpd	Observed 2012-18 µeq/l	Predicted w 29.4 tpd	Observed 2012-18 µeq/l	Predicted w 29.4 tpd	Observed 2012-18	Predicted CL Exceedance meq/m²/yr	Observed ΔANC 2012-18 µeq/l
Sensitive Lakes								
LAK006	10.3	2.5	-8.1	2.0	-0.2	0.2	1.5	2.0
LAK012	10.6	6.8	-6.4	1.3	-0.1	0.5	-50.0	1.3
LAK022	11.5	8.6	-7.8	5.1	-0.1	0.1	-24.7	5.1
LAK023	9.2	-6.7	-7.1	6.7	-0.2	0.2	-3.1	6.7
LAK028	3.1	71.5	-1.7	0.5	-0.1	0.0	20.8	0.5
LAK042	7.1	-0.8	-6.3	26.1	-0.1	0.5	-4.5	26.1
LAK044	7.1	-1.9	-6.9	3.7	-0.3	0.2	11.7	3.7
Less Sensitive Lakes								
LAK007	8.4	-4.4	0.0	-51.6	0.0	0.0	-1368.8	-51.6
LAK016	10.0	5.4	-4.4	21.1	0.0	0.3	-84.3	21.1
LAK024	4.6	14.1	0.0	163.7	0.0	0.4	-354.2	163.7
LAK034	7.2	-24.0	-3.2	40.2	0.0	-0.3	-111.1	40.2

Observed Changes vs. STAR Predictions Adjusted using Method B

Using Method B, which we think is the most accurate approach for making adjustments to the predictions of the modified ESSA-DFO model, the observed changes in $[SO_4^{2-}]$ in LAK028 are now 5.4 times what was predicted (Table 7.18). Predicted decreases in ANC and pH are now of a greater magnitude than those under Method A. LAK024 still has a greater observed change in $[SO_4^{2-}]$ than predicted.

It was not necessary to run the SSWC model for Method B. SSWC only depends on the ultimate long term deposition level, which was simulated under Method A.

Table 7.18. Predicted changes in lake chemistry assuming that the change in deposition is 62.1% of what was modelled in the STAR vs. observed changes from 2012 to 2018. (Method B, as described in Section 7.1.3.2.4). SO_4^* is the marine-adjusted sulphate concentration.

Predicted Changes with 0.621 of STAR deposition vs Observed Changes (2012 to 2016-2018)

	Predictions from Modified ESSA-DFO model					
	Δ[SO4*]		ΔANC		ΔpH	
	Predicted with 0.621 * STAR depn	Observed 2012 to 16-18 µeq/l	Predicted with 0.621 * STAR depn	Observed 2012 to 16-18 µeq/l	Predicted with 0.621 * STAR depn	Observed 2012 to 16-18
Sensitive Lakes						
LAK006	15.4	2.5	-12.2	2.0	-0.2	0.2
LAK012	15.6	6.8	-9.4	1.3	-0.1	0.5
LAK022	16.4	8.6	-11.2	5.1	-0.2	0.1
LAK023	14.2	-6.7	-10.9	6.7	-0.3	0.2
LAK028	13.2	71.5	-7.3	0.5	-0.3	0.0
LAK042	9.3	-0.8	-8.2	26.1	-0.1	0.5
LAK044	9.2	-1.9	-8.9	3.7	-0.4	0.2
Less Sensitive Lakes						
LAK007	12.0	-4.4	0.0	-51.6	0.0	0.0
LAK016	15.3	5.4	-6.7	21.1	0.0	0.3
LAK024	6.2	14.1	0.0	163.7	0.0	0.4
LAK034	9.2	-24.0	-4.2	40.2	0.0	-0.3

These results suggest that the STAR modelling predictions were generally conservative since the they have almost exclusively predicted changes of greater magnitude than have been observed. The one notable exception is the result for SO_4 at LAK028 that suggests that deposition levels close to the smelter (LAK028 is by the far the closest to the smelter and all of the other lakes are much further north) have been much higher than the model estimates of deposition from the STAR.

7.1.3.2.5 Critical loads, exceedances and predicted changes in pH

The modeling, analyses and sensitivity analyses associated with critical loads, exceedances and predicted change in pH are documented in Appendix G.

7.1.3.2.6 Application of the Evidentiary Framework

NOTE: The application of the evidentiary framework is described and discussed in the chapter of the main report.

7.1.3.2.7 Episodic acidification studies

Continuous pH monitoring

The data collected from the continuous pH monitors has been judged to be insufficient quality to use for the intended studies of acidifications, episodic events, and temporal trends in pH (Limnotek, 2019)).

Limnotek (2019) make the following recommendations with respect to instrument effects on pH measurement (quoted direction from Section 4.2 in Limnotek, 2019):

Recommendation 1: *Develop a curve showing time to stabilization of pH to determine the minimum time needed for a stable pH to be attained. Observations in 2018 and in earlier years showed that if a measurement was occurring after calibration in buffer solutions that have high conductivity, a stable reading was attained after a longer period than if a reading occurred following a measurement in a solution having a similar conductance to the sample being tested. This observation suggests the test of time effects on stabilization of a pH reading should be stratified according to conductivity of a previously measured solution (calibration buffer or sample) to which the sensor was exposed. Those strata are: (1) buffer solution during calibration (buffers have high conductance), (2) lower conductance water compared to the sample being tested, (3) higher conductance water compared to the sample being tested.*

Recommendation 2: *It is recommended that time course pH measured by the Mantas in a moored setting (autonomous recording of pH while moored in a lake or stream) not be used to interpret temporal variation in actual pH of the EEM lakes or streams for three reasons:*

1. *Insufficient time allowed in factory settings on the instruments for electrode stabilization between measurements that can lead to erroneous pH data,*
2. *Evidence of pH drift by up to 0.5 pH units between dates of calibration that can lead to erroneous data, and*
3. *Absence of features that prevent bio-fouling that may interfere with ion exchange at the glass bulb electrode and produce erroneous pH readings.*

Recommendation 3: *It is recommended that instantaneous measurements following sensor stabilization defined in Recommendation 1 be used for analyses of temporal and spatial variation in pH among the EEM Lakes and streams. Data from the Manta moorings should not be used for this purpose for reasons given in Recommendation 2. Of the instruments and labs used in the EEM program to date, data from WTW field pH meter and the lab at Trent University meet the requirement of adequate time for sensor stabilization in addition to standard sample handling and calibration protocols. This attention to how the pH is measured provides confidence in the resulting data.*

Recommendation 4: *Given that Manta instruments designed for a moored application have been purchased for the EEM program, it is recommended that options be explored with the manufacturer to change the factory set stabilization period from 5 seconds to at least 10 minutes. The Mantas should then be tested to examine pH drift and variability against other instruments (e.g. WTW and Trent Lab) to determine future suitability for providing pH data in a moored application.*

Recommendation 5: *If the Mantas are used in 2019, the glass bulb electrodes on all instruments that have been used in End Lake, Little End Lake, West Lake, and LAK028 require replacement in 2019 because they will be in their final year of effective life. This recommendation follows advice from the manufacturer that electrodes be replaced every 5 years.*

> ***Recommendation 6:*** *Regardless of what instrument or lab is used for pH measurement, field technicians must ensure there is no air space in sample bottles to ensure minimal drift of pH in sample bottles caused by gas exchange at the water – air interface, samples are kept cool, and pH measurement occurs as soon as possible after collection.*

Independent research project
The results from Dr. Weidman's research are not yet available for review.

7.1.3.2.8 Kitimat River water quality

The results of the water quality sampling at the Rio Tinto intake on the Kitimat River are shown in Appendix H. None of the results showed exceedances of the BC water quality objectives. The maximum measured sulphate concentration was less than 1% of the BC Drinking Water Guideline.

7.1.3.2.9 Results from previously reported analyses

As discussed in Section 7.1.2.8, other sampling and analyses have been conducted during the EEM program beyond the core water chemistry sampling. Those additional elements of the Program have been previously reported in Annual Reports and their appendices, and other technical memos. This section only summarizes some of the key results.

Fish sampling
Fish presence/absence surveys were conducted in in some of the sensitive lakes (LAK006, LAK012, LAK023, LAK044, LAK028) and some of the less sensitive lakes (LAK007, LAK016, LAK034) during the monitoring campaigns of 2013, 2015 and 2017. Each of the lakes was sampled once. Key findings include:

a) The 2013 fish survey in four acid-sensitive lakes (i.e., LAK023, LAK006, LAK012 and LAK044) found no fish in LAK044 (which has no inlets or outlets). Three-spine stickleback (*Gasterosteus aculeatus*) was present in three of the lakes (i.e., LAK023, LAK006 and LAK012). Lakes LAK006 and LAK012 had also coastal cutthroat trout (*Oncorhynchus clarkii*), coho salmon (*Oncorhynchus kisutch*) and dolly varden char (*Salvelinus malma*). LAK023 had residualized coho (discussed under point "c" below) as confirmed by DNA analysis of the fish tissue.

b) The 2015 survey of the three less sensitive lakes found coastal cutthroat trout to be common in all three lakes. Both LAK007 and LAK016 also had coastal coho salmon and dolly varden char. LAK034 only had coastal cutthroat trout and threespine stickleback.

c) Both LAK023 (sampled in 2013) and LAK016 (sampled in 2015) had mature coho showing freshwater residualism (i.e., remaining in freshwater for all of their life history rather than migrating to the sea), apparently due to ephemeral outlets which leave adults trapped in the lake (Parkinson et al. 2016).

d) The 2017 survey of LAK028 found no fish, due to physical features of the channel which prevent upstream fish migration.

e) Given small fish populations in small lakes, future gill netting presents a risk of depleting the fish population in one or more lakes due to mortalities caused by gill netting (C. Perrin, pers. comm.). Discretion will be needed in cooperation with ENV on deciding whether fish sampling using gill netting is needed in future cases, or whether other less intrusive methods of sampling (e.g., eDNA) could be used.

Additional details are documented and discussed in the relevant technical reports from Limnotek – i.e., Perrin et al. 2013, Limnotek 2016, Bennett and Perrin 2018.

Regional amphibians and potential risks of aquatic acidification

Based on the literature review conducted in 2017, we identified that at least 7 amphibian species occur within the overall study area. Six of these species require aquatic breeding habitats in low-lying areas; i.e, within the isopleth of 10 kg/ha/yr. Two of the seven species identified (Coastal Tailed Frog – *Ascaphus truei* – and Western Toad – *Anaxyrus boreas*) are listed as 'Special Concern' federally.

The observation data collected indicate that 6 of the amphibian species have been observed within the zone of highest deposition close to the smelter, indicating tolerance to historic and current levels of deposition and their effects on soils and aquatic environments.

Two critical knowledge gaps remain:

1. Acid sensitivity of the smaller ponds (< 1 ha) and wetlands occupied by amphibians in the Kitimat area is unknown. Smaller bodies of water are expected to have a wider range of acid sensitivity than larger lakes (i.e., both more acid sensitive and less acid sensitive).
2. Sensitivity of local amphibians to acidification is partially known. Literature available only for the two observed species: Wood Frog and Western Toad. It is not possible to confidently extrapolate acid-sensitivity from studies of species with similar life histories and habitats to the seven species or populations found in the Kitimat Valley.

Lake level monitoring

Water level was measured in 2018 using sensors and data loggers in the acid-sensitive lakes called LAK006, LAK012, LAK023 in May through October, and in acid-sensitive LAK028 during September and October. Observations of surface water level (in cm) were registered every 30 minutes and mean daily values were derived from these data.

It was observed in both 2017 and 2018 that water surface elevation declined over the summer in all lakes and increased in October corresponding with increasing rainfall during the autumn. The timing of change in water surface elevation was similar among the four lakes (Figure 7.25). Magnitude and rate of change differed because of differences in drainage area, lake morphometry, and other hydrological attributes.

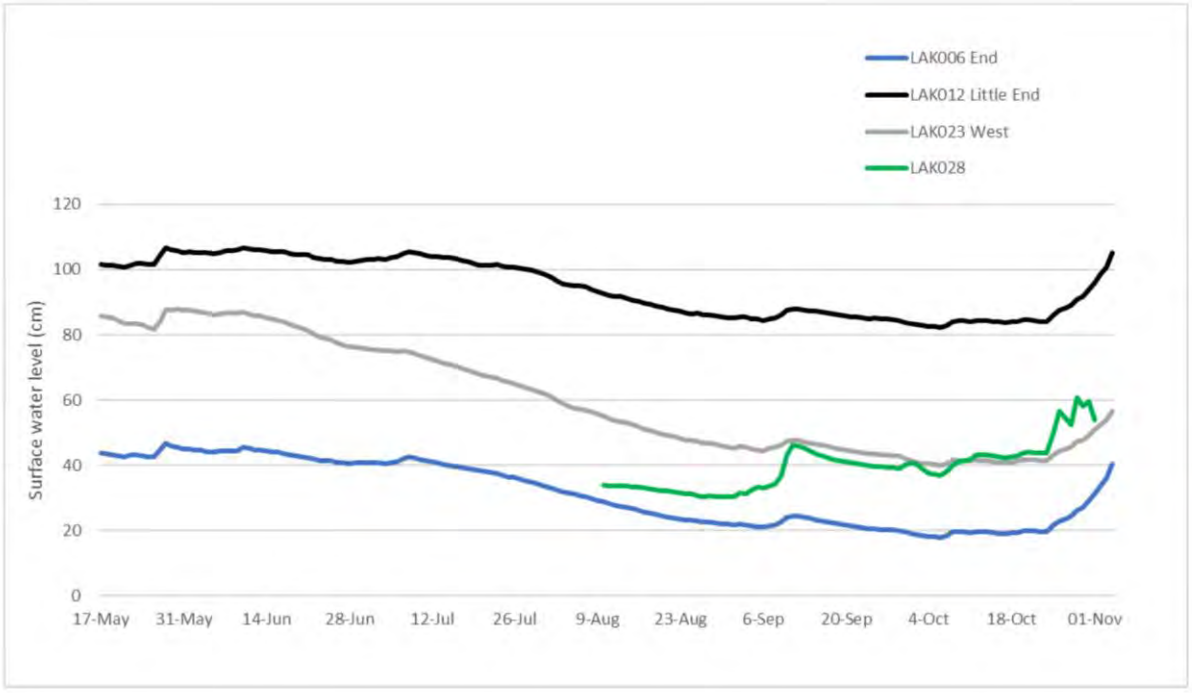


Figure 7.25. Mean daily surface water levels as measured in 2018 in End Lake (LAK006), Little End Lake (LAK012), West Lake (LAK023) and LAK028. Note that water level is relative to a benchmark at each lake and not to a common benchmark (Source: Limnotek 2019).

Bathymetric analyses

Bathymetric surveys were conducted for LAK006, LAK012 and LAK023 in 2015, and then for LAK028 in 2018. The purpose of the surveys were to assist with interpretation of lake biogeochemistry by improving the calculation of lake water residence time.

As an example of this work, Figure 7.26 shows the bathymetric map of LAK028, colour-coded by depth interval. At full pool, the volume of LAK028 is 105,840 m^3 with an error of ±4.0% (details in Limnotek 2019). Volume calculations showed that lake volume declines linearly with elevation over the top 1m of water depth.

Full details on collection and analysis of the bathymetry data are reported in specific technical memos associated with the work.

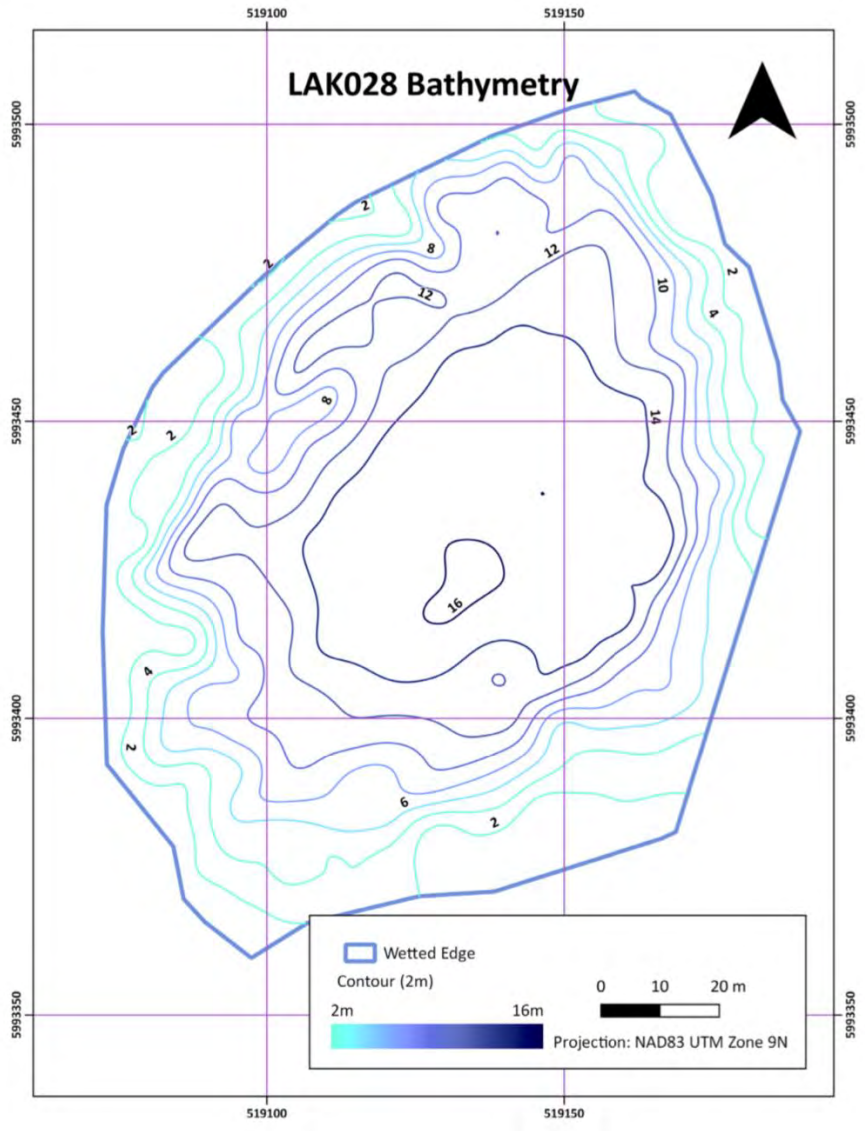


Figure 7.26. Bathymetric map of LAK028 (Source: Limnotek 2019).

Water residence time for lakes

Table 7.19 shows the estimated water residence time for each of the seven EEM sensitive lakes. Initial estimates were presented in Table 25 of the EEM Plan but these estimates have been improved by additional data on lake depths, a revision to the calculation used in the EEM Plan, and/or more precise estimates of lake volume from bathymetric analyses conducted as part of the EEM Program. The results show that five of the seven EEM sensitive lakes have estimated water residence times of less than one year. LAK006 has an estimated residence time of 1.4 years and LAK044 has an estimated residence time of 2.1 years. Overall this indicates that for all of the sensitive lakes, lake chemistry properties would be expected to respond to changes in deposition and/or other changes in the watershed within essentially 1-2 years.

Table 7.19. Estimates of water residence time for the EEM sensitive lakes. The estimates from the EEM Plan (Table 25) are shown, versions of those estimates based on additional depth information and revised calculation, and the results from the bathymetric analyses of lake volume for four of the lakes. The orange cells indicate the best available estimate of water residence time for each lake.

				Initial Estimate from 2012 Data (Table 25 in EEM Plan)			Revised Estimates			Bathymetric Analysis	
Lake	Lake Area (ha)	Watershed Area (ha)	Runoff (m)	Depth at sampling point (m)	Estimated Midrange Lake Volume (m^3)[1]	Estimated Midrange Residence Time (yr)	Depth at sampling point (m)[2]	Estimated Lake Volume (m^3)[3]	Estimated Water Residence Time (yr)	Lake Volume (m^3)	Calculated Water Residence Time (yr)
LAK006	10.25	91.2	0.88	5.7	584,232	0.7	20.1	1,029,613	1.3	1,129,350	1.4
LAK012	2.30	90.1	0.86	3.5	80,538	0.1	6.7	76,820	0.1	94,455	0.1
LAK022	5.74	39.9	0.83	10.1	580,128	1.7	7.6	218,120	0.7		
LAK023	6.77	40.3	0.90	2.7	182,857	0.5	8.5	288,741	0.8	185,064	0.5
LAK028	1.02	11.9	1.58	15.5	158,726	0.8	15.2	77,520	0.4	105,840	0.6
LAK042	1.46	37.2	0.60	12.0	175,186	0.8	13.5	98,842	0.4		
LAK044	2.01	9.9	0.64	15.0	300,832	4.8	13.4	134,871	2.1		

[1] Lake volume estimated as [lake area] * [mean depth], where mean depth is assumed to be depth at the sampling point
[2] Average depth at sampling point across all samples taken from 2012 to 2018
[3] Lake volume estimated as [lake area] * [mean depth], where mean depth is assumed to be *half* of the depth at the sampling point

Depth profile, water column chemistry, and deep water sampling for LAK028

The 2017 water column sampling from LAK028 strongly suggested the presence of meromixis (i.e., surface and bottom waters do not mix), which was also implied by the small surface area relative to lake depth. The results of the water column sampling (see Bennett and Perrin 2018) show that thermal and chemical conditions change significantly at depths >9 m.

The surface mixed layer (<9 m) had water temperature typical of north coast lakes in the fall, high dissolved oxygen that could support fish, conductivity and inorganic nitrogen concentrations typical of nutrient deficient lakes, and a surface pH (~ 5) at the low end of tolerances for aquatic organisms. The bottom water layer was anoxic and would not support fish, with higher pH, higher conductivity, a warming thermocline, an odour of H_2S, and other evidence of sulphur-reducing green and/or purple bacteria.

In 2018, the deep water sampling of LAK028 confirmed earlier observations of stable chemical stratification, consistent with meromixis. Mean sulphate concentrations were 5.0 mg·L-1 in the epilimnion (surface layer), 4.1 mg·L-1 in the chemocline (transition layer), and close to nil in the hypolimnion, which showed high availability of sulphate and presence of oxygen at the surface and reduction to sulphide, given the sample odor, in the bottom waters.

Limnotek (2019) concluded:

> *The surface mixed layer contained oxygen which favoured sulphate compared to sulphides that were present in the bottom mixed layer. Due to the chemically reduced environment, fish are not be expected to survive in the bottom mixed layer. The reducing conditions also favour release of solutes from the sediments and potential growth of cyanobacteria or purple sulphur bacteria in the bottom mixed layer.*

Non-EEM sites

Table 7.20 provides a summary of the "non-EEM" sites sampled during the course of the EEM Program to date and the associated recommendations. Additional details and sample data are reported in the annual reports and technical memos associated with each year of the program.

Lakes MOE3 and MOE6 were sampled in 2013 and 2014, respectively. MOE expressed concern that lakes MOE3 and MOE6 could potentially be sensitive to increased emissions and thus requested that they should be sampled. It was determined that neither lake is sensitive to the predicted increases in acidic deposition (based on MOE3 having a very high critical load, and MOE6 having high base cations and high Gran ANC[13]). The final recommendation was not to add these lakes to the EEM Program. Similarly, Cecil Creek was sampled at three sites in 2013 because it receives drainage from one the EEM lakes (i.e., LAK023 or West Lake). The sampling data showed that Cecil Creek also has a high critical load and therefore it was not added to the EEM Program for further monitoring.

[13] A critical load was not calculated for MOE6 because it was sampled only in 2014. Critical loads were calculated for the one-off additional locations sampled in 2013 (i.e., MOE3 and Cecil Creek) but not for those sampled in 2014. The calculation of critical loads requires modeled deposition that is relevant to the year of sampling (for the modeled estimate of pre-industrial SO_4^{2-} and by 2014, we concluded that the emissions had changed to significantly from the "pre-KMP" conditions for which deposition had been modeled. Even in 2013, when critical loads were re-estimated for the EEM lakes (to compare the effect of changing the sampling season), emissions had already decreased from 2012, but it was decided that critical loads should not be calculated again with the 2014 sampling data.. The high Gran ANC and high base cations indicate that the estimated critical load for MOE6 would be high. As part of the SSWC modeling in the present work, a critical load was estimated for MOE6 (despite the flaws previously identified) in order to be able to use MOE6 in the full data set of all the lakes. The estimated critical load is very high (>400 meq/m^2/yr).

Goose Creek constitutes a network of streams draining the acid-sensitive lake LAK028. A reconnaissance of water chemistry of these streams started in 2013 following a request by MOE to obtain water quality information to assist with understanding conditions of cutthroat trout (*Oncorhynchus clarkii*) spawning habitat in lower Goose Creek. Multiple sites within the drainage were sampled in 2014 and 2015. This initial assessment concluded that the Goose Creek drainage is not sensitive to acidic deposition and should not be added as a regular component of the EEM Program. In 2018, several of these sites were resampled and additional samples were collected from a region of the watershed that had not been previously sampled. These new data did not change the original conclusion.

In 2014, a continuous pH monitor was established Anderson Creek as a Rio Tinto voluntary initiative. The results of the STAR showed that Anderson Creek has a high critical load and was predicted to have no change in pH with increased deposition. However, Rio Tinto decided to install the monitor as a source of additional information because of the proximity of the stream to the smelter (immediately north). Monitoring was continued through 2018, although some years had substantial technical difficulties with the instrument (as described in annual reports). Each year, the recommendation was to continue monitoring. However, the recommendation presently is to discontinue monitoring at this location because it is not providing information that is critical to the EEM Program.

7.1.3.3 Modifications to the EEM Program

The following subsections describe modifications that *have occurred* during the first six years of the EEM program (i.e., not prospective proposals).

7.1.3.3.1 Adjustments to sampling program

Adjustments to the sampling program

- After not being included in the initial EEM design for 2013 (due to its high ANC and lack of sensitivity to acidification), LAK024 (Lakelse Lake) was added into the Program in 2014 because of its high public value.
- Three control lakes were added to the program in 2015 to provide the ability to discriminate smelter effects from general regional patterns of change in water chemistry caused by environmental variability.
- Additional intra-annual sampling was added to 3 sensitive lakes in 2014 and 3 more sensitive lakes in 2016, to provide higher statistical power to detect changes.
- Continuous pH monitors were added to 3 sensitive lakes in 2014 and 1 additional lake in 2018 to assess the seasonal and diurnal variability in pH.
- Water level monitoring was added to the lakes with continuous pH monitors to detect when storm events occurred that might affect chemical conditions.
- Bathymetric data was collected and analyzed for 4 lakes in order to develop accurate estimates of lake volume for better estimates of residence time, and therefore how long it will take lake chemistry to respond to changes in emissions.
- A depth profile was developed for LAK028, plus additional sampling of the chemistry at depth, to explore the location and potential effects of hypolimnetic sulphate reduction.

Modification of methods

- Applied the improved methodology for defining watershed area that was applied in the KAA
- When the additional within-season sampling was first added (2014), the inter-annual changes in water chemistry were calculated using only the sample taken on the "annual sampling" day and the other samples were used to explore variability separate from the reporting of inter-annual change. We moved to reporting mean values and standard errors for lakes with multiple samples within the index period in the 2016 Annual Report.
- Various minor corrections to calculations and/or computational errors, as needed.
- Exploration of variable organic charge density (as explained elsewhere in this appendix).
- In 2013, the use of a commercial laboratory for additional measurement of pH from lake samples was added to the program.

Refining how we interpret the results

As explored and discussed in multiple places through the aquatic chapter and appendices, the results of the initial couple years of sampling indicated that the pH of the EEM lakes has much greater natural variability (in addition to measurement uncertainty) than was understood during the development of the EEM program. This has resulted in a critical change in perspective – that pH is highly variable with low power to detect changes of the defined effect size of concern. This change in how the data are interpreted directly lead to many if not most of the changes in the sampling program described above, additional emphasis on the importance of taking a multi-metric view as defined in the evidentiary framework, as well as providing the rationale for conducting the rigorous statistical analysis of changes in water chemistry within a probabilistic framework (see Appendix F).

7.1.3.4 Comprehensive synthesis ('pulling all the pieces together')

NOTE: The content of this section exists solely in the Aquatic Ecosystems chapter of the main report.

7.1.3.5 Conclusions

NOTE: The content of this section exists solely in the Aquatic Ecosystems chapter of the main report.

7.1.4 What Do We Recommend for the EEM Program Going Forward?

7.1.4.1 Recommendations regarding EEM lakes

NOTE: The content of this section exists solely in the Aquatic Ecosystems chapter of the main report.

7.1.4.2 Recommendations regarding non-EEM lakes and stream sites

During the course of the EEM Program, water chemistry samples were also collected and analyzed at the following "non-EEM" sites to assess concerns that there were additional sites outside of the EEM lakes that could potentially be sensitive to increases in deposition. These sites included several sites in Cecil Creek, lakes MOE3 and MOE6, and multiple sites within the Goose Creek drainage. In all cases these sites have been determined to have low to very low sensitivity and our recommendations have been that further sampling is not required and they do not need to be added to the EEM Program.

Table 7.20. Summary of monitoring actions taken and recommendations for non-EEM sites through the 2013-2018 period

Year	Actions at non-EEM sites	Recommendations for non-EEM sites
2013	• Lake MOE3 was sampled • Cecil Creek receives drainage from West Lake (LAK023) and was sampled in three locations	• The non-EEM sites MOE3, MOE6 and Cecil Creek were considered insensitive to increased deposition (based on high critical loads and/or high base cations and Gran ANC) and not added to the annual EEM sampling. • Calculate critical loads for Goose Creek sites[14]
2014	• Additional sampling of non-EEM lakes and stream identified as being potentially sensitive to increased emissions, including Lake MOE6 and six sites within the Goose Creek watershed • Continuous monitoring of stream pH was initiated in Anderson Creek in the fall of 2014 for a 10-day trial period (November 19-28), and was restarted on March 31, 2015 • Critical loads and exceedances were calculated for the MOE3 and Cecil Creek in order to determine if they are sensitive to increased emissions of SO_2. For MOE6, sensitivity was assessed based on Gran ANC and the concentration of base cations[15]. • A preliminary assessment of the sensitivity of the Goose Creek sites was conducted based on the water chemistry samples collected and analyzed in 2014	
2015	• Sampling of two additional sites within the Goose Creek watershed, previously identified as being potentially sensitive to increased emissions. • A preliminary assessment of the sensitivity of the additional Goose Creek sites was conducted based on the water chemistry samples collected and analyzed in 2015. • Continuous monitoring of stream pH was continued in Anderson Creek	• The preliminary assessment of water chemistry at Goose Creek sites suggests that these sites are insensitive to potential increases in acid deposition. No further action required.
2016	• Maintained continuous pH monitoring in Anderson Creek • Terms of reference were drafted for reviewing the literature and available regional data to understand the potential risks to amphibians in the Kitimat Valley	• Continue continuous pH monitoring at Anderson Creek.

[14] Subsequent to this recommendation in the 2013/2014 Annual EEM Report, we chose not to do this work because the high values for base cations and Gran ANC indicated that these stream sites were not sensitive.

[15] As per earlier footnote, the critical load for MOE6 was estimated for the purposes of the present Comprehensive Review.

Year	Actions at non-EEM sites	Recommendations for non-EEM sites
2017	• Maintained continuous pH monitoring in Anderson Creek • Literature review on potential effects of acidification on amphibians in the Kitimat Valley was completed	• No additional changes to the lake sampling program were recommended at this time. • Continue continuous pH monitoring at Anderson Creek. • It was recommended to re-sample for water chemistry the eight tributaries of Goose Creek that were previously sampled in 2014 and 2015, in order to determine if there have been any significant changes. It was also recommended to assess the benthic community of Goose Creek and compare its composition with that of similar streams.
2018	• Water chemistry measurements were done in 7 stream sites from the Goose Creek network • Potential stream sites were ranked for bioassessment but not sampled in 2018 • Continuous monitoring of pH in Anderson Creek	• Continue continuous pH monitoring at Anderson Creek as part of the episodic acidification study sub-component.

7.2 Aquatic Appendix B: Acid neutralizing capacity (ANC) as a biological indicator of the effects of freshwater acidification

7.2.1 Definitions of ANC and related terms

Acid neutralizing capacity (ANC) is a measure of the sensitivity of surface waters to acidification. ANC can be defined in several different ways, and it is closely related to the term *alkalinity* (various definitions in Hemond 1990). *Gran ANC* has been the primary measure of ANC for all the analyses in the STAR and EEM. ANC is a measure of the capacity of a solution to neutralize strong acids and is determined by titration to the inflection point of the pH-alkalinity titration curve. **Gran ANC** includes the buffering effect of organic anions. Another commonly used metric is Charge Balance ANC or Charge Balance Alkalinity (CBANC or CBALK), hereafter referred to as **CBANC**. CBANC is generally calculated as the equivalent sum of base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) minus the equivalent sum of strong acid anions (SO_4^{2-}, NO_3-, Cl^{-}). CBANC does not take into account the buffering effect of organic anions.

In surface waters with organic anions, Gran ANC will be lower than CBANC. The relationship between Gran ANC and CBANC depends on the nature of the organic anions present in the sample. Hemond (1990) notes that for organic anions which follow the model developed by Oliver et al. (1983), CBANC = Gran ANC + 4.6 * DOC, where Gran ANC and CBANC are measured in µeq/l , DOC (Dissolved Organic Carbon) is measured in mg/l, and 4.6 is the assumed charge density of organic anions (CD = µeq of organic anions per mg of DOC). For example, using the above formula, a water sample with CBANC = 23 µeq/l and DOC = 5 mg/l (roughly the average DOC in the seven sensitive lakes included in the EEM program), would have a GranANC of 0 µeq/l. Charge densities reported in the literature are generally in the range of 4-6 µeq per mg DOC (Hemond 1990), but can range from 2 to 10 µeq per mg DOC (Table 3 in Marmorek et al. 1996). The more general formula relating CBANC and Gran ANC is: CBANC = Gran ANC + CD * DOC, where CD is the charge density.

Measurements of pH and ANC can be substantially influenced by dissolved organic carbon (DOC). In recognition of this dynamic, Base Cation Saturation (**BCS**, Lawrence et al. 2007), previously described in Europe as Organic Acid Adjusted ANC (ANC_{OAA}, Lyderson et al. 2004), was developed as an alternative measure of ANC taking into consideration that only a subset of organic anions are strongly acidic. BCS (or ANC_{OAA}) is equal to CBANC minus strongly acidic organic anions (Lawrence et al. 2007, 2013, Lyderson et al. 2004). A distinct threshold for inorganic aluminum (Al) mobilization occurs at a BCS value that closely approximates 0, regardless of the DOC (Lawrence et al. 2007). Values of BCS < 0 would indicate that acid-neutralization within the watershed is not sufficient to buffer acidic deposition without mobilization of toxic inorganic Al (Baldigo et al. 2009). Though the definitions of BCS and ANC_{OAA} are identical, the methods of calculating these metrics differ slightly among the above authors. In citing results from a given author, we use whatever metric they used. Figure 7.27 compares the three ANC metrics, assuming that BCS and ANC_{OAA} are estimated as CBANC – 1/3 * [CD * DOC].

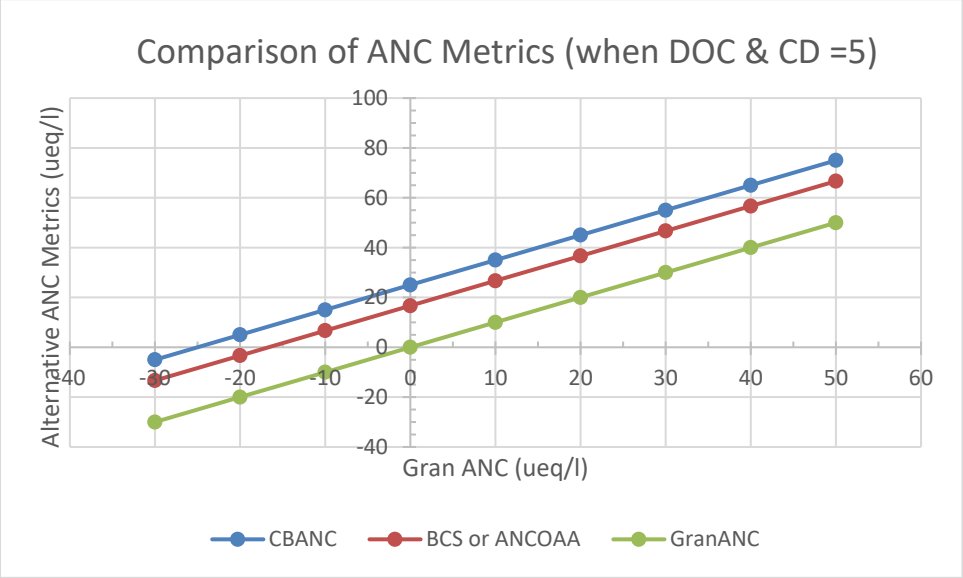


Figure 7.27. Comparison of Gran ANC, CBANC and ANC_{OAA} for a water sample with a charge density (CD) of 5 µeq per mg DOC, and a DOC level of 5 mg/L.

7.2.2 ANC and acidification of surface waters

Acidification of surface waters, accompanied by high concentrations of H+ and elevated levels of inorganic Al, impoverishes fish communities due to negative biological effects, including damage to the tissues by aluminum accumulation on fish gills (Baker et al. 1990, Section 3.5.5 of the STAR, ESSA et al. 2013).

Water bodies with Gran ANC values below 0 are considered acidic (Baker et al. 1991). Low ANC values make lakes and streams more susceptible to episodic acidification (Baron et al. 2011) following strong hydrological events (e.g., storms and snowmelt).

While pH was historically the dominant variable used to predict effects of acidification on biota, either independently or together with calcium and inorganic aluminum concentrations (Baker et al. 1990), ANC has also been extensively used as a predictive variable (Driscoll et al. 2001, Posch et al. 2007, Solheim et al. 2008). Driscoll et al. (2001) studied water chemistry in lakes in the Northeastern United States during summer (low flow) conditions, which likely represent the highest ANC values throughout the year. Lakes with ANC values below 0 µeq/l during low flow conditions are considered chronically acidic (i.e., they are likely to remain acidic throughout the year). Lakes with ANC within the 0-50 µeq/l range are considered susceptible to episodic acidification (i.e., ANC might decrease below 0 during high flow events such as storms or spring freshets). Finally, lakes with ANC values greater than 50 µeq/l are considered relatively insensitive to inputs of acidic deposition.

7.2.3 ANC values and aquatic biota in the KMP study area

In the STAR, an ANC limit of 26 µeq/L[16] was applied in the Steady State Water Chemistry model that estimated critical loads of acidity for the 41 lakes and 20 streams sampled. Eight of the 41 sampled lakes had a Gran ANC value less than the defined ANC limit of 26 µeq/L. Another 4 lakes and 1 stream had an ANC between 26 and 50 µeq/L and therefore could potentially experience acidic episodes during storm and snowmelt events (Driscoll et al. 2001). The remaining 70% of the sampled lakes and 95% of the sampled streams had an ANC >50 µeq/L and therefore are relatively insensitive to acidic deposition. The distribution of Gran ANC values across the STAR lakes and streams is shown in Figure 7.28.

In general, little is known about the aquatic biota in the lakes within the study area, except for Lakelse Lake. The Kitimat River supports runs of all five species of Pacific salmon (i.e., Chinook, Sockeye, Coho, Pink and Chum), anadromous steelhead (*Oncorhynchus mykiss*), Dolly Varden char (*Salvelinus malma*), and coastal cutthroat trout (*Oncorhynchus clarkii*); the lower 10 km of the river is a major salmon migration route (ESSA et al. 2013). Non-salmonids include coastrange sculpin (*Cottus aleuticus*), slimy sculpin (*C. cognatus*), Pacific lamprey (*Entosphenus tridentatu*), and three-spine stickleback (*Gasterosteus aculeatus*). Freshwater fish species of special conservation status, as identified on provincial red and blue lists, include cutthroat trout, bull trout, and Dolly Varden char. Eulachon were abundant historically in the Kitimat River, but began to decline in the mid-1970's and are now virtually extirpated; fishing for eulachon was halted in 1972 due to contamination from pulp mill effluent (Olson et al. 2015).

[16] Recall: The ANC limit applied in the STAR was developed by starting with a pH threshold of 6.0 pH units (as supported in the research literature as a threshold for avoiding adverse impacts on aquatic ecosystems). The threshold of 6.0 pH units was equated to a comparable ANC threshold by using a regional pH-ANC relationship fit to all the sample data. See ESSA et al., 2013.

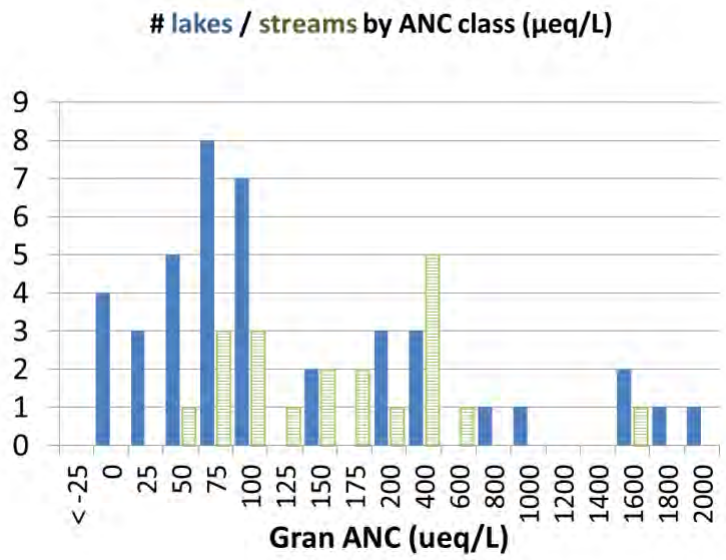


Figure 7.28: Distribution of Gran Acid Neutralizing Capacity amongst lakes (blue solid bars) and streams (green cross-hatched bars) sampled as part of the STAR program in 2012 . The number on the x-axis shows the maximum value of the ANC interval (e.g., "25" indicates waters with ANC between 0 and 25 µeq/L). Note that the ANC interval is 25 µeq/L up to 200 µeq/L, and then increases to 200 µeq/L. Source: ESSA et al. 2013

Fish sampling was conducted in 2013, 2015 and 2017 as part of the EEM program to confirm presence/absence of fish in some of the sensitive lakes (LAK006, LAK012, LAK023, LAK044, LAK028) and some of the less sensitive lakes (LAK007, LAK016, LAK034). Each of the above lakes was only sampled once; details are in Perrin et al. 2013, Limnotek 2016, Bennett and Perrin 2018. Key findings were as follows:

a) The 2013 fish survey in four acid-sensitive lakes (i.e., LAK023, LAK006, LAK012 and LAK044) found no fish in LAK044, as well as presence of stickleback in three of the lakes (i.e., LAK023, LAK006 and LAK012). Lakes LAK006 and LAK012 also had coastal cutthroat trout, coho salmon and dolly varden char. LAK023 had residualized coho (discussed under point c) below).
b) The 2015 survey of the three less sensitive lakes found coastal cutthroat trout to be common in all three lakes. Both LAK007 and LAK016 also had coastal coho salmon (*Oncorhynchus kisutch*) and dolly varden char. LAK034 only had coastal cutthroat trout and threespine stickleback (*Gasterosteus aculeatus*).
c) Both LAK023 (sampled in 2013) and LAK016 (sampled in 2015) had mature coho showing freshwater residualism (i.e., remaining in freshwater for all of their life history rather than migrating to the sea), apparently due to ephemeral outlets which leave adults trapped in the lake (Parkinson et al. 2016).
d) The 2017 survey of LAK028 found no fish, due to physical features of the channel which prevent upstream fish migration.

7.2.4 Use of ANC as indicator of impacts of acidification on aquatic biota

Fish, and other aquatic species, exhibit complex responses to changes in water chemistry and their susceptibility to acidification varies depending on their life stage and local adaptation, as well as on the duration, frequency and magnitude of exposure to acidic conditions (Kernan et al. 2010).

Multiple studies have identified ANC critical levels for specific fish species (Lien et al. 1996, Laudon et al. 2005, Kernan et al. 2010), invertebrates (Raddum and Skjelkvåle 1995) or for broader categories of aquatic biota (Wright et al. 2005, Posch et al. 2007). A CBANC threshold of 20 µeq/L has been widely used in Europe as a water quality indicator protective of most key indicator organisms (Wright et al. 2005). Most of these studies have been conducted in Northern Europe.

Setting thresholds is complicated by the nonlinear dynamics involved in the relation between water chemistry and physiological responses and by the influence of multiple factors that operate at diverse spatial and temporal scales (Groffman et al. 2006).

Most of the studies conducted on the relationships between ANC values and the biological response of aquatic biota have been conducted in Northern Europe (Lien et al. 1996, Laudon et al. 2005), especially for brown trout (*Salmo trutta*). In North America, research on chemical thresholds as indicators for the impacts of acidification on freshwater biota has focused on Eastern North America (Driscoll et al. 2001, Baldigo and Lawrence 2007, Baldigo et al. 2019), especially on fish populations and communities in parts of the Adirondack Mountains of northern New York (Baldigo and Lawrence 2001, Baldigo et al. 2009); an area with soils of low buffering capacity that was severely affected by acid rain in the late 1980s.

7.2.4.1 Generic ANC thresholds for aquatic biota

As an example of a generic ANC threshold, Posch et al. (2007), in their assessment of critical loads of acidity for alpine lakes in Switzerland, adopted a critical CBANC value of 20 µeq/L as critical ANC value for the Steady-State Water Quality (SSWC) model, assuming this value to be generally protective of fish and invertebrates. This CBANC threshold follows the recommendations from the manual for modeling and mapping critical loads and air pollution in Europe (UNECE 2004).

A CBANC of 20 µeq/L has been widely used in Europe as a water quality threshold sufficient for protecting most key indicator organisms (Wright et al. 2005, Kernan et al. 2010). According to a study in Norway by Lien et al. (1996), this ANC value corresponds to a 10% probability of damaged brown trout populations (Kernan et al. 2010). In the UK, a lower CBANC value of 0 µeq/L, which corresponds to a damage probability of 50% for brown trout populations, has been used for naturally acidic sites (Kernan et al. 2010).

In their study on the recovery and evolution of acidified surface waters in Europe, Wright et al. (2005) established three CBANC ranges based on expected impact on brown trout and other aquatic biota: surface waters with CBANC < 0 µeq/L would be eventually be barren of fish; CBANC 0–20 would indicated sparse fish populations and CBANC > 20 would not have a detrimental effect on fish populations.

In North America, Baldigo et al. (2009) sampled 36 Adirondack streams as part of the Western Adirondack Stream Survey (WASS). They found a strong (R^2 = 0.69) relationship between BCS and an index of benthic community structure (acidBAP, acid Biological Assessment Profile, derived from percent mayfly richness and percent acid-tolerant taxa, Burns et al., 2008). Based on these results, the authors derived four biologically relevant ranges of BCS thresholds (Figure 8 in Baldigo et al. 2009):

1) above 50 µeq/L of BCS, there would be no biological impacts;
2) between BCS values of 0 and 50 µeq/L, biota would be exposed to background toxic levels of Al with a *slight* biological impact;
3) BCS values between -35 and 0 µeq/L would indicate chronic toxicity and a *moderate* biological impact; and
4) BCS below -35 µeq/L would point to acutely toxic waters and a *severe* biological impact.

Baldigo et al. (2009) concluded that acidBAP and BCS were useful indicators of ecosystem effects and potential recovery at the local and regional scale.

Baldigo et al. (2019), in their study on long-term effects of acidification on streams in in the Western Adirondacks (New York state, United States), found a non-linear asymptotic relationship between Gran ANC and biological effects on aquatic biota (Figure 7.29); i.e., the biomass of all fish communities is generally zero at or below a Gran ANC of 0 µeq/L and typically increases with ANC to a maximum of about 2,500 g/0.1 ha at and above a Gran ANC of 250–300 µeq/L. They also found that chronic and acute Al_i thresholds (1.0–2.0 µmol/L) correspond to Gran ANC values of approximately 20 to -10 µeq/L.

Decreased pH leads to complexation of DOC with inorganic Al to form nontoxic organic aluminum (Al_o). Thus, low pH and low DOC levels can increase the concentrations of biologically labile Al_i and increase toxicity to resident biota (Baldigo et al. 2019).

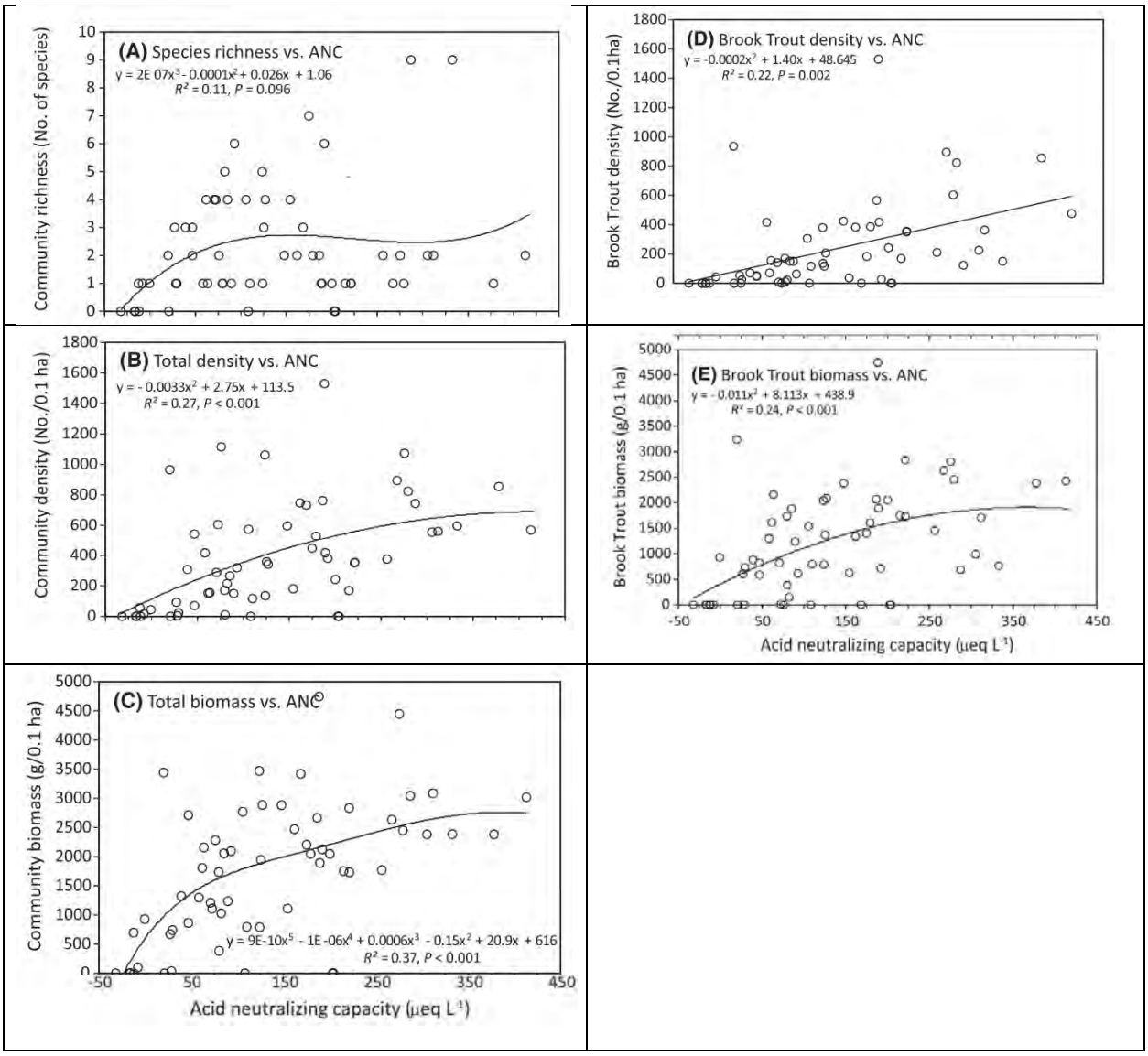


Figure 7.29: Relationships between acid-neutralizing capacity (ANC; µeq/L) and (A) fish community richness, (B) total fish community density, (C) total fish community biomass, (D) density of Brook Trout, and (E) biomass of Brook Trout. Source: Baldigo et al., 2019.

7.2.4.2 Species-specific ANC thresholds for fish

Lien et al. (1996) analyzed the empirical correlation between observed CBANC and the status of various fish species populations (fish data obtained from interview surveys) in 1095 lakes and Atlantic salmon (*Salmo salar*) populations in 30 rivers in Norway. While most of these lakes had sufficient water chemistry data to estimate CBANC, in some lakes with more limited data they used a modified estimate of ANC (based on measured bicarbonate, hydrogen ion, dissolved aluminum and estimated organic anions). They found a strong relationship between fish status and CBANC values, and derived CBANC thresholds for various species (Table 7.21). Atlantic

salmon was the fish species most sensitive to low ANC concentrations. According to this study, perch tolerated the lowest ANC –in lakes where perch had disappeared all the other species were also lost.

In general, the results from Lien et al. (1996) showed that lakes with healthy fish populations had higher mean pH, positive calculated CBANC, higher Ca and lower labile Al. Overall, results indicated that in lakes with CBANC < -40 µeq/L, very few fish communities had survived. Lakes with CBANC > 40 µeq/L showed no evidence of reduced fish population levels. At CBANC = 10 µeq/L, several of the species studied showed reductions in their populations of about 25%. The results for Atlantic salmon in the surveyed rivers suggest that no population was affected when the mean CBANC exceeded 20 µeq/L. To put that CBANC value in context, a CBANC of 20 µeq/L would be equivalent to a Gran ANC of -3 µeq/L for an example lake with a charge density of 4.6 µeq/mg of DOC, and a DOC level of 5 mg/L – see definitions in Section 7.2.1. Some Atlantic Salmon populations became extinct at positive ANC, and at CBANC = 0 µeq/L (≈GranANC of -23 µeq/L for the above-described example lake) nearly 50% of the populations had been lost. CBANC values lower than -20 µeq/L (≈GranANC of -43 µeq/L for the above-described example lake)were associated with the extinction of Atlantic salmon in nearly all the rivers.

Table 7.21: Thresholds of CBANC concentration (µeq/l) for different fish species where 25% and 50% of the lakes showed reduced or extinct populations (Source: Lien et al. 1996). The values in parentheses are approximate values due to low sample size.

Fish species	CBANC (µeq/l) at which 25 or 50% of lakes show reduced populations		CBANC (µeq/l) at which 25 or 50% of lakes show extinct populations	
	25%	50%	25%	50%
Atlantic salmon (*Salmo salar*)	10	5	5	0
Brown trout (*Salmo trutta*)	10	0	-10	-20
Arctic char (*Salvelinus alpinus*)	10	-5	-10	-15
Pike (*Esox lucius*)	10	-5	(-15)	(-30)
Minnow (*Phoxinus phoxinus*)	5	-5	-5	-15
Whitefish (*Coregonus lavaretus*)	(-5)	(-10)	(-15)	(-20)
Perch (*Perca fluviatilis*)	-5	-15	-30	-35

The authors proposed Atlantic salmon status as a good indicator of acidification of rivers, and brown trout (the most common fish species found in lakes in Norway) as an indicator for acidification in lakes.

Laudon et al. (2005) also studied the biological effects of acidification on brown trout by experimentally analyzing the effects of spring snow melt events on six streams in northern Sweden that differed in their concentrations of dissolved organic carbon (DOC). The authors studied mortality and physiological responses to declines in pH and found that the index that

best separated the response classes in the brown trout populations was the ratio **ANC/H⁺**. Based on their results, Laudon et al. (2005) identified two ANC/H⁺ thresholds (Figure 7.30): *ANC/H⁺ = 5* as a limit for *high* mortality and *ANC/H⁺ = 20* as a limit for *some* mortality. However, the large of variability in this ratio (note that the y-axis is on a log scale) suggests that it is preferable to use a fixed threshold rather than a ratio for ANC or BCS. As summarized below in Section 7.2.5, most literature recommends a fixed value rather than a ratio for an ANC or BCS threshold.

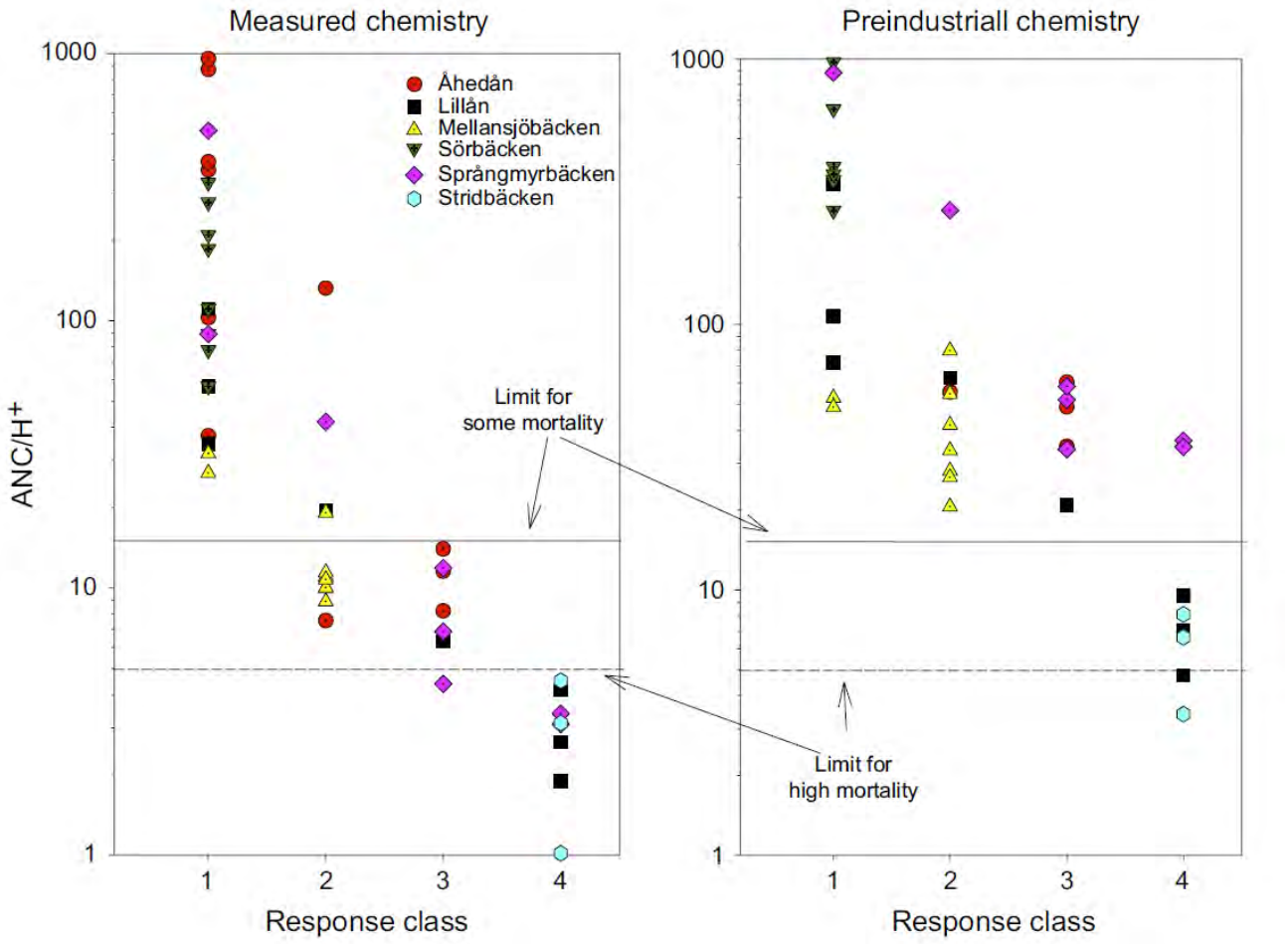


Figure 7.30: Relationship between the response pattern of the experimental fish and the ANC/H⁺ ratio during spring flood as observed in six study streams (left pane) and predicted for pre-industrial water chemistry at the same locations. The response classes are: 1) no significant response; 2) physiological response without mortality; 3) physiological response with some mortality and 4) high mortality. Each point represents a sample location. Source: Laudon et al. 2005

The results from Laudon et al. (2005) suggest that fish in DOC-rich streams can tolerate higher acidity and inorganic aluminium levels than fish in low DOC streams. These findings are aligned with other studies (Solheim et al. 2008) documenting that fish in humic waters can tolerate higher acidity (lower pH) than fish in clear waters, mostly due to lower toxicity of Al in humic

waters. The review on acidification studies by Solheim et al. (2008) found that humic content had a positive effect for most acid-sensitive indicators.

When considering ANC as a predictive variable for the biological effects of acidification, Solheim et al. (2008) highlighted the need to consider that the correlation between ANC and pH is dependent on the TOC level, as acidified humic lakes have lower pH than clear water lakes at the same value of ANC.

A later Norwegian study connecting ANC_{OAA}[17] with acidification effects on brown trout populations was conducted by Hesthagen et al. (2016) in the Vikedal watershed, which is recovering from acidification and has seen an increase in brown trout population since the late 1990s. The authors performed a principal component analysis of nine selected chemical variables considered to affect the survival of young brown trout. They found a significant (R^2 = 0.61) correlation between ANC_{OAA} and densities of young of year (YoY) brown trout in the streams (Figure 7.31a), and also a significant relationship (R^2 = 0.55) between ANC_{OAA} and older parr (Figure 7.31b).

They identified three ranges of BCS values corresponding to three stages in the process of recovery from acidification (Hesthagen et al. 2016): (i) low density with 10-20 specimens per 100 m^2 at an ANC_{OAA} of -18 to -5 µeq/L; (ii) medium and unstable density with 20-30 specimens per 100 m^2 at an ANC_{OAA} of -5 to 10 µeq/L; and (iii) increasing density to 40-50 specimens per 100 m^2 at an ANC_{OAA} of 10-25 µeq/L.

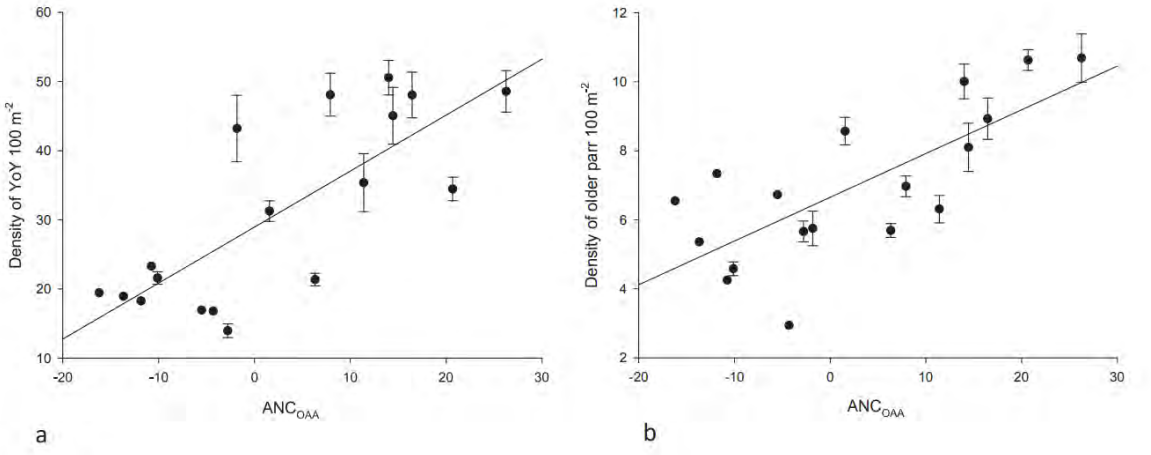


Figure 7.31: Densities 100 m2 ± 95% CL of YoY (a) and older parr (b) of brown trout in the study streams in River Vikedal watershed in relation to ANC_{OAA} between 1987 and 2010. CL limits for 1987-1992 are not available due to one sampling run. Source: Hesthagen et al. 2016

[17] North American research and literature often uses the term Base Cation Surplus, whereas the convention in European research and literature (which is generally more extensive) has been to apply the term "organic anion adjusted ANC" or ANC_{OAA}. These are different terms for the same metric, though the methods of calculation differ slightly among different authors.

In North America, there have been several studies on the effects of acidification on fish species (Baldigo and Lawrence 2001, 2007) in streams in the Adirondack Mountains; an area which was affected by acid rain, especially in the late 1980s, and has been recovering since the late 1990s.

Baldigo and Lawrence (2001) analyzed water quality, physical habitat, and population (density and biomass) data for various fish species from the Neversink River Basin for the period 1991–95. They conducted a regression analysis between population variables and environmental factors and found a strong relation between fish population and acid-related parameters. Specifically, slimy sculpin (*Cottus cognatus*) density ($r^2 = 0.83$; $p \leq 0.1$) and biomass ($r^2 = 0.74$; $p \leq 0.1$) was strongly related to Gran ANC.

This study (Baldigo and Lawrence 2001) did not identify ANC thresholds but found reference pH values for the various fish species: brook trout (*Salvelinus fontinalis*) were observed only at sites where mean pH exceeded 4.77, slimy sculpin at sites where mean pH exceeded 5.26, brown trout (*Salmo trutta*) and longnose dace (*Rhinichthys cataractae*) at sites where mean pH exceeded 5.69, and blacknose dace (*Rhinichthys atratulus*) and Atlantic salmon (*Salmo salar*) at sites where mean pH exceeded 6.36.

A later study by Baldigo et al. (2007) empirically explored the effects of exposure of caged brook trout (*Salvelinus fontinalis*), a member of the char genus *Salvelinus* native to Eastern North America, to acidified streams in the southwestern Adirondack Mountains of New York. This is an area that is geologically susceptible to acidification and has received some of the most acidic deposition in North America. Following the enactment of the Clean Air Act Amendments of 1990, there were significant ANC increases in two of the local streams over the period from 1991 to 2001. This study aimed at comparing the biological responses of brook trout to stream water chemistry in 2001-03, with the responses observed during similar tests conducted in 1984–1985, 1988–1990, and 1997 (Baldigo et al. 2007).

Baldigo et al. (2007) documented daily cumulative mortality of brook trout in six headwater streams, as well as 15-min stream discharge and water chemistry data (pH, Gran ANC, and inorganic monomeric aluminum Al_{im}). . Based on these results, the authors developed regression equations between brook trout mortality at the end of each test and median Al_{im} concentrations during each test. Concentrations of Al_{im} greater than 2.0 and 4.0 µmol/L were closely correlated with low and high mortality rates, respectively, and accounted for 83% of the variation in mortality. Despite reductions in acidic deposition and increases in ANC, they found little difference in stream toxicity to brook trout between the later period and the earlier period. Two to four days of exposure to Al_{im} concentrations greater than 4.0 µmol/L resulted in 50–100% mortality. Critical values of ANC were not identified in this study.

7.2.4.3 Other studies using ANC as an indicator for aquatic biota

In Norway, Raddum and Skjelkvåle (1995) analyzed water quality and aquatic invertebrates from 108 localities. They observed that sensitive species/taxa are associated with high ANC and pH, while tolerant species/taxa are associated with low pH and ANC. The authors also found that in oligotrophic water bodies, such as those found in Norway, sensitive fauna can tolerate lower ANC (CBANC) than in areas with originally high ionic strength and high pH, as in

Central Europe. Raddum and Skjelkvåle (1995) suggest a CBANC threshold of 20 µeq/l for oligotrophic waters with low ionic strength and a critical level of a critical level of 50 µeq/l for waters with higher ionic strength. Further studies based on 10 years of chemical and biological data from various localities in Norway, UK and Ireland confirmed this CBANC critical range from 20 to 50 µeq/l, depending on the type of water chemistry, type of invertebrate fauna and their adaptation to native water chemistry (Raddum and Skjelkvåle 2001).

Another regional study on acidification and its effects on aquatic biota in Norwegian lakes and rivers (Lien et al. 1996) explored the status of invertebrate communities (i.e., zooplankton and benthic invertebrates) from 165 sites in relation to water chemistry. Results from this study indicate that sites with CBANC <10 µeq/L had less diverse invertebrate assemblages than sites with higher ANC values. A CBANC value of *-30 µ*eq/L seems to be a critical threshold for severe impacts since water bodies with CBANC below this value showed a very restricted invertebrate faunal assemblage. No effects on invertebrate diversity were detected at CBANC *>30 µeq/l*. Lien et al. (1996) also observed that, at sites with pH >5.5, invertebrate fauna varied considerably as a function of Ca concentration, but that Ca concentrations had little or no influence on the diversity of fauna at pH < 5.0.

While European countries have quite different assemblages of fish species than Western North America, there's a somewhat greater similarity in invertebrate species, and similar patterns of changes in zooplankton species richness with acidification (Marmorek and Korman 1993). Therefore, thresholds derived in Europe for invertebrate assemblages may be more directly transferable to lakes in the Kitimat Valley than are thresholds derived for fish species. Work by Holt et al. (2003) identified pH 6.0 as a threshold for significant changes in the structure of zooplankton communities in Ontario lakes, which in the STAR was found to correspond to a critical GranANC of 26 µeq/L (calculations of critical ANC to be redone with a larger dataset as part of the Comprehensive Review).

Vinebrooke and Graham 1997explored the use of **periphyton** assemblages as indicators of acidification recovery in acidified Canadian Shield lakes. () They found that DIC (Dissolved Inorganic Carbon), DOC and Al explained more of the variation in periphyton metrics than did ANC; periphyton metrics included rates of biomass accrual (total, filamentous greens, desmids), and species richness. ANC was however helpful in discriminating three species from other clusters of periphyton (Figure 5 in Vinebrooke and Graham 1997). ANC was measured in the field, so likely this was neither GranANC nor CBANC. This study therefore has little relevance to developing ANC thresholds for the EEM program.

7.2.5 Summary of ANC thresholds found in the literature

The ANC thresholds discussed in this literature review correspond to various measurements of ANC (i.e., CBANC, Gran ANC, BCS), different levels of impact (e.g., good population status, some damage to populations, or extinction of population) and different aquatic receptors, from specific fish species to broader taxonomic groups (e.g., invertebrates, general fish population). Table 7.22 shows the range of ANC critical values found in the literature for all these different cases.

The most common ANC measurement reported in the studies is the charge balance or **CBANC** (Figure 7.32). In general, CBANC values over 20 µeq/l are expected to support most aquatic biota. Lien et al. (1996) derived species-specific CBANC critical values for fish species found in Norway and found Atlantic salmon to be the most sensitive species. Because the species analyzed in Lien et al. (1996) are not found in the Kitimat Valley, these thresholds can provide relevant guidance for developing appropriate regional ANC thresholds but do not offer prescriptive thresholds that are directly transferable.

Base Cation Saturation (**BCS**) has also been used as a biological indicator for the effects of acidification. In their study in acidified streams in Northeast America, Baldigo et al. (2009) identified three BCS related to levels of aluminum toxicity (Figure 7.33).

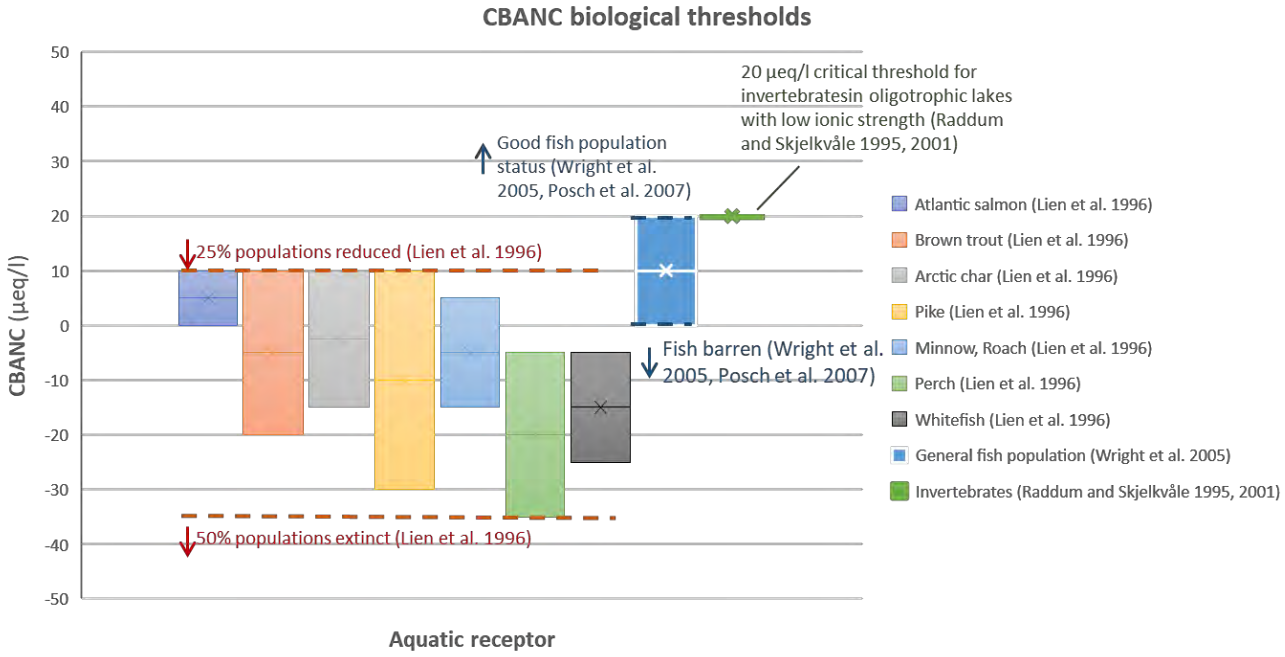


Figure 7.32: CBANC biological thresholds found in the literature

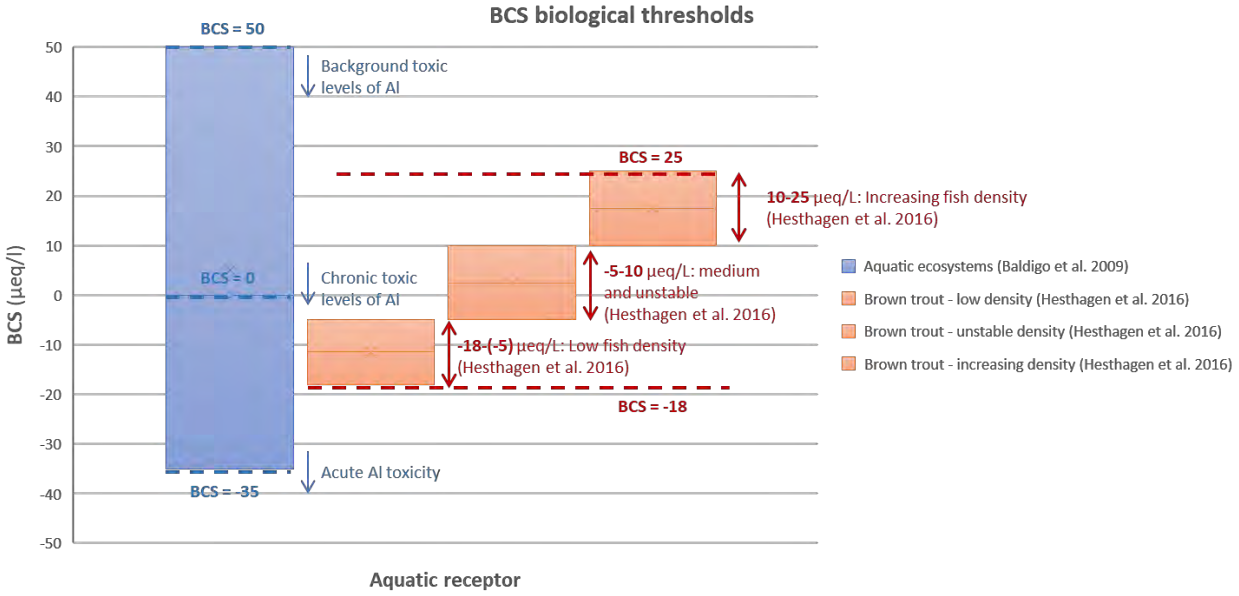


Figure 7.33: Biological thresholds for BCS / ANC_{OAA} found in the literature

Baldigo et al. (2019) recently studied fish communities from 48 streams in the western Adirondacks (NY, USA) in order to assess present-day effects of acidification on fish assemblages and identify biological targets and chemical effect thresholds. They identified ANC biological thresholds in relation to fish biomass density and inorganic Al toxicity levels (Figure 7.34).

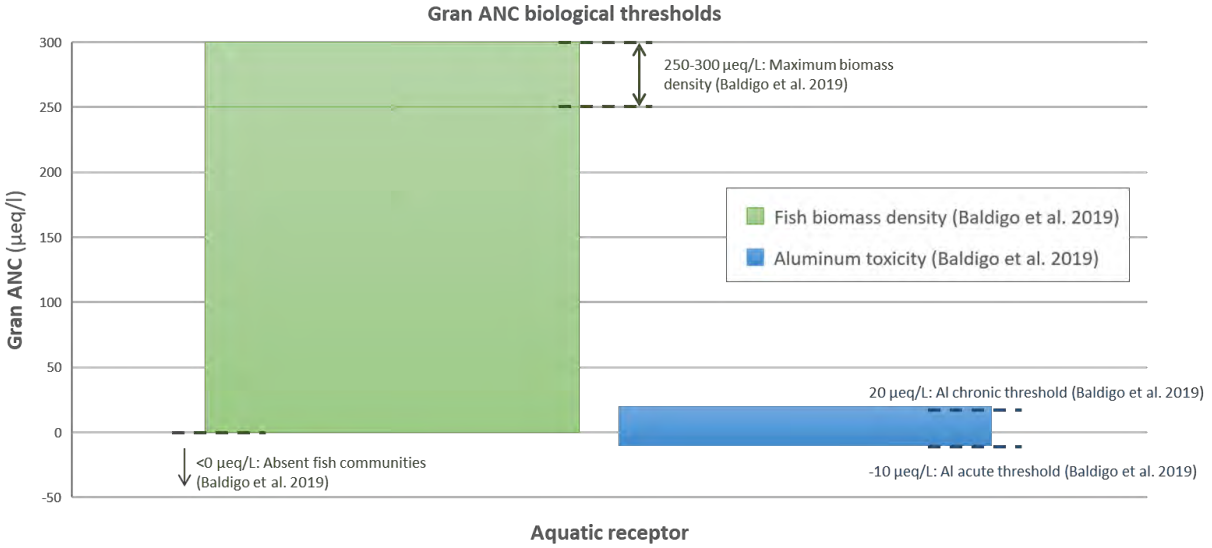


Figure 7.34: Gran ANC biological thresholds for fish biomass and inorganic aluminum toxicity (Source: Baldigo et al. 2019)

Table 7.22: Overview of ANC thresholds found in the literature

Source	Study Location	Indicator of Biological Effect	Chemistry metric	Threshold
Baldigo et al. 2007	Adirondack Mountains (New York, North America) – streams	Brook trout - mortality	Inorganic monomeric aluminium (Al_{im}) µmol/l	Concentrations of Al_{im} greater than 2.0 and 4.0 µmol/L were closely correlated with low and high mortality rates
Baldigo et al. 2009	Adirondack Mountains (New York, North America) – streams	(General) aquatic ecosystems – toxicity due to mobilization of inorganic Al	BCS (µeq/l)	BCS values corresponding to Al concentrations • no impact when BCS ≥ 50 • 50: background toxic level • *slight* impact at BCS between 50 and 0 • 0: chronic toxic • *moderate* impact at BCS between 0 and -35 • -35: acutely toxic • *severe* impact at BCS below -35
		Macroinvertebrate community structure – - acidBAP		
Baldigo et al. 2019	Adirondack Mountains (New York, North America)	Fish community - biomass	Gran ANC (µeq/l)	0: no fish 250 – 300: maximum biomass -10 to – 20: acute to chronic Al toxicity
Wright et al. (2005), Kernan et al. (2010)	Europe – lakes and streams	Fish (brown trout but applies to aquatic biota in general) – population status (presence and abundance)	CBANC (µeq/l)	CBANC < 0: barren of fish CBANC 0–20: sparse fish population CBANC > 20: good population status
Posch et al. (2007)	Europe - lakes	Fish and invertebrates – damage threshold	CBANC (µeq/l)	20
Raddum and Skjelkvåle (1995, 2001)	Norway – surface water	Invertebrates - Abundance	CBANC (µeq/l)	20: oligotrophic waters (Norway) 50: waters with high ionic strength (Central Europe)
Lien et al. (1996)	Norway – 1095 lakes and 30 rivers	Atlantic salmon, brown trout, Arctic char, pike, minnow, whitefish and perch - Fish population status (reduced and extinct)	CBANC (µeq/l)	Atlantic salmon[1]: 5/0 Brown trout: 0/-20 Arctic char: -5/-15 Pike: -5/-30 Minnow: -5/-15 Whitefish: -10/-20 Perch: -15/-35
Laudon et al. (2005)	Sweden – streams (effect of spring melt)	Brown trout – Physiological responses and mortality (4 classes from no response to high mortality)	ANC/H+	5: high mortality 20: some mortality
Hesthagen et al. 2016	Norway	Brown trout – Population density; YoY (age 0+) and older parr (age ≥1+)	ANC_{OAA} (µeq/l)	-18 to -5: low density -5 to 10: medium and unstable density 10 to 25: increasing density

7.2.6 Recommendations for ANC Thresholds

The recommendations resulting from this literature review are described and discussed in the Aquatic Ecosystems chapter (i.e., Section 7 of the SO_2 EEM 2019 Comprehensive Review report).

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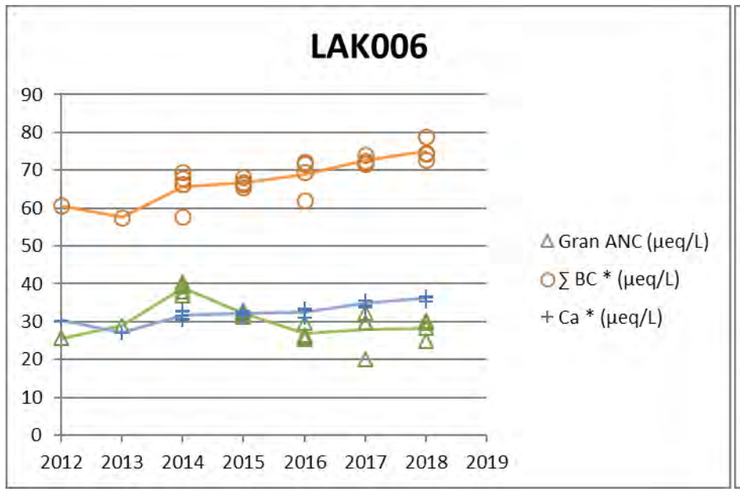
7.2.8 Articles overview

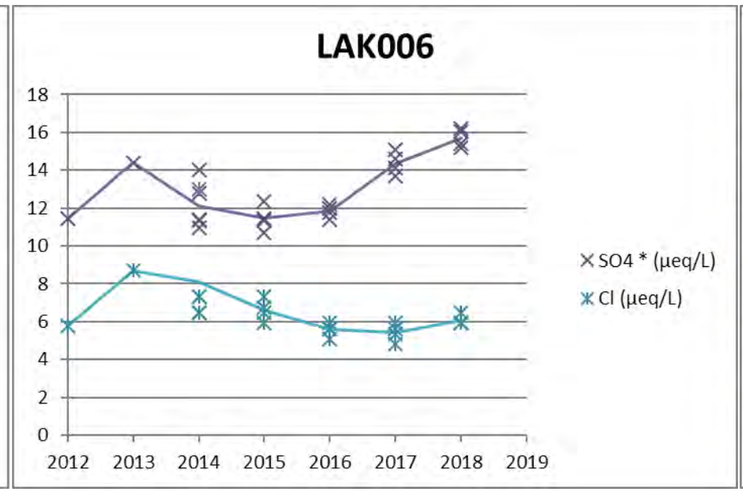
Citation	Summary	Relevance
Lien et al. 1996	Analysis of status of fish and invertebrate populations in Norway in the context of surface water acidification. Critical levels of ANC are proposed for various species.	High
Baron et al. 2011	Determination of critical for N deposition for headwater lakes in regions of the United States where the primary environmental impacts come from N deposition and climate change.	Medium
Vinebrooke and Graham 1997	Survey of acidified shield lakes (Canada) to assess periphyton assemblages as indicators of natural recovery. Regression analyses showed that DIC (dissolved inorganic carbon) and DOC (dissolved organic carbon) were the only significant predictors of periphyton abundance (biomass)	Low
Hesthagen et al. 2016	Studied the recovery of recovery of young allopatric brown trout (*Salmo trutta*) in acid-sensitive streams in a Norwegian watershed. Their densities correlated significantly with ANC_{OAA}, and at least three stages in the recovery process were recognised.	Medium
Houle et al. 2006	ANC is highly predictable ($r^2 = 0.75$) based on the size of the exchangeable Ca^{2+} reservoir in soil in 21 catchments representative of soil and lake conditions encountered in northeastern North America (Quebec)	Low
Burns et al. 2008	Study to document the extent of biological recovery within the Neversink River watershed since the 1980s. Statistical comparisons of data on stream chemistry and an acid biological assessment profile (Acid BAP) derived from invertebrate data showed no significant differences between the two years (1987 and 2003)	Low
Driscoll et al. 2001	Acidic Deposition in the Northeastern United States: Sources and Inputs, Ecosystem Effects, and Management Strategies. This paper analyzes the state of knowledge on acidification and ecosystems recovery in response to emissions reduction.	Medium
Groffman et al. 2006	This paper discusses methods for identifying and investigating thresholds using a variety of examples from terrestrial and aquatic environments, at ecosystem, landscape and regional scales.	Low
Laudon et al. 2005	Mortality and physiological responses in brown trout (*Salmo trutta*) were studied during spring snow melt in six streams in northern Sweden that differed in concentrations of dissolved organic carbon (DOC) and pH declines. The results suggest that fish in these systems can tolerate higher acidity and inorganic aluminium levels than fish in low DOC streams.	Medium
Solheim et al. 2008	This paper presents the main conclusions from the work on lakes in the REBECCA project. Reports on previous work on the use of ANC as threshold for aquatic organisms	Medium
Lydersen et al. 2004	The authors propose a propose a modified ANC calculation where the permanent anionic charge of the organic acids is assumed as a part of the strong acid anions.	High
Baldigo and Lawrence 2001	Study of water quality, physical habitat, and fisheries at sixteen reaches in the Neversink River Basin (1991–95) to identify the effects of acidic precipitation. Regression analyses revealed strong relations ($r^2 \pm 0.41$ to 0.99; $p \leq 0.05$) between characteristics of the two most common species (brook trout and slimy sculpin) populations and ANC, among other water chemistry parameters.	High
Baldigo and Lawrence 2007	Water chemistry, discharge, and mortality of caged brook trout Salvelinus fontinalis were characterized in six headwater streams in the southwestern Adirondack Mountains of New York during spring 2001–2003. Results were compared with mortality recorded during similar tests during 1984–1985, 1988–1990, and 1997. Concentrations of Alim greater than 2.0 and 4.0 lmol/L were closely correlated with low and high mortality rates, respectively, and accounted for 83% of the variation in mortality. Two to four days of exposure to Alim concentrations greater than 4.0 lmol/L resulted in 50–100% mortality.	High
Baldigo et al. 2009	As part of the Western Adirondack Stream Survey, water chemistry from 200 streams was sampled five times and macroinvertebrate communities were surveyed once from a subset of 36 streams in the Oswegatchie and Black River Basins during 2003–2005 and evaluated to: (a) document the effects that chronic and episodic acidification have on macroinvertebrate communities across the region, (b) define the relations between acidification and the health of affected species assemblages, and (c) assess indicators and thresholds of biological effects.	High
Baldigo et al. 2019	The authors characterized fish communities at 48 streams in the western Adirondacks (NY, USA) to assess present-day effects of acidification on fish assemblages, refine important relations, and identify biological targets and chemical effect thresholds that could help gauge biological recovery across the region	High

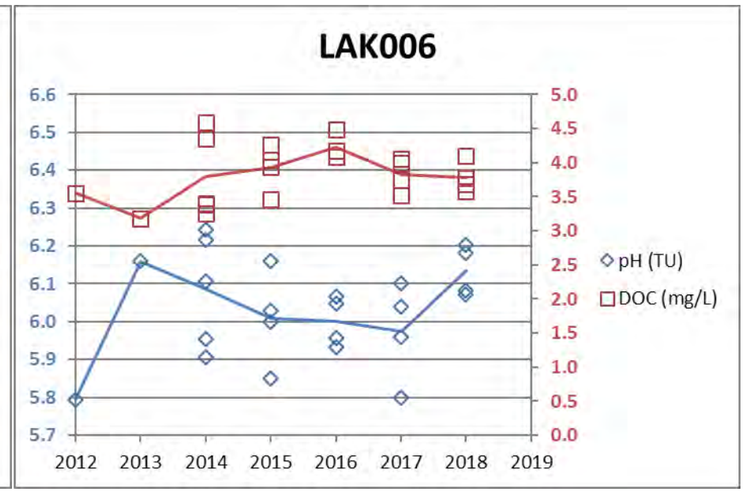
7.3 Aquatic Appendix C: Changes in Ion Concentrations from 2012 to 2018

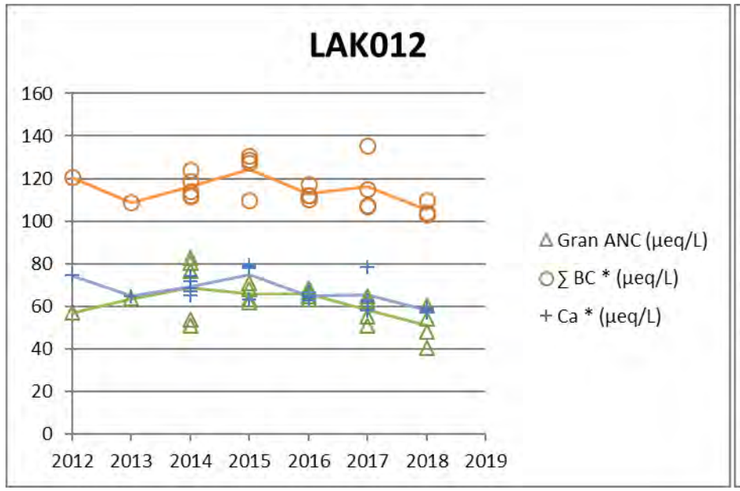
For each of the EEM lakes, the figures in this appendix show the inter-annual changes in six major water chemistry metrics from 2012 to 2018: Gran ANC, base cations and calcium (left panel), sulfate and chloride (centre panel), and pH and dissolved organic carbon (right panel). The selection of each pair of metrics is solely based on optimizing graphical representation across all metrics and lakes (i.e., metrics with somewhat similar numeric ranges are shown together). The right panel has two Y-axes, neither of which start at zero – be aware that this can make relatively minor changes appear to be much more substantial than they are. Due to large variation among the lakes for some of the metrics, the Y-axis is not consistent across the lakes, therefore extra caution is required for making comparisons among lakes with respect to the magnitude of changes. However, these graphs are especially useful for looking at the patterns of changes across the sampling record and determining whether similar patterns are observed across lakes and/or metrics.

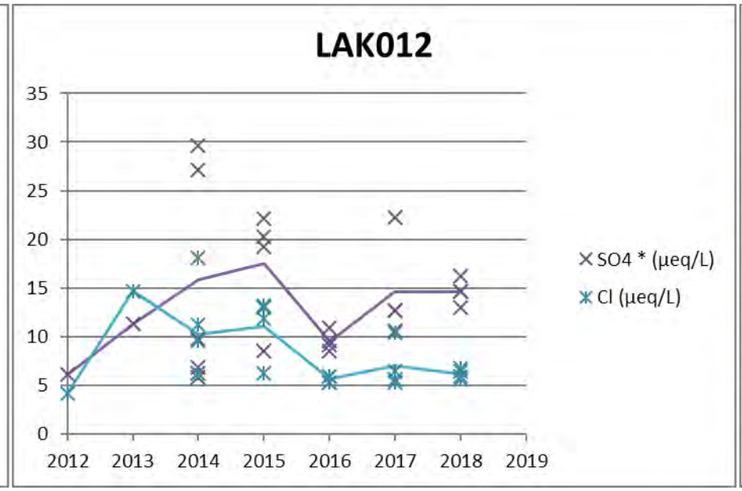
7.3.1 Sensitive Lakes

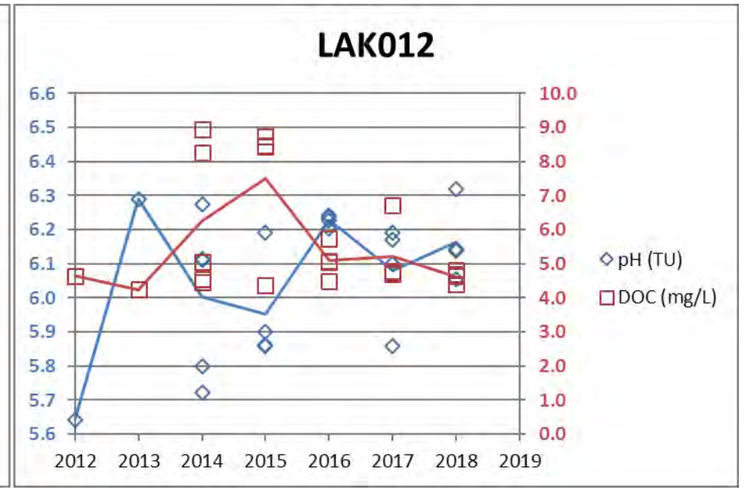


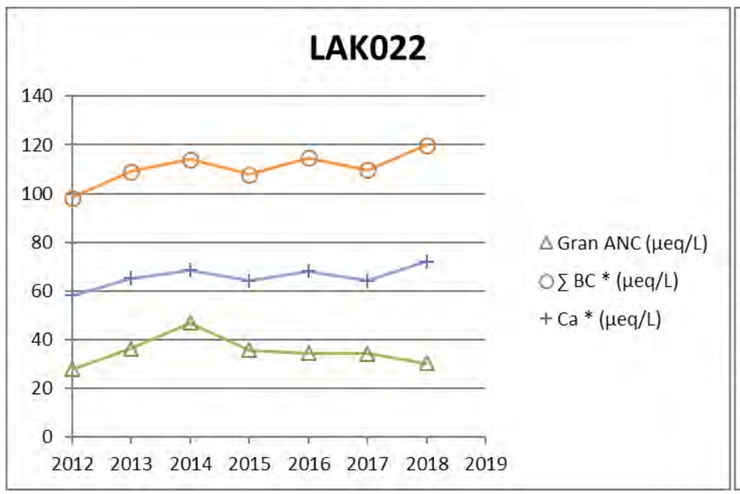


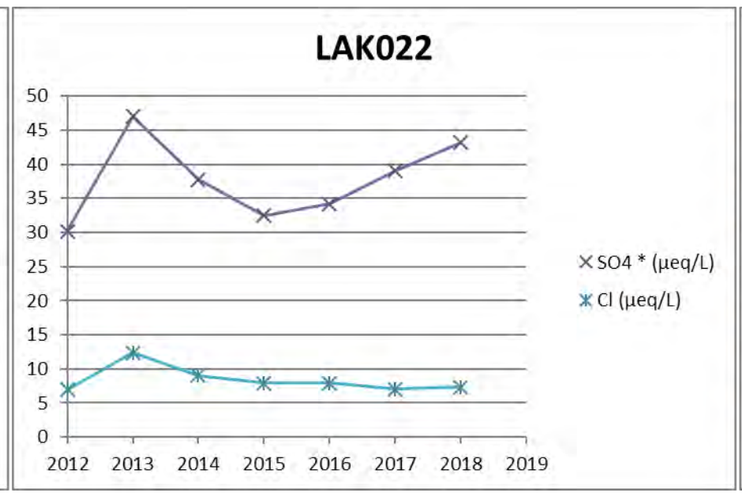


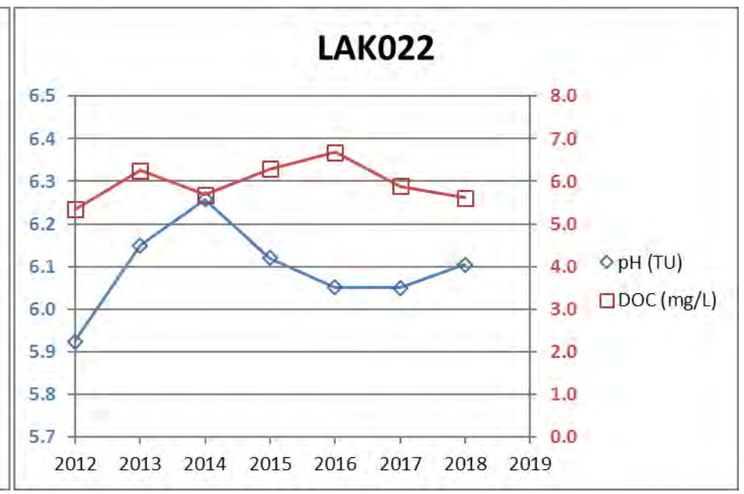

LAK012
160
140
120
100
80
60
40
20
0
2012 2013 2014 2015 2016 2017 2018 2019
Gran ANC (µeq/L)
∑ BC * (µeq/L)
Ca * (µeq/L)

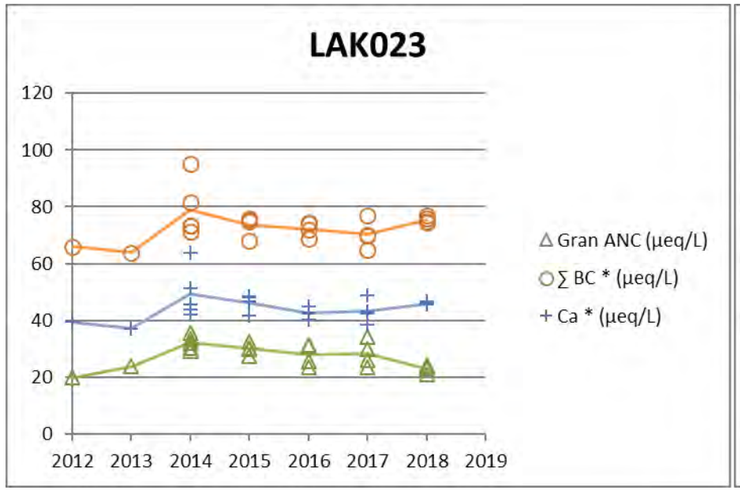

LAK012
35
30
25
20
15
10
5
0
2012 2013 2014 2015 2016 2017 2018 2019
SO4 * (µeq/L)
Cl (µeq/L)

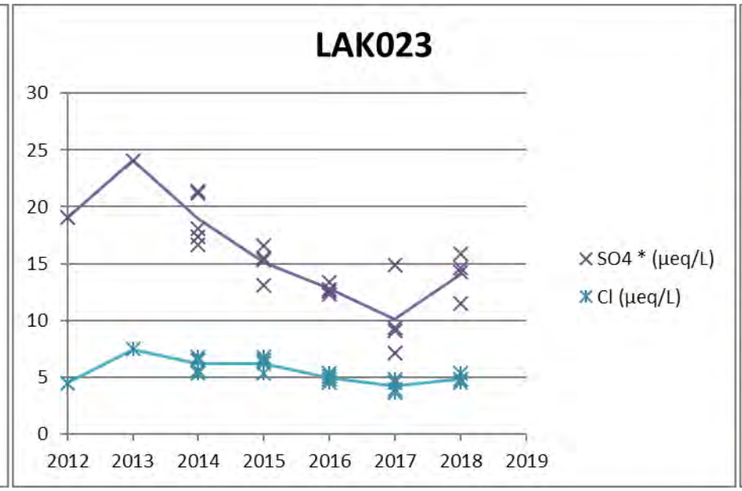

LAK012
6.6
6.5
6.4
6.3
6.2
6.1
6.0
5.9
5.8
5.7
5.6
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2012 2013 2014 2015 2016 2017 2018 2019
pH (TU)
DOC (mg/L)

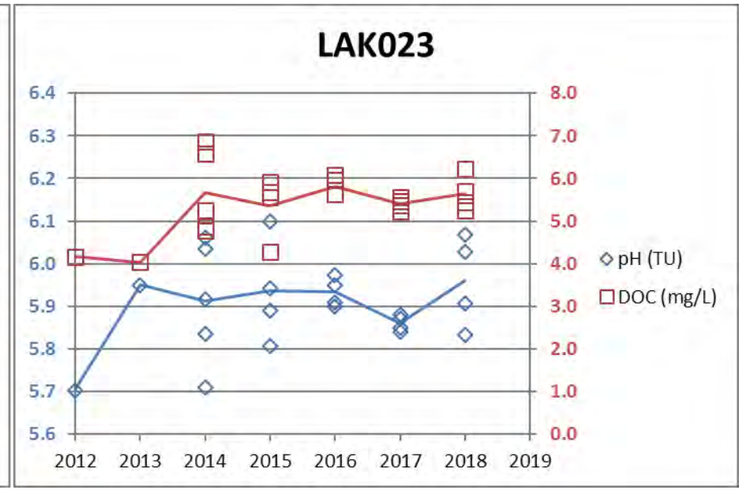

LAK022
140
120
100
80
60
40
20
0
2012 2013 2014 2015 2016 2017 2018 2019
Gran ANC (µeq/L)
∑ BC * (µeq/L)
Ca * (µeq/L)

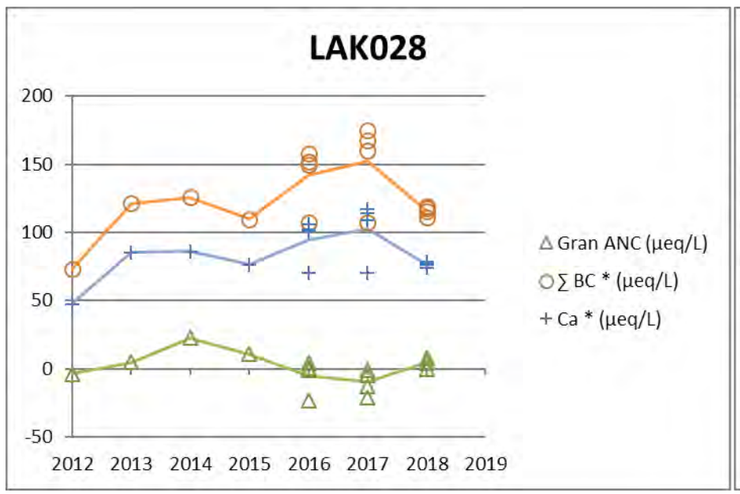

LAK022
50
45
40
35
30
25
20
15
10
5
0
2012 2013 2014 2015 2016 2017 2018 2019
SO4 * (µeq/L)
Cl (µeq/L)

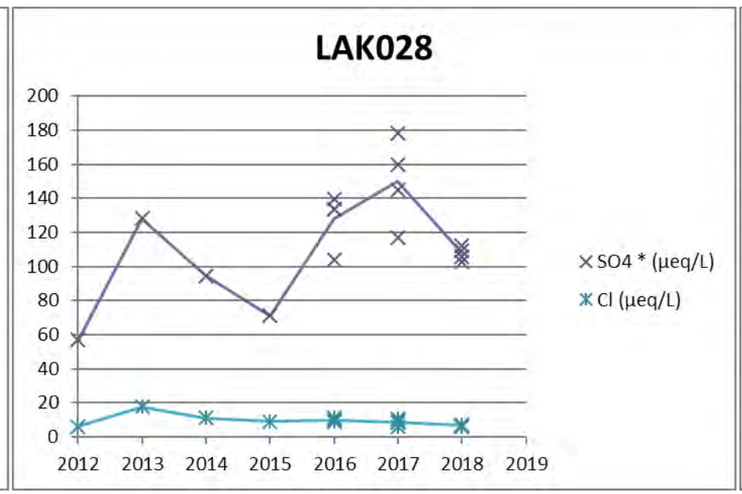

LAK022
6.5
6.4
6.3
6.2
6.1
6.0
5.9
5.8
5.7
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2012 2013 2014 2015 2016 2017 2018 2019
pH (TU)
DOC (mg/L)

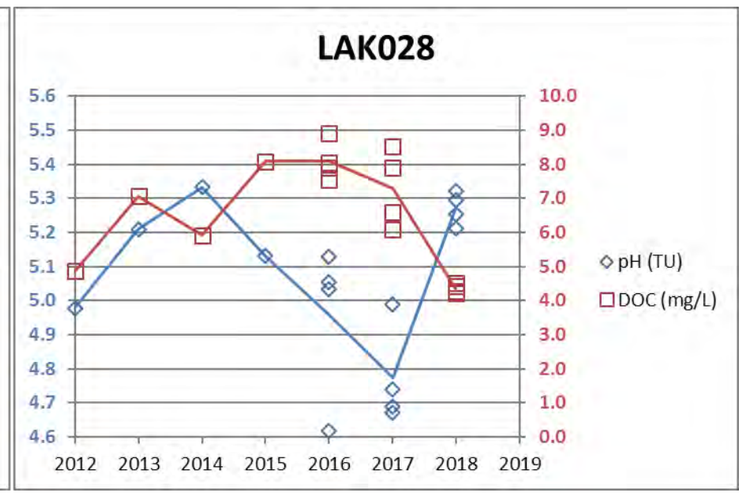

LAK023
120
100
80
60
40
20
0
2012 2013 2014 2015 2016 2017 2018 2019
Gran ANC (µeq/L)
∑ BC * (µeq/L)
Ca * (µeq/L)

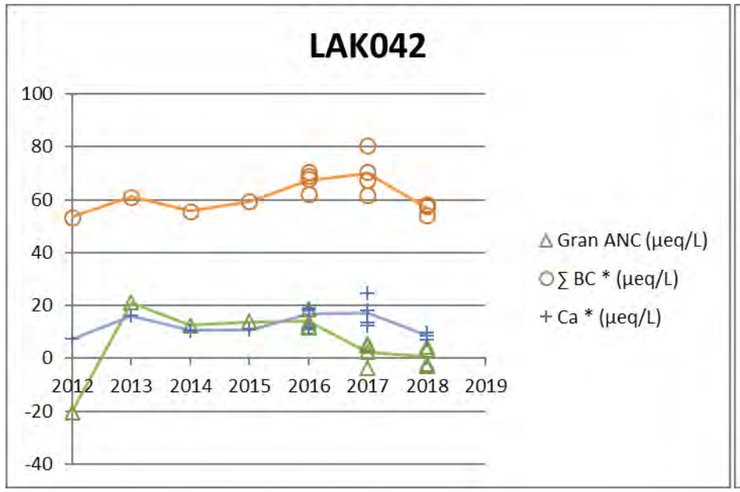

LAK023
30
25
20
15
10
5
0
2012 2013 2014 2015 2016 2017 2018 2019
SO4 * (µeq/L)
Cl (µeq/L)

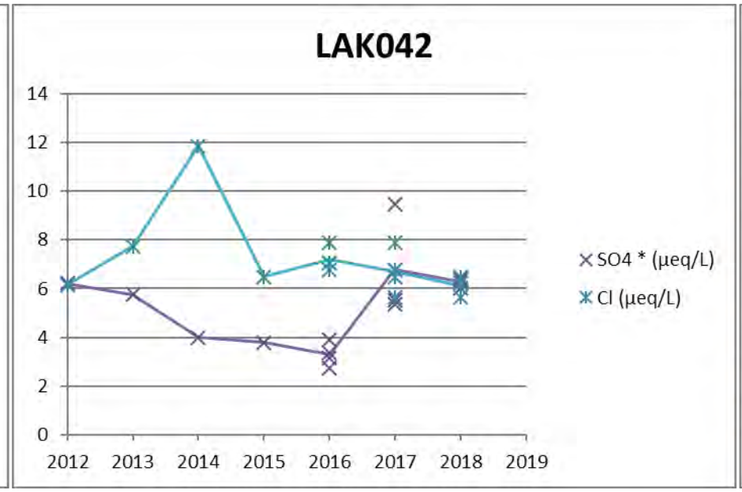

LAK023
6.4
6.3
6.2
6.1
6.0
5.9
5.8
5.7
5.6
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2012 2013 2014 2015 2016 2017 2018 2019
pH (TU)
DOC (mg/L)

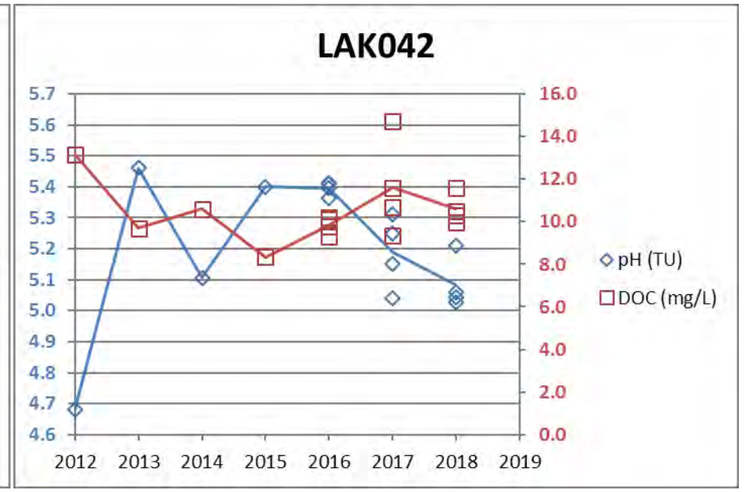

LAK028
200
150
100
50
0
-50
2012 2013 2014 2015 2016 2017 2018 2019
Gran ANC (µeq/L)
∑ BC * (µeq/L)
Ca * (µeq/L)

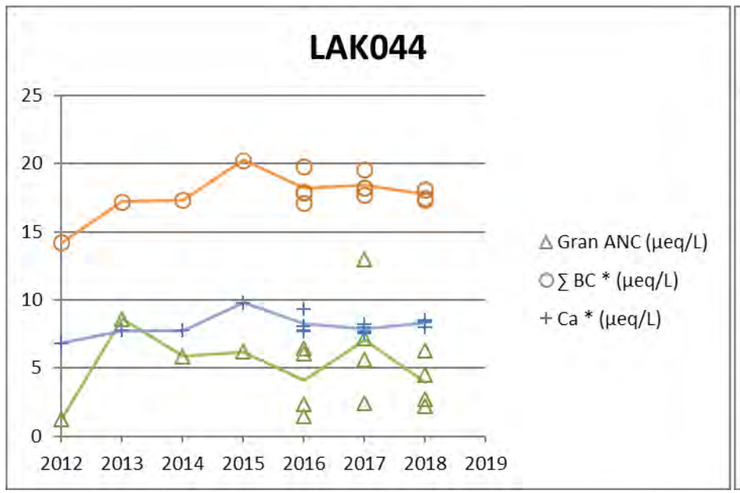

LAK028
200
180
160
140
120
100
80
60
40
20
0
2012 2013 2014 2015 2016 2017 2018 2019
SO4 * (µeq/L)
Cl (µeq/L)

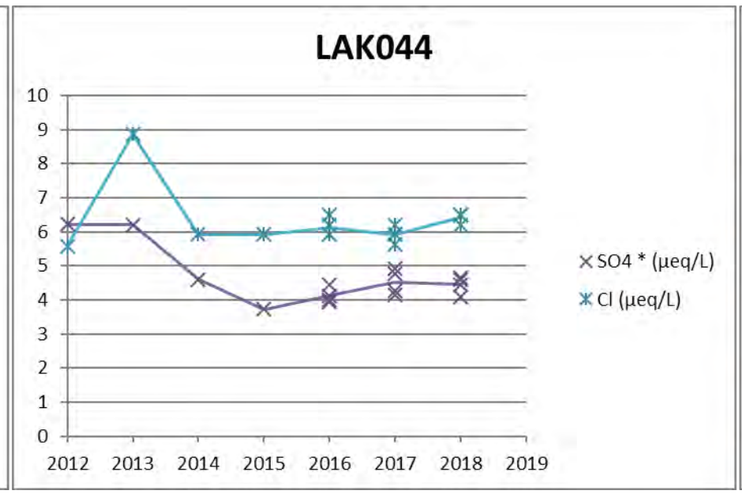

LAK028
5.6
5.5
5.4
5.3
5.2
5.1
5.0
4.9
4.8
4.7
4.6
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2012 2013 2014 2015 2016 2017 2018 2019
pH (TU)
DOC (mg/L)

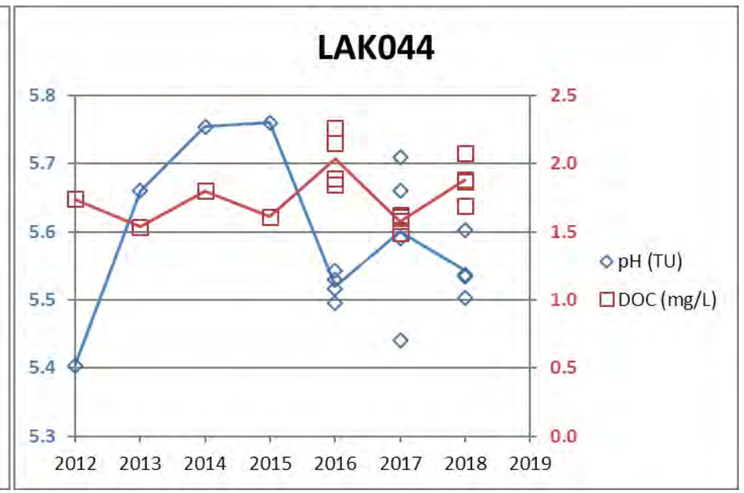

LAK042
100
80
60
40
20
0
-20
-40
2012 2013 2014 2015 2016 2017 2018 2019
Gran ANC (µeq/L)
∑ BC * (µeq/L)
Ca * (µeq/L)


LAK042
14
12
10
8
6
4
2
0
2012 2013 2014 2015 2016 2017 2018 2019
SO4 * (µeq/L)
Cl (µeq/L)

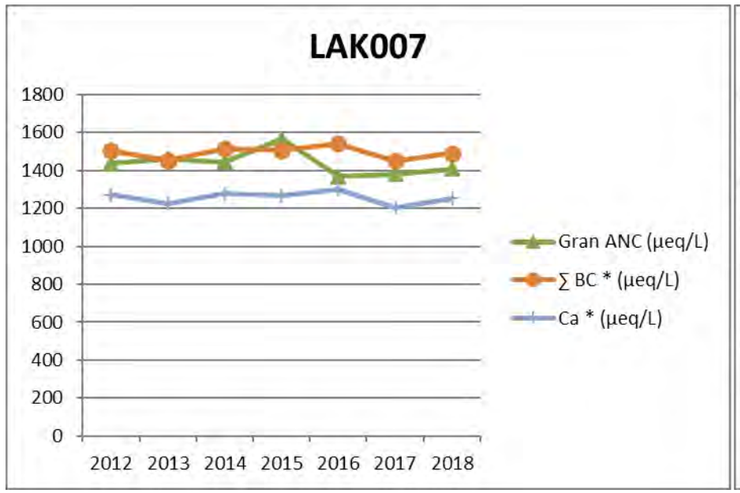

LAK042
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5.0
4.9
4.8
4.7
4.6
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
2012 2013 2014 2015 2016 2017 2018 2019
pH (TU)
DOC (mg/L)

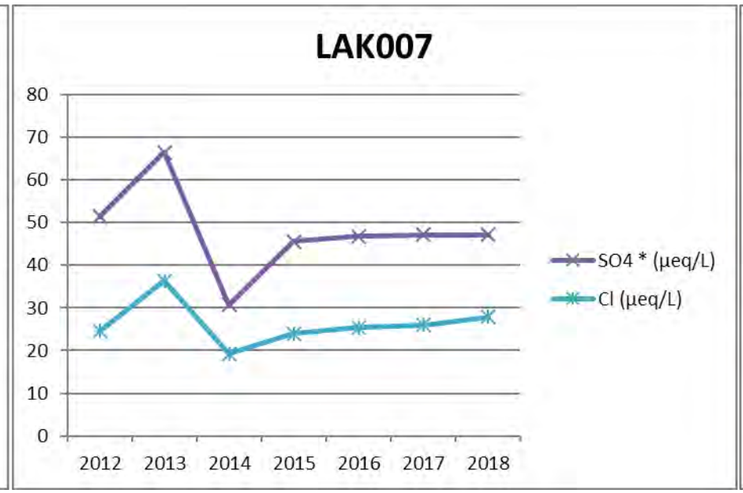

LAK044
25
20
15
10
5
0
2012 2013 2014 2015 2016 2017 2018 2019
Gran ANC (µeq/L)
∑ BC * (µeq/L)
Ca * (µeq/L)

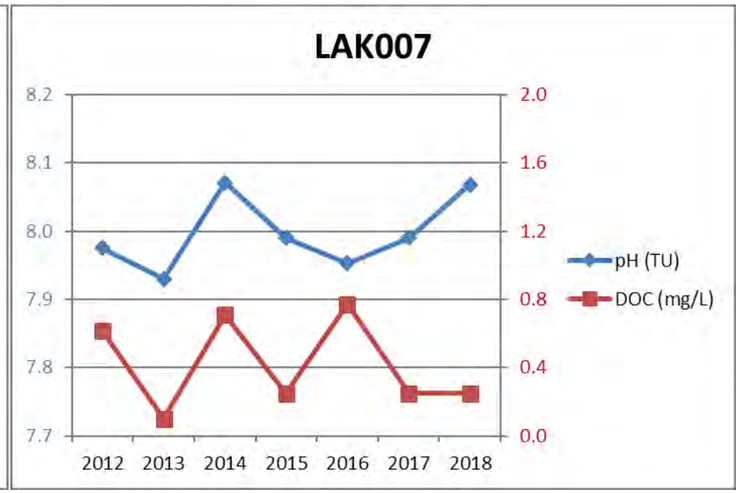

LAK044
10
9
8
7
6
5
4
3
2
1
0
2012 2013 2014 2015 2016 2017 2018 2019
SO4 * (µeq/L)
Cl (µeq/L)

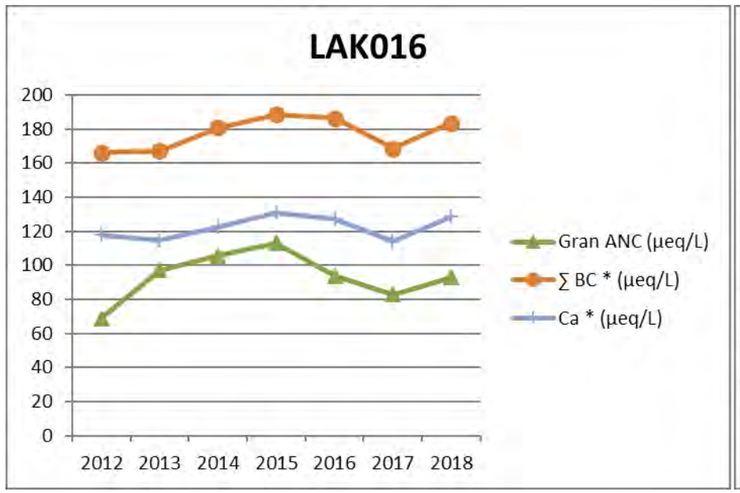

LAK044
5.8
5.7
5.6
5.5
5.4
5.3
2.5
2.0
1.5
1.0
0.5
0.0
2012 2013 2014 2015 2016 2017 2018 2019
pH (TU)
DOC (mg/L)

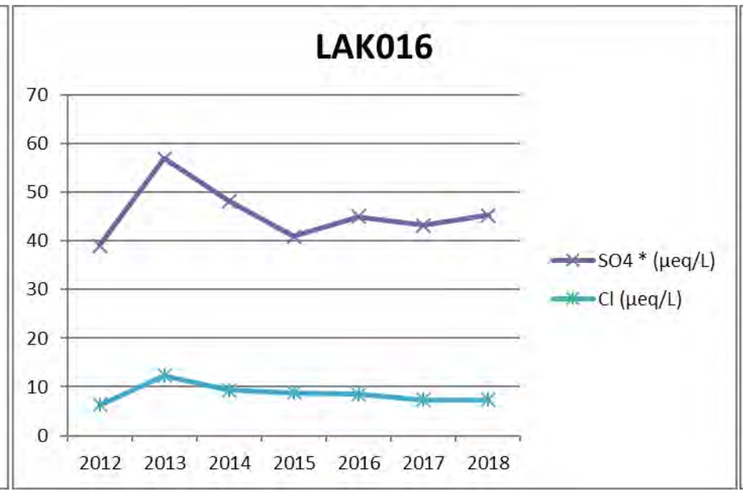
7.3.2 Less Sensitive Lakes

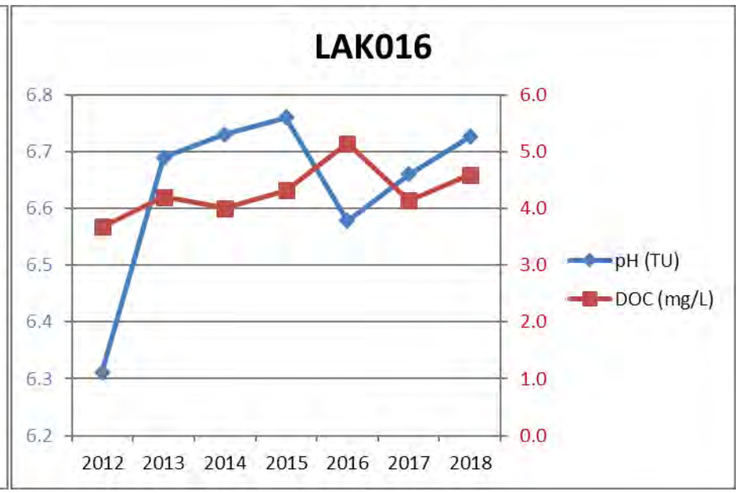


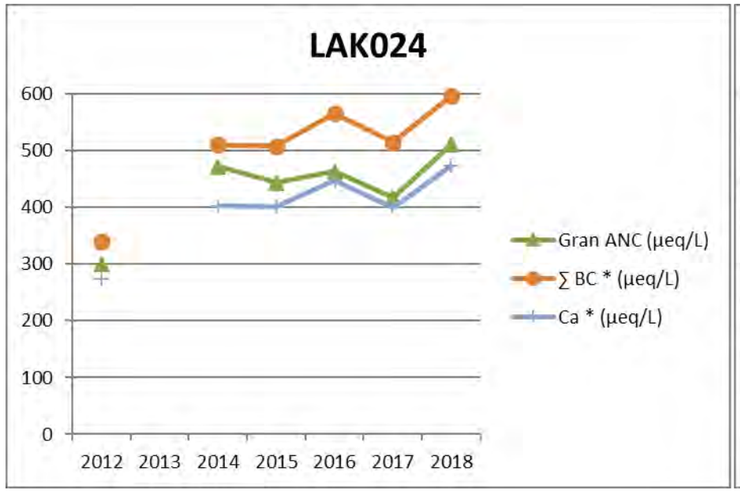


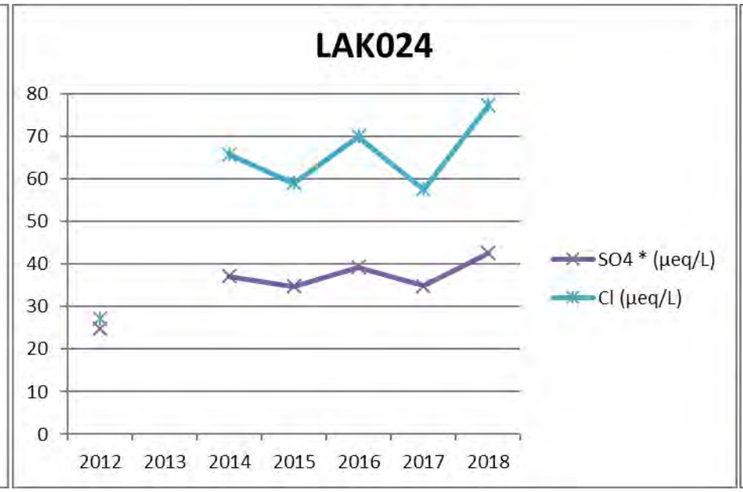


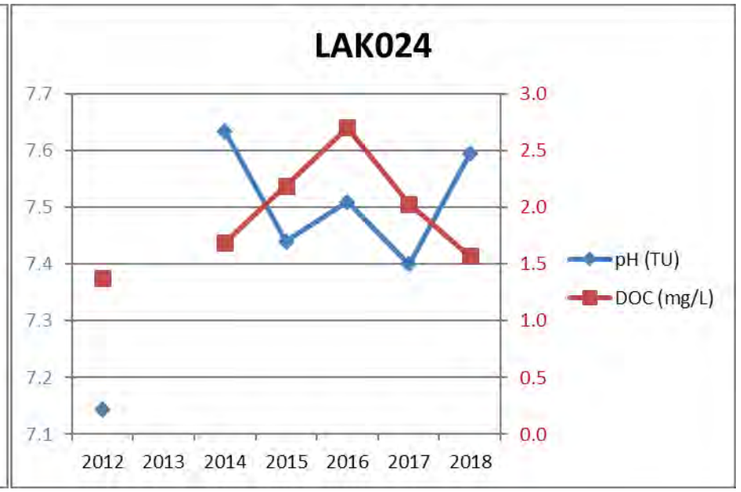


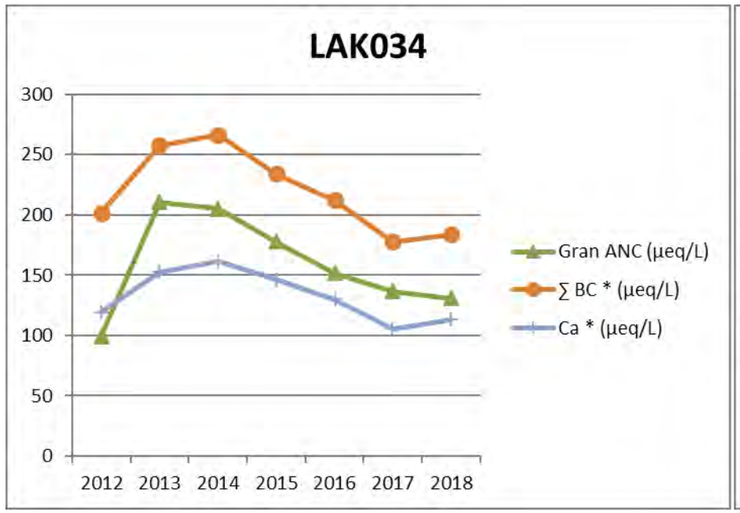


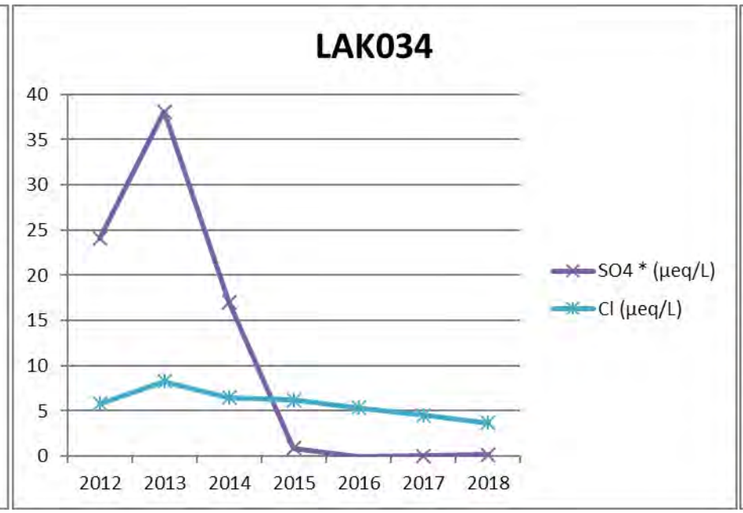


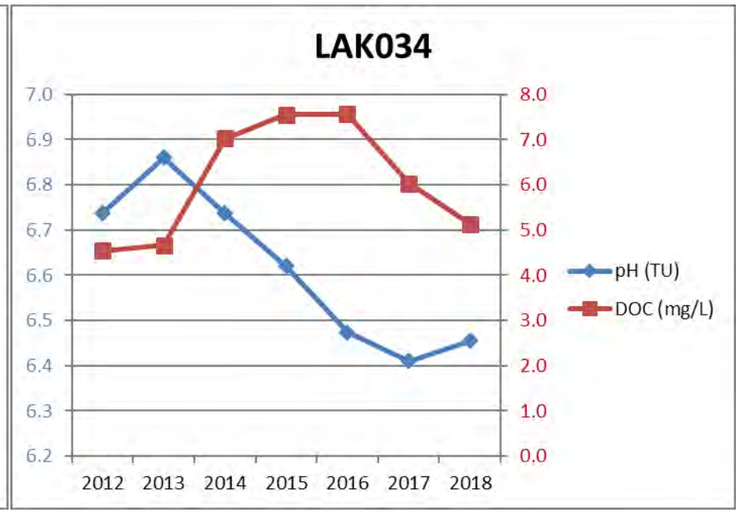

LAK024
600
500
400
300
200
100
0
2012 2013 2014 2015 2016 2017 2018
Gran ANC (µeq/L)
∑ BC * (µeq/L)
Ca * (µeq/L)


LAK024
80
70
60
50
40
30
20
10
0
2012 2013 2014 2015 2016 2017 2018
SO4 * (µeq/L)
Cl (µeq/L)

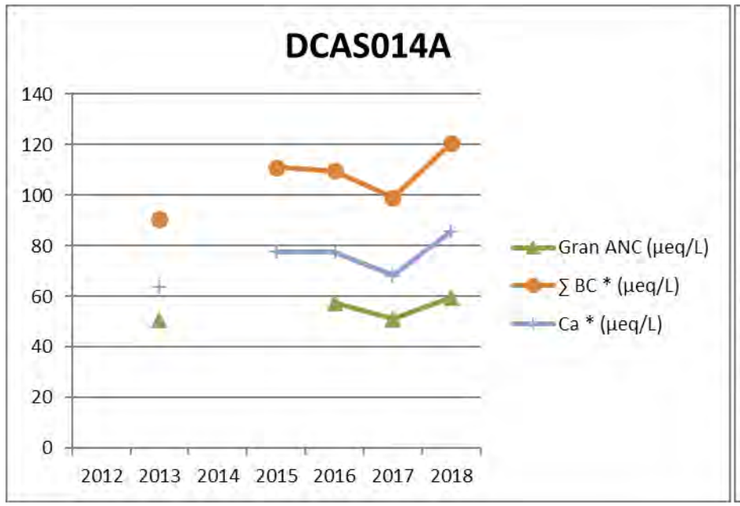

LAK024
7.7
7.6
7.5
7.4
7.3
7.2
7.1
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2012 2013 2014 2015 2016 2017 2018
pH (TU)
DOC (mg/L)

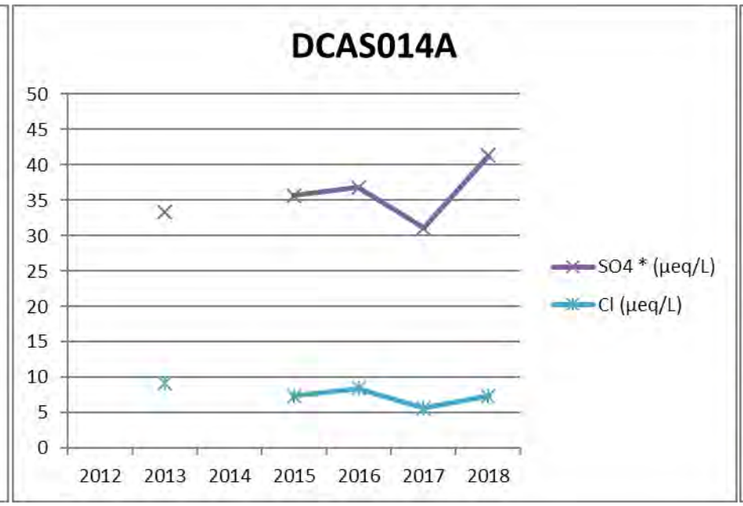

LAK034
300
250
200
150
100
50
0
2012 2013 2014 2015 2016 2017 2018
Gran ANC (µeq/L)
∑ BC * (µeq/L)
Ca * (µeq/L)

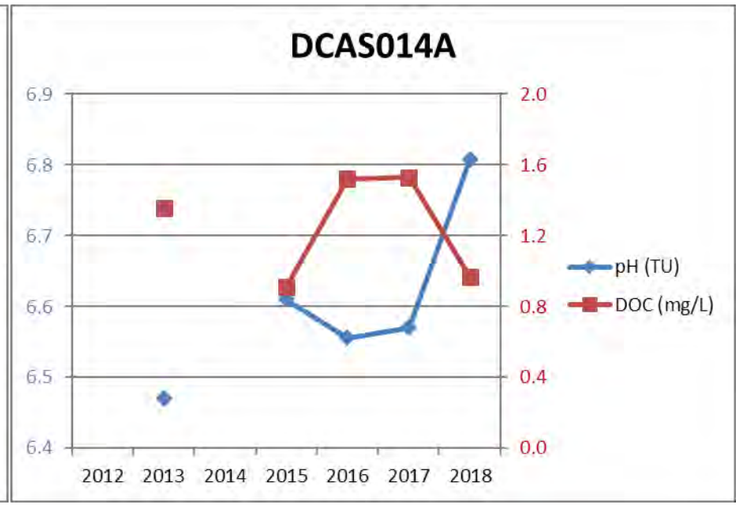

LAK034
40
35
30
25
20
15
10
5
0
2012 2013 2014 2015 2016 2017 2018
SO4 * (µeq/L)
Cl (µeq/L)

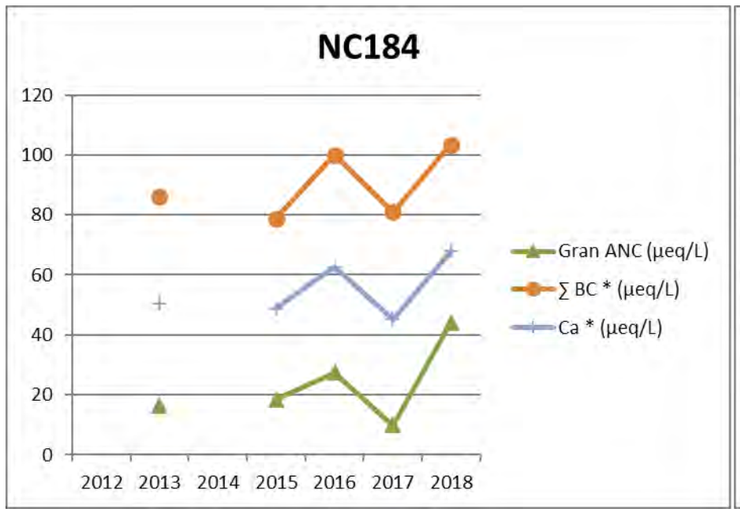

LAK034
7.0
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2012 2013 2014 2015 2016 2017 2018
pH (TU)
DOC (mg/L)

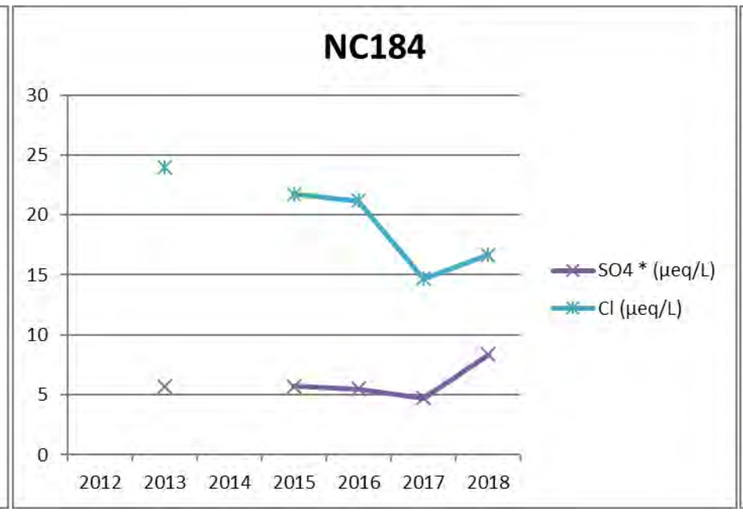
7.3.3 Control Lakes

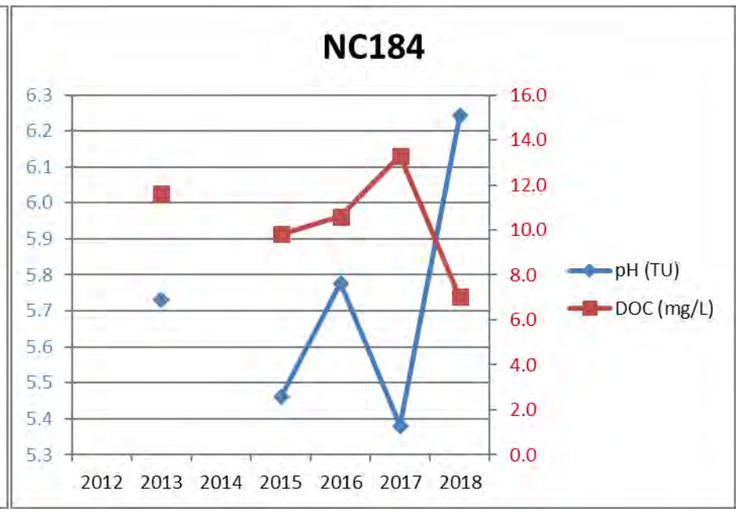


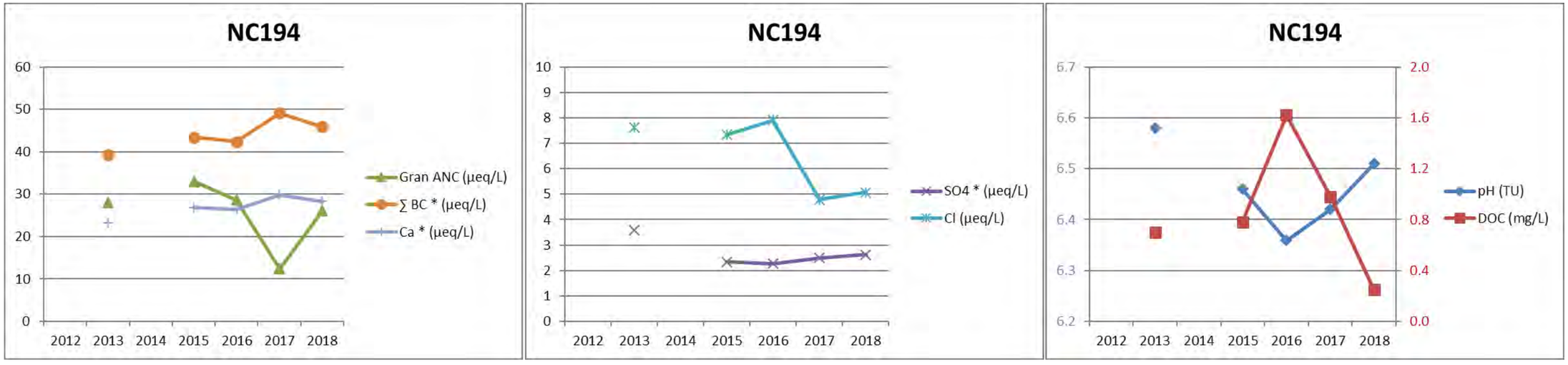











NC194
60
50
40
30
20
10
0
2012 2013 2014 2015 2016 2017 2018
Gran ANC (µeq/L)
∑ BC * (µeq/L)
Ca * (µeq/L)
NC194
10
9
8
7
6
5
4
3
2
1
0
2012 2013 2014 2015 2016 2017 2018
SO4 * (µeq/L)
Cl (µeq/L)
NC194
6.7
6.6
6.5
6.4
6.3
6.2
2.0
1.6
1.2
0.8
0.4
0.0
2012 2013 2014 2015 2016 2017 2018
pH (TU)
DOC (mg/L)

7.4 Aquatic Appendix D: Water Chemistry Data from Annual Sampling (2012-2018)

The two tables below shows the sample results for each of the EEM lakes and control lakes from annual monitoring conducted from 2012 to 2018, including pH, dissolved organic carbon (DOC), Gran ANC, and the concentration of major anions and cations, as well as the sum of all base cations (BC). In 2013-2016, the pH of the water samples was measured by two different laboratories (Trent University and ALS). The first table provides the mean annual value and standard error for each metric for lakes with multiple within-season samples, as calculated from all the within-season samples. The second table presents the sampling data in its "raw" units, as measured, without converting concentration values to charge equivalents. Although acidification studies require converting measured concentrations to charge equivalents, these unconverted values may be more familiar and therefore easier to interpret for some audiences.

Note: these tables provide the original, unadjusted values for base cations and sulphate (i.e., not corrected for marine influence, as done prior to the analyses and explorations presented throughout the Comprehensive Review).

Mean Annual Values

The mean annual values and standard deviation have been calculated for all lakes with multiple within-season samples. Sample values with no standard deviation indicate that only a single annual sample was taken for that particular lake in that particular year.

Lake	Year	pH TU	SE[1]	pH ALS	SE	DOC mg/L	SE	Gran ANC µeq/L	SE	SO_4 µeq/L	SE	Cl µeq/L	SE	F µeq/L	SE	Ca µeq/L	SE	Mg µeq/L	SE	K µeq/L	SE	Na µeq/L	SE	∑ BC µeq/L
Lak006	2012	5.8				3.6		25.7		11.4		5.8		4.5		30.3		12.5		2.9		14.9		60.6
LAK007	2012	8.0				0.6		1437.6		51.4		24.6		2.8		1272.2		157.0		19.3		55.4		1503.9
LAK012	2012	5.6				4.6		57.0		6.1		4.2		5.0		74.5		20.8		5.2		20.0		120.6
LAK016	2012	6.3				3.7		68.7		39.0		6.3		7.8		117.7		20.5		7.3		20.8		166.3
LAK022	2012	5.9				5.3		27.8		30.2		6.9		6.1		58.1		16.0		3.2		20.8		98.1
LAK023	2012	5.7				4.2		19.8		19.0		4.5		5.6		39.4		12.0		3.7		10.8		65.9
LAK024	2012	7.1				1.4		299.5		24.8		27.3		1.6		273.2		33.0		4.2		29.6		340.0
LAK028	2012	5.0				4.9		-4.0		56.9		6.1		20.7		47.5		9.5		3.1		12.8		72.9
LAK034	2012	6.7				4.5		99.4		24.1		5.8		5.8		119.3		31.6		5.8		44.9		201.7
LAK042	2012	4.7				13.2		-20.4		6.2		6.1		3.2		7.4		22.7		3.1		20.3		53.4
LAK044	2012	5.4				1.7		1.3		6.2		5.6		2.9		6.8		3.2		4.1		0.0		14.2
Lak006	2013	6.2		6.1		3.2		29.0		14.4		8.7		5.6		27.1		13.0		5.3		12.2		57.6
LAK007	2013	7.9		8.1		0.1		1462.1		66.5		36.3		3.7		1226.0		156.5		21.9		47.6		1452.0
LAK012	2013	6.3		6.1		4.2		63.5		11.3		14.7		8.2		64.8		20.3		9.2		14.6		108.9
LAK016	2013	6.7		7.2		4.2		96.9		56.9		12.3		11.5		114.4		23.9		11.2		17.6		167.1
LAK022	2013	6.2		6.1		6.2		36.4		47.1		12.4		8.7		65.1		19.2		6.0		18.8		109.1
LAK023	2013	6.0		6.0		4.0		23.8		24.1		7.5		7.4		37.1		13.3		5.1		8.3		63.9
LAK024	2013																							
LAK028	2013	5.2		5.5		7.1		4.8		128.1		17.7		32.0		85.1		18.3		5.0		13.0		121.3
LAK034	2013	6.9		7.4		4.7		210.4		38.1		8.2		10.0		152.7		41.7		9.2		54.1		257.7
LAK042	2013	5.5		5.4		9.7		21.0		5.7		7.7		3.2		16.0		22.3		3.4		19.3		61.0
LAK044	2013	5.7		6.0		1.5		8.6		6.2		8.9		3.8		7.8		3.6		5.9		-2.0		15.3
Lak006	2014	6.1	*0.1*	6.6	*0.2*	3.8	*0.3*	38.8	*0.6*	12.1	*0.6*	8.1	*1.2*	4.8	*0.1*	31.7	*0.5*	14.6	*0.4*	4.7	*0.3*	14.5	*1.2*	65.5
LAK007	2014	8.1		8.0		0.7		1445.7		30.7		19.2		1.9		1276.8		156.7		20.2		61.8		1515.5
LAK012	2014	6.0	*0.1*	6.7	*0.2*	6.3	*1.0*	68.8	*6.8*	15.8	*5.2*	10.3	*2.2*	5.2	*0.2*	69.3	*1.6*	21.3	*0.6*	7.3	*0.5*	18.3	*1.6*	116.1
LAK016	2014	6.7		6.7		4.0		105.7		48.2		9.3		9.5		122.4		25.0		10.1		23.3		180.8
LAK022	2014	6.3		6.4		5.7		46.9		37.8		9.0		6.9		68.5		18.9		5.2		21.4		114.0
LAK023	2014	5.9	*0.1*	6.7	*0.3*	5.7	*0.4*	32.1	*1.1*	18.9	*1.0*	6.1	*0.3*	6.2	*0.2*	49.3	*3.9*	14.9	*0.4*	4.0	*0.1*	10.8	*0.3*	79.0
LAK024	2014	7.6		7.5		1.7		472.1		37.2		65.7		2.3		402.3		50.1		7.8		50.2		510.4
LAK028	2014	5.3		5.7		5.9		22.6		94.4		11.0		23.3		85.9		17.7		4.4		17.6		125.7
LAK034	2014	6.7		7.0		7.0		205.0		17.0		6.5		7.7		161.4		43.6		9.4		51.9		266.3
LAK042	2014	5.1		5.4		10.6		12.5		4.0		11.8		2.6		10.5		23.6		3.7		17.9		55.7

Lake	Year	pH TU	SE[1]	pH ALS	SE	DOC mg/L	SE	Gran ANC µeq/L	SE	SO_4 µeq/L	SE	Cl µeq/L	SE	F µeq/L	SE	Ca µeq/L	SE	Mg µeq/L	SE	K µeq/L	SE	Na µeq/L	SE	∑ BC µeq/L
LAK044	2014	5.8		5.6		1.8		5.9		4.6		5.9		2.8		7.8		3.9		5.3		0.4		17.3
Lak006	2015	6.0	0.1	6.4	0.3	3.9	0.2	32.4	0.4	11.5	0.3	6.6	0.3	4.4	0.1	32.3	0.3	14.8	0.2	3.9	0.1	15.7	0.3	66.7
LAK007	2015	8.0		7.9		0.3		1565.6		45.6		24.0		2.6		1266.6		161.5		21.0		58.6		1507.7
LAK012	2015	6.0	0.1	6.3	0.2	7.5	1.0	65.9	2.1	17.6	3.1	11.1	1.7	4.7	0.1	74.8	3.9	23.2	0.9	8.1	0.8	18.0	0.8	124.2
LAK016	2015	6.8		6.9		4.3		113.1		40.9		8.7		8.6		130.9		25.0		9.8		22.9		188.6
LAK022	2015	6.1		6.2		6.3		35.6		32.5		7.9		5.9		64.1		18.1		4.4		21.2		107.8
LAK023	2015	5.9	0.1	6.2	0.1	5.4	0.4	30.0	1.0	15.1	0.7	6.2	0.3	5.2	0.2	46.1	1.5	13.9	0.3	3.8	0.1	9.7	0.1	73.5
LAK024	2015	7.4		7.5		2.2		443.0		34.7		59.0		2.1		400.5		49.3		8.7		49.0		507.6
LAK028	2015	5.1		5.3		8.1		10.8		71.1		9.0		20.5		76.5		15.7		3.2		14.4		109.8
LAK034	2015	6.6		6.7		7.6		177.8		0.9		6.2		4.7		146.5		37.1		5.3		45.1		234.0
LAK042	2015	5.4		5.5		8.3		13.8		3.8		6.5		2.3		10.7		23.1		2.5		23.0		59.3
LAK044	2015	5.8		5.8		1.6		6.2		3.7		5.9		2.7		9.8		4.4		5.5		0.5		20.3
Lak006	2016	6.0	0.0	6.3	0.1	4.2	0.1	26.9	1.0	11.8	0.2	5.6	0.2	4.2	0.1	32.6	0.5	14.8	0.7	4.2	0.6	17.2	0.9	68.8
LAK007	2016	8.0		8.1		0.8		1368.6		46.7		25.4		2.6		1301.5		162.8		20.2		58.3		1542.8
LAK012	2016	6.2	0.0	6.5	0.1	5.1	0.3	65.8	1.2	9.5	0.5	5.6	0.2	4.6	0.1	64.7	0.8	20.8	0.6	6.0	0.6	21.6	0.8	113.0
LAK016	2016	6.6		6.9		5.2		93.9		44.9		8.5		8.2		127.4		26.4		8.9		23.7		186.5
LAK022	2016	6.1		6.4		6.7		34.4		34.2		7.9		5.8		68.1		19.2		4.2		23.1		114.6
LAK023	2016	5.9	0.0	6.2	0.1	5.8	0.1	27.9	1.9	12.7	0.2	4.9	0.2	5.1	0.1	42.5	0.9	14.1	0.4	4.7	0.5	11.0	0.8	72.3
LAK024	2016	7.5		7.6		2.7		463.1		39.2		70.0		2.3		446.5		55.3		9.5		53.9		565.3
LAK028	2016	5.0	0.1	5.1	0.1	8.1	0.3	-4.9	6.2	127.8	8.1	10.0	0.5	26.8	0.8	94.7	8.3	23.8	1.7	3.7	0.2	19.5	1.6	141.6
LAK034	2016	6.5		7.1		7.6		151.6		0.0		5.4		4.4		130.0		34.3		3.8		44.1		212.3
LAK042	2016	5.4	0.0	5.7	0.0	9.8	0.2	14.0	1.5	3.3	0.2	7.2	0.2	2.2	0.1	16.7	1.7	24.7	0.4	2.7	0.2	23.3	0.2	67.4
LAK044	2016	5.5	0.0	6.0	0.1	2.0	0.1	4.1	1.3	4.1	0.1	6.1	0.1	2.3	0.1	8.2	0.4	4.1	0.0	5.5	0.1	0.3	0.2	18.2
Lak006	2017	6.0	0.1	6.4	0.1	3.8	0.1	27.9	2.7	14.4	0.3	5.4	0.2	4.2	0.0	34.8	0.5	15.6	0.2	4.1	0.1	18.0	0.4	72.5
LAK007	2017	8.0		8.0		0.3		1381.6		47.1		25.9		2.4		1201.7		165.2		19.9		62.6		1449.4
LAK012	2017	6.1	0.1	6.5	0.1	5.2	0.5	58.2	3.2	14.6	2.6	7.0	1.2	4.4	0.1	65.4	4.5	21.7	1.2	7.7	1.0	21.5	0.9	116.3
LAK016	2017	6.7		6.8		4.1		82.7		43.2		7.3		7.7		114.0		24.7		6.9		22.9		168.6
LAK022	2017	6.1		6.3		5.9		34.2		39.0		7.1		5.4		64.1		19.5		3.8		22.2		109.6
LAK023	2017	5.9	0.0	6.2	0.0	5.4	0.1	28.5	2.4	10.1	1.7	4.2	0.3	4.6	0.0	43.2	2.1	13.8	0.3	2.3	0.2	11.2	0.3	70.5
LAK024	2017	7.4		7.6		2.0		416.6		34.9		57.5		2.0		399.6		52.2		8.5		54.2		514.4
LAK028	2017	4.8	0.1	5.1	0.1	7.3	0.6	-9.9	4.5	150.0	13.0	8.7	1.0	27.2	1.7	102.5	11.0	26.5	2.5	3.5	0.4	19.9	1.6	152.4
LAK034	2017	6.4		6.8		6.0		136.5		0.1		4.5		3.4		105.6		30.3		2.7		39.1		177.8
LAK042	2017	5.2	0.1	5.4	0.1	11.6	1.1	2.3	2.1	6.8	0.9	6.7	0.5	2.4	0.0	17.1	2.7	26.9	1.1	2.8	0.3	23.2	0.5	70.0
LAK044	2017	5.6	0.1	6.0	0.1	1.6	0.0	7.0	2.2	4.5	0.2	5.9	0.1	2.2	0.0	7.9	0.1	4.2	0.1	5.6	0.1	0.7	0.2	18.4

Lake	Year	pH		pH		DOC		Gran ANC		SO_4		Cl		F		Ca		Mg		K		Na		∑ BC
		TU	SE[1]	ALS	SE	mg/L	SE	µeq/L	SE	µeq/L	SE	µeq/L	SE	µeq/L	SE	µeq/L	SE	µeq/L	SE	µeq/L	SE	µeq/L	SE	µeq/L
Lak006	2018	6.1	0.0	6.4	0.0	3.8	0.1	28.3	1.2	15.7	0.2	6.1	0.1	4.2	0.1	36.2	0.3	16.1	0.5	4.3	0.3	18.5	0.6	75.1
LAK007	2018	8.1		8.1		0.3		1407.6		47.1		27.9		2.6		1251.5		157.4		20.6		61.3		1490.8
LAK012	2018	6.2	0.1	6.6	0.1	4.6	0.1	50.9	4.3	14.6	0.7	6.2	0.3	4.6	0.1	58.3	0.4	19.7	0.6	6.2	0.3	21.1	0.8	105.2
LAK016	2018	6.7		6.9		4.6		92.8		45.3		7.3		8.1		128.5		23.3		7.3		24.3		183.5
LAK022	2018	6.1		6.3		5.6		30.3		43.2		7.3		5.8		72.1		19.3		4.2		24.4		119.9
LAK023	2018	6.0	0.1	6.4	0.1	5.6	0.2	23.0	0.7	14.1	0.9	4.9	0.2	4.9	0.1	45.9	0.3	15.0	0.3	3.3	0.2	11.4	0.4	75.5
LAK024	2018	7.6		7.6		1.6		509.9		42.6		77.3		2.4		472.7		56.4		9.4		57.2		595.7
LAK028	2018	5.3	0.0	5.5	0.0	4.4	0.1	4.2	1.6	107.5	2.0	6.6	0.2	20.9	0.3	76.4	0.9	19.0	0.5	2.8	0.1	17.9	0.7	116.0
LAK034	2018	6.5		6.6		5.1		130.6		0.1		3.7		3.7		113.1		27.7		2.1		40.8		183.7
LAK042	2018	5.1	0.0	5.3	0.0	10.6	0.4	0.6	1.9	6.3	0.1	6.1	0.2	2.3	0.1	8.8	0.6	23.9	0.5	2.3	0.1	21.8	0.1	56.8
LAK044	2018	5.5	0.0	5.9	0.0	1.9	0.1	3.9	0.9	4.5	0.1	6.4	0.1	2.2	0.0	8.3	0.1	4.1	0.2	5.5	0.1	-0.2	0.3	17.7
NC184	2012																							
NC194	2012																							
DCAS14A	2012																							
NC184	2013	5.7				11.6		16.2		5.7		24.0		0.3		50.5		17.5		4.4		13.8		86.2
NC194	2013	6.6				0.7		28.0		3.6		7.6		0.3		23.2		3.4		5.2		7.4		39.2
DCAS14A	2013	6.5				1.4		50.6		33.4		9.2		0.6		63.9		10.3		10.3		6.1		90.6
NC184	2014																							
NC194	2014																							
DCAS14A	2014																							
NC184	2015	5.5		5.6		9.8		18.4		5.7		21.7		0.5		48.8		16.1		2.9		10.8		78.7
NC194	2015	6.5		6.5		0.8		33.0		2.3		7.3		0.5		26.9		4.4		4.3		7.9		43.4
DCAS14A	2015	6.6		6.7		0.9				35.7		7.3		0.5		77.6		12.4		11.2		9.9		111.0
NC184	2016	5.8		6.2		10.6		27.3		5.5		21.2		0.5		62.6		19.3		2.7		15.5		100.1
NC194	2016	6.4		6.6		1.6		28.7		2.3		7.9		0.5		26.4		4.3		3.8		7.9		42.4
DCAS14A	2016	6.6		6.8		1.5		57.5		36.8		8.5		0.5		77.5		11.8		10.5		9.7		109.6
NC184	2017	5.4		6.0		13.3		9.8		4.7		14.7		0.5		45.2		17.4		2.5		15.9		81.0
NC194	2017	6.4		6.4		1.0		12.4		2.5		4.8		0.5		29.9		5.7		3.6		9.9		49.1
DCAS14A	2017	6.6		6.7		1.5		51.0		31.1		5.6		0.5		68.2		11.8		9.1		9.9		99.0
NC184	2018	6.2		6.4		7.0		44.0		8.3		16.6		0.5		67.8		17.3		3.1		15.3		103.4
NC194	2018	6.5		6.7		0.3		26.1		2.6		5.1		0.5		28.3		4.3		4.1		9.1		45.8
DCAS14A	2018	6.8		6.8		1.0		59.3		41.3		7.3		0.5		85.6		12.6		11.5		10.7		120.4

[1] SE = standard error

Sampling Data in "Raw" Units

The annual or mean annual values (depending on whether the lake had multiple within-season samples) are presented in their "raw" units, as measured, without converting concentration values to charge equivalents.

Lake	Year	pH (TU)	pH (ALS)	DOC (mg/L)	Gran Alkalinity (mg/L)	Conduct-ivity (µS/s)	SO_4 (mg/L)	Cl (mg/L)	F (mg/L)	NO3 (µg/L)	NH4 (µg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)
Lak006	2012	5.8		3.6	1.3	6.7	0.6	0.2	0.1	0.1	3.0	0.6	0.2	0.1	0.5	0.0	0.1	0.0
Lak007	2012	8.0		0.6	71.9	148.9	2.6	0.9	0.1	4.7	1.8	25.5	2.0	0.8	1.8	0.0	0.0	0.0
LAK012	2012	5.6		4.6	2.9	12.7	0.3	0.1	0.1	0.7	3.4	1.5	0.3	0.2	0.5	0.7	0.1	0.2
LAK016	2012	6.3		3.7	3.4	17.9	1.9	0.2	0.1	0.8	3.9	2.4	0.3	0.3	0.6	0.0	0.1	0.0
LAK022	2012	5.9		5.3	1.4	10.7	1.5	0.2	0.1	0.7	3.7	1.2	0.2	0.1	0.6	0.0	0.1	0.0
LAK023	2012	5.7		4.2	1.0	7.5	0.9	0.2	0.1	0.3	3.3	0.8	0.2	0.1	0.3	0.0	0.1	0.0
LAK024	2012	7.1		1.4	15.0	40.0	1.3	1.0	0.0	0.4	2.4	5.5	0.5	0.2	1.2	0.0	0.0	0.0
LAK028	2012	5.0		4.9	-0.2	12.2	2.8	0.2	0.4	1.5	3.4	1.0	0.1	0.1	0.4	0.1	0.4	0.0
LAK034	2012	6.7		4.5	5.0	22.4	1.2	0.2	0.1	1.6	4.9	2.4	0.4	0.2	1.1	0.0	0.0	0.0
LAK042	2012	4.7		13.2	-1.0	11.9	0.3	0.2	0.1	0.7	8.5	0.2	0.3	0.1	0.6	0.6	0.4	0.0
LAK044	2012	5.4		1.7	0.1	3.1	0.3	0.2	0.1	0.4	3.0	0.1	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2013	6.2	6.1	3.2	1.5	7.0	0.7	0.3	0.1	2.5	2.5	0.5	0.2	0.2	0.5	0.0	0.0	0.0
Lak007	2013	7.9	8.1	0.1	73.2	147.0	3.4	1.3	0.1	2.5	2.5	24.6	2.0	0.9	1.8	0.0	0.0	0.0
LAK012	2013	6.3	6.1	4.2	3.2	12.8	0.6	0.5	0.2	2.5	2.5	1.3	0.3	0.4	0.6	0.4	0.1	0.0
LAK016	2013	6.7	7.2	4.2	4.9	20.3	2.8	0.4	0.2	22.7	7.1	2.3	0.3	0.4	0.6	0.0	0.0	0.0
LAK022	2013	6.2	6.1	6.2	1.8	13.8	2.3	0.4	0.2	2.5	2.5	1.3	0.3	0.2	0.7	0.1	0.1	0.0
LAK023	2013	6.0	6.0	4.0	1.2	9.6	1.2	0.3	0.1	30.1	2.5	0.7	0.2	0.2	0.3	0.0	0.1	0.0
LAK024	2013																	
LAK028	2013	5.2	5.5	7.1	0.2	20.3	6.2	0.6	0.6	20.4	2.5	1.7	0.3	0.2	0.6	0.2	0.6	0.0
LAK034	2013	6.9	7.4	4.7	10.5	28.3	1.9	0.3	0.2	2.5	2.5	3.1	0.5	0.4	1.4	0.0	0.0	0.0
LAK042	2013	5.5	5.4	9.7	1.1	8.0	0.3	0.3	0.1	2.5	2.5	0.3	0.3	0.1	0.6	0.3	0.3	0.0
LAK044	2013	5.7	6.0	1.5	0.4	3.3	0.3	0.3	0.1	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2014	6.1	6.6	3.8	1.9	8.5	0.6	0.3	0.1	7.7	40.5	0.6	0.2	0.2	0.5	0.0	0.1	0.0
Lak007	2014	8.1	8.0	0.7	72.4	154.2	1.6	0.7	0.0	2.5	2.5	25.6	2.0	0.8	1.8	0.0	0.0	0.0
LAK012	2014	6.0	6.7	6.3	3.4	13.9	0.8	0.4	0.1	7.6	5.3	1.4	0.3	0.3	0.6	0.3	0.1	0.0
LAK016	2014	6.7	6.7	4.0	5.3	21.5	2.4	0.3	0.2	2.5	6.7	2.5	0.3	0.4	0.7	0.0	0.1	0.0
LAK022	2014	6.3	6.4	5.7	2.3	14.4	1.9	0.3	0.1	2.5	2.5	1.4	0.3	0.2	0.7	0.1	0.1	0.0
LAK023	2014	5.9	6.7	5.7	1.6	9.3	0.9	0.2	0.1	10.9	5.3	1.0	0.2	0.2	0.4	0.0	0.1	0.0
LAK024	2014	7.6	7.5	1.7	23.6	63.1	2.1	2.3	0.0	5.1	2.5	8.1	0.8	0.4	2.5	0.0	0.0	0.0
LAK028	2014	5.3	5.7	5.9	1.1	20.2	4.6	0.4	0.4	2.5	2.5	1.7	0.2	0.2	0.6	0.1	0.5	0.0
LAK034	2014	6.7	7.0	7.0	10.3	27.5	0.9	0.2	0.1	2.5	2.5	3.2	0.5	0.4	1.3	0.1	0.0	0.0
LAK042	2014	5.1	5.4	10.6	0.6	10.8	0.3	0.4	0.1	2.5	2.5	0.2	0.3	0.2	0.6	0.4	0.3	0.0

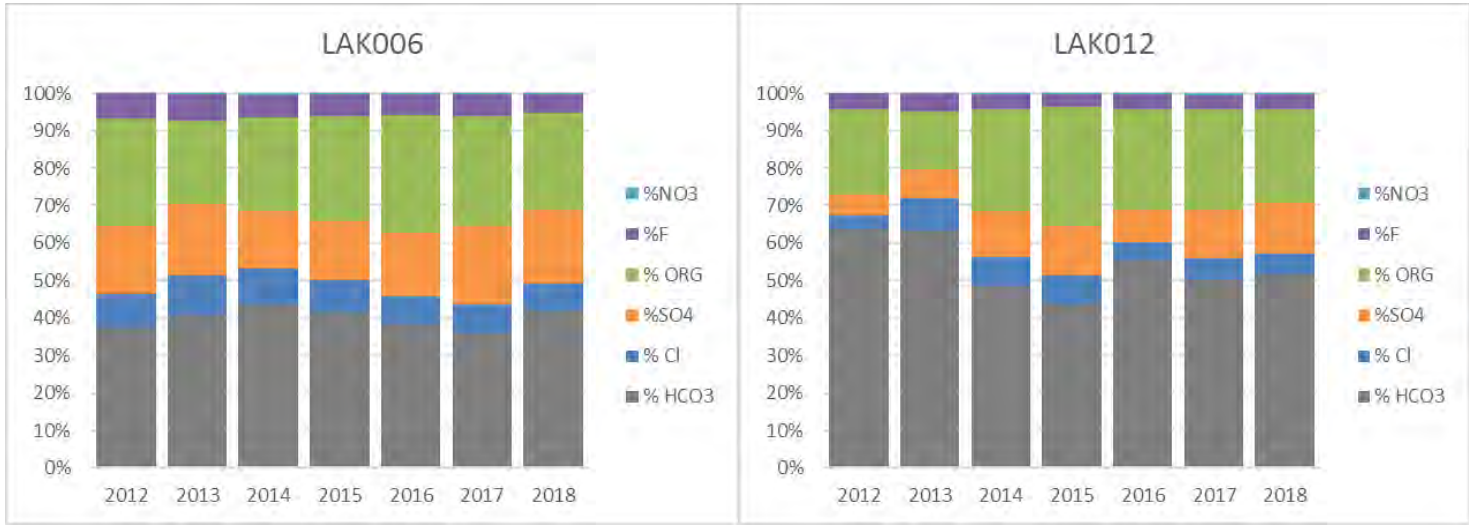
Lake	Year	pH (TU)	pH (ALS)	DOC (mg/L)	Gran Alkalinity (mg/L)	Conduct-ivity (µS/s)	SO_4 (mg/L)	Cl (mg/L)	F (mg/L)	NO3 (µg/L)	NH4 (µg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)
LAK044	2014	5.8	5.6	1.8	0.3	3.6	0.3	0.2	0.1	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2015	6.0	6.4	3.9	1.6	5.6	0.6	0.2	0.1	3.4	5.4	0.7	0.2	0.2	0.5	0.1	0.1	0.0
Lak007	2015	8.0	7.9	0.3	78.4	151.2	2.3	0.9	0.0	5.6	2.5	25.4	2.0	0.8	1.8	0.0	0.0	0.0
LAK012	2015	6.0	6.3	7.5	3.3	10.1	0.9	0.4	0.1	8.3	8.0	1.5	0.3	0.3	0.6	0.3	0.1	0.0
LAK016	2015	6.8	6.9	4.3	5.7	20.7	2.0	0.3	0.2	7.9	2.5	2.6	0.3	0.4	0.7	0.0	0.1	0.0
LAK022	2015	6.1	6.2	6.3	1.8	12.8	1.6	0.3	0.1	2.5	2.5	1.3	0.2	0.2	0.6	0.1	0.1	0.0
LAK023	2015	5.9	6.2	5.4	1.5	5.9	0.8	0.2	0.1	6.3	2.5	0.9	0.2	0.2	0.3	0.0	0.1	0.0
LAK024	2015	7.4	7.5	2.2	22.2	58.7	2.0	2.1	0.0	8.1	2.5	8.1	0.7	0.4	2.3	0.1	0.0	0.0
LAK028	2015	5.1	5.3	8.1	0.5	17.8	3.5	0.3	0.4	2.5	2.5	1.5	0.2	0.1	0.5	0.2	0.6	0.0
LAK034	2015	6.6	6.7	7.6	8.9	22.3	0.1	0.2	0.1	2.5	2.5	2.9	0.5	0.2	1.2	0.1	0.0	0.0
LAK042	2015	5.4	5.5	8.3	0.7	8.1	0.2	0.2	0.0	2.5	2.5	0.2	0.3	0.1	0.7	0.2	0.3	0.0
LAK044	2015	5.8	5.8	1.6	0.3	3.5	0.2	0.2	0.1	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2016	6.0	6.3	4.2	1.3	7.8	0.6	0.2	0.1	2.5	2.5	0.7	0.2	0.2	0.5	0.0	0.1	0.0
Lak007	2016	8.0	8.1	0.8	68.5	153.7	2.4	0.9	0.1	6.5	2.5	26.1	2.0	0.8	1.8	0.0	0.0	0.0
LAK012	2016	6.2	6.5	5.1	3.3	12.4	0.5	0.2	0.1	5.0	4.7	1.3	0.3	0.2	0.6	0.3	0.1	0.0
LAK016	2016	6.6	6.9	5.2	4.7	20.8	2.2	0.3	0.2	10.9	2.5	2.6	0.3	0.4	0.7	0.0	0.1	0.0
LAK022	2016	6.1	6.4	6.7	1.7	13.7	1.7	0.3	0.1	2.5	2.5	1.4	0.3	0.2	0.7	0.1	0.1	0.0
LAK023	2016	5.9	6.2	5.8	1.4	9.1	0.6	0.2	0.1	2.5	5.1	0.9	0.2	0.2	0.4	0.0	0.1	0.0
LAK024	2016	7.5	7.6	2.7	23.2	66.3	2.2	2.5	0.0	20.7	2.5	9.0	0.8	0.4	2.6	0.1	0.0	0.0
LAK028	2016	5.0	5.1	8.1	-0.2	23.7	6.2	0.4	0.5	21.5	2.5	1.9	0.3	0.2	0.6	0.1	0.7	0.0
LAK034	2016	6.5	7.1	7.6	7.6	22.1	0.0	0.2	0.1	2.5	2.5	2.6	0.4	0.2	1.1	0.1	0.0	0.0
LAK042	2016	5.4	5.7	9.8	0.7	8.8	0.2	0.3	0.0	2.5	3.7	0.3	0.3	0.1	0.7	0.2	0.3	0.0
LAK044	2016	5.5	6.0	2.0	0.2	3.9	0.2	0.2	0.0	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2017	6.0	6.4	3.8	1.4	8.8	0.7	0.2	0.1	2.5	2.5	0.7	0.2	0.2	0.5	0.0	0.1	0.0
Lak007	2017	8.0	8.0	0.3	69.1	149.0	2.4	0.9	0.0	2.5	2.5	24.1	2.1	0.8	2.0	0.0	0.0	0.0
LAK012	2017	6.1	6.5	5.2	2.9	12.9	0.7	0.2	0.1	9.7	5.6	1.3	0.3	0.3	0.6	0.3	0.1	0.0
LAK016	2017	6.7	6.8	4.1	4.1	18.5	2.1	0.3	0.1	2.5	2.5	2.3	0.3	0.3	0.7	0.0	0.1	0.0
LAK022	2017	6.1	6.3	5.9	1.7	12.8	1.9	0.3	0.1	2.5	2.5	1.3	0.3	0.2	0.6	0.0	0.1	0.0
LAK023	2017	5.9	6.2	5.4	1.4	7.9	0.5	0.2	0.1	7.7	2.5	0.9	0.2	0.1	0.3	0.0	0.1	0.0
LAK024	2017	7.4	7.6	2.0	20.9	57.4	2.0	2.0	0.0	11.2	2.5	8.1	0.8	0.4	2.4	0.1	0.0	0.0
LAK028	2017	4.8	5.1	7.3	-0.5	26.9	7.2	0.3	0.5	25.3	3.3	2.1	0.3	0.1	0.6	0.1	0.7	0.0
LAK034	2017	6.4	6.8	6.0	6.8	17.6	0.0	0.2	0.1	2.5	2.5	2.1	0.4	0.1	1.0	0.1	0.0	0.0
LAK042	2017	5.2	5.4	11.6	0.1	9.8	0.4	0.2	0.0	2.5	5.4	0.3	0.3	0.1	0.7	0.3	0.4	0.0
LAK044	2017	5.6	6.0	1.6	0.4	4.4	0.2	0.2	0.0	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0

Lake	Year	pH (TU)	pH (ALS)	DOC (mg/L)	Gran Alkalinity (mg/L)	Conduct-ivity (µS/s)	SO_4 (mg/L)	Cl (mg/L)	F (mg/L)	NO3 (µg/L)	NH4 (µg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)
Lak006	2018	6.1	6.4	3.8	1.4	8.8	0.8	0.2	0.1	2.5	2.5	0.7	0.2	0.2	0.5	0.0	0.1	0.0
Lak007	2018	8.1	8.1	0.3	70.4	147.4	2.4	1.0	0.0	2.5	2.5	25.1	2.0	0.8	2.0	0.0	0.0	0.0
LAK012	2018	6.2	6.6	4.6	2.5	11.5	0.7	0.2	0.1	2.5	2.5	1.2	0.3	0.2	0.6	0.3	0.1	0.0
LAK016	2018	6.7	6.9	4.6	4.6	20.0	2.2	0.3	0.2	2.5	2.5	2.6	0.3	0.3	0.7	0.0	0.1	0.0
LAK022	2018	6.1	6.3	5.6	1.5	13.4	2.1	0.3	0.1	2.5	2.5	1.5	0.3	0.2	0.7	0.0	0.1	0.0
LAK023	2018	6.0	6.4	5.6	1.1	9.4	0.7	0.2	0.1	2.5	2.5	0.9	0.2	0.1	0.4	0.0	0.1	0.0
LAK024	2018	7.6	7.6	1.6	25.5	70.2	2.4	2.7	0.0	2.5	2.5	9.5	0.9	0.4	2.8	0.0	0.0	0.0
LAK028	2018	5.3	5.5	4.4	0.2	17.7	5.2	0.2	0.4	2.5	3.3	1.5	0.2	0.1	0.5	0.1	0.5	0.0
LAK034	2018	6.5	6.6	5.1	6.5	17.8	0.0	0.1	0.1	2.5	2.5	2.3	0.3	0.1	1.0	0.0	0.0	0.0
LAK042	2018	5.1	5.3	10.6	0.0	8.6	0.3	0.2	0.0	2.5	2.5	0.2	0.3	0.1	0.6	0.3	0.4	0.0
LAK044	2018	5.5	5.9	1.9	0.2	3.6	0.2	0.2	0.0	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
NC184	2012																	
NC194	2012																	
DCAS14A	2012																	
NC184	2013	5.7		11.6	0.8	10.0	0.4	0.9	0.0	5.0	1.0	1.0	0.3	0.2	0.8			
NC194	2013	6.6		0.7	1.4	3.9	0.2	0.3	0.0	1.0	1.0	0.5	0.1	0.2	0.3			
DCAS14A	2013	6.5		1.4	2.5	10.6	1.7	0.3	0.0	52.6	2.5	1.3	0.1	0.4	0.3	0.0	0.0	0.0
NC184	2014																	
NC194	2014																	
DCAS14A	2014																	
NC184	2015	5.5	5.6	9.8	0.9	11.6	0.4	0.8	0.0	2.5	2.5	1.0	0.2	0.1	0.7	0.2	0.3	0.0
NC194	2015	6.5	6.5	0.8	1.7	5.4	0.1	0.3	0.0	2.5	2.5	0.5	0.1	0.2	0.3	0.0	0.0	0.0
DCAS14A	2015	6.6	6.7	0.9		14.0	1.8	0.3	0.0	6.8	2.5	1.6	0.2	0.4	0.4	0.0	0.0	0.0
NC184	2016	5.8	6.2	10.6	1.4	12.8	0.4	0.8	0.0	2.5	2.5	1.3	0.3	0.1	0.8	0.1	0.3	0.0
NC194	2016	6.4	6.6	1.6	1.4	5.9	0.1	0.3	0.0	2.5	2.5	0.5	0.1	0.2	0.3	0.0	0.0	0.0
DCAS14A	2016	6.6	6.8	1.5	2.9	14.8	1.8	0.3	0.0	2.5	2.5	1.6	0.2	0.4	0.4	0.0	0.0	0.0
NC184	2017	5.4	6.0	13.3	0.5	11.4	0.3	0.5	0.0	2.5	2.5	0.9	0.2	0.1	0.7	0.2	0.3	0.0
NC194	2017	6.4	6.4	1.0	0.6	4.9	0.1	0.2	0.0	2.5	2.5	0.6	0.1	0.1	0.3	0.0	0.0	0.0
DCAS14A	2017	6.6	6.7	1.5	2.6	11.7	1.5	0.2	0.0	2.5	2.5	1.4	0.2	0.4	0.3	0.0	0.0	0.0
NC184	2018	6.2	6.4	7.0	2.2	12.3	0.5	0.6	0.0	2.5	2.5	1.4	0.3	0.1	0.7	0.1	0.2	0.0
NC194	2018	6.5	6.7	0.3	1.3	5.4	0.2	0.2	0.0	2.5	2.5	0.6	0.1	0.2	0.3	0.0	0.0	0.0
DCAS14A	2018	6.8	6.8	1.0	3.0	14.7	2.0	0.3	0.0	2.5	2.5	1.7	0.2	0.5	0.4	0.0	0.0	0.0

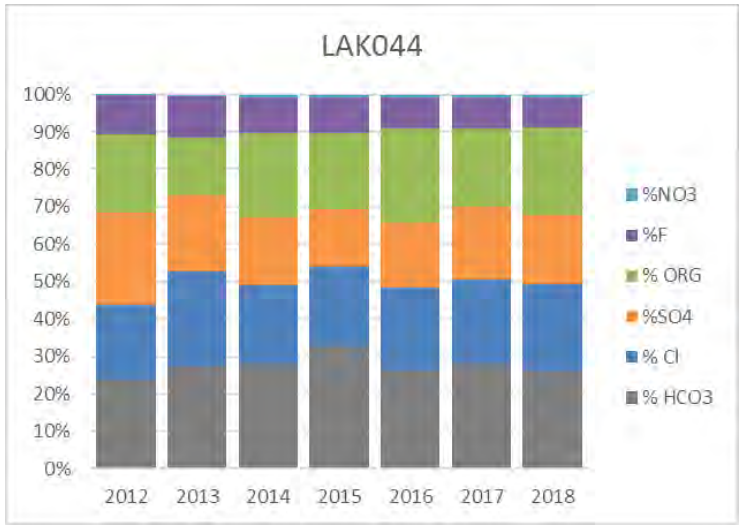
7.5 Aquatic Appendix E: Anion Composition

For each of the EEM lakes, the figures in this appendix show the inter-annual changes in the composition of major anions (HCO_3^-, SO_4^{2-}, F^-, Cl^-, NO_3^-, and organic anions) from 2012 to 2018. Composition is expressed in terms of the percent of total anions.

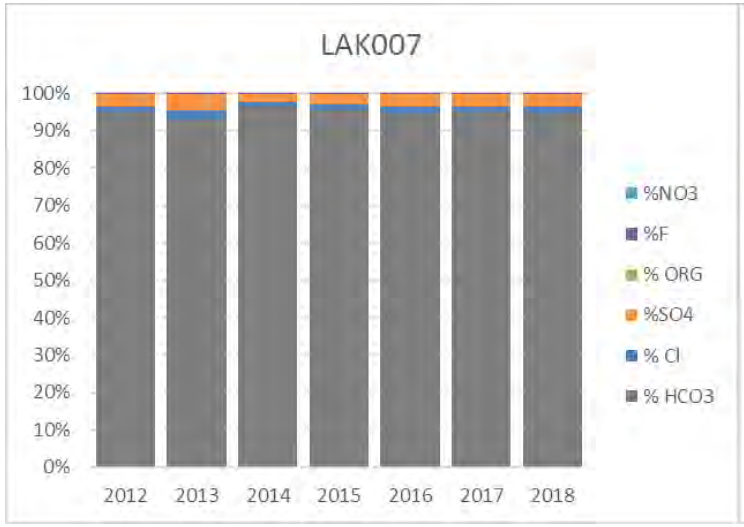
7.5.1 Sensitive Lakes

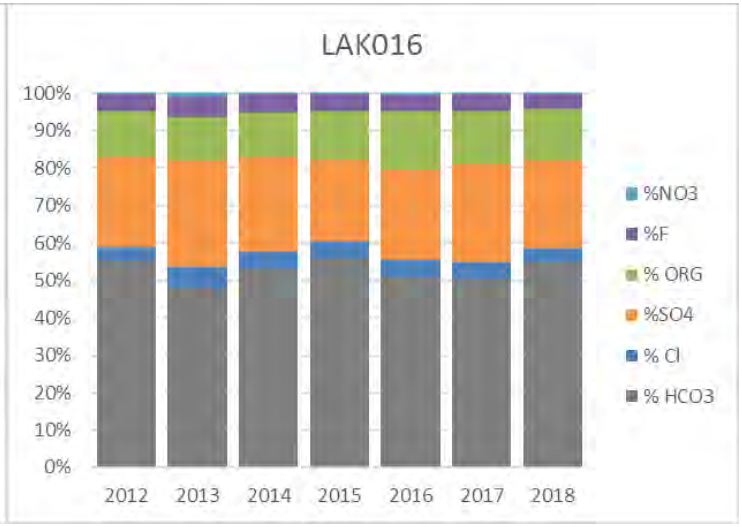


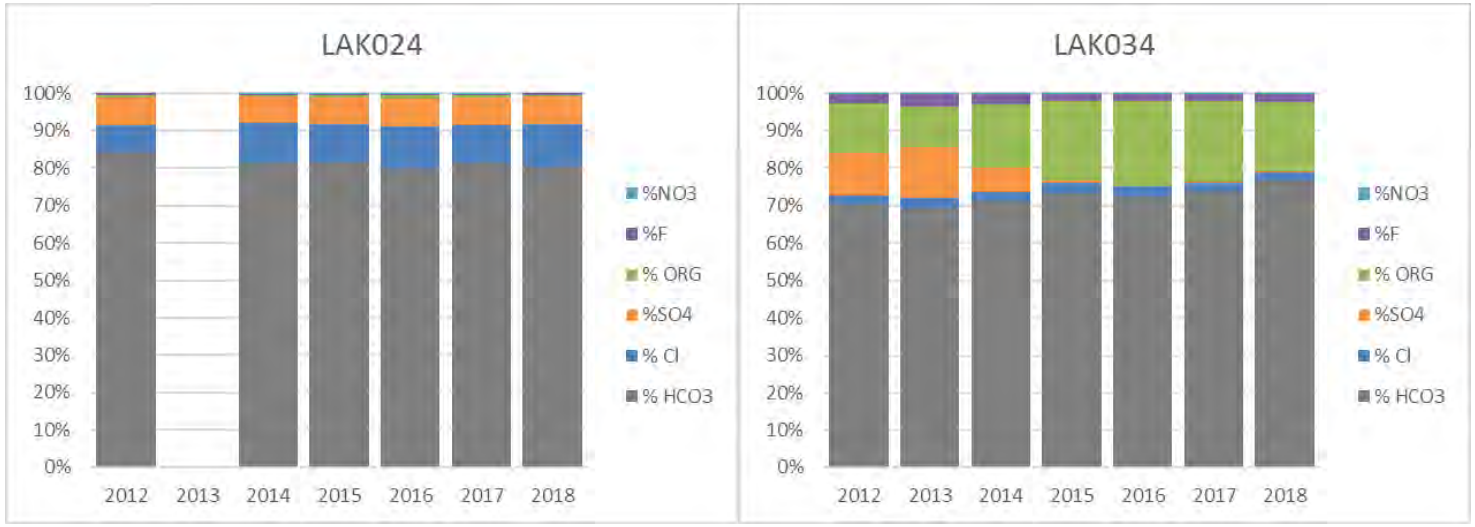

LAK022
LAK023
LAK028
LAK042
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2012
2013
2014
2015
2016
2017
2018
%NO3
%F
% ORG
%SO4
% Cl
% HCO3



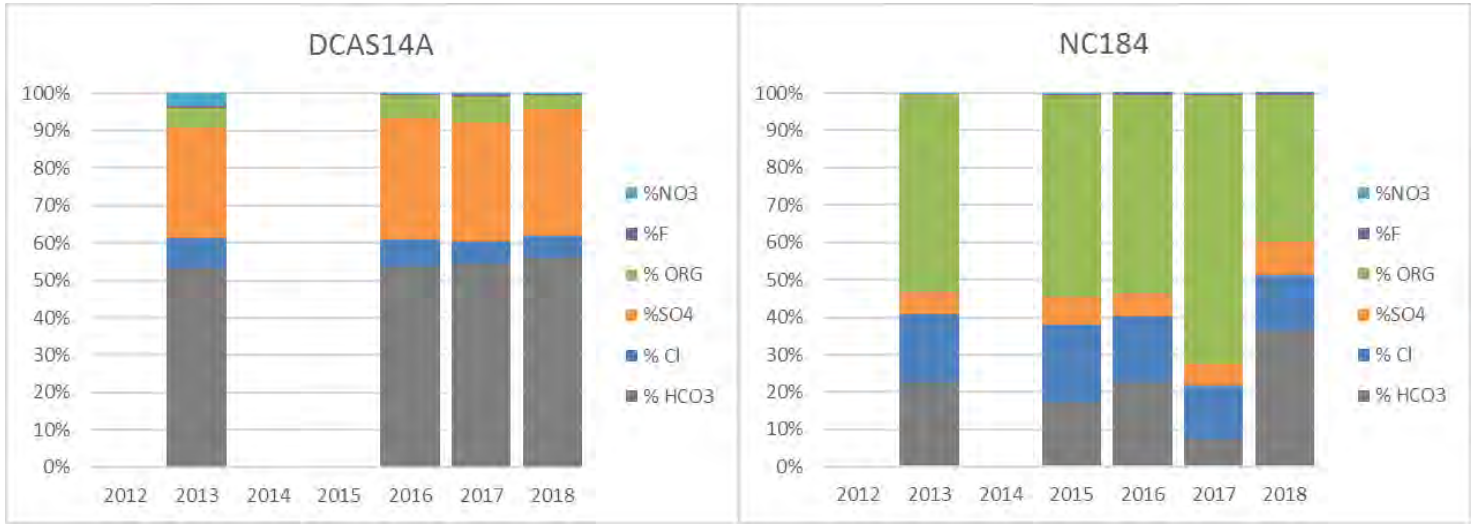
7.5.2 Less Sensitive Lakes

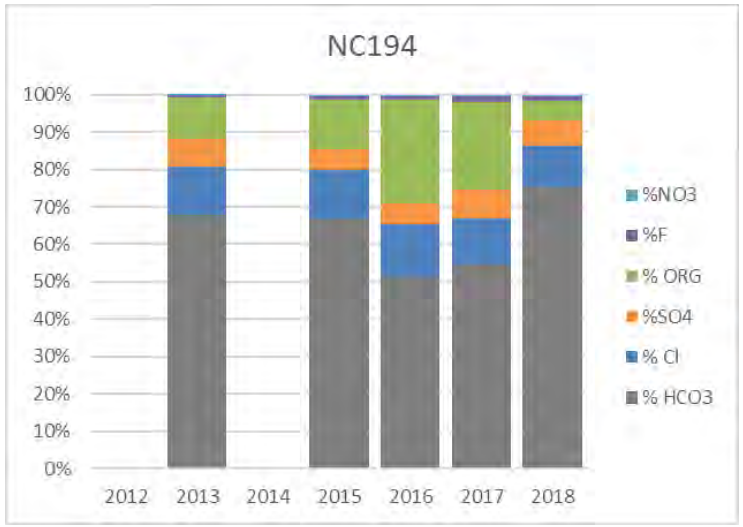






7.5.3 Control Lakes




NC194
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2012
2013
2014
2015
2016
2017
2018
%NO3
%F
% ORG
%SO4
% Cl
% HCO3

7.6 Aquatic Appendix F: Statistical Analysis of Water Chemistry Data

7.6.1 Introduction

The EEM Plan (ESSA et al. 2014; chapter 7) described an evidentiary framework for assessing whether or not changes in lake chemistry could be causally attributed to emissions from the Kitimat smelter. Figure 7.35 is a simplified representation of the evidentiary framework, helpful for providing context for the analyses which follow. Section 7.6.2 is a reference section, providing graphs of the patterns of change in water chemistry within each lake, both over time and in relation to precipitation and emissions. In Section 7.6.3 we provide an overview of the statistical power analyses completed in 2016. Section 7.6.4 is the core of this Appendix, with statistical analyses of changes in water chemistry in support of the evidentiary framework. Building on Figure 7.35, we focus first on changes in lake sulphate (Section 7.6.4.2, where statistical methods are described), and then examine pH (Section 7.6.4.3) and Gran ANC (Section 7.6.4.4), using the data collected from fall samples. In Section 7.6.4.5, we consider the data collected from three intensively monitored lakes. Section 7.6.4.6 summarizes all of the changes in the three primary variables by lake. It is worth emphasizing that the goal of these analyses is to determine whether or not the smelter has caused lake acidification, and if so, whether the magnitude of acidification exceeds thresholds for biological effects. While it may be of scientific interest to understand the causes of all chemical changes in each lake, that is beyond the scope of the EEM, the Comprehensive Report and this analysis.

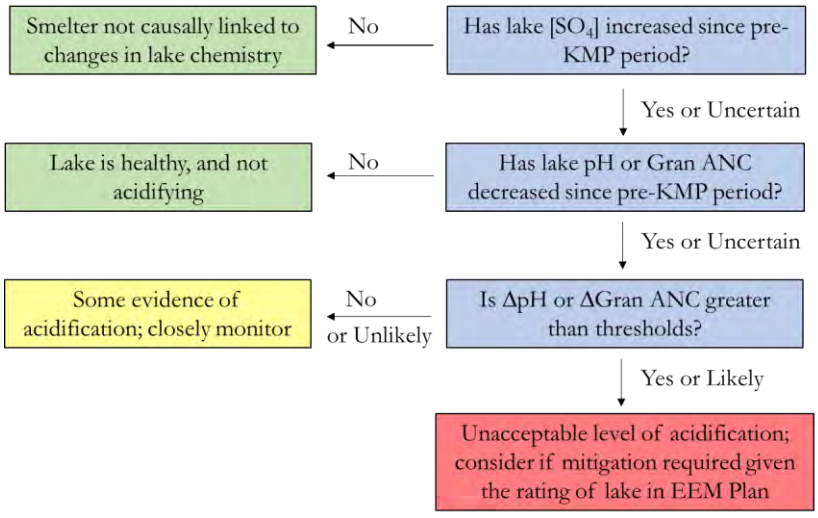


Figure 7.35: Simplification of the evidentiary framework presented in chapter 7 of the SO_2 EEM Plan.

7.6.2 General Patterns of Variability and Change

7.6.2.1 Water Chemistry Time Series

Description of Analyses:

- Time series of lake chemistry data

Purpose of Analyses:

- To first understand patterns of change in water chemistry over space and time, prior to exploring possible reasons for these patterns
- The patterns of interest include variability across and within years within each lake, differences in the magnitude of variability across different lakes, and differences in water chemistry between different groups of lakes (e.g., sensitive, less sensitive, control)
- These graphs are meant to simply display general patterns of changes over time or relationships between variables, independent of any statistical analysis, assignment of causality or application of the evidentiary framework.

7.6.2.1.1 SO_4 over time

- See Section 7.6.4.2 for statistical analyses of changes in sulphate
- See Section 7.6.4.6 for an integration of analyses of changes in sulphate, pH and ANC by lake

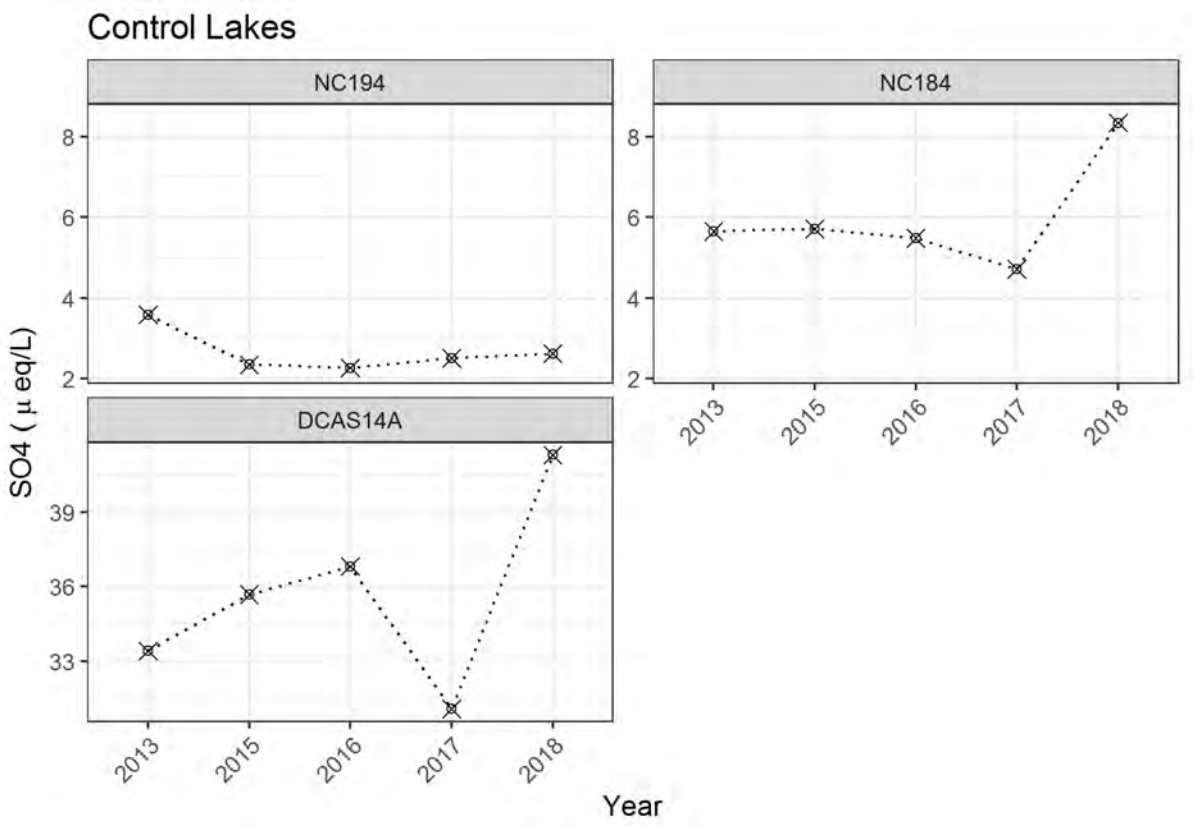


Figure 7.36: Annual trend of SO_4 concentrations for the control lakes (DCAS14A, NC184, NC194) for the years 2013-2018. Note that the scales are different on the y-axes. Graphs use the minimum and maximum concentrations for each lakes to make the relative patterns comparable. The magnitude of change in DCAS14A (Alastair Lake) is much larger than in the other two control lakes.

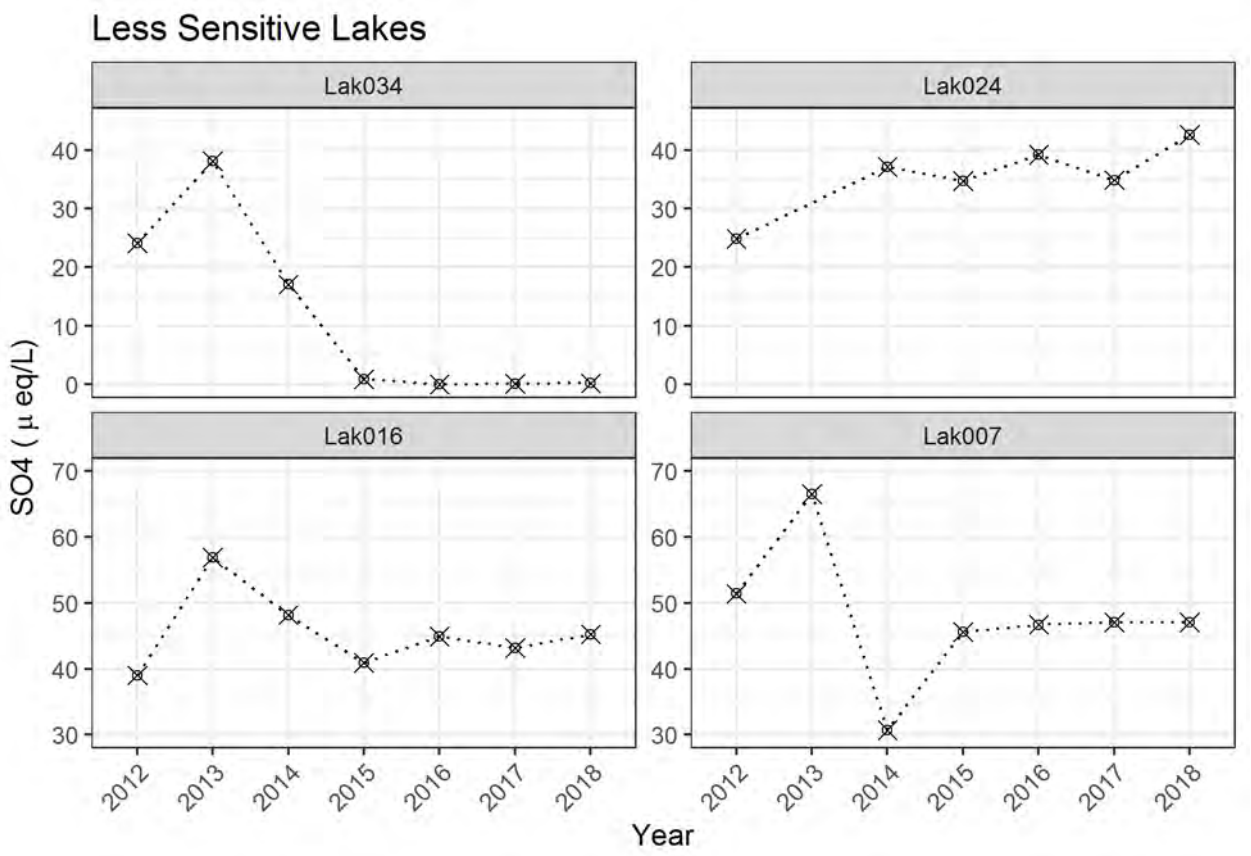


Figure 7.37: Annual trend of SO_4 concentrations for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034) for the years 2012-2018. Note that the scales are different on the y-axes.

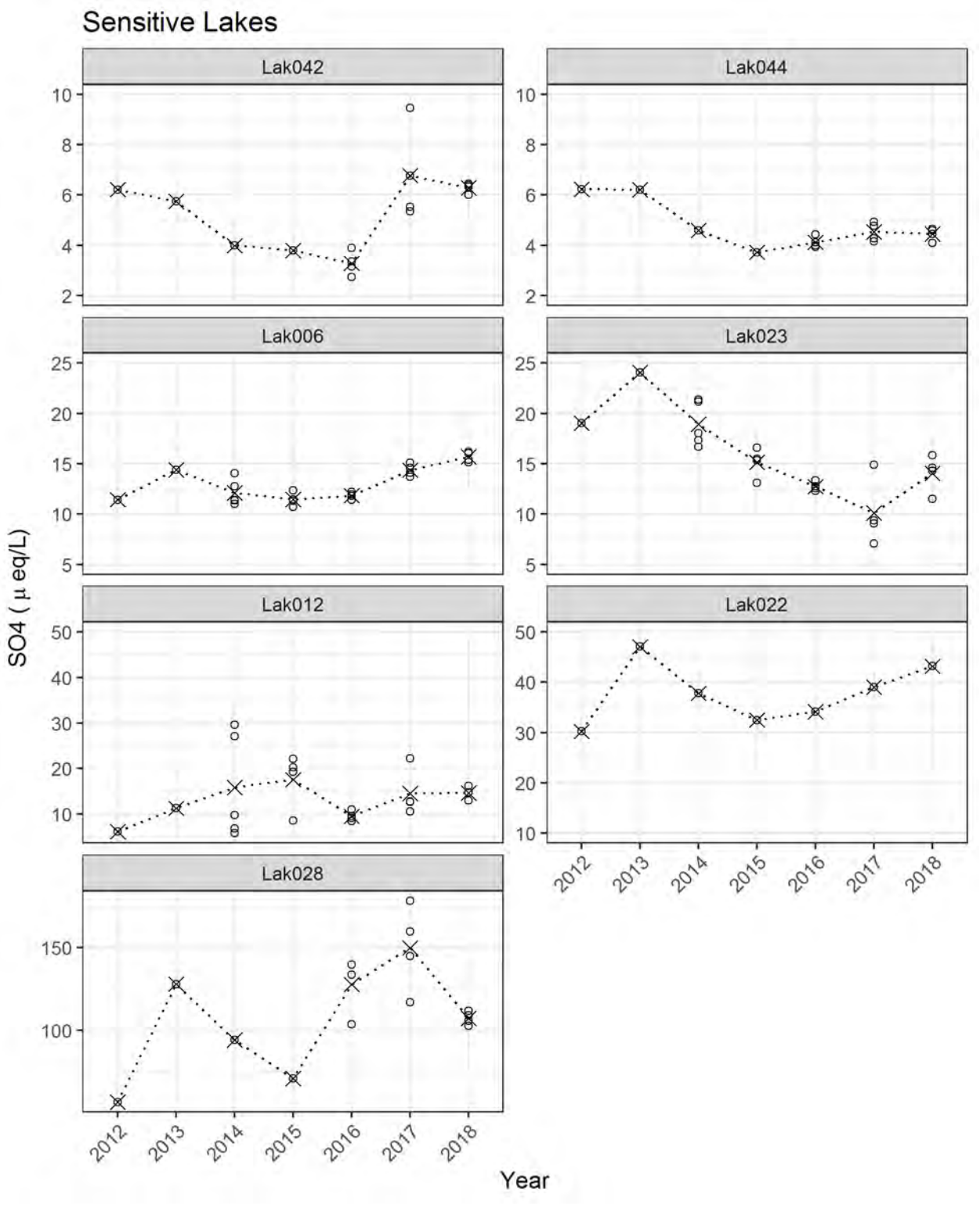


Figure 7.38: Annual trend of SO_4 for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044) for the years 2012-2018. Note that the scales are different on the y-axes.

7.6.2.1.2 Gran ANC over time

- See Section 7.6.4.4 for statistical analyses of changes in Gran ANC
- See Section 7.6.4.6 for an integration of analyses of changes in sulphate, pH and ANC by lake

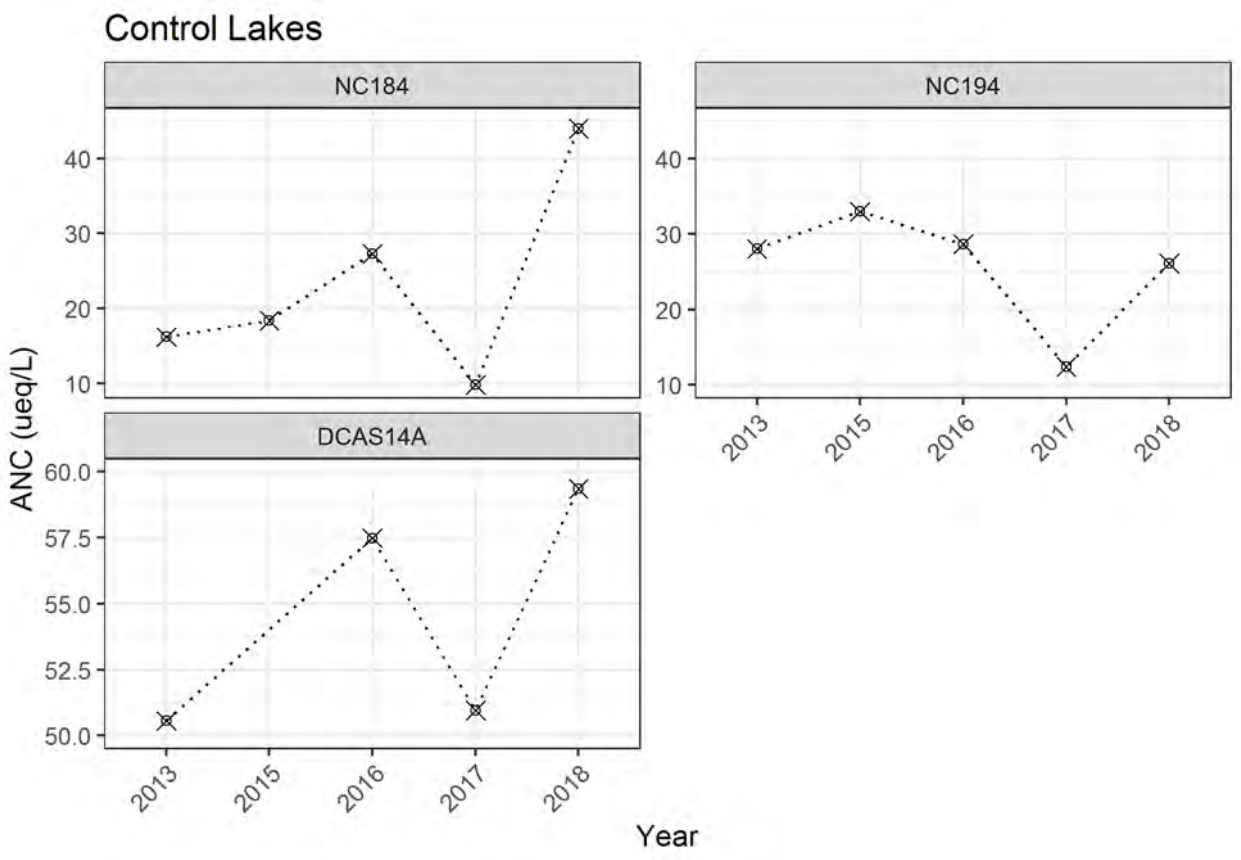


Figure 7.39: Annual trend in Gran ANC (µeq/L) for the control lakes (DCAS14A, NC184, NC194) for the years 2013-2018.

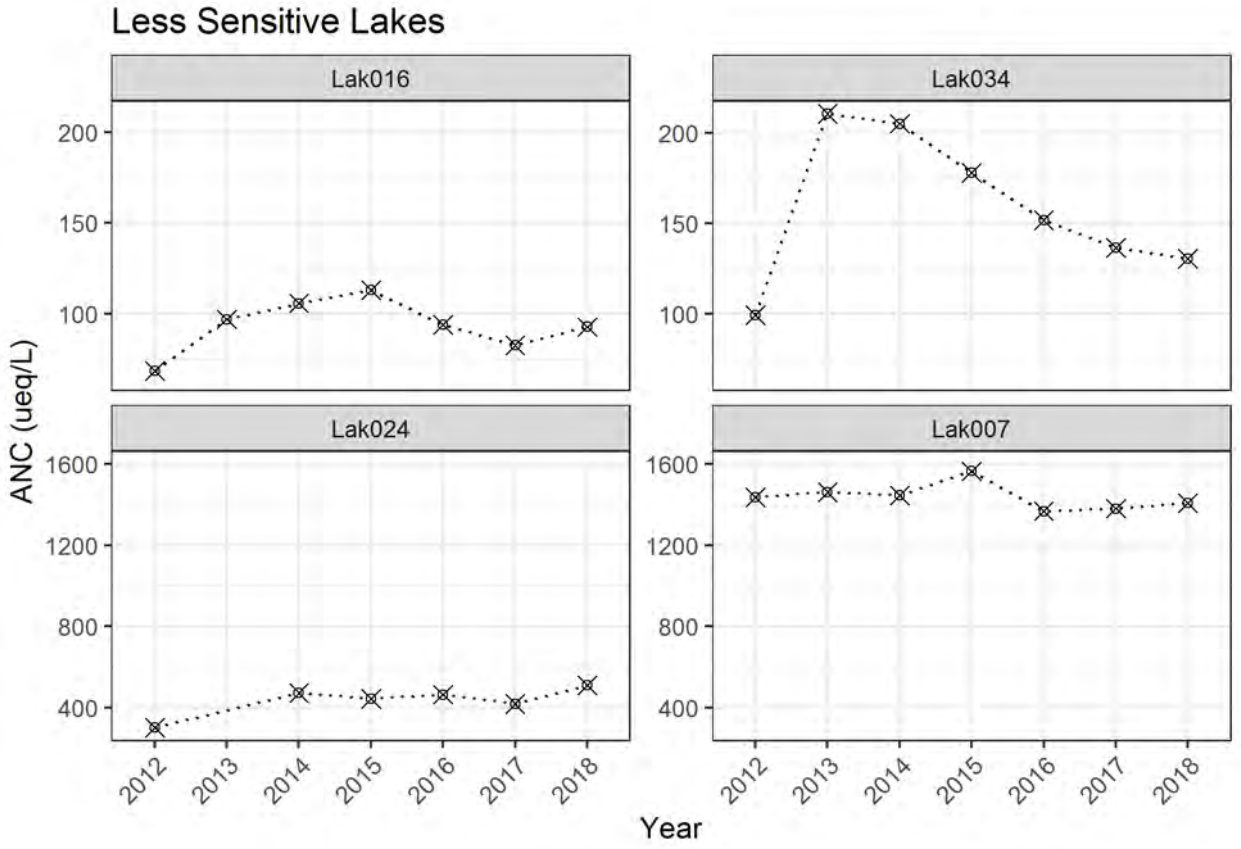


Figure 7.40: Annual trend in Gran ANC (µeq/L) for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034) for the years 2012-2018. Note that the scales are different on the y-axes.

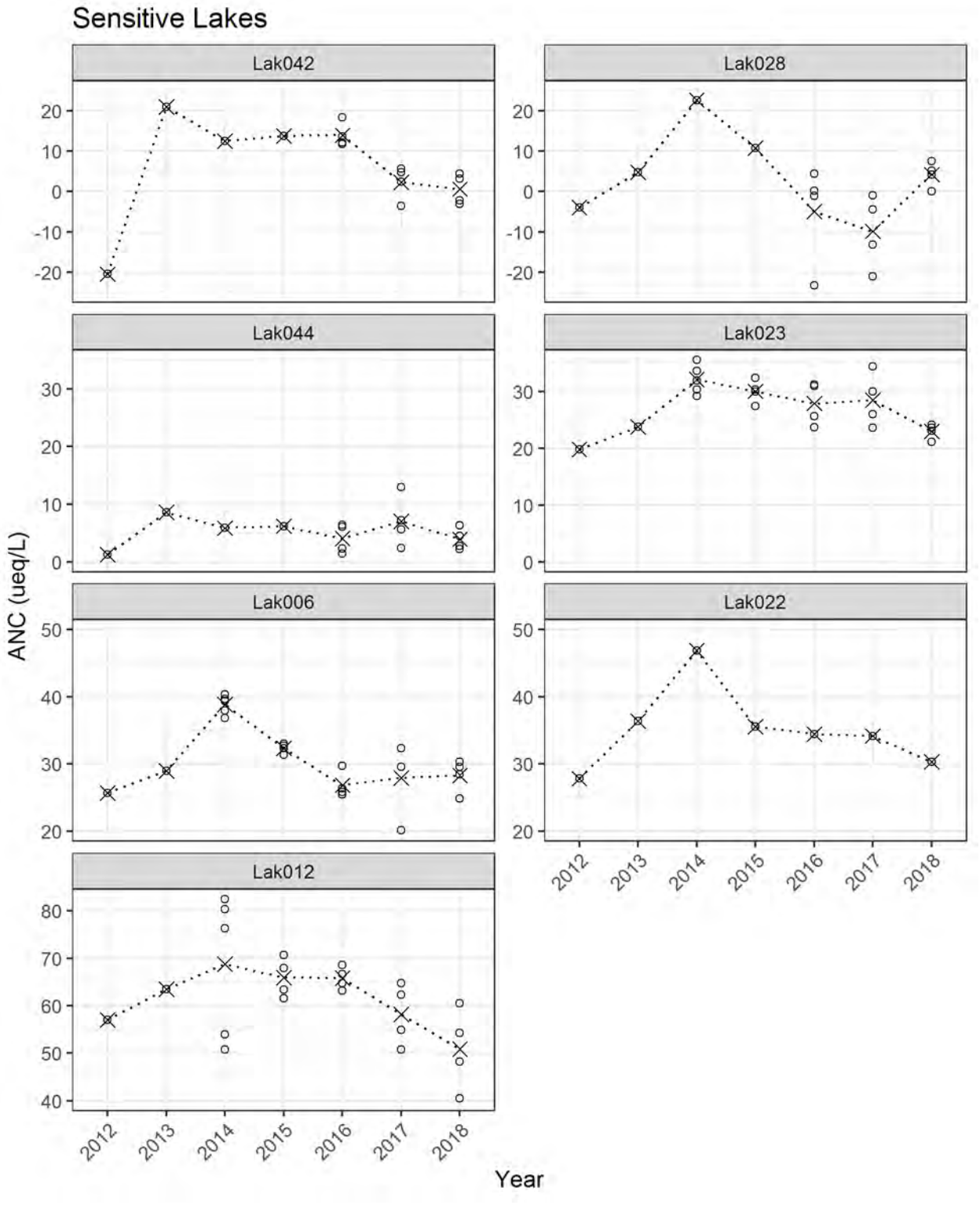


Figure 7.41: Annual trend of Gran ANC (µeq/L) for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044) for the years 2012-2018. Note that the scales are different on the y-axes.

7.6.2.1.3 pH over time

- See Section 7.6.4.3 for statistical analyses of changes in pH
- See Section 7.6.4.6 for an integration of analyses of changes in sulphate, pH and ANC by lake

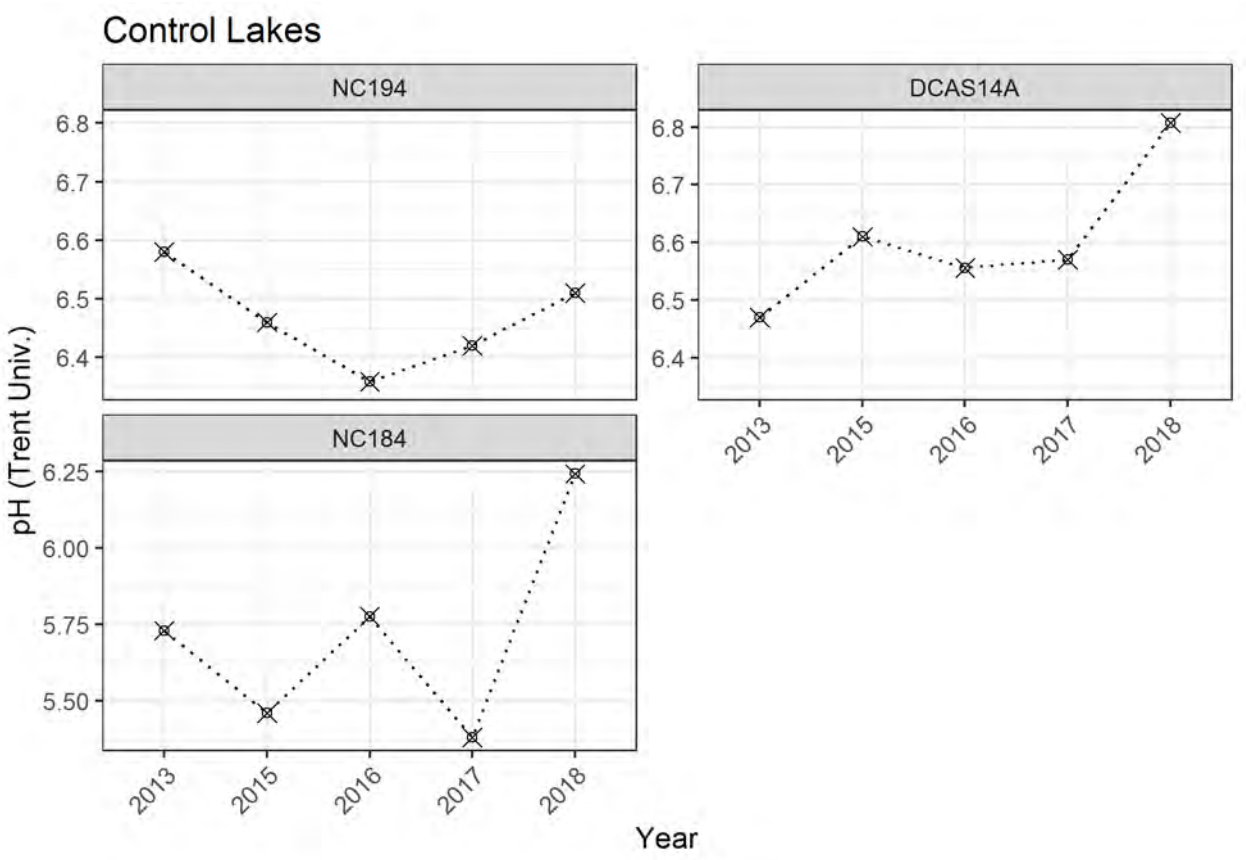


Figure 7.42: Annual trend of pH for the control lakes (DCAS14A, NC184, NC194) for the years 2013-2018. Note that the scales are different on the y-axes.

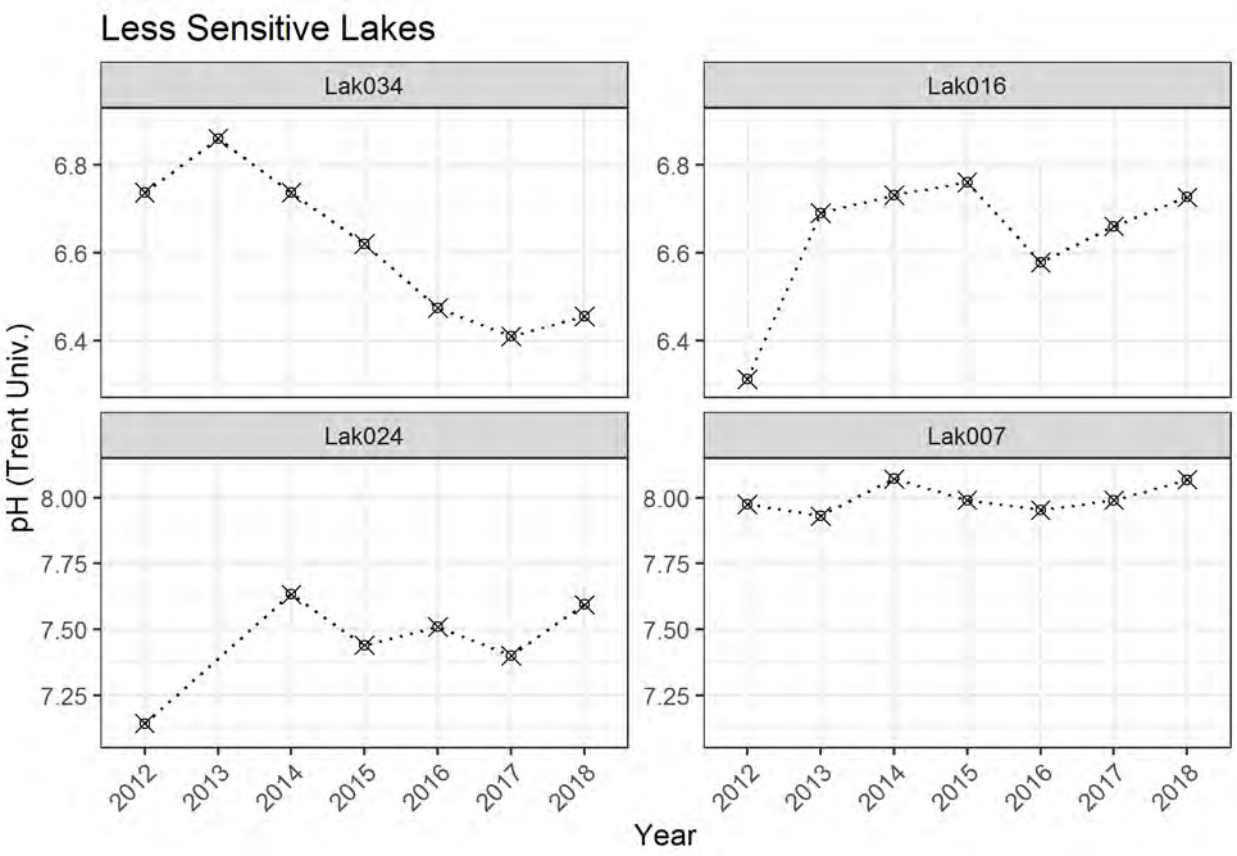


Figure 7.43: Annual trend of pH for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034) for the years 2012-2018. Note that the scales are different on the y-axes.

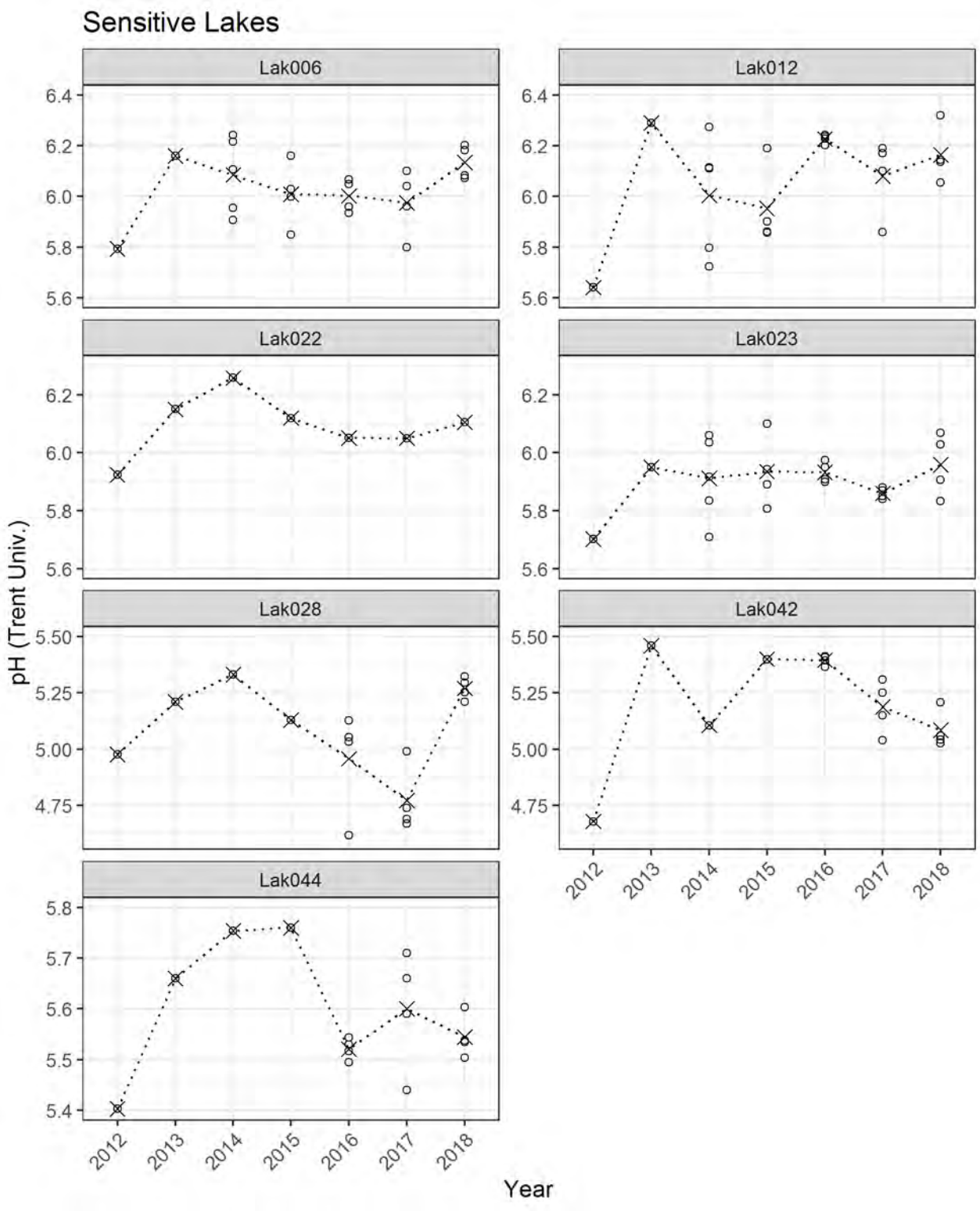


Figure 7.44. Annual trend of pH for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044) for the years 2012-2018.

7.6.2.1.4 DOC over time

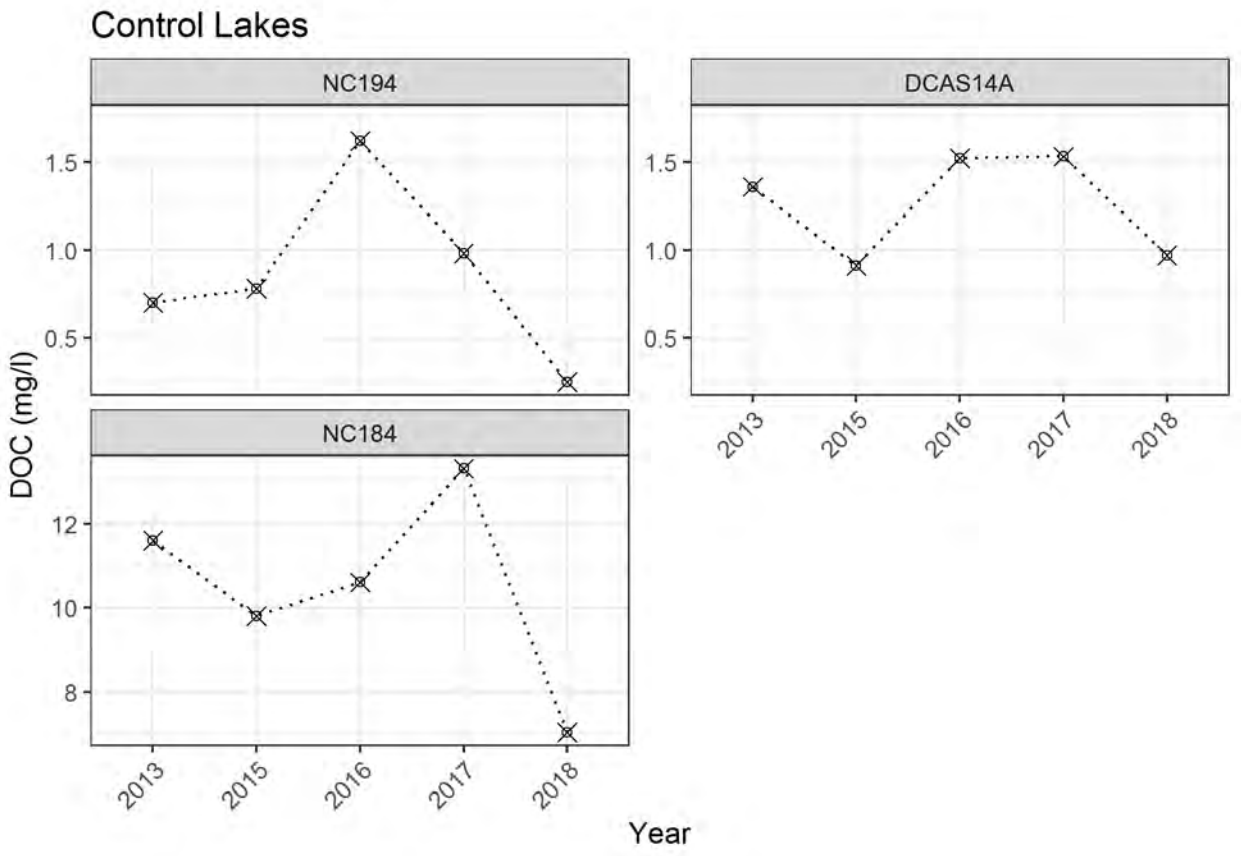


Figure 7.45: Annual trend in DOC (mg/L) for the control lakes (DCAS14A, NC184, NC194) for the years 2013-2018.

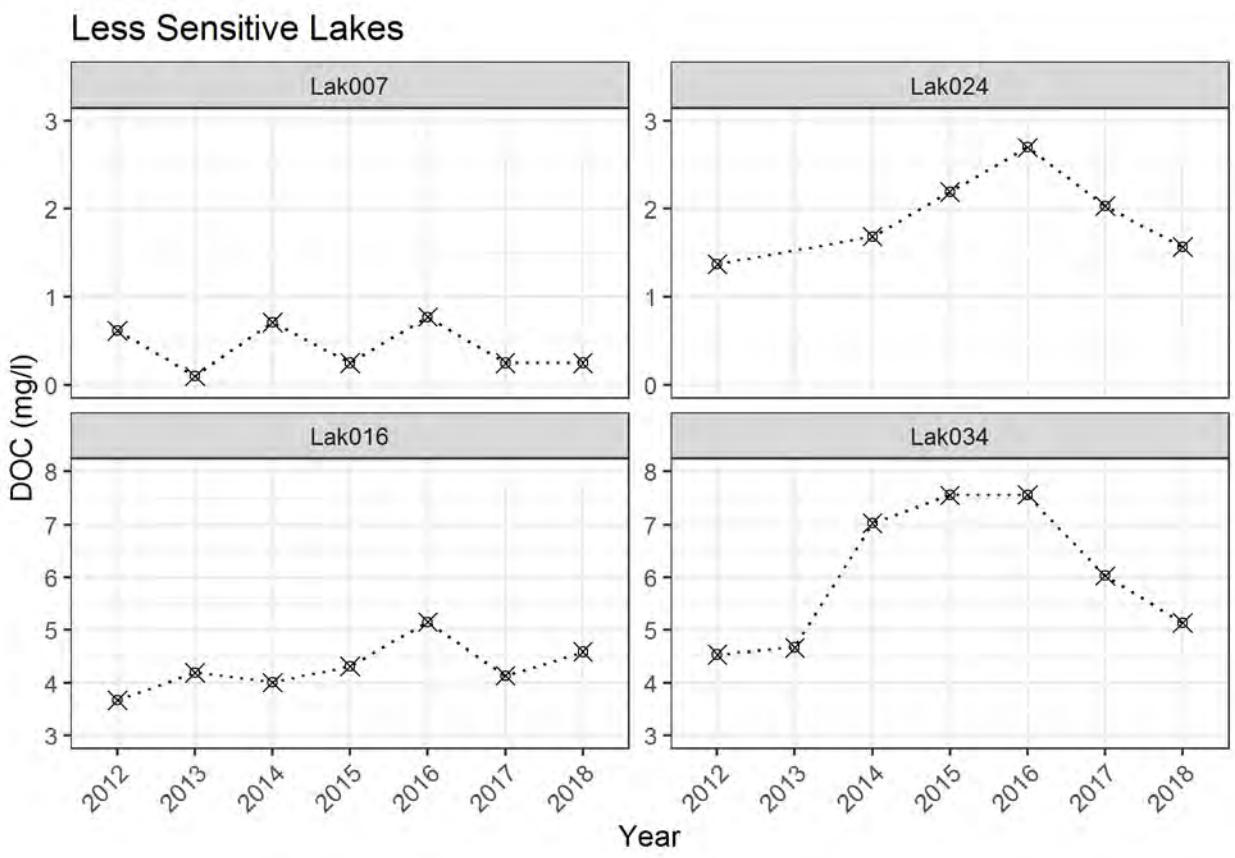


Figure 7.46: Annual trend in DOC (mg/L) for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034) for the years 2012-2018.

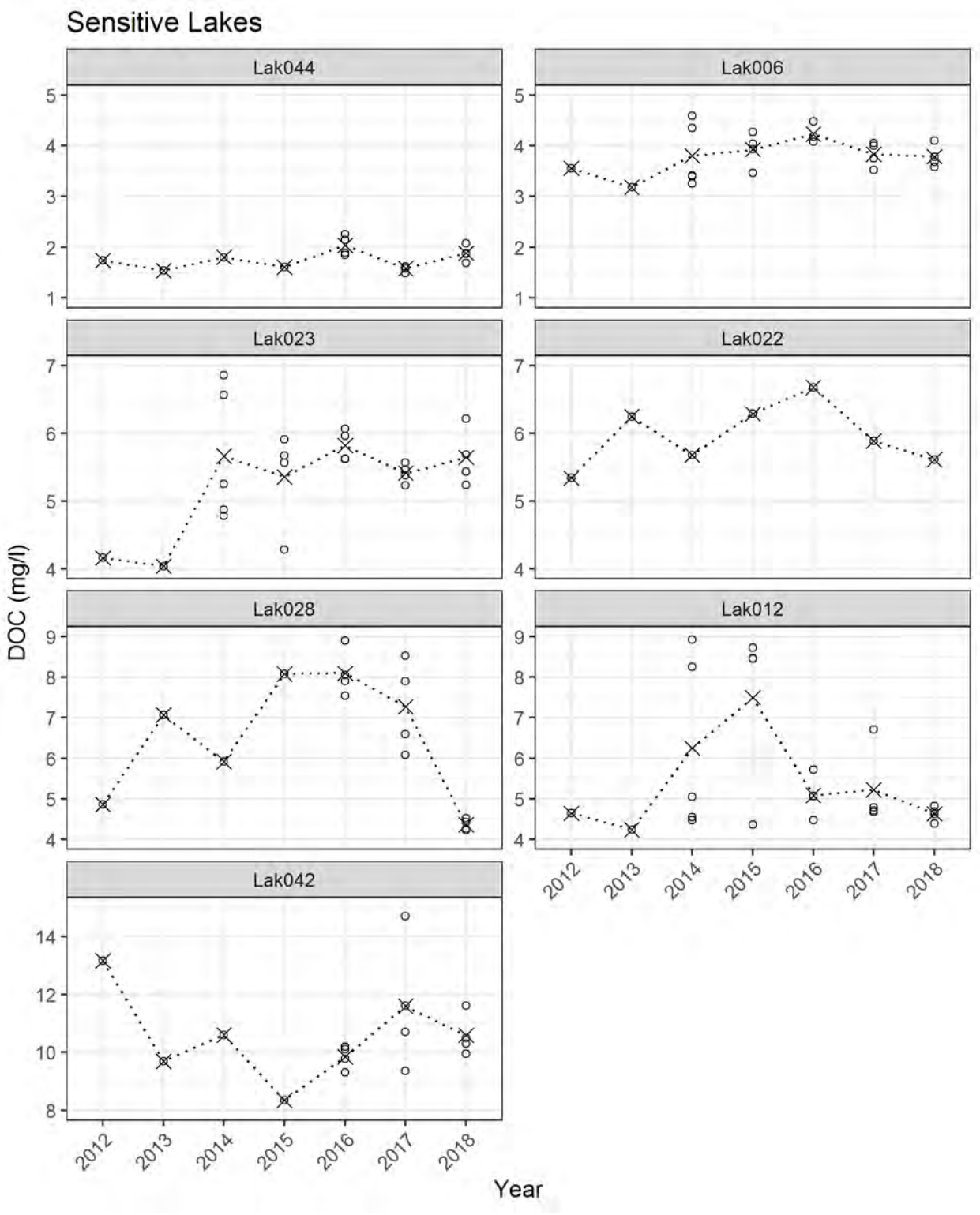


Figure 7.47: Annual trend of DOC (mg/L) for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044) for the years 2012-2018.

7.6.2.1.5 Base cations over time

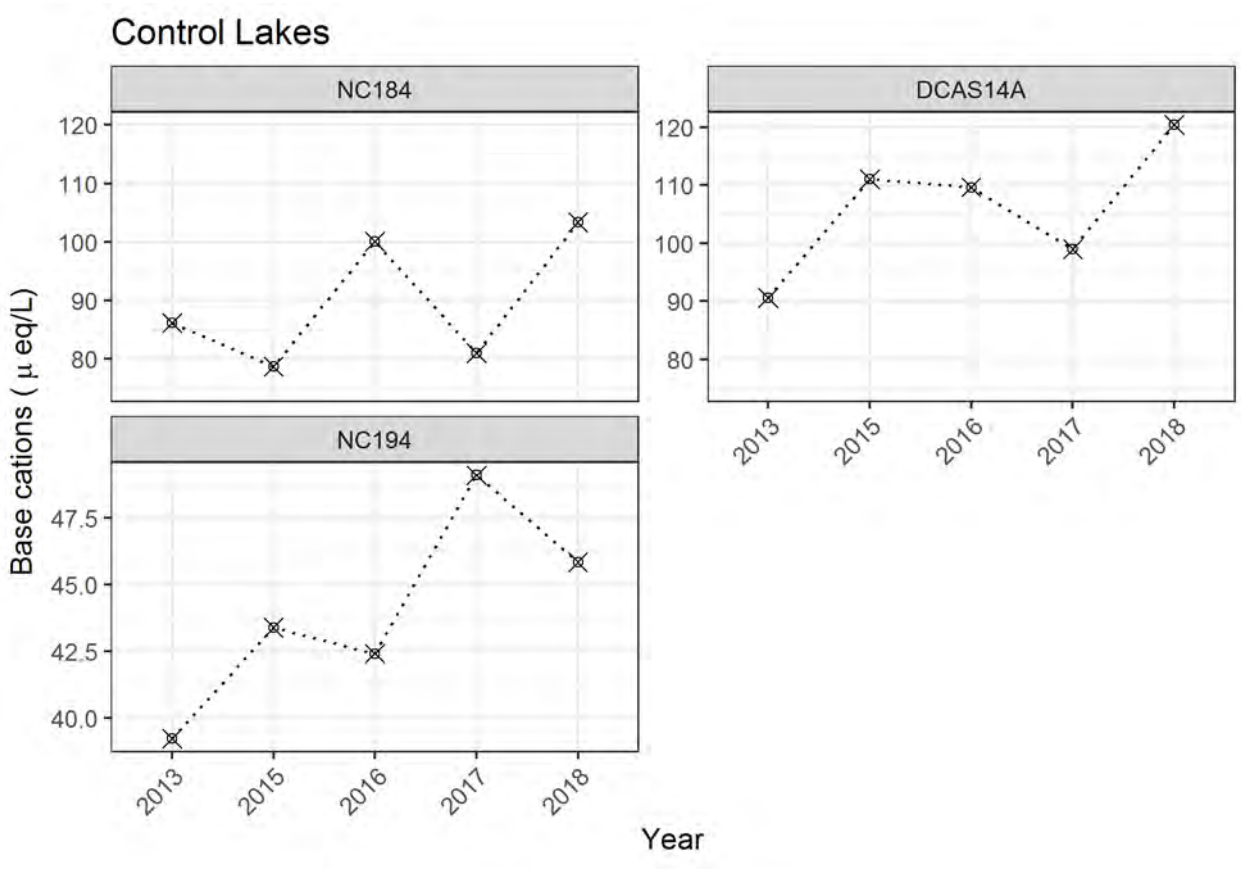


Figure 7.48: Annual trend in Base cations for the control lakes (DCAS14A, NC184, NC194) for the years 2013-2018.

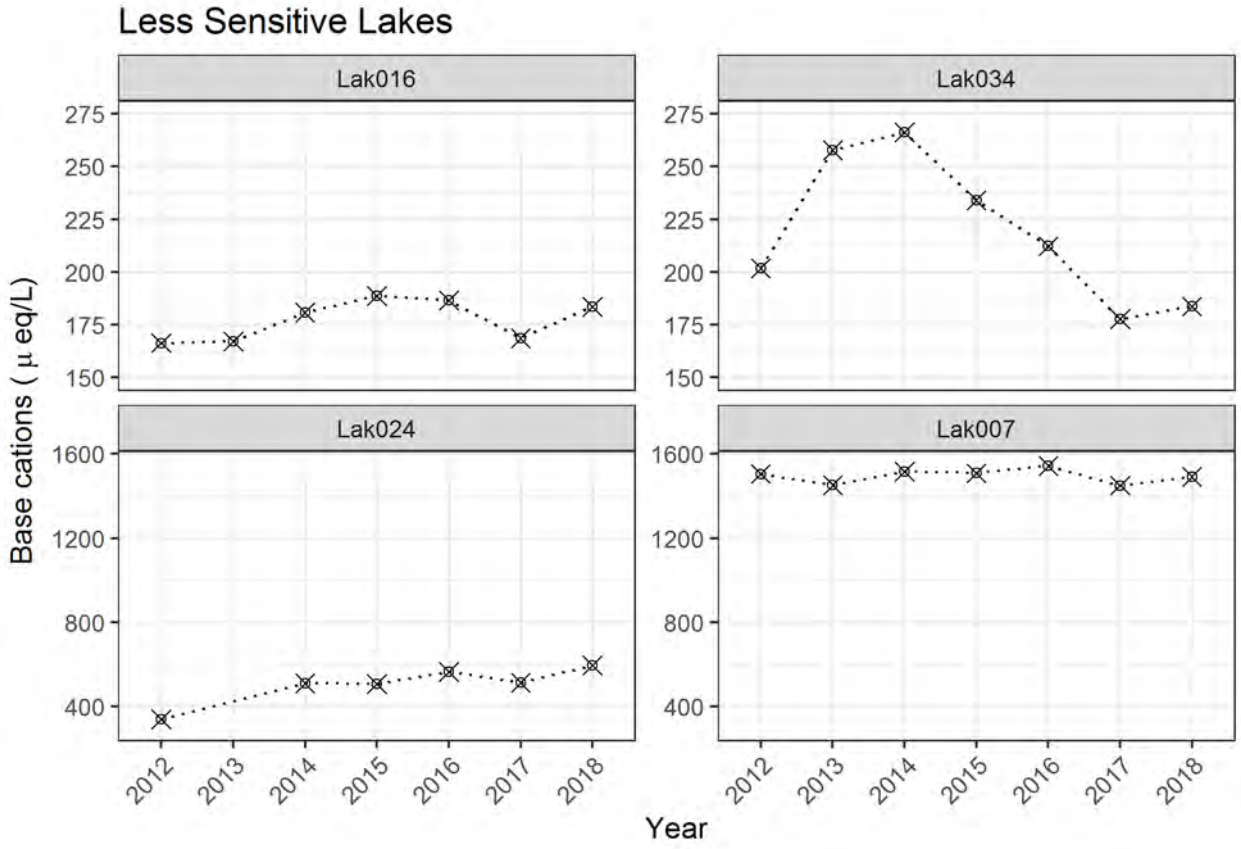


Figure 7.49: Annual trend in Base Cations for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034) for the years 2012-2018.

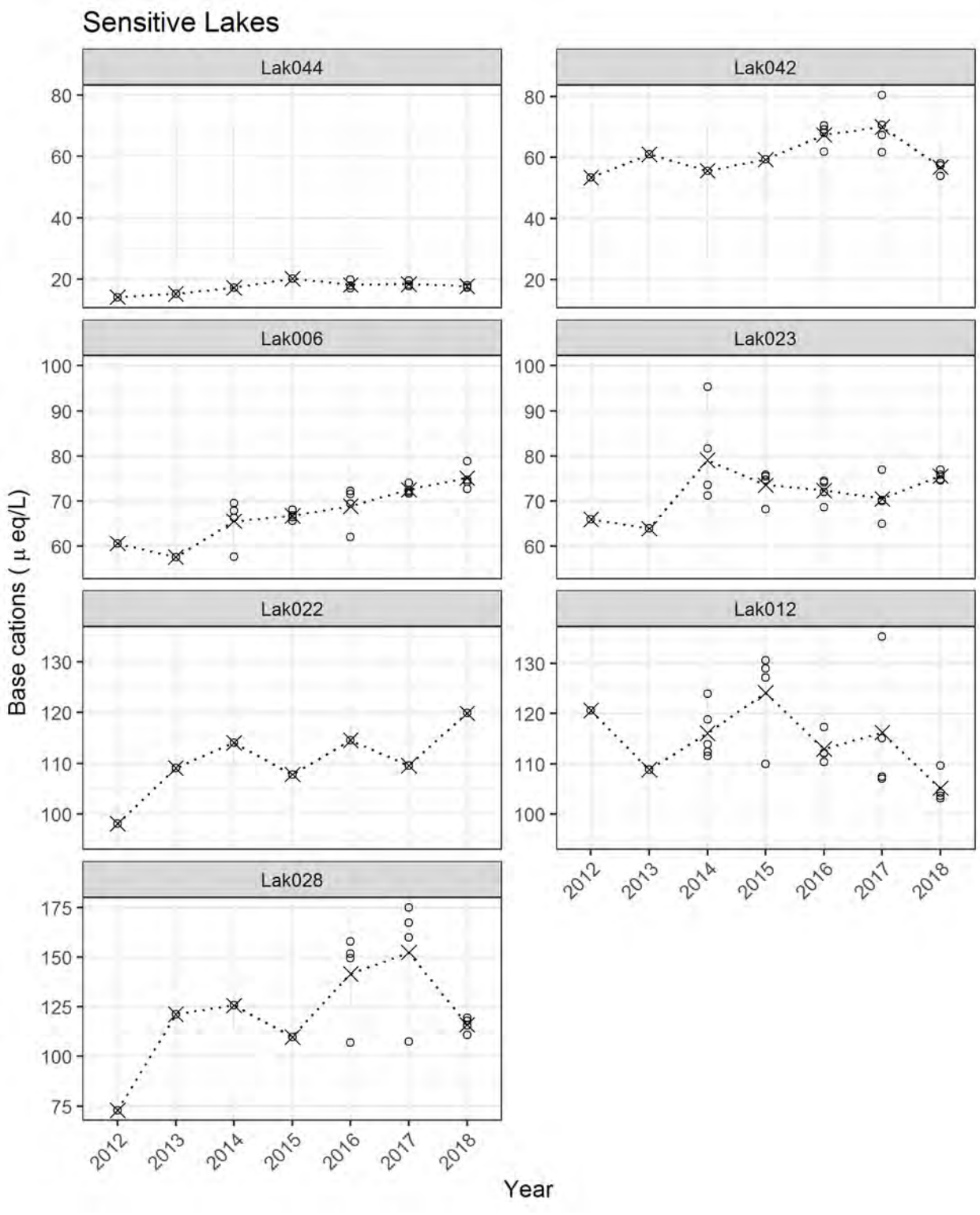


Figure 7.50: Annual trend of Base Cations for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044) for the years 2012-2018.

7.6.2.1.6 Calcium over time

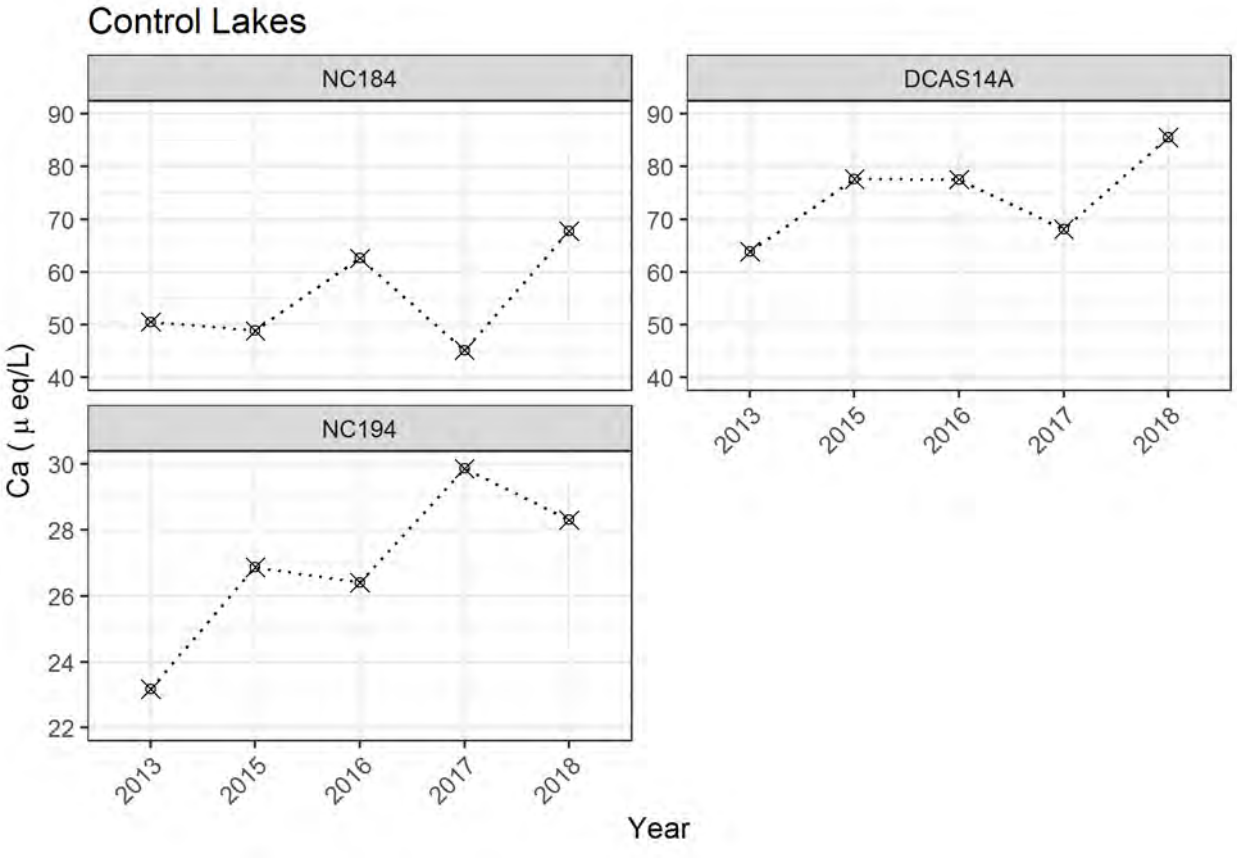


Figure 7.51: Annual trend in Calcium for the control lakes (DCAS14A, NC184, NC194) for the years 2013-2018.

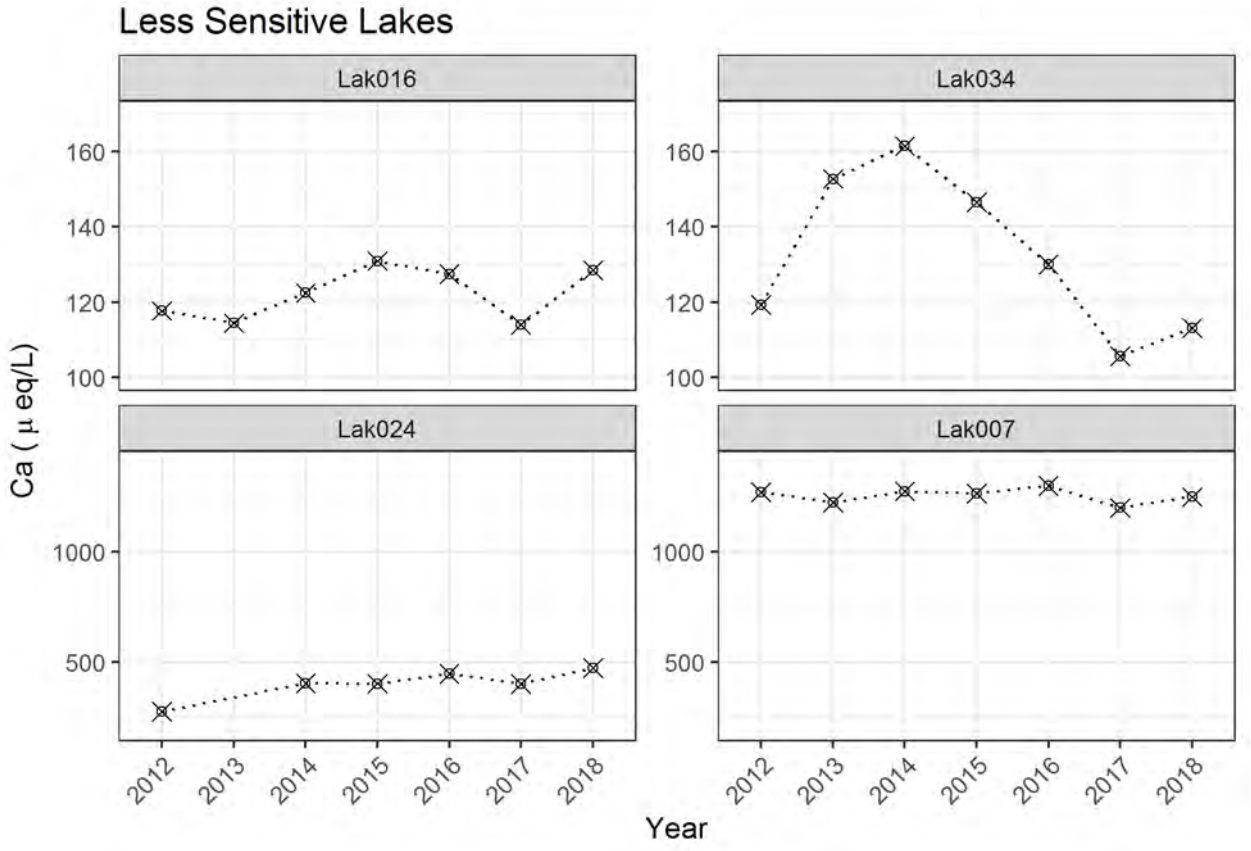


Figure 7.52: Annual trend in Calcium for the less sensitive lakes (LAK007, LAK016, LAK024, LAK034) for the years 2012-2018.

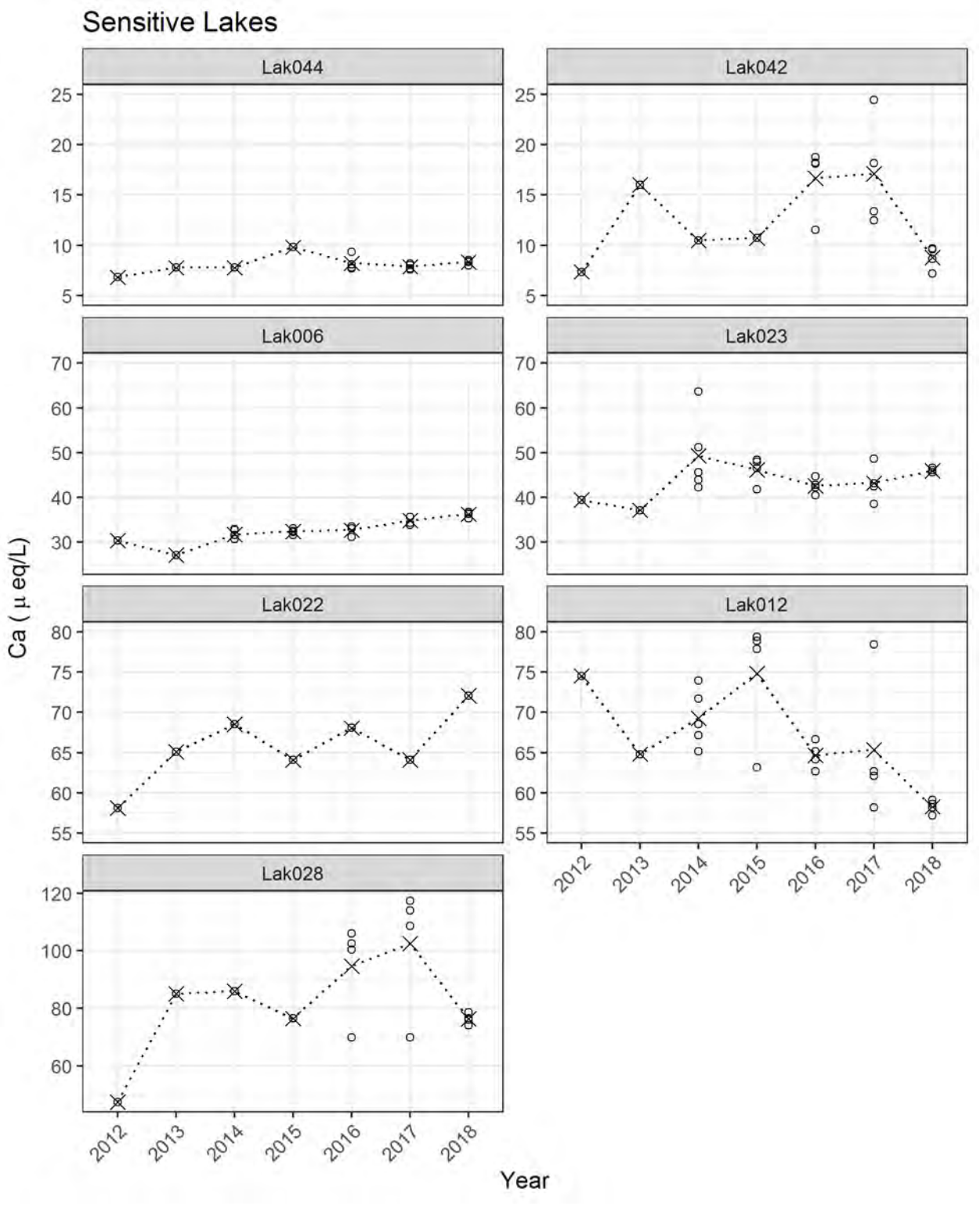


Figure 7.53: Annual trend of Calcium for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044) for the years 2012-2018.

7.6.2.2 Lake Chemistry Relative to Recent Precipitation

The EEM is designed to detect long term trends, not episodic changes in water chemistry. Eight lakes are sampled annually during the fall index period, while six lakes are sampled four times during this period. We are however interested in understanding the extent to which late summer and fall storms may affect lake chemistry, and the apparent trends over multiple years. Snowmelt and rainstorms may affect water chemistry through a number of natural and anthropogenic mechanisms, summarized succinctly by Wiggington et al. 1996:

> "Four major natural processes can produce [acidic] episodes: (1) dilution, (2) nitrification, (3) organic acid production, and (4) the sea salt effect (Galloway et al. 1987, Peters and Driscoll 1987, Turner et al. 1990, Heath et al. 1992, Kahl et al. 1992). Atmospheric deposition can contribute to episodic acidification by (1) providing direct inputs of acidic water to surface waters, (2) conditioning watersheds via the accumulation of $S042^-$, $NO3^-$, $NH4^+$, and H^+ from atmospheric de- position in the upper layers of watershed soils during relatively dry periods, and (3) lowering the chronic ANC of some systems and subsequently lowering the minimum ANC values attained during episodes (Galloway et al. 1987)."

Intensive studies of acidic episodes require very frequent sampling (i.e., hourly) before, during and after a storm event to detect ANC and pH declines and deduce the most likely causes of these declines. Such fine scale examinations are beyond the scope of the EEM. Looking at the patterns of change in water chemistry vs. total precipitation over 3-day and 14-day intervals is the best that we can do with the data that we have. We cannot detect effects which occur on finer time scales than our sampling frequency.

7.6.2.2.1 SO_4 vs. Precipitation

Purpose of analysis: These graphs are intended to explore whether SO_4 is associated with the magnitude of recent precipitation, which could create a spurious long-term trend. For example, if big storms occurred prior to the annual sampling later in the 7-year time series (i.e., 2017 or 2018), and increased SO_4, due to washout of atmospheric or watershed SO_4, this might generate a false long-term pattern of increasing SO_4 over multiple years. Conversely, if major storms occurred prior to annual sampling early in the time series (i.e., 2012 or 2013), and increased concentrations of SO_4, this might generate a false long-term pattern of decreasing SO_4 over multiple years. Since most of the sensitive lakes were sampled four times in the fall (beginning in 2014), averaging over a range of weather conditions in October, there is a lower risk that the mean of these four values will generate a false pattern of SO_4 concentrations confounded by storm events. Storm events which carry smelter-origin sulphate into the lakes would however represent a real effect of the smelter on lake chemistry.

Explanation of the graphs: We used two explanatory variables: the total amount of precipitation in the 3 days prior to sampling (i.e., prior week's precipitation, estimated from the Haul Road site); and the total amount of precipitation in the 14 days (2 weeks) prior to sampling.

- See Section 7.6.4.2.6 for statistical analyses of the ability of covariates describing recent precipitation to explain observed patterns of changes over time in sulphate, beyond those patterns observed in control lakes.

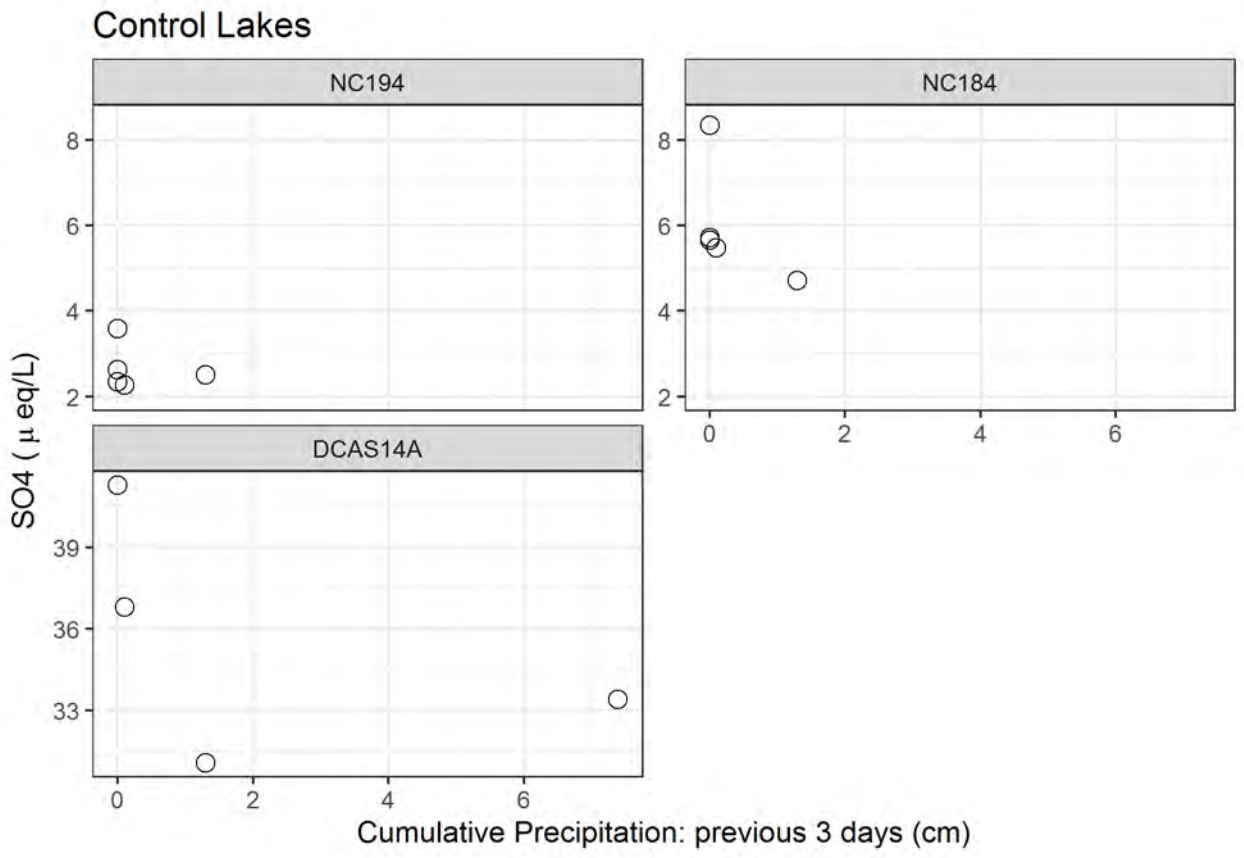


Figure 7.54: Concentration of SO_4 vs. cumulative precipitation (cm) over the previous three days for the control lakes (DCAS14A, NC184, NC194).

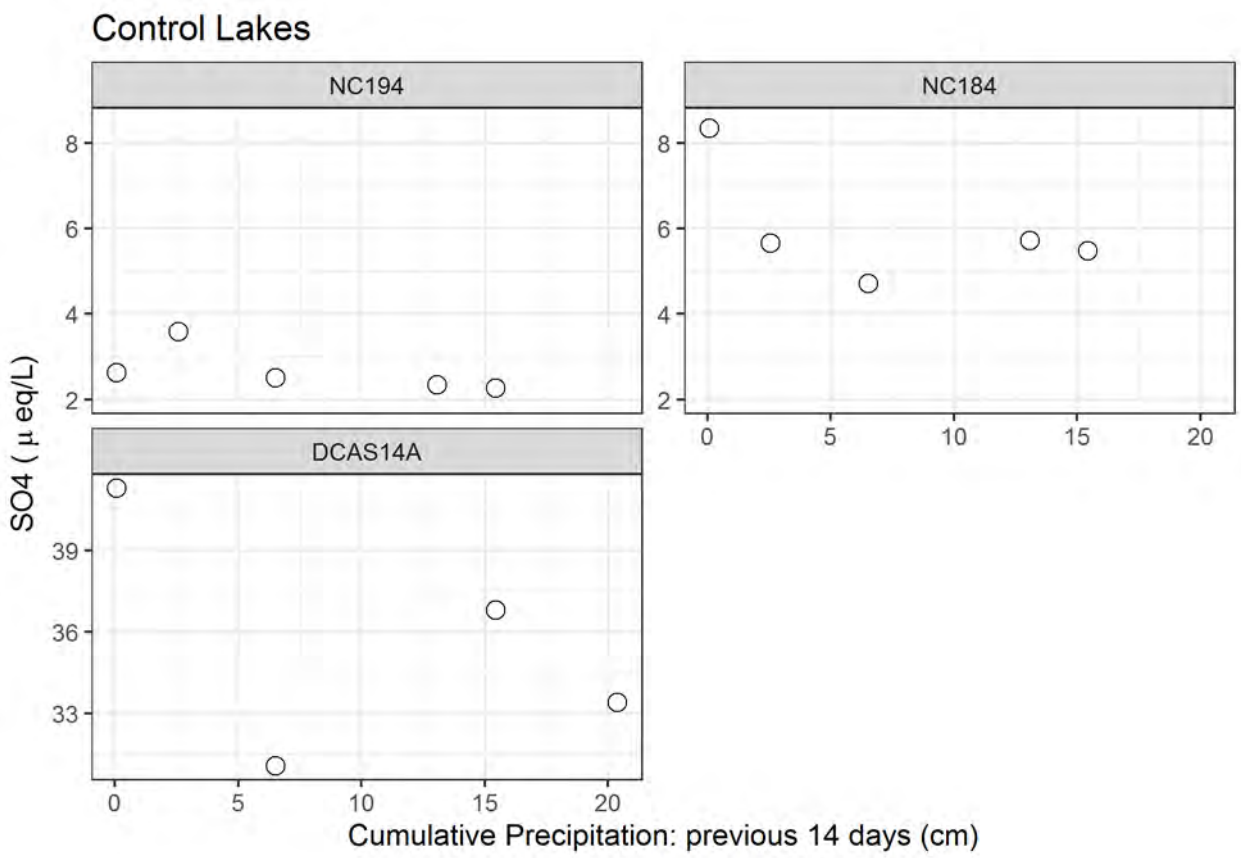


Figure 7.55: Concentration of SO_4 vs. cumulative precipitation (cm) over the previous 14 days for the control lakes (DCAS14A, NC184, NC194).

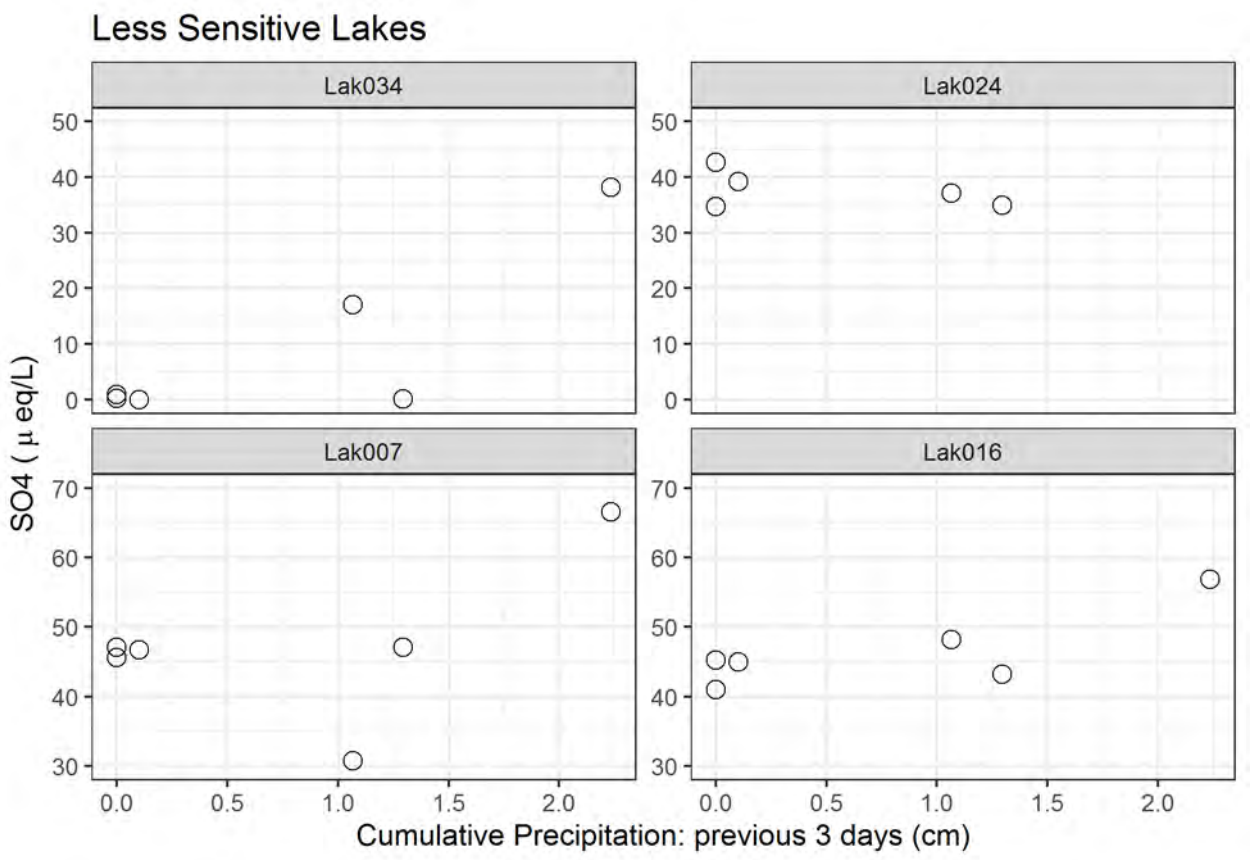


Figure 7.56: Concentration of SO_4 vs. cumulative precipitation (cm) over the previous three days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

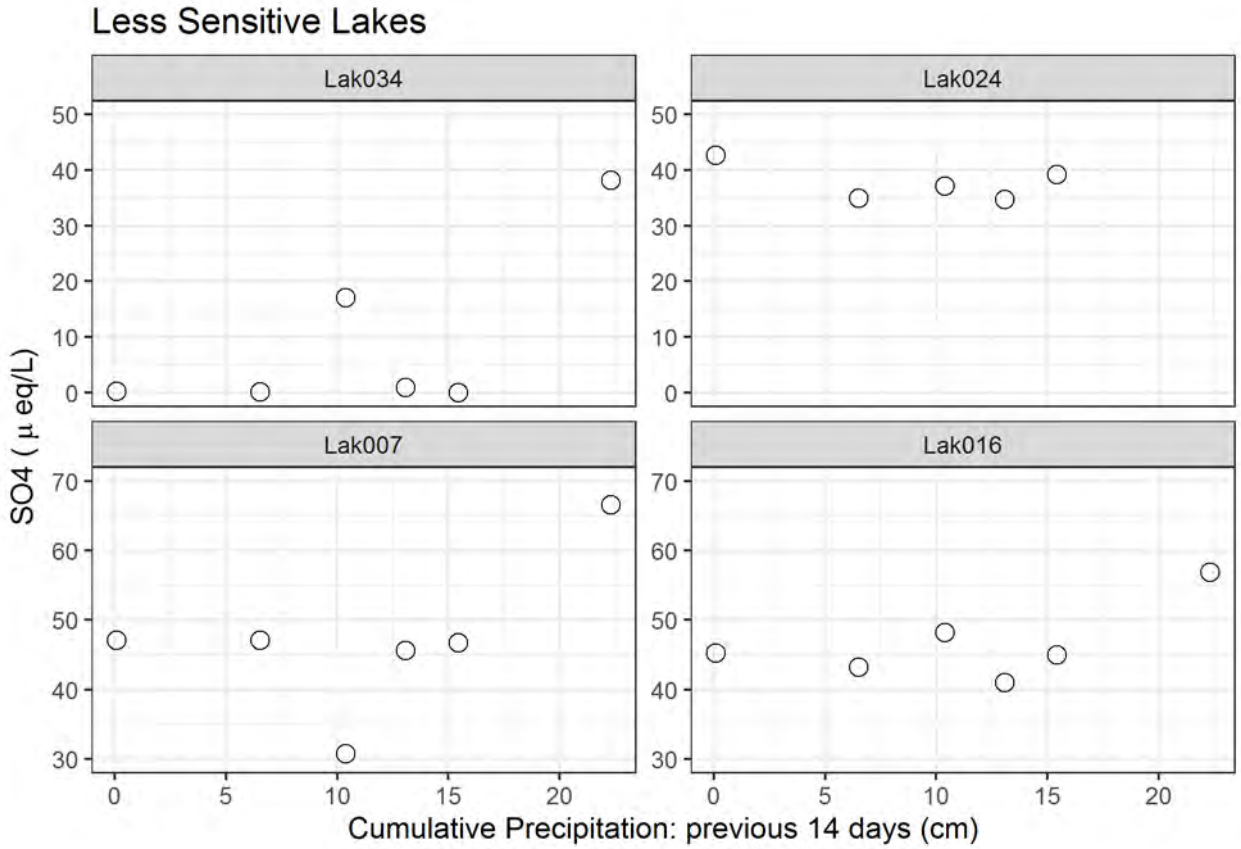


Figure 7.57: Concentration of SO_4 vs. cumulative precipitation (cm) over the previous 14 days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

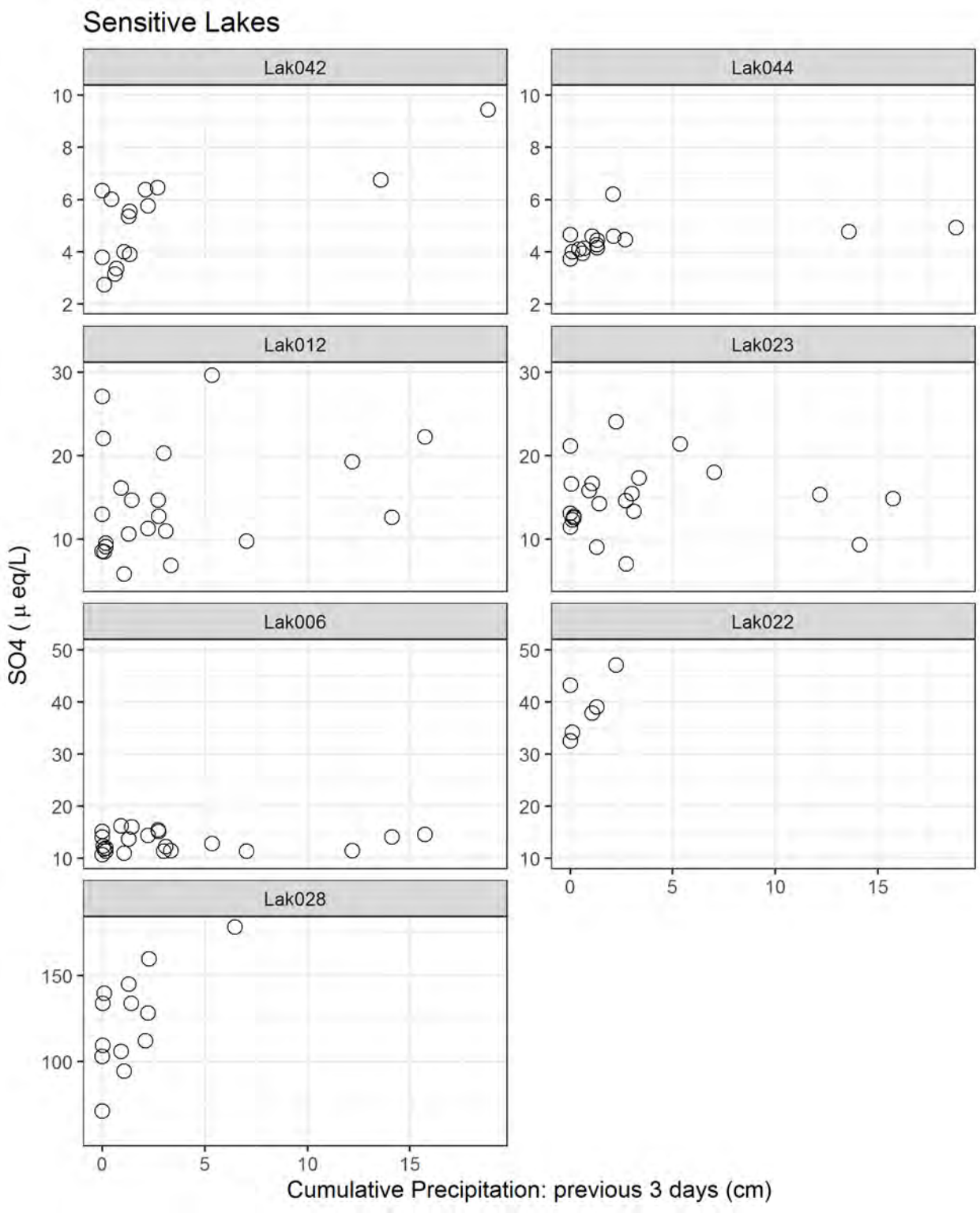


Figure 7.58: Concentration of SO_4 vs. cumulative precipitation (cm) over the previous three days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

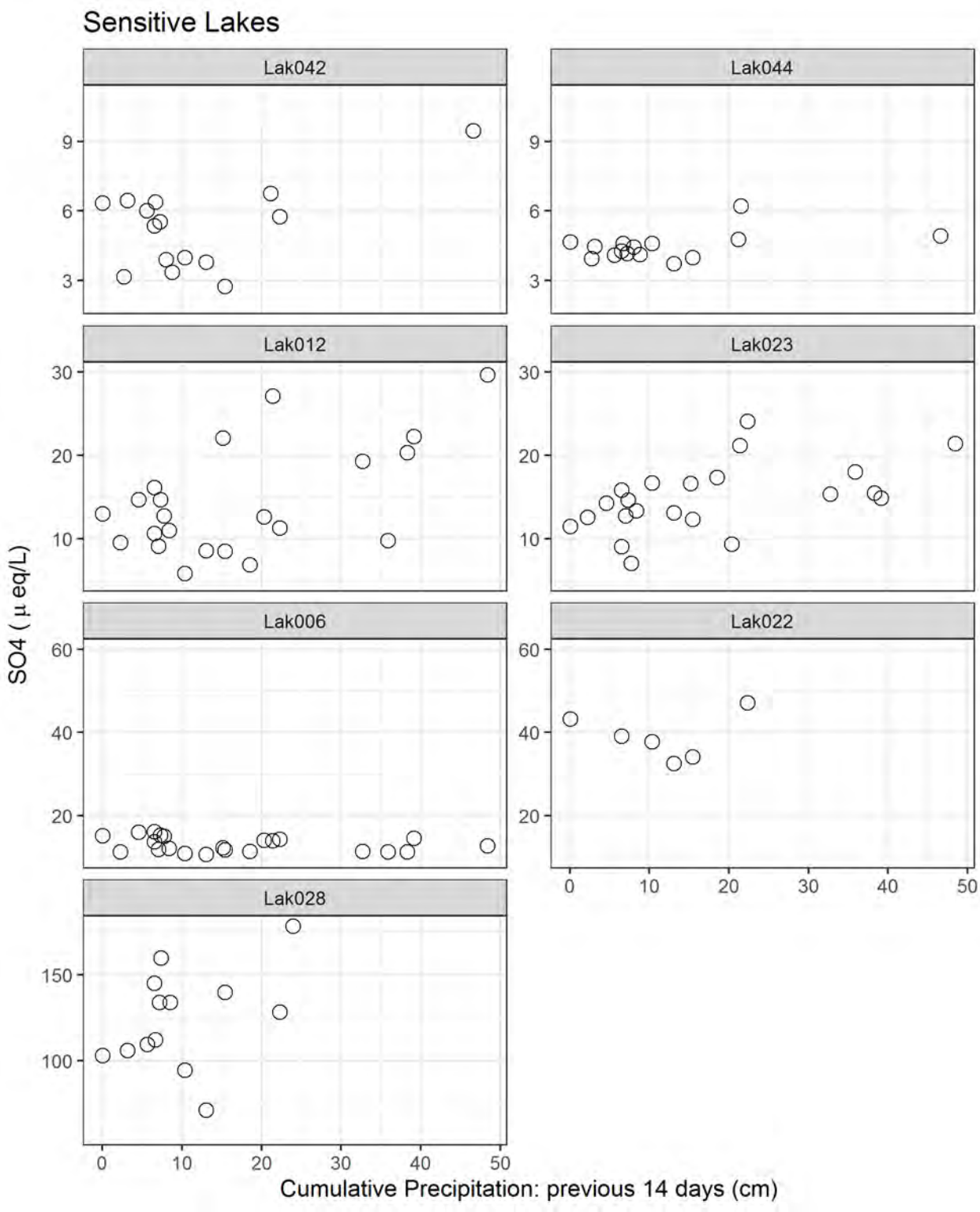


Figure 7.59: Concentration of SO_4 vs. cumulative precipitation (cm) over the previous 14 days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.2.2.2 Gran ANC vs. Precipitation

Purpose of analysis: Similar to what is described above, but unlike for SO_4 (where a positive correlation with precipitation is hypothesized), these graphs are intended to explore whether Gran ANC is *inversely* associated with the magnitude of recent precipitation, which could create a spurious long-term trend. For example, if big storms occurred prior to the annual sampling later in the 7-year time series (i.e., 2017 or 2018), and depressed Gran ANC, this might generate a false long-term pattern of declining Gran ANC over multiple years. Conversely, if major storms occurred prior to annual sampling early in the time series (i.e., 2012 or 2013), and depressed Gran ANC, this might generate a false long-term pattern of increasing Gran ANC over multiple years. Since most of the sensitive lakes were sampled four times in the fall (beginning in 2014), averaging over a range of weather conditions in October, there is a lower risk that the mean of these four values will generate a false pattern of Gran ANC declines due to confounding with storm events. Storm events which carry smelter-origin sulphate and hydrogen into the lakes (and cause a decline in a lake's Gran ANC) would however represent a real effect of the smelter on lake chemistry.

Explanation of the graphs: We used the same two explanatory variables explained above – precipitation over the week prior to sampling, and over the previous 4 weeks, as measured at Haul Road.

- See Section 7.6.4.4.6 for statistical analyses of the ability of covariates describing recent precipitation to explain patterns of changes over time in Gran ANC, beyond those patterns observed in control lakes.

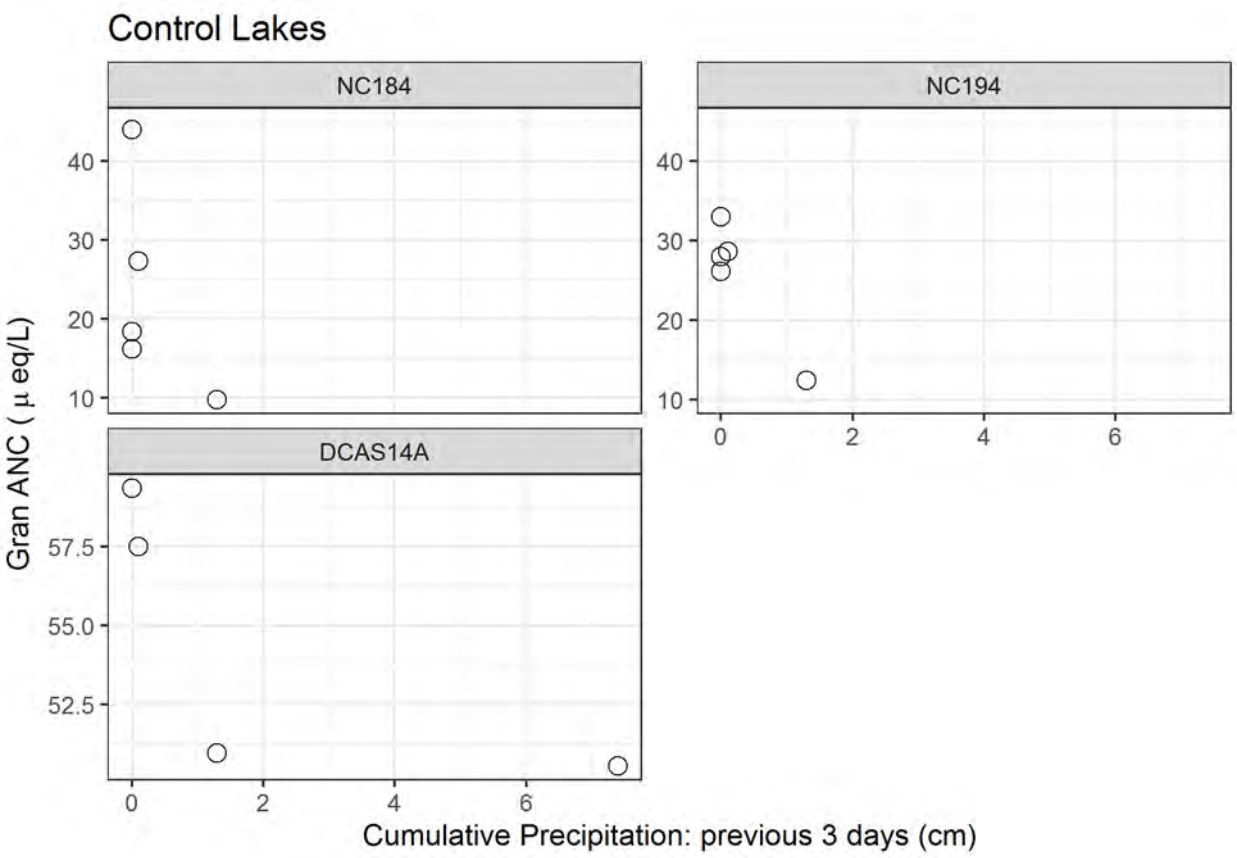


Figure 7.60: Gran ANC (µeq/L) vs. cumulative precipitation (cm) over the previous three days for the control lakes (DCAS14A, NC184, NC194).

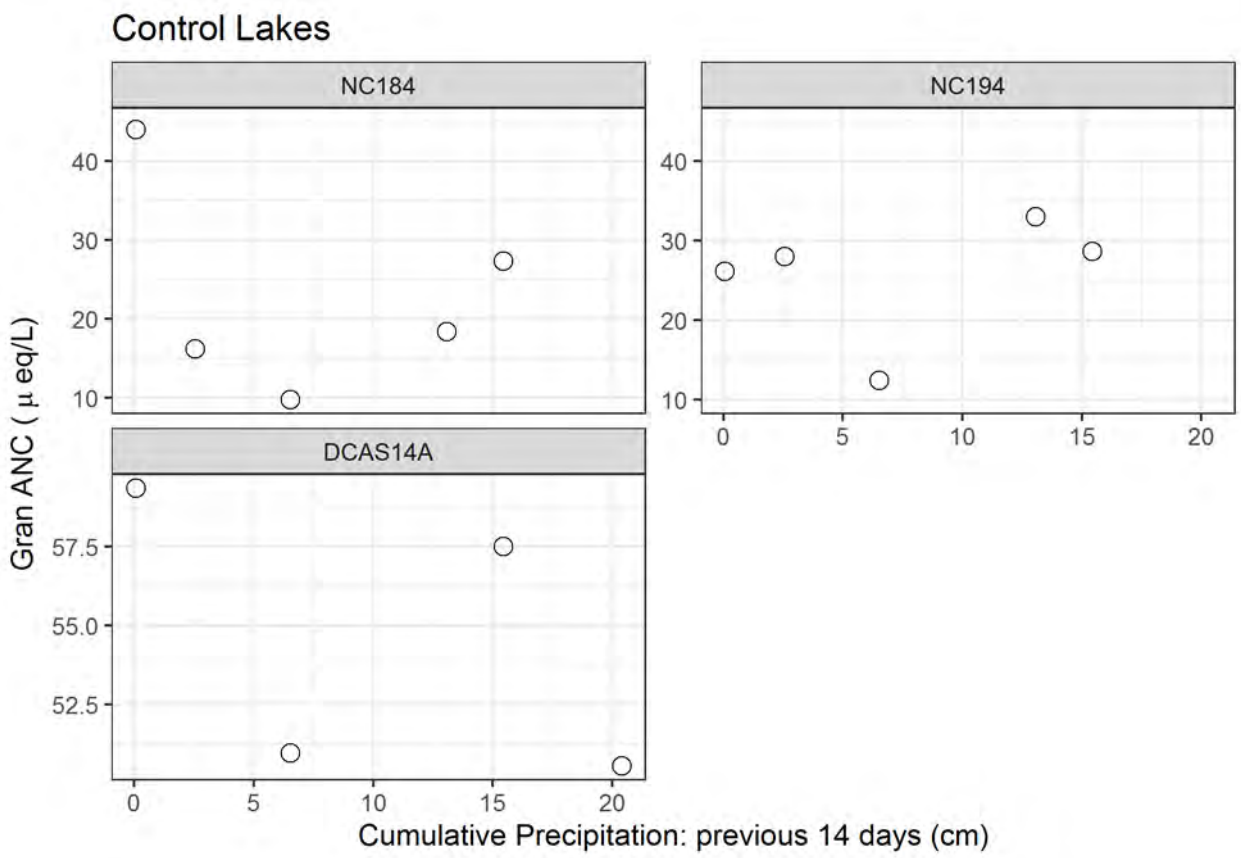


Figure 7.61: Gran ANC (µeq/L) vs. cumulative precipitation (cm) over the previous 14 days for the control lakes (DCAS14A, NC184, NC194).

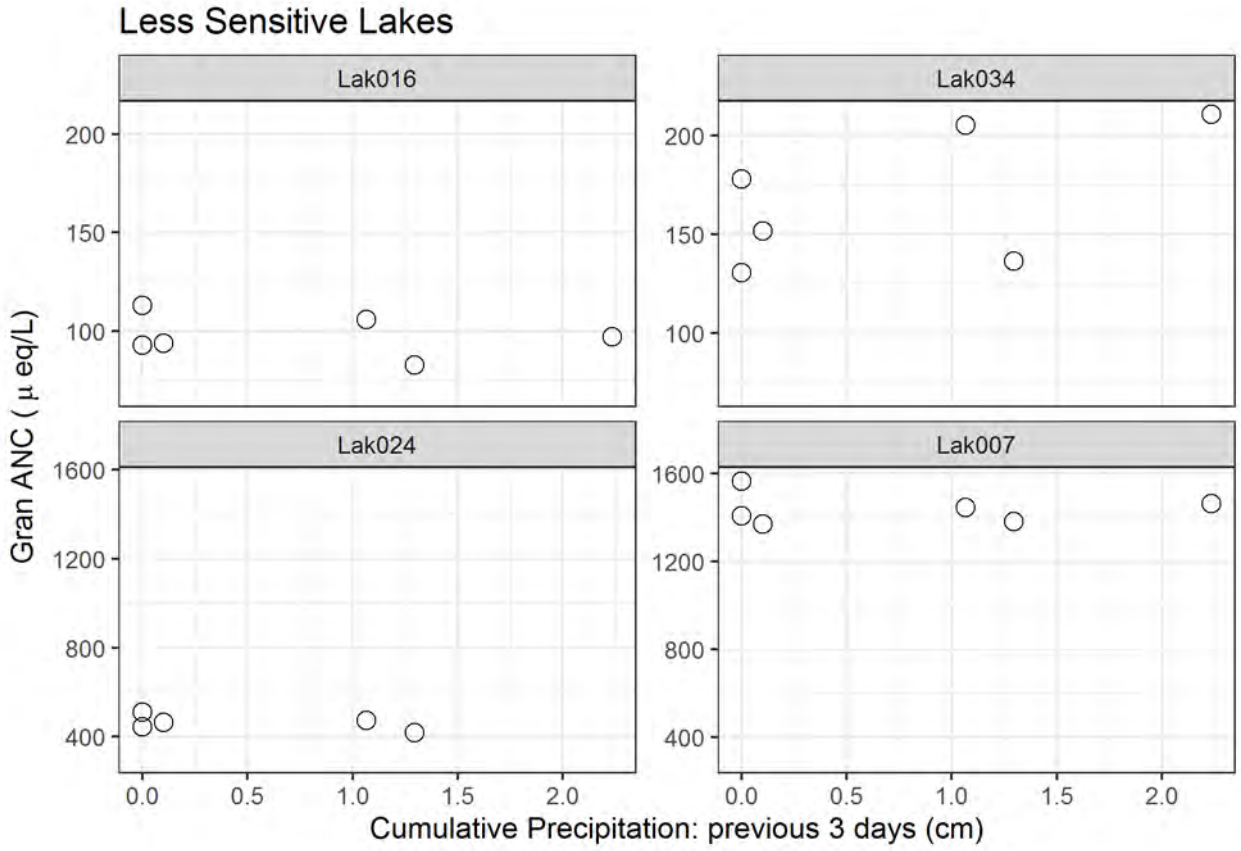


Figure 7.62: Gran ANC (µeq/L) vs. cumulative precipitation (cm) over the previous three days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

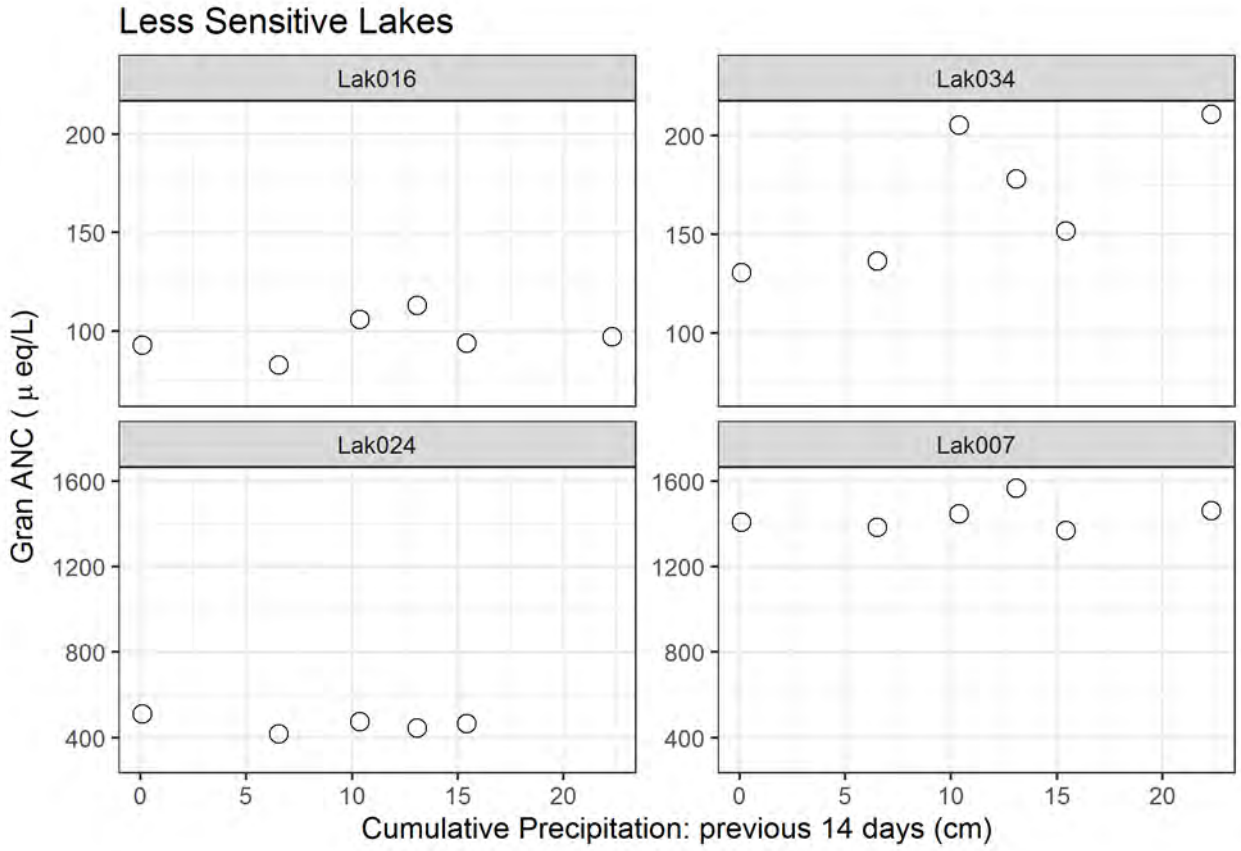


Figure 7.63: Gran ANC (µeq/L) vs. cumulative precipitation (cm) over the previous 14 days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

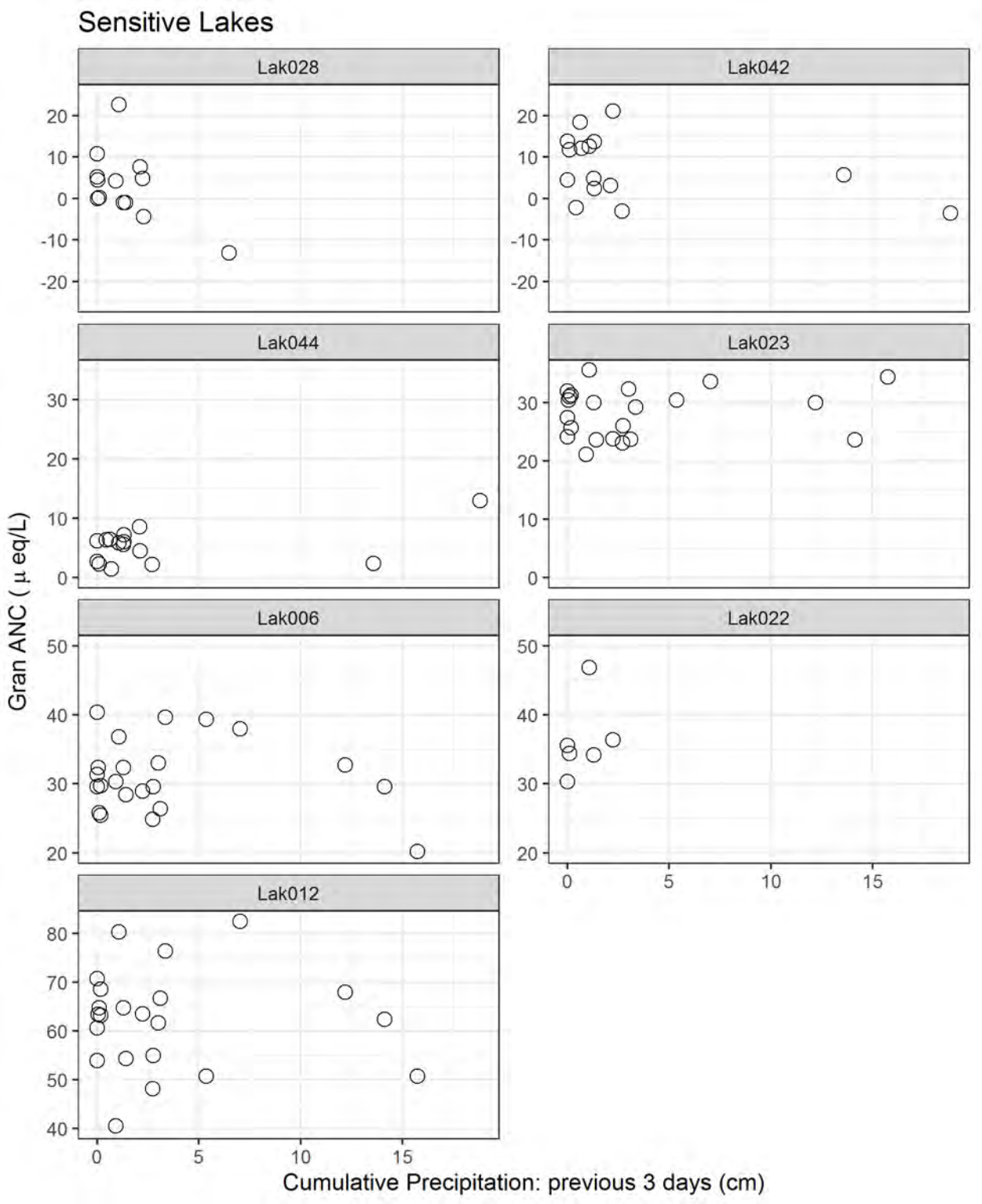


Figure 7.64: Gran ANC (µeq/L) vs. cumulative precipitation (cm) over the previous three days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

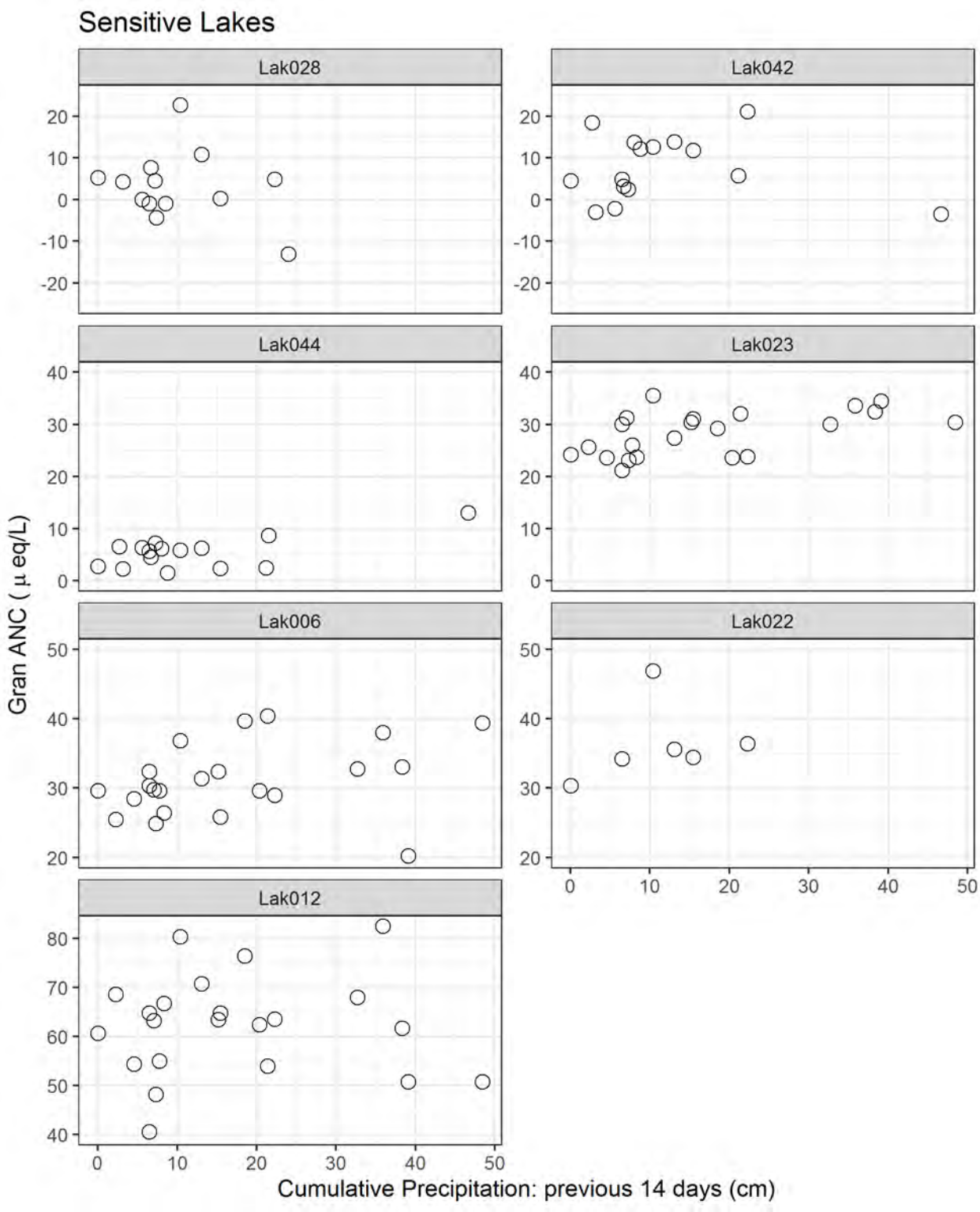


Figure 7.65: Gran ANC (µeq/L) vs. cumulative precipitation (cm) over the previous 14days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.2.2.3 pH vs. Precipitation

Purpose of analysis: As for Gran ANC, described above.

Explanation of the graphs: We used the same two explanatory variables explained above – precipitation over the 3-days prior to sampling, and over the previous 2 weeks, as measured at Haul Road.

- See Section 7.6.4.3.6 for statistical analyses of the ability of covariates describing recent precipitation to explain patterns of changes over time in pH, beyond those patterns observed in control lakes.

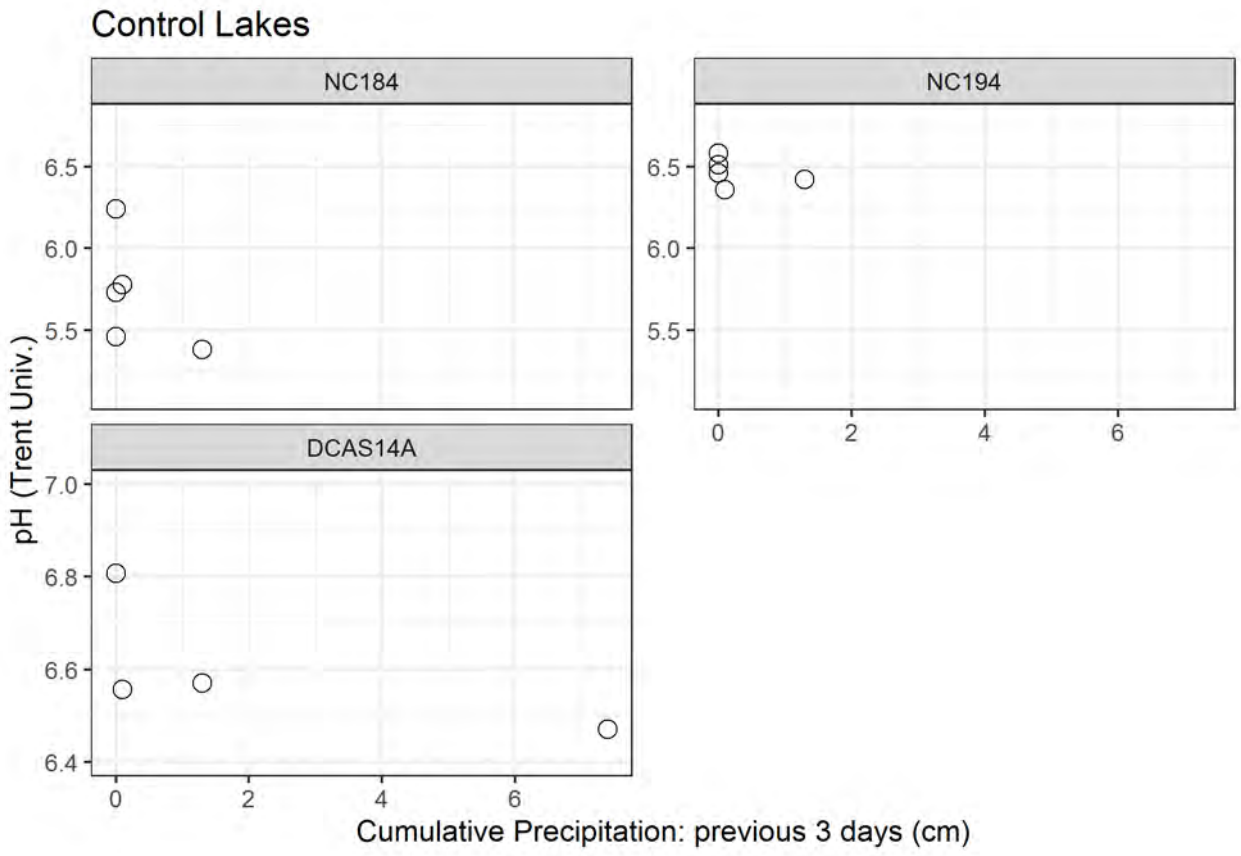


Figure 7.66: pH (+/-0.2) vs. cumulative precipitation (cm) over the previous three days for the control lakes (DCAS14A, NC184, NC194).

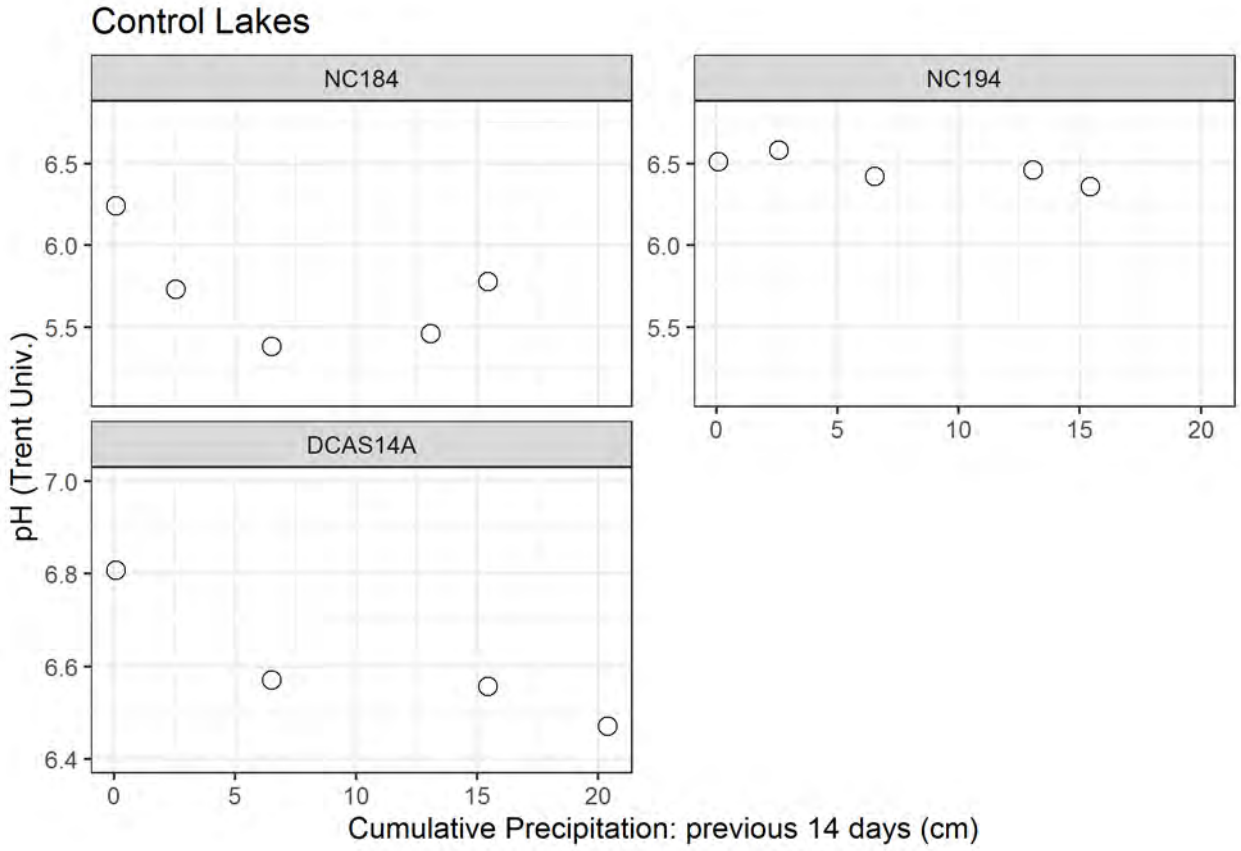


Figure 7.67: pH (+/-0.2) vs. cumulative precipitation (cm) over the previous 14 days for the control lakes (DCAS14A, NC184, NC194).

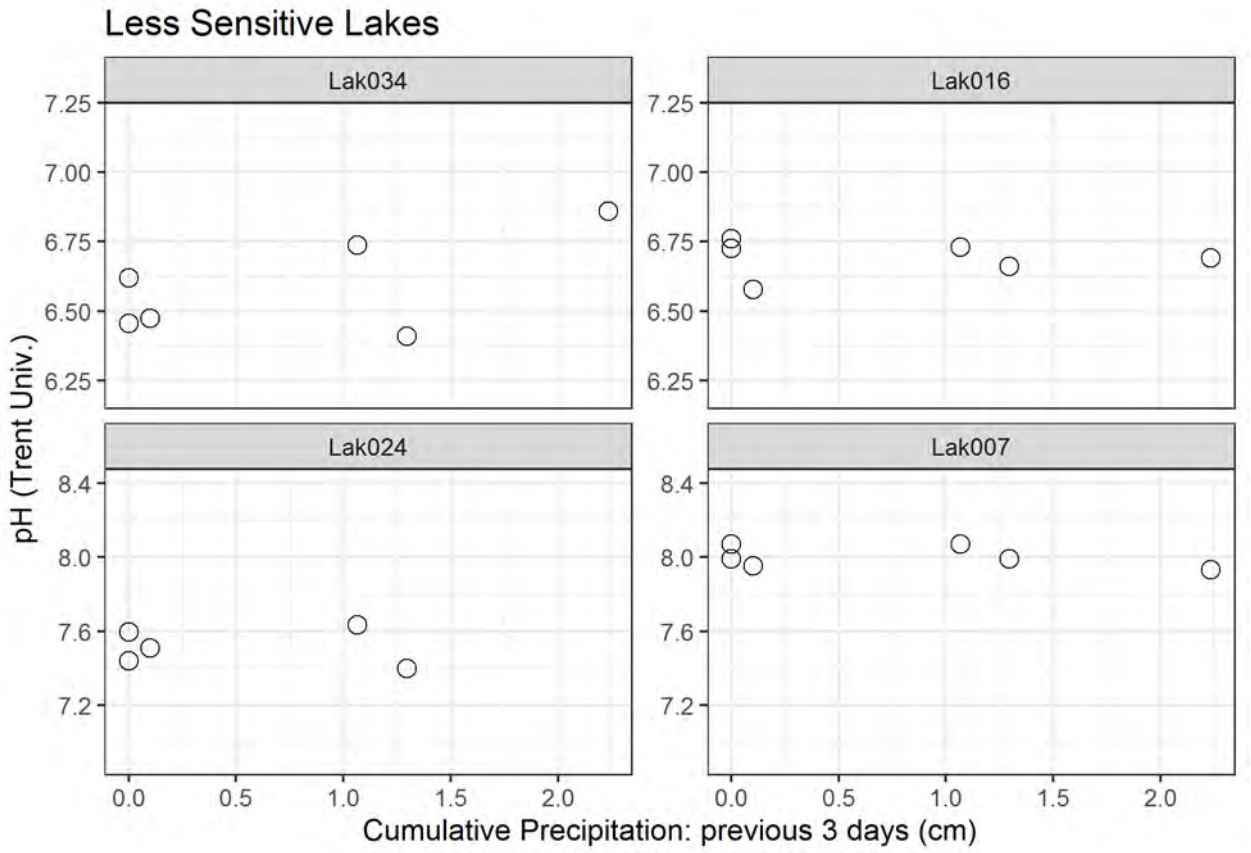


Figure 7.68: pH (+/-0.2) vs. cumulative precipitation (cm) over the previous three days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

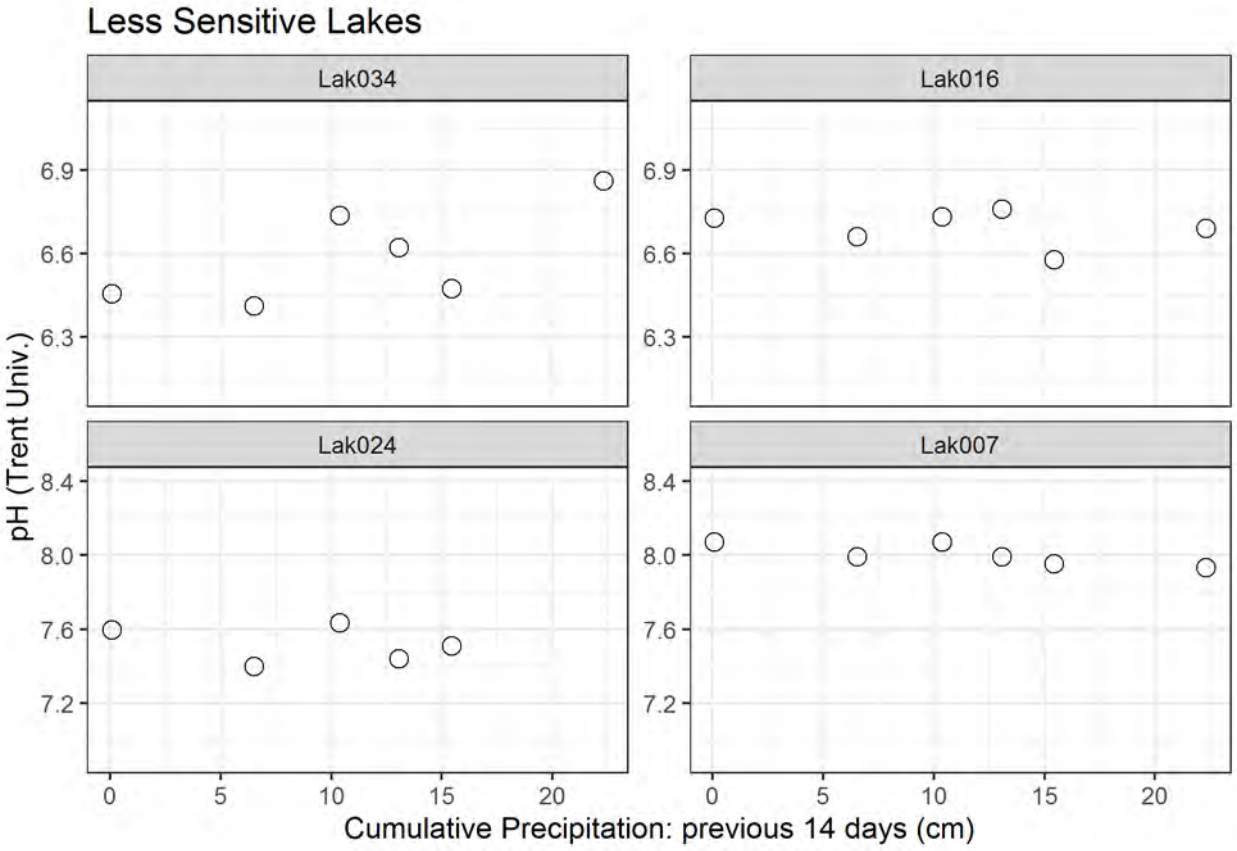


Figure 7.69: pH (+/-0.2) vs. cumulative precipitation (cm) over the previous 14 days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

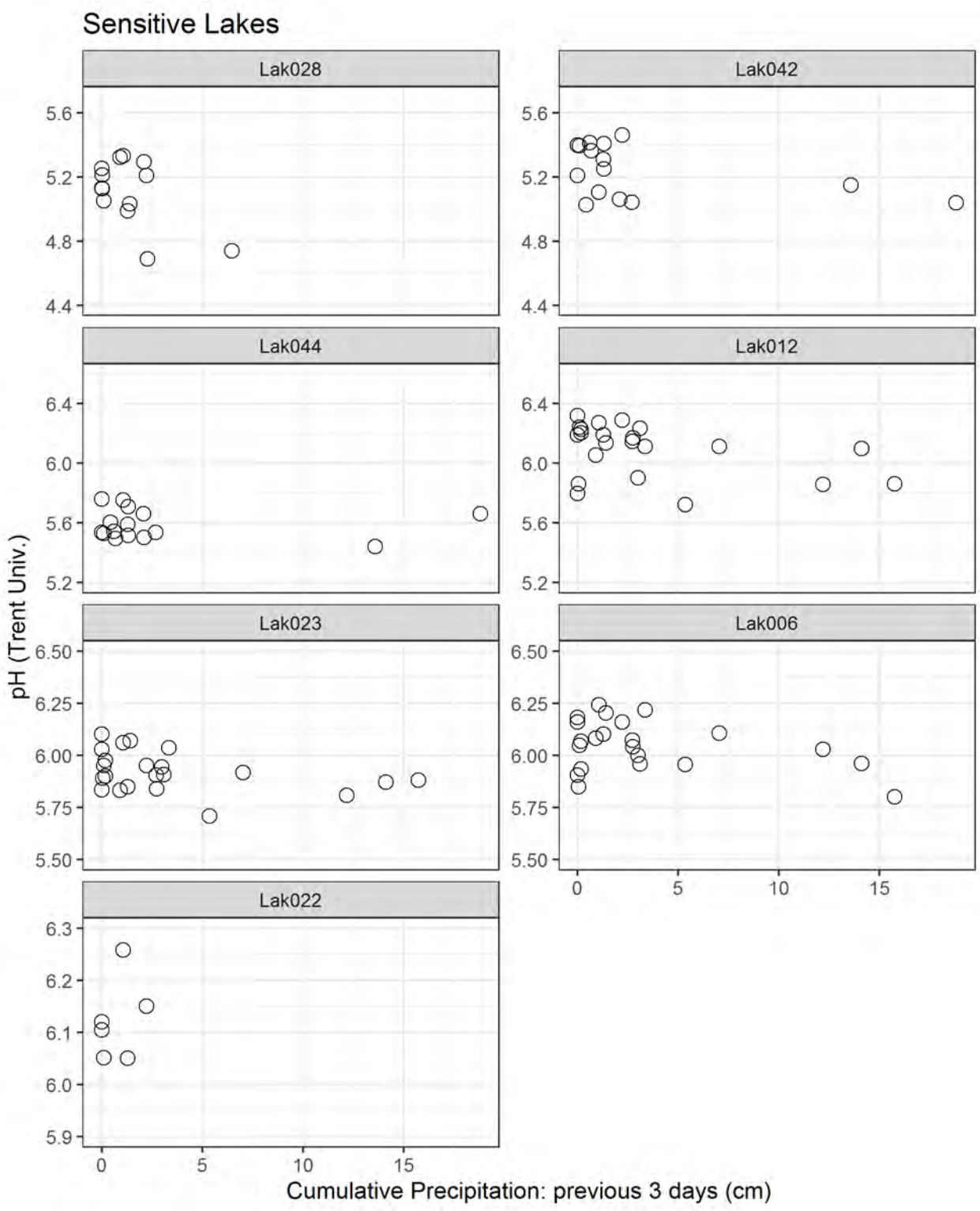


Figure 7.70: pH (+/-0.2) vs. cumulative precipitation (cm) over the previous three days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

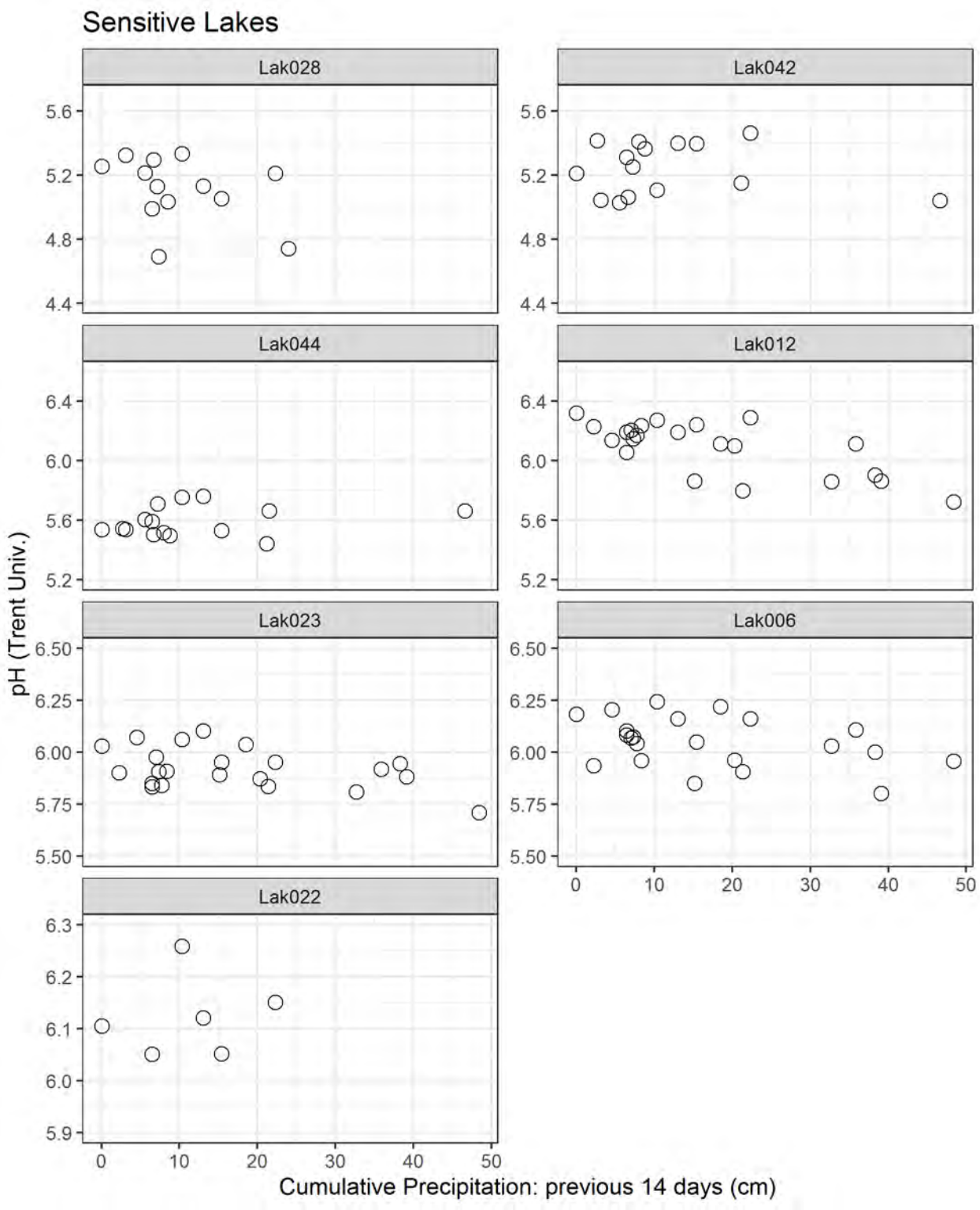


Figure 7.71: pH (+/-0.2) vs. cumulative precipitation (cm) over the previous 14 days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.2.2.4 Other Lake Chemistry Metrics vs. Precipitation

- Other metrics explored
- Only against recent precipitation

Purpose of analyses: Base cation dilution can be one of the most frequent causes of declines in ANC and pH during and following storm events (Wiggington et al. 1996). We are therefore interested to see if there is any pattern of declining base cation concentrations following periods of higher levels of precipitation. As noted above, intensive studies of acidic episodes require very frequent sampling during a storm event to deduce the most likely causes of ANC and pH declines. Looking at broad patterns between base cations and total precipitation is the best that we can do with the data that we have, but misses effects which occur on finer time scales.

Dissolved Al tends to increase as pH declines, particularly at lower pH levels. We are therefore interested to see if there is any pattern of increasing Al associated with storm events.

Marine storms can in theory bring pulses of chloride to lakes in the Kitimat Valley (concentrations of Ca, Mg, Na and K are decremented for sea-salt contributions based on the ratios of these cations to chloride). Pulses of chloride could potentially cause a seasalt effect, as sodium is exchanged for other ions in the soil, including H+ and Al, which is one of the mechanisms of natural acidification noted by Wiggington et al. (1996), and explained further in the references they cite. We are therefore interested to see if chloride is positively associated with precipitation, as this is another possible confounding factor affecting long term trends in pH and ANC.

We have only performed statistical analyses of changes over time for sulphate, pH and Gran ANC, as these are the primary metrics in the evidentiary framework. If the primary metrics show evidence of changes that are of concern for a given lake, we can then do quantitative analyses of other chemical parameters to better understand the full picture of chemical changes with the subject lake.

Explanation of the graphs and tables of results: We used the same two explanatory variables explained above – precipitation over the 3-days prior to sampling, and over the previous 2 weeks, as measured at Haul Road.

7.6.2.2.5 Base cations vs. Precipitation

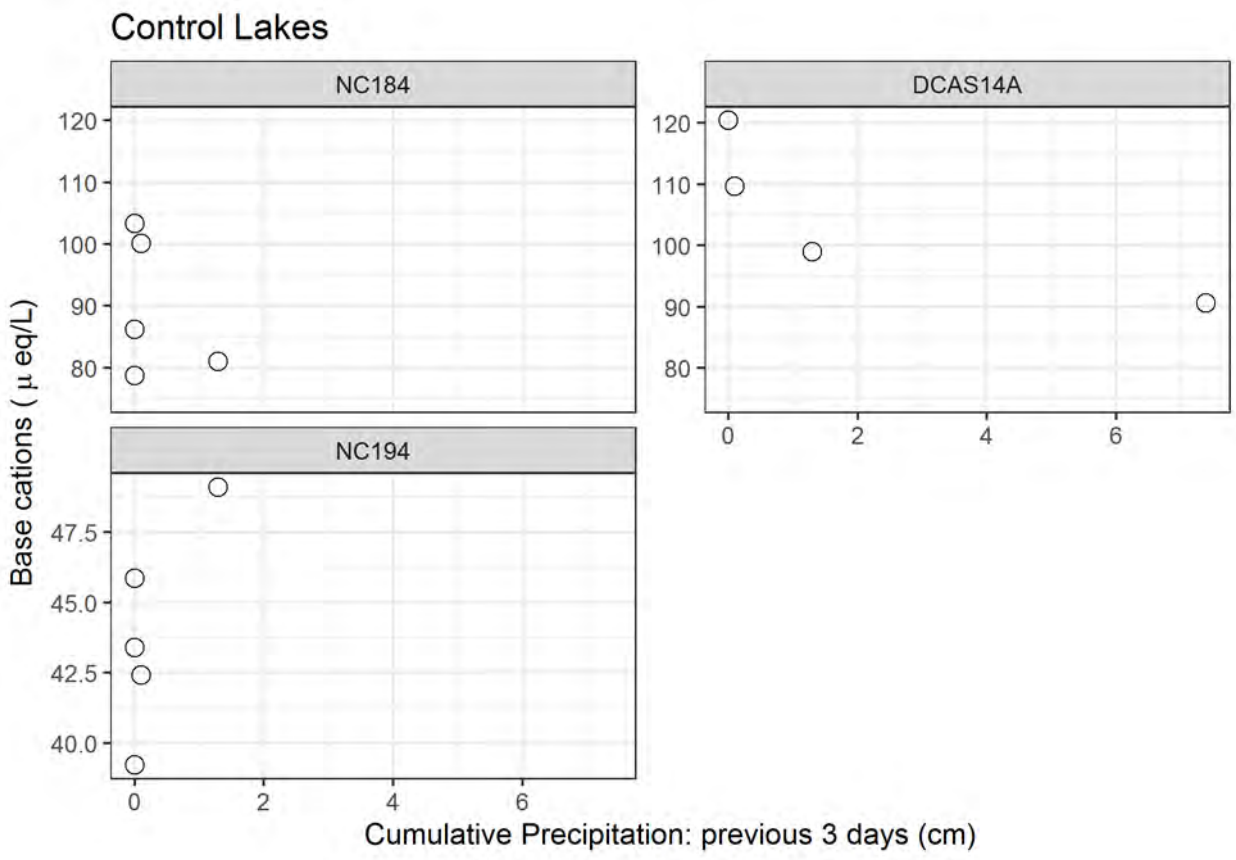


Figure 7.72: Base Cations (Ca + Na + Mg + K) vs. cumulative precipitation (cm) over the previous three days for the control lakes (DCAS14A, NC184, NC194).

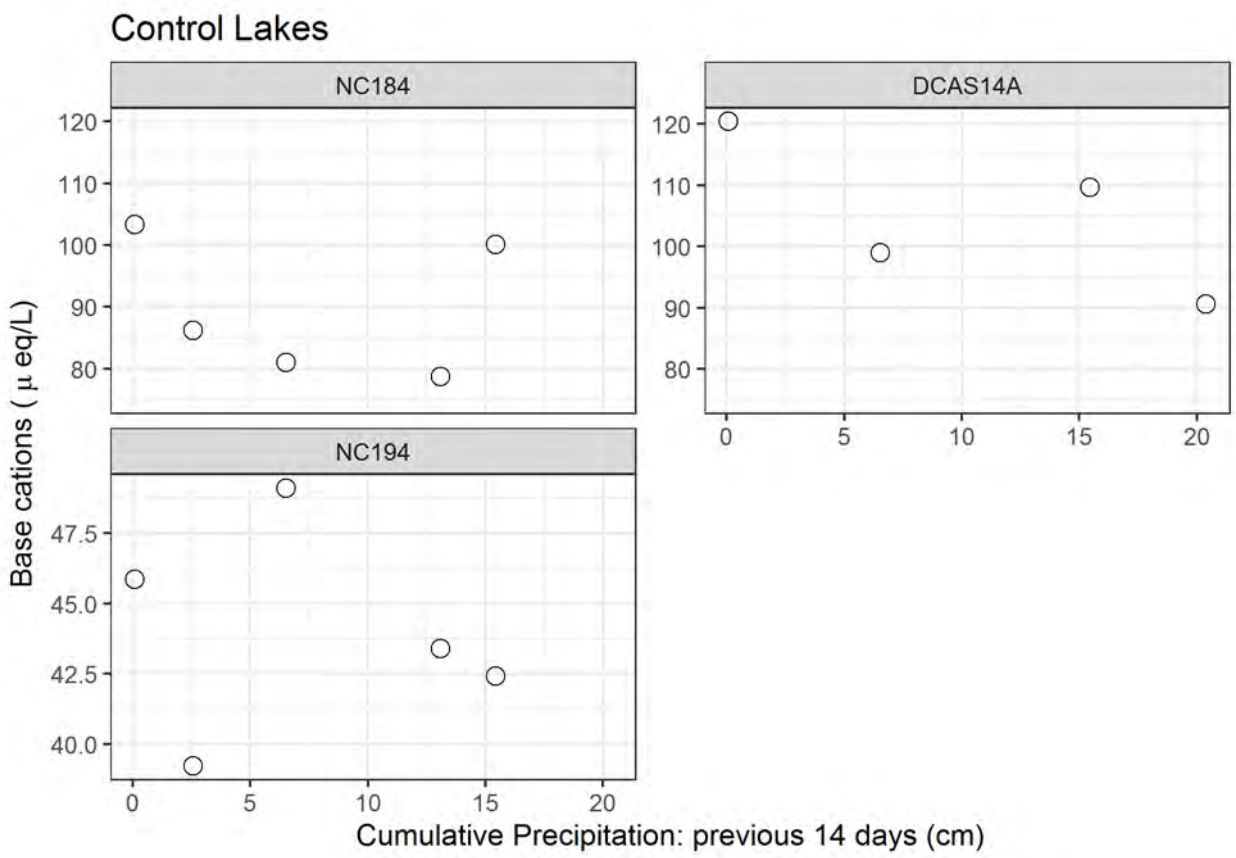


Figure 7.73: Base Cations (Ca + Na + Mg + K) vs. cumulative precipitation (cm) over the previous fourteen days for the control lakes (DCAS14A, NC184, NC194).

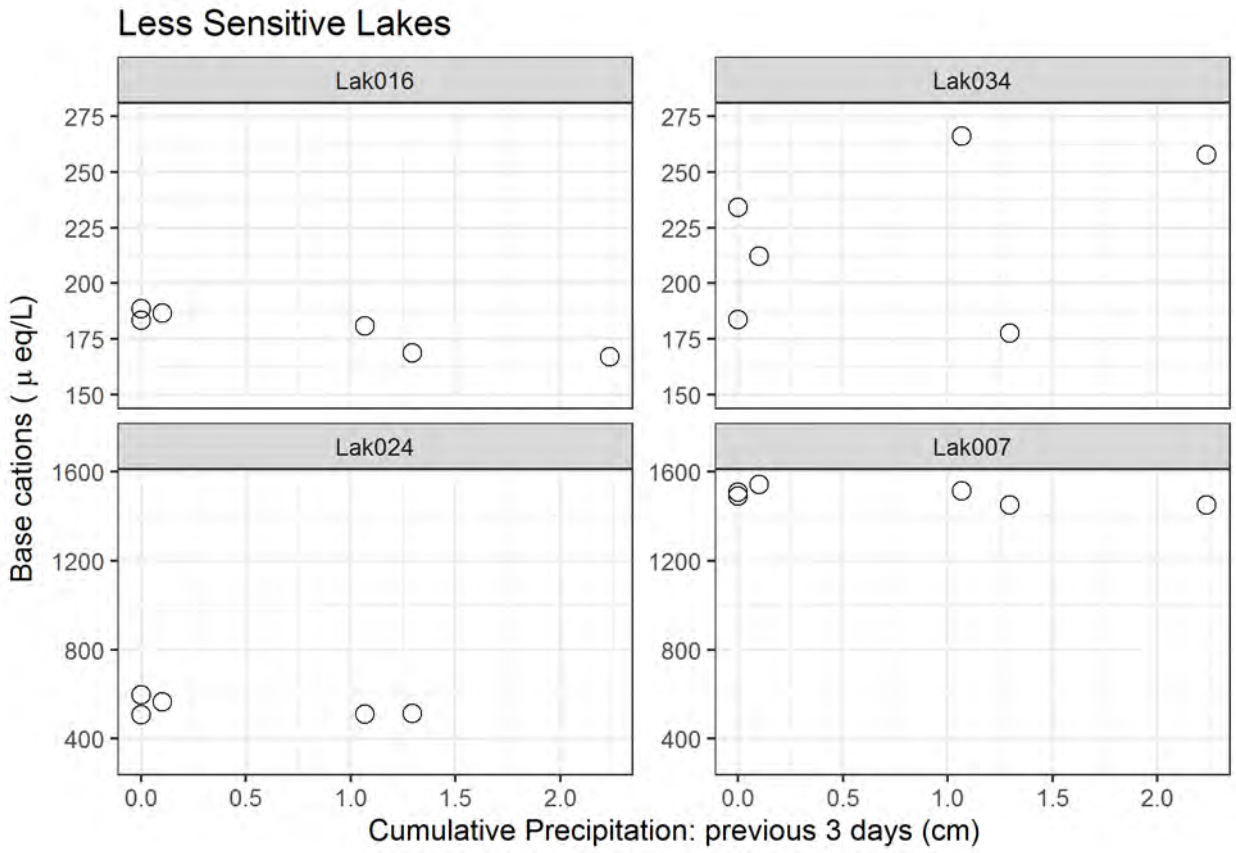


Figure 7.74: Base Cations (Ca + Na + Mg + K) vs. cumulative precipitation (cm) over the previous three days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

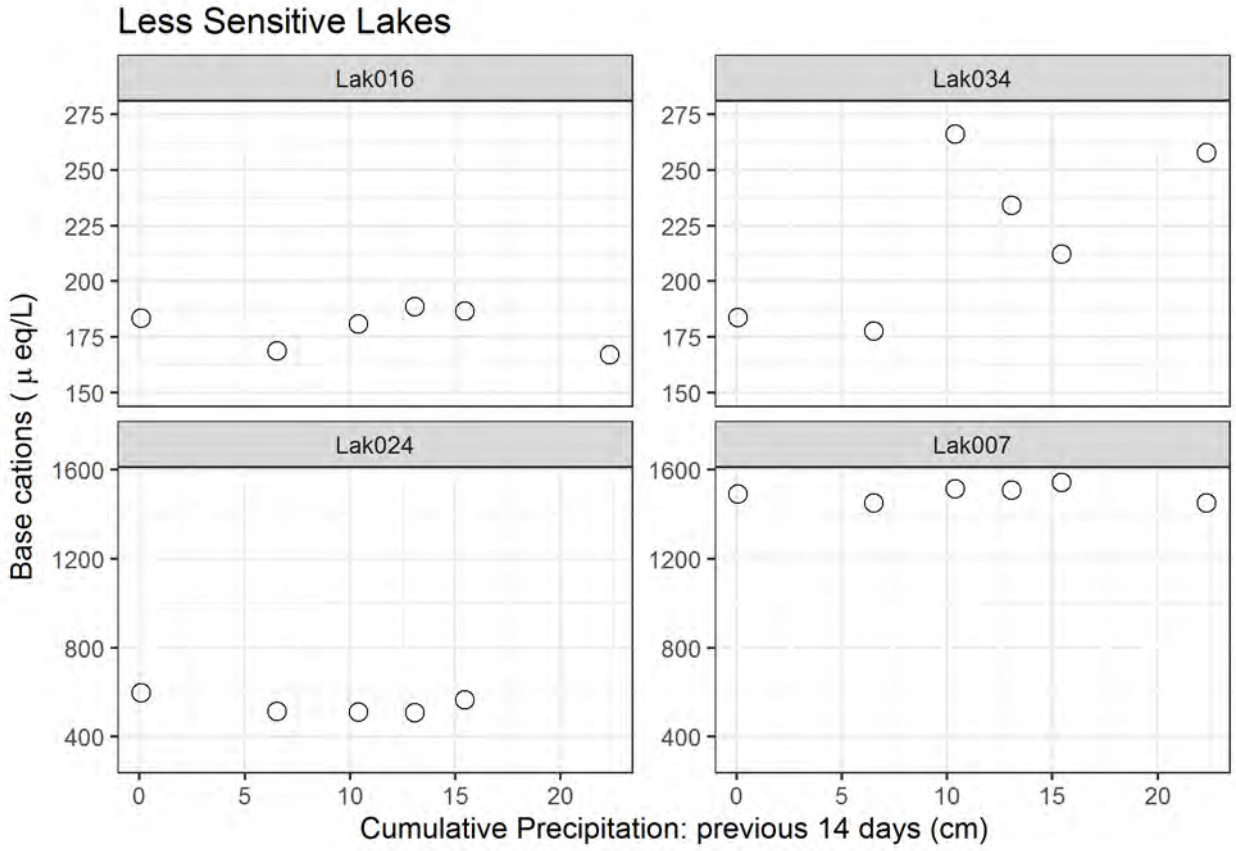


Figure 7.75: Base Cations (Ca + Na + Mg + K) vs. cumulative precipitation (cm) over the previous fourteen days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

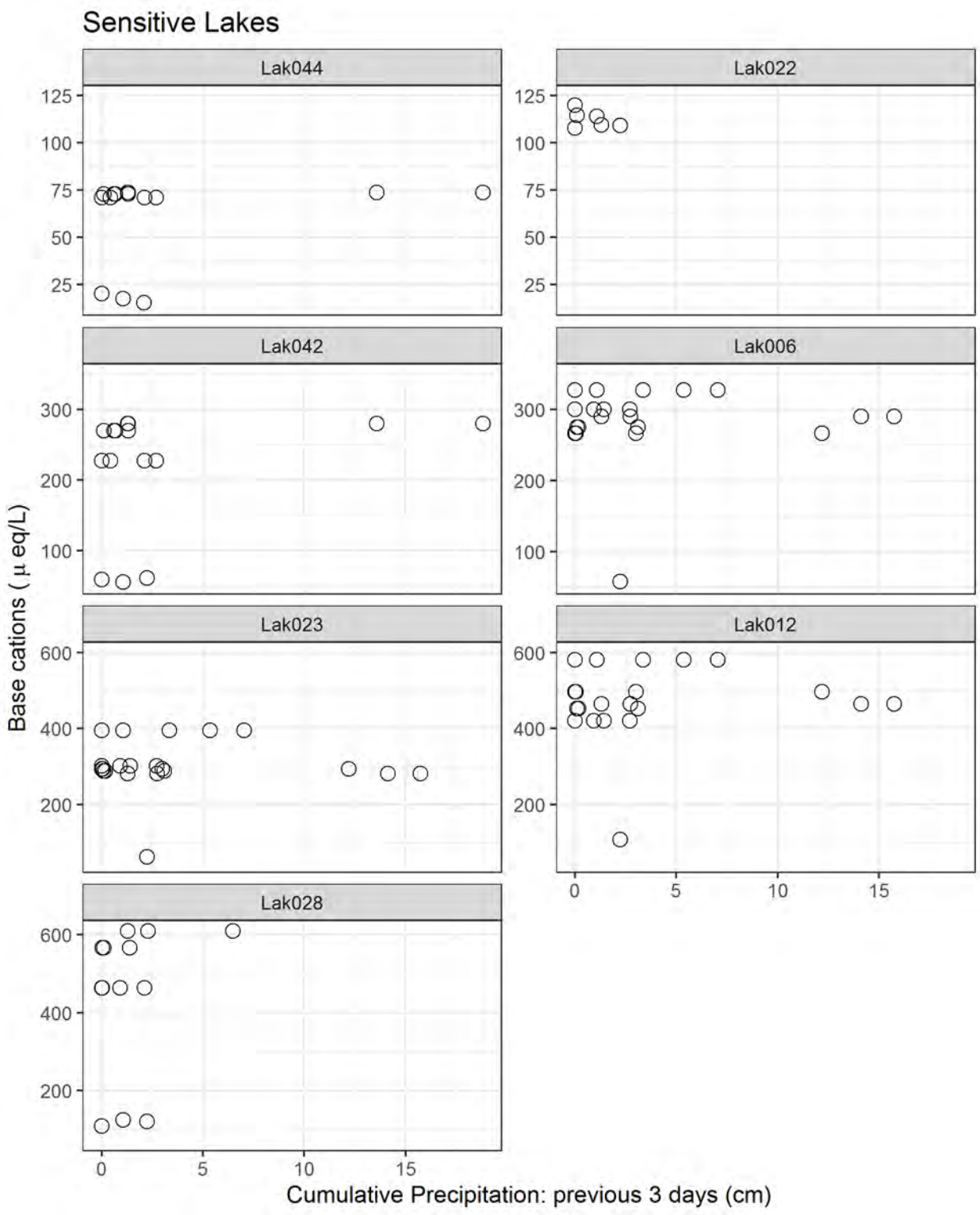


Figure 7.76: Base Cations (Ca + Na + Mg + K) vs. cumulative precipitation (cm) over the previous three days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

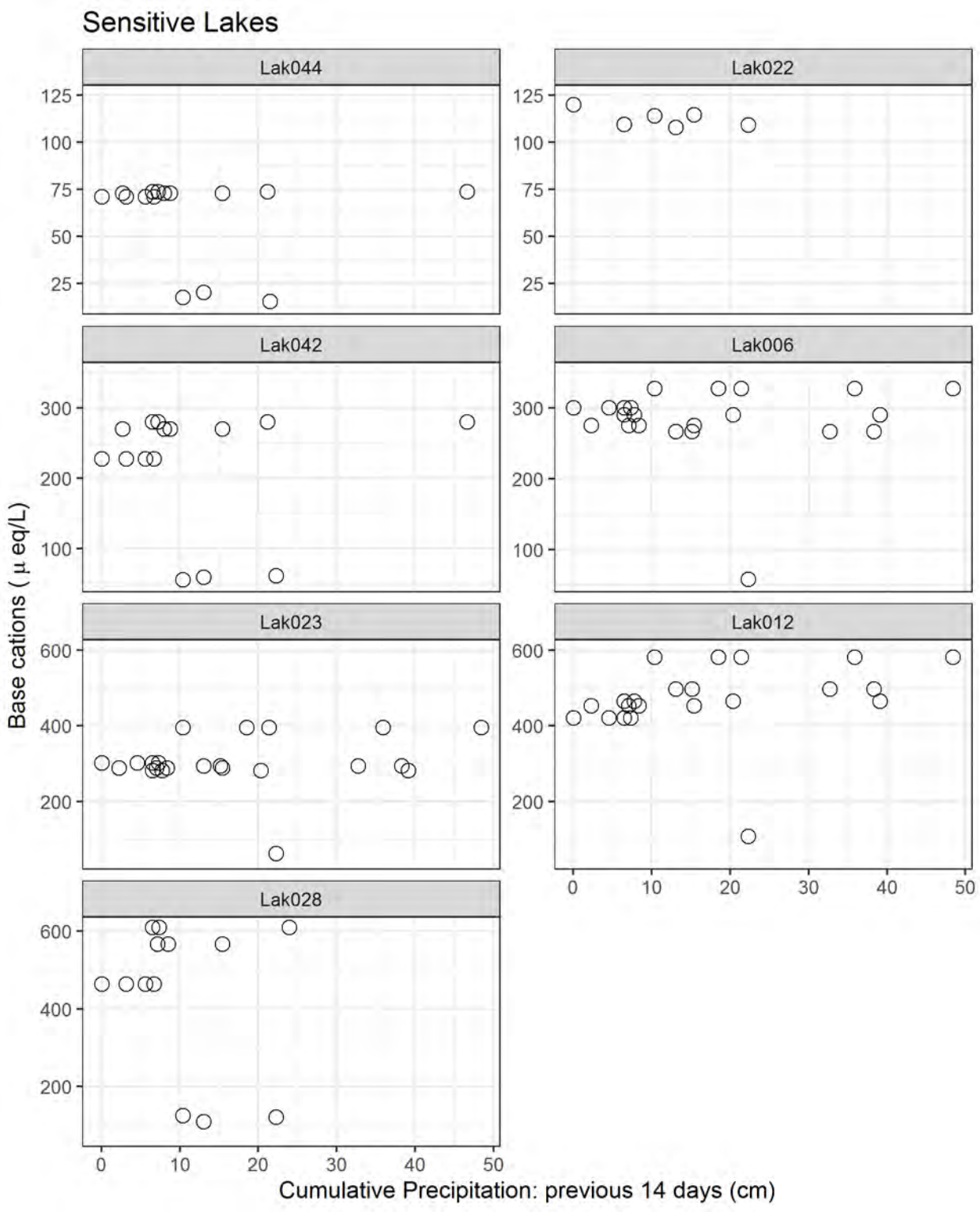


Figure 7.77: Base Cations (Ca + Na + Mg + K) vs. cumulative precipitation (cm) over the previous fourteen days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.2.2.6 Aluminum vs. Precipitation

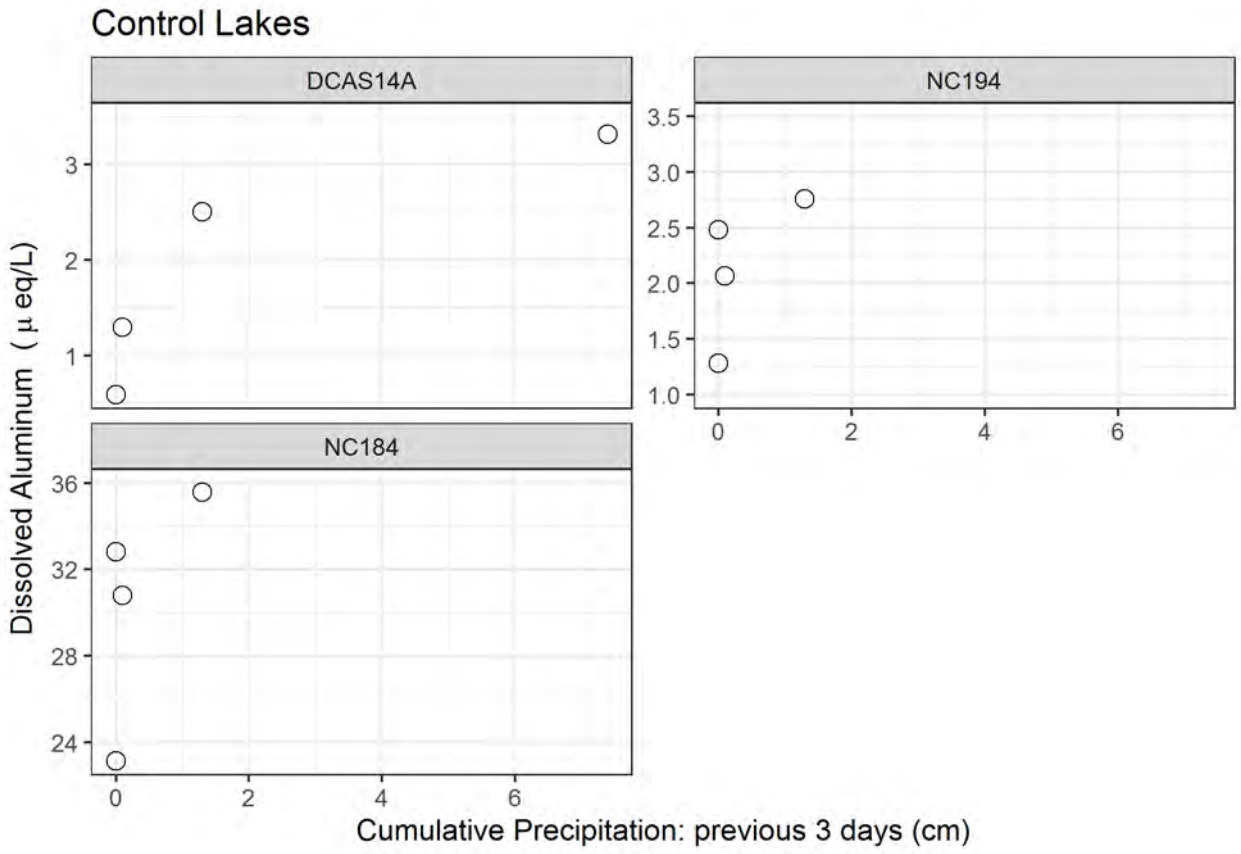


Figure 7.78: Dissolved Aluminum (µeq/l) vs. cumulative precipitation (cm) over the previous three days for the control lakes (DCAS14A, NC184, NC194).

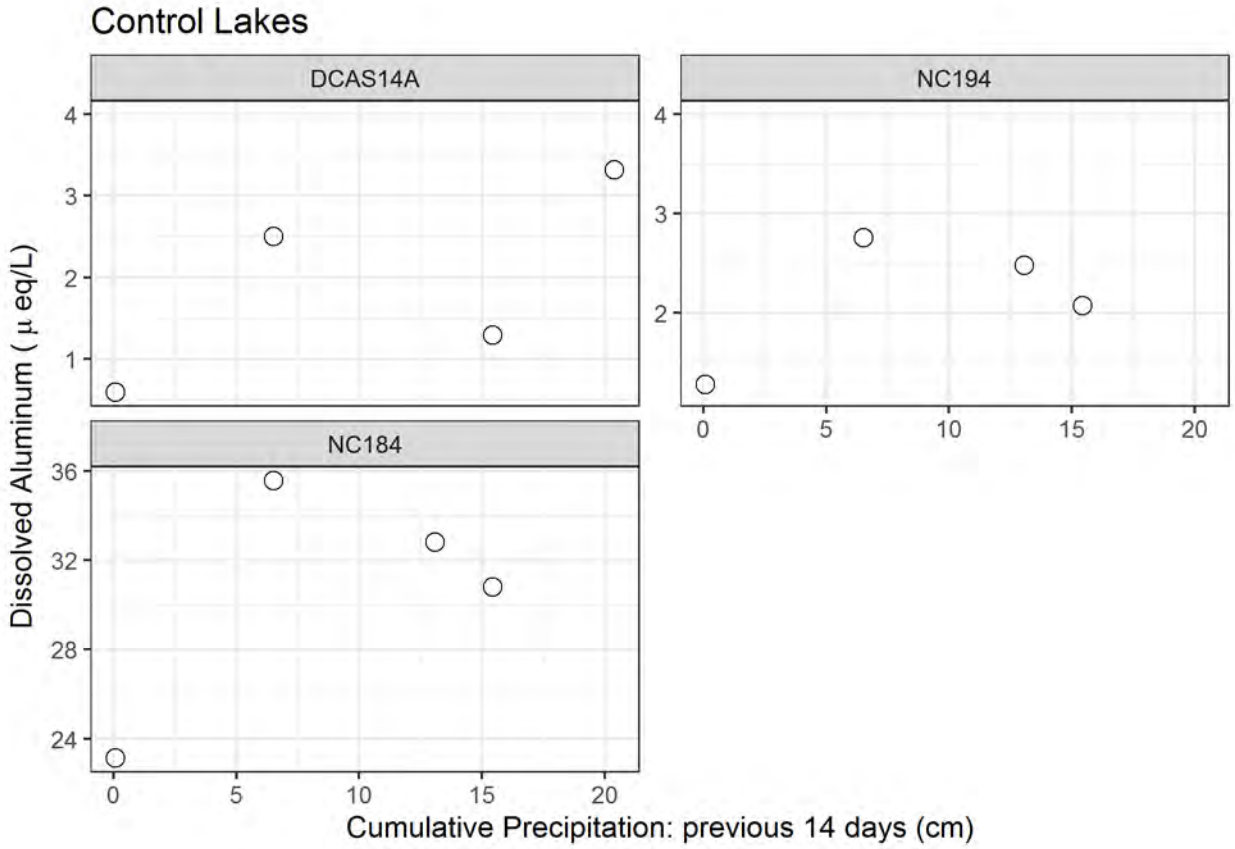


Figure 7.79: Dissolved Aluminum (µeq/l) vs. cumulative precipitation (cm) over the previous fourteen days for the control lakes (DCAS14A, NC184, NC194).

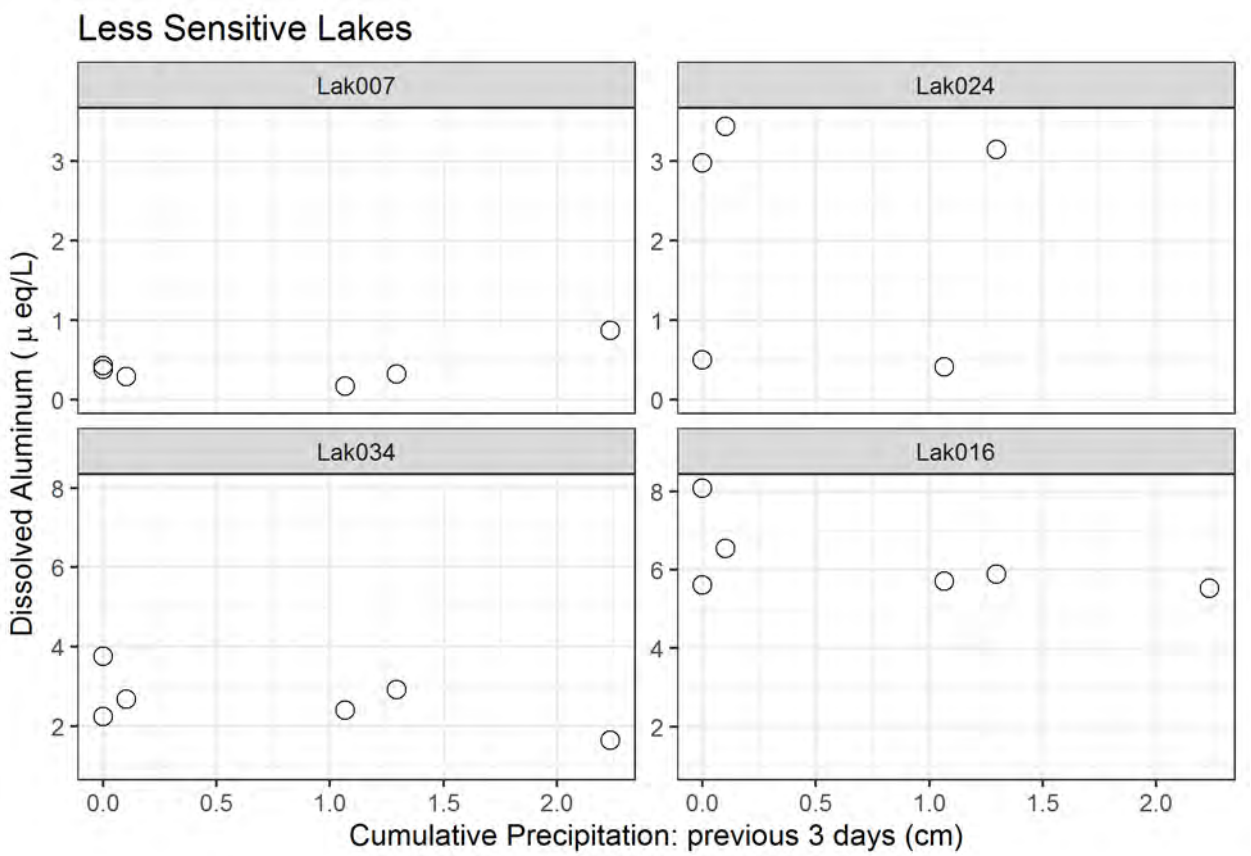


Figure 7.80: Dissolved Aluminum (µeq/l) vs. cumulative precipitation (cm) over the previous three days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

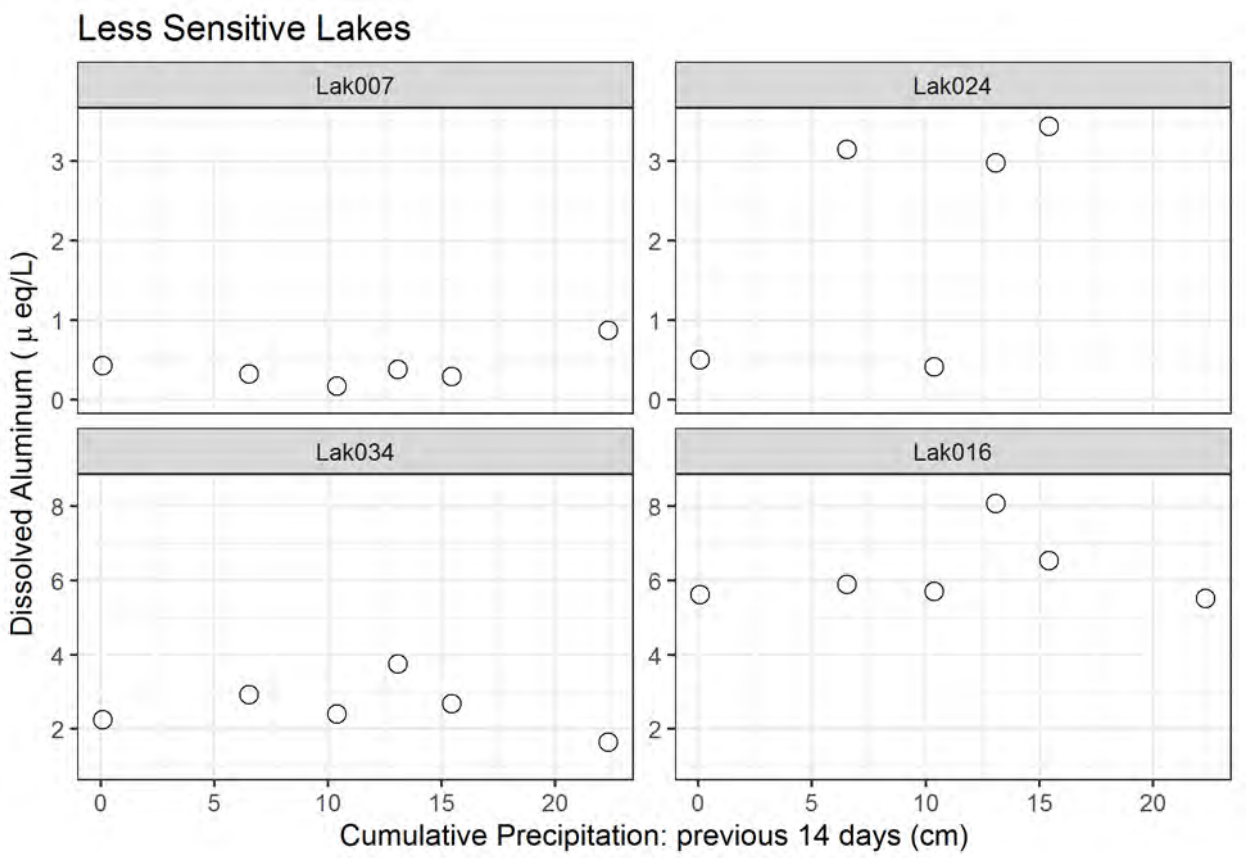


Figure 7.81: Dissolved Aluminum (µeq/l) vs. cumulative precipitation (cm) over the previous fourteen days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

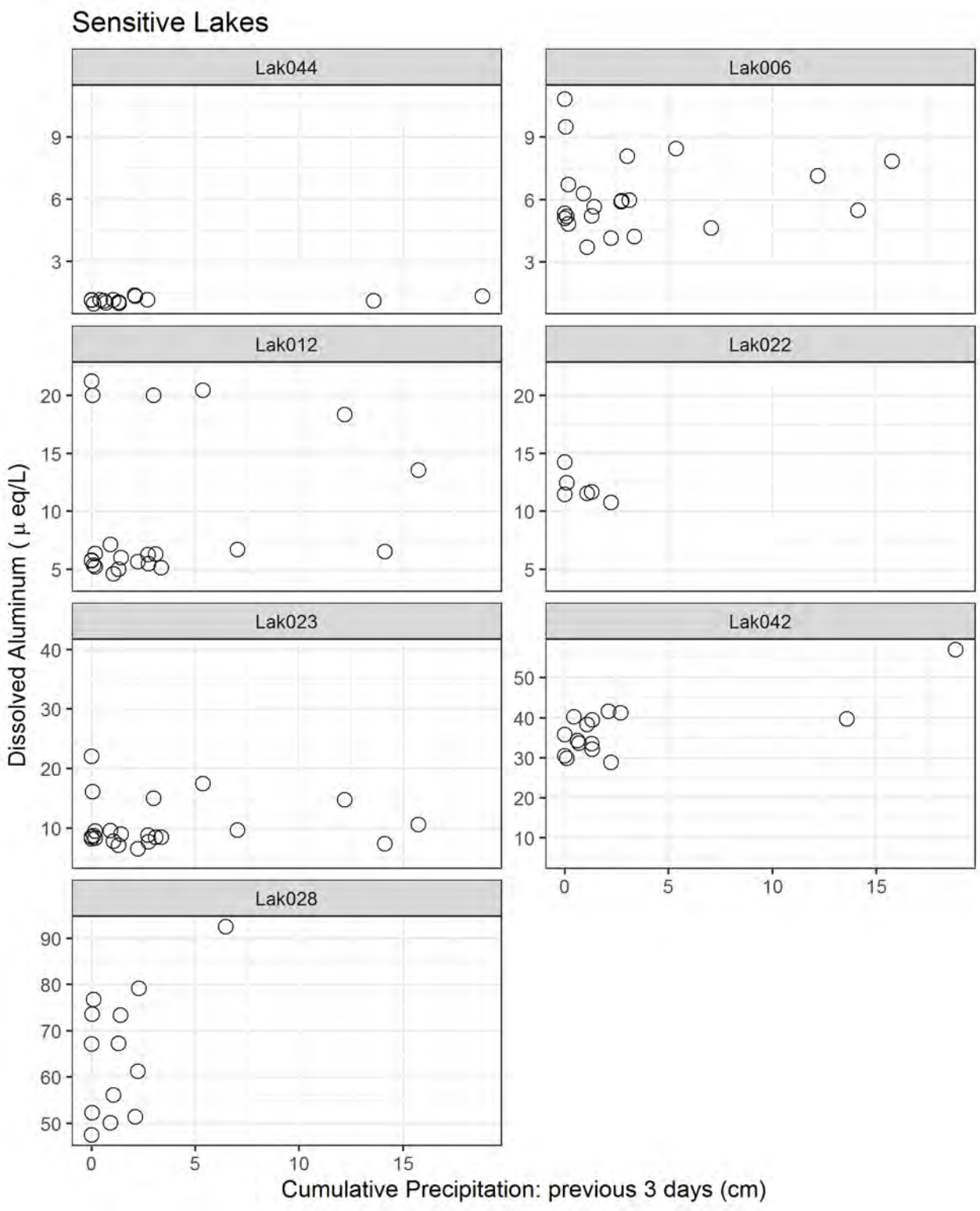


Figure 7.82: Dissolved Aluminum (µeq/l) vs. cumulative precipitation (cm) over the previous three days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

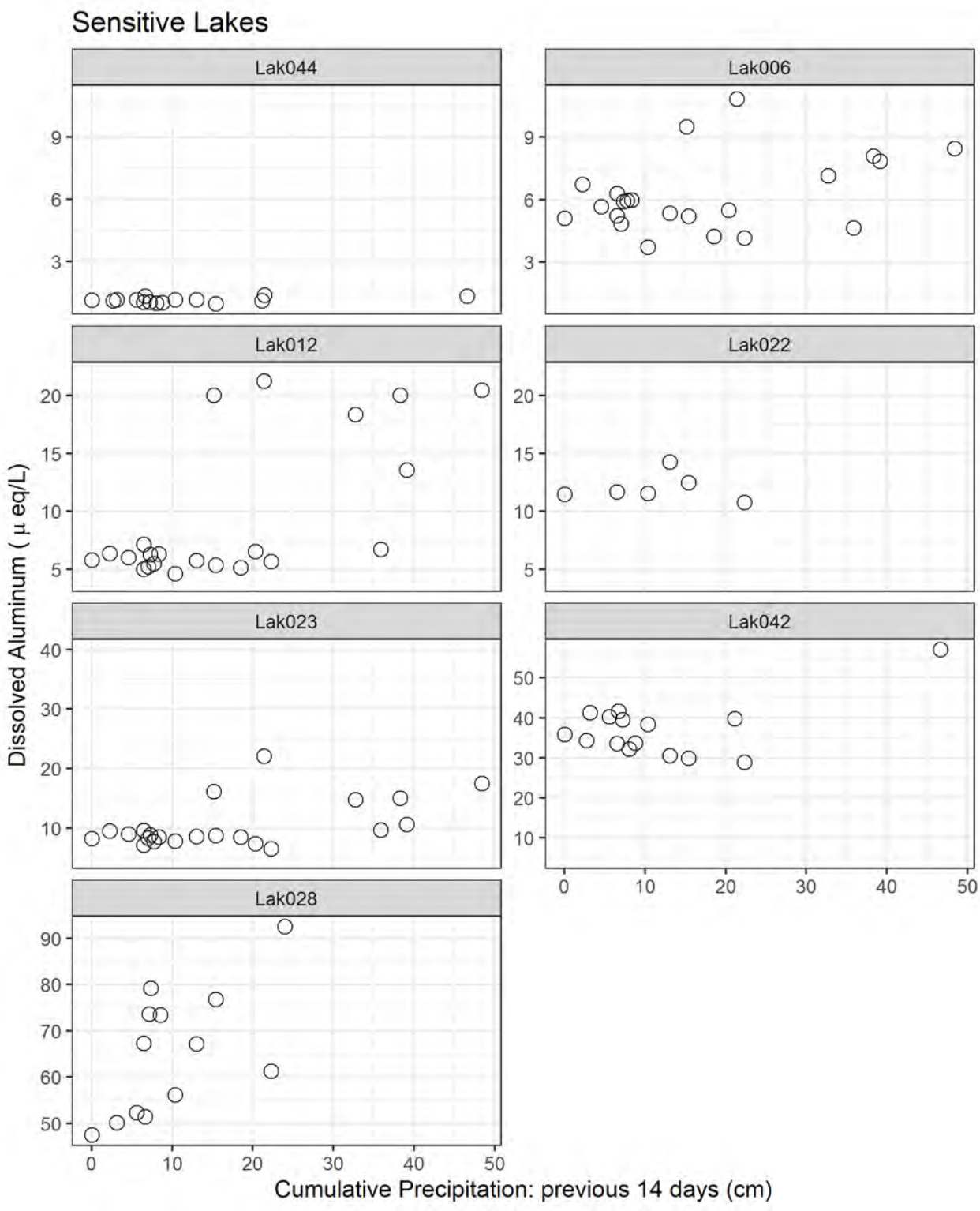


Figure 7.83: Dissolved Aluminum (µeq/l) vs. cumulative precipitation (cm) over the previous fourteen days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.2.2.7 Chloride vs. Precipitation

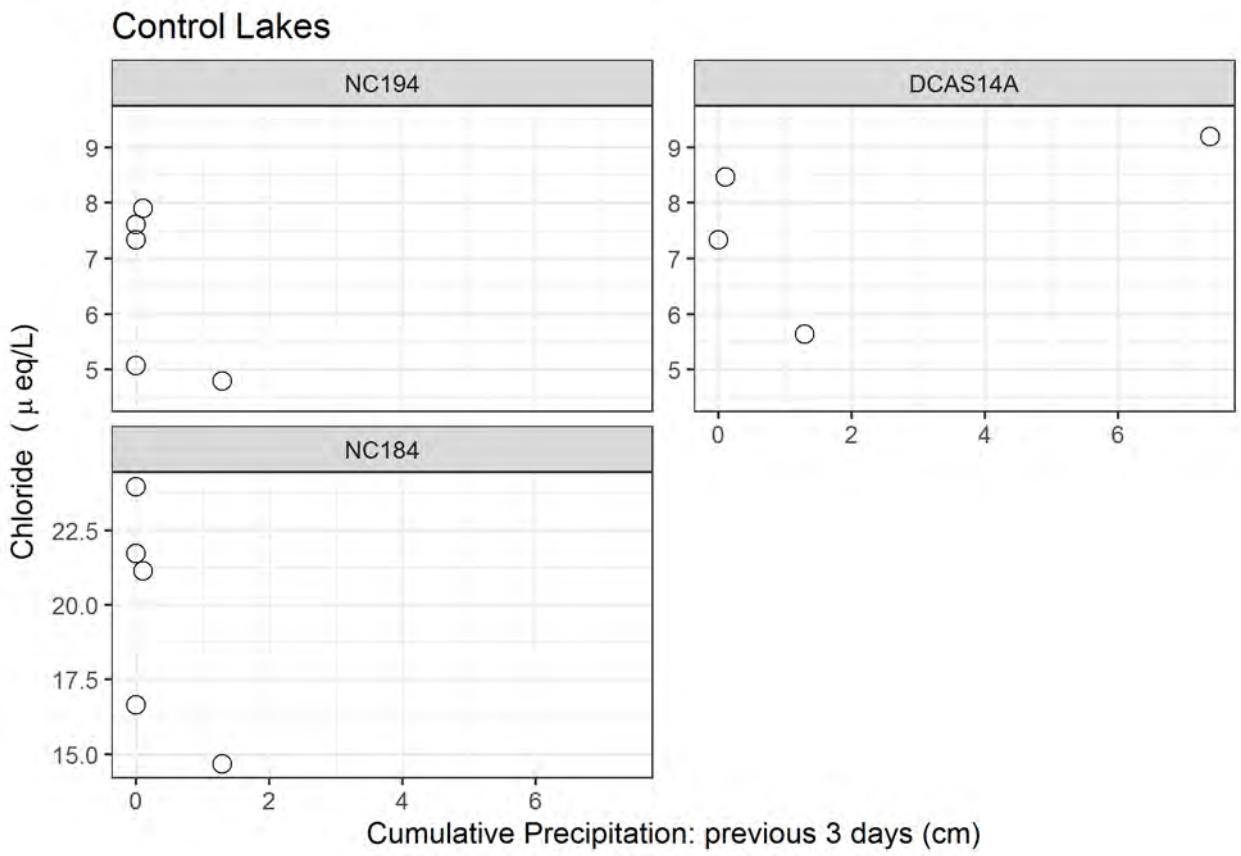


Figure 7.84: Chloride (µeq/l) vs. cumulative precipitation (cm) over the previous three days for the control lakes (DCAS14A, NC184, NC194).

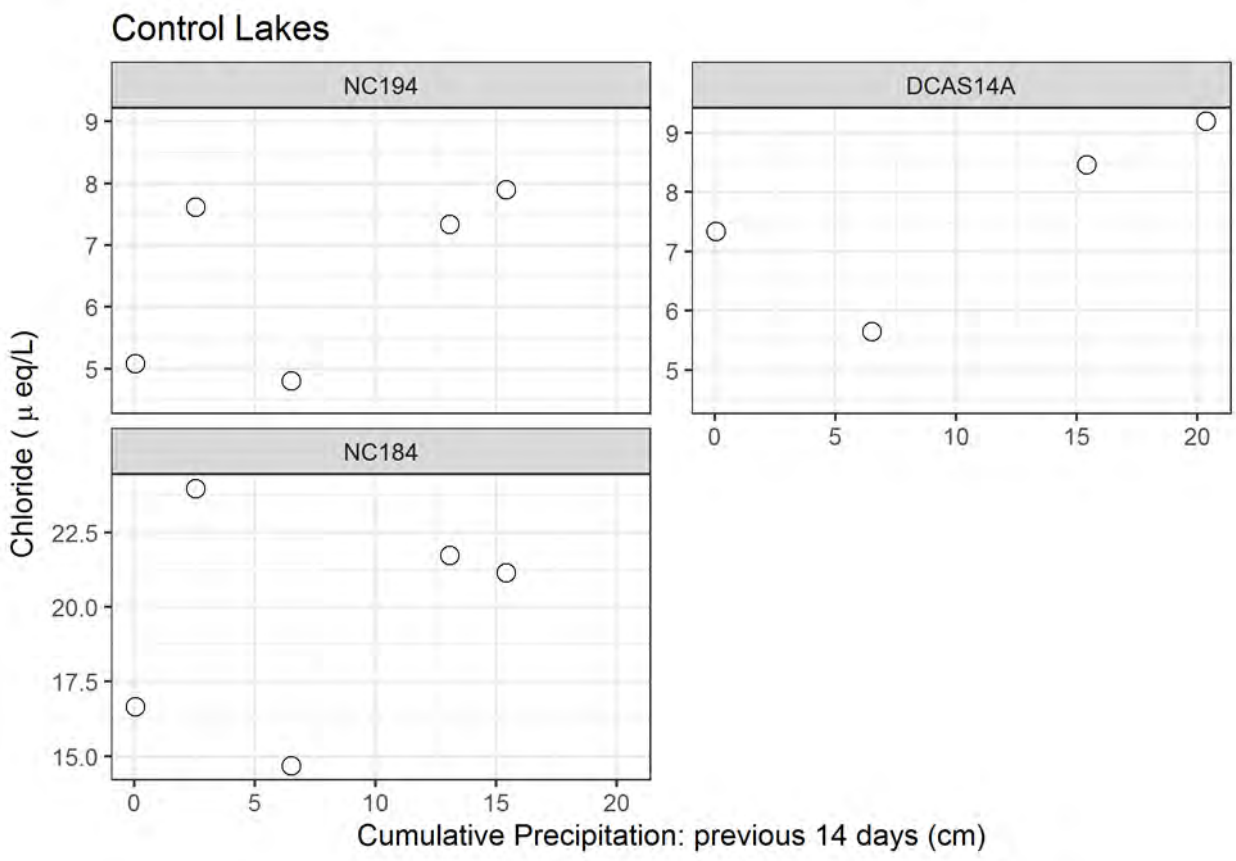


Figure 7.85: Chloride (µeq/l) vs. cumulative precipitation (cm) over the previous fourteen days for the control lakes (DCAS14A, NC184, NC194).

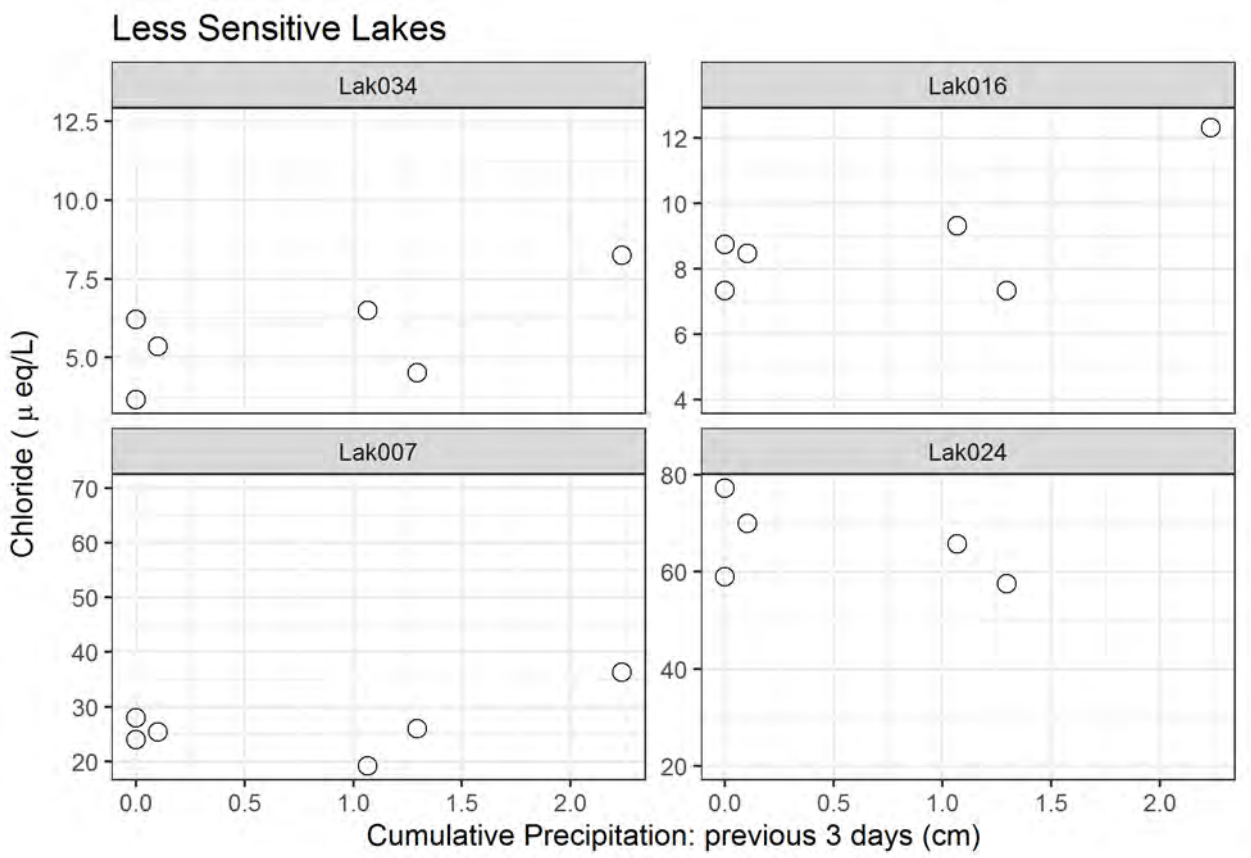


Figure 7.86: Chloride (µeq/l) vs. cumulative precipitation (cm) over the previous three days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

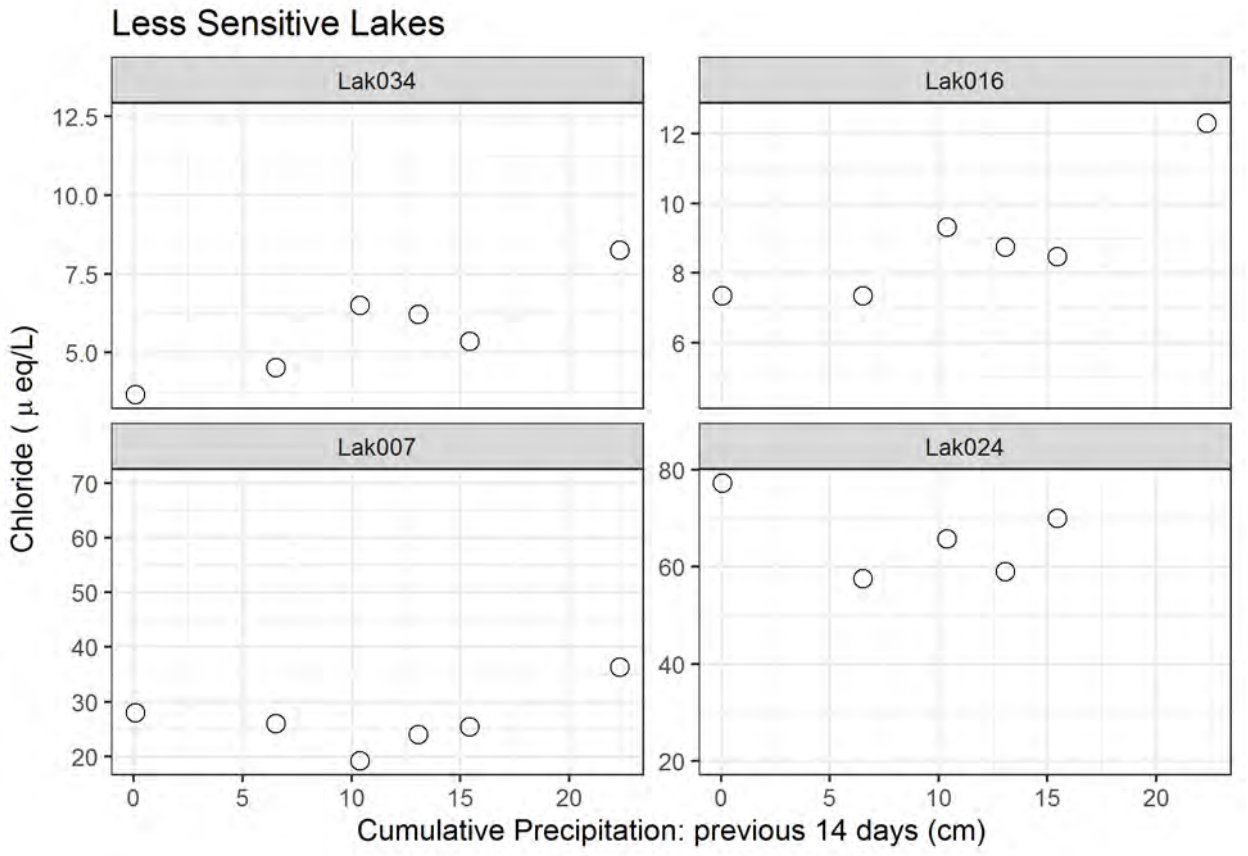


Figure 7.87: Chloride (µeq/l) vs. cumulative precipitation (cm) over the previous fourteen days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

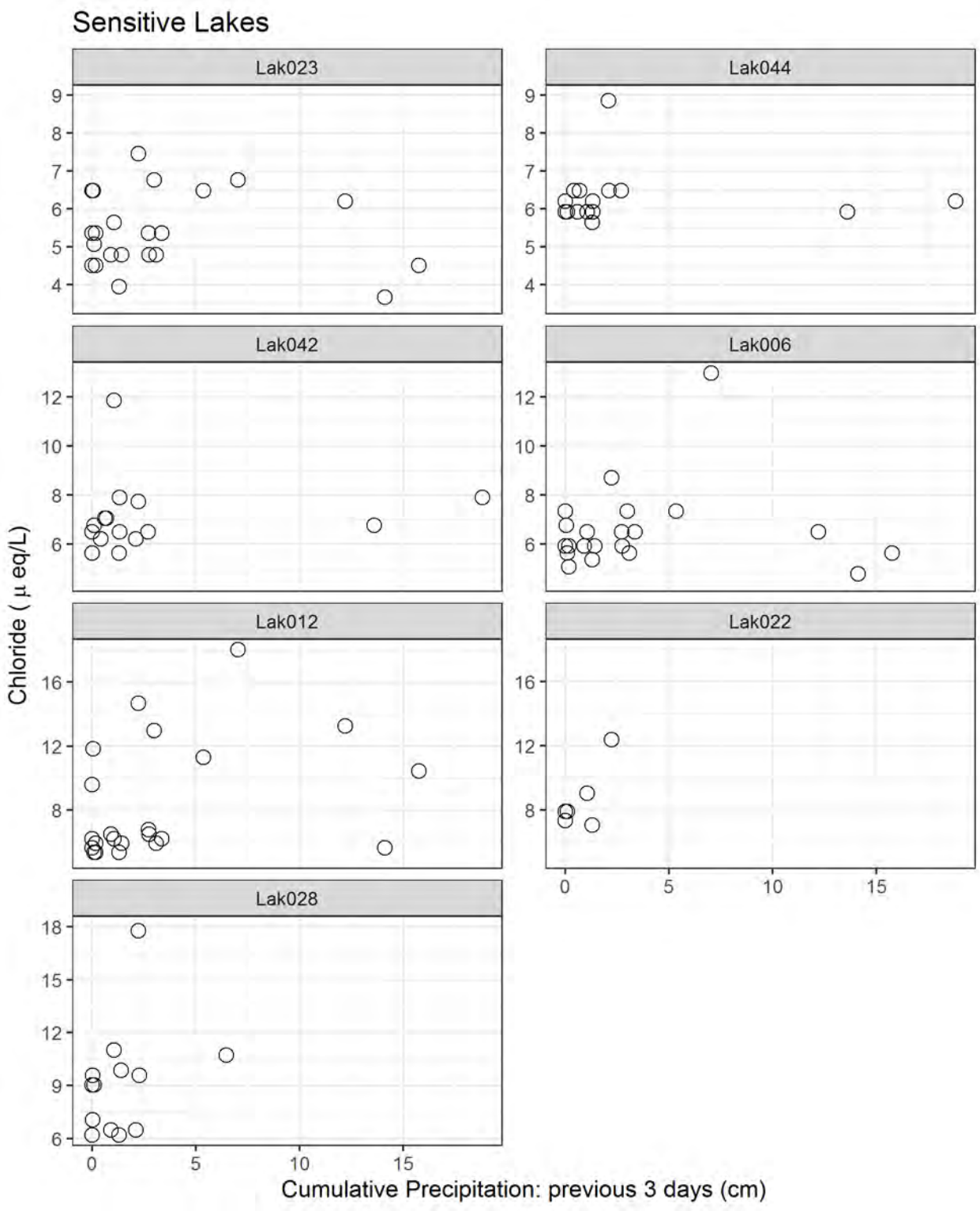


Figure 7.88: Chloride (µeq/l) vs. cumulative precipitation (cm) over the previous three days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

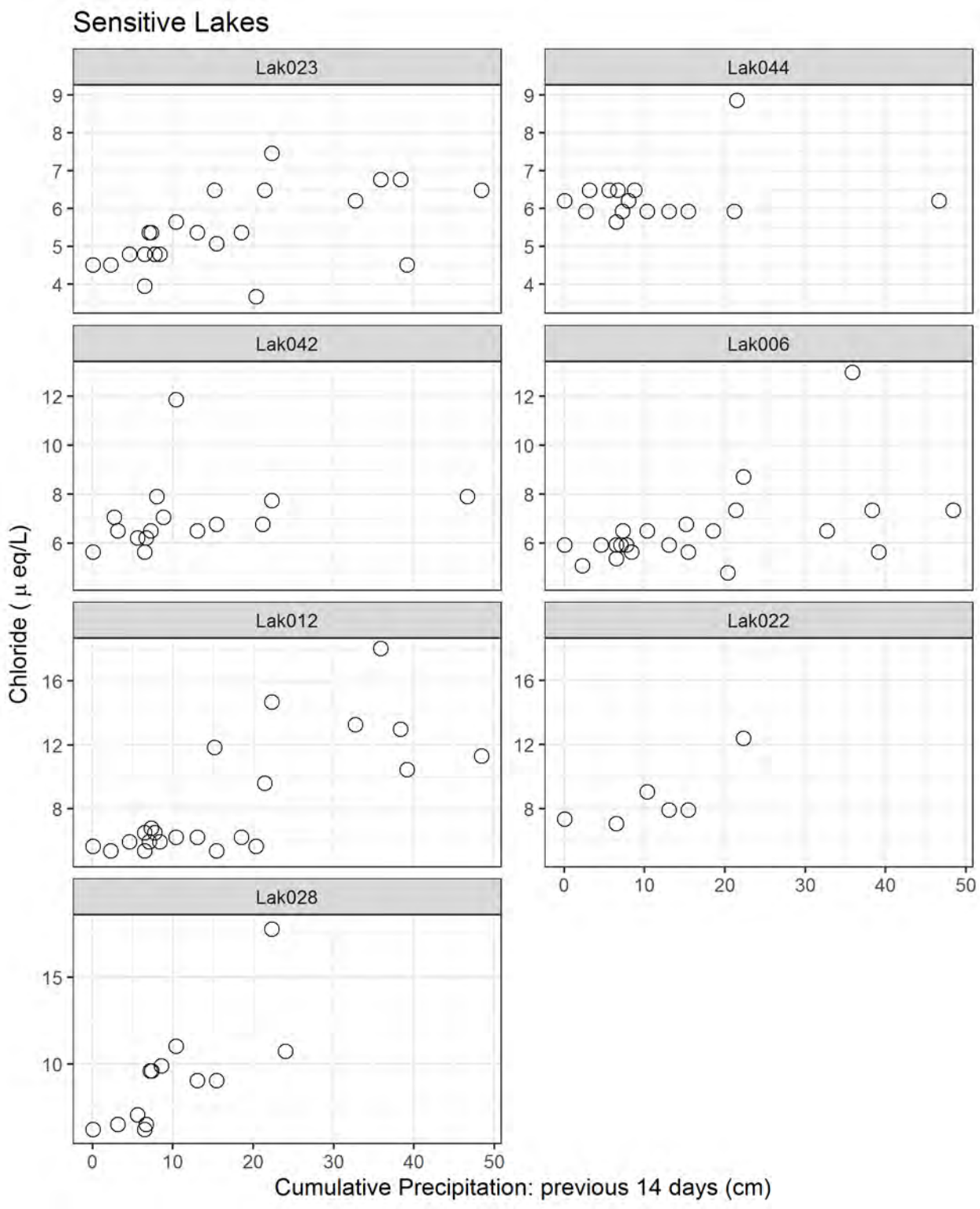


Figure 7.89: Chloride (µeq/l) vs. cumulative precipitation (cm) over the previous fourteen days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.2.2.8 DOC vs. Precipitation

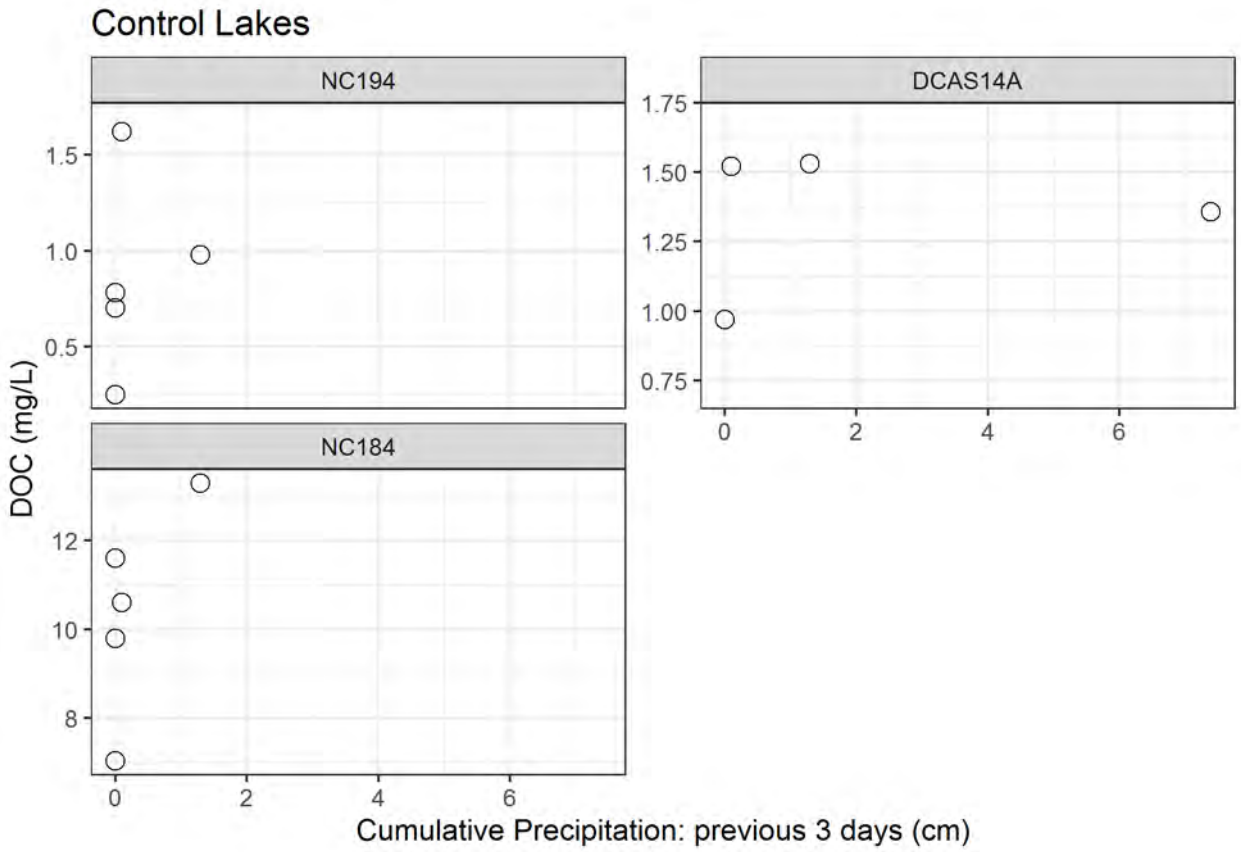


Figure 7.90: DOC (mg/L) vs. cumulative precipitation (cm) over the previous three days for the control lakes (DCAS14A, NC184, NC194).

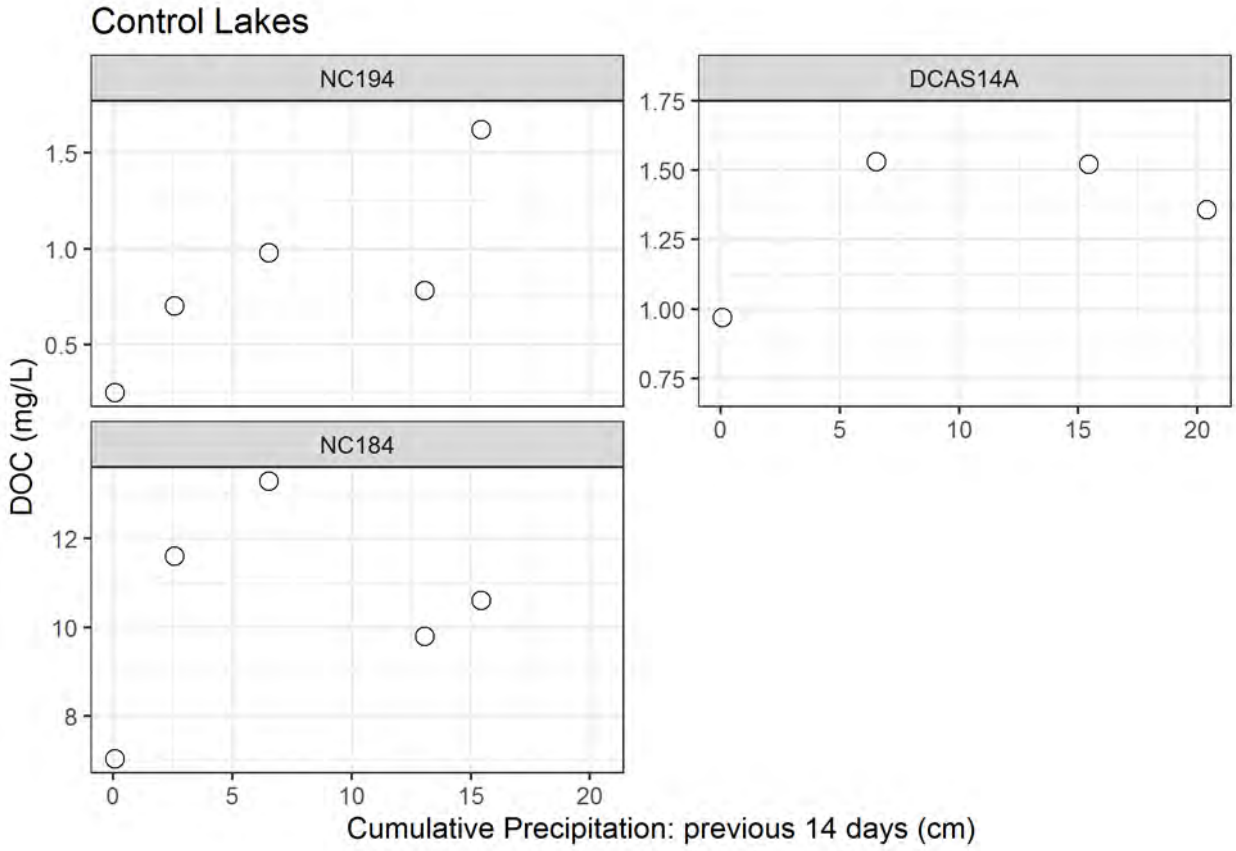


Figure 7.91: DOC (mg/L) vs. cumulative precipitation (cm) over the previous fourteen days for the control lakes (DCAS14A, NC184, NC194).

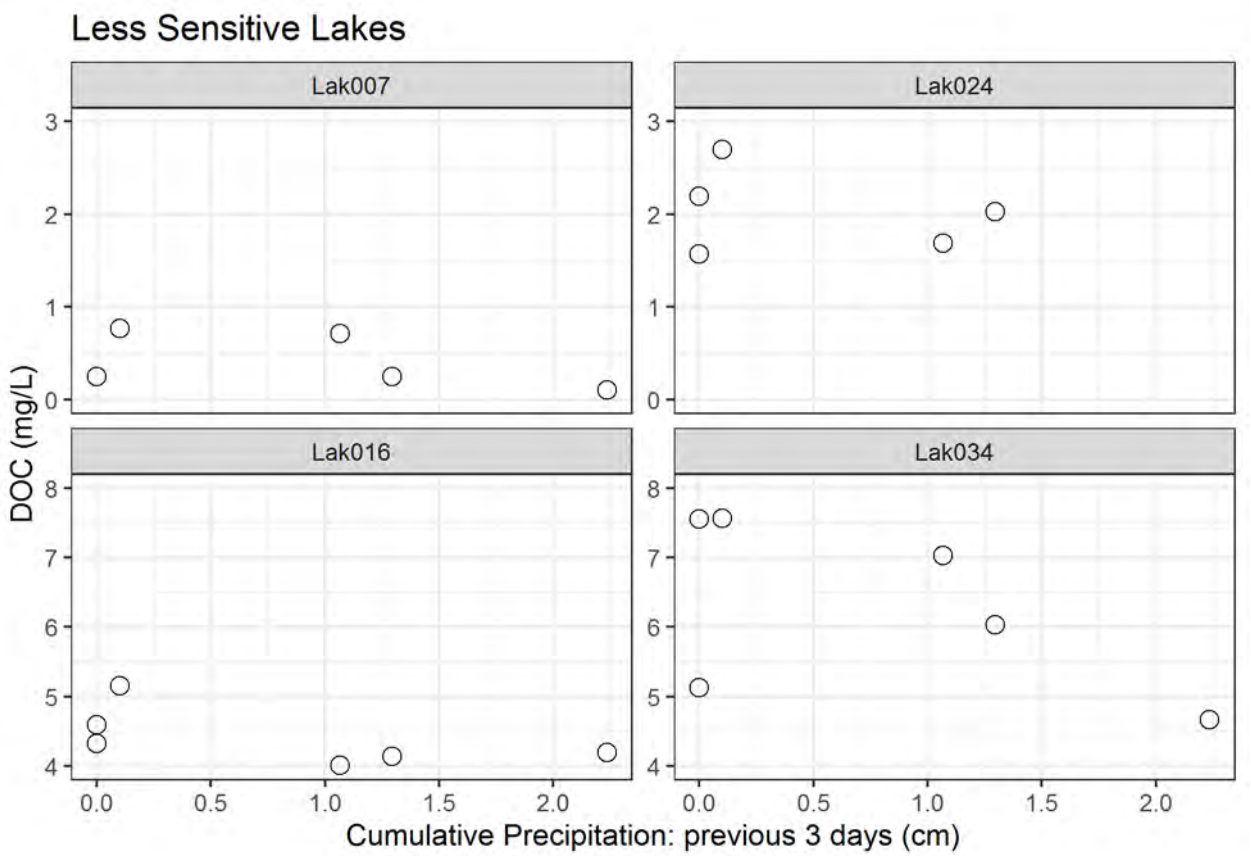


Figure 7.92: DOC (mg/L) vs. cumulative precipitation (cm) over the previous three days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

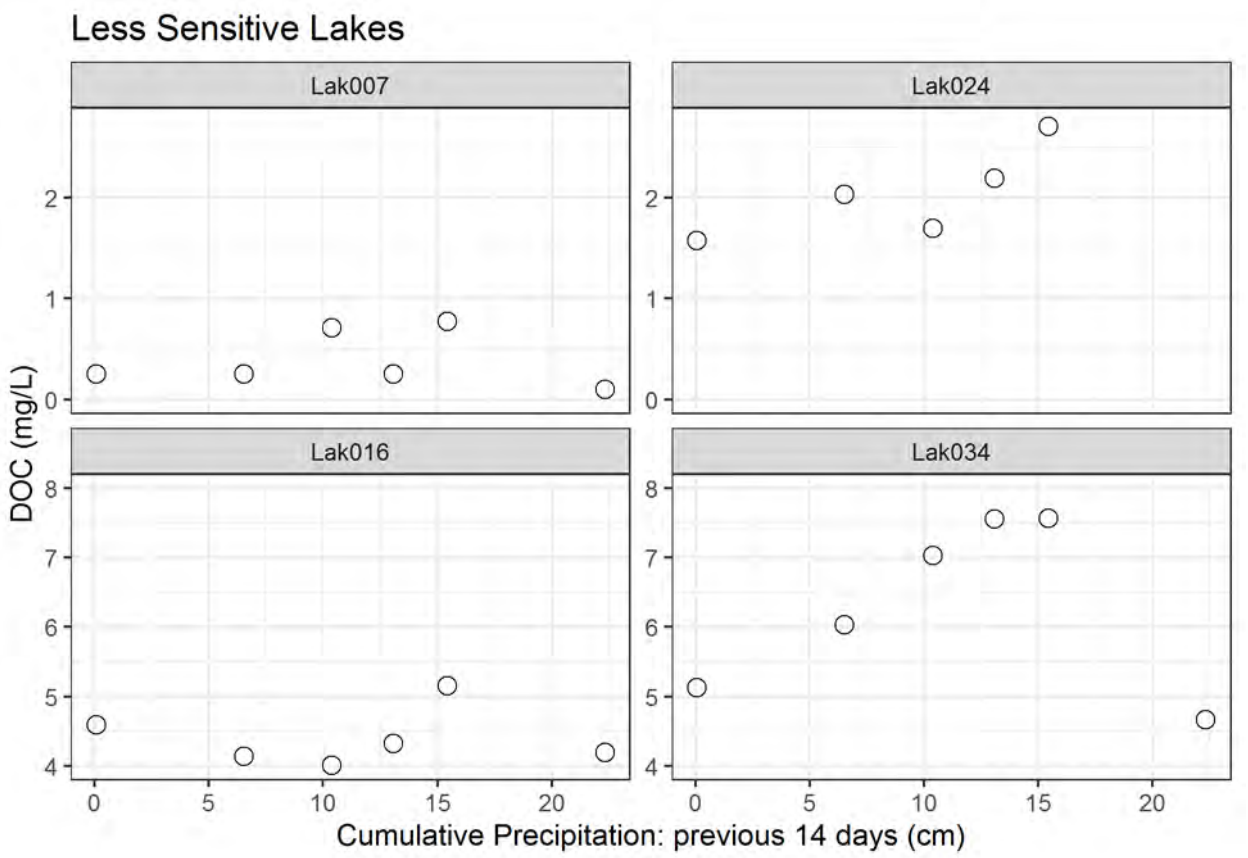


Figure 7.93: DOC (mg/L) vs. cumulative precipitation (cm) over the previous fourteen days for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

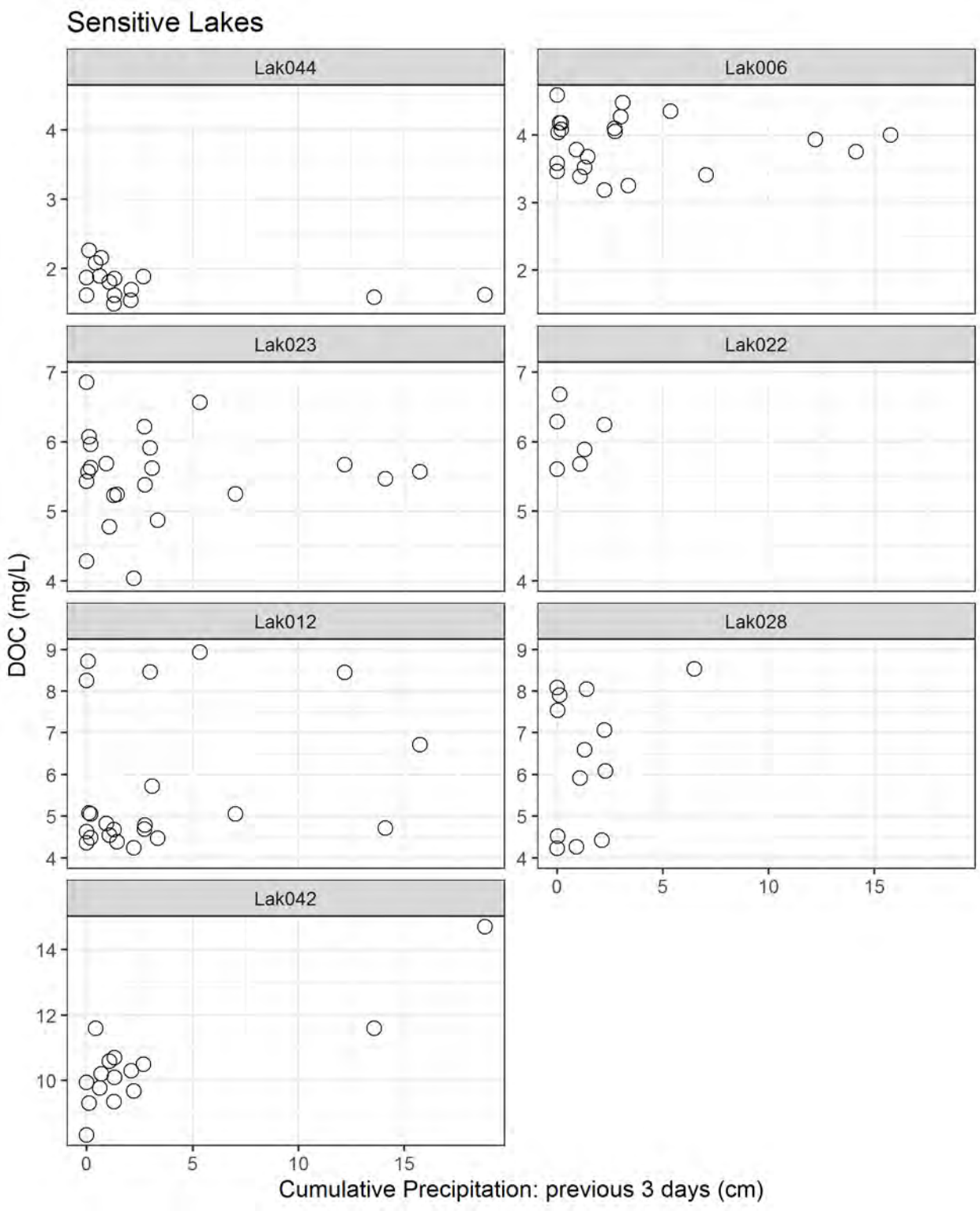


Figure 7.94: DOC (mg/L) vs. cumulative precipitation (cm) over the previous three days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

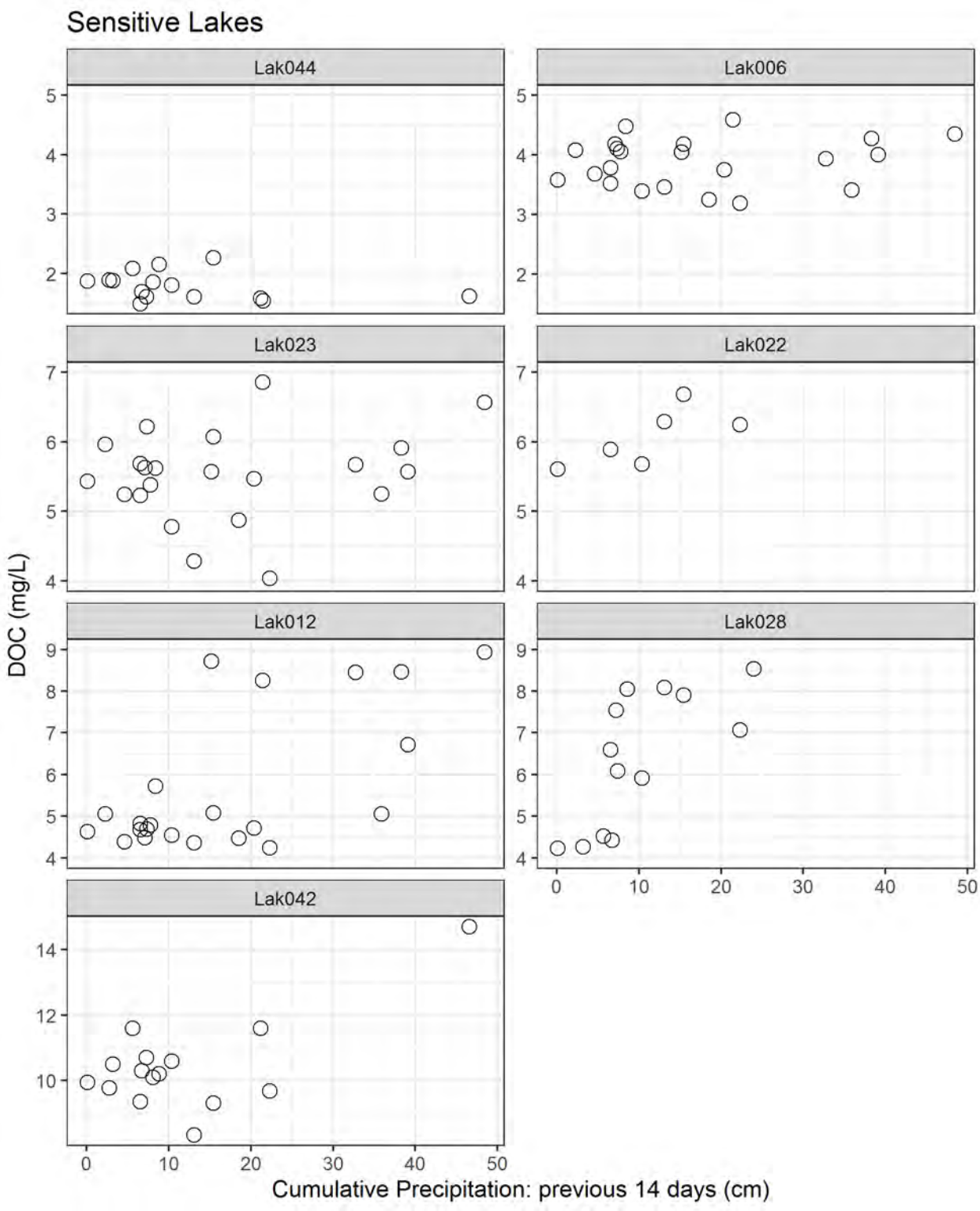


Figure 7.95: DOC (mg/L) vs. cumulative precipitation (cm) over the previous fourteen days for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.2.3 Water Chemistry Relative to Emissions

Purpose of analyses: As discussed in the evidentiary framework (Section 7 of the EEM Program Plan), the relationship between lake SO_4 concentrations and recent SO_2 emissions can help to inform the interpretation of the causes of changes in water chemistry. The absence of any positive correlation between lake SO_4 concentrations and recent SO_2 emissions (or any temporal trend of increasing SO_4) is evidence against the new smelter being a cause of changes in lake SO_4. However, the lack of a correlation could also reflect the fact that emissions are only a proxy indicator of the actual deposition at each lake. Estimates of lake-specific deposition are only available with the revised CALPUFF model for the period from 2016 to 2018, and therefore don't provide contrast between the pre-KMP and post-KMP period. While the presence of a positive correlation between lake SO_4 concentrations and SO_2 emissions is consistent with the hypothesis of the new smelter causing changes in lake SO_4, such a correlation is not by itself incontrovertible evidence that smelter emissions caused the increase in lake SO_4. For example, drought conditions can cause SO_4 that was historically stored in a reduced form in wetlands to be re-oxidized and then (once the drought is over) washed into the lake, causing an increase in SO_4 and decreased pH (Yan et al. 1996). It is important therefore to look at multiple factors before drawing conclusions on the most likely causes of year-to-year changes in lake chemistry. Since the control lakes were deliberately chosen to be well outside the main plume of the smelter, we would expect to see no correlation between lake SO_4 concentrations and recent SO_2 emissions in the control lakes. We expect to see stronger correlations in lakes directly within the plume.

An increase in lake SO_4 with recent SO_2 emissions is a necessary condition for there to be a causal connection between smelter emissions and lake chemistry, though increased lake SO_4 does not necessarily mean that a lake has acidified. Assessing whether acidification has occurred in a lake with increased lake SO_4 requires an examination of changes in Gran ANC and pH (see simplified evidentiary framework in Figure 7.35). Less sensitive lakes will show increases in lake SO_4 without any decrease in Gran ANC or pH, as they have sufficient buffering capacity in their watersheds and surface waters to neutralize the acidity that accompanies SO_4.

Explanation of the graphs and tables of results: The graphs in Sections 7.6.2.3.1, 7.6.2.3.2, and 7.6.2.3.3 show (respectively) mean lake SO_4, Gran ANC and pH, in an October sampling period versus the total emissions (in tonnes) during the previous 12 months (i.e., from October 1 of the previous year to September 30 of the year in which the sampling occurred).

7.6.2.3.1 SO_4 vs. Emissions

- See Section 7.6.4.2.6 for statistical analyses of the ability of total SO_2 emissions to explain observed patterns of changes in sulphate over time, beyond those patterns observed in control lakes.

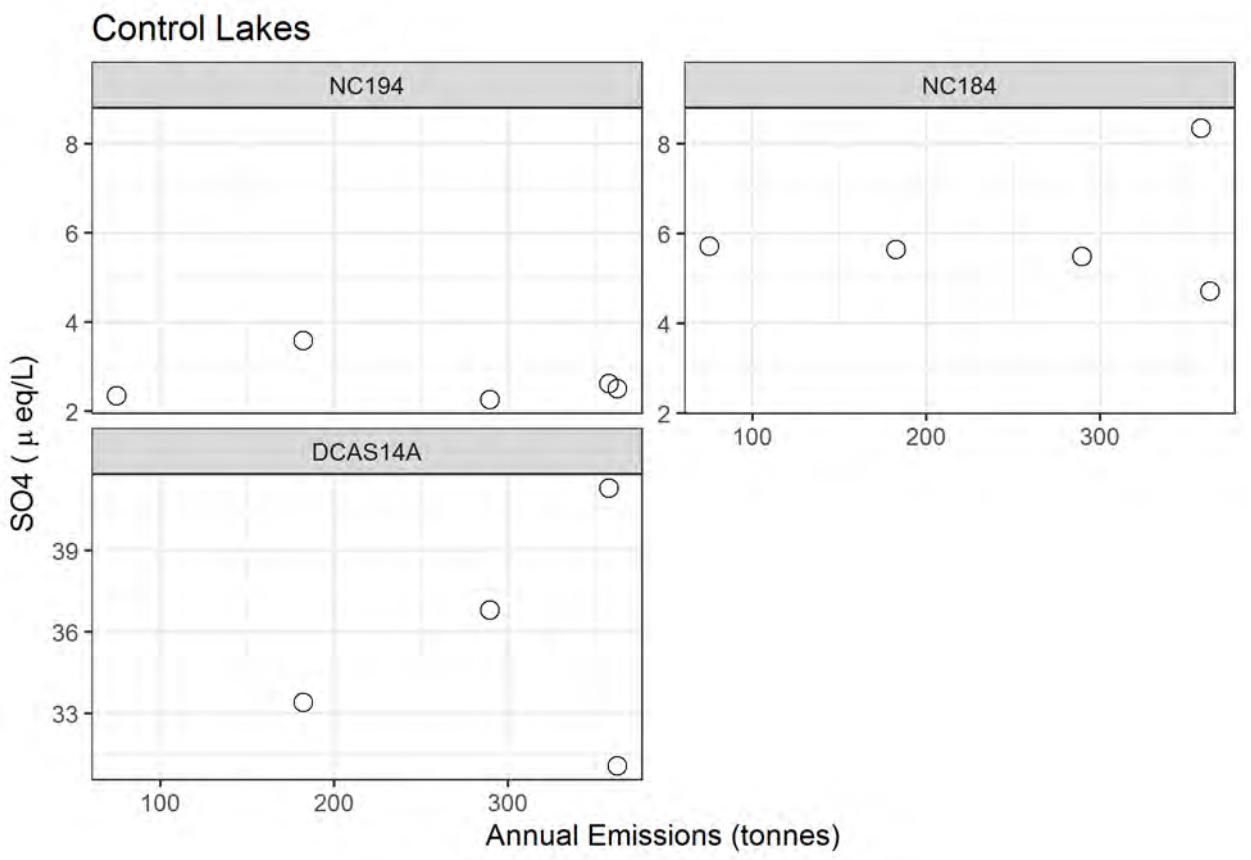


Figure 7.96: SO_4 concentrations vs. annual emissions (in tonnes) for the control lakes (DCAS14A, NC184, NC194).

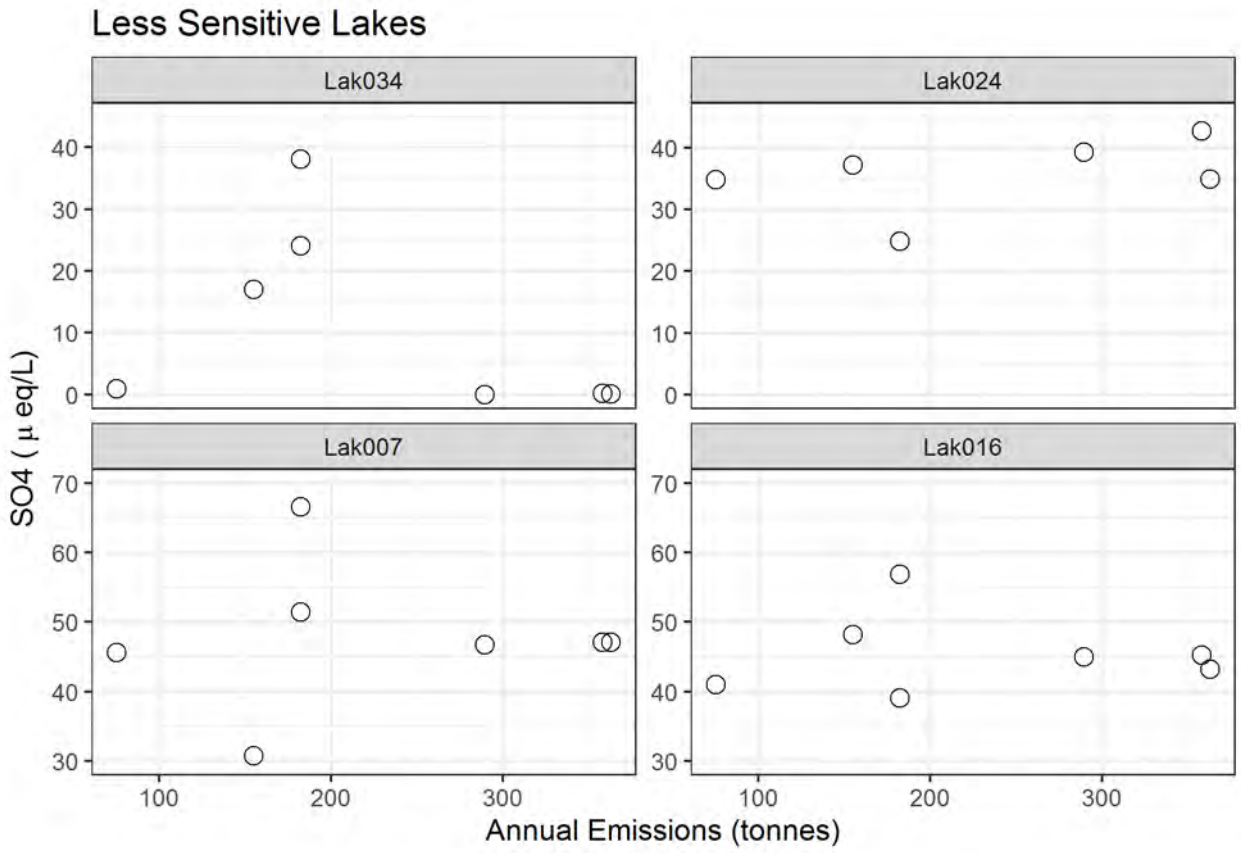


Figure 7.97: SO_4 concentrations vs. annual emissions (in tonnes) for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

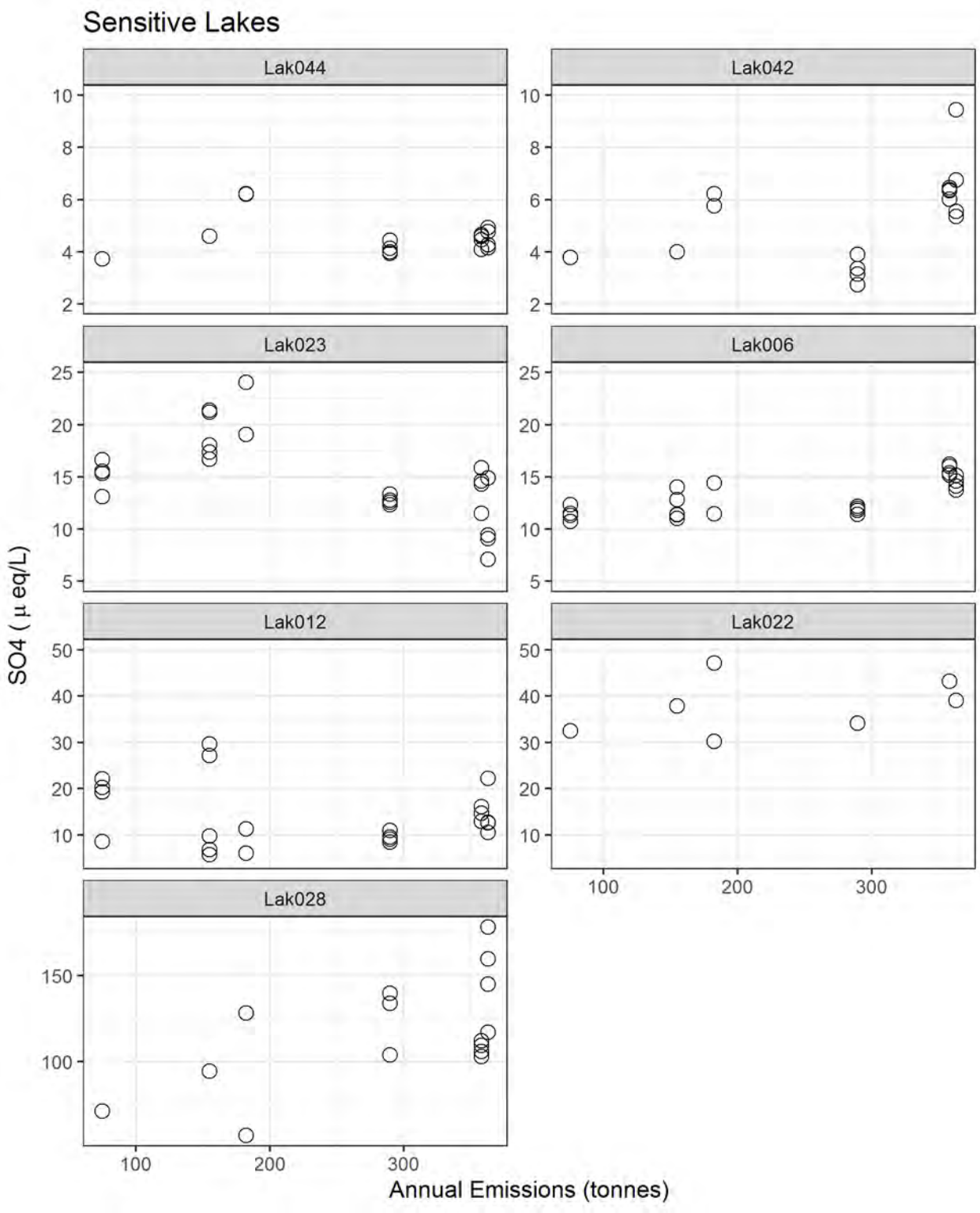


Figure 7.98: SO_4 concentrations vs. annual emissions (in tonnes) for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.2.3.2 Gran ANC vs. Emissions

- See Section 7.6.4.4.6 for statistical analyses of the ability of total SO_2 emissions to explain observed patterns of changes in Gran ANC over time, beyond those patterns observed in control lakes.

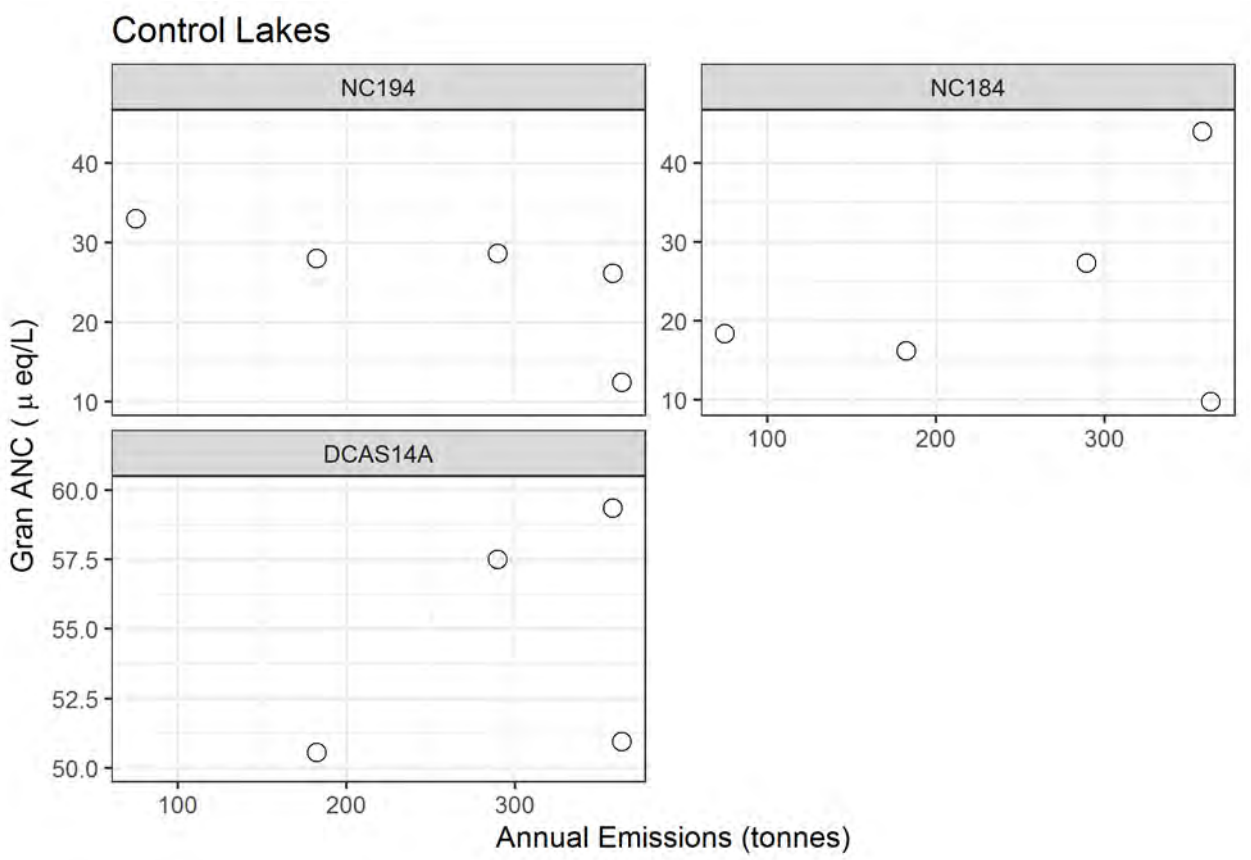


Figure 7.99: Gran ANC vs. annual emissions of SO_2 (in tonnes) for the control lakes (DCAS14A, NC184, NC194).

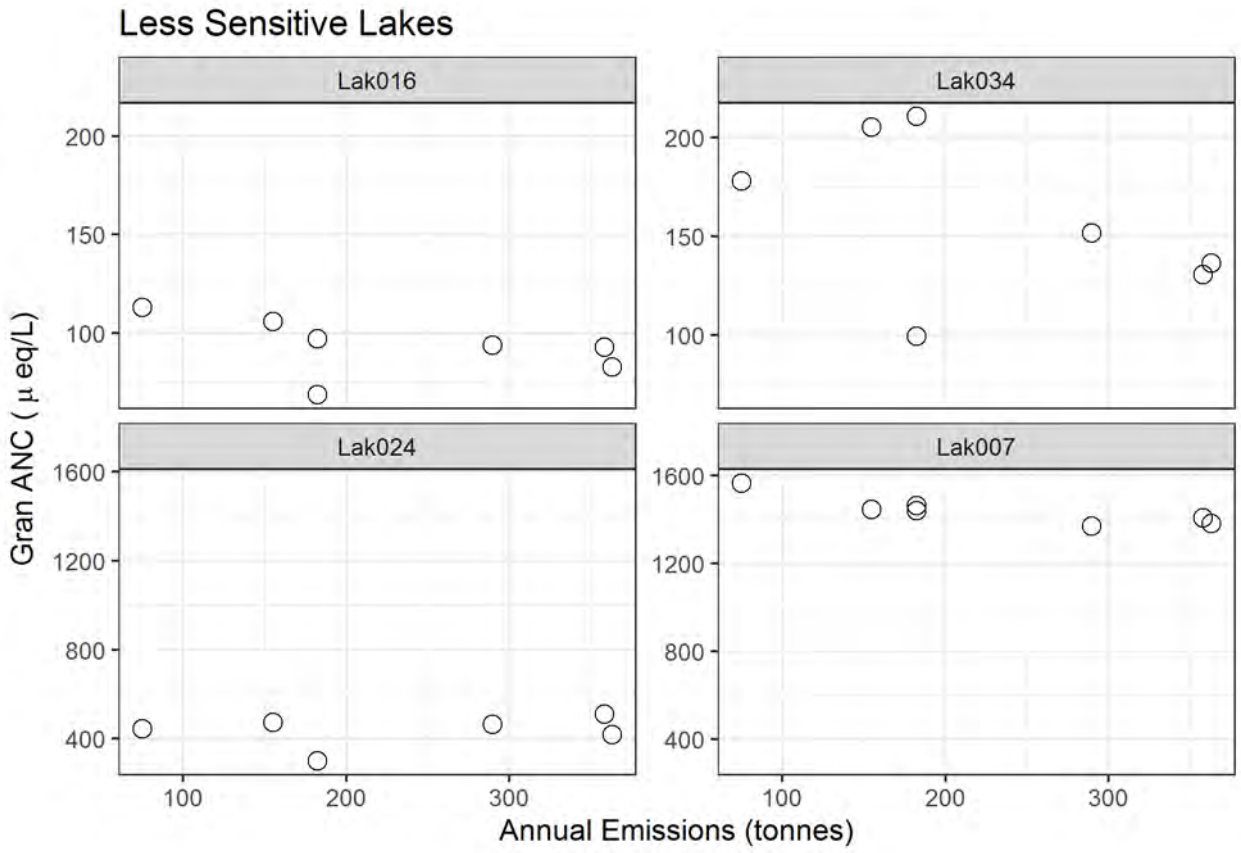


Figure 7.100: Gran ANC vs. annual emissions of SO_2 (in tonnes) for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

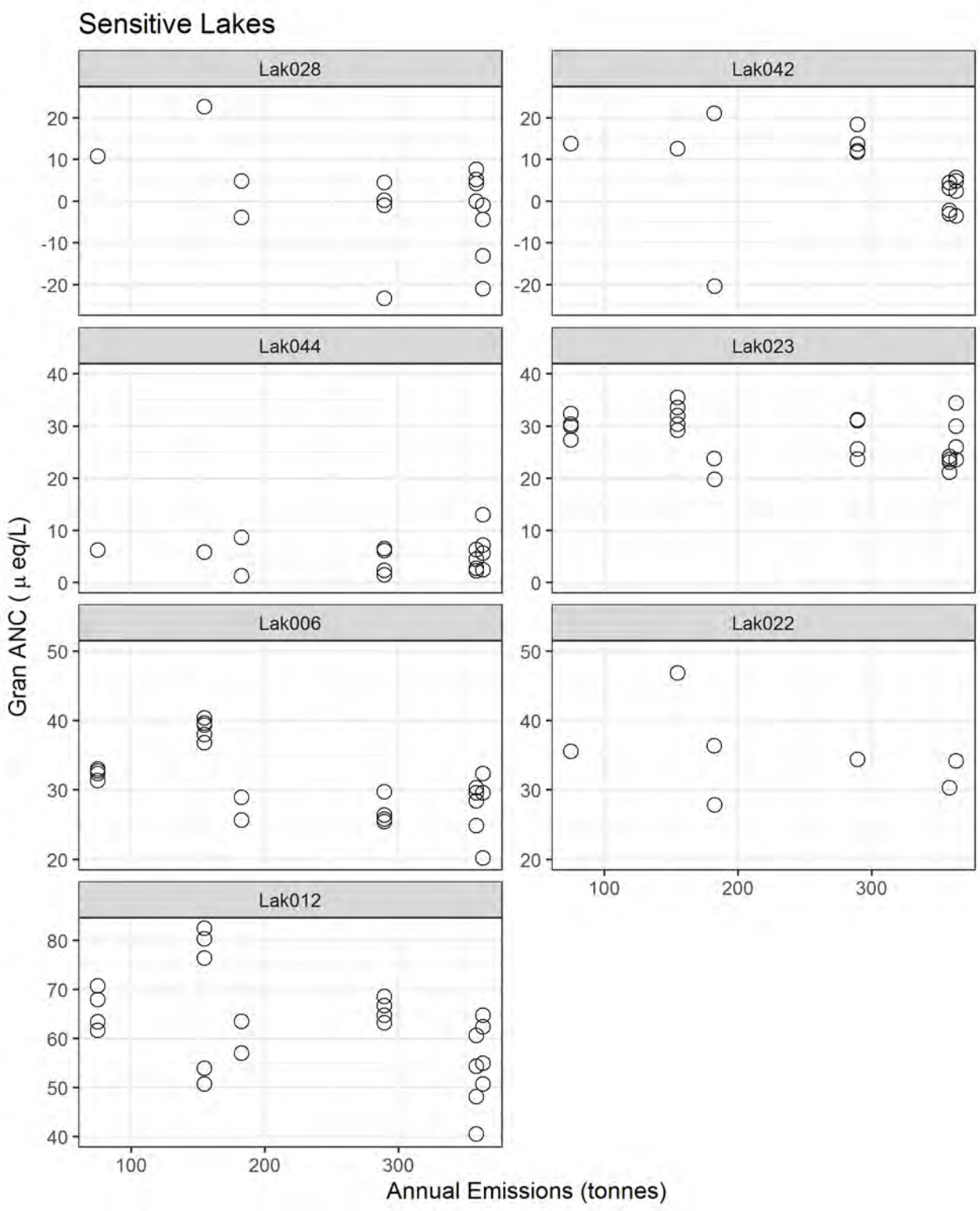


Figure 7.101: Gran ANC vs. annual emissions of SO_2 (in tonnes) for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.2.3.3 pH vs. Emissions

- See Section 7.6.4.3.6 for statistical analyses of the ability of total SO_2 emissions to explain observed patterns of changes in pH over time, beyond those patterns observed in control lakes.

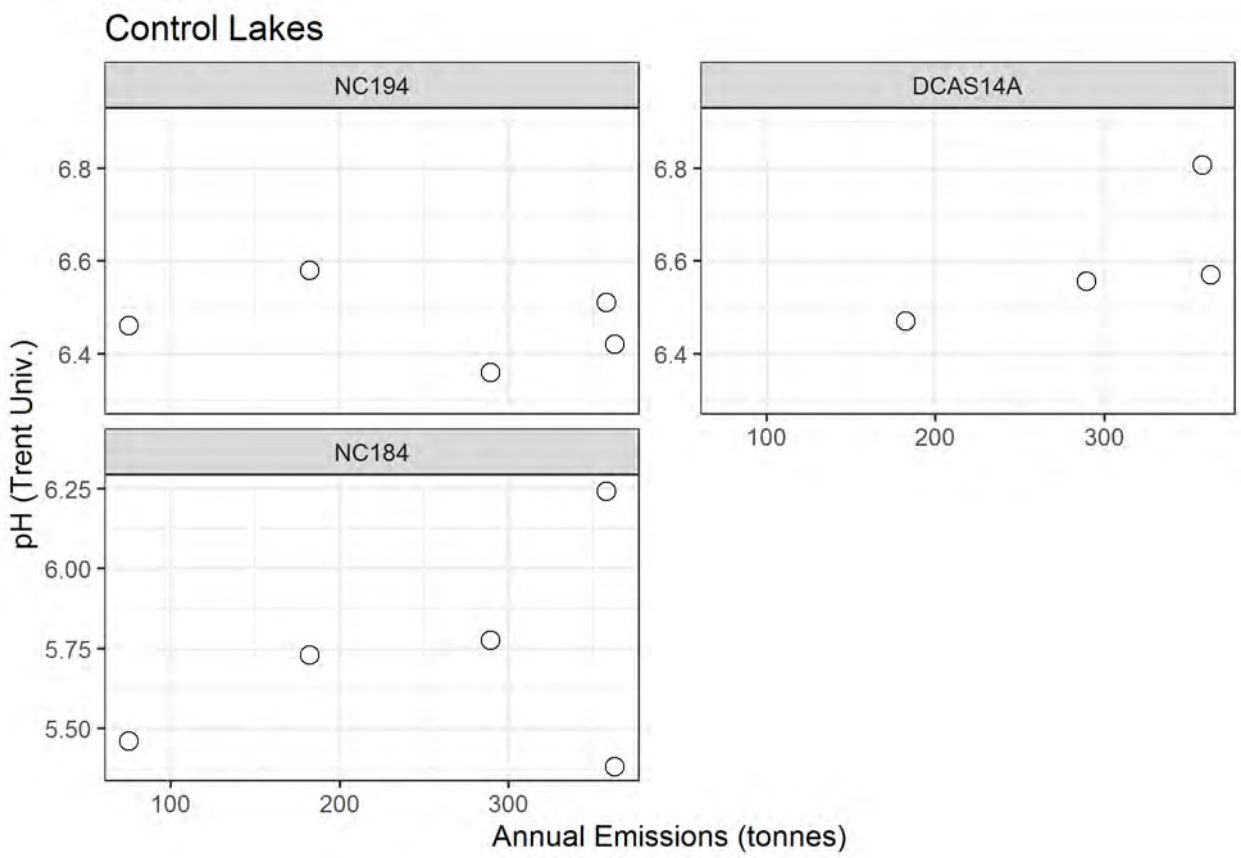


Figure 7.102: pH vs. annual emissions (in tonnes) for the control lakes (DCAS14A, NC184, NC194). The grey vertical lines correspond to measurement error of +/- 0.2.

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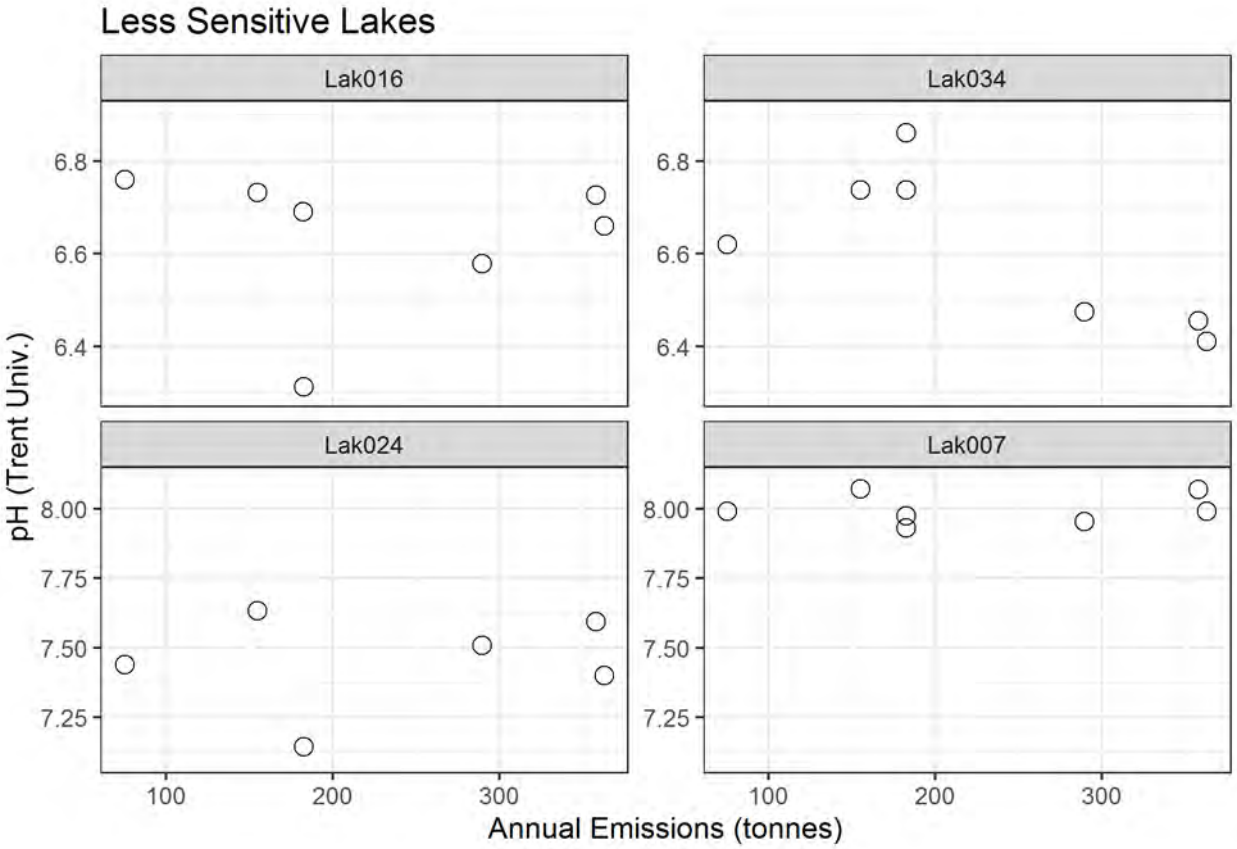


Figure 7.103: pH vs. annual emissions (in tonnes) for the EEM less sensitive lakes (LAK007, LAK016, LAK024, LAK034).

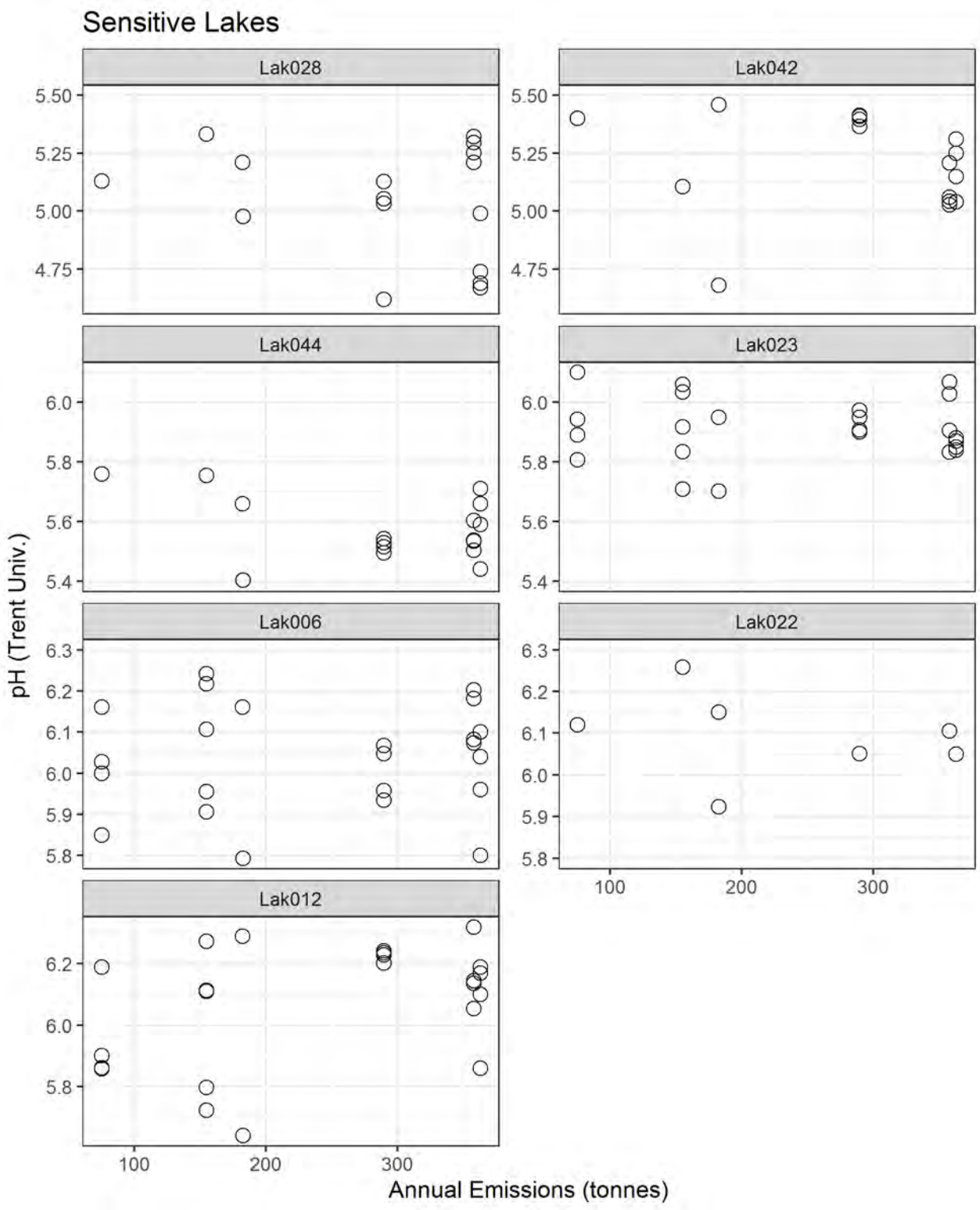


Figure 7.104: pH vs. annual emissions (in tonnes) for the EEM sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, LAK044).

7.6.3 Overview of Statistical Power Analyses

In 2015, ESSA conducted a power analysis to assess the ability to reliably detect changes in pH, Gran ANC and sulphate. This work was based on the data available from 2012 through 2014. Here are the key findings, adapted from ESSA 2016a (2015 EEM report) and ESSA 2016b (Technical Memo W05 on the power analysis):

- On average, the power to detect changes in pH that exceed the KPI threshold is low (< 0.5) and the lowest among the three primary metrics of pH, ANC and SO_4^{2-}.
- However, the power to detect changes in ANC and SO_4^{2-} is high (> 0.8 after a 5-year period) for 4 of the 7 sensitive EEM lakes (LAK006, 012, 022, 023), indicating the benefit of using multiple metrics.
- On average, power is lower for the combined set of metrics than each of them individually, indicating that although there is a definite benefit of considering all three metrics, it is best to analyse them individually.
- Power to detect changes varies by lake and parameter:
  - Across all of the metrics, LAK022 and LAK023 consistently have among the highest power, due to lower levels of variability in their water chemistry.
  - LAK028 and LAK042 have very low power (< 0.1) for ANC.
  - LAK028 has very low power (< 0.1) for SO_4^{2-}.
  - LAK012 and LAK042 have low power (< 0.2) for pH.
- If the long term variability in lake chemistry is actually lower than was observed during 2012-2014, then statistical power increases for most of the lakes for pH.
  - It is plausible that variability of the EEM lakes may have been overestimated given that the baseline period is short and non-static, the old smelter was being decommissioned, and the time of sampling varied (August in 2012, October in 2013 and 2014).
- If the simulated effect is a gradual change over 10 years rather than an abrupt change immediately following KMP, then the changes in all three metrics were much harder to successfully detect.
  - With gradual changes in lake chemistry, statistical power is very low across all lakes for ANC and pH and for half of the lakes for SO_4^{2-}.
- For all three lakes with intra-annual sampling during 2014 (LAK006, LAK012, LAK023), increasing the frequency of sampling increased the power
  - This was most pronounced for pH, which is important since pH has the lowest power
  - The increase in power for ANC and SO_4^{2-} is of minimal benefit since the three lakes already have high to very high power for those two metrics after 5 years.
  - Based on these findings, intra-annual sampling was added for LAK028, LAK042, and LAK044 through 2015 to 2018. It is not feasible to access LAK022 for multiple samples in the fall index period.
- Continuous monitoring further increased the power for pH, which again is particularly important given the otherwise low power to detect changes in pH.
- Across most of the lakes, metrics and scenarios, power was low or very low in the first few years after KMP. In general, at least five years of post-KMP data are required to reach adequate statistical power for Gran ANC. For this report, we have only 3 years of post-KMP data. Therefore, at least 2 more years of post-KMP data are required to attain adequate

statistical power for Gran ANC, preferably 3 more years of data (see Recommendations, Section 7.4 in the main report).

- Across most of the lakes and scenarios, false positive rates were generally very low for ANC and pH, but significantly higher for SO_4^{2-}, especially when fewer than 5 years of post-KMP observations were analyzed.
- Table 7.23 (from results summarized in Technical Memo W05) shows how the power to detect changes in ANC, SO_4 and pH varies across lakes and over different periods of time of post-KMP monitoring (3, 5 or 10 years). The power to detect changes in ANC and SO_4 was generally higher than the power to detect changes in pH in most of the lakes (except LAK028). Two of the lakes (LAK028 and LAK042) showed very low power to detect changes in ANC due to high variability in ANC over the 2012-14 period. Monitoring for 10 years did not significantly improve statistical power over monitoring for 5 years, when there was an immediate change in lake chemistry after the 3-year baseline period.

Table 7.23 Summary of results of power analysis, showing power to detect a change in lake chemistry by lake, using 2012-14 EEM data to estimate variability. The values shown are the statistical power to detect a decrease in pH or ANC, and an increase in SO_4 (i.e., threshold of change equal to zero) when a lake simulated an immediate pH decrease of 0.3 units (and the associated changes in ANC and SO_4 computed via the SSWC model) . Values greater than 0.8 are shown in green, values between 0.5 and 0.8 are shown in yellow, and values below 0.5 are shown in red.

Lake	ANC			SO4			pH		
	3 years	5 years	10 years	3 years	5 years	10 years	3 years	5 years	10 years
LAK006	0.95	0.99	1.00	0.99	1.00	1.00	0.22	0.29	0.31
LAK012	0.75	0.87	0.98	1.00	1.00	1.00	0.10	0.09	0.13
LAK022	0.77	0.94	1.00	0.95	0.99	1.00	0.34	0.37	0.47
LAK023	0.60	0.82	0.98	0.91	0.97	1.00	0.33	0.37	0.44
LAK028	0.03	0.06	0.07	0.04	0.05	0.05	0.31	0.37	0.43
LAK042	0.01	0.01	0.01	0.51	0.51	0.54	0.09	0.11	0.14
LAK044	0.50	0.65	0.83	0.46	0.43	0.46	0.33	0.36	0.42

Table 7.24 shows the number of years required to achieve power greater than 0.8 for each metric under two differing assumptions about the level of variability in the lakes. Two of the EEM lakes (LAK028 and LAK042) require more than 10 years of post-KMP monitoring to obtain 0.8 statistical power for Gran ANC, pH and SO_4. None of the EEM lakes achieve 0.8 statistical power in pH, even after 10 years.

The results in Table 7.24 show little effect of the two assumptions of variability, which requires some explanation. The results under the column "Observed variability (based on 2012-14 EEM data)" assume that long term variability in lake chemistry will reflect the variability observed in each EEM lake during 2012-14. This assumption may over-estimate variability and under-estimate the power to detect changes in lake chemistry, since 2012-2014 was the transition period during which the old smelter was being decommissioned, resulting in a reduction in emissions of SO_2 and potentially additional variability in the chemistry of some EEM lakes due to reduced sulphur deposition. The assumption "Lower Variability (based on EC lakes)" decreased the variability of each chemical parameter in each EEM lake by a fraction that reflected the ratio

of variability in EC lakes to EEM lakes. These ratios were calculated from the 10 lakes monitored by Environment Canada from 2005 to 2014 in their Georgia Basin study in southwestern British Columbia (unpublished data provided by Dr. Patrick Shaw, Environment Canada). Like the EEM lakes, though to a lesser degree, the Environment Canada lakes showed greater variability in pH than in Gran ANC and sulphate.

Table 7.24 Summary of results from the 2015 power analyses, showing the number of years of post-KMP data required for power >0.8 to detect decreases in pH and ANC, or increases in SO_4, based on assuming variability is best represented by the observation from 2012-2014 or from the Environment Canada (EC) lakes in Georgia Basin.

Lake	ANC		SO_4		pH	
	Lower variability (based on EC lakes)	Observed variability (based on 2012-14 EEM data)	Lower variability (based on EC lakes)	Observed variability (based on 2012-14 EEM data)	Lower variability (based on EC lakes)	Observed variability (based on 2012-14 EEM data)
LAK006	3	3	3	3	>10	>10
LAK012	3	5	3	3	>10	>10
LAK022	3	5	3	3	>10	>10
LAK023	3	5	3	3	>10	>10
LAK028	>10	>10	>10	>10	>10	>10
LAK042	>10	>10	>10	>10	>10	>10
LAK044	5	10	>10	>10	>10	>10

7.6.4 Statistical Analyses of Trend and Temporal Patters, and comparison to EEM thresholds

The EEM Thresholds of interest are 0.3 units for ΔpH, and lake-specific thresholds for ΔANC that correspond to 0.3 units of ΔpH in each lake, as derived from multiple ANC titrations performed at Trent University. We know from the power analyses (summarized in Section 7.7.3) that pH is more variable than ANC, and that there is lower statistical power to detect changes in pH than to detect changes in ANC. Consistent with the simplified evidentiary framework in Figure 7.35, we begin by analyzing changes in sulphate concentrations between the pre-KMP period and the post-KMP period, and then move on to assess pH and Gran ANC.

We used the simplest methods first (in which all sources of variation are present in the data), and then use more complex methods to explicitly account for individual sources of variation. In the TOR for the Comprehensive Report, we proposed completing 8 analyses, which build incrementally, and are applied using both frequentist and Bayesian approaches. As we proceeded through the analysis we converged on seven frequentist methods:

1. Two-Sample Before-After T-Test Using Mean Values
2. Two-Sample Before-After T-Test Using Individual Samples
3. Before-After Control-Impact (BACI), Using Mean Values[18]

[18] Measurements from the Control Lakes include 2013 samples as an estimate of pre-KMP conditions, and 2016-2018 samples as an estimate of post-KMP conditions.

4. Before-After Control-Impact (BACI), Using Individual Samples
5. Before-After Control-Impact (BACI), with Assumption of No Change in Control Lakes
6. Using Other Covariates to Explain Inter-Annual Variation
7. Temporal Trend Analyses

Given that we applied multiple statistical tests, we used an alpha level of 0.01 for examining the probability of an effect (or rejecting a null hypothesis), rather than a level of 0.05.

We also applied two Bayesian approaches:
1. Bayesian Analysis Supersedes the T-Test (using a range of informative priors)
2. Bayesian analysis with uninformative priors

In the TOR we indicated that if the frequentist approach showed a clear result for a lake (e.g., 99% confidence intervals for ΔANC do not overlap that lake's threshold for ΔANC) then there was no need to proceed with the Bayesian analysis for that parameter in that lake. However, to provide reviewers with the ability to compare results across all lakes and methods we have applied all frequentist and Bayesian analyses to each lake, for each of the three primary metrics.

7.6.4.1 Primer on Confidence Intervals

The confidence interval describes the amount of uncertainty surrounding our parameter estimate. It is possible to calculate confidence intervals for different levels of confidence (90%, 95%, 99%). Within a 99% confidence interval, we are 99% confident that the calculated interval contains the true value of the population parameter. In other words, if the experiment were repeated 100 times, in 99 cases we would expect the confidence interval to contain the true population parameter.

The figure below shows the 99% confidence interval for a parameter estimate across five experiments (A through E). The two dotted vertical lines are at zero and at -11, which corresponds to a "threshold", and anything lower than -11 is deemed to have exceeded the threshold.

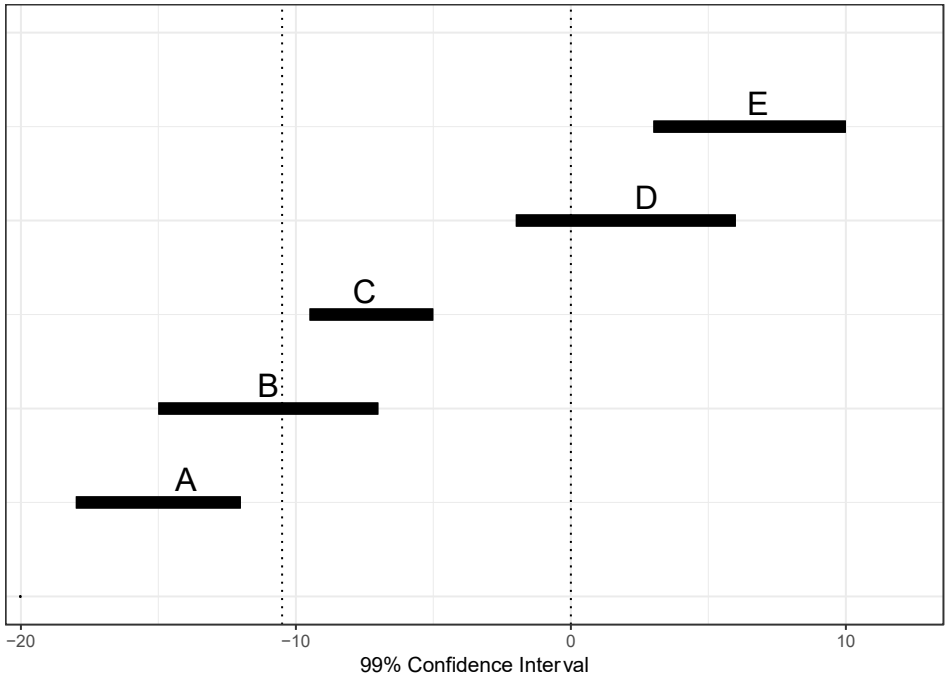


Figure 7.105: Example of confidence intervals with a threshold.

- Experiment A: The 99% CI spans values that are all lower than -11. In this case, there is 99% confidence that the parameter is lower than the -11 threshold.
- Experiment B: The 99% CI spans the -11 threshold and is entirely less than zero. In this case, we are 99% confident that the true parameter value is along this line, and shows a value below zero, but we cannot say whether it is above or below the -11 threshold.
- Experiment C: The 99% CI is entirely greater than the -11 threshold, and entirely less than zero. We can say with 99% confidence that the true value is negative, and that it is not lower than the threshold.
- Experiment D: The 99% CI spans zero. We cannot say with any confidence that the true parameter value is different from zero.
- Experiment E: The 99% CI is entirely greater than zero. We can say with 99% confidence that the true value is greater than zero and falls within the line.

7.6.4.2 Key Metric: SO_4

7.6.4.2.1 Method 1 (Frequentist): Two-Sample Before-After T-Test Using Mean Values

Description of Analyses:

We applied Two-sample Before-After t-tests of pre-KMP chemistry (either 2012 or 2012-2014, see discussion below) vs. post-KMP chemistry (2016-2018) for each individual lake, using mean values for each year, building on the methods of Kilgour et al. 1998. This is the simplest analysis, providing (for each lake) an estimate of the change in the mean value of each chemical component between the pre-KMP period and the post-KMP period (2016-2018). This analysis does not

account for various sources of variation (e.g., natural variability unrelated to the smelter (as reflected in the control lakes), or variability within the October sampling period).

From the power analysis we know that it will be very difficult to show a statistically significant change given only 1 pre-KMP observation and 3 post-KMP observations. We calculated the Minimum Detectable Difference (MDD) to demonstrate what level of change would be detectable with high statistical power.

- *Form of Test:* $Y_t \sim BA$; where *Y* is the overall mean across both before and after categories of years, and BA is the effect of Pre-KMP (Before) vs Post-KMP (After).
- *Assumptions:*
  - The chemistry of component Y in a given lake is a function only of the time period (before vs after).
  - The mean value of component Y represents the state of component Y in a given year.
  - We can use process error from 2016-18 to provide an estimate of the year to year variability for the 2012 measurement.

Purpose of analyses:

Figures 11 and 12 in Volume 1 of the STAR (ESSA et al., 2013) demonstrate the expectation that the new smelter would result in both a higher level of sulphur deposition, and a different spatial pattern of deposition. We are therefore interested to learn which lakes experienced an increase in SO_4 concentrations, and which lakes experienced a decrease. There are four purposes to these analyses:

1. Assess if there has been a statistically significant change in SO_4 (i.e., Δ SO_4 is significantly different from 0) between two time periods: pre-KMP (2012) and post-KMP (2016-2018). This t-test simply assesses if there has been *any* statistically significant change in SO_4. Δ SO_4 is computed as the post-KMP mean minus the pre-KMP mean.

2. Assess whether the confidence intervals for Δ SO_4 span 0.0 (level of confidence that there has been an increase or decrease in SO_4) .

3. Assess what the Minimum Detectable Difference (MDD) in SO_4 is for each lake, under four different assumptions of the true standard deviation of SO_4.

4. Expanding the definition of the baseline / pre-KMP period to 2012-2014, assess if there has been a statistically significant change in SO_4 between the expanded pre-KMP period (2012-2014) and post-KMP (2016-2018). Emissions from the old smelter were declining between 2012 and 2014, so we would expect to see a greater likelihood of sulphate increases using the expanded baseline period.

We have **not** applied an expanded baseline period to pH and Gran ANC, because doing so would increase the risk of Type I error (a false positive) in testing for exceedances of pH and ANC thresholds. In most of the sensitive lakes, the pH and Gran ANC increased during the 2012-2014 period as SO_2 emissions from the old smelter declined (Figure 7.44, Figure 7.41). Including pH and ANC observations from 2013 and 2014 in the estimates of mean pre-KMP pH and mean pre-KMP Gran ANC would increase those metrics to a level that is not representative of the pre-KMP period prior to and including 2012, and increase the risk of a false exceedance of the thresholds

for changes in pH and Gran ANC. However, as there are no thresholds applied to changes in SO_4 (lake biota are unaffected by increases in SO_4 as long as pH and Gran ANC do not decline), we are able to expand the pre-KMP baseline to 2012-2014 without increasing the risk of a Type 1 error.

Explanation of the graphs and tables of results:

See captions below.

Table 7.25: T-test of changes in mean SO_4 for each lake, between the pre-KMP period (2012) and post-KMP period (2016-2018). P-value is the probability of the ΔSO_4 being significantly different from zero ($p<0.01$ is the appropriate signficance level given the multiple statistical tests). Lwr and Upp are the lower and upper confidence levels for Δ SO_4. Sd_post is the standard deviation of mean SO_4 levels over the 3-year post-KMP period. MDD_sd is the minimum detectable difference in SO_4 that would be statistically significant at $p<0.01$ with 80% statistical power, given four different assumptions about the standard deviation of SO_4 during the pre-KMP period (1, 5, 10, 20 µeq/L). For example, in LAK006, a SO_4 change of 9.5 µeq/L is the minimum detectable difference with a pre-KMP SD of 1 µeq/L, but the MDD increases to 96 µeq/L if the SO_4 pre-KMP SD were 20 µeq/L.

SUBSET	SITE	p-value	lwr	upp	sd_post	MDD_sd_1	MDD_sd_5	MDD_sd_10	MDD_sd_20
Less Sensitive	LAK007	0.003	-7	-2	0.2	5	24	48	96
Less Sensitive	LAK016	0.053	-7	18	1.1	7	25	48	96
Less Sensitive	LAK024	0.088	-30	59	3.9	19	30	52	98
Less Sensitive	LAK034	0	-25	-23	0.09	5	24	48	96
Sensitive	LAK006	0.391	-17	22	1.7	9	25	49	96
Sensitive	LAK012	0.221	-21	30	2.2	12	26	49	97
Sensitive	LAK022	0.241	-43	60	4.5	22	32	53	98
Sensitive	LAK023	0.054	-28	11	1.7	9	25	49	96
Sensitive	LAK028	0.112	-191	335	23.0	110	113	120	146
Sensitive	LAK042	0.579	-23	20	1.9	10	26	49	96
Sensitive	LAK044	0.037	-6	2	0.3	5.	24	48	96

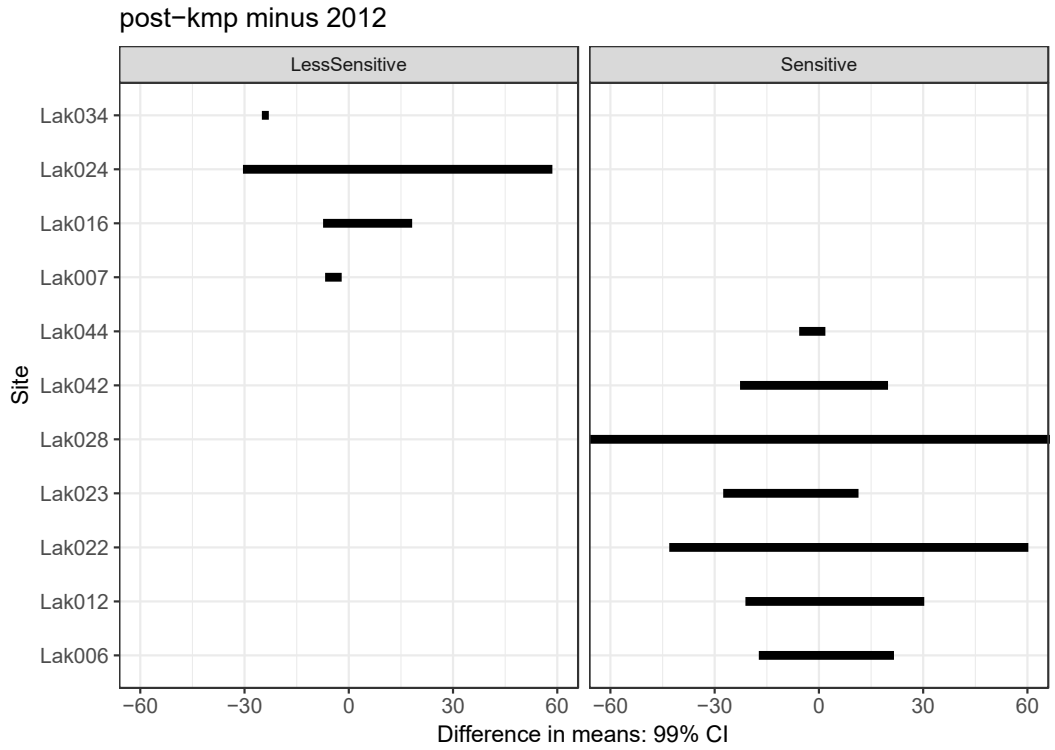


Figure 7.106: Using Method 1, 99% confidence intervals for the ΔSO_4 (mean SO_4 in post-KMP period (2016-2018) minus the mean SO_4 in the pre-KMP period (2012 only). The confidence intervals for ΔSO_4 overlap 0.0 for all sensitive lakes, and for LAK024 (Lakelse Lake) and LAK016. LAK028 has very wide confidence intervals for ΔSO_4. At the other extreme, LAK034 has very narrow 99% confidence intervals for ΔSO_4 and strong evidence of a significant decrease in SO_4 (about 24 µeq/L). LAK007 also has narrow 99% confidence intervals for ΔSO_4 and evidence of roughly a 3-8 µeq/L decrease in SO_4. There are no specific thresholds for ΔSO_4.

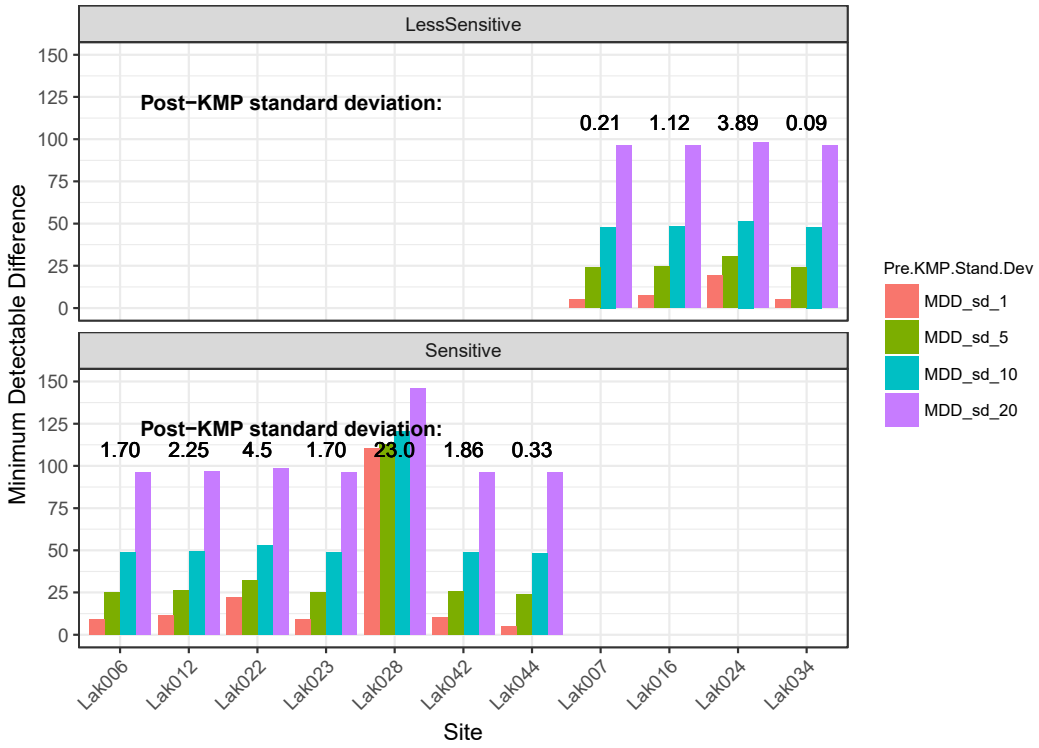


Figure 7.107: Minimum detectable differences (MDD) are shown for each lake, assuming four different values for the standard deviation (SD) of SO_4 in the pre-KMP period (2012). Since we have only one observation for the pre-KMP period (a single measurement in 2012), we can't compute the SD, but must assume it. LAK028 has very high values for MDD, due to its high variability in SO_4 (highest post-KMP SD). By contrast, LAK034 has a very low post-KMP SD. There are no specific thresholds for ΔSO_4.

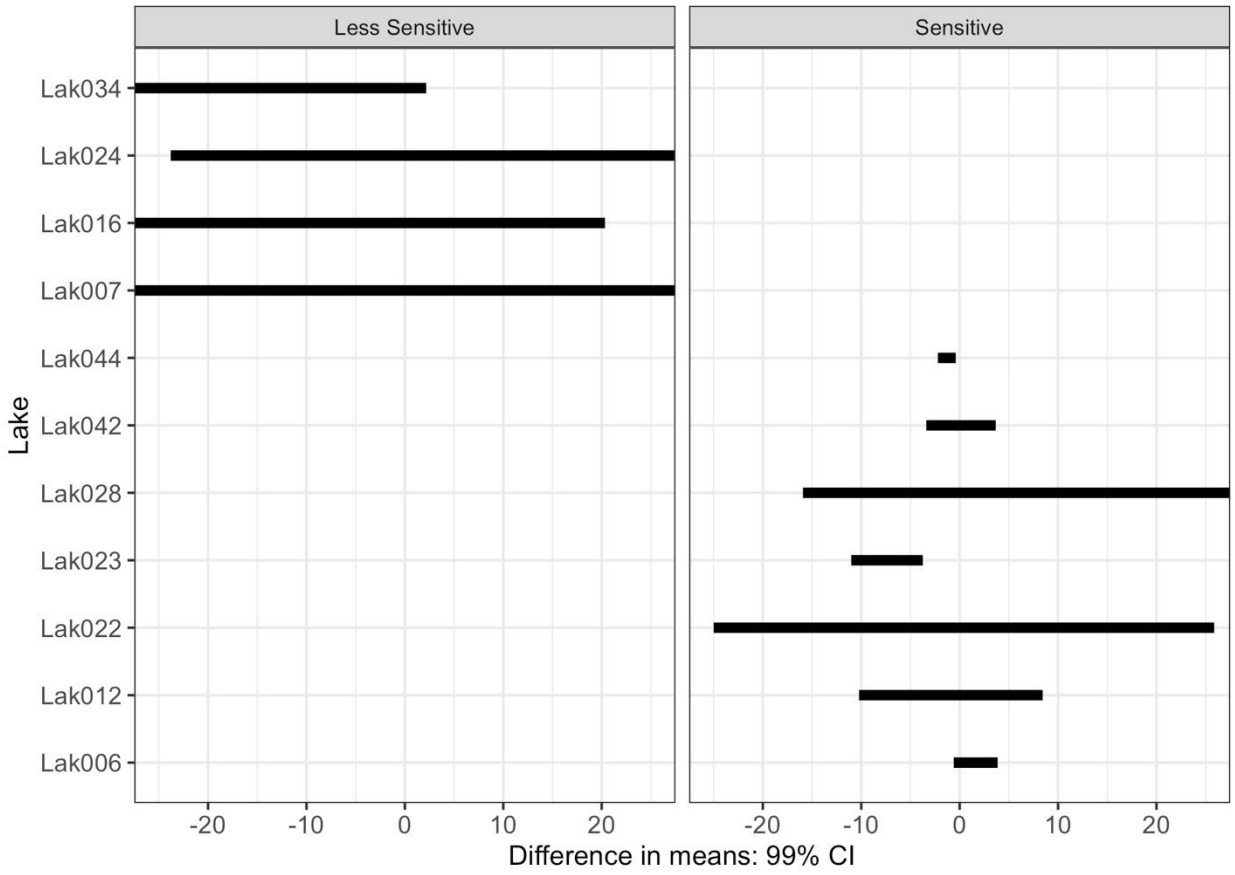


Figure 7.108: Using Method 1, 99% confidence intervals for the ΔSO_4 (mean SO_4 in post-KMP period (2016-2018) minus the mean SO_4 in the expanded pre-KMP period (2012-2014). The confidence intervals for ΔSO_4 are narrower with the expanded pre-KMP period, compared to using just 2012 (compare to Figure 7.106, noting the difference in the x-axis labels). The confidence intervals for ΔSO_4 overlap 0.0 for 5 of the 7 sensitive lakes, but now show declines in SO_4 for LAK023 and LAK044 (a pattern not apparent when just 2012 was used for the baseline - Figure 7.106). There are no specific thresholds for ΔSO_4.

Table 7.26. Minimum detectable difference (MDD) for a difference in SO_4 between the pre-KMP (2012-2014) and post-KMP (2016-2018) groups for each lake. The MDD is based on a significance level (alpha) of 0.05 with 80% power.

Lake	SUBSET	MDD
LAK006	Sensitive	6
LAK012	Sensitive	13
LAK022	Sensitive	21
LAK023	Sensitive	17
LAK028	Sensitive	111

LAK042	Sensitive	5
LAK044	Sensitive	3
LAK007	Less Sensitive	39
LAK016	Less Sensitive	20
LAK034	Less Sensitive	54

KEY FINDINGS:

- Only support for significant difference in SO_4 between baseline (2012) and Post-KMP period (2016-2018) is for two of the less sensitive lakes (LAK007 and LAK034), and support is for a *decline* in SO_4 over time. The confidence intervals for Δ SO_4 overlap zero in all of the sensitive lakes.
- With an expanded baseline period (2012-2014), two of the sensitive lakes (LAK023 and LAK044) show support for a decline in SO_4, but the confidence intervals for Δ SO_4 overlap zero in all of the less sensitive lakes.
- Due to high variability in SO_4, the minimum detectable differences are largest for LAK028.

7.6.4.2.2 Method 2 (Frequentist): Two-Sample Before-After T-Test Using Individual Samples

Description of Analyses:

This is a Two-sample Before-After test of 2012 chemistry vs. 2016-2018 for each individual lake, using 4 measurements from each year. This method provides greater insight than method 1, as it accounts for unequal sampling in various years and lakes (e.g., 1 sample in some lakes in some years, 4 samples in most lakes and years). The estimated before-after change between the pre-KMP and post-KMP periods removes the effect of natural variability within the sampling period.

- *Form of test:* $Y_t \sim BA + YRE$, where YRE = Year Random Effect due to multiple samples taken in the October sampling period;
- *Assumptions:*
  - Same as analysis 1, plus:
  - The chemistry of component Y in a given lake is a function of the time period (before vs after), as well as the variability within the October sampling window
  - All of the measured values of component Y during the October sampling window represent the state of component Y in a given year
  - Only include lakes with multiple within year measurements

Purpose of analyses:

The purpose of this analysis is similar to Method 1 (i.e., to determine if there is a significant difference between the post-KMP and pre-KMP values of SO_4), but the analysis removes the effect of natural variability during the sampling period. We are interested to see if this reduces the uncertainty in estimates of the ΔSO_4 between the post-KMP and pre-KMP periods, and narrows the confidence intervals on these estimates.

Explanation of the graphs and tables of results:

See captions below.

Table 7.27: Results for T-test for post-KMP SO_4 (2016-18) versus baseline SO_4 (2012), using individual samples, for the six sensitive lakes with multiple within-year samples. The "est.diff" is the SO_4 in the post-KMP period minus the SO_4 in the baseline period. A positive value for "est.diff" means that the SO_4 increased from the baseline period to the post-KMP period (e.g., LAK006, LAK012, LAK028), while a negative value indicates a decrease in SO_4 (e.g., LAK023, LAK042, LAK044) The "est.diff.se" is the standard error in SO_4, which is highest for LAK028 and LAK012, and lowest for LAK044. The "est.diff.lcl" and "est.diff.ucl" are the lower and upper confidence intervals (respectively) for "est.diff". The "p.value" is the probability of a significant difference in mean SO_4 between the two time periods (all p-values are >0.01, and therefore the differences between the two time periods are not statistically significant).

SITE	est. diff	SE	Lower	Upper	p.value
LAK006	2.5	2.3	-7	12	0.379
LAK012	6.8	4.3	-4	18	0.179
LAK023	-6.7	3.0	-14	1	0.075
LAK028	71.5	29.0	-11	154	0.073
LAK042	-0.8	2.4	-9	7	0.771
LAK044	-1.9	0.4	-3	-1	0.001

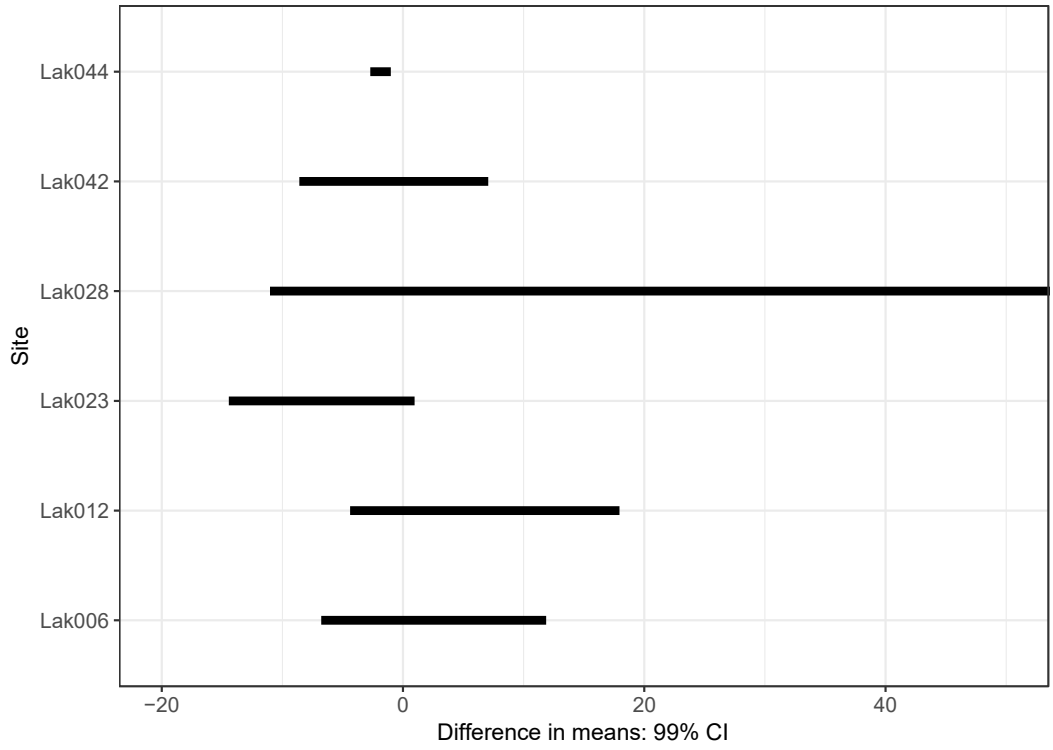


Figure 7.109: Using Method 2, 99% confidence intervals for the ΔSO_4 (mean SO_4 in post-KMP period (2016-2018) minus the mean SO_4 in the pre-KMP period (2012), accounting for within year variability. The confidence intervals for changes in mean SO_4 overlap 0.0 for all lakes except LAK044 (strong evidence of a small decrease in SO_4).

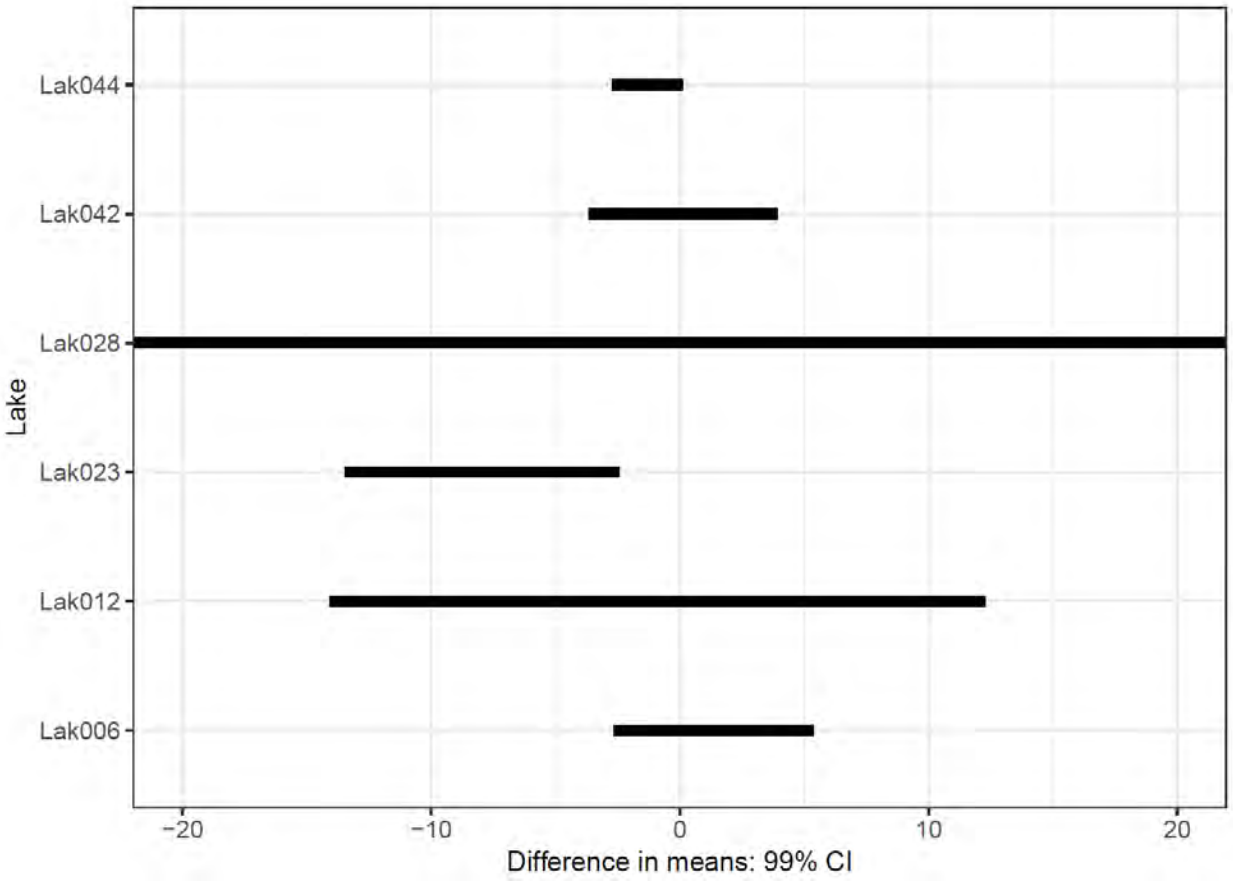


Figure 7.110: Using Method 2, 99% confidence intervals for the ΔSO_4 (mean SO_4 in post-KMP period (2016-2018) minus the mean SO_4 in the extended pre-KMP period (2012-2014), accounting for within year variability. The 99% confidence intervals for changes in mean SO_4 overlap 0.0 for all six lakes except LAK023 (strong evidence of a decrease in SO_4). The 99% confidence intervals for LAK044 do overlap zero, unlike in Figure 7.109.

KEY FINDINGS:

- The confidence intervals using Method 2 (Figure 7.109) are narrower than using Method 1 (Figure 7.108), showing the benefit of Method 2 over Method 1.
- Using 2012 as the baseline period, the only support for difference in mean SO_4 between baseline and Post-KMP period is for LAK044, and that support is for a decline over time. All other 99% confidence intervals overlap zero (the data are consistent with increases, decreases as well as no change in SO_4).
- Using 2012-2014 as the baseline period, the only support for difference in mean SO_4 between baseline and Post-KMP period is for LAK023, and that support is for a decline over time. All other 99% confidence intervals overlap zero.

7.6.4.2.3 Method 3 (Frequentist): Before-After Control-Impact (BACI), Using Mean Values

Description of Analyses:

The BACI (Before-After-Control-Impact) approach compares data from one sensitive lake to the data from a group of 3 control lakes. The focal questions for this analysis are slightly different: *how much change has occurred in chemical indicator Y between the pre-KMP period and the post-KMP period, relative to the changes observed in the control lakes? Is the direction and magnitude of change in the sensitive lake different from what was observed in the control lakes?*
This method explicitly accounts for natural variation in lake chemistry due to factors other than the smelter (e.g., year to year changes in precipitation and temperature) which affect both the EEM lakes and the control lakes. The effect of the smelter on a given lake is expressed in terms of how the chemical changes over time (between the pre-KMP and post-KMP periods) differ from the changes observed in the control lakes (taken as a group), taking into account before-after changes that have affected all lakes.

- *Form of test:* $Y_t \sim$ BA + ICE + BACI Interaction + LRE + YRE, where
  - ICE = Impact/Control Effect;
  - BACI Interaction = Treatment * Time Interaction (difference in how impact and control lakes changed over time; key variable in the analysis);
  - LRE = Lake Random Effect due to consistent differences between lakes (e.g., the sensitive lake always has a lower pH than two of the control lakes);
  - BA and YRE as in analysis 2
- *Assumptions:*
  - Same as analysis 2, plus:
  - Observed value from 2013 serves as a pre-KMP value for the control lakes (control lakes were not sampled in 2012); implicitly assume that 2012 and 2013 were similar
  - Variability in the control lakes over 2013, 2015-2018 used to help estimate variability in the sensitive lake in 2012

Purpose of analyses:

Use a BACI analysis to determine how the ΔSO_4 (post-KMP vs. pre-KMP) in each sensitive lake (Figure 7.38) compares to the Δ SO_4 in the control lakes (Figure 7.36), taken as a group. This analysis accounts for broad scale regional / climatic effects which could affect both the sensitive lakes and the control lakes.

Explanation of the graphs and tables of results:

See captions below.

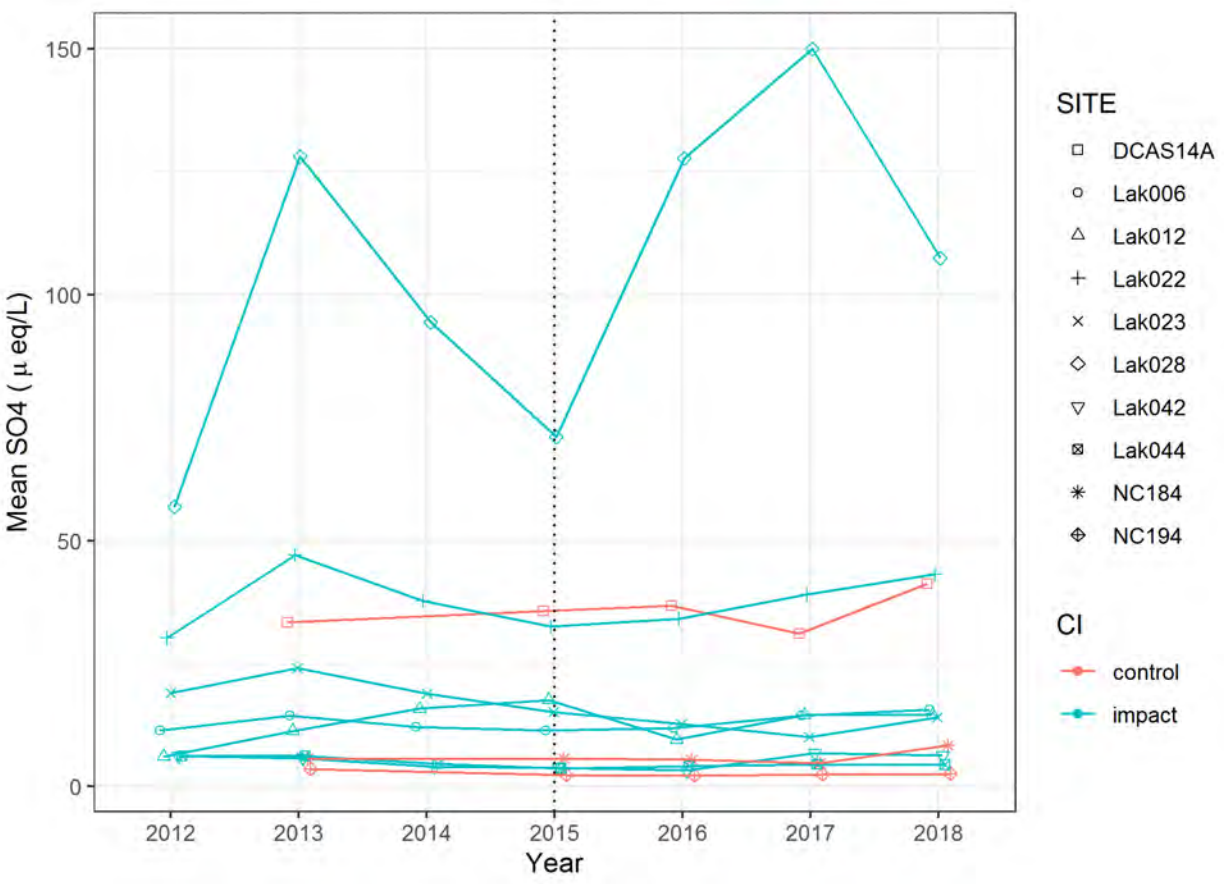


Figure 7.111: Change in mean SO_4 over time for sensitive lakes (blue lines) and control lakes (orange lines)

Table 7.28: BACI analyses of mean SO_4 for 7 sensitive and 3 control lakes, using Method 3. "BACI estimate" is a bit counter-intuitive: it is the Δ mean SO_4 in the controls (i.e., $SO_{4\ post\text{-}KMP}$ minus $SO_{4\ pre\text{-}KMP}$), averaged over the 3 control lakes, minus the Δ mean SO_4 in the sensitive lake. If BACI value is <0, then the Δ SO_4 was lower in the controls than in the sensitive lake (and, equivalently, the Δ SO_4 was greater (more positive) in the sensitive lake than in the controls). If BACI value is >0, then the SO_4 change in the controls was greater than that in the sensitive lake (and, equivalently, the Δ SO_4 was lower (less positive) in the sensitive lake than in the controls). The "t.ratio" is the t-statistic for the BACI estimate, and the p.value the significance of the test. LAK042 showed the strongest evidence of an increase in Δ mean SO_4but the estimate for this factor was not statistically significant.

Site	BACI estimate	SE	p.value	Interpretation of BACI estimate
LAK006	-1.7	2.2	0.437	change in SO_4 was more positive in LAK006 than in the control lakes (but NOT statistically significant)
LAK012	-6.0	2.7	0.038	change in SO_4 was more positive in LAK012 than in the control lakes (but NOT statistically significant)
LAK022	-7.8	3.5	0.059	change in SO_4 was more positive in LAK022 than in the control lakes (but NOT statistically significant)
LAK023	7.5	1.8	0.001	change in SO_4 was less positive in LAK023 than in the control lakes (and **statistically significant**)
LAK028	-70.7	13.2	0	change in SO_4 was more positive in LAK028 than in the control lakes (and **statistically significant**)
LAK042	1.6	1.6	0.532	change in SO_4 was less positive in LAK042 than in the control lakes (but NOT statistically significant)
LAK044	2.7	2.2	0.24	change in SO_4 was less positive in LAK044 than in the control lakes (but NOT statistically significant)

Table 7.29: BACI analysis of SO_4 with all lakes combined, using Method 3. BACI estimate is the average Δ mean SO_4 in the 3 control lakes (i.e., $SO_{4\ post\text{-}KMP}$ minus $SO_{4\ pre\text{-}KMP}$, averaged over the 3 control lakes), minus the average Δ mean SO_4 in the 7 sensitive lakes (i.e., $SO_{4\ post\text{-}KMP}$ minus $SO_{4\ pre\text{-}KMP}$, averaged over the 7 sensitive lakes). SE is the standard error of the BACI estimate. The t.ratio is the t-statistic for the BACI estimate, and the p.value the significance of the test.

contrast	estimate	SE	p.value
baci	-4.6	6.9	0.505

KEY FINDINGS:

- Support for an effect for LAK023 (decrease in SO_4 relative to controls) and LAK028 (increase in mean SO_4 relative to controls).
- No support for an effect when all lakes are combined.

7.6.4.2.4 Method 4 (Frequentist): Before-After Control-Impact (BACI), Using Individual Samples

Description of Analyses:

BACI approach with individual measurements rather than just using mean values. Same model as analysis #3 + lake*year interaction random effect. The differences between analyses 4 and 3 are analogous to the differences between analyses 2 and 1. The form of output is the same as in method #3, but now takes into account the variability observed during the sampling period.

Form of test: $SO_4 \sim BA*CI + (1|year2) + (1|SITE) + (1|year2:SITE)$

Purpose of analyses:

We wish to see if there is any change in the results of the BACI analysis (relative to Method 3) when we account for variability during the sampling period. This analysis is only possible for the 6 sensitive lakes with four samples / year; LAK022 has only one sample per year.

Explanation of the graphs and tables of results:

See captions below.

Table 7.30: BACI analysis of ΔSO_4 using Method 4. See Table 4-4 in main report for explanation of terms.

Site	BACI estimate	SE	p.value	Interpretation of BACI estimate
LAK006	-1.7	3.0	0.585	change in SO_4 was more positive in LAK006 than in the control lakes (but NOT statistically significant)
LAK012	-6.0	4.1	0.174	change in SO_4 was more positive in LAK012 than in the control lakes (but NOT statistically significant)
LAK023	7.5	2.7	0.016	change in SO_4 was less positive in LAK023 than in the control lakes (but NOT statistically significant)
LAK028	-70.7	22.7	0.011	change in SO_4 was more positive in LAK028 than in the control lakes (but NOT statistically significant)
LAK042	1.6	3.3	0.646	change in SO_4 was less positive in LAK042 than in the control lakes (but NOT statistically significant)
LAK044	2.7	3.1	0.41	change in SO_4 was less positive in LAK044 than in the control lakes (but NOT statistically significant)

Table 7.31. BACI analysis of ΔSO_4 with all lakes combined, using Method 4.

contrast	estimate	SE	p.value
baci	-3.2	8.7	0.714

KEY FINDINGS:

- Support for an effect diminishes when accounting for individual intra-annual SO_4 measurements; none are statistically significant.
- No support when all lakes are combined.

7.6.4.2.5 Method 5 (Frequentist): Before-After Control-Impact (BACI), with Assumption of No Change in Control Lakes

Description of Analyses:

Method 4 + assumption of no change in the mean of the control lakes between the before period and the after period. If we assume that there's no B/A change in control lakes (forcing ΔY in control lakes to be zero), the B/A change in the sensitive lake becomes the absolute change in component Y. This analysis removes some of the terms in the model 4. The form of output is the same as in method #4.

Purpose of analyses:

This is a sensitivity analysis on Method 4, to see how much difference the observations from the control lakes (and common patterns of year to year variability in the control lakes) make to the outcome of the BACI analysis. Removing the data from the control lakes reduces the number of degrees of freedom in the analysis. The analysis is done first using just mean values (as in Method 1), and then using all of the data (as in Method 2). We also use ANOVA to compare the fit of models which keep the control lakes' data constant, vs. allowing the control lakes' data to vary.

Explanation of the graphs and tables of results:

- See captions below

All lakes combined, mean SO_4, control lakes held constant

Table 7.32: BACI analysis using Method 5 applied to mean SO_4 values, holding control lakes' SO_4 constant. Structure of this table is similar to Method 3 (Table 7.29), but has only 7.44 degrees of freedom compared to 127.01

contrast	estimate	SE	p.value
baci	1.1	3.8	0.784

ANOVA (mean SO_4: control lakes either constant or allowed to vary)

Table 7.33: ANOVA analysis using Method 5 comparing the fit of two models to mean SO_4 values ("vary", which includes data from the control lakes; and "cons", which holds the control lakes constant). Analysis applied using two information criteria (AIC = Aikike Information Criteron; BIC = Bayesian Information Criteron). Lower (i.e., more negative) values for AIC and BIC indicate a better fit of the model to the data. Assuming constant values for the control lakes ("cons") provides a slightly better fit, but the differences between the two models are not statistically significant.

	Df	AIC	BIC	logLik	deviance	Chisq	ChiDF	Pr(>Chisq)
cons	6	1125.9	1143.6	-556.93	1113.9			
vary	7	1127.6	1148.3	-556.8	1113.6	0.257	1	0.612

All lakes combined: individual annual SO_4, control lakes held constant

Table 7.34: BACI analysis using Method 5 applied to all SO_4 values in the sensitive lakes (i.e., including within-year variability), holding control lakes' SO_4 constant. Structure of this table is similar to Method 4 (Table 7.31), but has only 6.5 degrees of freedom compared to 74.2

contrast	estimate	SE	p.value
baci	0.69	4.1	0.872

ANOVA (individual annual SO_4: control lakes held constant or allowed to vary)

Table 7.35: ANOVA analysis using Method 5 comparing the fit of two models to all SO_4 values ("vary", which includes data from the control lakes; and "cons", which holds the control lakes constant). Analysis applied using two information criteria (AIC = Aikike Information Criteron; BIC = Bayesian Information Criteron). Lower (i.e., more negative) values for AIC and BIC indicate a better fit of the model to the data. Assuming constant values for the control lakes ("cons") provides a slightly better fit, but the differences between the two models are not statistically significant.

	Df	AIC	BIC	logLik	deviance	Chisq	ChiDF	Pr(>Chisq)
cons	7	1134.2	1155	-560.11	1120.2			
vary	8	1136.2	1159.9	-560.09	1120.2	0.044	1	0.833

KEY FINDINGS:

- No support for an effect (for annual mean SO_4 or annual individual SO_4 measurements) when change in control lakes held constant over the time-frame.
- ANOVAs show no difference between models with control lakes varying or held constant over time.

7.6.4.2.6 Method 6 (Frequentist): Using Other Covariates to Explain Inter-Annual Variation

Description / Purpose of Analyses:

These analyses add other covariates (i.e., emissions, precipitation) to explain year to year variation. If these covariates help to explain variability in chemistry, then we could use 2013-2014 data, in addition to data from 2012, to characterize pre-KMP conditions, and contrast these conditions with post-KMP data from 2016-2018. The test ascribes some of the observed changes in chemical components to these covariates (e.g., changes in [SO_4] with emissions of SO_2 in the year prior to October sampling; changes in component concentrations with precipitation in either the 3 days or the 14 days prior to sampling). The overall form of the results is similar to method 4 (i.e., a BACI analysis), but potentially separates out variation due to changes in emissions, or due to fluctuations in precipitation (if these covariates are shown to be correlated with the measured chemistry).

Explanation of the graphs and tables of results:

We used total SO_2 emissions over the prior year (i.e., October 1 through Sept. 30, see Section 7.6.2.3) either the last 3-days or the last 14-days of precipitation at Haul Road (see Section 7.6.2.2) as covariates. The model also includes terms for three random effects: year, site, and year by site interactions.

Form of test: $SO_4 \sim BA*CI + EMISSIONS + PRECIPITATION + (1|YEAR) + (1|SITE) + (1:YEAR:SITE)$

Table 7.36: Before-After t-test for changes in SO_4, including covariates for emissions and the last 3 days of precipitation.

Fixed effects:	Estimate	Std Error	Pr(>|t|)
(Intercept)	-81.64	210.5	0.701
BAbefore	44.72	42.9	0.348
CIimpact	246.74	209.1	0.248
Emissions	0.29	0.2	0.270
Precipitation (3 day)	-1.05	0.9	0.245
BAbefore:CIimpact	-19.78	30.1	0.516

Table 7.37: Estimates of the random effects for year, site and year by site interactions, for the analyses in Table 7.36.

Random effects:			
Groups	Name	Variance	Std.Dev.
YEAR:SITE	(Intercept)	1174	34.2
SITE	(Intercept)	116869	341
YEAR	(Intercept)	16.0	4.0
Residual		426	20.6

Table 7.38: Before-After t-test for changes in SO_4, including covariates for emissions and the last 14 days of precipitation.

Fixed effects:	Estimate	Std Error	df	Pr(>|t|)
(Intercept)	-72.41	213.02	32	0.736
BAbefore	37.41	46.49	5	0.458
CIimpact	244.23	208.75	28.	0.252
Emissions	0.26	0.24	3	0.337
Precipitation (14 day)	-0.16	0.38	29	0.679
BAbefore:CIimpact	-16.55	31.34	38	0.601

Table 7.39: Estimates of the random effects for year, site and year by site interactions, for the analyses in Table 7.38.

Random effects:			
Groups	Name	Variance	Std.Dev.
YEAR:SITE	(Intercept)	1297	36
SITE	(Intercept)	116426	341
YEAR	(Intercept)	39	6.3
Residual		398	20.0

KEY FINDINGS:

- Looking over all sensitive and less sensitive lakes, there is no evidence of a significant before-after change in mean SO_4 after accounting for year effects, site effects, emissions and the last 3 days of precipitation, or the last 14 days of precipitation.
- The signs of the covariates for precipitation were negative, consistent with a hypothesis of dilution of sulphate concentrations following precipitation events, but neither the 3-day or 14-day covariates were statistically significant.
- The sign of the emissions covariate was positive, consistent with expectations, but also not statistically significant when examined across all lakes. This isn't surprising given the range in responses of sulphate concentrations among the set of lakes in the EEM program.

7.6.4.2.7 Approach Supportive of Methods 8 and 9 (Frequentist): Temporal Trend Analyses

Description of Analyses:

We applied the Mann-Kendall (MK) non-parametric test for detecting monotonic trends. The MK test evaluates if values increase, decrease or stay the same over time. It analyses the sign of the difference between later-measured and earlier-measured data. The test assumes that values can be greater than, equal to, or less than another data. We tested for a change in SO_4 over time, and used alpha = 0.01 to correct for multiple tests

Purpose of analyses:

We are interested in testing the hypothesis that there is no monotonic trend in SO_4 over time (a significant increase or decrease in SO_4 would cause this hypothesis to be rejected). The Mann-Kendall non-parametric test for monotonic trend detection is similar to the non-parametric Seasonal Kendall tests used to assess water chemistry trends in other studies of acidification effects (e.g., Stoddard et al. 1993, 1996, 1998, 2003).

Explanation of the graphs and tables of results:

The Mann-Kendall non-parametric test calculates the sign of the differences between all possible pairs of differences between observations, and estimates *S*, the number of positive differences minus the number of negative differences. If *S* is a positive number, observations obtained later in time tend to be larger than observations made earlier. If *S* is a negative number, then observations made later in time tend to be smaller than observations made earlier. Transformations of *S* (described here) generate a statistic *Z*, which can be evaluated for its statistical significance. A positive value of *Z* indicates that the data tend to increase, while a negative value of *Z* indicates that the data tend to decrease. The value of the slope can be calculated using the Sen's slope approach, which is a nonparametric method to calculate the slope and is appropriate for time series data used in this trend analysis. However, if the Mann-Kendall test is not significant, there is no reason to proceed with the Sen's slope analysis.

Table 7.40: Results of the Mann-Kendall non-parametric test for monotonic trend in SO_4 values. No lakes exhibit a significant result for detecting a monotonic trend.

Lake	p.value
LAK006	0.955
LAK012	0.500
LAK022	0.955
LAK023	0.367
LAK028	0.633
LAK042	0.633
LAK044	0.846
LAK007	0.955
LAK016	0.846
LAK024	0.846
LAK034	0.500
NC184	0.500
NC194	0.500
DCAS14A	0.769

KEY FINDINGS:

- None of the lakes' data provide sufficient evidence to reject the null hypothesis that there was no monotonic trend in mean SO_4 (i.e., all p values are > 0.01)

7.6.4.2.8 Method 1a (Bayesian): Two-Sample Before-After Bayesian Analysis (Bayesian Estimation Supersedes the T-Test with informative priors) as applied to SO_4

Description of Analyses:

The intent of Bayesian analyses is to estimate the *posterior* distribution of a parameter of interest, which is the probability distribution of the parameter taking into account the data. The first step is for the analyst to specify a *prior* belief, or prior credibility distribution of possible parameter values. After the data have been collected, the prior beliefs are then updated using Bayes' rule to obtain the posterior distribution. We used the BEST approach (Kruschke 2013), applied to frequentist method 1. Results are expressed in terms of the posterior belief that a lake's SO_4 concentration increased between the pre-KMP and post-KMP periods.

Purpose of analyses:

The parameter of interest is the ΔSO_4 from the pre-KMP period (either 2012 or 2012-2014) to the 2016-2018 post-KMP period. This is the first question in the simplified evidentiary framework (Figure 7.35): *Has lake* SO_4 *increased since the pre-KMP period?*

Explanation of the graphs and tables of results:

See captions below. The statistical software used for analysis in Figure 7.112 computes Δ mean SO_4 as the mean SO_4 for the baseline pre-KMP period minus the mean SO_4 for the 2016-2018 post-KMP period. Positive values of this parameter are therefore indicative of a SO_4 decline. Figure 7.113 and Figure 7.114 (respectively) show the posterior distribution of Δ mean SO_4 for LAK028 and LAK034.

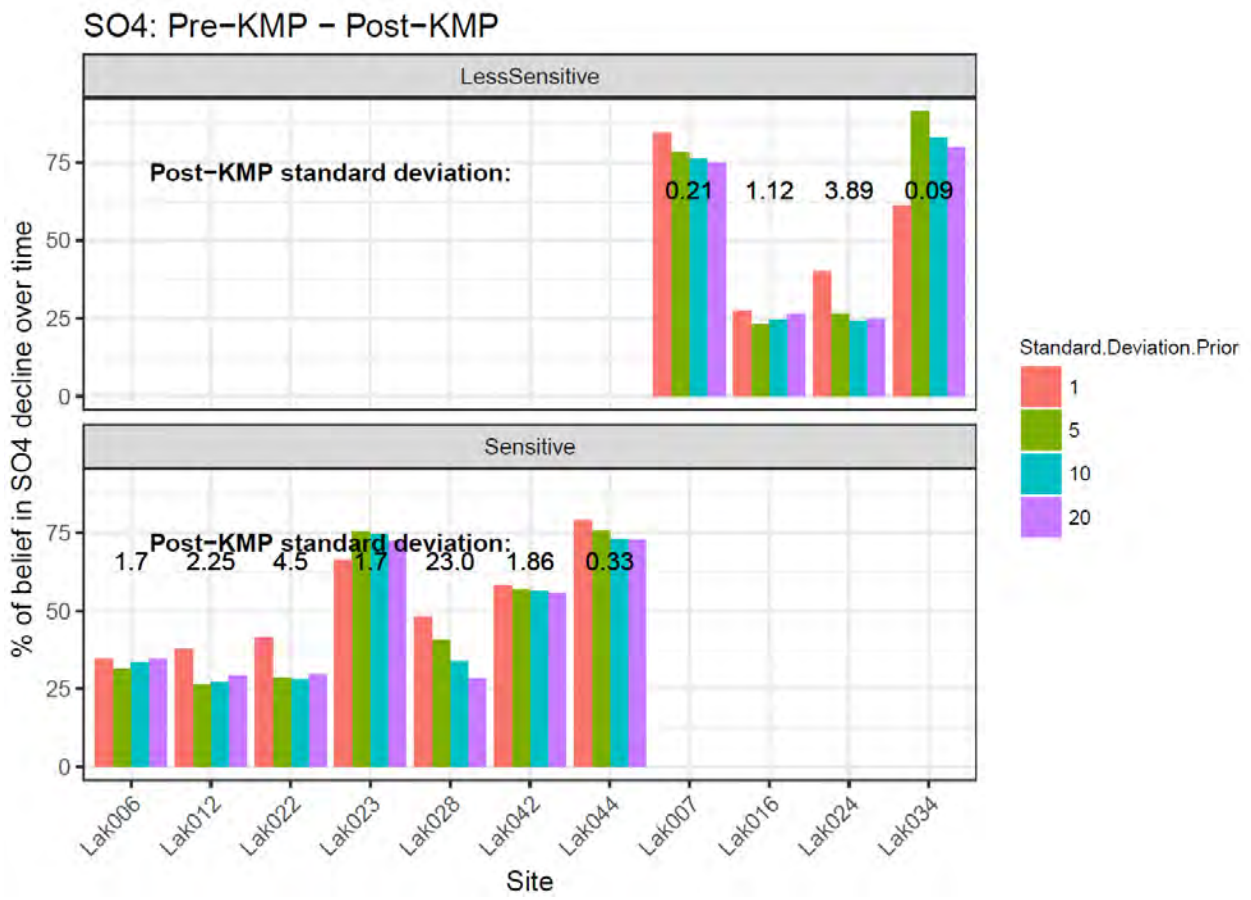


Figure 7.112: Percentage belief in a SO_4 decline over time, using Two-Sample Before-After Bayesian Analysis. The bars show the percentage belief for four different prior assumptions about the standard deviation of SO_4 across all lakes. The SD of SO_4 for the post-KMP period is included to provide some context for each lake, but is not directly comparable to the prior assumptions of SD. Strongest support for a decline in SO_4 is for lakes 007, 034, 023 and 044.

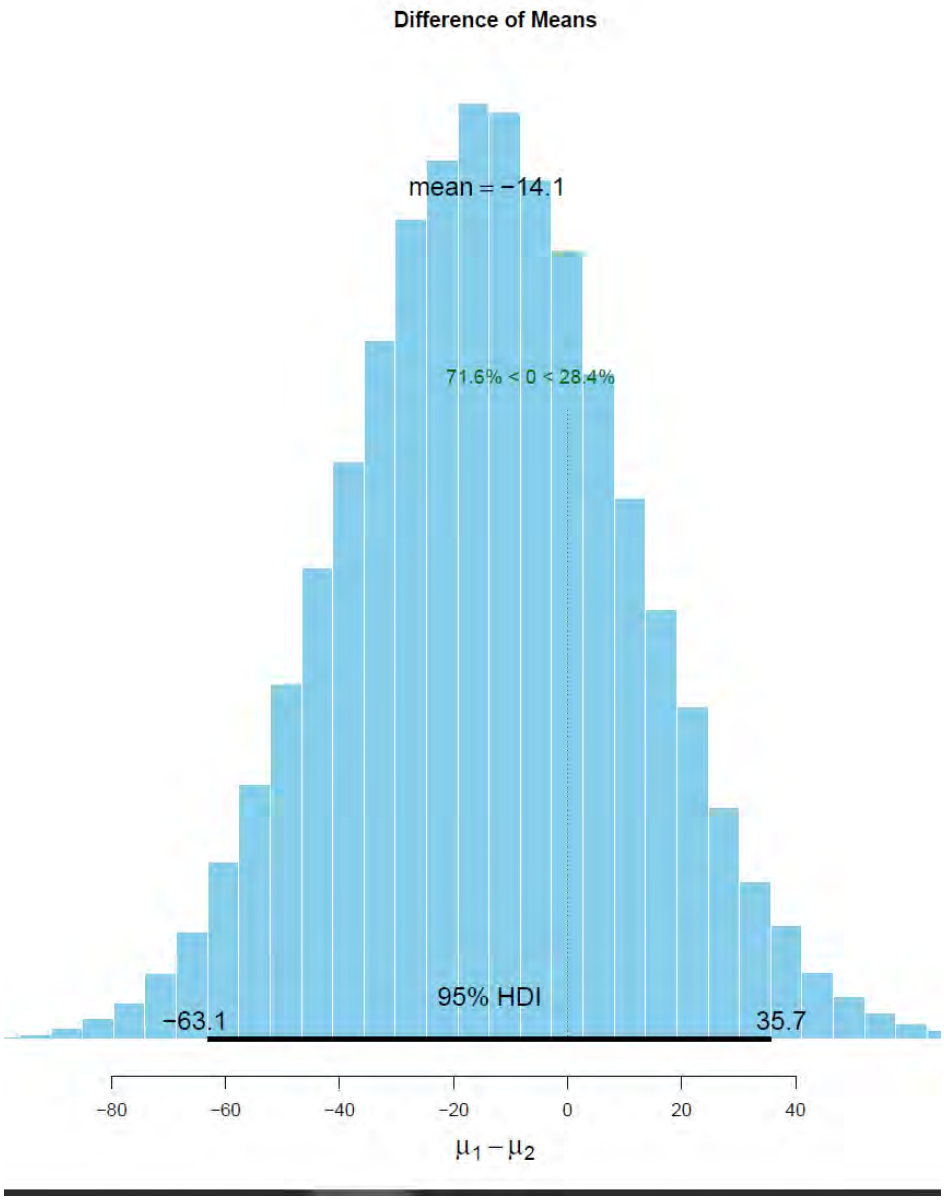


Figure 7.113: 95% High Density Interval for ΔSO_4 in LAK028 (Mean SO_4 during baseline - Mean SO_4 during post-KMP period), assuming a SD of SO_4 of 20. Negative values are consistent with an increase in SO_4 (71.6% belief). Positive values are consistent with an decrease in SO_4 (28.4% belief).

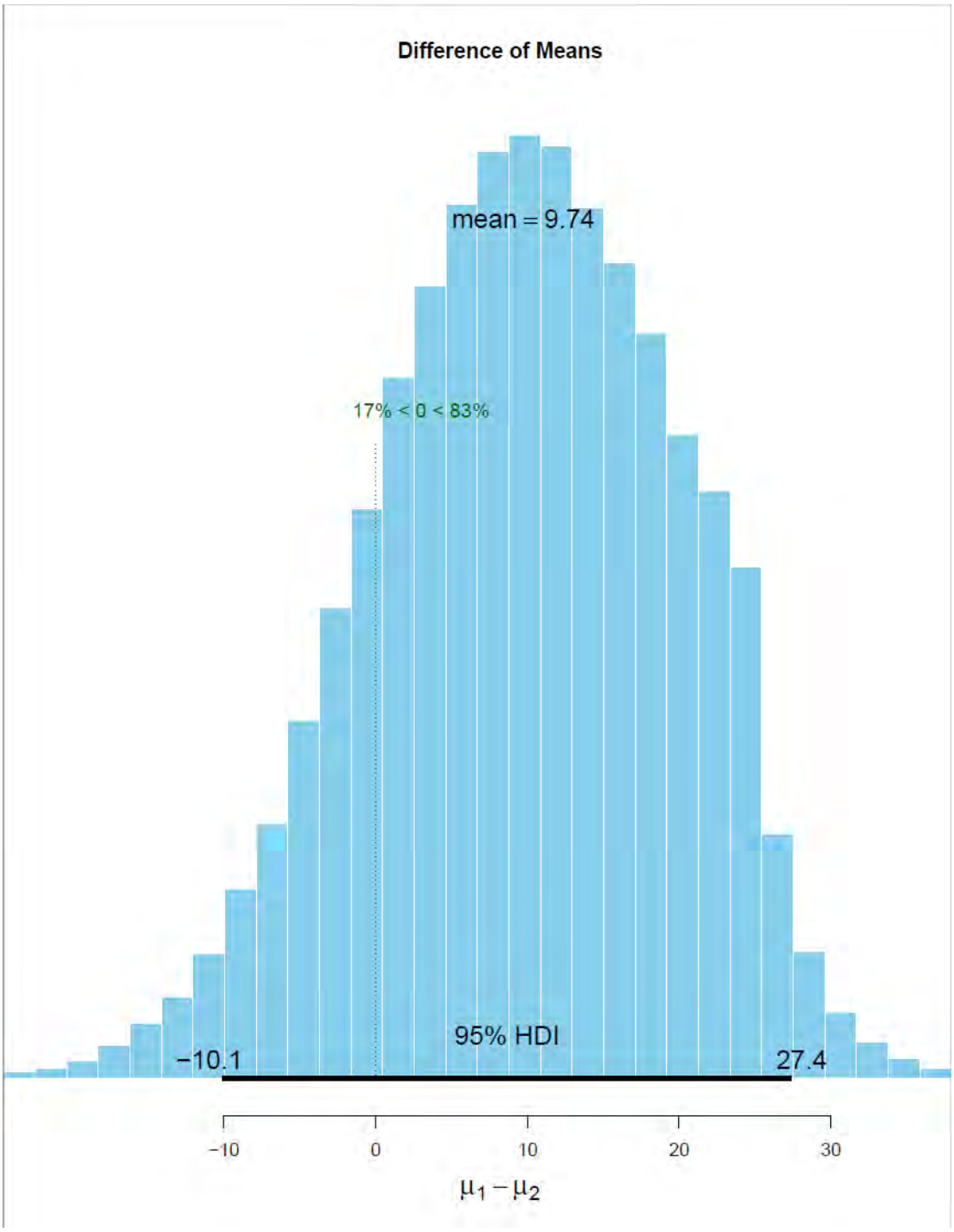


Figure 7.114: 95% High Density Interval for ΔSO_4 in LAK034 (Mean SO_4 during baseline - Mean SO_4 during post-KMP period), assuming a SD of SO_4 of 10. Negative values are consistent with an increase in SO_4 (17% belief). Positive values are consistent with an decrease in SO_4 (83% belief).

7.6.4.2.9 Method 1b (Bayesian): Two-Sample Before-After Bayesian Analysis (with uninformative priors)

Figure 7.115 and Figure 7.116 are violin plots showing the percent of the posterior distribution for ΔSO_4 that is greater than zero (i.e., an increase in SO_4). A violin plot is similar to the distributions of credible values of ΔSO_4 (e.g., Figure 7.113), except that the distribution is shown vertically rather than horizontally. Figure 7.115 uses a pre-KMP period of 2012, and Figure 7.116 uses a pre-KMP period of 2012-2014. The violin plots in Figure 7.115 and Figure 7.116 estimate the posterior distributions of Δ mean SO_4 without any prior assumption about its variability.

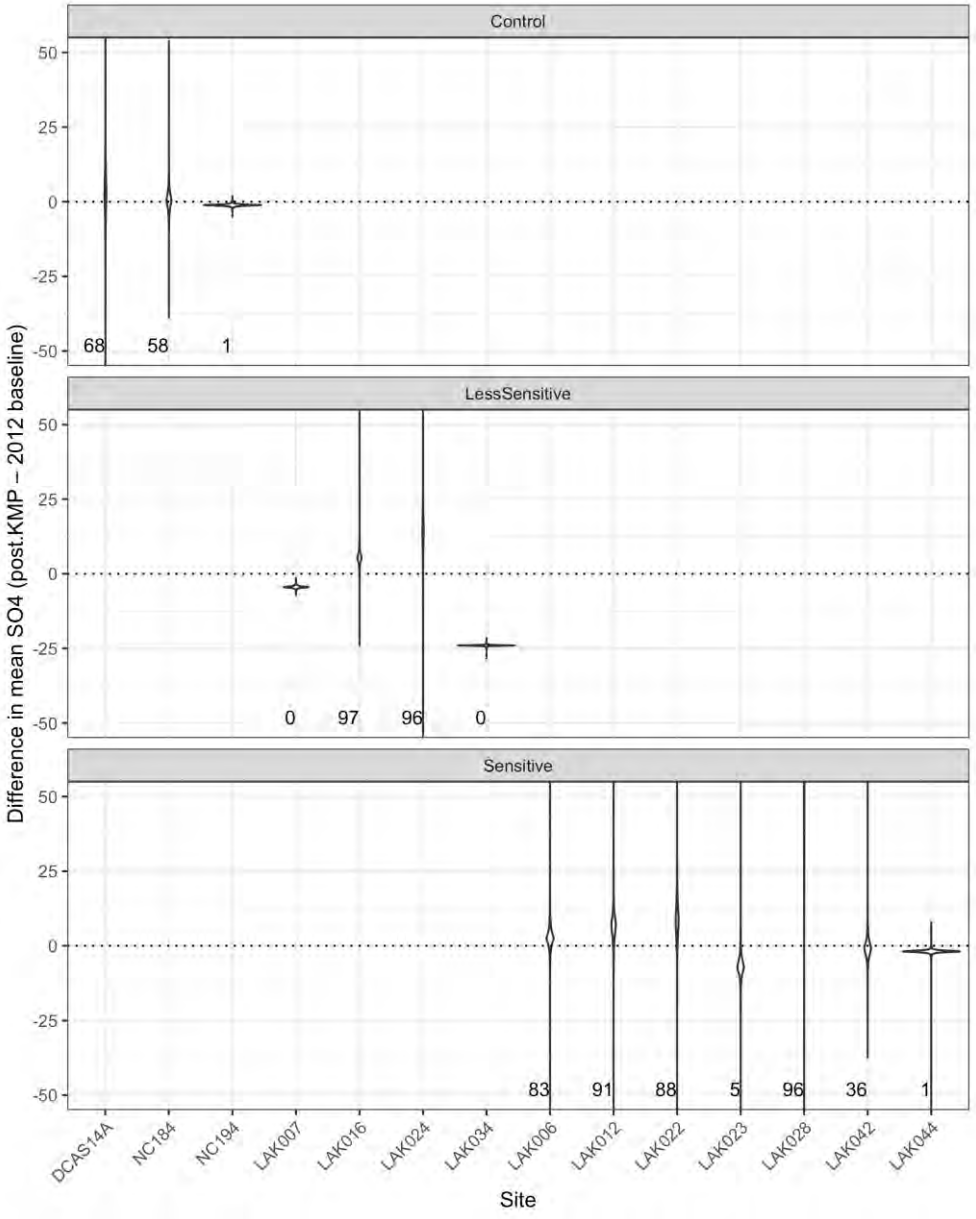


Figure 7.115: Violin plots showing the the posterior distributions of credible values for ΔSO_4, an increase in SO_4, and the percent of these distributions that is greater than 0 (indicating an increase over time between 2012 and 2016-2018).

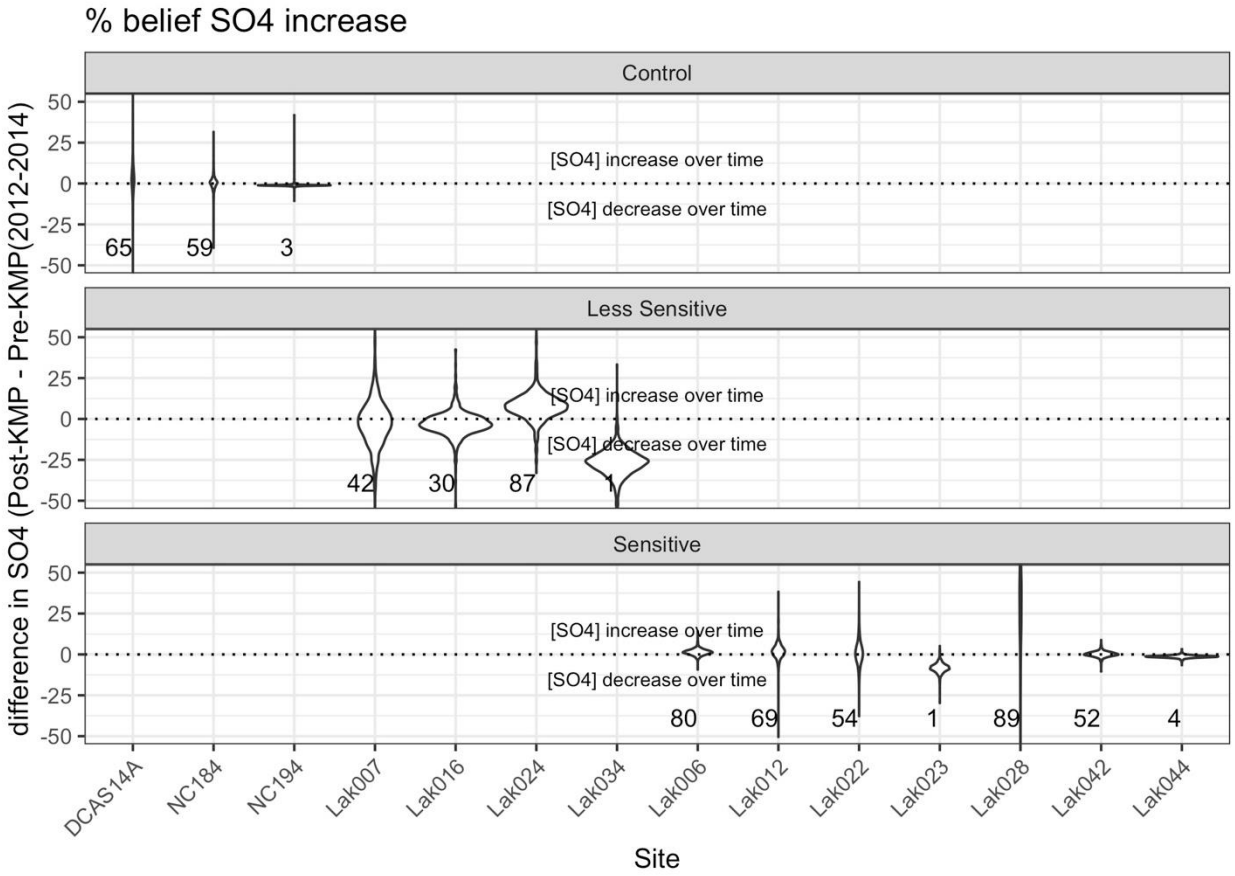


Figure 7.116: Violin plots showing the the posterior distributions of credible values for ΔSO_4, and the percent of these distributions that is greater than 0 (indicating an increase over time between 2012-2014 and 2016-2018).

KEY FINDINGS:

- Lakes with strong support (>80%) for an increase in mean SO_4 between pre-KMP (either 2012 or 2012-2014) and post-KMP (2016-2018) time periods: sensitive lakes LAK006, LAK012, LAK022 and LAK028, and less sensitive lakes LAK016 and LAK024 (Figure 7.115 and Figure 7.116).
- Lakes with very weak support (≤5%) for an increase in mean SO_4: sensitive lakes LAK023 and LAK044, less sensitive lakes LAK007 and LAK034, and control lake NC194 (Figure 7.115). Lakes 007, 023, 034 and 044 have intermediate to strong support for a sulphate decrease (Figure 7.112).

7.6.4.2.10 Method 2 (Bayesian): Two-Sample Before-After Bayesian Analysis, Using Individual Samples

Description of analyses:

This analysis is the Bayesian version of Method 2, taking into account all of the data, and accounting for variability within each year.

Purpose of analyses:

The purpose is similar to Method 1, but Method 2 uses all of the data rather than just the mean values.

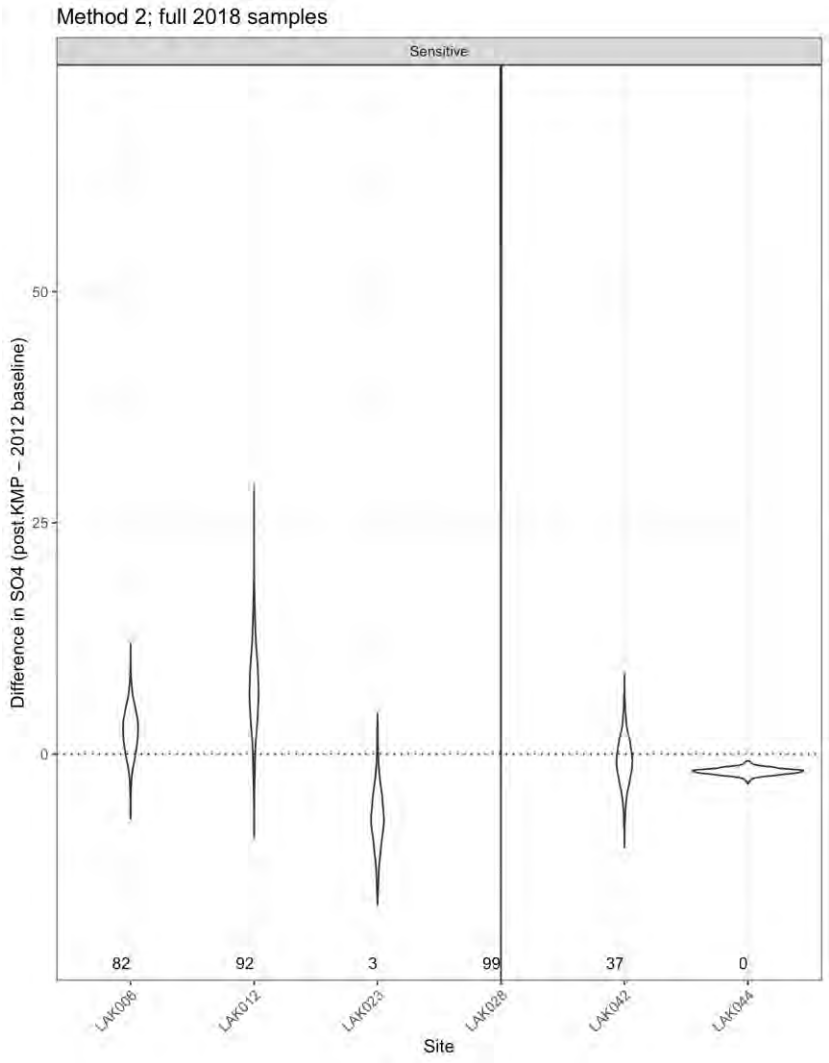


Figure 7.117: Violin plot showing the the posterior distributions of credible values for ΔSO_4 (2016-2018 vs. 2012) for the six sensitive lakes with multiple samples per year, with no prior assumptions about the variability in SO_4. The percent of these distributions that correspond to a change greater than zero is shown in numerals at the bottom of each plot.

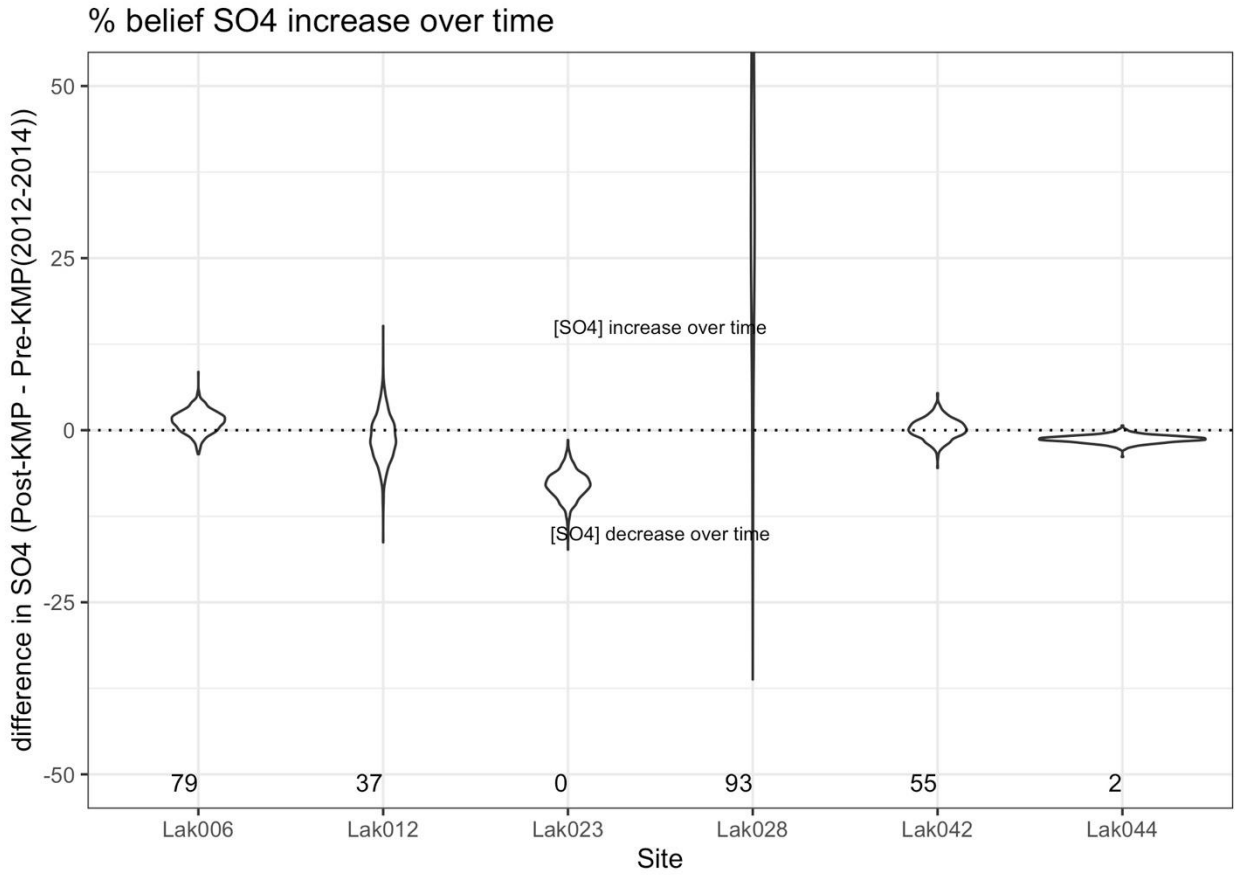


Figure 7.118: Violin plot showing the the posterior distributions of credible values for ΔSO_4 (2016-2018 vs. 2012-2014) for the six sensitive lakes with multiple samples per year, with no prior assumptions about the variability in SO_4. The percent of these distributions that correspond to a change greater than zero is shown in numerals at the bottom of each plot.

KEY FINDINGS:

- Sensitive lakes with strong support (> 80% belief) for an SO_4 increase in mean SO_4 since 2012: LAK006 (82%), LAK012 (92%), and LAK028 (99%)
- Sensitive lakes with intermediate support for an increase in SO_4: LAK042 (37%)
- Sensitive lakes with weak support for an increase in SO_4: LAK023 (3%) and LAK044 (0%)

7.6.4.3 Key Metric: pH

7.6.4.3.1 Method 1 (Frequentist): Two-Sample Before-After T-Test Using Mean Values

Description of Analyses:

See Section 7.6.4.2.1 for SO_4.

Purpose of Analyses:

Similar to Section 7.6.4.2.1 for SO_4. There are four purposes to these analyses:

1. Assess if there has been a statistically significant change in pH (i.e., Δ pH is significantly different from 0) between two time periods: pre-KMP (2012) and post-KMP (2016-2018). This t-test simply assesses if there has been *any* statistically significant change in pH. Δ pH is computed as the post-KMP mean minus the pre-KMP mean.

2. Assess whether the confidence intervals for Δ pH span 0.0 (level of confidence that there has been an increase or decrease in pH)

3. Assess whether the confidence intervals for Δ pH span the EEM threshold of -0.3 pH units (as described above).

4. Assess what the Minimum Detectable Difference (MDD) in pH is for each lake, under four different assumptions of the true standard deviation of pH during the pre-KMP period.

Explanation of the Graphs and Tables of Results:

Please see the captions below for each graph and table.

Table 7.41: T-test of changes in mean pH for each lake, between the pre-KMP period (2012) and post-KMP period (2016-2018). T.stat is the T-statistic. P-value is the probability of the ΔpH being significantly different from zero (p<0.01 is the appropriate signficance level given the multiple statistical tests). Lwr and Upp are the lower and upper confidence levels for ΔpH. Sd_post is the standard deviation of mean pH levels over the 3-year post-KMP period. MDD_sd is the minimum detectable difference in pH that would be statistically significant at p<0.01 with 0.8 statistical power, given four different assumptions about the standard deviation of pH during the pre-KMP period (0.05, 0.1, 0.2, 0.3). For example, in LAK007, a pH change of 0.37 is the minimum detectable difference with a pre-KMP SD of 0.05, but the MDD increases to 1.468 if the pre-KMP SD were 0.3.

SUBSET	LAKE	p-value	lwr	upp	sd_post	MDD_sd_0.05	MDD_sd_0.1	MDD_sd_0.2	MDD_sd_0.3
LessSensitive	LAK007	0.714	-0.64	0.70	0.06	0.37	0.56	1.00	1.47
LessSensitive	LAK016	0.057	-0.50	1.19	0.07	0.43	0.60	1.02	1.48
LessSensitive	LAK024	0.086	-0.76	1.47	0.10	0.53	0.67	1.07	1.51
LessSensitive	LAK034	0.017	-0.67	0.09	0.03	0.29	0.51	0.97	1.45
Sensitive	LAK006	0.132	-0.74	1.22	0.09	0.48	0.63	1.05	1.50
Sensitive	LAK012	0.026	-0.32	1.36	0.07	0.43	0.60	1.02	1.48
Sensitive	LAK022	0.058	-0.22	0.51	0.03	0.28	0.50	0.97	1.45
Sensitive	LAK023	0.068	-0.37	0.80	0.05	0.34	0.54	0.99	1.46
Sensitive	LAK028	0.943	-2.85	2.91	0.25	1.23	1.30	1.54	1.88
Sensitive	LAK042	0.097	-1.27	2.36	0.16	0.80	0.90	1.23	1.63
Sensitive	LAK044	0.084	-0.31	0.62	0.04	0.31	0.52	0.98	1.45

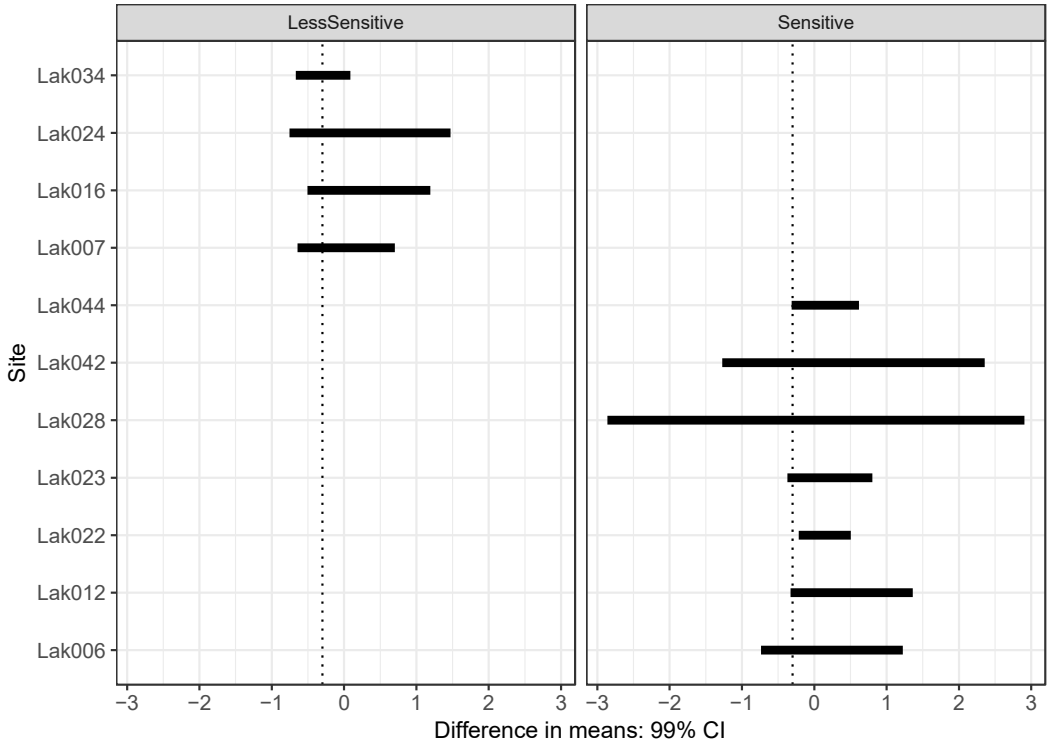


Figure 7.119: Using Method 1, 99% confidence intervals for the ΔpH (mean pH in post-KMP period minus the mean pH in the pre-KMP period). The confidence intervals for changes in mean pH overlap 0.0 and -0.3 for all lakes except for LAK022. The vertical dotted line is at -0.3 pH units.

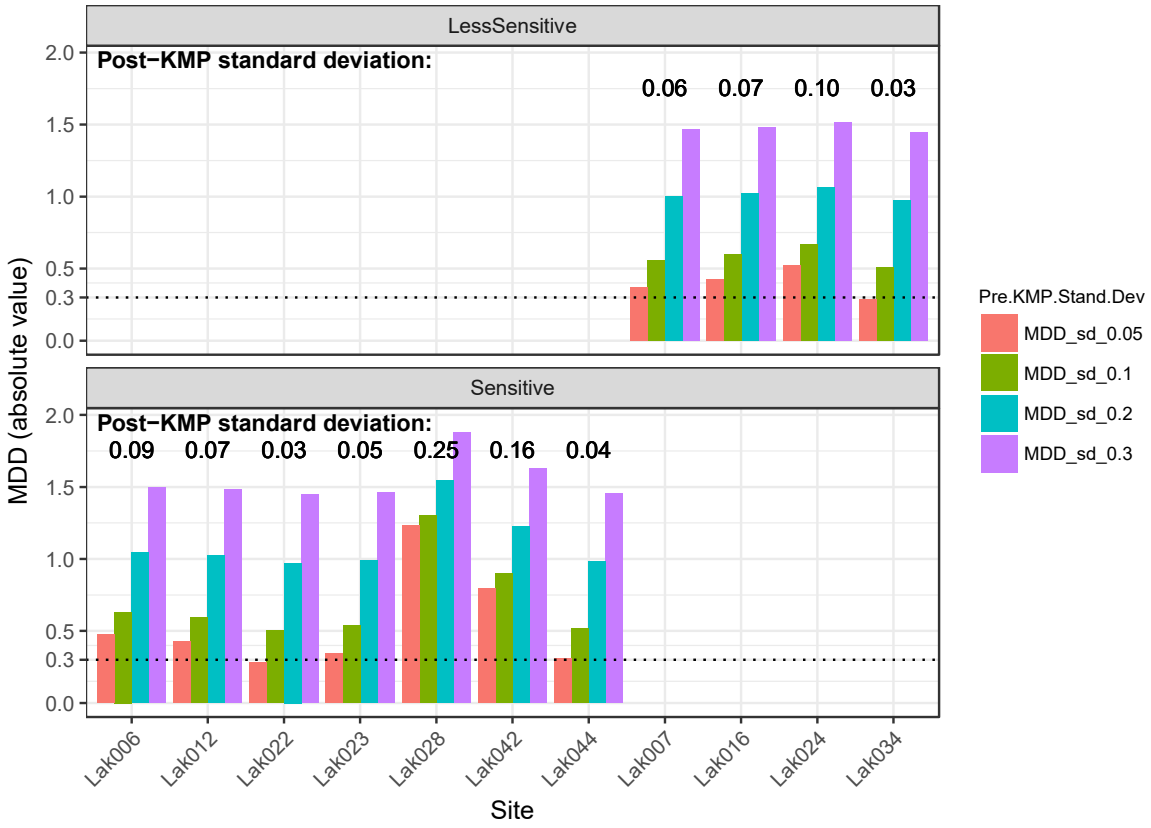


Figure 7.120: Minimum detectable differences (MDD) are shown for each lake, assuming four different values for the standard deviation (SD) of pH in the pre-KMP period (2012). Since we have only observation for the pre-KMP period (a single measurement in 2012), we can't compute the SD, but must assume it. The SD for the post-KMP period is written above the bars to provide some context for the pre-KMP assumptions, though variability could vary between the two periods. LAK028 has the highest SD in the post-KMP period, and also has the highest values for MDD. The dotted, horizontal line marks 0.3 pH units. Only LAK022 and LAK034 show an MDD < 0.3 (i.e., can detect a pH change of 0.3), and only for the lowest assumed value for SD (0.05).

KEY FINDINGS:

- As expected, it was very difficult to show a statistically significant change with such a small sample
- All 99% Confidence Intervals overlap -0.3 and zero (except LAK022)
- No t-statistics for any site have a p-value below 0.01
- Minimum Detectable Differences are generally greater than 0.3 at all assumed baseline KMP standard deviations (except for LAK022, LAK023, LAK034 and LAK044 at SD = 0.05)
- Cannot detect a difference in mean pH between baseline and Post-KMP groups

7.6.4.3.2 Method 2 (Frequentist): Two-Sample Before-After T-Test Using Individual Samples

Description of Analyses:

Same as for SO_4 in Section 7.6.4.2.2, but applied to pH.

Purpose of analyses:

The purpose of this analysis is similar to Method 1 (i.e., to determine if there is a significant difference between the post-KMP and pre-KMP values of pH), but the analysis removes the effect of natural variability during the sampling period. We are interested to see if this reduces the uncertainty in estimates of the ΔpH between the post-KMP and pre-KMP periods, and narrows the confidence intervals on these estimates.

Explanation of the graphs and tables of results:

See captions below.

Table 7.42: Results for T-test for post-KMP pH (2016-18) versus baseline pH (2012), using individual samples, for the six sensitive lakes with multiple within-year samples.. The "est.diff" is the pH in the post-KMP period minus the pH in the baseline period. A positive value for "est.diff" means that the pH increased from the baseline period to the post-KMP period, while a negative value indicates a decrease in pH. The "est.diff.se" is the standard error in pH, which is highest for LAK028, and lowest for LAK044. The "est.diff.lcl" and "est.diff.ucl" are the lower and upper confidence intervals (respectively) for "est.diff". The "p.value" is the probability of a significant difference in mean pH (<0.01 for LAK012, >0.01 for all other lakes).

SITE	est.diff	est.diff.se	est.diff.lcl	est.diff.ucl	p.value
LAK006	0.24	0.13	-0.08	0.57	0.11
LAK012	0.52	0.13	0.22	0.81	0.004
LAK023	0.22	0.08	0.02	0.42	0.04
LAK028	0.02	0.32	-1.00	1.05	0.95
LAK042	0.54	0.20	-0.13	1.21	0.08
LAK044	0.15	0.08	-0.03	0.33	0.09

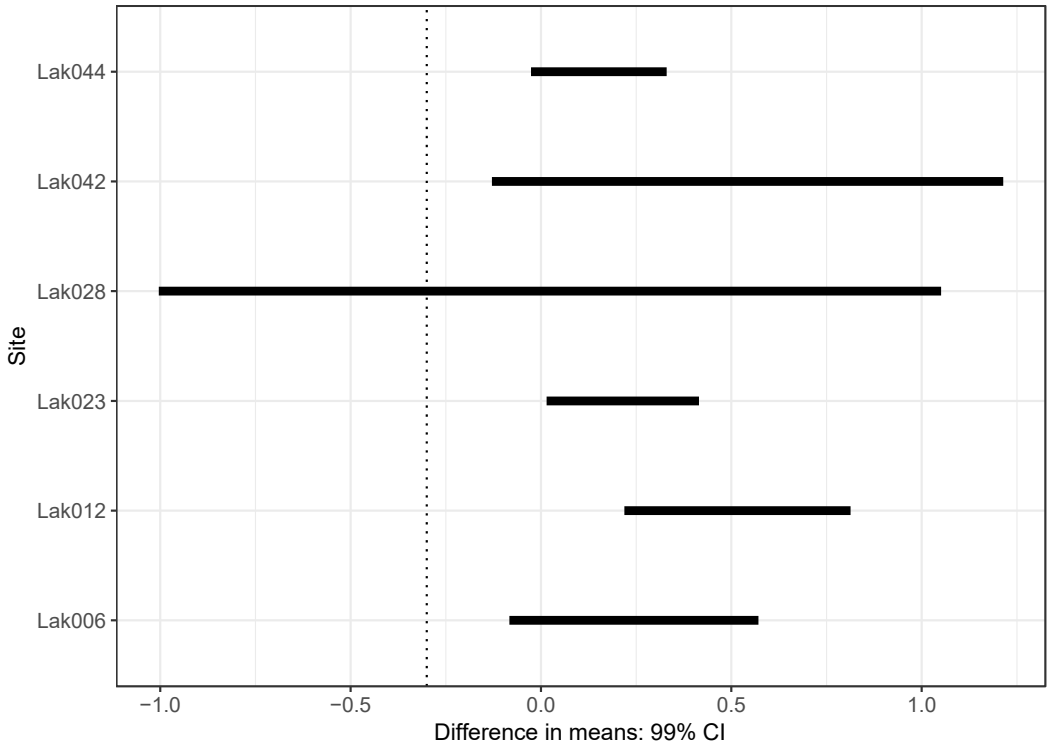


Figure 7.121: Using Method 2, 99% confidence intervals for the ΔpH (mean pH in post-KMP period minus the mean pH in the pre-KMP period, accounting for within year variability). The vertical dotted line is at -0.3 pH units. The confidence intervals for changes in mean pH do not overlap -0.3 in five of the six lakes, but do overlap -0.3 in LAK028. The confidence intervals are greater than zero for LAK012 and LAK023.

KEY FINDINGS:

- Including individual measurements during the fall index period (Method 2; Figure 7.121) narrows the confidence intervals on the before-after effect relative to Method 1 (Figure 7.119). This emphasizes the value of taking multiple samples (4) during the fall index period.
- For LAK006, LAK012, LAK023, LAK042, LAK044, the 99% Confidence Intervals using Method 2 are entirely greater than -0.3, providing strong evidence that the ΔpH did not exceed the threshold of -0.3 in these five lakes.
- In LAK028, which has the highest variability in pH, the 99% Confidence Interval overlaps -0.3 and zero (i.e., we cannot reject the hypothesis that the ΔpH exceeded the threshold of -0.3).
- LAK012 and LAK023 have CIs that are greater than zero, providing support for an increase in mean pH between 2012 and the post-KMP period.

7.6.4.3.3 Method 3 (Frequentist): Before-After Control-Impact (BACI), Using Mean Values

Description of Analyses:

Same as described for SO_4 in Section 7.6.4.2.3, but applied to pH.

Purpose of analyses:

Use a BACI analysis to determine how the post-KMP vs. pre-KMP ΔpH in each sensitive lake compares to the ΔpH in the control lakes, taken as a group. This analysis accounts for broad scale regional/climatic effects which could affect both the sensitive lakes and the control lakes.

Explanation of the graphs and tables of results:

See figure and table captions below. We are using the significance value of 0.01 throughout as correction for multiple tests (it is not precisely the Bonferroni correction, but an analogous approximation).

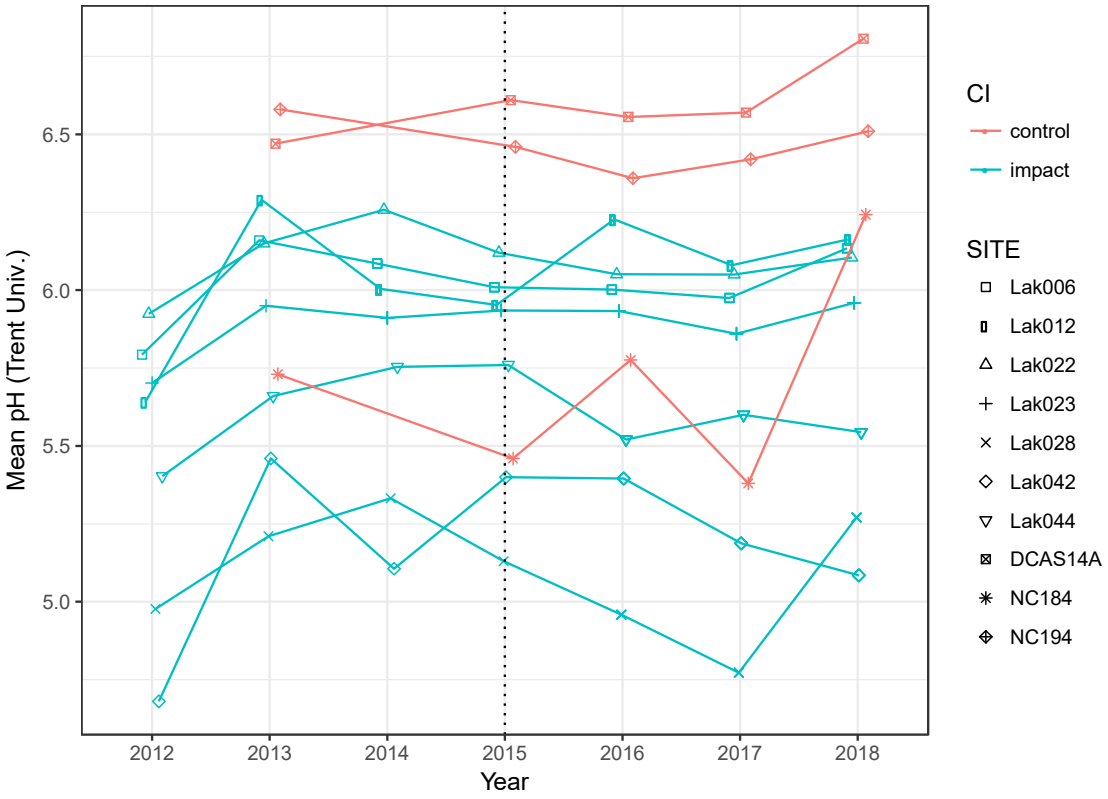


Figure 7.122: Change in mean pH over time for sensitive lakes (blue lines) and control lakes (orange lines).

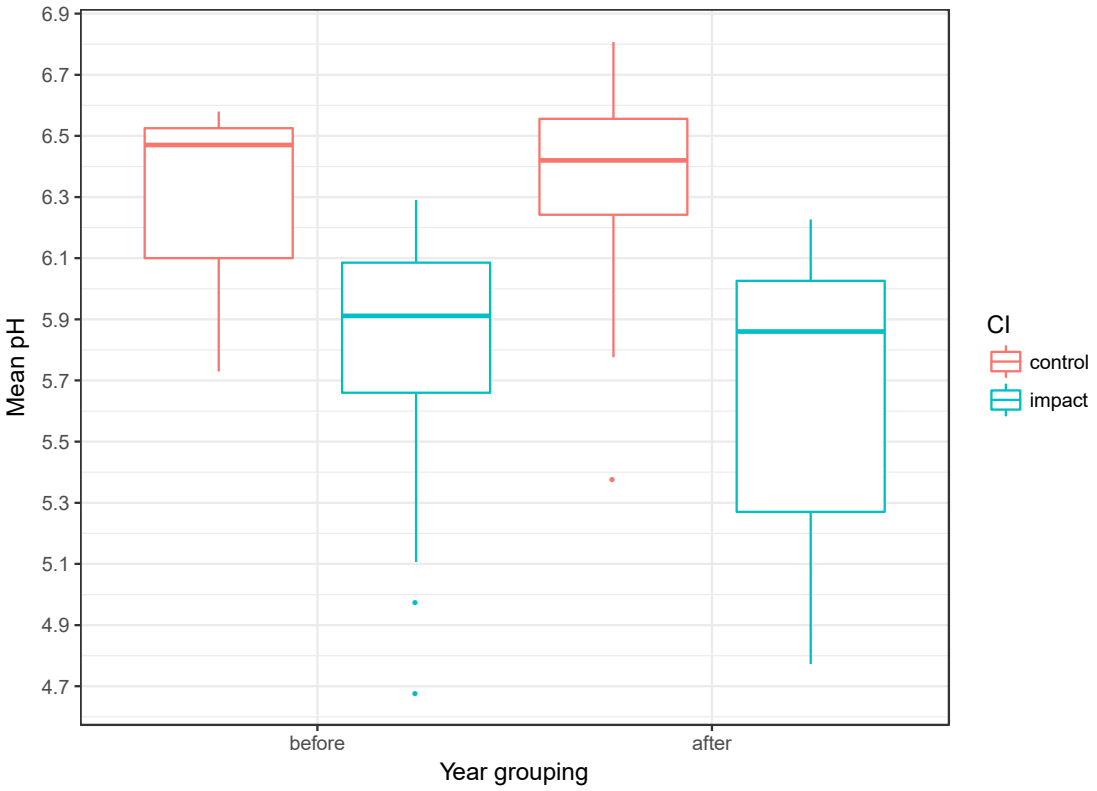


Figure 7.123: Box plots of the pH across the 3 control lakes (orange) and across the 7 sensitive lakes (blue). Top of box, mid-line and bottom of box are (respectively) the 75th, 50th and 25th percentiles of the distributions of the values of mean pH during the pre-KMP (before) and post-KMP periods (after). The medians for the before and after impact groups are similar, but the 25th percentile is lower in the after period than the before period. None of the lakes show significant changes between the after (post-KMP) period and the before (pre-KMP period).

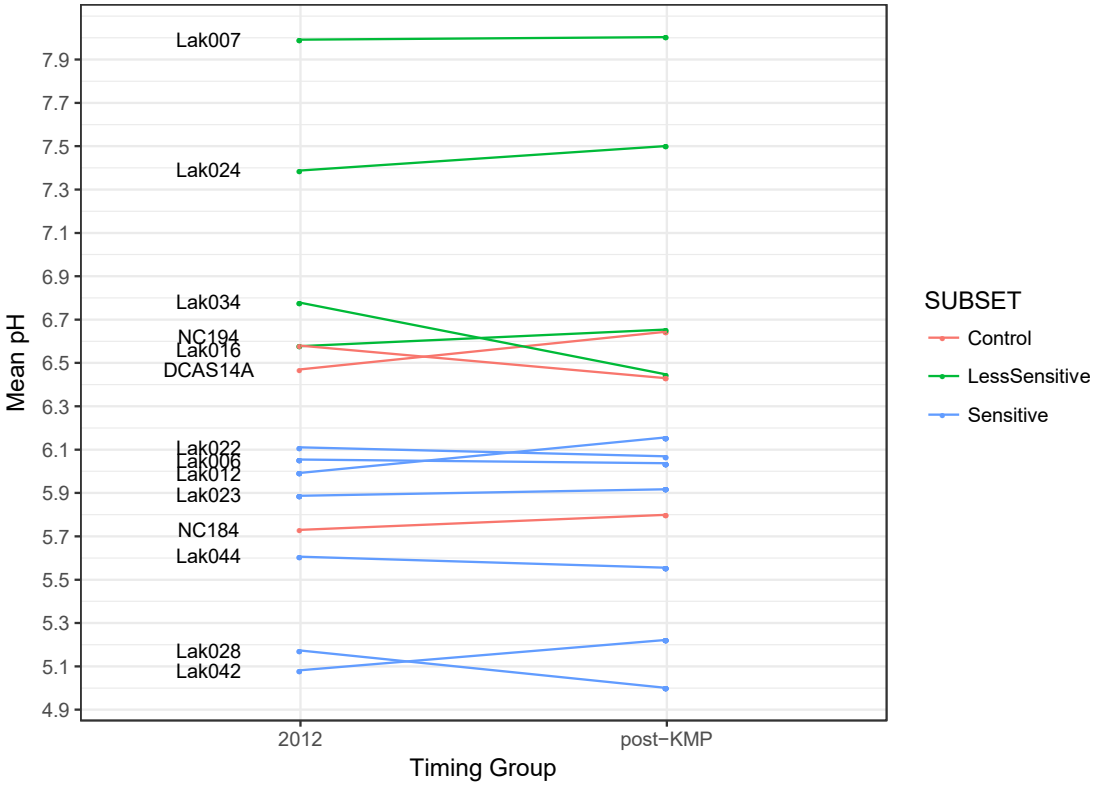


Figure 7.124: Changes in mean pH for control lakes (red), less sensitive lakes (green) and sensitive lakes (blue) between the pre-KMP period (2012) and the post-KMP period (average of mean annual pH for 2016, 2017, 2018).

Table 7.43: BACI analyses of mean pH for 7 sensitive and 3 control lakes, using Method 3. "BACI estimate" is a bit counter-intuitive: it is the Δ mean pH in the controls (i.e., $pH_{post\text{-}KMP}$ minus $pH_{pre\text{-}KMP}$), averaged over the 3 control lakes, minus the Δ mean pH in the sensitive lake (i.e., the mean difference of the control-impact differences). If BACI value is <0, then the ΔpH was lower in the controls than in the sensitive lake (and, equivalently, the ΔpH was greater in the sensitive lake than in the controls). If BACI value is >0, then the pH change in the controls was greater than that in the sensitive lake (and, equivalently, the ΔpH was less in the sensitive ake than in the controls). The "t.ratio" is the t-statistic for the BACI estimate, and the p.value the significance of the test.

Site	BACI estimate	SE	p.value	Interpretation of BACI estimate
LAK006	-0.21	0.15	0.183	change in pH was more positive in LAK006 than in the control lakes (but NOT statistically significant)
LAK012	-0.49	0.18	0.013	change in pH was more positive in LAK012 than in the control lakes (but NOT statistically significant)
LAK022	-0.11	0.24	0.648	change in pH was more positive in LAK022 than in the control lakes (but NOT statistically significant)
LAK023	-0.18	0.16	0.28	change in pH was more positive in LAK023 than in the control lakes (but NOT statistically significant)
LAK028	0.008	0.14	0.957	change in pH was similar in LAK028 to changes in the control lakes
LAK042	-0.51	0.23	0.037	change in pH was more positive in LAK042 than in the control lakes (but NOT statistically significant)
LAK044	-0.12	0.19	0.527	change in pH was more positive in LAK044 than in the control lakes (but NOT statistically significant)

Table 7.44: BACI analysis of ΔpH with all lakes combined, using Method 3. BACI estimate is the Δ mean pH in the 3 control lakes (i.e., $pH_{post\text{-}KMP}$ minus $pH_{pre\text{-}KMP}$, averaged over the 3 control lakes), minus the Δ mean pH in the 7 sensitive lakes (i.e., $pH_{post\text{-}KMP}$ minus $pH_{pre\text{-}KMP}$, averaged over the 7 sensitive lakes). SE is the standard error of the BACI estimate. The t.ratio is the t-statistic for the BACI estimate, and the p.value the significance of the test.

contrast	BACI estimate	SE	p.value
baci	-0.18	0.10	0.059

KEY FINDINGS:

- For the analysis of each sensitive lake compared to the 3 control lakes as a group:
  - None of the lakes showed a statistically significant effect – i.e., before-after differences that were significantly different than the before-after changes in the control lake group
  - Six of the seven sensitive lakes showed a ΔpH that was more positive than the ΔpH observed in the group of control lakes (negative effect in the BACI analysis), but none of these differences were statistically significant at p<0.01
  - Before-after changes in mean pH in LAK028 were similar to those observed in the control lakes.
  - All lakes have p-value above 0.01.
  - No support for an effect across any of the lakes individually or an effect for all lakes combined.
- For the analysis of the group of 7 sensitive lakes compared to the group of 3 control lakes:
  - The sensitive lake group showed a more positive ΔpH compared to the control lake group, but this difference was not statistically significant at p<0.01.

7.6.4.3.4 Method 4 (Frequentist): Before-After Control-Impact (BACI), Using Individual Samples

Description of Analyses:

Same as described for SO_4 in Section 7.6.4.2.4, but applied to pH.

Purpose of analyses:

We wish to see if there is any change in the results of the BACI analysis when we account for variability during the sampling period. This analysis is only possible for the 6 sensitive lakes with four samples / year; LAK022 has only one sample per year.

Explanation of the graphs and tables of results:

See captions below

Table 7.45: BACI analysis of ΔpH using Method 4. See caption for Table 4-19 for explanation of terms. Power is the statistical power to detect ΔpH of 0.3, given the number of subsamples, number of years, and different standard deviation components.

Site	BACI estimate	SE	p.value	Power (%)	Interpretation of BACI estimate
LAK006	-0.21	0.22	0.36	23	change in pH was more positive in LAK006 than in the control lakes (but NOT statistically significant)
LAK012	-0.49	0.24	0.076	20	change in pH was more positive in LAK012 than the change in pH in the control lakes (but NOT statistically significant)

Site	BACI estimate	SE	p.value	Power (%)	Interpretation of BACI estimate
LAK023	-0.18	0.23	0.453	21	change in pH was more positive in LAK023 than in the control lakes (but NOT statistically significant)
LAK028	0.008	0.20	0.97	26	change in pH was in LAK028 was similar to changes in the control lakes
LAK042	-0.51	0.29	0.113	16	change in pH was more positive in LAK042 than in the control lakes (but NOT statistically significant)
LAK044	-0.12	0.25	0.645	19	change in pH was more positive in LAK044 than in the control lakes (but NOT statistically significant)

Table 7.46: BACI analysis of ΔpH with all lakes combined, using Method 4. Structure of this table is similar to Table 7.44.

contrast	BACI estimate	SE	p.value
baci	-0.18	0.12	0.154

KEY FINDINGS:

- All lakes have p-value above 0.01. In all six lakes, the p-values were higher using Method 4 than Method 3, indicating that inclusion of within-year variability for 6 sensitive lakes (Method 4) made an effect for ΔpH even less likely than under Method 3.
- No support for BACI effect in ΔpH across any of the lakes individually (Table 7.45) or an effect for all lakes combined (Table 7.46).
- The analysis for six sensitive lakes combined as a group under Method 4 (Table 7.46) has fewer degrees of freedom and a higher p-value than when all seven lakes were combined under Method 3 (Table 7.44), confirming that Method 4 did not reduce the uncertainty in the estimated effect relative to Method 3.

7.6.4.3.5 Method 5 (Frequentist): Before-After Control-Impact (BACI), with Assumption of No Change in Control Lakes

Description of Analyses:

Same as described for SO_4 in Section 7.6.4.2.5, but applied to pH. Note that the range of fluctuation in pH in the control lakes over 2013 and 2015-2018 is generally close to the range of pH measurement error of ± 0.2 pH units.

Purpose of analyses:

This is a sensitivity analysis on Method 4, to see how much difference the observations from the control lakes (and common patterns of year to year variability in the control lakes) make to the outcome of the BACI analysis. Removing the data from the control lakes reduces the number of degrees of freedom in the analysis. The analysis is done first using just mean values (as in Method 1), and then using all of the data (as in Method 2). We also use ANOVA to compare the fit of models which keep the control lakes' data constant, vs. allowing the control lakes' data to vary.

Explanation of the graphs and tables of results:

See captions below

Table 7.47: BACI analysis using Method 5 applied to mean pH values, holding control lakes' pH constant. Structure of this table is similar to Method 3 (Table 7.44).

contrast	BACI estimate	SE	p.value
baci	0.20	0.08	0.026

Table 7.48: ANOVA analysis using Method 5 comparing the fit of two models to mean pH values ("vary", which includes data from the control lakes; and "cons", which holds the control lakes constant). Analysis applied using two information criteria (AIC = Aikike Information Criteron; BIC = Bayesian Information Criteron). Lower (i.e., more negative) values for AIC and BIC indicate a better fit of the model to the data. Including data from the control lakes ("vary") provides a slightly better fit, but the differences between the two models are not statistically significant.

	Df	AIC	BIC	logLik	deviance	Chisq	ChiDF	Pr(>Chisq)
vary	6	-46.16	-29.96	29.08	-58.158			
cons	7	-44.25	-25.34	29.12	-58.246	0.0884	1	0.766

Table 7.49: BACI analysis using Method 5 applied to all pH values in the sensitive lakes (i.e., including within-year variability), holding control lakes' pH constant. Structure of this table is similar to Method 3 (Table 7.44).

contrast	BACI estimate	SE	p.value
baci	0.07	0.09	0.453

Table 7.50: ANOVA analysis using Method 5 comparing the fit of two models to all pH values ("vary", which includes data from the control lakes; and "cons", which holds the control lakes constant). Analysis applied using two information criteria (AIC = Aikike Information Criteron; BIC = Bayesian Information Criteron). Lower (i.e., more negative) values for AIC and BIC indicate a better fit of the model to the data. Including data from the control lakes ("vary") provides a slightly better fit, but the differences between the two models are not statistically significant.

	Df	AIC	BIC	logLik	deviance	Chisq	ChiDF	Pr(>Chisq)
Vary	7	-36.03	-17.13	25.02	-50.031			
Cons	8	-34.09	-12.49	25.05	-50.095	0.0639	1	0.801

KEY FINDINGS:

- Removing the variability contributed by the data from the control lakes (Method 5) yields a positive effect in the BACI analysis (Table 7.47), as compared to a negative effect when control lake data were included (Method 3 (Table 7.44) and Method 4 (Table 7.46)). However, none of these methods showed statistically significant effects at $p<0.01$.
- The ANOVA analyses (Table 7.48 and Table 7.50) indicate that inclusion of data from the control lakes provides a slightly better fit to the data than assuming no changes in the control lakes, but the differences in model fit between these two approaches are not statistically significant.
- Since comparisons of Method 5 with Methods 3 and 4 indicate that data from the control lakes can affect the sign of the BACI analysis, and since accounting for regional climate effects is important, we conclude that sampling should continue in the control lakes, and these data should continue to be used in BACI analyses.

7.6.4.3.6 Method 6 (Frequentist): Using Other Covariates to Explain Inter-Annual Variation

Description of Analyses:

Same as described for SO_4 in Section 7.6.4.2.6, but applied to pH.

Purpose of analyses:

The previously described analyses intentionally excluded 2013 and 2014 from the baseline period. We did this because the winding down of the old smelter during this period resulted in reduced emissions and apparent increases in pH in some of the sensitive lakes (Figure 7.44), which would lead to an inaccurate estimate of baseline pH if we had used 2012-2014 data to compute baseline pH. If covariates such as emissions and precipitation help to explain variability in water chemistry, then we could potentially include data from 2012-2014 in the baseline period, and have three years of baseline data rather than just one, which, together with three years of post-KMP data (2016-2018) would improve statistical power.

Explanation of the graphs and tables of results:

We used total SO_2 emissions over the prior year (i.e., October 1 through Sept. 30, see Section 7.6.2.3) and the last 3-days and 14-days of precipitation at Haul Road (see Section 7.6.2.2) as covariates. The model also includes terms for three random effects: year, site, and year by site interactions.

*pH_trent ~ BA*CI + EMISSIONS + PRECIPITATION + (1|YEAR) + (1|SITE) + (1:YEAR:SITE)*

Table 7.51: Before-After t-test for changes in pH, including covariates for emissions and previous 3-day sum of precipitation. No effect of timing (BA, before KMP vs. post-KMP), treatment (CI, control lake or impact lake) or the BACI interaction (BA:CI), 3-day precipitation or Emissions was observed for pH.. df is degrees of freedom. t-value is the test statistics. Pr(>|t|) is the pvalue.

Fixed effects:	Estimate	Std Error	df	Pr(>|t|)
(Intercept)	6.16	0.56	12	0.00
BAbefore	0.04	0.19	3	0.84
CIimpact	0.30	0.48	27	0.54
Emissions	0.00	0.00	2	0.73
Precipitation (3 day)	-0.01	0.00	39	0.06
BAbefore:CIimpact	0.14	0.11	39	0.22

Table 7.52: Variance and standard deviation of the random effects for year, site and year by site interactions. The SITE random effect accounts for a substantial portion of the variation in pH.

Random effects:		
Groups	Variance	Std.Dev.
YEAR:SITE	0.01	0.11
SITE	0.60	0.78
YEAR	0.002	0.04
Residual	0.01	0.10

Table 7.53: Before-After t-test for changes in pH, including covariates for emissions and previous 14-day sum of precipitation. No effect of timing (BA, before KMP vs. post-KMP) or treatment (CI, control lake or impact lake) or the BACI interaction (BA:CI), 14-day precipitation or Emissions was observed for pH. df is degrees of freedom. t-value is the test statistics. Pr(>|t|) is the pvalue.

Fixed effects:	Estimate	Std Error	df	Pr(>|t|)
(Intercept)	6.29E+00	5.82E-01	1.06E+01	4.85E-07
BAbefore	-3.48E-02	2.06E-01	2.45E+00	0.879
CIimpact	2.78E-01	4.79E-01	2.66E+01	0.566
Emissions	4.96E-05	1.08E-03	1.87E+00	0.968
Precipitation (14 day)	-2.73E-03	1.94E-03	3.92E+01	0.168
BAbefore:CIimpact	1.74E-01	1.16E-01	3.97E+01	0.141

Table 7.54: Variance and standard deviation of the random effects for year, site and year by site interactions. The SITE random effect accounts for a substantial portion of the variation in pH.

Random effects:			
Groups	Name	Variance	Std.Dev.
YEAR:SITE	(Intercept)	0.01	0.10
SITE	(Intercept)	0.61	0.78
YEAR	(Intercept)	0.002	0.05
Residual		0.001	0.11

KEY FINDINGS:

- Adding covariates for emissions and precipitation did not help to explain variability in the ΔpH between the post-KMP and pre-KMP periods.
- The signs of the covariates for 3-day and 14-day precipitation are negative, which is consistent with our expectations (i.e., pH is negatively correlated with the amount of precipitation during the previous time-period), but these terms are not statistically significant at alpha = 0.05.

7.6.4.3.7 Approach Supportive of Methods 8 and 9 (Frequentist): Temporal Trend Analyses

Description and Purpose of Analyses:

As explained in Section 7.6.4.2.7 for SO_4.

Table 7.55: Results of the Mann-Kendall non-parametric test for monotonic trend in pH values. No lakes exhibit a significant result for detecting a monotonic trend.

Lake	p.value
LAK006	0.500
LAK012	0.633
LAK022	0.367
LAK023	0.500
LAK028	0.500
LAK042	0.045
LAK044	0.367
LAK007	0.765
LAK016	0.500
LAK024	0.633
LAK034	0.154
NC184	0.597
NC194	0.403
DCAS14A	0.890

KEY FINDINGS:

- None of the lakes' data provide sufficient evidence to reject the null hypothesis that there was no monotonic trend in mean pH (i.e., all p values are > 0.01)

7.6.4.3.8 Method 1a (Bayesian): Two-Sample Before-After Bayesian Analysis (Bayesian Estimation Supersedes the T-Test with informative priors)

Description of Analyses:

The intent of Bayesian analyses is to estimate the *posterior* distribution of a parameter of interest, which is the probability distribution of the parameter taking into account the data. The first step is for the analyst to specify a *prior* belief, or prior credibility distribution of possible parameter values. After the data have been collected, the prior beliefs are then updated using Bayes' rule to obtain the posterior distribution. In this case, the parameter of interest is the ΔpH from the baseline 2012 measurement to the 2016-2018 post-KMP period. The statistical software used for this analysis computes Δ mean pH as the mean pH for the baseline period minus the mean pH for the 2016-2018 post-KMP period. Positive values of this parameter are therefore indicative of a pH decline.

In the introduction to these analyses in the TOR we stated that if the frequentist approach shows a clear result for a lake (e.g., 99% confidence intervals for ΔpH do not overlap that lake's threshold for ΔpH) then there's no need to proceed with the Bayesian analysis for that parameter in that lake. Using frequentist method 1 for ΔpH, all of the 99% confidence intervals for the seven sensitive lakes overlapped the 0.3 threshold, so it would be logical to use the Bayesian approach for all seven sensitive lakes. However, with frequentist method 2 for ΔpH, the 99% confidence intervals for ΔpH did not overlap -0.3 in five of the six sensitive lakes with multiple samples in October: LAK006, LAK012, LAK023, LAK042 and LAK044. Using Method 2, the 99% confidence intervals for LAK028 did however overlap -0.3 in LAK028. Based on Method 2, we only need to include the Bayesian approach for LAK028. However, we decided to complete the Bayesian approach for all lakes, so that we could see how consistent our inferences would be using different statistical methods.

We also examine the percent belief that there was any decline in mean pH between the pre-KMP (2012) and post-KMP (2016-18) periods (Figure 7.128). The percent belief in any decline covers a larger fraction of the posterior distribution of ΔpH, and therefore generates higher values of percent belief than for a decline with exceeds the 0.3 unit threshold.

Explanation of the graphs and tables of results:

See captions below.

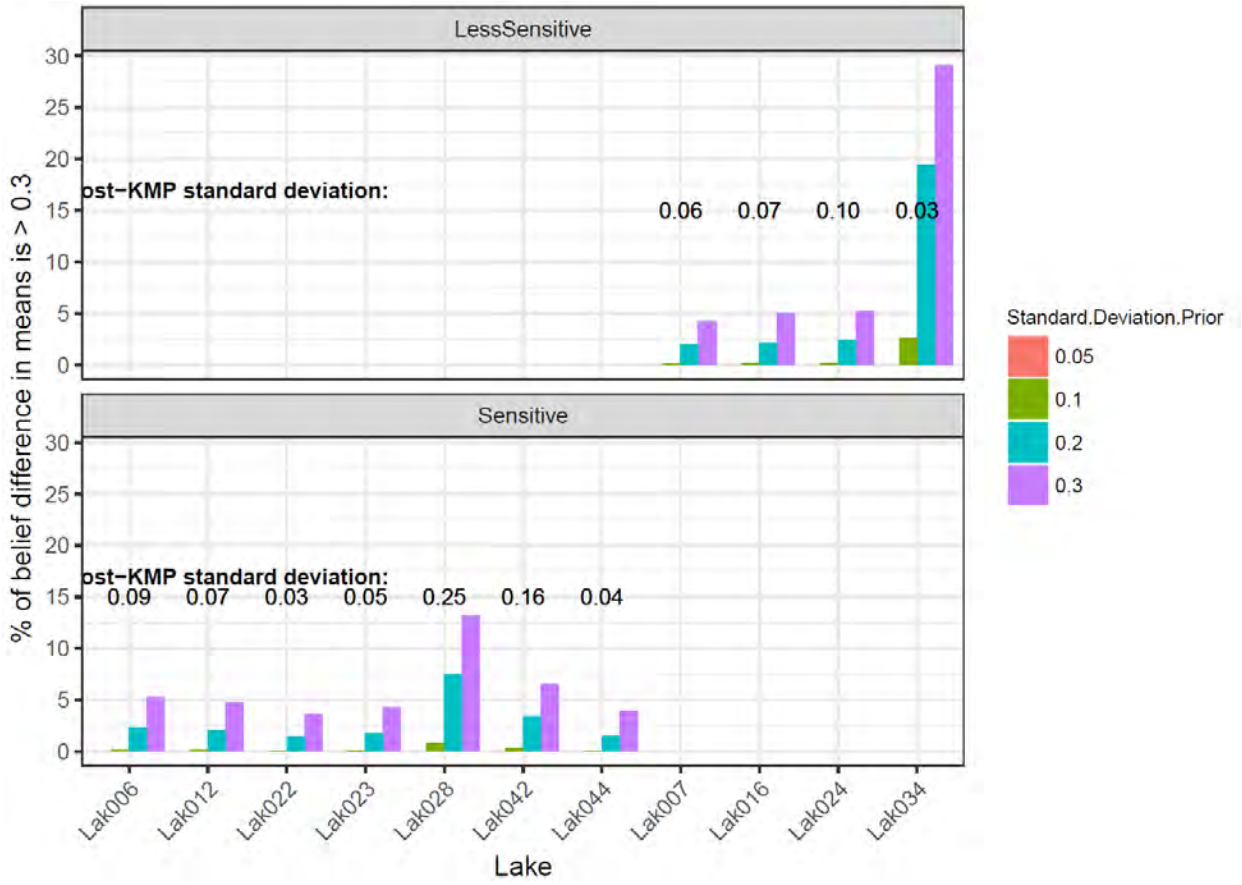


Figure 7.125: Percentage belief that ΔpH is greater than 0.3, using Two-Sample Before-After Bayesian Analysis. The bars show the percentage belief for four different prior assumptions about the standard deviation of pH of a lake across the entire time period (note that the orange bars for a SD of 0.05 are too small to be visible on the graphs). The SD of pH for the post-KMP period is included to provide some context for each lake, but is not directly comparable to the prior assumptions of SD. For example, using an SD prior of 0.2 (blue bars), only LAK028 and LAK034 have more than a 5% belief that ΔpH is greater than 0.3. Figure 7.126 provides a further illustration of the posterior distribution for ΔpH.

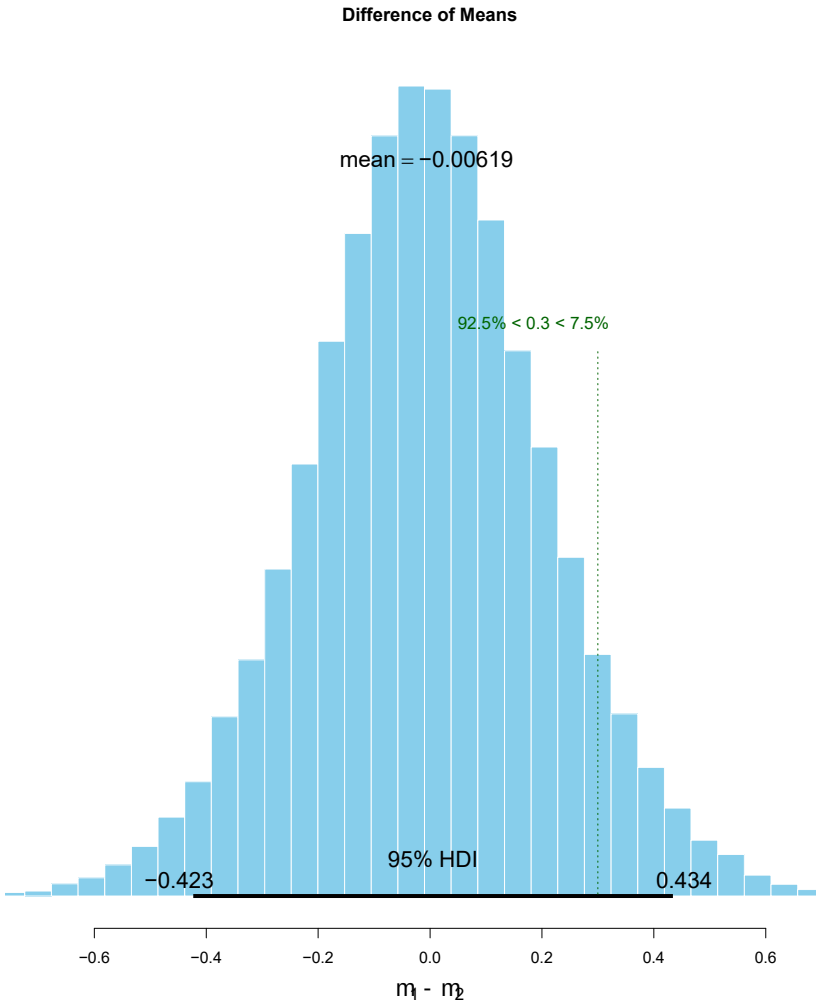


Figure 7.126: Example of BEST output, for LAK028 using an SD prior of 0.2, of a histogram of the percent belief in different values for ΔpH (i.e., the posterior distribution of ΔpH). (NOTE: the configuration of this analyses is [baseline] – [post-KMP] so therefore positive values represent a pH decrease from the baseline). The bold horizontal bar shows the values that lay within the 95% high density interval (HDI). The dashed vertical line represents a change of 0.3 pH units, showing that there is a 7.5% belief (percent of the total area under the distribution to the right of the 0.3 line) that there has been a decrease in pH in LAK028 of greater than 0.3 pH units. Conversely, there is a 92.5% belief that the ΔpH is less than 0.3.

7.6.4.3.9 Method 1b (Bayesian): Two-Sample Before-After Bayesian Analysis (with uninformative priors)

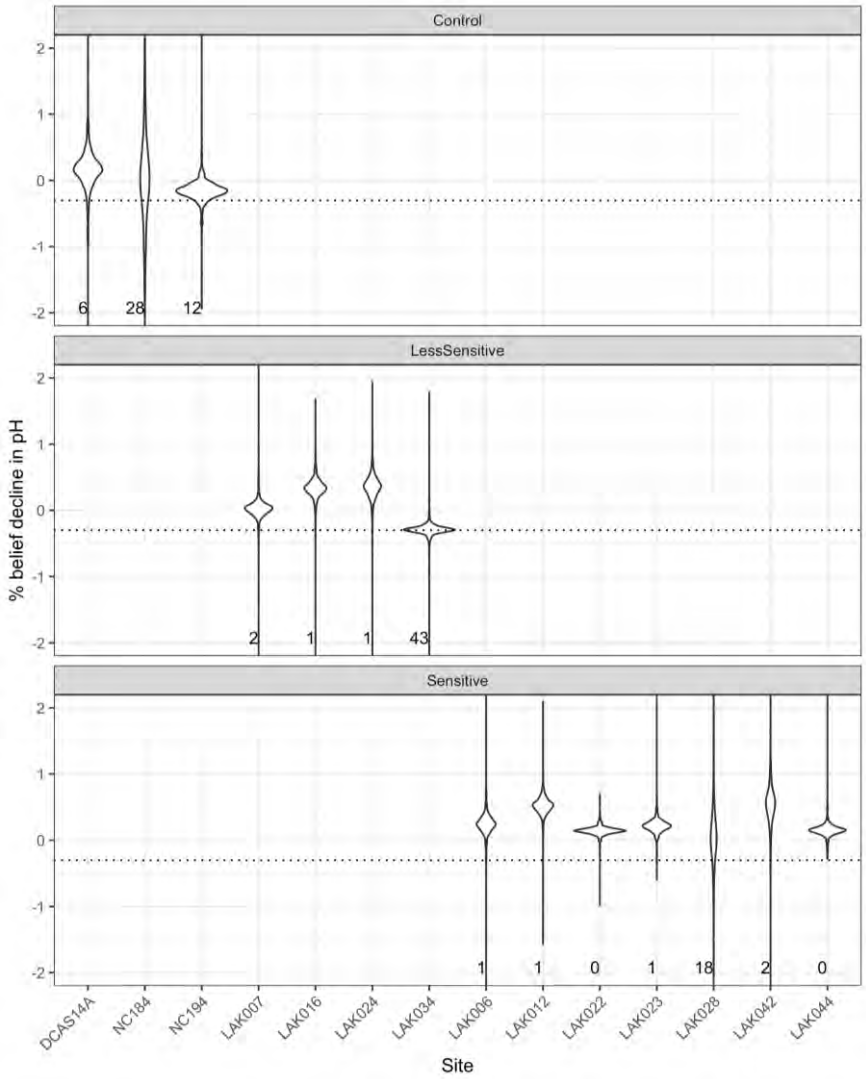


Figure 7.127: Violin plots showing the the posterior distributions of credible values for ΔpH, with no prior assumptions about the variability in pH. The percent of these distributions that correspond to a change greater than 0.3 (dotted line) are shown in numerals at the bottom of each plot.

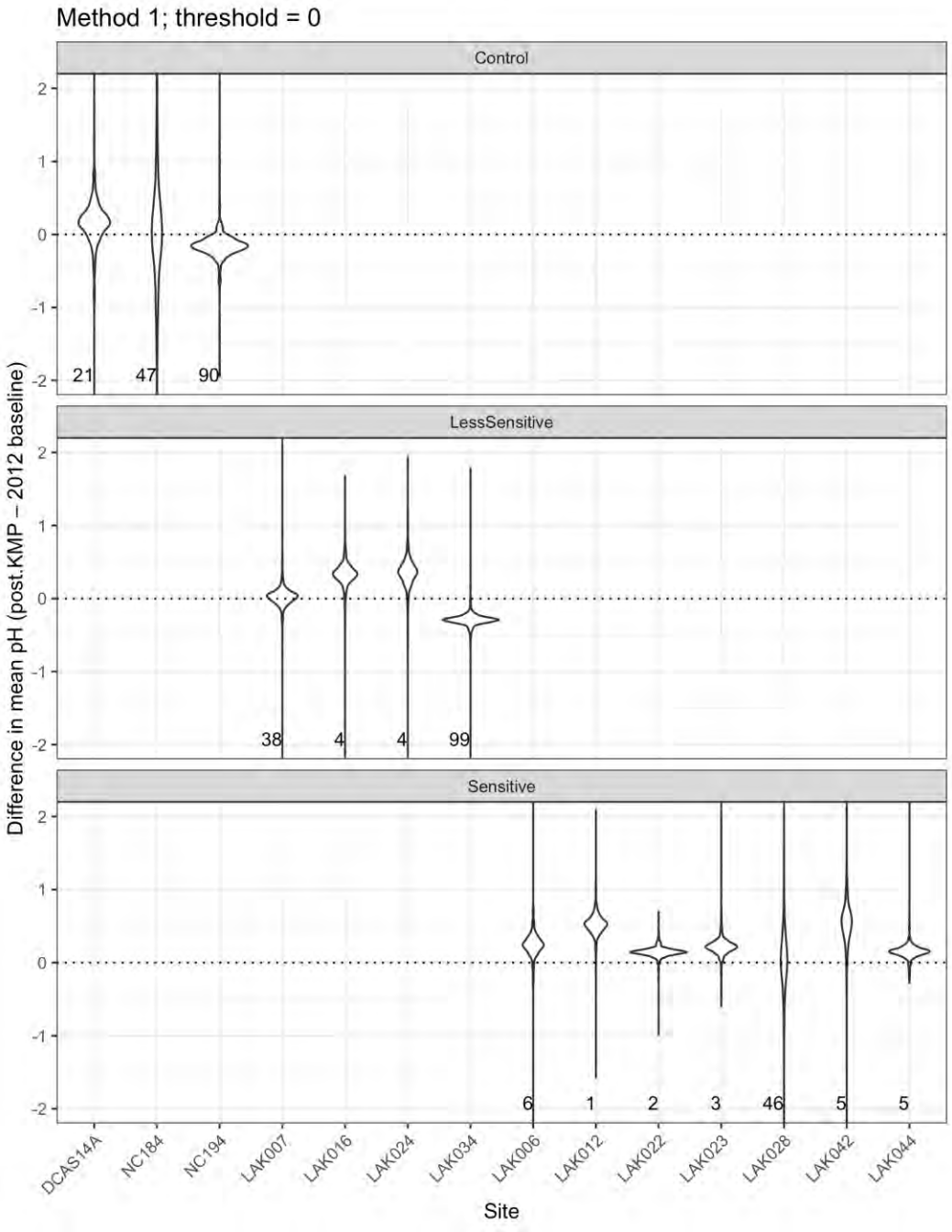


Figure 7.128: Violin plots showing the the posterior distributions of credible values for ΔpH, with no prior assumptions about the variability in pH. The percent of these distributions that correspond to a change greater than 0.0 (i.e. any decrease in mean pH between the two time periods) are shown in numerals at the bottom of each plot.

KEY FINDINGS:

- Six of the seven sensitive lakes, and three of the four less sensitive lakes show very little support for the hypothesis that ΔpH (baseline mean pH minus post-KMP mean pH) was greater than 0.3. This is demonstrated by the fact that the percent belief in a ΔpH > 0.3 is less than 6% for all of these lakes, across a wide range of prior assumptions about the standard deviation of pH (Figure 7.125), and less than 3% when no prior assumptions are made about the variability in pH (violin plot in Figure 7.127). LAK028 shows a 18% belief that the ΔpH exceeded the 0.3 threshold (Figure 7.127), or conversely, a 82% belief that the ΔpH did not exceed the 0.3 threshold. In Figure 7.128, LAK028 shows a 46% belief in some pH decline (i.e., roughly equal chances of a pH increase or a pH decrease)
- For the less sensitive lakes, only LAK034 exhibited more than a 3% belief that ΔpH is greater than 0.3 (violin plot in Figure 7.127). LAK034 showed close to a 0.3 unit decline in pH over the period from 2012 to 2016-2018 (Figure 7.43), consistent with a 43% belief that it exceeded the 0.3 threshold of change in pH Figure 7.127). As noted above, SO_4 declined concurrently with pH in LAK034, so the pH decline in LAK034 was not associated with SO_2 emissions.
- Two of the control lakes (NC184 and NC194) show intermediate levels of belief that their ΔpH was greater than 0.3 (28% and 12% respectively).

7.6.4.3.10 Method 2 (Bayesian): Two-Sample Before-After Bayesian Analysis, Using Individual Samples

Description of Analyses:

This analysis is the Bayesian version of Method 2, taking into account all of the data, and accounting for variability within each year.

Purpose of analyses:

The purpose is similar to Bayesian Method 1, but uses all of the data rather than just the mean values.

Explanation of the graphs and tables of results:

See figure captions.

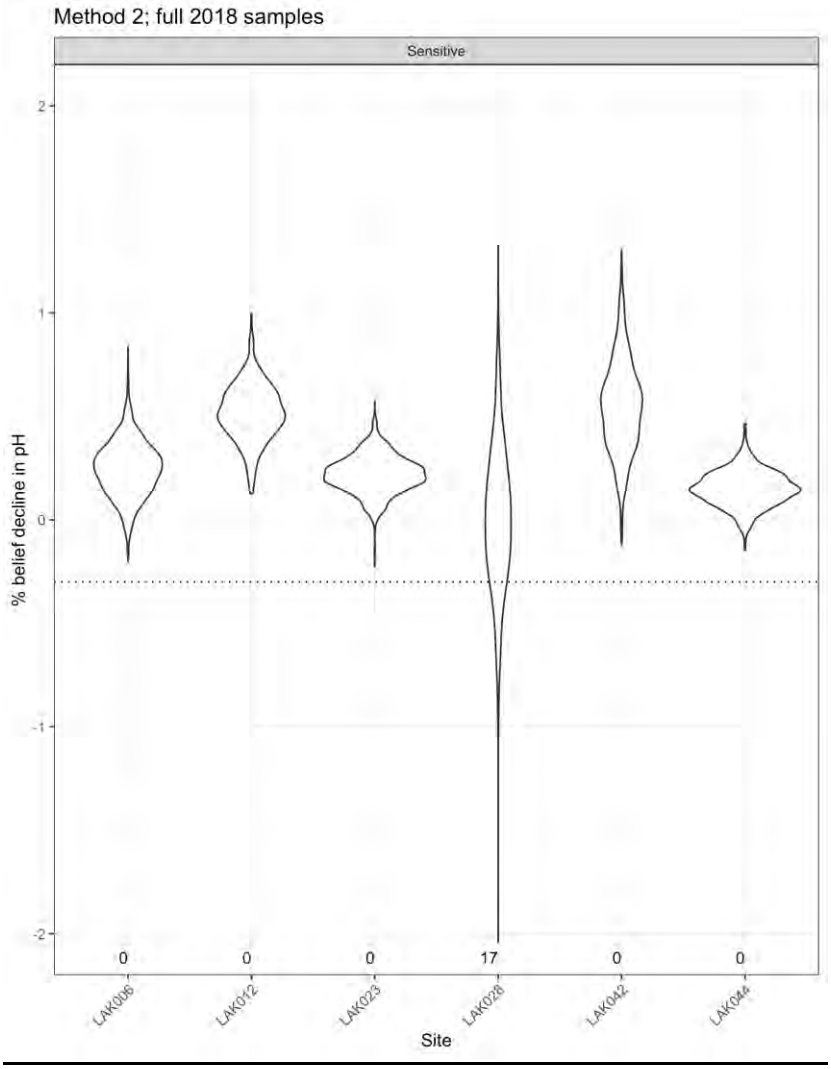


Figure 7.129: Violin plot showing the the posterior distributions of credible values for ΔpH for the six sensitive lakes with multiple samples per year, with no prior assumptions about the variability in pH. The percent of these distributions that correspond to a change greater than 0.3 (dotted line) are shown in numerals at the bottom of each plot.

KEY FINDINGS:

- Using all of the data under Method 2 provides a narrower distribution for 6 of the 7 sensitive lakes, which all have 0% belief that the ΔpH exceeded the 0.3 threshold.
- For LAK028, using all of the data under Method 2 provides a similar level of belief (17%, versus 18% under Method 1) that the ΔpH exceeded the 0.3 threshold.

7.6.4.4 Key Metric: ANC

7.6.4.4.1 Method 1 (Frequentist): Two-Sample Before-After T-Test Using Mean Values

Description of Analyses:

See Section 7.6.4.2.1 for SO_4.

Purpose of analyses:

This is exactly the same analysis as Method 1 for pH, except applied to ANC, for which there are lake-specific ANC thresholds reflecting the ΔANC that within each lake would correspond to a ΔpH of 0.3 units below the 2012 pH values. These thresholds were derived from laboratory titrations completed at the Trent University lab, and reflect the particular mix of buffering (i.e., bicarbonate and organic anions) found within each lake.

Explanation of the graphs and tables of results:

Please see captions below.

Table 7.56: T-test of changes in mean ANC for each lake, between the pre-KMP period (2012) and post-KMP period (2016-2018). T.stat is the T-statistic. P-value is the probability of the ΔANC being significantly different from zero (p<0.01 is the appropriate signficance level given the multiple statistical tests). Lwr and Upp are the lower and upper confidence levels for ΔANC. Sd_post is the standard deviation of mean ANC levels over the 3-year post-KMP period (much lower for the sensitive lakes than the less sensitive lakes since their GranANC is lower). MDD_sd is the minimum detectable difference in ANC that would be statistically significant at p<0.01 with 80% statistical power, given four different assumptions about the standard deviation of ANC during the pre-KMP period (1, 5, 10, 15 µeq/L). For example, in LAK006, a Gran ANC change of 6 µeq/L is the minimum detectable difference with a pre-KMP SD of 1 µeq/L, but the MDD increases to 72 µeq/L if the pre-KMP SD were 15 µeq/L.

SUBSET	SITE	p-value	lwr	upp	sd_post	MDD_sd_1	MDD_sd_5	MDD_sd_10	MDD_sd_15
LessSensitive	LAK007	0.153	-279	176	30	96	98	107	120
LessSensitive	LAK016	0.096	-49	91	12	30	38	56	78
LessSensitive	LAK024	0.093	-371	698	90	224	225	229	235
LessSensitive	LAK034	0.085	-84	165	22	52	57	71	89
Sensitive	LAK006	0.147	-6	11	1	6	24	48	72
Sensitive	LAK012	0.895	-84	87	6	36	43	60	80
Sensitive	LAK022	0.194	-21	32	3	12	26	49	73
Sensitive	LAK023	0.197	-28	41	4	15	28	50	73
Sensitive	LAK028	0.961	-82	82	6	35	42	59	80
Sensitive	LAK042	0.09	-57	109	14	35	42	59	80
Sensitive	LAK044	0.206	-16	24	2	10	25	49	72

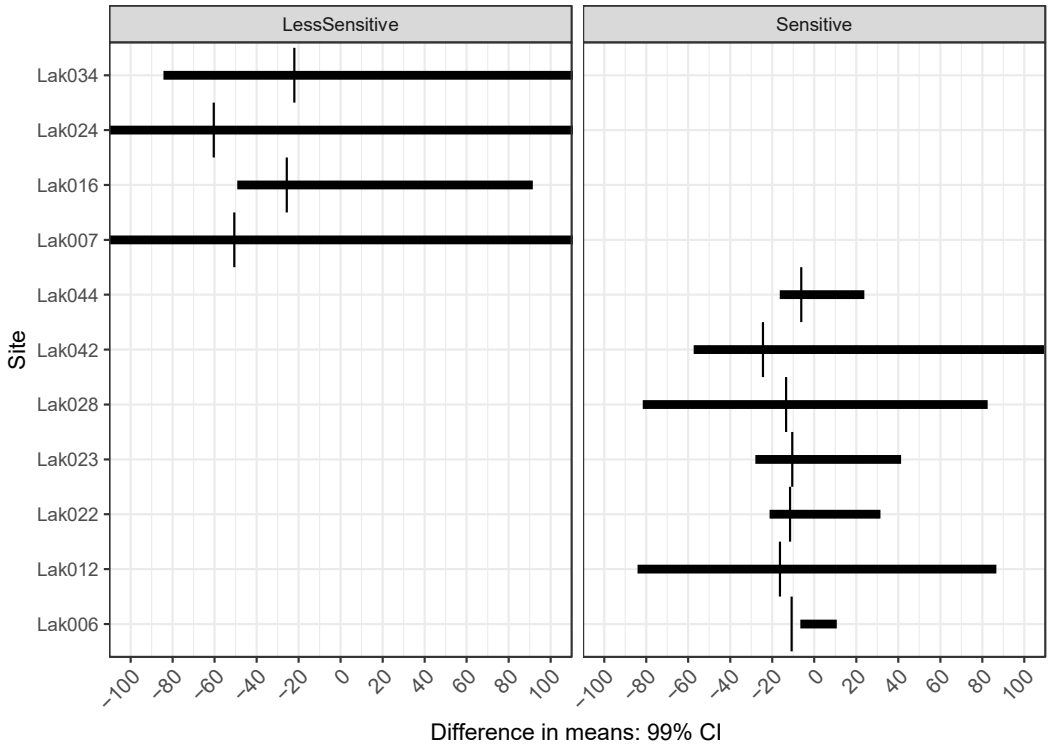


Figure 7.130: Using Method 1, 99% confidence intervals for the ΔANC (mean ANC in post-KMP period minus the mean ANC in the pre-KMP period). The confidence intervals for changes in mean pH overlap 0.0 and the lake-specific ANC thresholds (vertical lines) for all lakes except for LAK006 (where the confidence interval overlaps 0.0 but not the lake's ANC threshold).

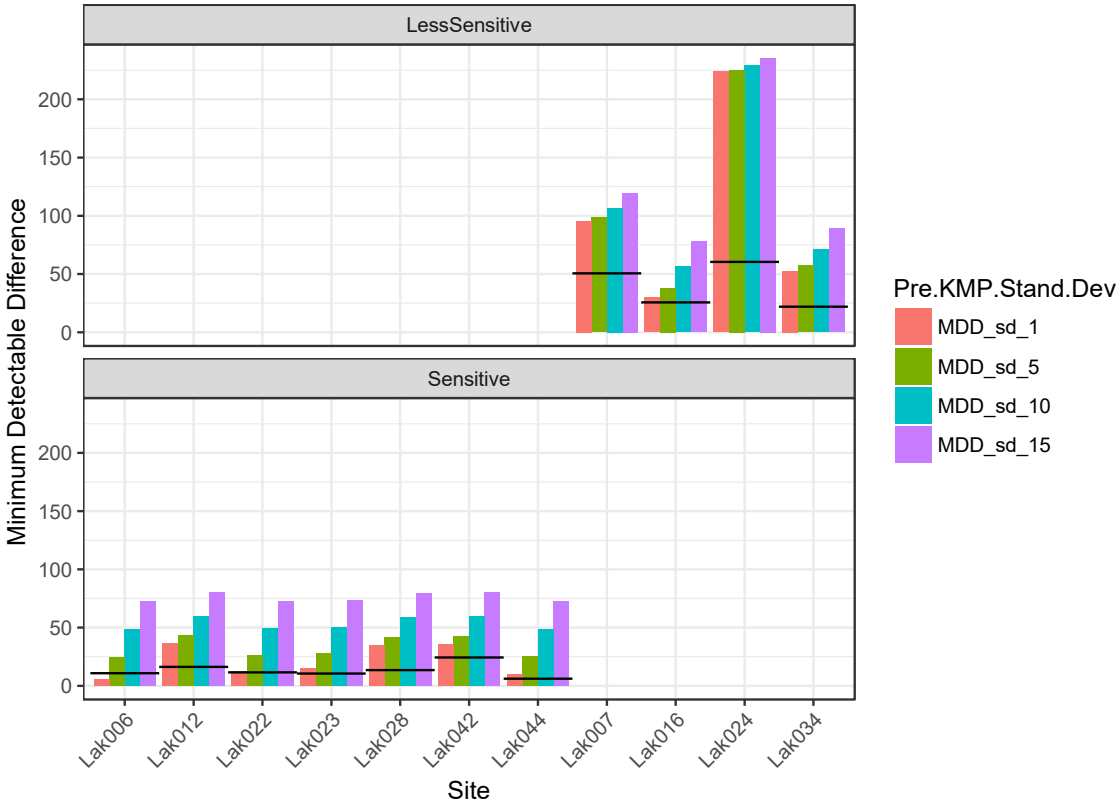


Figure 7.131: Minimum detectable differences (MDD) are shown for each lake, assuming four different values for the standard deviation (SD) of Gran ANC in the pre-KMP period (2012). Since we have only one observation for the pre-KMP period (a single measurement in 2012), we can't compute the SD, but must assume it. The horizontal lines mark the lake-specific thresholds for Gran ANC. Only LAK006 has an MDD less than its threshold, and only for the lowest assumed SD (1 µeq/L). For this lowest assumed SD, the t-test is able to detect (with high statistical power) changes less than the ANC threshold within LAK006. In all other lakes, this t-test is only able to detect changes greater than the lake-specific ANC thresholds.

KEY FINDINGS:

- All 99% Confidence Intervals for ΔANC overlap zero and all but one (LAK006) overlap their lake specific thresholds.
- No t-statistics for any site have a p-value below 0.01.
- All Minimum Detectable Differences are greater than the lake-specific median threshold, except for LAK006.

7.6.4.4.2 Method 2 (Frequentist): Two-Sample Before-After T-Test Using Individual Samples

Description of Analyses:

Same as for SO_4 in Section 7.6.4.2.2, but applied to Gran ANC.

Purpose of analyses:

The purpose of this analysis is similar to Method 1 (i.e., to determine if there is a significant difference between the post-KMP and pre-KMP values of ANC), but the analysis removes the effect of natural variability during the sampling period. We are interested to see if this reduces the uncertainty in estimates of the ΔANC between the post-KMP and pre-KMP periods, and narrows the confidence intervals on these estimates.

Explanation of the graphs and tables of results:

See captions below.

Table 7.57: Results for T-test for post-KMP Gran ANC (2016-18) versus baseline Gran ANC(2012), using individual samples, for the six sensitive lakes with multiple within-year samples. The "est.diff" is the ANC in the post-KMP period minus the ANC in the baseline period. A positive value for "est.diff" means that the ANC increased from the baseline period to the post-KMP period, while a negative value indicates a decrease in ANC. The "est.diff.se" is the standard error in ANC, which is highest for LAK028 and LAK012, and lowest for LAK044. The "est.diff.lcl" and "est.diff.ucl" are the lower and upper confidence intervals (respectively) for "est.diff". The "p.value" is the probability of a significant difference in mean ANC between the two time periods (all p-values are >0.01, and therefore the differences between the two time periods are not statistically significant).

SITE	est.diff	est.diff.se	est.diff.lcl	est.diff.ucl	p.value
LAK006	2.0	3.4	-5.6	9.7	0.569
LAK012	1.3	10.1	-27.6	30.2	0.906
LAK023	6.6	4.7	-5.0	18.3	0.207
LAK028	0.5	11.4	-27.3	28.2	0.97
LAK042	26.1	9.0	-5.1	57.3	0.074
LAK044	3.7	3.4	-3.9	11.4	0.298

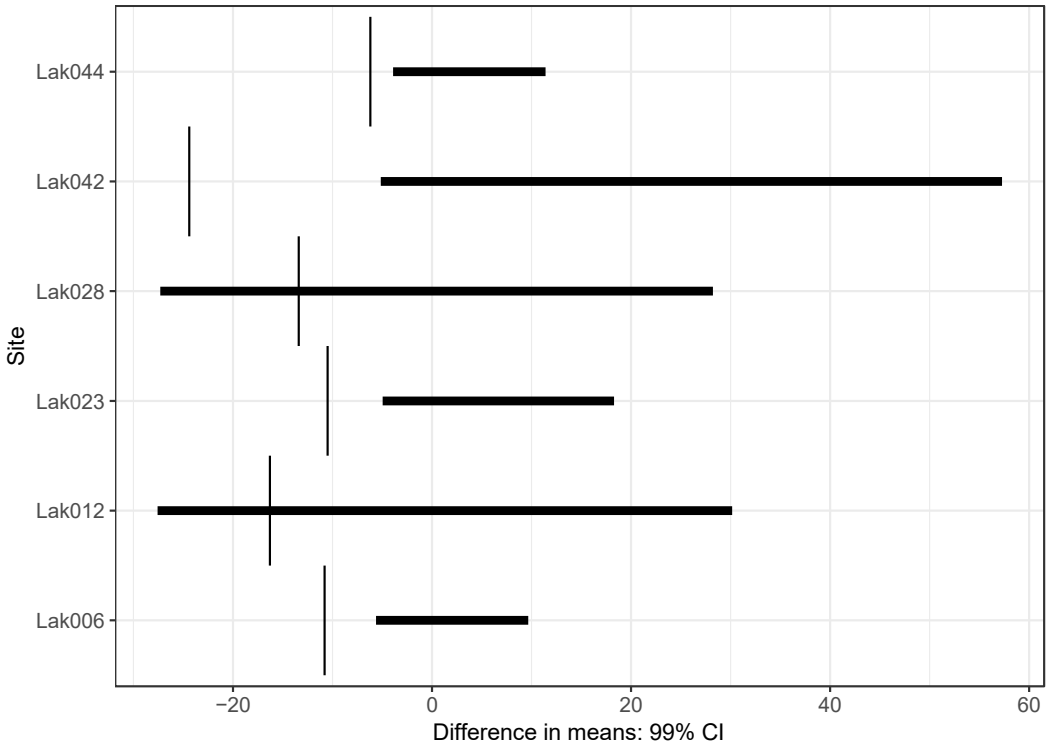


Figure 7.132: Using Method 2, 99% confidence intervals for the ΔANC (mean ANC in post-KMP period minus the mean ANC in the pre-KMP period, accounting for within year variability). The vertical lines provide the lake-specific ANC thresholds, as described above. The confidence intervals for changes in mean ANC do not overlap the ANC thresholds in four of the six lakes (LAK006, LAK023, LAK042, LAK044), but do overlap the thresholds in LAK012 and LAK028.

KEY FINDINGS:

- No support for any difference between pre-KMP (2012) and post-KMP (2016-2018) - all of the confidence intervals overlap zero, and none of the differences were significant at $p<0.01$.
- No support for any decline in mean Gran ANC greater than the threshold for LAK006, LAK023, LAK042, and LAK044 – i.e., the confidence intervals are completely above the threshold.
- The confidence intervals for LAK012 and LAK028 are relatively wide (Figure 7.132) and overlap their respective thresholds. This is partly because these two lakes had the lowest values of ΔANC (see "est.diff" column in Table 7.57) and partly because they had the highest variability in ΔANC (see "est.diff.se" column in Table 7.57). The data for these two lakes are therefore insufficient to reject the hypothesis (at a 99% level of confidence, using this T-test) that their ANC thresholds were exceeded.

7.6.4.4.3 Method 3 (Frequentist): Before-After Control-Impact (BACI), Using Mean Values

Description of Analyses:

Same as described for SO_4 in Section 7.6.4.2.3, but applied to Gran ANC.

Purpose of analyses:

Use a BACI analysis to determine how the ΔANC (post-KMP vs. pre-KMP) in each sensitive lake compares to the ΔANC in the control lakes, taken as a group. This analysis accounts for broad scale regional / climatic effects which could affect both the sensitive lakes and the control lakes.

Explanation of the graphs and tables of results:

See figure and table captions below. We are using the significance value of 0.01 throughout as correction for multiple tests (it is not precisely the Bonferroni correction, but an analogous approximation).

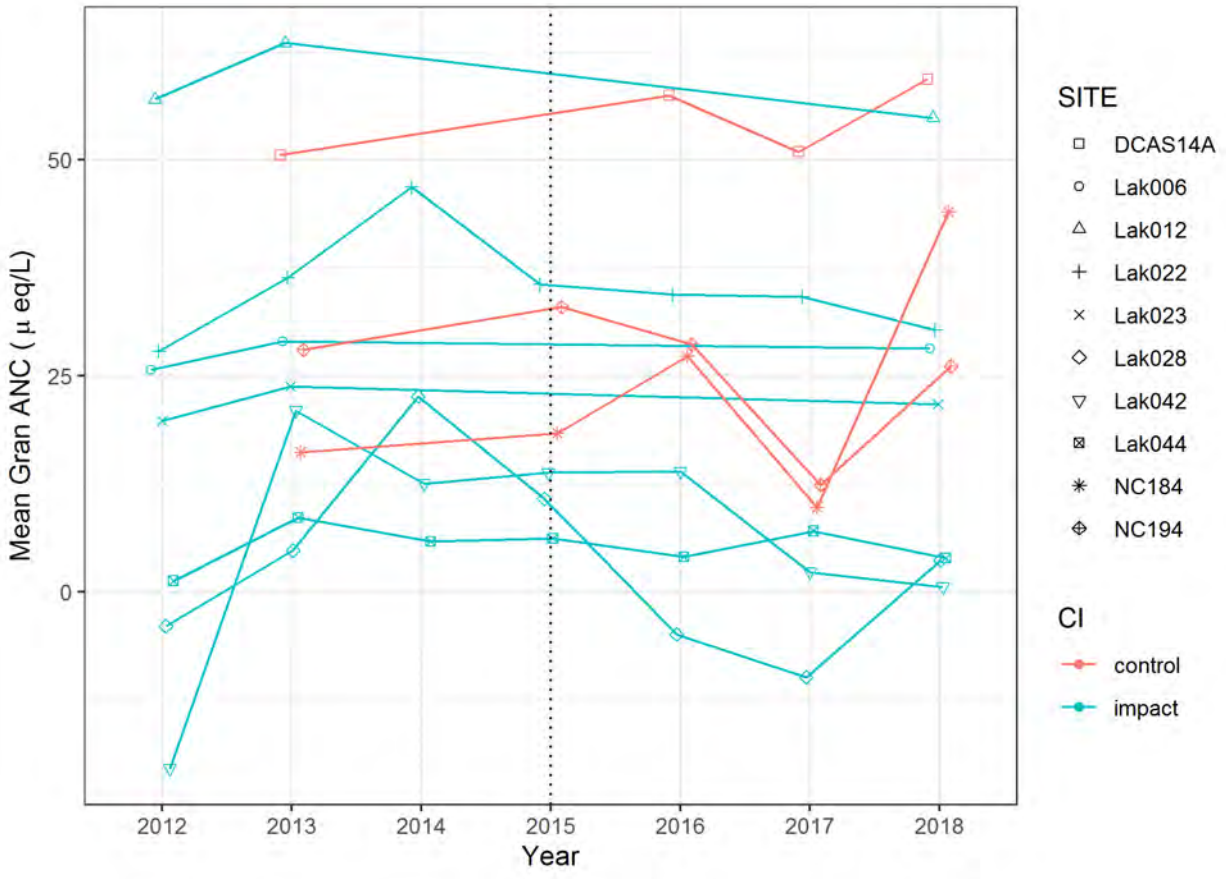


Figure 7.133: Change in mean Gran ANC over time for sensitive lakes (blue lines) and control lakes (orange lines).

Table 7.58: BACI analyses of mean Gran ANC for 7 sensitive and 3 control lakes, using Method 3. "BACI estimate" is a bit counter-intuitive: it is the Δ mean Gran ANC in the controls (i.e., $ANC_{post\text{-}KMP}$ minus $ANC_{pre\text{-}KMP}$), averaged over the 3 control lakes, minus the Δ mean ANC in the sensitive lake. If BACI value is <0, then the ΔANC was lower in the controls than in the sensitive lake (and, equivalently, the ΔANC was greater (more positive) in the sensitive lake than in the controls). If BACI value is >0, then the ANC change in the controls was greater than that in the sensitive lake (and, equivalently, the ΔANC was lower (less positive) in the sensitive lake than in the controls). The "t.ratio" is the t-statistic for the BACI estimate, and the p.value the significance of the test. LAK042 showed the strongest evidence for an increase in Gran ANC, but it is not statistically significant.

Site	BACI estimate	SE	p.value	Interpretation of BACI estimate
LAK006	1.5	8.4	0.846	change in Gran ANC was less positive in LAK006 than in the control lakes (but NOT statistically significant)
LAK012	2.2	8.4	0.813	change in Gran ANC was less positive in LAK012 than in the control lakes (but NOT statistically significant)
LAK022	-1.6	10.7	0.885	change in Gran ANC was more positive in LAK022 than in the control lakes (but NOT statistically significant)
LAK023	-3.1	8.4	0.721	change in Gran ANC was more positive in LAK023 than in the control lakes (but NOT statistically significant)
LAK028	3.0	5.9	0.607	change in Gran ANC was less positive in LAK028 than in the control lakes (but NOT statistically significant)
LAK042	-22.5	8.3	0.015	change in Gran ANC was more positive in LAK042 than in the control lakes (but NOT statistically significant)
LAK044	-0.2	8.3	0.979	change in Gran ANC was more positive in LAK044 than in the control lakes (but NOT statistically significant)

Table 7.59: BACI analysis of Gran ANC with all lakes combined, using Method 3. BACI estimate is the average Δ mean ANC in the 3 control lakes (i.e., $ANC_{post\text{-}KMP}$ minus $ANC_{pre\text{-}KMP}$, averaged over the 3 control lakes), minus the average Δ mean ANC in the 7 sensitive lakes (i.e., $ANC_{post\text{-}KMP}$ minus $ANC_{pre\text{-}KMP}$, averaged over the 7 sensitive lakes). SE is the standard error of the BACI estimate. The t.ratio is the t-statistic for the BACI estimate, and the p.value the significance of the test.

contrast	estimate	SE	p.value
baci	-14.1	12.9	0.2785

KEY FINDINGS:

- All lakes have p-value above 0.01. No support for a significant effect in Δmean Gran ANC across any of the lakes individually or a significant effect for all lakes combined.

7.6.4.4.4 Method 4 (Frequentist): Before-After Control-Impact (BACI), Using Individual Samples

Description of Analyses:

Same as described for SO_4 in Section 7.6.4.2.4, but applied to Gran ANC.

Purpose of analyses:

We wish to see if there is any change in the results of the BACI analysis (relative to Method 3) when we account for variability during the sampling period. This analysis is only possible for the 6 sensitive lakes with four samples / year; LAK022 has only one sample per year.

Explanation of the graphs and tables of results:

See captions below.

Table 7.60: BACI analysis of ΔGran ANC using Method 4. See Table 4-4 in the main report for explanation of terms.

Site	BACI estimate	SE	p.value	Interpretation of BACI estimate
LAK006	1.5	10.1	0.885	change in Gran ANC was less positive in LAK006 than in the control lakes (but NOT statistically significant)
LAK012	2.2	12.2	0.858	change in Gran ANC was less positive in LAK012 than in the control lakes (but NOT statistically significant)
LAK023	-3.1	11.1	0.784	change in Gran ANC was more positive in LAK023 than in the control lakes (but NOT statistically significant)
LAK028	3.1	10.1	0.765	change in Gran ANC was less positive in LAK028 than in the control lakes (but NOT statistically significant)
LAK042	-22.5	10.8	0.07	change in Gran ANC was more positive in LAK042 than in the control lakes (but NOT statistically significant)
LAK044	-0.2	10.7	0.984	change in Gran ANC was more positive in LAK044 than in the control lakes (but NOT statistically significant)

Table 7.61: BACI analysis of ΔANC with all lakes combined, using Method 4.

contrast	estimate	SE	p.value

baci	-11.0	18.5	0.5567

KEY FINDINGS:

- All lakes have p-value above 0.01. No support for a significant effect in Δ mean Gran ANC across any of the lakes individually or a significant effect for all lakes combined.
- The p-value for an effect for Gran ANC is higher under Method 4 (Table 7.60 and Table 7.61) than under Method 3 (Table 7.58 and Table 7.59), indicating that inclusion of within year variability under Method 4 makes an effect even less likely to be statistically significant.

7.6.4.4.5 Method 5 (Frequentist): Before-After Control-Impact (BACI), with Assumption of No Change in Control Lakes

Description of Analyses:

Same as described for SO_4 in Section 7.6.4.2.5, but applied to Gran ANC.

Purpose of analyses:

This is a sensitivity analysis on Method 4, to see how much difference the observations from the control lakes (and common patterns of year to year variability in the control lakes) make to the outcome of the BACI analysis. Removing the data from the control lakes reduces the number of degrees of freedom in the analysis. The analysis is done first using just mean values (as in Method 1), and then using all of the data (as in Method 2). We also use ANOVA to compare the fit of models which keep the control lakes' data constant, vs. allowing the control lakes' data to vary.

Explanation of the graphs and tables of results:

See captions below.

Table 7.62: BACI analysis using Method 5 applied to mean ANC values, holding control lakes' ANC constant. Structure of this table is similar to Method 3 (Table 7.59), but has only 13.94 degrees of freedom compared to 125.86.

contrast	estimate	SE	p.value
baci	3.84	9.74	0.70

Table 7.63: ANOVA analysis using Method 5 comparing the fit of two models to mean ANC values ("vary", which includes data from the control lakes; and "cons", which holds the control lakes constant). Analysis applied using two information criteria (AIC = Aikike Information Criteron; BIC = Bayesian Information Criteron). Lower (i.e., more negative) values for AIC and BIC indicate a better fit of the model to the data. Assuming constant values for the control lakes ("cons") provides a slightly better fit, but the differences between the two models are not statistically significant.

	Df	AIC	BIC	logLik	deviance	Chisq	ChiDF	Pr(>Chisq)
cons	6	1361.5	1379.2	-674.73	1349.5			
vary	7	1362.3	1383.1	-674.17	1348.3	1.1253	1	0.29

Table 7.64: BACI analysis using Method 5 applied to all ANC values in the sensitive lakes (i.e., including within-year variability), holding control lakes' ANC constant. Structure of this table is similar to Method 4 (Table 7.61).

contrast	estimate	SE	p.value
baci	-1.12	12.03	0.93

Table 7.65: ANOVA analysis using Method 5 comparing the fit of two models to all ANC values ("vary", which includes data from the control lakes; and "cons", which holds the control lakes constant). Analysis applied using two information criteria (AIC = Aikike Information Criteron; BIC = Bayesian Information Criteron). Lower (i.e., more negative) values for AIC and BIC indicate a better fit of the model to the data. Assuming constant values for the control lakes ("cons") provides a slightly better fit, but the differences between the two models are not statistically significant.

	Df	AIC	BIC	logLik	deviance	Chisq	ChiDF	Pr(>Chisq)
cons	7	1288.2	1308.9	-637.1	1274.2			
vary	8	1289.6	1313.3	-636.82	1273.6	0.5494	1	0.46

KEY FINDINGS:

- No support for a significant effect in ΔANC (for annual mean Gran ANC or annual individual Gran ANC measurements) when change in control lakes held constant over the time-frame.
- ANOVAs show no difference between models with control lakes varying or held constant over time.
- It is important to continue to monitor the control lakes and use all their actual data in BACI analyses, as this will provide greater power to detect an effect than assuming constant values in the control lakes.

7.6.4.4.6 Method 6 (Frequentist): Using Other Covariates to Explain Inter-Annual Variation

Description of Analyses:

Same as described for SO_4 in Section 7.6.4.2.6, but applied to Gran ANC.

Purpose of analyses:

As described for Method 6 under pH, the previously described analyses intentionally excluded 2013 and 2014 from the baseline period. We did this because the winding down of the old smelter during this period resulted in reduced emissions and apparent increases in Gran ANC in some of the sensitive lakes (Figure 7.41), which would lead to an inaccurate estimate of baseline Gran ANC if we had used 2012-2014 data to compute baseline Gran ANC. If covariates such as emissions and precipitation help to explain variability in water chemistry, then we could potentially include data from 2012-2014 in the baseline period, and have three years of baseline data rather than just one, which, together with three years of post-KMP data (2016-2018) would improve statistical power.

Explanation of the graphs and tables of results:

We used total SO_2 emissions over the prior year (i.e., October 1 through Sept. 30, see Section 7.6.2.3) and the last 3-days or 14-days of precipitation at Haul Road (see Section 7.6.2.2) as covariates. The model also includes terms for three random effects: year, site, and year by site interactions

Table 7.66: Before-After t-test for changes in ANC, including covariates for emissions and 3-day precipitation.

Fixed effects:	Estimate	Std Error	df	Pr(>|t|)
(Intercept)	-47.4	203.7	56	0.817
BAbefore	41.5	80.7	60	0.609
CIimpact	261.4	173.2	27	0.143
Emissions	0.2	0.4	60	0.495
Precipitation (3-day)	-3.3	2.8	62	0.25
BAbefore:CIimpact	-8.8	62.6	60	0.889

Table 7.67: Estimates of the random effects for year, site and year by site interactions.

Random effects:			
Groups	Name	Variance	Std.Dev.
YEAR:SITE	(Intercept)	0	0
SITE	(Intercept)	77479	278
YEAR	(Intercept)	0	0
Residual		7155	84.6

Table 7.68: Before-After t-test for changes in ANC, including covariates for emissions and 14-day precipitation.

Fixed effects:	Estimate	Std Error	df	Pr(>|t|)
(Intercept)	-13.8	208.8	8	0.95
BAbefore	18.2	82.2	3	0.84
CIimpact	254.1	174.1	27	0.16
Emissions	0.15	0.4	1	0.75
Precipitation (14-day)	-0.08	1.2	15	0.95
BAbefore:CIimpact	-5.2	63.8	47	0.94

Table 7.69: Estimates of the random effects for year, site and year by site interactions.

Random effects: Groups	Name	Variance	Std.Dev.
YEAR:SITE	(Intercept)	0	0
SITE	(Intercept)	78325	279
YEAR	(Intercept)	59.5	7.72
Residual		7262	85.2

KEY FINDINGS:

- Adding covariates for emissions and precipitation do not help explain variability in Gran ANC.
- The sign of the covariates for precipitation are negative, consistent with our expectations from the literature, but the terms are not statistically significant.

7.6.4.4.7 Approach Supportive of Methods 8 and 9 (Frequentist): Temporal Trend Analyses

Description of Analyses:

As explained in Section 7.6.4.2.7 for SO_4.

Table 7.70: Results of the Mann-Kendall non-parametric test for monotonic trend in SO_4 values. No lakes exhibit a significant result for detecting a monotonic trend.

Lake	p.value
LAK006	0.500
LAK012	0.045
LAK022	0.045
LAK023	0.154
LAK028	0.367
LAK042	0.154
LAK044	0.367
LAK007	0.500
LAK016	0.154
LAK024	0.633
LAK034	0.045
NC184	0.769
NC194	0.231
DCAS14A	0.846

KEY FINDINGS:

- None of the lakes' data provide sufficient evidence to reject the null hypothesis that there was no monotonic trend in Gran ANC (i.e., all p values are > 0.01)

7.6.4.4.8 Method 1a (Bayesian): Two-Sample Before-After Bayesian Analysis (Bayesian Estimation Supersedes the T-Test with informative priors) as applied to Gran ANC

Description of Analyses:

As described for pH in Section 7.6.4.3.8.

Purpose of analyses:

The rationale for this analysis is described in Section 7.6.4.3.8 for pH. In this case, the parameter of interest is the ΔGran ANC from the baseline 2012 measurement to the 2016-2018 post-KMP period. The statistical software used for this analysis computes Δ mean ANC as the mean ANC for the baseline period minus the mean ANC for the 2016-2018 post-KMP period. Positive values of this parameter are therefore indicative of an ANC decline.

In the introduction to these analyses in the TOR we stated that if the frequentist approach shows a clear result for a lake (e.g., 99% confidence intervals for ΔANC do not overlap that lake's threshold for ΔANC) then there's no need to proceed with the Bayesian analysis for that parameter in that lake. Using frequentist method 1 for ΔANC, all of the 99% confidence intervals for the seven sensitive lakes overlapped their lake-specific ANC thresholds, so it would be logical to use the Bayesian approach for all seven sensitive lakes. However, with frequentist method 2 for ΔANC, the 99% confidence intervals for ΔANC did not have that overlap their ANC thresholds in four of the six sensitive lakes with multiple samples in October: LAK006, LAK023, LAK042 and LAK044. Using method 2, the 99% confidence intervals for LAK012 and LAK028 did however overlap their lake-specific thresholds. Based on Method 2, we only need to include the Bayesian approach for LAK012 and LAK028. However, we decided to complete the Bayesian approach for all lakes, so that we could see how consistent our inferences would be using different statistical methods.

Explanation of the graphs and tables of results:

See captions below.

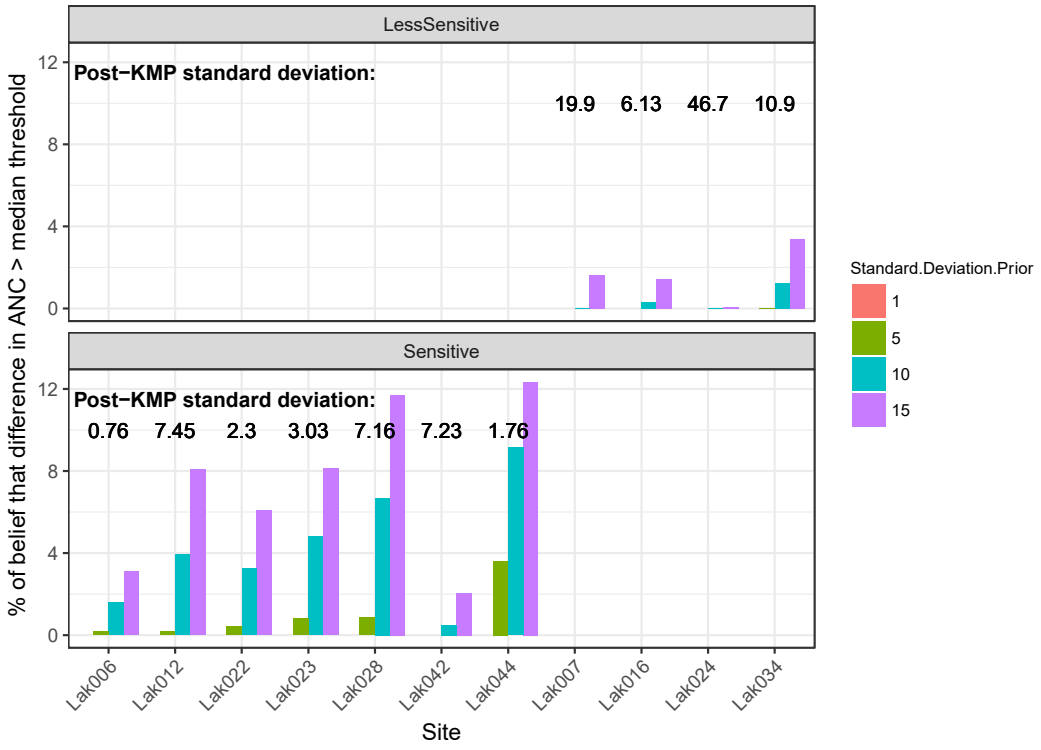


Figure 7.134: Percentage belief that ΔANC is greater than the lake-specific median threshold for ΔANC, using Two-Sample Before-After Bayesian Analysis. The bars show the percentage belief for four different prior assumptions about the standard deviation of Gran ANC across all lakes (note that the orange bars for a SD of 1 µeq/L are too small to be visible on the graphs). The SD of Gran ANC for the post-KMP period is included to provide some context for each lake, but is not directly comparable to the prior assumptions of SD. For example, using an SD prior of 5 µeq/L (green bars), all lakes have less than a 5% belief that ΔANC is greater than their lake-specific thresholds. Using an SD prior of 10 µeq/L (blue bars), all but two lakes have less than a 5% belief that they've exceeded their thresholds for ΔGran ANC. The two exceptions are LAK028 (6% belief that it has exceeded its threshold) and LAK044 (8.5% belief).

7.6.4.4.9 Method 1b (Bayesian): Two-Sample Before-After Bayesian Analysis (with uninformative priors)

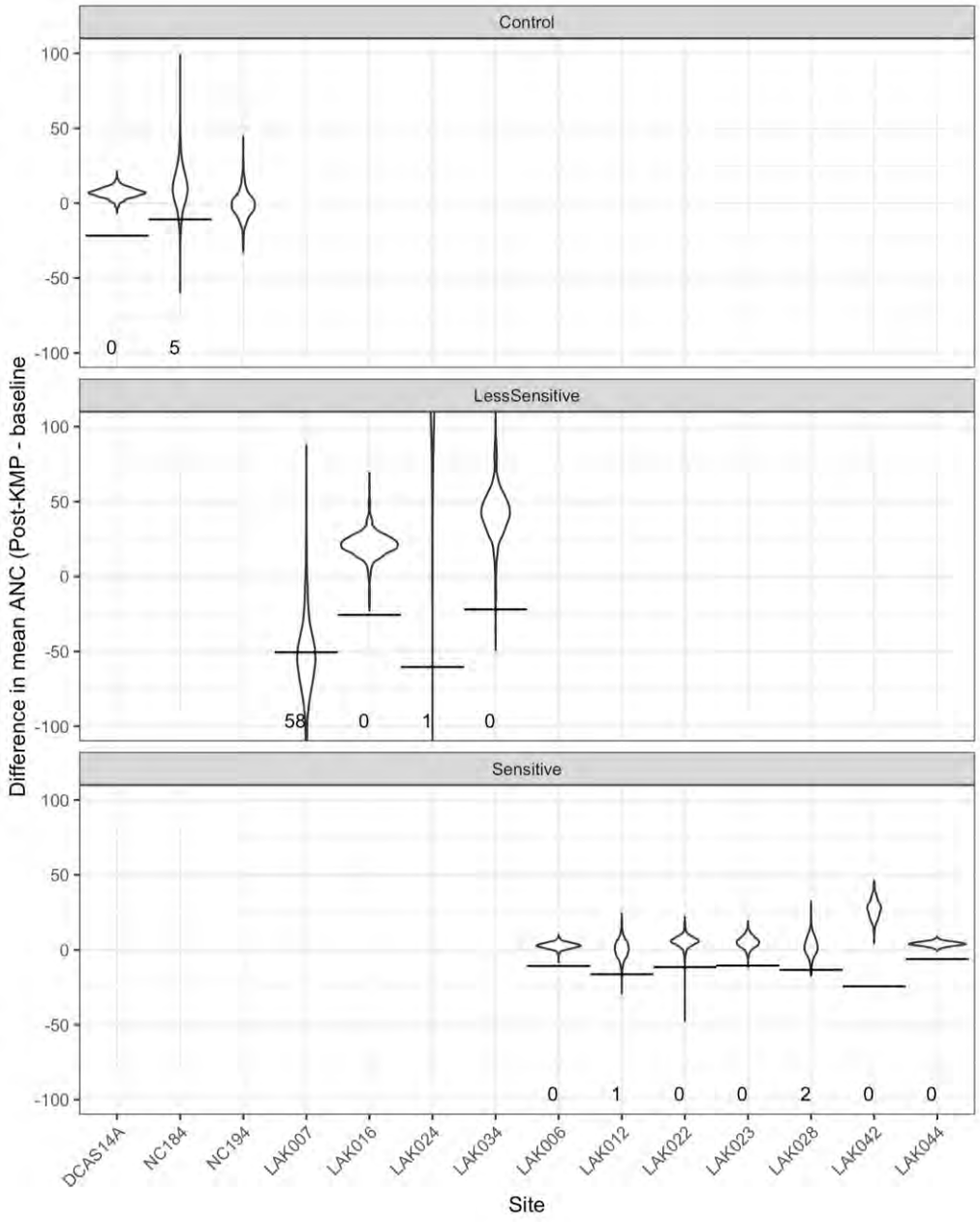


Figure 7.135: Violin plots showing the the posterior distributions of credible values for ΔGran ANC, with no prior assumptions about the variability in GranANC. The percent of these distributions that correspond to a change greater than lake-specific thresholds (dotted line) are shown in numerals at the bottom of each plot.

KEY FINDINGS:

- Minimal % of belief that Δ mean Gran ANC (between baseline and post-KMP periods) is greater than the lake-specific threshold for ΔGran ANC.
- With a low SD prior of 5 µeq/L (Figure 7.134, green bars), all seven sensitive lakes have less than a 5% belief that ΔGran ANC is greater than their lake-specific thresholds.
- With an intermediate SD prior of 10 µeq/L (Figure 7.134, blue bars), only LAK028 and LAK044 exhibit more than a 5% belief that the observed Δ mean Gran ANC is greater than their lake-specific thresholds (6% and 8.5% belief respectively).
- With no prior assumptions about variability in ANC (violin plots in Figure 7.135), 3 of the 4 less sensitive lakes have ≤1% belief that Δ mean Gran ANC is greater than their lake-specific thresholds, while LAK007 has a 58% belief that Δ mean Gran ANC is greater than its lake-specific threshold (note however that LAK007 has very high Gran ANC and shows no significant increase in SO_4 or decrease in pH) so these changes are not related to the smelter.
- All 7 sensitive lakes show ≤ 2% belief that Δ mean Gran ANC is greater than their lake-specific thresholds.

7.6.4.4.10 Method 2 (Bayesian): Two-Sample Before-After Bayesian Analysis, Using Individual Samples

Description of analyses:

This analysis is the Bayesian version of Method 2, taking into account all of the data, and accounting for variability within each year.

Purpose of analyses:

The purpose is similar to Method 1, but Method 2 uses all of the data rather than just the mean values.

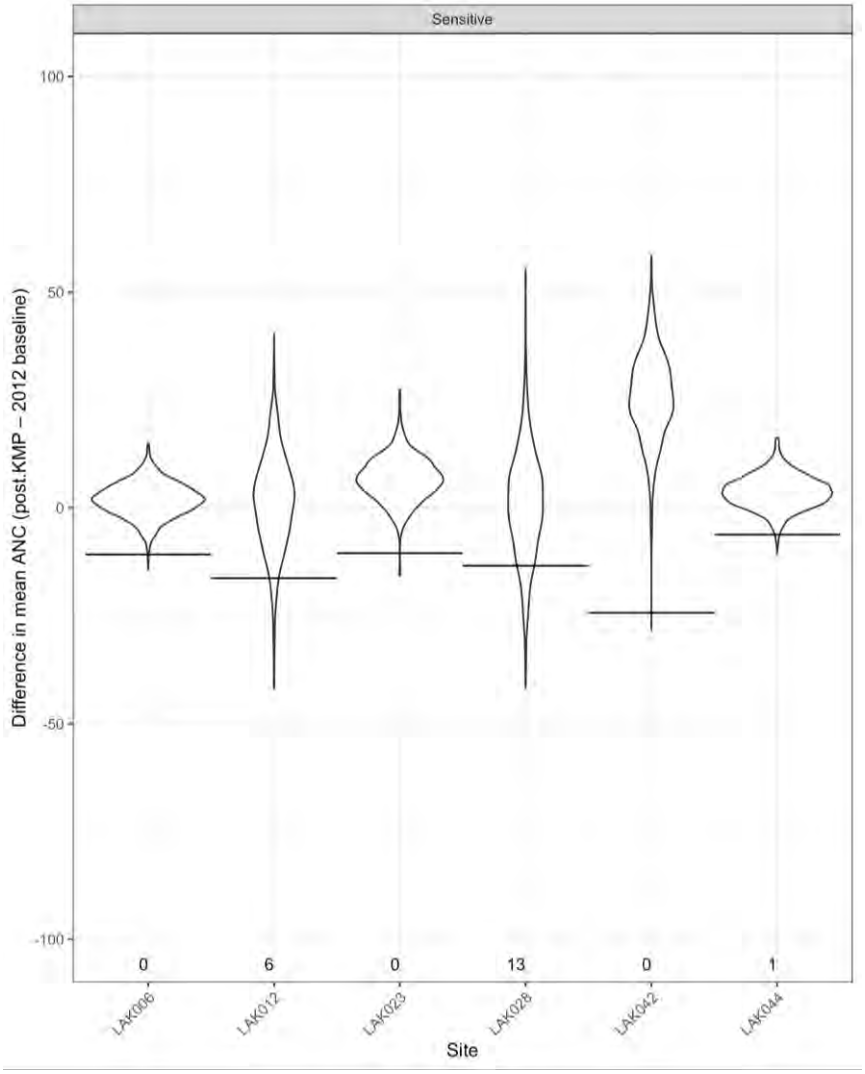


Figure 7.136: Violin plot showing the posterior distributions of credible values for ΔGranANC for the six sensitive lakes with multiple samples per year, with no prior assumptions about the variability in GranANC. The percent of these distributions that correspond to a change greater than the lake-specific threshold (dotted line) are shown in numerals at the bottom of each plot.

KEY FINDINGS:

- Using all of the data under Method 2, two sensitive lakes (LAK012 and LAK028) show a higher % belief that the ΔGran ANC exceeded their lake specific thresholds than was found for either lake in Method 1.
- LAK012 and LAK028, which have shown an increase in SO_4, show 6% and 13% belief that the ΔGran ANC exceeded their lake specific thresholds. These are still low levels of percent belief (< 20%).

7.6.4.5 Analyses of Data from Intensively Monitored Lakes

Starting in 2014, intensive monitoring was implemented in three of the EEM lakes – End Lake (LAK006), Little End Lake (LAK012) and West Lake (LAK023). These three lakes were selected based on being accessible by road, thus making repeated visits much more feasible than for remote lakes requiring access by helicopter or hiking. During the fall of 2014, the intensive monitoring included continuous pH monitors and multiple site visits to collect intra-season water samples for additional lab analyses and pH measurements. In 2015, the continuous pH monitors were deployed from mid-April until mid-November. During October 2015, three additional within-season water chemistry samples were taken at these three lakes, subsequent to annual sampling across all of the lakes (i.e., four samples in total for each of the intensively monitored lakes in 2015). Lake level monitoring was added in 2016-2018 in End Lake, Little End Lake, and West Lake to provide an accurate, local measure of the timing of storm events, so as to better explain observed variation in pH (monitored continuously) and other water quality parameters of interest monitored during October (particularly sulphate, nitrate, DOC, ANC, and base cations).

Continuous pH monitoring has occurred since 2015 in three lakes: LAK006 (End Lake), LAK012 (Little End Lake) and LAK023 (West Lake). From 2015 to 2018, a Manta2 model 2.5 multiprobe was used to take pH measurements every half hour in each of the three intensively monitored lakes. Each meter was recalibrated every two weeks against known buffer solutions (Limnotek 2019). Statistical analyses have shown that the Manta pH measurements were consistently significantly higher that field pH measurements using a WTW ProfilLine 3210 meter and higher than lab analyses of air-equilibrated pH completed at Trent University using an auto-titrator (Limnotek 2019). The cause of these differences was determined to be that the Manta meters' settings did not allow enough time for the pH to stabilize, which can take up to 30 minutes in low ionic strength waters. In addition, by 2019 the Manta meters had reached the end of their expected lifetime. They have since been replaced by Onset pH loggers which compare well with field pH measurements.

Due to the above-described problems, we are not able to make use of the data from the Manta meters. However, we have been able to make use of the calibration data from the fall of 2014 through the summer of 2019, which provide estimates of field pH every two weeks in each of these three lakes. We applied a Seasonal Mann-Kendall test, using average values for each season per year to reduce auto-correlation. The data show trends in field pH in all three lakes (Figure 7.137, Figure 7.138, Figure 7.139), but only the trends in West Lake were statistically significant (Table 7.71). The measurements of field pH were generally lower in the fall than in spring and summer (in 9 out the 12 lake-years of data with spring, summer and fall measurements), and highest in the spring or summer.

There are three important caveats about this analysis: 1) SO_2 emissions declined from 2012 to 2014, and lab pH values increased in each of these three lakes (Figure 7.44*),* so the field pH values in late 2014 and early 2015 are not representative of pre-KMP conditions; 2) field pH values are more variable than lab pH values, due to super saturation of CO_2 in the samples; and 3) lake sulphate declined in West Lake (LAK023) between the pre-KMP and post-KMP periods (see Section 7.6.4.2.1).

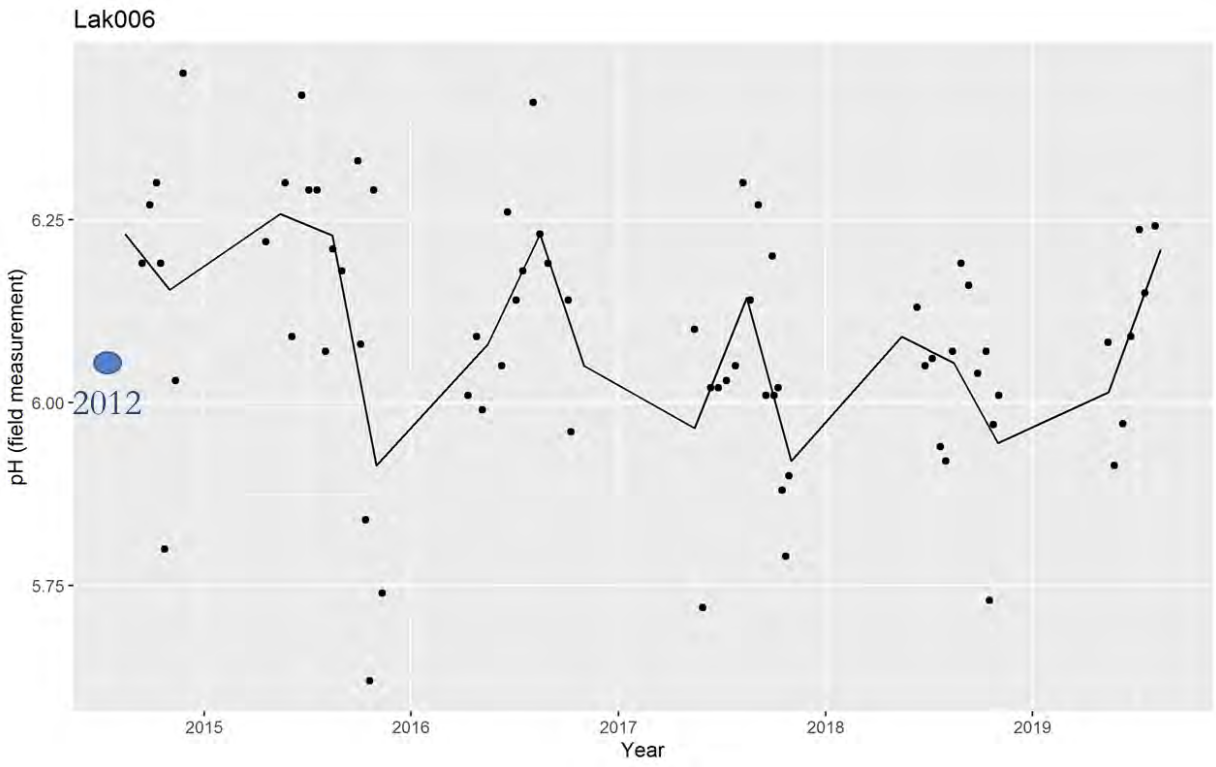


Figure 7.137: Trend in field pH in LAK006 (End Lake). Points shown are the seasonal mean values. The spring mean pH is the average of measurements in April, May, and June. The summer mean pH is the average of measurements in July and August. The fall mean pH was the average of measurements in September, October, and November. Blue dot is the field pH measurement in August of 2012.

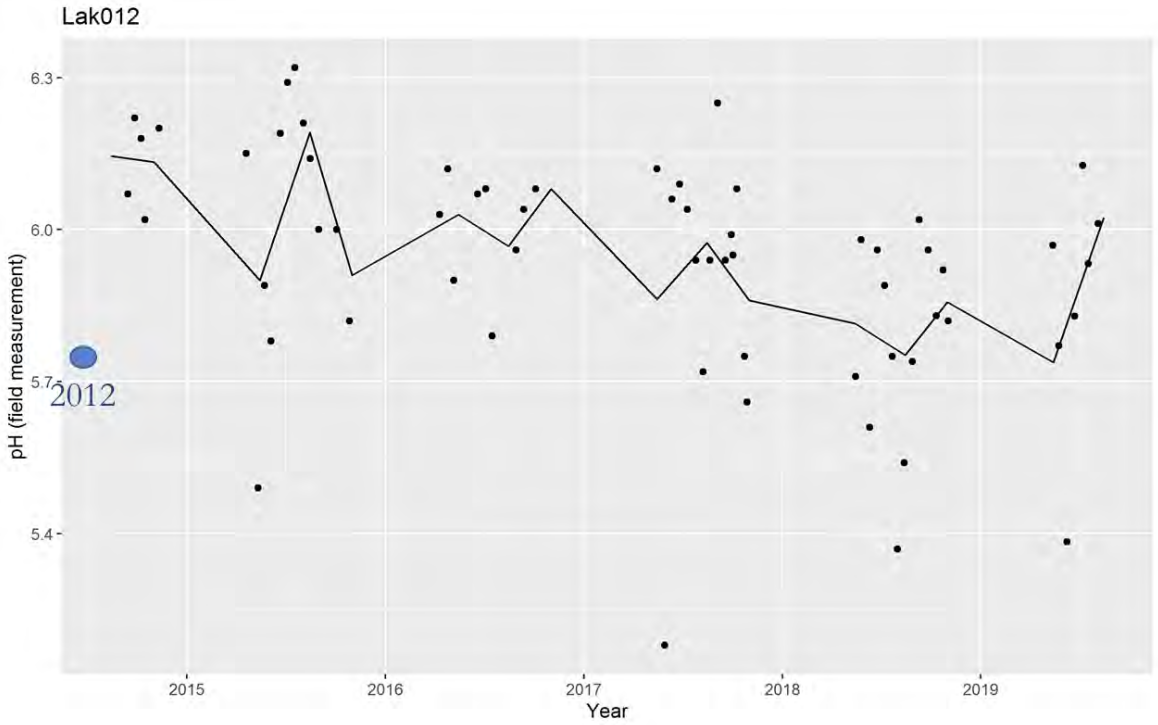


Figure 7.138: Trend in field pH in LAK012 (Little End Lake). Points shown are the seasonal mean values. The spring mean pH is the average of measurements in April, May, and June. The summer mean pH is the average of measurements in July and August. The fall mean pH was the average of measurements in September, October, and November. Blue dot is the field pH measurement in August of 2012.

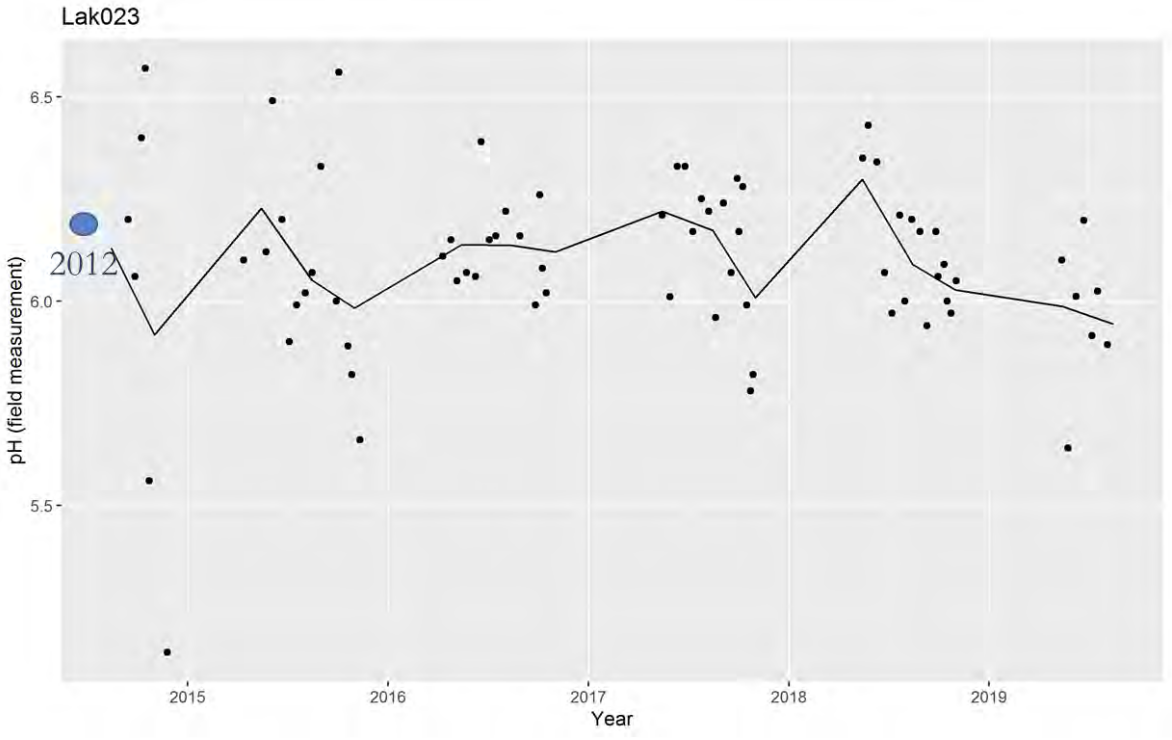


Figure 7.139: Trend in field pH in LAK023 (West Lake). Points shown are the seasonal mean values. The spring mean pH is the average of measurements in April, May, and June. The summer mean pH is the average of measurements in July and August. The fall mean pH was the average of measurements in September, October, and November. Blue dot is the field pH measurement in August of 2012.

Table 7.71: Results of Seasonal Mann-Kendall tests on the three intensively monitored lakes.

Lake	n	p.value	Sen's Slope (pH/year)	Slope over 5 years
LAK006	17	0.039	-0.052	-0.26
LAK012	17	0.464	-0.048	-0.24
LAK023	17	0.008	-0.023	-0.12

7.6.4.6 Summary of Statistical Analyses

7.6.4.6.1 Summary of Results of the Statistical Analysis Methods Applied

Below we summarize the complete set of statistical analyses of changes in SO_4 (Table 7.72), pH (Table 7.73), and Gran ANC (Table 7.74), based on the annual fall sampling. The order of these tables is important, as illustrated in the simplified evidentiary framework (Figure 7.35). A lake which has limited support for an increase in sulphate (e.g., LAK023, LAK044, LAK007, LAK034, all with % belief < 2%) does not require any further consideration of its changes in

pH and ANC, since those chemical changes are not related to SO_2 emissions from the smelter. Of the six lakes which **do** show strong evidence of increases in sulphate (i.e., LAK006, 012, 022, 028, 016, 024), all had limited support for pH declines below the 0.3 threshold (Table 7.73) and limited support for ANC declines below the lake-specific thresholds (Table 7.74).

Table 7.72: Summary of statistical analyses of changes in lake [SO_4] in the EEM lakes.

Statistical Analysis of Changes in SO_4

	Method 1 t-test w means (frequentist)			Method 2 t-test w 4 #/yr (frequentist)			Method 3 BACI_mean (freq)		Method 4 BACI_4#/yr (freq)		Method 5 (freq) BACI_const. controls				Method 6 Covariates						Method 9 Trend (freq)		Method 1 t-test w means (Bayesian)		Method 2 t-test w 4#/yr (Bayesian)	
											Mean		Individ.														
	T-test p-value	CI (SO4 increase since 2012?)	CI (SO4 increase since 2012-2014)	Estimated difference	p-value	CI (SO4 increase?)	Support for ΔSO4 different from controls?	p-value	Support for ΔSO4 different from controls?	p-value	Support for ΔSO4 different from controls?	p-value	Support for ΔSO4 different from controls?	p-value	Support for SO2 Emissions as covariate?	p-value	Support for 3-day Precipitation?	p-value	Support for 14-day Precipitation?	p-value	Trend	p-value	% belief in SO4 increase since 2012	% belief in SO4 increase since 2012-2014	% belief in SO4 increase since 2012	% belief in SO4 increase since 2012-2014
Sensitive Lakes																										
LAK006	0.39	><	><	2.5	0.38	><	No	0.44	No	0.59											><	0.89	83%	80%	82%	79%
LAK012	0.22	><	><	6.8	0.18	><	No	0.04	No	0.17											><	0.82	91%	69%	92%	37%
LAK022	0.24	><	><				No	0.06													><	0.82	88%	54%		
LAK023	0.05	><	No ↓	-6.7	0.08	><	Yes	0.001 ↓	No	0.02											><	0.02	5%	1%	3%	0%
LAK028	0.11	><	><	71.5	0.07	><	Yes	0.001 ↑	Yes	0.011 ↑											><	0.82	96%	89%	99%	93%
LAK042	0.58	><	><	-0.7	0.77	><	No	0.53	No	0.65											><	0.50	36%	52%	37%	55%
LAK044	0.04	><	No ↓	-1.9	0.001	No ↓	No	0.44	No	0.41											><	0.07	1%	4%	0%	2%
All lakes							No	0.51	No	0.71	No	0.78	No	0.87	No	0.69	Yes	0.001	Yes	0.007						
Less Sensitive Lakes																										
LAK007	0.003	No	No ↓																		><	0.50	0%	42%		
LAK016	0.05	><	><																		><	0.50	97%	30%		
LAK024	0.09	><	><																		><	0.93	96%	87%		
LAK034	0.000	No	No ↓																		><	0.04	0%	1%		
Control Lakes																										
DCAS14A																							68%	65%		
NC184																							58%	59%		
NC194																							1%	3%		

confident increase in SO4 (>80% belief) or statistically significant increase
confident that SO4 did not increase (<20% belief) or statistically sig't decrease
>< uncertainty with respect to the threshold (20-80% belief) or no trend

n/a
x.xx statistically significant p-value
(↑ = statisticaly significant increase; ↓ = statistically significant decrease)

Table 7.73: Summary of statistical analyses of changes in lake pH in the EEM lakes.

Statistical Analysis of Changes in pH

	Method 1 t-test w means (frequentist)				Method 2 t-test w 4 #/yr (frequentist)				Method 3 BACI_mean (freq)		Method 4 BACI_4#/yr (freq)		Method 5 (freq) BACI_const. controls				Method 6 Covariates						Method 9 Trend (freq)		Method 1 t-test w means (Bayesian)		Method 2 t-test w 4#/yr (Bayesian)	
		Mean					Individ.																						
	T-test p-value	CI (pH decline beyond 0.3 theshold?)	CI (pH decline?)	MDD (assuming post-KMP SD)	Estimated difference	p-value	CI (pH decline beyond 0.3 theshold?)	CI (pH decline?)	Support for ΔpH different from controls?	p-value	Support for ΔpH different from controls?	p-value	Support for ΔpH different from controls?	p-value	Support for ΔpH different from controls?	p-value	Support for SO2 Emissions as covariate?	p-value	Support for 3-day Precipitation?	p-value	Support for 14-day Precipitation?	p-value	Trend	p-value	% belief in pH decline beyond 0.3	% belief in pH decline	% belief in pH decline beyond 0.3?	% belief in pH decline
Sensitive Lakes																												
LAK006	0.13	><	><	0.6	0.24	0.11	No	><	No	0.18	No	0.36											><	0.50	1%	6%	0%	3%
LAK012	0.03	><	><	0.4	0.52	0.00	No	No	No	0.013	No	0.076											><	0.73	1%	1%	0%	0%
LAK022	0.06	No	><	0.3					No	0.65													><	0.38	0%	2%		
LAK023	0.07	><	><	0.3	0.22	0.04	No	No	No	0.28	No	0.453											><	0.73	1%	3%	0%	1%
LAK028	0.94	><	><	1.9	0.02	0.95	><	><	No	0.96	No	0.97											><	0.38	18%	46%	17%	50%
LAK042	0.10	><	><	1.2	0.54	0.08	No	><	No	0.04	No	0.113											><	0.38	2%	5%	0%	1%
LAK044	0.08	><	><	0.3	0.15	0.09	No	No	No	0.53	No	0.645											><	0.50	0%	5%	0%	4%
All lakes									No	0.06	No	0.154	No	0.03	No	0.45	No	0.6	No	0.01 [2]	Yes	0.001 [3]						
Less Sensitive Lakes																												
LAK007	0.71	><	><	0.4																			><	0.78	2%	38%		
LAK016	0.06	><	><	0.4																			><	0.73	1%	4%		
LAK024	0.09	><	><	0.7																			><	0.65	1%	4%		
LAK034	0.02	><	><	0.3																			↓ [1]	0.01	43%	99%		
Control Lakes																												
DCAS14A																									6%	21%		
NC184																									28%	47%		
NC194																									12%	89%		

confident exceedance of threshold (>80% belief) or statistically significant decline in pH
confident non-exceedance of threshold (<20% belief) or statistically significant increase in pH
>< uncertainty with respect to the threshold (20-80% belief) or no trend
n/a
x.xx statistically significant p-value

Notes:
[1] Mann-Kendall non-parametric test for LAK034 showed Pr (null hypothesis of no trend in pH) = 0.011; negative trend in pH
[2] P=0.012; estimate = -0.033 (e.g., 3 cm of cumulative precipitation in last 3 days could lower pH by 0.1 units)
[3] P=0.001; estimate = -0.008 (e.g., 12.5 cm of cumulative precipitation in last 14 days could lower pH by 0.1 units)

Table 7.74: Summary of statistical analyses of changes in Gran ANC in the EEM lakes.

Statistical Analysis of Changes in Gran ANC

	Method 1 t-test w means (frequentist)			Method 2 t-test w 4 #/yr (frequentist)				Method 3 BACI_mean (freq)		Method 4 BACI_4#/yr (freq)		Method 5 (freq) BACI_const. controls Mean		Individ.		Method 6 Covariates						Method 9 Trend (freq)		Method 1 t-test w means (Bayesian)		Method 2 t-test w 4#/yr (Bayesian)	
	T-test p-value	CI (ANC decline beyond threshold?)	CI (ANC decline?)	Estimated difference	p-value	CI (ANC decline beyond threshold?)	CI (ANC decline?)	Support for ΔANC different from controls?	p-value	Support for ΔANC different from controls?	p-value	Support for ΔANC different from controls?	p-value	Support for ΔANC different from controls?	p-value	Support for SO2 Emissions as covariate?	p-value	Support for 3-day Precipitation?	p-value	Support for 14-day Precipitation?	p-value	Trend	p-value	% belief in ANC decline beyond threshold	% belief in ANC decline	% belief in ANC decline beyond threshold	% belief in ANC decline
Sensitive Lakes																											
LAK006	0.15	No	><	2.0	0.56	No	><	No	0.85	No	0.89											><	0.50	0%	6%	0%	30%
LAK012	0.90	><	><	1.3	0.90	><	><	No	0.81	No	0.86											><	0.27	1%	46%	6%	44%
LAK022	0.20	><	><					No	0.89													><	0.18	0%	6%		
LAK023	0.20	><	><	6.7	0.21	No	><	No	0.72	No	0.78											><	0.50	0%	8%	0%	9%
LAK028	0.96	><	><	0.4	0.97	><	><	No	0.61	No	0.76											><	0.27	2%	34%	13%	47%
LAK042	0.09	><	><	26.0	0.07	No	><	No	0.02	No	0.07											><	0.38	0%	0%	0%	1%
LAK044	0.21	><	><	3.7	0.30	No	><	No	0.98	No	0.98											><	0.50	0%	0%	1%	16%
All lakes								No	0.28	No	0.55	No	0.7	No	0.93	No	0.32	No	0.73	No	0.52						
Less Sensitive Lakes																											
LAK007	0.15	><	><																			><	0.27	58%	97%		
LAK016	0.10	><	><																			><	0.50	0%	1%		
LAK024	0.09	><	><																			><	0.77	1%	2%		
LAK034	0.09	><	><																			><	0.12	0%	2%		
Control Lakes																											
DCAS14A																								0%	3%		
NC184																								5%	19%		
NC194																									55%		

confident exceedance of threshold (>80% belief) or statistically significant decline in ANC
confident non-exceedance of threshold (<20% belief) or statistically significant increase in ANC
>< uncertainty with respect to the threshold (20-80% belief) or no trend

n/a
x.xx statistically significant p-value

7.6.4.6.2 Summary of Findings of Statistical Analyses

Table 7.75: Summary of findings across all lakes monitored in the EEM program. The % belief values are derived from the Bayesian version of Method 1, as described in Aquatic Appendix F. Values of % belief < 20% are coloured green, 20-80% yellow, and >80% red.

LAKE	Changes in SO_4 (% belief in SO_4 increase / decrease from Bayesian analysis - Method 1 violin plot)	Changes in Gran ANC (% belief that ANC threshold exceeded, from Bayesian analysis - Method 1 violin plot)	Changes in pH (% belief that pH threshold exceeded, from Bayesian analysis - Method 1 violin plot)	**OVERALL INTERPRETATION[1]**
Sensitive Lakes				
LAK006	83% belief in increase	0%	1%	SO_4 increase; no evidence of S-induced acidification
LAK012	91% belief in increase	1%	1%	SO_4^{2-} increase; some-evidence of S-induced acidification but no evidence of exceeding the ANC or pH thresholds established in the EEM Plan to protect aquatic biota
LAK022	88% belief in increase	0%	0%	SO_4 increase; no evidence of S-induced acidification
LAK023	5% belief in increase	0%	1%	SO_4 decrease; no evidence of S-induced acidification
LAK028	96% belief in increase	2%	18%	SO_4^{2-} increase; some evidence of S-induced acidification; low belief in exceeding the pH threshold and no evidence of exceeding its ANC threshold; conditions were potentially damaging to biota pre-KMP and remained so (see Section 7.3.4.2 in main report).
LAK042	36% belief in increase	0%	2%	No clear change in SO_4; no evidence of S-induced acidification
LAK044	1% belief in increase	0%	0%	SO_4 decrease; no evidence of S-induced acidification
Less Sensitive Lakes				
LAK007	0% belief in increase	58%	2%	SO_4 decrease; no evidence of S-induced acidification
LAK016	97% belief in increase	0%	1%	SO_4 increase; no evidence of S-induced acidification
LAK024	96% belief in increase	1%	1%	SO_4 increase; no evidence of S-induced acidification
LAK034	0% belief in increase	0%	43% [2]	SO_4 decrease; no evidence of S-induced acidification
Control Lakes				
DCAS14A	68% belief in increase[3]	0%	6%	No clear change in SO_4; no evidence of S-induced acidification
NC184	58% belief in negligible increase [3]	5%	28% [4]	No clear change in SO_4; no evidence of S-induced acidification
NC194	1% belief in increase	TBD[5]	12% [4]	SO_4 decrease; no evidence of S-induced acidification

[1] The overall interpretation is also based in part on the level of support for any level of decline in ANC or pH, as are shown in Section 7.6.4.6 of Aquatic Appendix F (see Tables 7.72 and 7.73). Only two lakes show evidence of any level of decline in ANC or pH. LAK028 shows moderate support for declines in ANC and pH (34% belief and 46% belief, respectively) and LAK012 shows moderate support for a decline in ANC only (46% belief), but both of these lakes show no to low support for exceedance of the ANC and pH thresholds (as shown in the table). The coding of these two lakes in this table thus aligns with the results of the Evidentiary Framework.

[2] Not related to S deposition as lake SO_4 has declined in LAK034.

[3] Magnitude of increase in [SO_4] between 2013 and 2016-2018 is very small in NC184 (0.5 µeq/L), and only 4 samples were available for statistical analysis.

[4] Mean pH in NC184 changed from ~5.7 (2013) to ~5.8 (2016-18); Mean pH in NC194 changed from ~6.6 (2013) to ~6.4 (2016-18).

[5] Lake NC194 did not have a lab titration from which we could determine an ANC threshold. It had a 55% belief in an ANC decline (about 6 µeq/L between 2013 and 2016-2018), though very low belief (1%) in a SO_4 increase, so the ANC decline was not related to SO_4.

Applying the simplified evidentiary framework from Figure 7.35 to the entire set of 14 lakes, we obtain Figure 7.140. The results of applying this decision tree are as follows:

- At the first blue decision box (Has lake [SO_4] increased since pre-KMP period?), six lakes are eliminated from further consideration of smelter effects, as there is strong evidence of decreases in their sulphate concentrations: Sensitive lakes 023 and 044; Less Sensitive lakes 007 and 034; Control lakes NC194 and NC184. Control lake DCAS14A is also eliminated from further consideration, as all of the control lakes are well outside of the smelter's plume (see Figure 7.35), and therefore any changes in lake sulphate were not associated with the smelter. In addition, observed increases over time in sulphate were negligible in both NC184 (0.5 µeq/L), and DCAS14A (i.e., 3 µeq/L); Table 7.30. Control lake NC194 showed an observed decrease in sulphate concentrations of 1.1 µeq/L (Table 7.30).
- At the second blue decision box (Has lake pH or Gran ANC decreased since pre-KMP period?), five more lakes are eliminated from further consideration of smelter effects, as there is strong evidence that their pH and Gran ANC concentrations have not declined: Sensitive lakes 006, 022, 042; and Less Sensitive lakes 016, 024. The evidence is insufficient to reject the hypothesis of declines in Gran ANC for sensitive lakes 012 and 028 (46% and 34% belief in an ANC decline, Table 7.74), so they move on to the next part of the decision tree.
- At the third blue decision box, we find that lakes 012 and 028 have not exceeded the thresholds for either pH or Gran ANC (low % belief, see Table 7.75). These lakes should be closely monitored over time. In the ranking of lakes within the EEM Plan (Appendix D in ESSA et al., 2014), both of these lakes were considered to be of low importance.

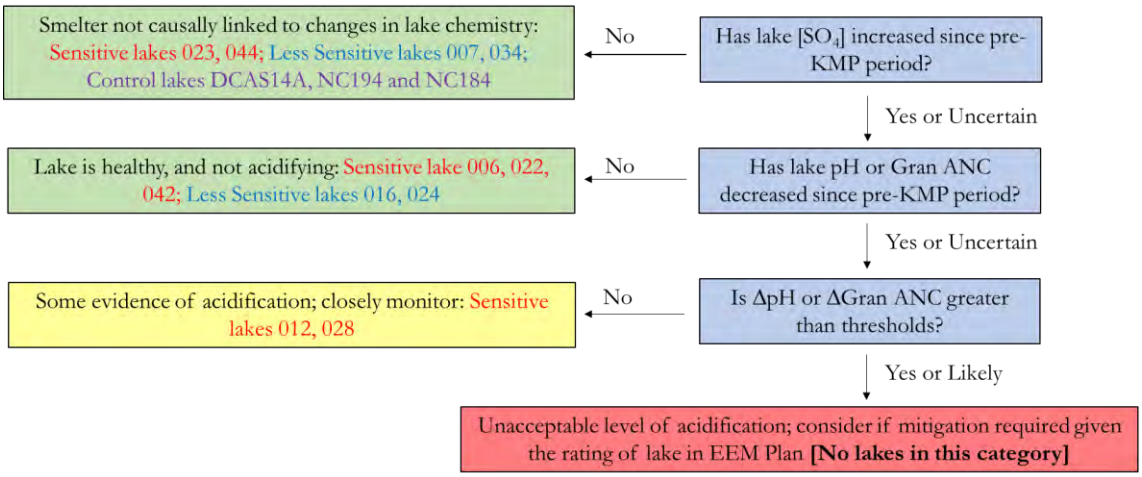


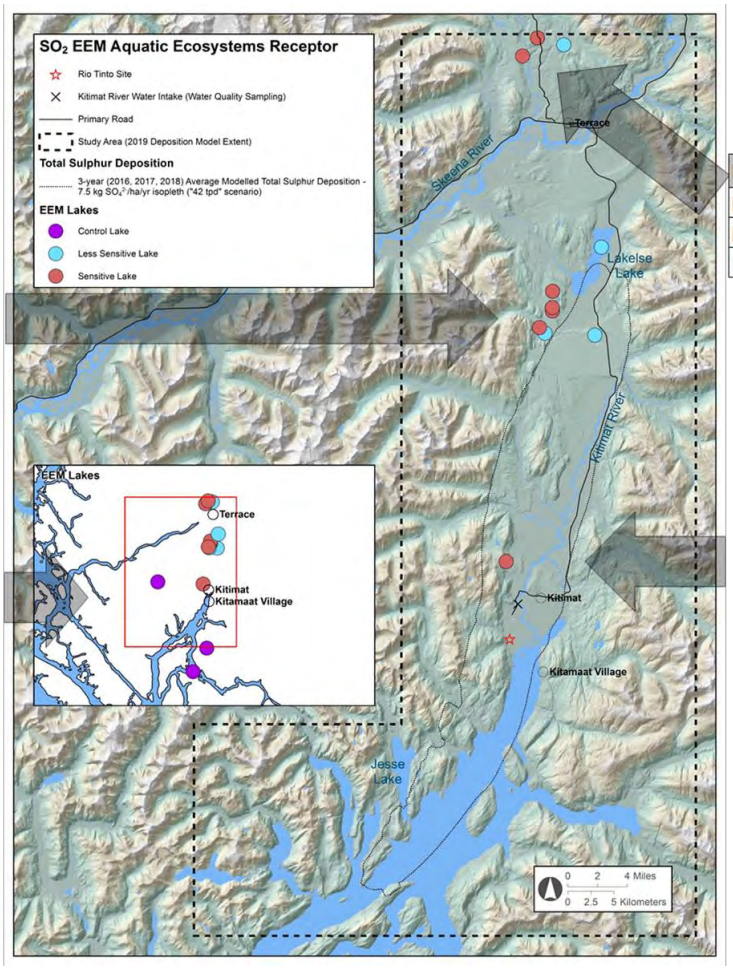
Figure 7.140: Application of the simplified evidentiary framework to the entire set of 14 lakes.

Figure 7.141 summarizes the patterns of change in water chemistry on a map of the study area, so as to elucidate any effects of lake location, specifically distance from the smelter. Six of the eight lakes to the south of Lakelse Lake showed strong evidence of increases in sulphate. It isn't clear why LAK023 and LAK007 were exceptions to this pattern – perhaps they are topographically more isolated from the path of the plume. None of the lakes with strong evidence for increases in sulphate showed any support for changes in pH or Gran ANC beyond the thresholds. Lakes to the north of Terrace (LAK034, LAK044, LAK042) are well outside of the deposition isopleth for 7.5

kg SO_4 / ha / year, consistent with low to intermediate support for sulphate change (0%, 32% and 0% belief, respectively). The control lakes were selected to be well outside of the plume. Two of the control lakes showed intermediate levels of support for increases in sulphate between 2013 and 2016-2018, but the amount of change in sulphate concentrations was very small (Figure 7.36).

	% belief in change		
LAKE	↑ SO_4^{2-}	↓ ANC	↓ pH
LAK006	83%	0%	1%
LAK012	91%	1%	1%
LAK022	88%	0%	0%
LAK023	5%	0%	1%
LAK007	0%	58%	2%
LAK016	97%	0%	1%
LAK024	96%	1%	1%

	% belief in change		
LAKE	↑ SO_4^{2-}	↓ ANC	↓ pH
DCAS14A	68%**	0%	6%
NC184	58%	5%	28%
NC194	1%	TBD	12%



	% belief in change		
LAKE	↑ SO_4^{2-}	↓ ANC	↓ pH
LAK042	36%	0%	2%
LAK044	1%	0%	0%
LAK034	0%	0%	43%

	% belief in change		
LAKE	↑ SO_4^{2-}	↓ ANC	↓ pH
LAK028	96%	2%	18%

Figure 7.141: Spatial distribution of percent belief in chemical change. Numbers show % belief in: a) SO_4^{2-} increase (no threshold), b) pH decrease below 0.3 threshold, and c) ANC decrease below lake-specific ANC threshold. The % belief values are derived from the Bayesian version of Method 1, as described in Aquatic Appendix F. NC194 does not have an estimated ANC threshold because it did not have appropriate titration data available. **The increase in SO_4^{2-} in control lake DCAS014A was only ~3 µeq/L, and only 0.5 µeq/L in NC184. Background deposition of 3.6 kg SO_4^{2-}/ha/yr is not included in the isopleth.

7.6.4.7 Other methods described in the Terms of Reference

7.6.4.7.1 Principal Component Analyses (PCA)

In the TOR we considered using Principle Components Analysis (PCA) on each lake's measurements, and then using the Principle Components in the BACI analysis, and comparing the

results to methods 3 and 4. The PCA approach would describe (for each lake) the combination of chemical constituents which explains the greatest amount of variability in the 2012-2018 dataset. The overall form of the results would be similar to methods 3 and 4, but would show the changes in the first principle component, over time and relative to the control lakes. We did not pursue this approach, because we didn't think it would yield any information of incremental benefit. Principle Components are difficult to interpret, and PCA is more helpful for exploratory analysis of multiple metrics to generate hypotheses. In this situation, we have specific questions and hypotheses of interest, as summarized in the simplified evidentiary framework (Figure 7.35), and a strong foundation of acidification literature describing the expected relationships among water chemistry variables in lakes subjected to acidic deposition.

7.6.4.7.2 Control-Impact Analysis with Three Time Periods

In the TOR we also considered building on method #6, conducting an analysis with 3 time periods: Before (2012); Transition (2013-2015); and After (2016-2018), using covariates established in method #6. The advantage of this approach would be that having more years gives a better estimate of process error. The overall form of the results would be similar to method 4, but with three time periods (before, transition, after) rather than just two (before, after). Unfortunately, we were not able to pursue this approach, because we found in method #6 that neither emissions nor precipitation covariates were statistically significant in explaining the observed changes in sulphate, pH or Gran ANC. We considered using lake-specific estimates of deposition as covariates (from the revised CALPUFF model), but these are only available for the post-KMP period of 2016-2018 and therefore do not provide sufficient contrast with the pre-KMP period of 2012-2014. CALPUFF modelling of deposition in the STAR did include estimates for the pre-KMP period, but used a different set of meteorological years (2006, 2008, 2009) and had other differences in methodology.

7.6.4.7.3 Examination of Temporal Trends within Groups of Lakes

In the TOR we considered examining temporal trends in lake chemistry within groups of lakes (e.g., those closest to the smelter, those at an intermediate distance, and those furthest away). Grouping lakes would provide higher levels of statistical power, and is the approach used by Stoddard et al. (1993, 1996, 1998, 2003) for assessing trends in the northeastern U.S. Due to the paucity of baseline data, analyses of covariance may be helpful in elucidating trends (e.g., Wiens and Parker 1995). We concluded that we did not have enough sensitive lakes (n=7) to apply this approach. The spatial analysis of changes in water chemistry (Figure 7.141) does provide insights on the patterns of changes in lakes at different distances from the smelter.

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7.7 Aquatic Appendix G: Critical Loads and Steady-state pH Modeling

This report has been inserted in its original format as a PDF file on the subsequent pages, and as such has different headers and footers from this main appendix file.

Aquatic Appendix G:
Critical Loads and Steady-state pH Modeling

1 Appendix Introduction

The purpose of this appendix is to document and communicate the details of the critical loads modeling and prediction of future steady-state pH of the EEM and STAR lakes under a variety of scenarios. This appendix contains descriptions and results of extensive sensitivity analyses conducted but only the results of the core analyses (i.e., base case and/or "best case") are reported in the aquatic chapter of the main report.

2 Critical Loads and Exceedances

2.1 Introduction / Background

The first major component of the analyses presented in this appendix is the modeling of critical loads and estimation of potential exceedances.

We used the Steady-State Water Chemistry (SSWC) model (Henriksen and Posch 2001, Henriksen et al. 2002 and UNECE 2004) to estimate both the critical loads of acidity for each of the lakes and streams in the study area and the amount (if any) by which these critical loads might be exceeded under scenarios of increased deposition from emissions. We followed closely the implementation of the model as described in Henriksen et al. 2002. Section 8.6.3.4 of the STAR report (ESSA et al. 2013) offers a detailed description of the model application and how its components were adapted for our analyses (i.e., STAR, EEM and Comprehensive Review).

The critical load for each lake or water body measures the amount of acid that could be neutralized by cation exchange and is calculated using hydrological (i.e., average annual runoff), water chemistry (i.e., base cations, F-factor or proportion of incoming acidity neutralized by cation exchange, and the limit of acid neutralizing capacity, ANC, protective for aquatic biota) and pre-KMP sulphate deposition data. These critical load values were then compared with modelled current and potential future sulphur deposition values in order to predict whether the critical loads would be exceeded – i.e., if deposition is higher than the critical load it indicates that the natural buffering or neutralizing capacity of the watershed has been exceeded, which could potentially lead to the acidification of the water body.

We calculated the level of exceedance (if any) of the critical loads estimated in the STAR (or KAA) for every lake within the study area under multiple deposition scenarios. We then generated new, improved estimates of the critical loads for the EEM lakes using the data collected from 2012 to 2018, again calculating the level of exceedance under multiple deposition scenarios. We also conducted a broad set of sensitivity analyses that apply varying assumptions about the model inputs.

2.2 Objectives for Critical Loads Modeling

Critical Loads Objectives:

1. Do the updated modeled emissions show changes in the number and magnitude of exceedances of the CLs estimated in the STAR?
2. How do improved data inputs change the CLs and exceedances originally estimated?
3. For lakes with post-STAR sampling data, what are our best, improved estimates of the CLs?
4. What is the number and magnitude of exceedances of the new CLs under the update deposition scenarios?
5. How sensitive are the new CLs and exceedances for the EEM lakes to the input assumptions?
6. How sensitive are the estimated exceedances to uncertainty in the deposition estimates?

2.3 SSWC Model Inputs

The model inputs for the SSWC model are described below in terms of what improvements are available relative to the data used in the STAR. These data are only described at a very high level so as to communicate the key elements of each input. These inputs are described extensively elsewhere (e.g., STAR, KAA, and/or other receptor/pathway chapters within the Comprehensive Review).

The lakes included in these analyses are: 41 lakes from the STAR (including the 7 sensitive EEM lakes and 4 less sensitive EEM lakes), 8 lakes from the KAA that fall within the CALPUFF model area, and 2 additional lakes sampled as one-off requests during the early years of the EEM.

2.3.1 Lake Chemistry Data

In the STAR, the available lake chemistry data was from a single sampling event in 2012. Similarly, the additional lakes only have lake chemistry data for a single year (i.e., 2013 for the KAA lakes, 2013 for MOE3, and 2014 for MOE6). For the lakes included in the EEM program, we now have six additional years of data, including multiple samples per year for particular lakes and years. In general, the critical load of a lake is a property of the lake that is not expected to change with time – additional years of data can help improve our estimate of the critical load but should not be interpreted as representing a change in the critical load over time. [1] To develop the best estimate of critical load for each of the lakes with additional data (i.e., those within the EEM program), we used all of the annual and/or with-season samples for each lake. As an alternative approach, we used only the post-KMP chemistry data (2016-2018) as a sensitivity analysis.

2.3.2 Runoff Estimates

The runoff estimates used in the STAR were generated from a runoff model that used precipitation data from the historic climate normal period of 1961-1990. In recent years, precipitation has been notably lower than historic levels. Steady-state modeling requires an understanding of long-term average conditions. However, we

[1] The only exception to this statement would be for a lake that has undergone considerable acidification over the time period of monitoring, such that its watershed base cation supply has been depleted, and its current lake chemistry no longer reflects the future ability of the lake and its watershed to neutralize deposition. In such a situation of rapid change, calculations based on current lake chemistry could lead to an over-estimate of a lake's critical load. This is not the case for any of the EEM lakes. LAK028 (the only lake with evidence of acidification) also showed evidence of acidification in the pre-KMP period. It has not shown subsequent declines in pH or ANC in excess of the established thresholds despite an increase in sulphate and shows no evidence of a declining supply of base cations.

do not yet know if the observed decrease in precipitation will prove to have been only a temporary deviation from the long-term average or a shift in the long-term average. To understand the implications of a longer-term decline in runoff, we revised the STAR estimate of runoff based on the ratio of recent precipitation (2016-2018) to historic precipitation (1961-1990). The table below shows that on average, across the four stations available, the average precipitation in 2016-2018 was 91% of the average precipitation during the reference period upon which the STAR estimate of runoff was based. The sensitivity analyses we conducted used a 10% reduction in precipitation. The table below also shows that the average precipitation in 2010-2012 was not strongly different than the reference period, which suggests that the runoff estimates used in the STAR appear were reasonable to use.

Station Name	Precipitation			No. Months with Recorded Precipitation		Change in Precipitation	
	1961-1990 (Reference) (mm / year)	2010-2012 (mm / year)	2016-2018 (mm / year)	2010-2012	2016-2018	Reference period to 2010-2012	Reference period to 2016-2018
Terrace PCC	1173	1163	1016	36	36	0.99	0.87
Terrace A	1290	NA	1195	0	36	NA	0.93
Kitimat Townnsite	2241	2299	2095	36	36	1.03	0.93
Kitimat 2	2262	2548	1913[a]	32	12[a]	1.13	0.85[a]
AVERAGE	1741	1793[b]	1435	NA	NA	1.03[b]	0.91

[a] While 18 months of data were available; the months were not randomly distributed. Only the data for 2018 was retained.
[b] Average for 2010-2012 was calculated as "=(Average(Terrace PCC, Average(Kitimat Townsite, Kitimat 2)))"

2.3.3 F-factor

We used the model-based F-factors estimated during the STAR. For the EEM lakes only, we conducted a sensitivity analysis in which we developed and applied new model-based F-factors using only post-KMP lake chemistry data and estimated runoff – i.e., this represents the F-factor that *would have* been estimated if we only had the recent, post-KMP data. However, we believe that these revised estimates are not as strong as the original estimates because they rely on data from a period in which lake chemistry is dynamically responding to increased deposition. For example, if the F-factor of a particular lake is greater than zero and SO_4 has increased, then we would expect to see an observable increase in base cations, but if we re-estimate the F-factor based on this new chemistry (as per the rules of the SSWC model, see Table 8.6-3, pg. 240 in Volume 2 of the STAR) the higher concentration of base cations would result in a higher F-factor.

Empirical Estimates of F-factor

It may be possible to estimate the F-factor based on observed changes in lake chemistry (i.e., F-factor = $\Delta BC / SO_4$). We expected that even with seven years of monitoring data, the changes in base cations and sulphate were too small relative to the inherent variability in the data to estimate valid F-factors, with the potential exception of LAK028. However, we tested the calculation of an empirical-based F-factor over four different time intervals to a) determine if this generated any valid values (i.e., between 0 and 1), and b) compare such values to the estimates from the STAR and the sensitivity estimates from the 2013 EEM program (see table below).

As shown in the table, most of the empirical estimates do not result in valid values (red in table). As expected, LAK028 is the only lake that consistently resulted in seemingly valid estimates across different intervals. In cases where a lake resulted in a valid value in only one or two of the four time intervals tested, we believe that this

result was only due to random chance and does not represent a reasonable estimate of the F-factor. We therefore only applied sensitivity analyses with an empirical-based F-factor for LAK028.

The F-factor is meant to represent soil cation exchange (i.e., deposited hydrogen ions being exchanged for base cations in the watershed. However, there are two other possible explanations for the post-KMP increase in the concentration base cations in LAK028: 1) post-KMP increases in the deposition of base cations that originate from the smelter; and 2) a concentration effect (reduced dilution), due to an almost 20% decrease in precipitation in the post-KMP period at Haul Road site (but not at Lakelsle Lake, see section 3.2 of the main report). The first possible explanation (increased emissions of base cations) is not supported by the deposition monitoring results at Haul Road, which showed increased deposition of H^+ and SO_4, but not base cations, between pre-KMP (2013-2015) and post-KMP (2016-2018) periods. The second possible explanation (a concentration effect) might be responsible for ~20% increases in the concentrations of *both* base cations and sulphate at LAK028. But since the F-factor is the ratio of changes in base cations to changes in sulphate, this concentration effect would be present in both the numerator and denominator, and therefore would not affect the estimate of the F-factor.

	Model-based Estimates		Empirical-based Estimates			
LAKE	STAR (2012)	EEM (2013)	2012 to 2018	2012 to avg 2016-18	avg 2012-14 to 2018	avg 2012-14 to avg 2016-18
Lak006	0.21	0.20	*3.40*	*4.54*	*4.55*	*8.28*
LAK007	1.00	1.00	*3.03*	*2.16*	*-0.13*	*-1.49*
LAK012	0.40	0.36	*-1.81*	*-1.35*	*-2.82*	*-2.04*
LAK016	0.56	0.56	*2.77*	*2.44*	*-4.36*	*-2.27*
LAK022	0.32	0.35	*1.68*	*1.93*	*2.66*	*17.46*
LAK023	0.23	0.22	*-1.93*	*-1.02*	*-0.89*	*-0.38*
LAK024	1.00		*14.37*	*15.52*	*14.66*	*16.85*
LAK028	0.44	0.69	0.85	0.89	0.65	0.85
LAK034	0.55	0.68	0.75	0.44	*2.22*	*1.92*
LAK042	0.13	0.14	*45.77*	*-14.81*	0.15	*61.04*
LAK044	0.04	0.04	*-1.99*	*-2.10*	*-1.75*	*-1.93*

2.3.4 Pre-industrial Sulphate - $SO_{4\,o}$

In the STAR, we estimated pre-industrial sulphate as the difference between observed and expected lake sulphate ($SO_{4\,o} = SO_{4\,t} - SO_{4\,exp}$), where expected sulphate was based on current sulphur deposition (as sulphate) and runoff ($SO_{4\,exp}$ = S_dep / Q). This method is based on the assumption that sulphur deposition and lake chemistry are currently in equilibrium. However, we do not believe this has been the case in the first few post-KMP years and therefore have continued to use the estimates from the STAR. We believe this is the most defensible approach as lake chemistry was likely to have been in greater equilibrium with deposition during the STAR since it did not follow an abrupt change.

2.3.5 Critical ANC Limit

As in the STAR, we determined the critical ANC limit by fitting the Small and Sutton (1986) model to the regional laboratory pH and Gran ANC to define the relationship between pH and ANC and then identify the ANC level

equivalent to pH = 6.0. However, as compared to the STAR, we have much more data – we used all the data from the STAR lakes plus all the lake samples collected during 2013-2018. Whereas the STAR had 61 data points (41 lakes and 20 streams) with which to characterize the regional pH-ANC relationship, we now have 270 data points with valid data. Similar to the STAR we also tested the "modified Small and Sutton curve" as developed by Marmorek et al. (1996) to account for the influence of DOC on pH; however, we again found that the modified version did not fit the data any better than the unmodified and therefore used the unmodified version. The results are shown in Figure 2-1. An ANC_{limit} of 31 µeq/L corresponds to a pH of 6.0.

The fitted equation is:

$$pH = 5.259 + \frac{1}{ln\,10} arcsinh\left[\frac{(Gran\ ANC) - 2.071}{10.731}\right]$$

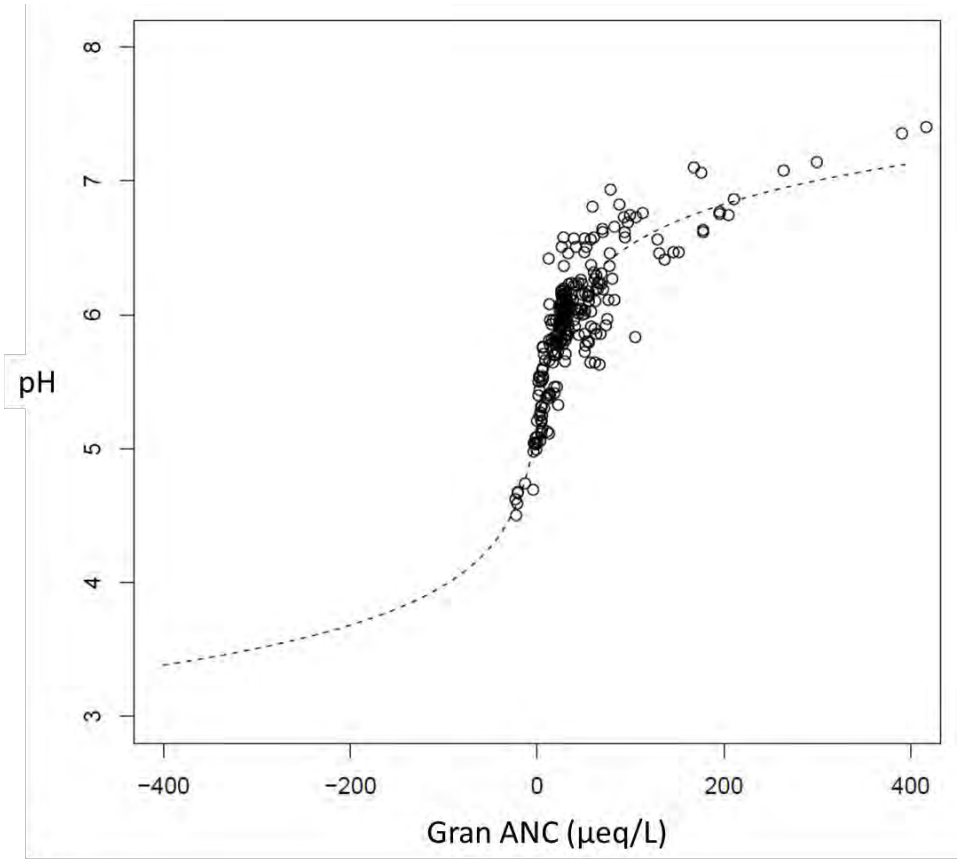


Figure 2-1. Application of the Small and Sutton (1986) equation to Gran ANC and lab pH data from 270 lake samples from STAR and EEM lakes and KAA lakes within the study boundary. An ANC_{limit} of 31 µeq/L corresponds to a pH of 6.0.

Using ANC_{OAA}

We explored the possibility of using an alternative critical ANC limit based on ANC_{OAA}. Based on the ANC literature review in Aquatic Appendix B, a threshold of ANC_{OAA} = 25 µeq/L would be appropriate to use as an ANC critical limit. However, because this limit is lower than the ANC critical limit identified above, it would result

in the estimation of higher critical loads and therefore lower exceedances (see description of SSWC model in Table 8.6-3, pg. 240 in Volume 2 of the STAR). But because the values are not highly different (25 µeq/L vs. 31 µeq/L), the absolute differences in the estimated critical loads and exceedances would not be expected to be substantially different. Therefore rather than recalculate the critical loads and exceedances with both critical limits we decided to simply apply the 31 µeq/L critical limit only as the more conservative of the two (i.e., evaluating the potential impacts on aquatic ecosystems using the higher critical limit that results in lower estimates of critical loads and higher exceedances is a more cautious approach).

2.3.6 Sulphur Deposition Estimates

We applied the new sulphur deposition estimates as derived from the updated CALPUFF modelling for three emissions scenarios (as described in Section 3). The three emissions scenarios are intended to represent: 1) actual current emissions (29.3 tpd SO_2), 2) likely future emissions (35 tpd SO_2), and 3) the maximum emissions under the permit (42 tpd). For each scenario, we used the gridded output from the CALPUFF model to estimate the area-weighted deposition within the watershed of each study lake, as per the methodology applied in the STAR and KAA.

As described in Section 3, we compared CALPUFF model estimates to the empirical observations from installed monitors to assess the level of agreement. The results showed that there can be substantial differences between the modelled estimates and the empirical observations at particular locations. To explicitly consider the potential impact of uncertainty in the CALPUFF model, we conducted sensitivity analyses with deposition values that were half or double the estimated levels.

The “pre-KMP” and “post-KMP” deposition estimates from the STAR are also referenced and/or used in limited places, as appropriate.

2.3.6.1 Background Sulphur Deposition

We added background sulphur deposition to the CALPUFF estimates of deposition. We used a value of 7.5 meq/m^2/yr, consistent with other chapters in the Comprehensive Review. The context and support for this value is provided in Terrestrial Ecosystems Appendix section titled “Background Sulphur Deposition”.

2.3.7 Summary of Model Inputs

The model inputs described above are summarized in Table 2-1, differentiating among STAR inputs, improved inputs, and potential alternatives.

Table 2-1. Model inputs for SSWC model, as used in the STAR plus updated data now available for improved estimates and/or sensitivity analyses.

	What was used in STAR	Updated / Improved Data	Sensitivity Analyses
Lake Chemistry	• 2012 lake data (2013 for KAA lakes)	• 2012-2018 lake data *[EEM lakes only]*	• 2016-2018 lake data *[EEM lakes only]*
Run-off	• STAR runoff		• STAR runoff scaled based on 2016-18 precipitation
F-factor	• Model-based (STAR estimates)		• Model-based (revised runoff, 2016-18 chemistry) *[EEM lakes only]*
$SO_{4\,o}$	• Model-based (STAR estimates)		
ANC limit	• STAR regional pH-ANC curve (@ pH=6)	• Updated regional pH-ANC curve (@ pH=6)	
Deposition estimates	2012 CALPUFF modeling based on 2006, 2008, 2009: • Pre-KMP • Post-KMP	2019 CALPUFF modeling based on 2016-2018 • 29.3 tpd (actual current) • 35 tpd (likely future) • 42 tpd (permit limit)	• 0.5x modeled deposition • 2.0x modeled deposition

2.4 SSWC Model Scenarios and Sensitivity Analyses

This section outlines the SSWC model scenarios and sensitivity analyses run to address each of the critical loads objectives. The table below gives a high-level overview of the types of model scenarios run for the extensive and intensive sets of lakes and the deposition scenarios used in each case.

Set of Lakes	Critical Loads	Exceedances (deposition scenarios)
All STAR lakes **(and add'l KAA lakes** in study area)	Base case - original STAR CLs	29.3 tpd, 35 tpd, 42 tpd
	Sensitivity analyses	29.3 tpd
EEM lakes	Base case – new CLs with best updated data	29.3 tpd, 35 tpd, 42 tpd
	Sensitivity analyses	42 tpd

2.4.1 Exceedance of STAR (and revised) Critical Loads for ALL lakes

Critical Loads Objective 1: Do the updated modeled emissions show changes in the number and magnitude of exceedances of the CLs estimated in the STAR?

SSWC CL Run #1 → original STAR (and KAA) CLs ("BASE CASE")

Exceedances → evaluated under all 3 deposition scenarios

Critical Loads Objective 2: How do improved data inputs change the CLs and exceedances originally estimated?

SSWC CL Run #2 (sensitivity) → BASE CASE + revised (lower) runoff

SSWC CL Run #3 (sensitivity) → BASE CASE + revised ANC limit based on updated pH-ANC rel'n

Exceedances → evaluated under actual current emissions scenario (29.3 tpd)

2.4.2 New Estimates of Critical Loads and Exceedances for EEM lakes only

Critical Loads Objective 3: For lakes with post-STAR sampling data, what are our best, improved estimates of the CLs?

SSWC CL Run #4 → new CLs with most defensible inputs ("BEST CASE")

The following table indicates the data inputs used to develop the "BEST CASE" new estimates for the CLs of the EEM lakes. The rationale for each selection is discussed in Section 2.3 above.

	Data to use **for "BEST CASE"**
Lakes	• EEM lakes (sensitive, less sensitive)
Lake Chemistry	• 2012-18 lake data
Run-off	• STAR runoff
F-factor	• STAR model estimate
$SO_{4\,o}$	• Model-based (STAR estimates)
ANC limit	• Updated pH-ANC curve (@ pH=6)

Critical Loads Objective 4: What is the number and magnitude of exceedances of the new CLs under the update deposition scenarios?

Exceedances → BEST CASE CLs evaluated under all 3 deposition scenarios

Critical Loads Objective 5: How sensitive are the new CLs and exceedances for the EEM lakes to the input assumptions?

SSWC CL Run #5 (sensitivity) → BEST CASE + 2016-2018 lake chemistry data

SSWC CL Run #6 (sensitivity) → BEST CASE + revised (lower) runoff

SSWC CL Run #7 (sensitivity) → BEST CASE + revised F-factor

SSWC CL Run #9 (sensitivity) → BEST CASE + original ANC limit

Exceedances → SSWC CL Runs #5-#9 evaluated under "permit" scenario (42 tpd)

2.4.3 Summary of Critical Loads Model Scenarios and Sensitivity Analyses

The table below provides a visual summary of all the SSWC model scenarios and sensitivity runs described in the previous sections. There are two "base cases" (denoted by the green columns) – one that is applicable to the entire set of STAR and additional lakes, and one that is applicable only to the EEM lakes. The data inputs used in each base case are marked with **black 'X's** whereas the **red 'X's** indicate the changes from the base case, as applied in various sensitivity analyses.

		STAR CLs with new deposition (All lakes)			New CLs calculated from present (EEM lakes only)				
Model Input	Data Set / Method	STAR CLs – original, unmodified	STAR CLs – revised run-off	STAR CLs – revised ANC limit	NEW CLs – with best inputs	NEW CLs – post-KMP lake chemistry	NEW CLs – revised run-off	NEW CLs – alternate F-factor	NEW CLs – original ANC limit
Estimation of CRITICAL LOADS (different versions with varying inputs)									
Lakes	All lakes	X	X	X					
	EEM lakes				X	X	X	X	X
Lake Chemistry	2012 lake data	X	X	X					
	2012-2018 lake data				X		X	X	X
	2016-2018 lake data					X			
Run-off	STAR (higher) runoff	X		X	X	X		X	X
	Revised (lower) runoff		X				X		
F-factor	Model-based (STAR estimate)	X	X	X	X	X	X		X
	Model-based (revised runoff, new chem.)							X	
ANC limit	STAR pH-ANC curve (@ pH=6)	X	X						X
	Updated pH-ANC curve (@ pH=6)			X	X	X	X	X	
Estimation of EXCEEDANCES of critical loads under each emissions scenario									
Deposition estimates	29.3 tpd (actual current)	✓	✓	✓	✓				
	35 tpd (likely future)	✓			✓				
	42 tpd (permit limit)	✓			✓	✓	✓	✓	✓

2.4.4 Sensitivity Analyses on CALPUFF Modeled Deposition Estimates

Critical Loads Objective 6: How sensitive are the estimated exceedances to uncertainty in the deposition estimates?

As discussed under the model inputs, we applied sensitivity analyses on the CALPUFF deposition estimates of 50% and 200% to assess the impact of uncertainty in the deposition modeling on the calculated exceedances. We conducted these sensitivity analyses on: a) exceedances of the base case critical loads for all lakes under current deposition levels, and b) exceedances of the best case critical loads for the EEM lakes under maximum future deposition levels, i.e.:

Ex(A) for SSWC CL Run #1 under 29.3 tpd & 42 tpd, uncertainty factors of 0.5, 1.0, 2.0

Ex(A) for SSWC CL Run #4 under 29.3 tpd & 42 tpd, uncertainty factors of 0.5, 1.0, 2.0

2.5 SSWC Model Results

2.5.1 Exceedance of STAR (and revised) Critical Loads for ALL lakes

2.5.1.1 Base Case

Exceedances of the base case (i.e., original critical loads as calculated in the STAR and/or KAA based on initial sampling in 2012 or 2013 only) under current deposition are shown in Table 2-2 and mapped in Figure 2-3.

Seven lakes show exceedances of those original critical loads. Of these seven lakes, five lakes have critical loads of zero (LAK044, LAK047, LAK054, DCAS09A, DCAS09B) and one lake has a critical load very near to zero (1.2 meq/m^2/yr; LAK056).

The number of exceedances does not change with the deposition scenario used and the magnitude of exceedance changes by a relatively small amount, especially relative to the difference with the STAR results. Under the STAR's "post-KMP" deposition estimates (based on the 42 tpd SO_2 emissions permit limit), there were three additional lakes with predicted exceedances that are no longer predicted to have exceedances. Even with the inclusion of background deposition (which was not accounted for in the STAR), these three lakes are not predicted to have exceedances under any of the new emissions scenarios.

Note that the KAA study did not have a specific equivalent post-KMP emissions scenario that isolated the operation of the smelter from increases in other regional emissions sources, therefore are only "post-KMP" results for the lakes that were part of the STAR.

Table 2-2. Original critical loads for the STAR and KAA lakes within the study area and exceedances under different emissions scenarios. Red cells indicate lakes with critical loads of zero and/or positive exceedances under a particular deposition scenario. Exceedances reported in the STAR under the "post-KMP" scenario are included for comparison. Note that the STAR "post-KMP" scenario did not include background deposition, whereas the exceedances estimated under the three new deposition scenarios do include background deposition of 7.5 meq/m²/yr. Exceedances are calculated based on sulphur deposition values (dominant factor) and nitrate leaching (minor factor), which is not shown in the table.

Lake	Years used for CL	Critical Load (meq/m²/yr)	Sulphur Deposition (under 29.3 tpd scenario)		Exceedance under different emissions scenarios (meq/m²/yr)			
			(meq/m²/yr)	(kg/ha/yr)	29.3 tpd	35 tpd	42 tpd	**STAR "post-KMP"**
EEM Sensitive Lakes								
LAK006	2012	28.4	8.9	4.3	-11.9	-10.5	-8.5	14.3
LAK012	2012	79.4	8.5	4.1	-63.1	-61.8	-59.9	-37.5
LAK022	2012	53.9	8.1	3.9	-38.0	-36.8	-34.9	-12.3
LAK023	2012	31.9	8.0	3.9	-16.1	-14.9	-13.1	9.1
LAK028	2012	47.5	47.0	22.6	7.6	13.6	24.2	49.8
LAK042	2012	15.9	2.4	1.2	-5.6	-5.2	-4.6	0.2
LAK044	2012	0.0	2.2	1.0	9.8	10.7	11.3	16.7
EEM Less Sensitive Lakes								
LAK007	2012	1393.5	15.7	7.5	-1369.8	-1367.1	-1363.4	-1358.4
LAK016	2012	115.6	9.6	4.6	-98.2	-96.8	-94.6	-71.0
LAK024	2012	370.0	8.4	4.0	-353.9	-352.4	-350.4	-347.6
LAK034	2012	124.7	3.2	1.5	-113.7	-113.0	-112.2	-105.5
Other STAR Lakes								
LAK001	2012	602.7	6.4	3.1	-588.5	-587.5	-586.0	-568.7
LAK002	2012	113.2	7.3	3.5	-98.1	-96.9	-95.2	-78.6
LAK003	2012	504.3	26.0	12.5	-470.5	-466.4	-460.3	-433.4
LAK004	2012	205.2	5.4	2.6	-192.0	-191.1	-189.8	-173.5
LAK005	2012	113.7	10.7	5.2	-95.3	-93.7	-91.2	-66.6
LAK008	2012	1696.9	15.0	7.2	-1673.9	-1671.5	-1668.0	-1650.2
LAK011	2012	99.3	4.9	2.3	-86.8	-86.0	-84.9	-70.2
LAK013	2012	720.6	9.3	4.5	-703.6	-702.1	-699.9	-687.0
LAK014	2012	110.9	9.2	4.4	-94.0	-92.7	-90.5	-68.1
LAK015	2012	225.6	26.5	12.7	-190.1	-185.4	-179.1	-162.3
LAK017	2012	231.7	21.7	10.4	-201.8	-198.0	-192.8	-198.5
LAK018	2012	1473.9	16.1	7.7	-1449.2	-1446.4	-1442.6	-1439.5
LAK027	2012	253.9	32.3	15.5	-214.0	-210.1	-202.8	-167.7
LAK030	2012	793.7	48.8	23.4	-730.0	-724.9	-714.1	-669.1
LAK032	2012	948.8	2.5	1.2	-938.5	-938.0	-937.4	-932.3
LAK035	2012	91.1	4.6	2.2	-78.7	-77.8	-76.7	-74.2
LAK037	2012	134.5	4.6	2.2	-122.1	-121.3	-120.3	-115.1
LAK038	2012	178.3	4.9	2.4	-165.7	-164.8	-163.7	-158.7
LAK039	2012	98.3	4.7	2.3	-85.9	-85.1	-84.1	-79.4
LAK041	2012	54.2	1.2	0.6	-44.3	-44.1	-43.8	-47.8
LAK045	2012	227.0	1.4	0.7	-215.9	-215.6	-215.3	-220.1
LAK047	2012	0.0	1.8	0.9	11.4	11.7	12.1	10.3
LAK049	2012	234.8	2.0	1.0	-223.1	-222.7	-222.2	-222.3
LAK050	2012	117.3	1.5	0.7	-103.7	-103.4	-103.0	-105.5
LAK051	2012	236.4	2.3	1.1	-226.3	-225.8	-225.3	-225.0
LAK053	2012	102.8	6.5	3.1	-87.8	-86.1	-84.5	-91.3
LAK054	2012	0.0	14.5	7.0	23.0	25.2	28.5	14.9
LAK055	2012	120.3	13.0	6.2	-99.4	-97.4	-94.5	-107.2
LAK056	2012	1.2	12.8	6.1	19.8	21.6	24.6	12.4
LAK057	2012	420.7	13.0	6.3	-399.1	-397.2	-394.2	-407.0
KAA Lakes Located within 2019 Deposition Modeling Area								
MOE3	2013	617.0	6.7	3.2	-601.8	-600.8	-599.3	
DCAS10A	2013	44.4	1.7	0.8	-34.3	-34.0	-33.6	
DCAS10B	2013	35.2	1.7	0.8	-25.1	-24.8	-24.4	
DCAS17A	2013	431.9	3.6	1.7	-420.1	-419.4	-418.5	
DCAS02C	2013	75.1	3.6	1.7	-63.6	-62.2	-61.2	

DCAS07A	2013	0.0	2.2	1.1	11.1	12.0	12.6	
DCAS07B	2013	0.0	2.4	1.1	11.3	12.2	12.9	
DCAS09A	2013	71.9	2.4	1.2	-55.4	-54.4	-53.7	
DCAS09B	2013	29.1	2.3	1.1	-18.2	-17.2	-16.6	
Additional Lakes Sampled During EEM								
MOE6[2]	2014	414.1	24.6	11.8	-388.1	-384.6	-379.1	

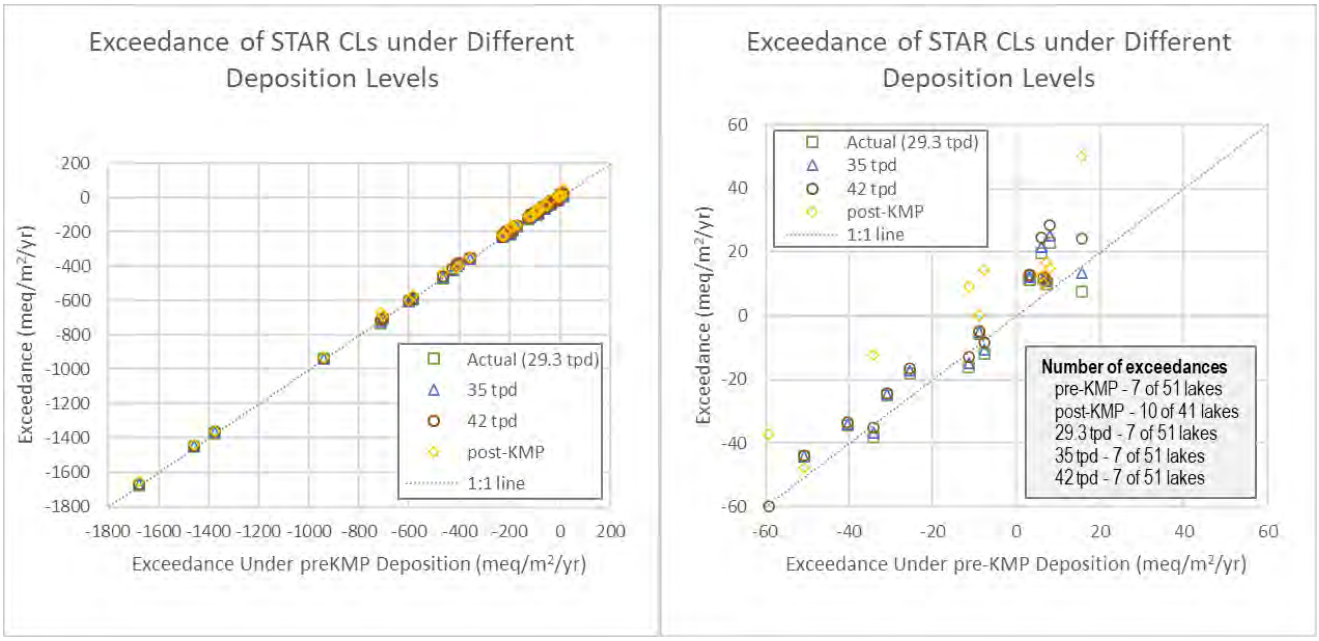


Figure 2-2. Exceedances of original STAR (or KAA) critical loads under different emissions scenarios (. The two panels show the same data, but the right-hand panel is focused on the distribution of lakes near Ex=0. As described in the text, there are nine lakes that do not have "post-KMP" results from earlier work.

[2] A critical load was not previously calculated for MOE6 (see 2013/14 Annual Report). However, this critical load was calculated using the same approach and data as applied to the STAR or KAA lakes, which assumes the pre-KMP deposition data used to estimate original sulphate is still appropriate to use even though this lake was sampled in 2014.

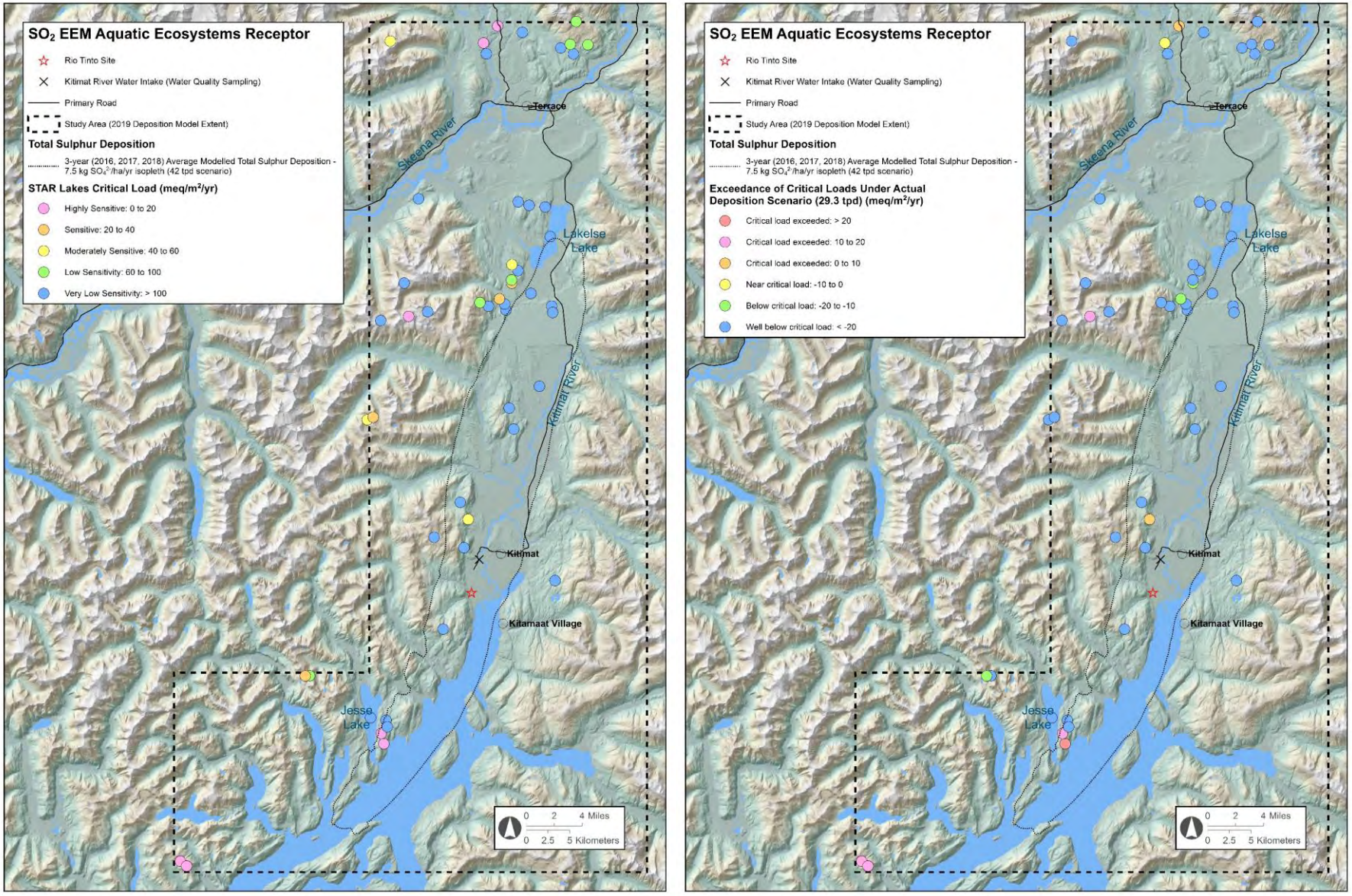


Figure 2-3. Original estimated critical loads (left) and predicted exceedances under actual current emissions (29.3 tpd; right) for all lakes within the study area.

2.5.1.2 Sensitivity Analyses

Results of the sensitivity analyses conducted on the original STAR (and/or KAA) critical loads and exceedances across all lakes in the study area are shown below.

Recall that the three sensitivity analyses are:

- Revised runoff: lower runoff (i.e., 90% of STAR levels, based on lower recent precipitation levels).
- Revised ANC_{limit}: higher ANC_{limit} based on the updated pH-ANC relationship developed from all the available data.

As shown in Figure 2-4, both lower run-off and a higher ANC_{limit} result in lower estimated critical loads. The revised ANC_{limit} (both versions) makes a negligible difference for larger critical loads (i.e., >100 meq/m^2/yr).

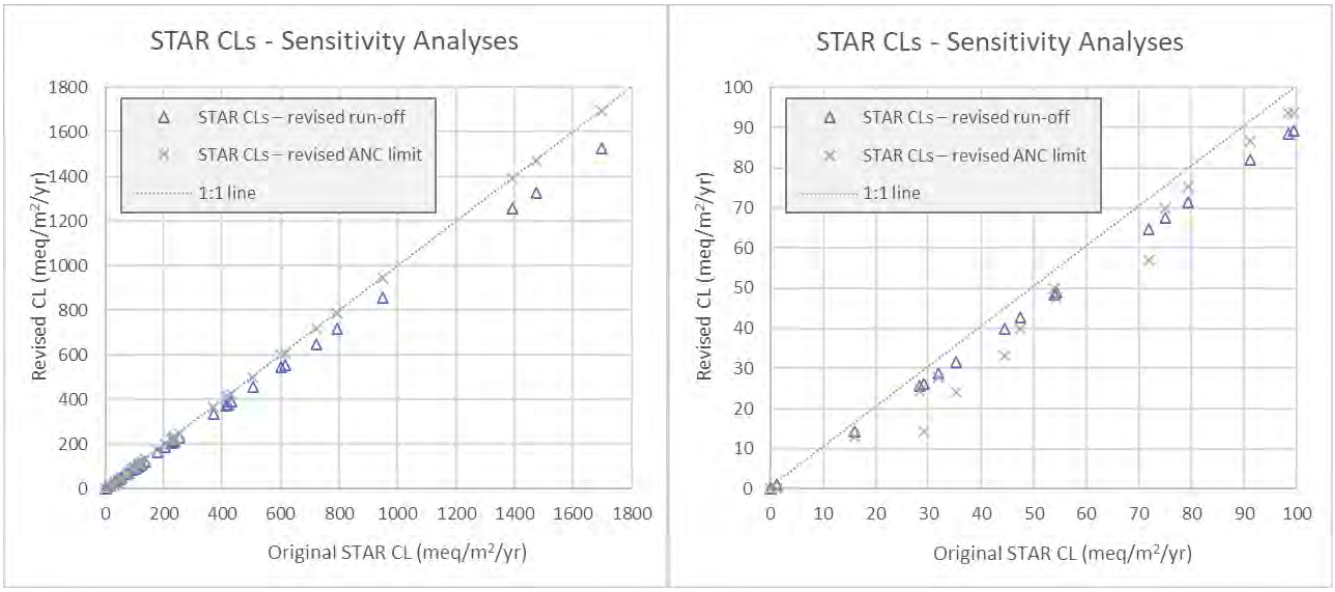


Figure 2-4. Sensitivity analyses on original critical loads for all lakes within the study area.

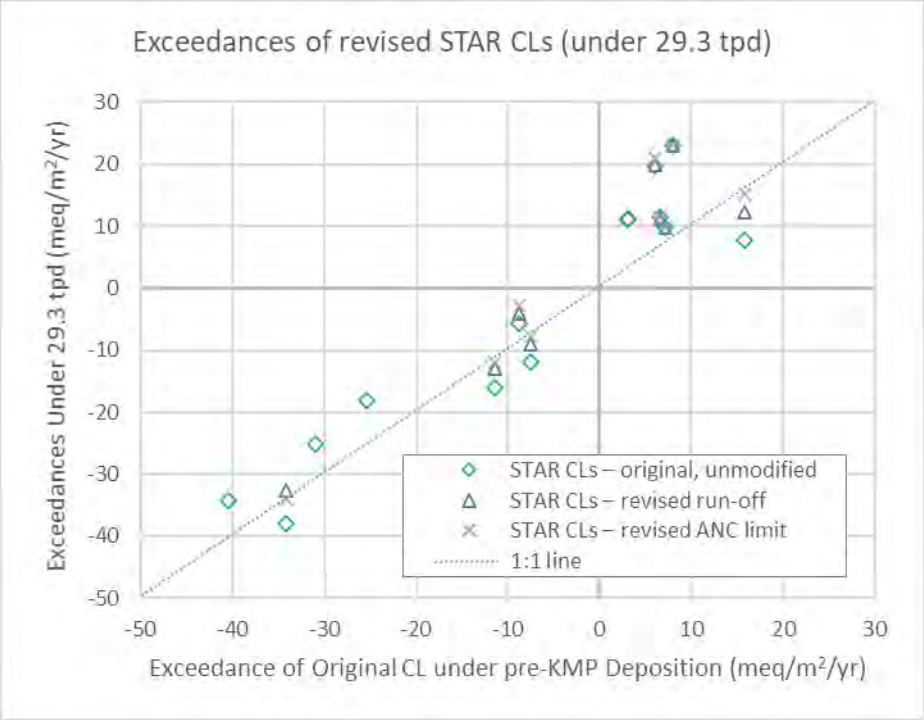


Figure 2-5. Exceedances of alternate sensitivity analyses on the original STAR critical loads under current deposition levels (i.e., 29.3 tpd modeled emissions). Results of sensitivity analyses are plotted relative to the exceedances calculated in the STAR under the "pre-KMP" emissions scenario.

Figure 2-5 shows how the number of lakes with calculated exceedances under current deposition (i.e., modeled deposition from the 29.3 tpd emissions scenario) varies with the sensitivity analyses applied to the estimation of critical loads. Using the original critical loads, there are 7 lakes (out of the 51 lakes in the study area) that show an exceedance under 29.3 tpd.

The results show that there are no additional exceedances under the 29.3 tpd scenario than were estimated under pre-KMP conditions.

The number of lakes with exceedances does not change when using lower runoff or the higher ANC_{limit} based on the complete data set of pH and Gran ANC.

2.5.2 New Estimates of Critical Loads and Exceedances for EEM lakes only

2.5.2.1 Best Case

The new "best case" estimates for critical loads for the EEM lakes and exceedances under different emissions scenarios are summarized in Table 2-3 and mapped in Figure 2-8.

Only one lake (LAK044) shows an exceedance an exceedance under the 42 tpd emissions scenario, and because it has a critical load of zero, it has an exceedance under all emissions scenarios. In the STAR, five of these lakes were predicted to have exceedances under the "post-KMP" emissions scenario (i.e., also based on 42 tons SO_2 per day).

Table 2-3. New estimates of critical loads and exceedances for the EEM lakes based on the best available model inputs. Red cells indicate lakes with critical loads of zero and/or positive exceedances under a particular deposition scenario. Exceedances are calculated based on sulphur deposition values (dominant factor) and nitrate leaching (minor factor), which is not shown in the table.

Lake	Years used for CL	Critical Load (meq/m²/yr)		Sulphur Deposition (under 42 tpd scenario)		Exceedance under different emissions scenarios (meq/m²/yr)		
		New	STAR	(meq/m²/yr)	(kg/ha/yr)	29.3 tpd	35 tpd	42 tpd
EEM Sensitive Lakes								
LAK006	2012-18	29.4	28.4	12.2	5.9	-12.3	-10.9	-8.9
LAK012	2012-18	68.1	79.4	11.8	5.7	-51.5	-50.2	-48.3
LAK022	2012-18	58.3	53.9	11.2	5.4	-42.4	-41.2	-39.3
LAK023	2012-18	33.3	31.9	11.1	5.3	-17.0	-15.8	-13.9
LAK028	2012-18	81.1	47.5	63.6	30.5	-25.0	-19.1	-8.5
LAK042	2012-18	17.4	15.9	3.4	1.6	-7.3	-6.9	-6.3
LAK044	2012-18	0.0	0.0	3.6	1.7	9.9	10.8	11.4
EEM Less Sensitive Lakes								
LAK007	2012-18	1383.4	1393.5	22.1	10.6	-1359.9	-1357.1	-1353.5
LAK016	2012-18	118.1	115.6	13.2	6.4	-100.3	-98.9	-96.7
LAK024	2012-18	551.6	370.0	11.8	5.7	-534.9	-533.3	-531.4
LAK034	2012-18	138.4	124.7	4.7	2.2	-127.4	-126.7	-126.0

For eight of the 11 EEM lakes, the revised estimates of critical loads are quite similar to the original estimates in the STAR (Table 2-4, Figure 2-6). The revised critical load estimates are higher than the STAR for LAK024 and LAK028 and lower for LAK012.

The exceedances of the revised critical loads under the 42 tpd emissions scenario are consistently smaller in magnitude than those predicted in the STAR (Figure 2-7). Among the three new modeled emissions scenarios, the magnitude of exceedance increases as deposition increases but there are no additional exceedances – that is, the number of exceedances is not sensitive to the emissions scenario.

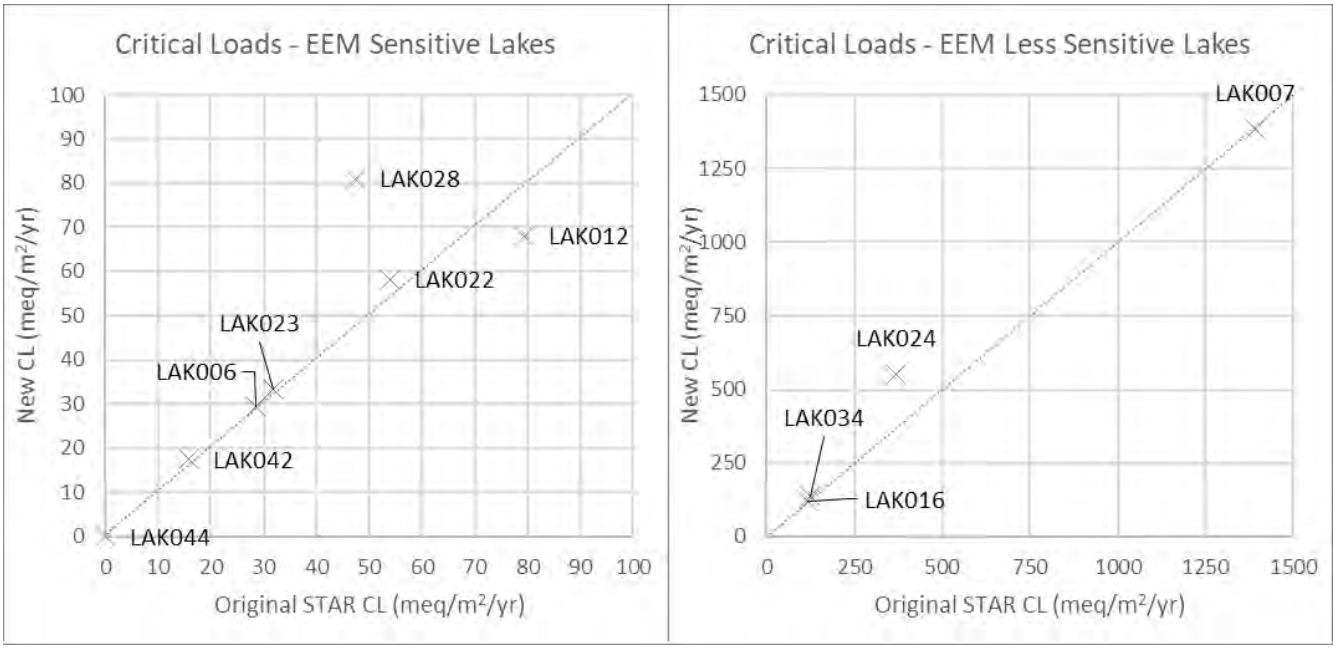


Figure 2-6. Critical loads for EEM lakes – "best case" revised estimates relative to estimates from the STAR. The sensitive lakes are shown in the left panel and the less sensitive lakes are shown in the right panel.

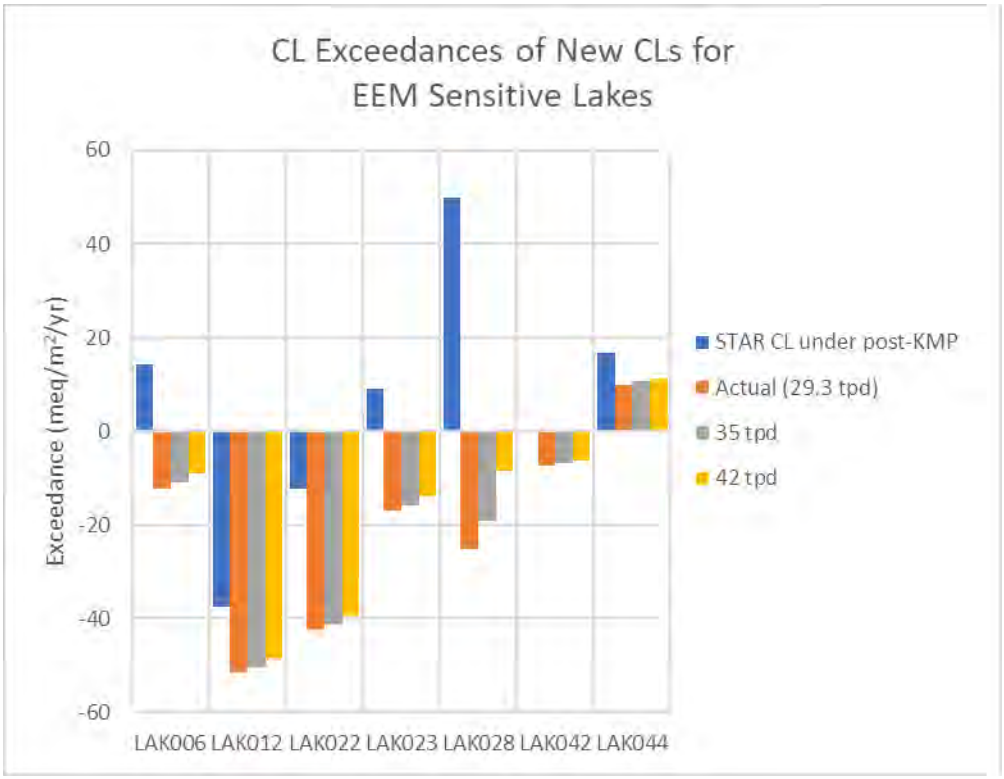


Figure 2-7. Critical load exceedances for the EEM lakes under different levels of deposition. Results from the STAR under the "post-KMP" emissions scenario are included for comparison. Note that the STAR "post-KMP" scenario did not include background deposition, whereas the exceedances estimated under the three new deposition scenarios do include background deposition of 7.5 meq/m2/yr. The exceedance for LAK042 from the STAR was smaller than perceptible on this graph (+0.2 meq/m²/yr).

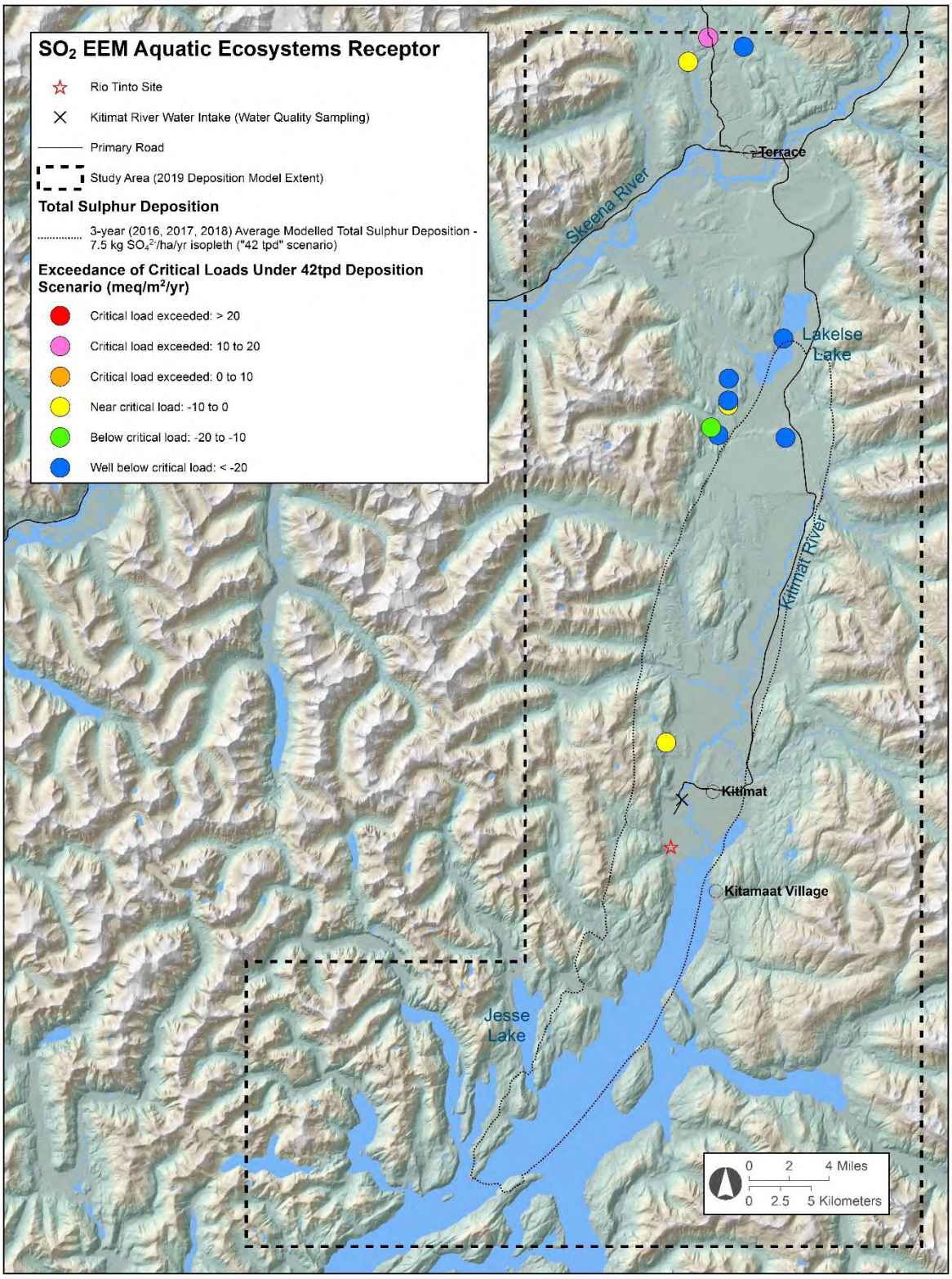


Figure 2-8. Exceedances of new critical loads for EEM lakes with modeled deposition under the 42 tpd emissions scenario.

2.5.2.2 Sensitivity Analyses

The critical loads estimated under the sensitivity analyses are shown in Table 2-4 and Figure 2-9

Table 2-4. New Critical Loads for EEM Lakes with best inputs and additional sensitivity analyses. Red cells indicate critical loads <5 meq/m²/yr.

	NEW CLs – with best inputs	NEW CLs – post-KMP lake chem.	NEW CLs – revised run-off	NEW CLs – alternate F-factor	NEW CLs – original ANC limit
EEM Sensitive Lakes					
LAK006	29.4	34.0	26.4	28.9	33.5
LAK012	68.1	65.2	61.3	68.4	72.2
LAK022	58.3	61.5	52.5	57.0	62.2
LAK023	33.3	35.3	30.0	33.0	37.5
LAK028	81.1	91.3	73.0	37.0	88.6
LAK042	17.4	20.0	15.7	17.4	20.3
LAK044	0.0	0.0	0.0	0.0	0.0
EEM Less Sensitive Lakes					
LAK007	1383.4	1384.1	1245.1	1383.4	1387.9
LAK016	118.1	120.6	106.3	117.0	122.4
LAK024	551.6	611.6	496.5	551.6	557.3
LAK034	138.4	118.0	124.6	138.4	141.9

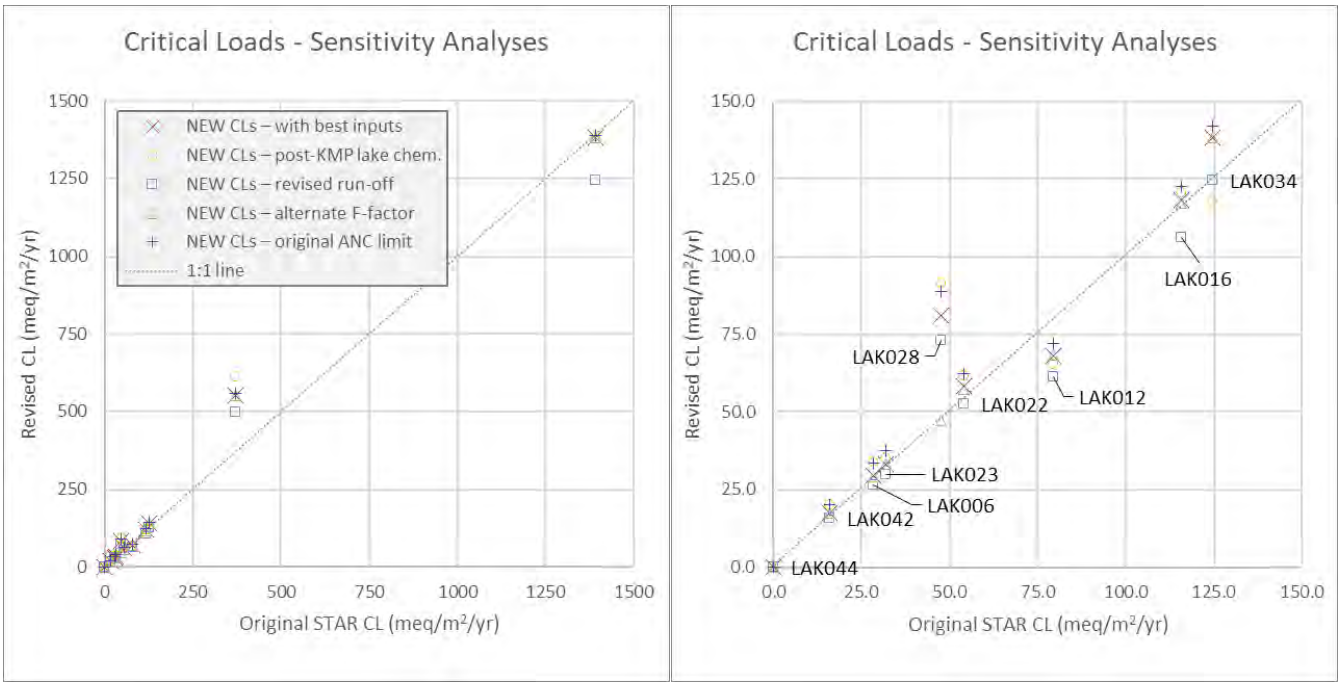


Figure 2-9. New critical loads for EEM Lakes with best inputs and additional sensitivity analyses, compared against the critical loads estimated in the STAR. Both panels contain the same data, with greater detail on results for the sensitive EEM lakes in the right panel.

The sensitivity analyses show:

- **Lower runoff:** If future run-off is lower than historic (i.e., decreased precipitation in the past three years is more representative of future conditions than the historic climate normal period), then critical loads will be lower. However, for lakes with the lowest runoff or lowest critical loads, this effect is smaller.
- **Post-KMP chemistry:** LAK024, LAK028 and LAK034 are the only lakes with strong sensitivity to using this reduced data set. These lakes have notable differences between the two potential data sets and therefore a notable difference in the estimated critical loads. For LAK024, Gran ANC, SO_4^{2-} and base cations are all higher when only using the data for 2016-2018. For LAK028, Gran ANC is lower but SO_4^{2-} and base cations are higher. For LAK034, SO_4^{2-} and base cations are lower.
- **Alternate F-factor:** LAK028 is the only lake that is sensitive to use of a revised F-factor. As SO_4^{2-} has increased, so have base cations (result of a non-zero F-factor indicating some watershed neutralization of acid deposition), but this means the base cation concentration used to calculate the model-based F-factor is higher, resulting in a higher estimated F-factor. In the SSWC model, a higher F-factor leads to a lower estimate of original base cations and therefore a higher critical load. The substantial difference in critical load may be somewhat distorted from the "true" critical load because current lake chemistry may not be in equilibrium with current emissions (which is a necessary assumption for some of the calculations in the SSWC).
- **Original ANC_{limit}:** The relatively small difference in ANC_{limit} between the STAR and updated value has minimal effect on the estimated critical loads.

LAK044 is not sensitive to changes in assumptions because the estimated critical load is always zero under all sensitivity analyses. The lakes with the next three lowest critical loads (LAK042, LAK006, and LAK023) are not very sensitive to any of the changes in assumptions.

Table 2-5. Exceedances of revised critical loads for EEM Lakes and sensitivity analyses, for deposition under the 42 tpd emissions scenario. Red cells indicate positive exceedances (>0 meq/m²/yr).

	Exceedances of critical loads sensitivity analyses under 42 tpd emissions scenario				
Lakes	NEW CLs – with best inputs	NEW CLs – post-KMP lake chem.	NEW CLs – revised run-off	NEW CLs – alternate F-factor	NEW CLs – original ANC limit
EEM Sensitive Lakes					
LAK006	-8.9	-13.9	-6.0	-8.7	-13.0
LAK012	-48.3	-45.3	-41.5	-48.5	-52.3
LAK022	-39.3	-42.5	-33.5	-38.3	-43.2
LAK023	-13.9	-16.2	-10.7	-13.6	-18.1
LAK028	-8.5	-18.0	-0.5	25.4	-16.0
LAK042	-6.3	-8.8	-4.6	-6.2	-9.1
LAK044	11.4	11.4	11.3	11.4	11.4
EEM Less Sensitive Lakes					
LAK007	-1353.5	-1354.1	-1215.2	-1353.5	-1357.9
LAK016	-96.7	-99.4	-84.9	-95.8	-101.0
LAK024	-531.4	-591.1	-476.3	-531.4	-537.1
LAK034	-126.0	-105.5	-112.1	-126.0	-129.4

The sensitivity analyses of the estimated exceedances of critical loads under the 42 tpd emissions scenario show (Table 2-5, Figure 2-10):

- LAK044 always shows exceedance because the critical load is zero
- LAK028 shows an exceedance when using the alternate F-factor. However, as discussed above, the calculation of the model-based F-factor estimation is greatly affected by changes in SO_4^{2-} and base cations and model-based estimation may not result in an appropriate F-factor when lake chemistry is not in equilibrium with deposition.

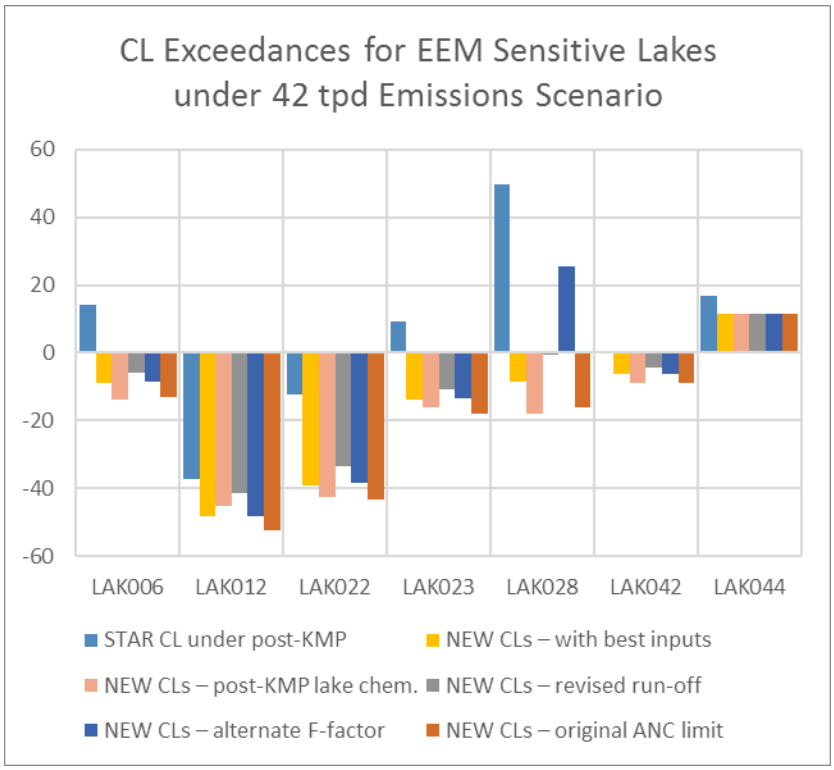


Figure 2-10. Estimated exceedances of critical loads under the 42 tpd emissions for each of the EEM sensitive lakes, by sensitivity analysis.

With seven years of sampling data, it is possible that an empirically based F-factor could be estimated based on the observational data. We had predicted that LAK028 would be the only lake with changes in base cations and sulphate of a sufficient magnitude to generate an empirically based estimate of the F-factor. However, we looked at the ratio of changes in base cations to changes in sulphate for all of the lakes across different time periods within the seven-year period of record. As predicted, LAK028 is the only lake for which a valid F-factor (i.e., between 0 and 1) could be calculated. Given the sensitivity of LAK028 to the alternate F-factor (as above), we explored multiple ways of estimating the F-factor, and the resulting impacts on the estimated critical load and exceedance, for LAK028 (Table 2-6).

All of the alternate methods of estimating a potential F-factor for LAK028 generate a higher F-factor and therefore a lower critical load (because the higher F-factor leads to a lower estimate of original pre-industrial base cations) and thus higher estimated exceedances. Interestingly, updating the estimate of the F-factor for LAK028 using the full observation record leads to an estimated CL of 47.2 (second row in Table 2-6), very similar

to the STAR estimate of 47.5 (Table 2-3). The various sensitivity analyses in Table 2-6 suggest that it is quite possible that the deposition associated with emissions of 42 tpd would be in excess of the CL for LAK028. Even so, LAK028 has shown no pH decrease from 2012 to 2016-2018, and is expected to have only a small decrease in pH (0.2 pH units) between 2016-2018 and steady state conditions under 42 tpd (see section 3 on steady state predictions of future pH).

Table 2-6. Sensitivity of LAK028 critical loads and exceedances to changes in the F-factor UNDER 42 tpd

Critical Loads Sensitivity Scenario		F-factor applied				Critical Load ($meq/m^2/yr$)	Exceedance under 42 tpd ($meq/m^2/yr$)
	Description / rationale	Type of estimate	Inputs		Value		
NEW CLs – with best inputs	STAR estimate	Model	STAR runoff, baseline chemistry		0.44	88.1	-8.5
NEW CLs – alternate F-factors	Update STAR estimate with full observation record	Model	STAR runoff, 2012-2018 chemistry		0.69	47.2	25.4
Post-KMP F-factor	If estimated only using post-KMP data	Model	Current runoff (lower), 2016-2018		0.70	45.2	27.4
Empirical F-factor	F-factor implied by observed changes	Measured	Observed changes in BC and SO_4 from 2012-2014 to 2016-2018		0.85	24.2	48.5
F-factor estimated from regression of observations	F-factor implied by observed relationship	Estimated	Slope of the regression for the relationship between BC and SO_4 for 2012 to 2018 based on:	Mean annual values	0.68	47.9	24.7
				Individual samples	0.81	29.8	42.9

2.5.3 Sensitivity Analyses on CALPUFF Modeled Deposition Estimates

As discussed elsewhere in the Comprehensive Review, the CALPUFF model may be under/overestimating deposition in different regions of the study area. We performed sensitivity analyses of exceedances under deposition levels of 50% (0.5x) and 200% (2.0x) of the modeled deposition estimates for the original critical loads across all lakes under 29.3 tpd (Table 2-7) and for the new critical loads for the EEM lakes under 42 tpd.

For the full set of lakes (using original critical loads under current emissions), the number of lakes with estimated exceedances decreases by one (LAK028) under the 50% reduction in deposition, but there is no change in the number of lakes with estimated exceedances under the doubling of deposition values.

For the EEM lakes (using new critical loads under maximum future emissions), there is one lake with an estimated exceedance under the existing modeled deposition (LAK044), which does not change under the 50%

reduction in deposition. When the deposition values are doubled, two additional lakes show exceedances (LAK006 and LAK028).

Table 2-7. Sensitivity of exceedances (under 29.3 tpd) of original STAR/KAA critical loads for all lakes within the study area to uncertainty in the CALPUFF deposition estimates.

	Exceedance of Original CLs under Actual Current Emissions (29.3 tpd)		
	0.5x deposition	1.0x deposition	2.0x deposition
EEM Sensitive Lakes			
LAK006	-16.3	-11.9	-3.0
LAK012	-67.4	-63.1	-54.6
LAK022	-42.1	-38.0	-29.9
LAK023	-20.2	-16.1	-8.1
LAK028	-15.9	7.6	54.7
LAK042	-6.8	-5.6	-3.2
LAK044	8.7	9.8	12.0
EEM Less Sensitive Lakes			
LAK007	-1377.7	-1369.8	-1354.2
LAK016	-103.0	-98.2	-88.6
LAK024	-358.1	-353.9	-345.5
LAK034	-115.3	-113.7	-110.4
Other STAR Lakes			
LAK001	-591.7	-588.5	-582.0
LAK002	-101.7	-98.1	-90.7
LAK003	-483.5	-470.5	-444.5
LAK004	-194.6	-192.0	-186.6
LAK005	-100.6	-95.3	-84.5
LAK008	-1681.4	-1673.9	-1658.9
LAK011	-89.3	-86.8	-82.0
LAK013	-708.3	-703.6	-694.2
LAK014	-98.6	-94.0	-84.9
LAK015	-203.3	-190.1	-163.6
LAK017	-212.6	-201.8	-180.1
LAK018	-1457.3	-1449.2	-1433.1
LAK027	-230.2	-214.0	-181.8
LAK030	-754.4	-730.0	-681.2
LAK032	-939.7	-938.5	-935.9
LAK035	-81.0	-78.7	-74.0
LAK037	-124.4	-122.1	-117.5
LAK038	-168.1	-165.7	-160.7
LAK039	-88.3	-85.9	-81.2
LAK041	-44.9	-44.3	-43.1
LAK045	-216.6	-215.9	-214.5
LAK047	10.5	11.4	13.2
LAK049	-224.1	-223.1	-221.1
LAK050	-104.4	-103.7	-102.1
LAK051	-227.5	-226.3	-224.0
LAK053	-91.1	-87.8	-81.3
LAK054	15.8	23.0	37.6

LAK055	-105.9	-99.4	-86.5
LAK056	13.4	19.8	32.6
LAK057	-405.7	-399.1	-386.1
KAA Lakes Located within 2019 Deposition Modeling Area			
MOE3	-605.2	-601.8	-595.1
DCAS10A	-35.2	-34.3	-32.6
DCAS10B	-26.0	-25.1	-23.4
DCAS17A	-421.9	-420.1	-416.5
DCAS02C	-65.4	-63.6	-60.0
DCAS07A	10.0	11.1	13.3
DCAS07B	10.1	11.3	13.6
DCAS09A	-56.6	-55.4	-53.0
DCAS09B	-19.3	-18.2	-15.9
Additional Lakes Sampled during the EEM			
MOE6	-400.4	-388.1	-363.5

Table 2-8. Sensitivity of exceedances (under 42 tpd) of new critical loads for EEM lakes to uncertainty in the CALPUFF deposition estimates.

	Exceedance of New CL for EEM Lakes under "Permit" Emissions (42 tpd)		
	0.5x deposition	1.0x deposition	2.0x deposition
EEM Sensitive Lakes			
LAK006	-15.0	-8.9	3.3
LAK012	-54.1	-48.3	-36.5
LAK022	-44.9	-39.3	-28.1
LAK023	-19.5	-13.9	-2.8
LAK028	-40.3	-8.5	55.1
LAK042	-8.0	-6.3	-2.9
LAK044	9.5	11.4	15.0
EEM Less Sensitive Lakes			
LAK007	-1364.5	-1353.5	-1331.4
LAK016	-103.3	-96.7	-83.4
LAK024	-537.3	-531.4	-519.6
LAK034	-128.3	-126.0	-121.3

3 Future Steady-state pH

3.1 Introduction / Background

The second major component of the analyses presented in this appendix is the prediction of future steady-state pH under conditions of increased acidic deposition.

To assess the eventual steady-state pH that will result from acidic deposition under a particular emissions scenario we have applied the same methodology as we used in the STAR. In the STAR we developed an approach based on the ESSA/DFO model described in Marmorek et al. (1990). This model predicts the change in ANC (ΔANC) based on the lake's water chemistry (i.e., it considers the F factor), the change in sulphur deposition and the runoff of the watershed. The implementation of this model is described in detail in Section 8.6.3.4 of the STAR report (ESSA et al. 2013).

We then used the resulting steady-state ANC value (ANC_∞) as an input to the titration curve based on Small and Sutton (1986) to calculate the steady-state pH (pH_∞). This semi-independent method for estimating potential change in pH, as it is based on the ESSA/DFO model rather than the SSWC model, relies on current ANC rather than current base cations as a starting point. It should be stressed that both methods use the same F-factor, which in turn is derived from current base cation concentrations and is a key uncertainty in both models.

We generated new, improved predictions of pH_∞ for the EEM lakes using the data collected from 2012 to 2018. Then we conducted a broad set of sensitivity analyses that apply varying assumptions about the model inputs. We also applied limited sensitivity analyses to the original predictions of pH_∞ (i.e., from the STAR or KAA) across all of the lakes within the study area, in places where updated model inputs are available across the entire set of lakes.

3.2 Objectives for Steady-state pH Modeling

Steady-state pH Objectives:

1. How do the STAR predictions of pH_∞ change with updated data that can be applied to all lakes?
2. For lakes with post-KMP sampling data, what is our best, improved prediction of pH_∞?
3. How sensitive are "best estimates" for pH_∞ to variation in the input assumptions?
4. How sensitive are the estimates of steady-state pH to uncertainty in the deposition estimates?

3.3 ESSA-DFO Model Inputs

The model inputs for the ESSA-DFO model are described below in terms of what improvements are available relative to the data used in the STAR. These data are only described at a very high level so as to communicate the key elements of each input. These inputs are described extensively elsewhere (e.g., STAR, KAA, and/or other receptor/pathway chapters within the Comprehensive Review).

3.3.1 Lake Chemistry Data

We have calculated "current" pH and Gran ANC as the average of 2016-2018 conditions.

3.3.2 Sulphur Deposition Estimates

The sulphur deposition estimates (including background deposition) are explained earlier in Section 2.3.6 and in full detail in the Atmospheric Pathways chapter and appendices.

The updated CALPUFF modelling allows prospective modelling of changes in pH using the ESSA-DFO model because it provides deposition estimates under current emissions levels (i.e., 29.3 tpd scenario) and two future scenarios – one representing the likely future emissions (i.e., 35 tpd) and one representing the maximum future emissions (i.e., 42 tpd). These data are essential because the ESSA-DFO model is based the magnitude of *changes in deposition.* However, this means that the updated CALPUFF estimates do no allow retrospective modelling of the change in pH from pre-KMP conditions to current conditions because we do not have deposition modeling estimates from those two time periods produced within the same modelling framework – i.e., the modelling framework (including meteorological years, input data and other assumptions) that was used to generate the pre-KMP scenario in the STAR is different than the framework used to produce the updated 29.3 tpd scenario, and therefore they cannot be directly compared to generate estimates of changes in deposition within a particular watershed.

3.3.3 Runoff Estimates

See Section 2.3.2.

3.3.4 F-factor

See Section 2.3.3.

3.3.5 pH-ANC Relationship

See Section 2.3.5.

3.3.6 Summary of Model Inputs

The model inputs described above are summarized in Table 3-1, differentiating among STAR inputs, improved inputs, and potential alternatives.

Table 3-1. Model inputs for ESSA-DFO model, as used in the STAR plus updated data now available for improved estimates and/or sensitivity analyses.

	What was used in STAR	Best updated data	Potential alternatives (sensitivity)
Lake Chemistry	• 2012 lake data (2013 for KAA)	• 2016-2018 lake data	
Δ S Dep	• Pre-KMP vs. Post-KMP	• 29.3 tpd (actual current) vs. 42 tpd (permit limit)	• 29.3 tpd (actual current) vs. 35 tpd (likely future) • 0.5x modeled deposition • 2.0x modeled deposition
Run-off	• STAR runoff		• STAR runoff scaled based on 2016-18 precipitation
F-factor	• Model-based (STAR estimate)		• Model-based (revised runoff, 2016-18 chemistry) *[EEM lakes only]*
pH-ANC relationship	• STAR pH-ANC curve	• Updated pH-ANC curve	

3.4 ESSA-DFO Model Scenarios

This section outlines the ESSA-DFO model scenarios and sensitivity analyses run to address each of the steady-state pH modeling objectives.

3.4.1 ESSA-DFO – Revisions to STAR predictions of pH_∞ for ALL lakes

Steady-state pH Objective 1: How do the STAR predictions of pH_∞ change with updated data that can be applied to all lakes?

ESSA-DFO Run #1 → original predictions ("BASE CASE")

ESSA-DFO Run #2 (sensitivity) → BASE CASE + revised (lower) runoff

ESSA-DFO Run #3 (sensitivity) → BASE CASE + revised pH-ANC relationship

3.4.2 ESSA-DFO – New, Improved Predictions of pH_∞ for EEM lakes only

Steady-state pH Objective 2: For lakes with post-KMP sampling data, what is our best, improved prediction of pH_∞ ?

ESSA-DFO Run #4 → new prediction of pH_∞ of with best inputs ("BEST CASE")

The following table indicates the data inputs used to develop the "BEST CASE" new estimates for the CLs of the EEM lakes. The rationale for each selection is discussed in Section 3.3 above.

	Data to use
Lakes	• EEM lakes (sensitive, less sensitive, control)
Lake Chemistry	• 2016-18 lake data
Δ S Dep	• 29.3 tpd to 42 tpd
Runoff	• STAR runoff
F-factor	• STAR model estimate
pH-ANC relationship	• Updated pH-ANC curve (@ pH=6)

Steady-state pH Objective 3: How sensitive are "best estimates" for pH_∞ to variation in the input assumptions?

ESSA-DFO Run #6 (sensitivity) → BEST CASE + revised (lower) runoff

ESSA-DFO Run #7 (sensitivity) → BEST CASE + revised F-factor

ESSA-DFO Run #8 (sensitivity) → BEST CASE + original pH-ANC relationship

3.4.3 Summary of ESSA-DFO Model Runs

The table below provides a visual summary of all the ESSA-DFO model scenarios and sensitivity runs described in the previous sections. There are two "base cases" (denoted by the green columns) – one that is applicable to the entire set of STAR and additional lakes, and one that is applicable only to the EEM lakes. The data inputs used in each base case are marked with **black 'X's** whereas the **red 'X's** indicate the changes from the base case, as applied in various sensitivity analyses.

		STAR predictions (All lakes)				New predictions (EEM lakes)			
Model Input	Data Set / Method	STAR pred. – original results	STAR pred. – revised runoff	STAR pred. – improved pH-ANC		NEW pred. – with best inputs	NEW pred. – revised runoff	NEW pred. – revised F-factors	NEW pred. – original pH-ANC
Estimation of pH∞									
Lake Chemistry	2012 lake data	X	X	X					
	2016-2018 lake data					X	X		X
Runoff (future)	Original (higher) runoff	X		X		X		X	X
	Revised (lower) runoff		X				X		
F-factor	Model-based (STAR estimate)	X	X	X		X	X		X
	Model-based (revised runoff, post-KMP chem.)							X	
pH-ANC relation	STAR regional pH-ANC curve	X	X						X
	Updated pH-ANC curve			X		X	X	X	
Emissions Scenario									
Δ S Dep	preKMP to postKMP	✓	✓	✓					
	29.3 tpd to 42 tpd					✓	✓	✓	✓
	29.3 tpd to 35 tpd					✓			

3.4.1 Sensitivity Analyses on CALPUFF Modeled Deposition Estimates

Steady-state pH Objective 4: How sensitive are the "best case" estimates of steady-state pH to uncertainty in the deposition estimates?

ESSA-DFO Run #4 under 29.3 tpd & 42 tpd, with uncertainty factors of 0.5, 1.0, 1.5, 2.0

3.5 ESSA-DFO Model Results

3.5.1 Original predictions of pH∞ for ALL lakes and sensitivity analyses

The following results and sensitivity analyses only apply to the STAR lakes. The KAA lakes could not be analyzed in the same way because we do not have deposition estimates for these lakes that align with the "post-KMP" emissions scenario in the STAR. The KAA study did not include a scenario that included maximum smelter emissions (i.e., 42 tpd SO_2 under the permit) in isolation from increases in emissions from other regional sources.

There are two sensitivity analyses that are possible to apply to the STAR predictions the entire set of available lakes – a) reduced run-off and b) the revised pH-ANC relationship. In order to compare the effect of changes in these inputs with the results from the STAR, the same deposition data must be used (i.e., changes in deposition between the "pre-KMP" and "post-KMP" modelled deposition used in the STAR). Furthermore, it is not possible to do a valid sensitivity analysis with the revised deposition modeling (i.e., to see the effect of using the new 42 tpd results) because we do not have an estimate of pre-KMP deposition that was generated within the same modeling framework in order to calculate a change in deposition.

The results of these sensitivity analyses and the original STAR results are shown in Table 3-2 and Figure 2-2.

The sensitivity analyses show that an assumption of lower run-off (i.e., if recent precipitation levels are more representative of future precipitation levels than the historic data used in the STAR) leads to a lower prediction for steady-state pH and therefore a greater ΔpH from 2012. The effect is largest for the lakes for which the STAR already predicted the largest changes in pH (i.e., the lakes selected for the EEM). Using the updated, revised pH-ANC relationship led to some increases and some decrease in the predicted ΔpH as compared to the STAR results, but generally had an effect of smaller magnitude. However, in both cases there was no change in the number of EEM lakes with decreases of more than 0.1 or 0.3 pH units

For the STAR lakes, there is one lake (LAK005) that shows a predicted decrease of more than 0.1 pH units under both sensitivity analyses (but did not in the original STAR results). However, this actually reflects a very minor change and there is no difference among the scenarios when rounded to a single decimal place (i.e., in the STAR the predicted was a decrease of 0.098 pH units.

The conclusions of the STAR are not sensitive to the changes tested.

Table 3-2. Predictions of pH_∞ and ΔpH (from 2012) from the STAR and two sensitivity analyses across all STAR lakes. Note that these analyses are based on the same deposition modelling as applied in the STAR (i.e., "pre-KMP" and "post-KMP" modeled deposition), as discussed further in the text.

Lake	2012 pH	STAR predictions		STAR prediction with revised (lower) runoff		STAR prediction with revised pH-ANC relationship	
		pH_∞	Δ pH	pH_∞	Δ pH	pH_∞	Δ pH
EEM Sensitive Lakes							
LAK006	5.8	5.3	-0.5	5.2	-0.6	5.3	-0.5
LAK012	5.6	5.5	-0.1	5.5	-0.1	5.5	-0.1
LAK022	5.9	5.5	-0.4	5.5	-0.5	5.5	-0.4
LAK023	5.7	5.2	-0.5	5.1	-0.6	5.2	-0.5
LAK028	5.0	4.6	-0.4	4.6	-0.4	4.7	-0.3
LAK042	4.7	4.5	-0.2	4.5	-0.2	4.5	-0.2
LAK044	5.4	4.9	-0.5	4.8	-0.6	4.9	-0.5
EEM Less Sensitive Lakes							
LAK007	8.0	8.0	0.0	8.0	0.0	8.0	0.0
LAK016	6.3	6.2	-0.1	6.2	-0.1	6.2	-0.1
LAK024	7.1	7.1	0.0	7.1	0.0	7.1	0.0
LAK034	6.7	6.7	0.0	6.7	0.0	6.7	0.0
Other STAR Lakes							
LAK001	7.6	7.6	0.0	7.6	0.0	7.6	0.0
LAK002	6.6	6.6	-0.1	6.6	-0.1	6.6	-0.1
LAK003	7.1	7.1	0.0	7.1	0.0	7.1	0.0
LAK004	6.5	6.5	0.0	6.5	0.0	6.5	0.0
LAK005	6.1	6.0	-0.1	6.0	-0.1	6.0	-0.1
LAK008	7.9	7.9	0.0	7.9	0.0	7.9	0.0
LAK011	6.6	6.6	0.0	6.6	0.0	6.6	0.0
LAK013	7.4	7.4	0.0	7.4	0.0	7.4	0.0
LAK014	6.5	6.4	-0.1	6.4	-0.1	6.4	-0.1
LAK015	6.0	6.0	0.0	6.0	0.0	6.0	0.0
LAK017	6.8	6.8	0.0	6.8	0.0	6.8	0.0
LAK018	8.1	8.1	0.0	8.1	0.0	8.1	0.0
LAK027	6.6	6.6	0.0	6.6	0.0	6.6	0.0
LAK030	7.4	7.4	0.0	7.4	0.0	7.4	0.0
LAK032	7.0	7.0	0.0	7.0	0.0	7.0	0.0
LAK035	6.2	6.2	-0.1	6.2	-0.1	6.2	-0.1
LAK037	6.6	6.5	0.0	6.5	0.0	6.5	0.0
LAK038	6.6	6.5	0.0	6.5	0.0	6.5	0.0
LAK039	6.4	6.3	0.0	6.3	0.0	6.3	0.0
LAK041	6.5	6.5	0.0	6.5	0.0	6.5	0.0
LAK045	6.9	6.9	0.0	6.9	0.0	6.9	0.0
LAK047	6.0	5.9	0.0	5.9	0.0	5.9	0.0
LAK049	6.8	6.8	0.0	6.8	0.0	6.8	0.0
LAK050	6.5	6.5	0.0	6.5	0.0	6.5	0.0
LAK051	6.8	6.7	0.0	6.7	0.0	6.7	0.0
LAK053	6.6	6.6	0.0	6.6	0.0	6.6	0.0
LAK054	4.6	4.5	-0.1	4.5	-0.1	4.5	-0.1
LAK055	6.2	6.1	0.0	6.1	0.0	6.1	0.0
LAK056	4.5	4.4	-0.1	4.4	-0.1	4.4	-0.1
LAK057	6.6	6.6	0.0	6.6	0.0	6.6	0.0

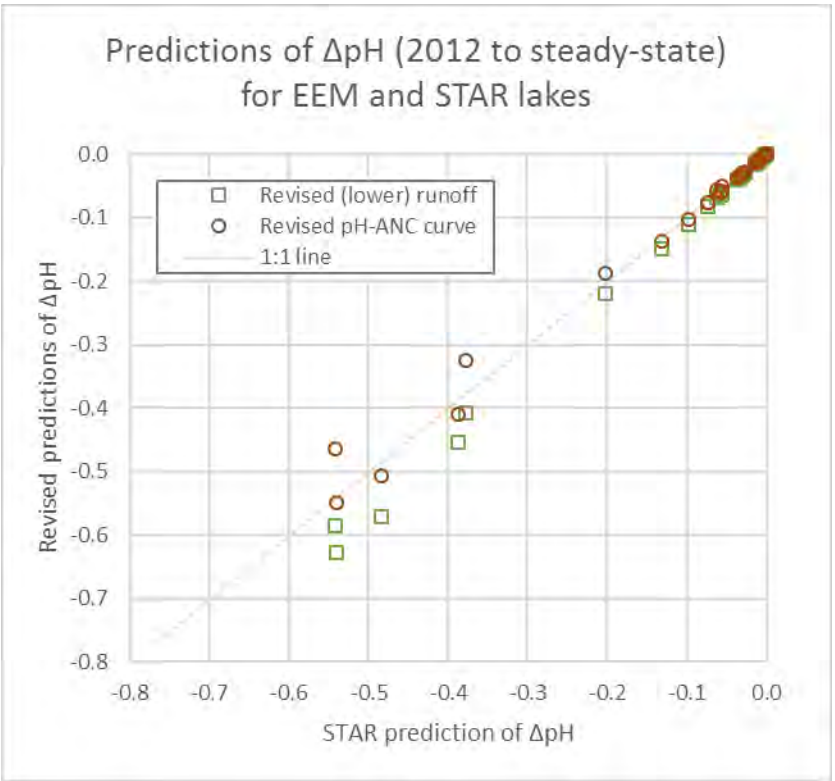


Figure 3-1. Sensitivity analyses of STAR predictions of the change from 2012 pH to steady-state pH.

3.5.2 New, Improved Predictions of pH_{∞} for EEM lakes only

The interpretation of the results in this section is confounded by the fact that while none of the EEM lakes are predicted to increase in pH under increased sulphur deposition (i.e., relative to post-KMP conditions, 2016-2018), the increases in pH already observed since 2012 mean that the new predictions for future steady-state pH are in fact still above 2012 pH levels. The new predictions for steady-state pH (i.e., based on post-KMP data, 2016-2018) show a decrease or no change for all EEM lakes relative to current condition; however, for 10 of the 11 EEM lakes, these changes are substantially smaller than the observed *increases* in pH from 2012 to the post-KMP period (Figure 3-2). The only exception is LAK034, which is not predicted to change at all from its current pH but has already shown a decrease in pH of 0.3 pH units (as described in the evidentiary framework, this change is not causally linked to the smelter because sulphate has decreased to zero over this same period and therefore the observed decrease in pH cannot possibly be associated with increasing sulphate) . These predicted changes in pH (from current levels) and smaller than those predicted in the STAR (Figure 3-3). Given that the predicted decreases are predominantly much smaller than the observed increase thus far, this means that when expressed as a change relative to 2012 (relevant for comparing results to the STAR and the baseline period defined in the EEM), *the calculated changes from 2012 show increases in pH for many of the lakes*. However, this is an indirect effect of the observed changes and should not be interpreted as a prediction that increased deposition will drive increases in pH in these particular lakes.

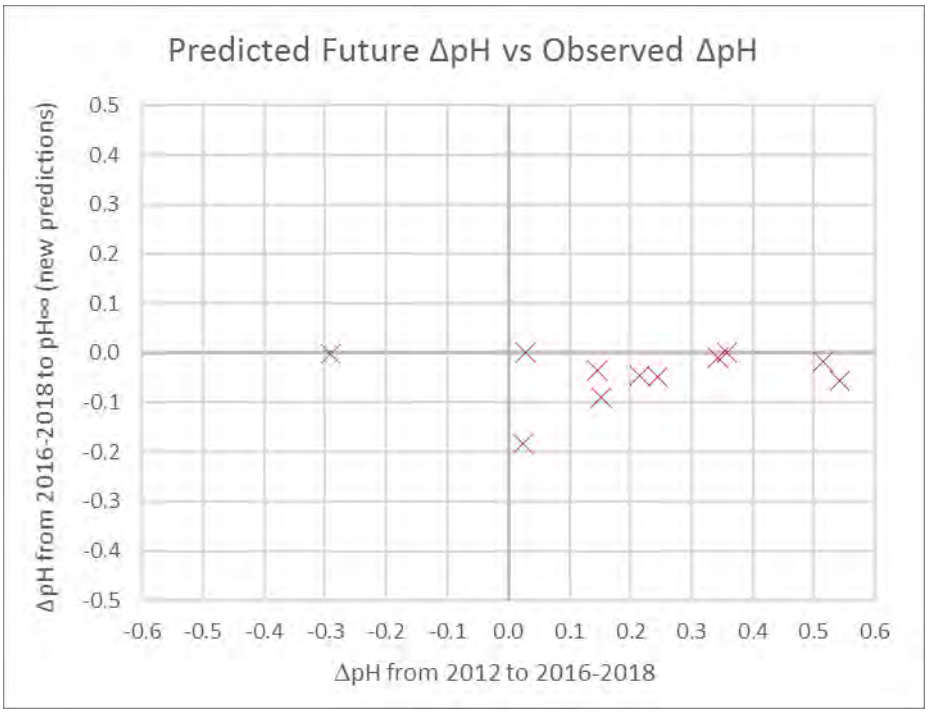


Figure 3-2. Predicted changes in pH from post-KMP (2016-2018) to future steady-state relative to the observed changes in pH during the EEM program thus far (i.e., 2012 to post-KMP). Predicted changes in pH are based on the increase in modeled deposition from current emissions (29.3 tpd) to the maximum future emissions level (42 tpd).

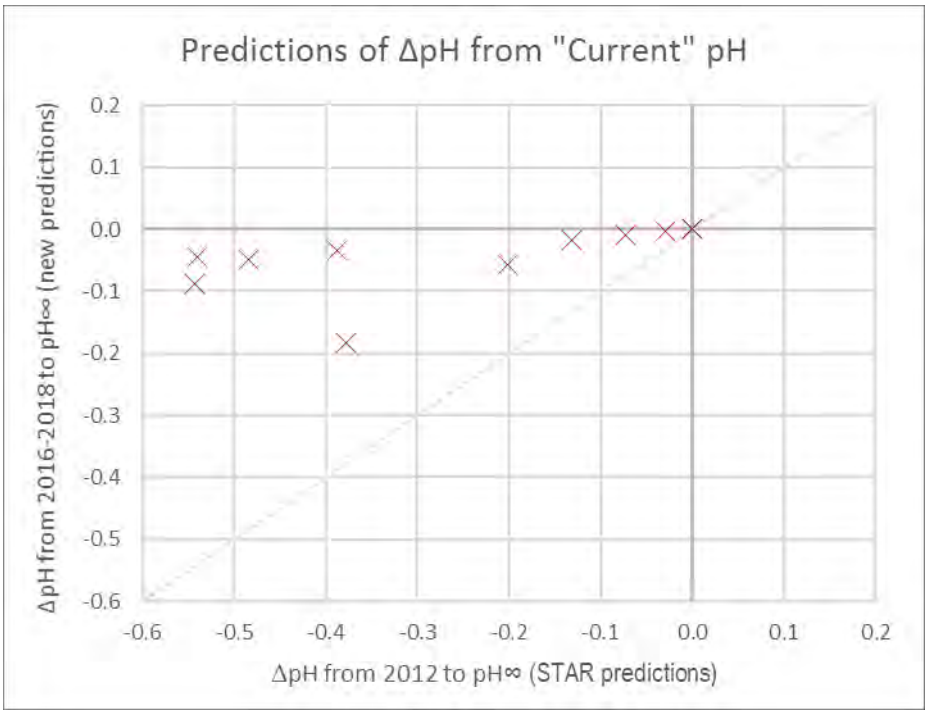


Figure 3-3. Predicted changes in pH from "current" time period (i.e, 2012 for the STAR predictions; 2016-2018 for new predictions). The STAR predictions were based on the change in deposition from the "pre-KMP" to the "post-KMP" modeled deposition. The new predictions are based on the increase in modeled deposition from current emissions (29.3 tpd) to the maximum future emissions level (42 tpd).

3.5.2.1 Core Scenario

The results for changes in pH from 2012 to steady-state conditions under 42 tpd based on the new, updated predictions of steady-state pH are shown in Figure 3-4. All lakes except LAK034 and LAK028 predict steady-state pH above 2012 levels (but still below post-KMP pH). The predicted decrease for LAK028 is smaller than predicted in the STAR. LAK034 shows larger predicted decrease than STAR prediction but this is misleading – LAK034 is not predicted to change at all from current pH, but pH is currently already below its 2012 levels (due to non-sulphate driven decrease in pH).

Figure 3-5 shows the STAR and current predictions for steady-state pH relative to observed pH values for 2012 and the post-KMP period (2016-2018) for all of the EEM lakes. This provides an alternative way of visualizing the common patterns – i.e., that pH is predicted to decrease or remain unchanged for all of the EEM lakes relative to current pH, but because current pH is predominantly above 2012 pH levels, these steady-state predictions appear to show an increase in pH when compared to 2012.

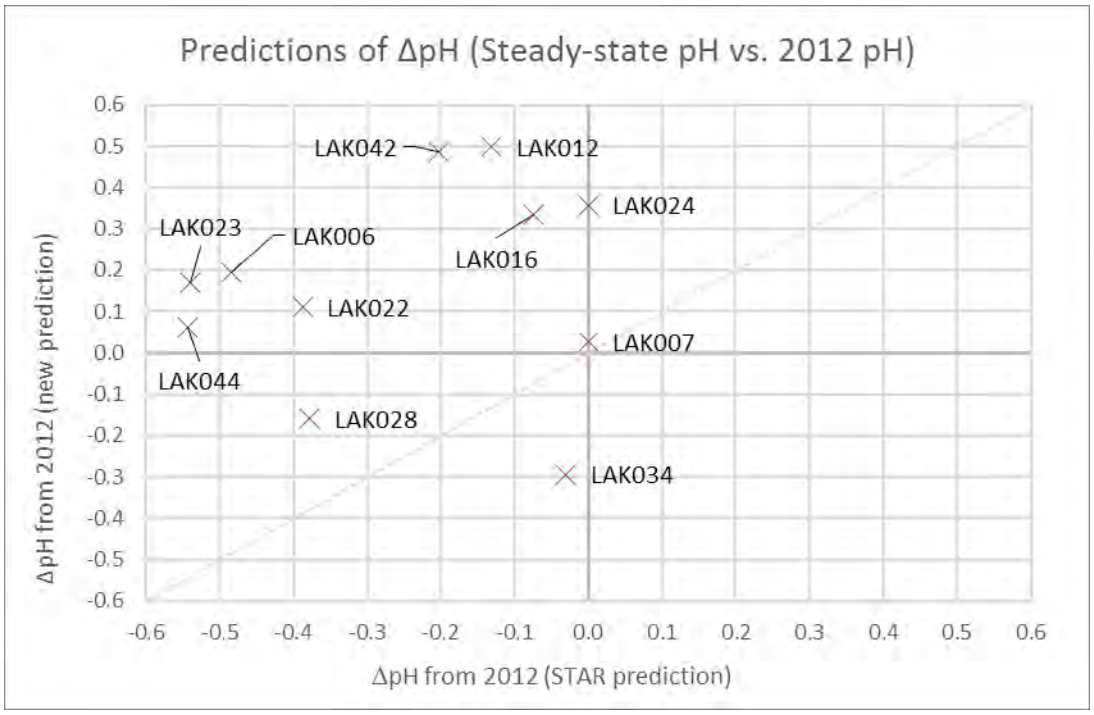


Figure 3-4. Predicted ΔpH (steady-state pH vs. 2012) based on new predictions of steady-state pH vs. STAR predictions. The STAR predictions were based on the change in deposition from the "pre-KMP" to the "post-KMP" modeled deposition. The new predictions are based on the increase in modeled deposition from current emissions (29.3 tpd) to the maximum future emissions level (42 tpd).

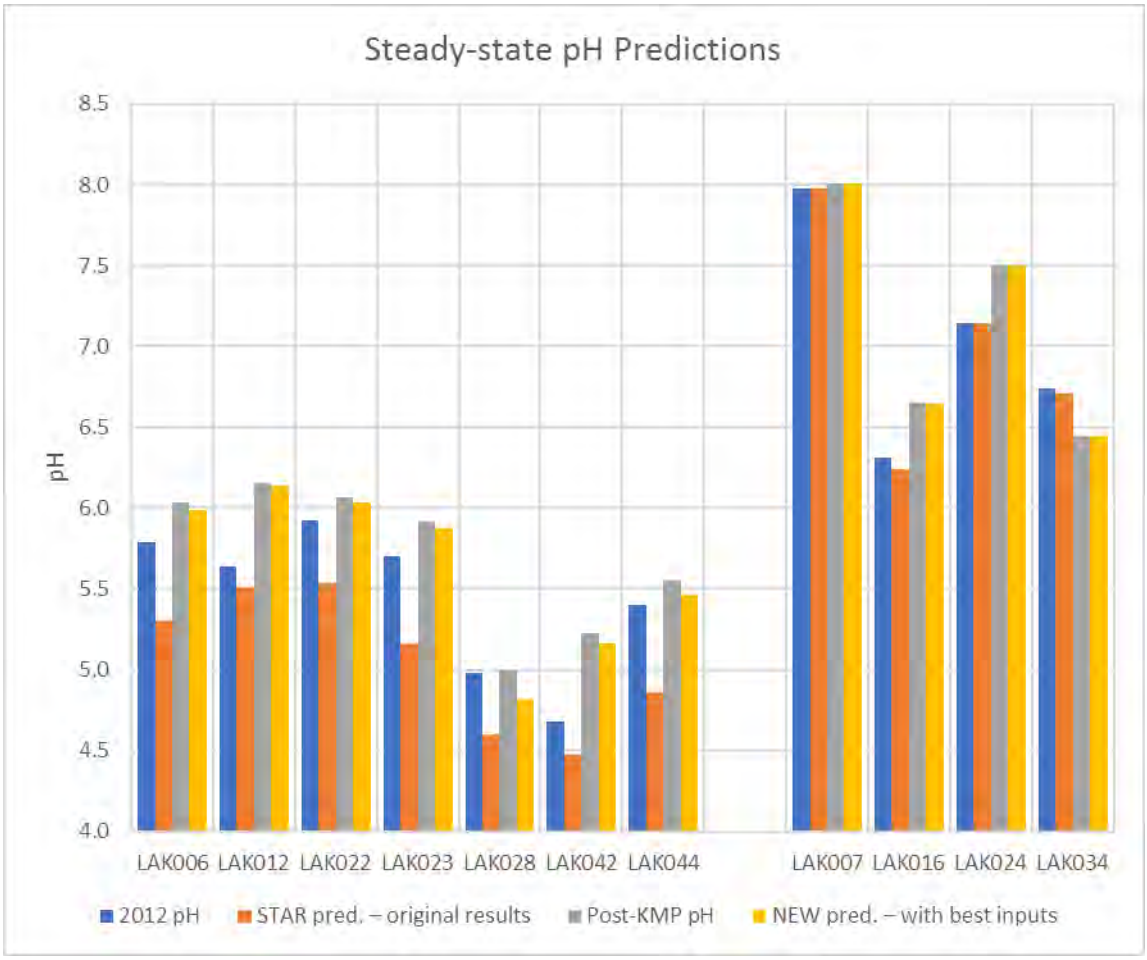


Figure 3-5.Observed pH and predicted steady-state pH for all of the EEM lakes. The STAR predictions were based on the change in deposition from the "pre-KMP" to the "post-KMP" modeled deposition. The new predictions are based on the increase in modeled deposition from current emissions (29.3 tpd) to the maximum future emissions level (42 tpd).

3.5.2.2 Sensitivity Analyses

The results of the sensitivity analyses on predictions of steady-state pH and calculated change from 2012 pH for all the EEM lakes are shown in Table 3-3 and Figure 3-6.

The sensitivity analyses show that the predicted steady-state pH and thus the calculated change from 2012 pH are generally not sensitive to the changes in the model inputs tested. LAK028 is the only lake that shows some variation among the sensitivity analyses performed, particularly with respect to the revised F-factor. As discussed at greater length, LAK028 is the only lake for which the revised estimation of the F-factor results in a meaningfully different value. Furthermore, given that LAK028 has experienced the highest levels of deposition and largest changes in lake chemistry, its results should be sensitive to the value of the F-factor.

Across all sensitivity analyses, LAK034 has a predicted decrease of 0.3 pH units relative to 2012. However, as described earlier the predicted pH change from current conditions is zero but its current pH is already 0.3 pH units below 2012 (as described in the evidentiary framework, this decline is unrelated to the smelter because sulphate has declined over the same period).

The sensitivity analyses on the broader set of all STAR lakes (Section 3.5.1) showed that using the revised runoff had a notable effect of on prediction greater decreases in pH. However, the new predictions of steady-state pH show negligible sensitivity to the revised runoff, which indicates that the effect of reduced run-off more than offset by the much lower changes in deposition from the new emissions modeling (i.e., the STAR predictions were based on much higher increases in deposition than predicted by the new emissions modeling)

Table 3-3. New predictions and sensitivity analyses of steady-state pH and resultant change in pH from 2012 for all EEM lakes, plus original predictions from the STAR. The STAR predictions were based on the change in deposition from the "pre-KMP" to the "post-KMP" modeled deposition. The new predictions are based on the increase in modeled deposition from current emissions (29.3 tpd) to the maximum future emissions level (42 tpd).

Lake	Empirical Observations		ORIGINAL: STAR predictions		NEW: Best Prediction		SENSITIVITY: Revised Runoff		SENSITIVITY: Revised F-factor		SENSITIVITY: Original pH-ANC curve	
	2012 pH	Post-KMP pH	pH_∞	Δ pH (2012)	pH_∞	Δ pH (2012)	pH_∞	Δ pH (2012)	pH_∞	Δ pH (2012)	pH_∞	Δ pH (2012)
EEM Sensitive Lakes												
LAK006	5.8	6.0	5.3	-0.5	6.0	0.2	6.0	0.2	6.0	0.2	6.0	0.2
LAK012	5.6	6.2	5.5	-0.1	6.1	0.5	6.1	0.5	6.1	0.5	6.1	0.5
LAK022	5.9	6.1	5.5	-0.4	6.0	0.1	6.0	0.1	6.0	0.1	6.0	0.1
LAK023	5.7	5.9	5.2	-0.5	5.9	0.2	5.9	0.2	5.9	0.2	5.9	0.2
LAK028	5.0	5.0	4.6	-0.4	4.8	-0.2	4.8	-0.2	4.9	-0.1	4.8	-0.2
LAK042	4.7	5.2	4.5	-0.2	5.2	0.5	5.2	0.5	5.2	0.5	5.2	0.5
LAK044	5.4	5.6	4.9	-0.5	5.5	0.1	5.5	0.1	5.5	0.1	5.5	0.1
EEM Less Sensitive Lakes												
LAK007	8.0	8.0	8.0	0.0	8.0	0.0	8.0	0.0	8.0	0.0	8.0	0.0
LAK016	6.3	6.7	6.2	-0.1	6.6	0.3	6.6	0.3	6.6	0.3	6.6	0.3
LAK024	7.1	7.5	7.1	0.0	7.5	0.4	7.5	0.4	7.5	0.4	7.5	0.4
LAK034	6.7	6.4	6.7	0.0	6.4	-0.3	6.4	-0.3	6.4	-0.3	6.4	-0.3

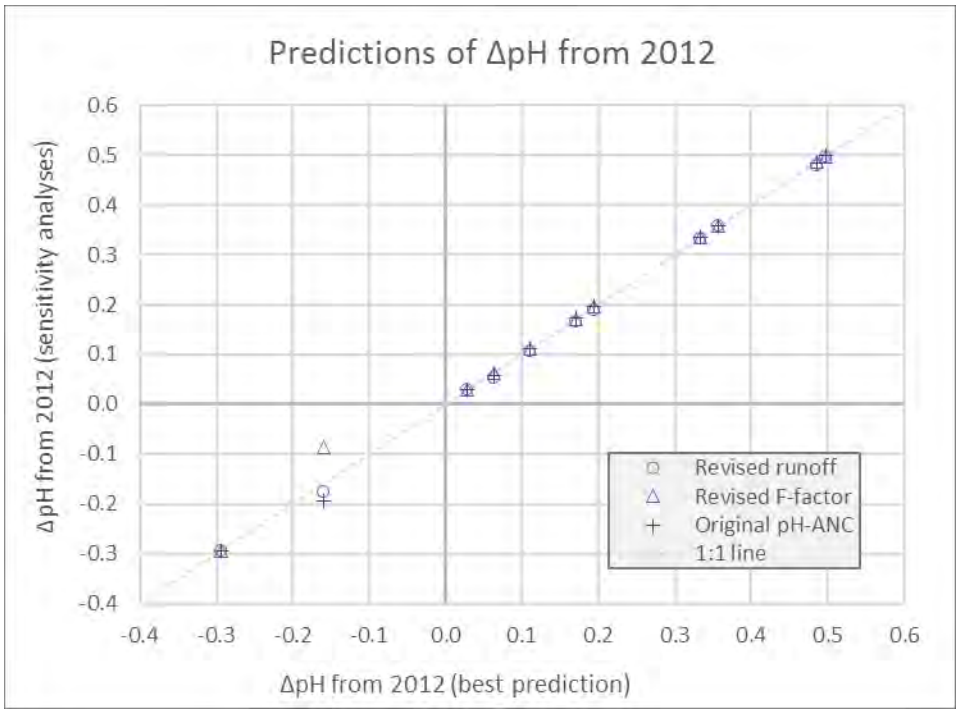


Figure 3-6. Predicted changes in pH (from 2012 to steady-state) based on the sensitivity analyses relative to the "best case" prediction. These predictions are based on the increase in modeled deposition from current emissions (29.3 tpd) to the maximum future emissions level (42 tpd).

3.5.3 Predictions of ANC_{∞} for EEM lakes only

The ESSA-DFO model includes a prediction of the change in Gran ANC that will occur under a particular level of deposition. Table 3-4 shows the Gran ANC predicted to occur under steady-state conditions with deposition associated with the 42 tpd emissions scenario. None of the sensitive EEM lakes are predicted to decline below their lake-specific thresholds identified from the analyses of the titration data (Figure 3-7). LAK007 is predicted below its lake-specific threshold but this is not a significant or concerning result because it has a very high Gran ANC (over an order of magnitude greater than other lakes) and its pH is not predicted to change at all even under maximum future deposition levels.

Table 3-4. Predicted future Gran ANC and resultant change in Gran ANC from 2012 with best inputs for ESSA-DFO model under modeled deposition from 42 tpd emissions scenario.

			NEW pred. – with best inputs		
	2012 Gran ANC	post-KMP Gran ANC (2016-2018)	Gran **ANC ∞**	**Δ Gran** ANC (2012)	**Δ Gran ANC (2012)** Threshold
EEM Sensitive Lakes					
LAK006	25.7	27.7	24.7	-1.0	-10.8
LAK012	57.0	58.3	56.0	-1.0	-16.3
LAK022	27.8	33.0	30.4	2.6	-11.5
LAK023	19.8	26.4	23.8	4.0	-10.5
LAK028	-4.0	-3.5	-9.3	-5.3	-13.4
LAK042	-20.4	5.6	4.2	24.6	-24.4
LAK044	1.3	5.0	2.8	1.5	-6.2
EEM Sensitive Lakes					
LAK007	1437.6	1385.9	1385.9	-51.6	-50.6
LAK016	68.7	89.8	88.0	19.4	-25.6
LAK024	299.5	463.2	463.2	163.7	-60.4
LAK034	99.4	139.6	138.7	39.3	-22.0

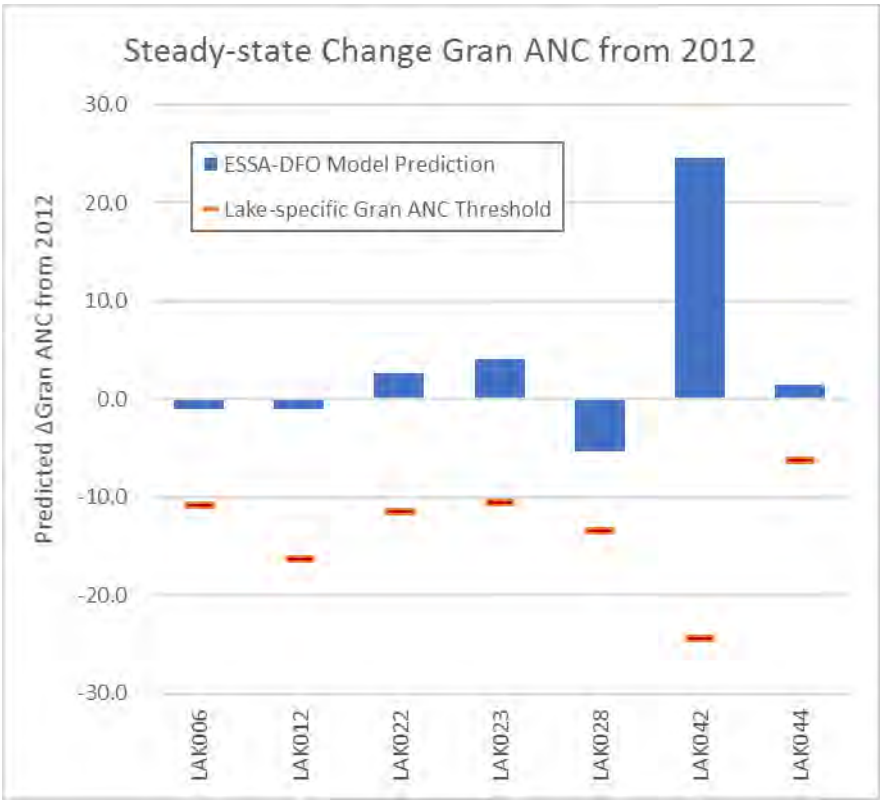


Figure 3-7. Predicted future Gran ANC using ESSA-DFO model under 42 tpd emissions scenario, compared against the lake-specific thresholds. The Gran ANC thresholds were developed from analysis of the lab titration data in order to determine the magnitude of change in Gran ANC equivalent to a 0.3 unit decrease in pH.

3.5.4 Sensitivity Analyses on CALPUFF Modeled Deposition Estimates

The results of the sensitivity analyses on the uncertainty in the CALPUFF deposition estimates are shown in Table 3-5 and Figure 3-8.

LAK028 is the only lake that shows a sensitivity to a change in deposition assumptions. If deposition under the 42 tpd emissions scenarios is assumed to be 50% of the CALPUFF model estimates, then the predicted change in pH from 2012 levels would no longer exceed a 0.1 unit decrease. If deposition under the 42 tpd emissions scenarios is assumed to be 200% of the CALPUFF model estimates, then the predicted change in pH from 2012 levels would increase to greater than a 0.3 unit decrease. The other sensitive lakes show slight changes that are visible in Figure 3 8 but are predominantly too small to show up in Table 3 5 where results are rounded to a single decimal place.

The steady-state pH predictions for the less sensitive lakes are completely insensitive to the halving or doubling of the CALPUFF deposition estimates.

LAK034 shows a decline of approximately 0.3 pH units (actual value is slightly less) from 2012 pH values under all of the tested deposition levels because this decline has already occurred (which is unrelated to the smelter as explained by the evidentiary framework) and the ESSA-DFO model does not actually predict any change in pH from current levels, even when the deposition estimate is doubled.

Table 3-5. Sensitivity analyses on uncertainty in CALPUFF modeled estimates of deposition. 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.

	Baseline Lake Chemistry (2012)		Post-KMP Lake Chemistry (2016-2018)		0.5x Deposition		1.0x Deposition		2.0x Deposition	
	pH	Gran ANC	pH	Gran ANC	**pH∞**	Δ pH (2012)	**pH∞**	**Δ pH** (2012)	**pH∞**	**Δ pH** (2012)
EEM Sensitive Lakes										
LAK006	5.8	25.7	6.0	27.7	6.0	0.2	6.0	0.2	5.9	0.1
LAK012	5.6	57.0	6.2	58.3	6.1	0.5	6.1	0.5	6.1	0.5
LAK022	5.9	27.8	6.1	33.0	6.1	0.1	6.0	0.1	6.0	0.1
LAK023	5.7	19.8	5.9	26.4	5.9	0.2	5.9	0.2	5.8	0.1
LAK028	5.0	-4.0	5.0	-3.5	4.9	-0.1	4.8	-0.2	4.7	-0.3
LAK042	4.7	-20.4	5.2	5.6	5.2	0.5	5.2	0.5	5.1	0.4
LAK044	5.4	1.3	5.6	5.0	5.5	0.1	5.5	0.1	5.4	0.0
EEM Less Sensitive Lakes										
LAK007	8.0	1437.6	8.0	1385.9	8.0	0.0	8.0	0.0	8.0	0.0
LAK016	6.3	68.7	6.7	89.8	6.6	0.3	6.6	0.3	6.6	0.3
LAK024	7.1	299.5	7.5	463.2	7.5	0.4	7.5	0.4	7.5	0.4
LAK034	6.7	99.4	6.4	139.6	6.4	-0.3	6.4	-0.3	6.4	-0.3

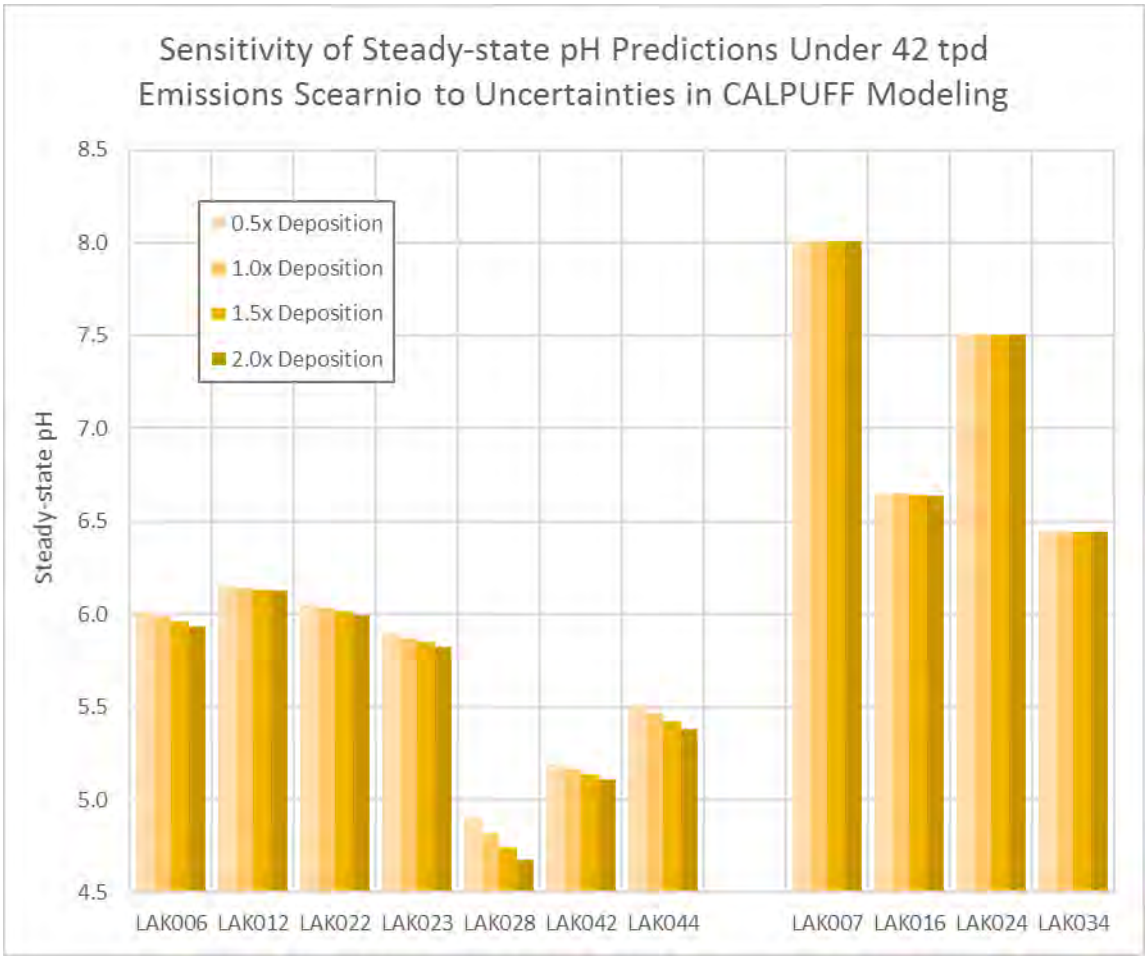


Figure 3-8. Sensitivity of steady-state pH predictions for EEM lakes to uncertainty in the CALPUFF modeled estimates of deposition.

4 Key Results

4.1 Critical Loads and Steady-state pH for EEM Lakes

The results from the "best case" analyses of the critical loads and steady-state pH for the EEM lakes are shown in Table 4-1. To be most conservative, these forward-looking analyses have been performed assuming the maximum level of emissions allowed under the permit (i.e., 42 tpd scenario). For each of the key metrics of interest (i.e., exceedances of critical loads, predicted changes in pH relative to the 2012 baseline, and predicted changes in Gran ANC thresholds relative to the 2012 baseline), there is only one lake that exceeds the reference threshold (as defined in the table caption):

Exceedance of critical loads

LAK044 has a critical load of zero and therefore shows a positive exceedance under all deposition scenarios. None of the other EEM lakes are predicted to show an exceedance of their critical loads (i.e., revised estimates based on the best data inputs) under the maximum predicted deposition levels (i.e., 42 tpd emissions scenario).

Future changes in pH from baseline conditions

LAK034 is shown to have a predicted future pH that is 0.3 pH units below its 2012 level; however, this decline is unrelated to the smelter because sulphate has also decreased during the same period (as explained by the evidentiary framework). In fact, LAK034 is predicted to have zero change in pH from current (2016-18) levels, but these levels are already below 2012.

Future changes in Gran ANC from baseline conditions

LAK007 is shown to have a predicted change in Gran ANC that is greater than its lake-specific threshold; however, this result is an artifact of a change that has already occurred and is unrelated to the smelter. Gran ANC has declined since 2012 but because sulphate is also lower than 2012, the decline must not be driven by smelter emission (as per the evidentiary framework). LAK007 is highly insensitive to acidic deposition – it has very high Gran ANC and is predicted to have zero change in Gran ANC from current levels with higher deposition (even under the sensitivity analyses of 200% deposition). Furthermore, its pH has not changed since 2012 and is not predicted to change under any deposition scenario or sensitivity analysis.

Table 4-1. Summary of the estimated critical loads and the predicted exceedances, pH and Gran ANC under the 42 tpd emissions scenarios. Red cells indicate critical loads of zero, positive exceedances, predicted declines in pH of greater than 0.3 pH units, or predicted declines in Gran ANC that exceed the lake-specific threshold. Yellow cells indicate predicted declines in pH of greater than 0.1 pH units (but less than 0.3 pH units). The changes in LAK007 and LAK034 are unrelated to the smelter, as per the evidentiary framework and further explained in the text.

	CALPUFF results		SSWC Model Results		ESSA-DFO Model Results								
	S Deposition (42tpd)		Critical load	Ex(A)	pH				**Gran ANC (µeq/L)**				
LAKE	meq/ m^2/yr	kg/ha/ yr	meq/ m^2/yr	meq/ m^2/yr	Baseline (2012)	Post-KMP (2016-18)	Future (steady-state)	ΔpH (from 2012)	Baseline (2012)	Post-KMP (2016-18)	Future (steady-state)	ΔANC (from 2012)	ANC threshold
EEM Sensitive Lakes													
LAK006	12.2	5.9	29.4	-8.9	5.8	6.0	6.0	0.2	25.7	27.7	24.7	-1.0	-10.8
LAK012	11.8	5.7	68.1	-48.3	5.6	6.2	6.1	0.5	57.0	58.3	56.0	-1.0	-16.3
LAK022	11.2	5.4	58.3	-39.3	5.9	6.1	6.0	0.1	27.8	33.0	30.4	2.6	-11.5
LAK023	11.1	5.3	33.3	-13.9	5.7	5.9	5.9	0.2	19.8	26.4	23.8	4.0	-10.5
LAK028	63.6	30.5	81.1	-8.5	5.0	5.0	4.8	-0.2	-4.0	-3.5	-9.3	-5.3	-13.4
LAK042	3.4	1.6	17.4	-6.3	4.7	5.2	5.2	0.5	-20.4	5.6	4.2	24.6	-24.4
LAK044	3.6	1.7	0.0	11.4	5.4	5.6	5.5	0.1	1.3	5.0	2.8	1.5	-6.2
EEM Less Sensitive Lakes													
LAK007	22.1	10.6	1383.4	-1353.5	8.0	8.0	8.0	0.0	1437.6	1385.9	1385.9	-51.6	-50.6
LAK016	13.2	6.4	118.1	-96.7	6.3	6.7	6.6	0.3	68.7	89.8	88.0	19.4	-25.6
LAK024	11.8	5.7	551.6	-531.4	7.1	7.5	7.5	0.4	299.5	463.2	463.2	163.7	-60.4
LAK034	4.7	2.2	138.4	-126.0	6.7	6.4	6.4	-0.3	99.4	139.6	138.7	39.3	-22.0

4.2 STAR Criteria for Inclusion in EEM

As shown Figure 4-1, the STAR identified lakes with low pH (<6.0 pH units) and/or predicted exceedances of their critical loads and/or predicted declines in pH of greater than 0.1 pH units. The seven lakes identified for inclusion in the EEM program were those with a predicted pH decline of greater than 0.1 pH units. Lakes with existing pH<6.0 that did not have a predicted pH decline greater than 0.1 pH units were not included. Lakes with a positive exceedance and pH>6.0 would have been considered for inclusion but none of the STAR lakes met those criteria.

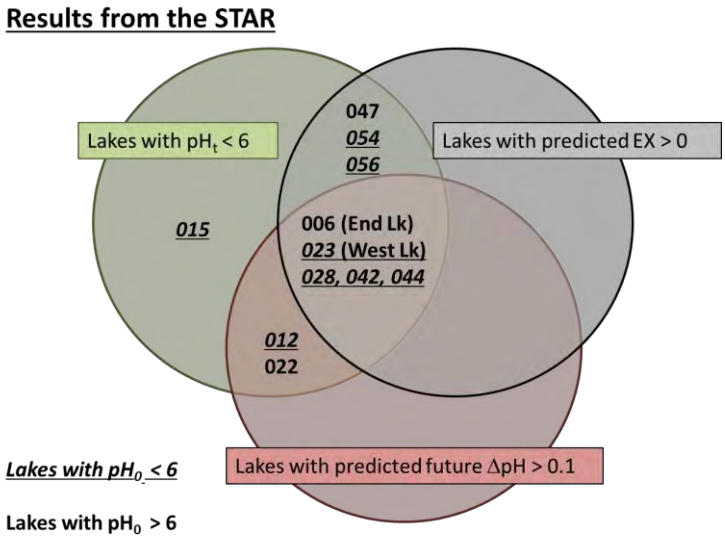


Figure 4-1. STAR classification of lakes with low pH, predicted exceedances of critical loads and/or predicted declines in pH greater 0.1 pH units. The EEM program selected the lakes with predicted pH decline >0.1 pH units.

We used the same criteria from the STAR to position the lakes within the study area (Figure 4-2). The updated classification shows that of the seven lakes previously predicted to have a future pH decline greater than 0.1 pH units relative to 2012, only one of the lakes (LAK028) remains in that classification. Furthermore, of the eight lakes previously predicted to have an exceedance under the maximum level of emissions, only four of those lakes remain in that classification and all those lakes are lakes with critical loads of zero. It should be noted that for Two KAA lakes added to the present study (but outside the boundaries of the STAR study area) also have exceedances predicted but similarly they also both have critical loads of zero, pre-KMP pH (i.e., 2013) less than 6.0 and also original pre-industrial pH less than 6.0 – therefore, had these lakes been included in the original STAR, they would have been identified as naturally acidic lakes with a negligible predicted change in pH and thus excluded for consideration as EEM lakes.

The results of the updated analyses of critical loads, exceedances and future pH, the results suggest that the STAR did not omit any lakes that should have been considered for inclusion in the EEM. Additionally, it suggests that many of the lakes included in the EEM no longer match the inclusion criteria initially applied.

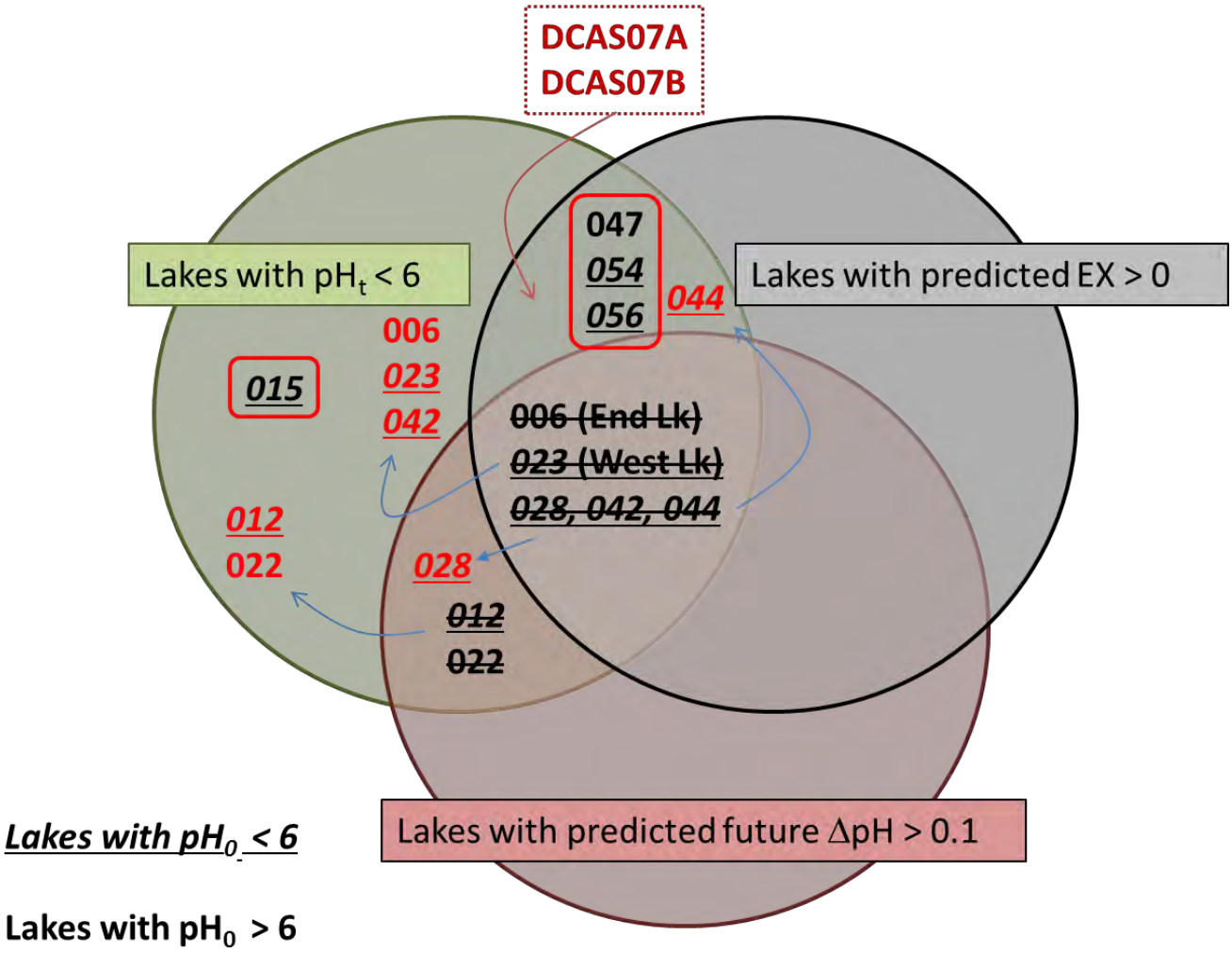


Figure 4-2. Application of the STAR criteria for identifying potential lakes for further monitoring using the new results available. Black font indicates original STAR position, strikethrough font indicates that the position has changed, red text indicates the new position, and red outline indicates that the position remained the same. Current pH (pH_t) and predicted change in pH are relative to 2012. DCAS07A and DCAS07B were from the KAA, therefore a) they were not included in the STAR classification, b) pH_t refers to 2013, and c) they do not have estimates of ΔpH (due to lacking deposition data for comparable emissions scenarios to the STAR). The results for LAK015, LAK047, LAK054, and LAK056 are based on their critical loads from the STAR (and do not have updated predictions of steady-state pH, as discussed elsewhere), whereas the results of LAK006, LAK012, LAK022, LAK023, LAK028, LAK042 and LAK044 (i.e., the EEM lakes) are based on the analyses using the most recent data.

7.8 Aquatic Appendix H: Kitimat River Water Quality

The following water quality sampling was conducted at the Rio Tinto intake from the Kitimat River during 2017 and 2018.

Water quality sampling results at Rio Tinto intake from Kitimat River during 2017

Parameter	Units	BC Drinking Water Quality Guidelines	Sampling date					
			26-Jun-17	31-Aug-17	30-Sep-17	9-Oct-17	30-Nov-17	31-Dec-17
Dissolved Sulphate (SO_4)	mg/l	500		2.04	1.85	1.95		3.94
Fluoride (F)	mg/l	1.5	0.032	0.028	0.036	0.037	0.041	0.017
Nitrate plus Nitrite (N)	mg/l			0.04	0.049	0.049	0.085	0.11
Total Suspended Solids	mg/l		<4.0	<4.0	8.5	53.8		
Dissolved Calcium (Ca)	mg/l		4.02	3.75	5.27	5.03	4.88	7.34
Dissolved Magnesium (Mg)	mg/l		0.384	0.398	0.588	0.598	0.579	0.883
Dissolved Hardness (CaCO3)	mg/l			11	15.6	15	14.6	22
pH			7.33	7.45	7.56	7.32	7.28	7.41
Dissolved Chloride (Cl)	mg/L							
Dissolved Aluminum (Al)	mg/l	9.5	0.0217	0.0225	0.0452	0.054	0.0931	0.0234
Dissolved Antimony (Sb)	mg/l		<0.00050		<0.00050	<0.00050	<0.00050	<0.00050
Dissolved Arsenic (As)	mg/l	0.01	<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Barium (Ba)	mg/l		0.0081		0.0113	0.0108	0.0108	0.0153
Dissolved Beryllium (Be)	mg/l		<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Bismuth (Bi)	mg/l		<0.0010		<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Boron (B)	mg/l		<0.050		<0.050	<0.050	<0.050	<0.050
Dissolved Cadmium (Cd)	mg/l	0.005	<0.000010		<0.000010	<0.000010	<0.000010	<0.000010
Dissolved Chromium (Cr)	mg/l		<0.0010		<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Cobalt (Co)	mg/l		<0.00020		<0.00020	<0.00020	<0.00020	<0.00020
Dissolved Copper (Cu)	mg/l	1	0.00312		0.0143	0.00727	0.0114	0.0042
Dissolved Iron (Fe)	mg/l	0.3	0.0427		0.0837	0.088	0.128	0.115
Dissolved Lead (Pb)	mg/l	0.01	<0.00020		<0.00020	<0.00020	<0.00020	<0.00020
Dissolved Lithium (Li)	mg/l		<0.0020		<0.0020	<0.0020	<0.0020	<0.0020
Dissolved Manganese (Mn)	mg/l	0.05	0.004		0.0068	0.0047	0.0148	0.0219
Dissolved Mercury (Hg)	mg/l	0.001	<0.000050					
Dissolved Molybdenum (Mo)	mg/l	0.25	<0.0010		<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Nickel (Ni)	mg/l		<0.0010		<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Selenium (Se)	mg/l	0.01	<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Silicon (Si)	mg/l		1.58		2.39	2.01	2.55	3.2
Dissolved Silver (Ag)	mg/l		<0.000020		<0.000020	<0.000020	<0.000020	<0.000020
Dissolved Strontium (Sr)	mg/l		0.0235		0.0322	0.0312	0.0281	0.0425
Dissolved Thallium (Tl)	mg/l		<0.000010		<0.000010	<0.000010	<0.000010	<0.000010
Dissolved Tin (Sn)	mg/l		<0.0050		<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Titanium (Ti)	mg/l		<0.0050		<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Uranium (U)	mg/l		<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Vanadium (V)	mg/l		<0.0050		<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Zinc (Zn)	mg/l	5	<0.0050		<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Zirconium (Zr)	mg/l		<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Potassium (K)	mg/l		0.354		0.605	0.548	0.429	0.658
Dissolved Sodium (Na)	mg/l		0.807		1.27	1.13	1.29	2.7
Dissolved Sulphur (S)	mg/l		<3.0		<3.0	<3.0	<3.0	<3.0

Water quality sampling results at Rio Tinto intake from Kitimat River during January to June 2018

Parameter	Units	BC Drinking Water Quality Guidelines	Sampling date				
			1-Jan-18	19-Mar-18	25-Apr-18	31-May-18	4-Jun-18
Dissolved Sulphate (SO_4)	mg/l	500	3.72	<0.50	2.09	1.86	2.31
Fluoride (F)	mg/l	1.5	0.045	0.045	0.049	0.035	0.036
Nitrate plus Nitrite (N)	mg/l		0.105	0.109	0.101	0.062	0.052
Total Suspended Solids	mg/l					4.5	<4.0
Dissolved Calcium (Ca)	mg/l		6.55	6.98	5.1	4.18	4.62
Dissolved Magnesium (Mg)	mg/l		0.731	0.86	0.561	0.484	0.469
Dissolved Hardness (CaCO3)	mg/l		19.4	21	15	12.4	13.5
pH			7.31	7.39	7.29	7.33	7.5
Dissolved Chloride (Cl)	mg/l					0.89	0.75
Dissolved Aluminum (Al)	mg/l	9.5	0.0436	0.0271	0.0731	0.041	0.0265
Dissolved Antimony (Sb)	mg/l		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Dissolved Arsenic (As)	mg/l	0.01	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dissolved Barium (Ba)	mg/l		0.0127	0.0155	0.0108	0.0095	0.0095
Dissolved Beryllium (Be)	mg/l		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dissolved Bismuth (Bi)	mg/l		<0.001	<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Boron (B)	mg/l		<0.050	<0.050	<0.050	<0.050	<0.050
Dissolved Cadmium (Cd)	mg/l	0.005	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Dissolved Chromium (Cr)	mg/l		<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Cobalt (Co)	mg/l		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Dissolved Copper (Cu)	mg/l	1	0.00415	0.0166	0.00356	0.00438	0.0047
Dissolved Iron (Fe)	mg/l	0.3	0.118	0.153	0.0833	0.055	0.0523
Dissolved Lead (Pb)	mg/l	0.01	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Dissolved Lithium (Li)	mg/l		<0.002	<0.0020	<0.0020	<0.0020	<0.0020
Dissolved Manganese (Mn)	mg/l	0.05	0.0163	0.0084	0.0069	0.0066	0.0061
Dissolved Mercury (Hg)	mg/l	0.001					
Dissolved Molybdenum (Mo)	mg/l	0.25	<0.001	<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Nickel (Ni)	mg/l		<0.001	<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Selenium (Se)	mg/l	0.01	0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dissolved Silicon (Si)	mg/l		2.97	2.79	2.55	1.91	1.88
Dissolved Silver (Ag)	mg/l		<0.00002	<0.00002	<0.00002	<0.00002	<0.00002
Dissolved Strontium (Sr)	mg/l		0.0359	0.0471	0.0298	0.0308	0.0281
Dissolved Thallium (Tl)	mg/l		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Dissolved Tin (Sn)	mg/l		<0.005	<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Titanium (Ti)	mg/l		<0.005	<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Uranium (U)	mg/l		<0.0001	<0.0001	0.0001	<0.0001	<0.0001
Dissolved Vanadium (V)	mg/l		<0.005	<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Zinc (Zn)	mg/l	5	<0.005	0.006	<0.0050	<0.0050	<0.0050
Dissolved Zirconium (Zr)	mg/l		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dissolved Potassium (K)	mg/l		0.539	0.548	0.423	0.401	0.396
Dissolved Sodium (Na)	mg/l		1.79	2.43	1.22	0.963	1.03
Dissolved Sulphur (S)	mg/l		<3.0	<3.0	<3.0	<3.0	<3.0

Water quality sampling results at Rio Tinto intake from Kitimat River during July to December 2018

Parameter	Units	BC Drinking Water Quality Guidelines	Sampling date					
			4-Jul-18	31-Aug-18	17-Sep-18	31-Oct-18	6-Nov-18	4-Dec-18
Dissolved Sulphate (SO_4)	mg/l	500	2.27	2.91	4.13	2.78	1.64	3.16
Fluoride (F)	mg/l	1.5	0.031	0.036	0.035	0.045	0.044	0.045
Nitrate plus Nitrite (N)	mg/l		0.036	0.027	0.051	0.122	0.129	0.136
Total Suspended Solids	mg/l		<4.0	<4.0	<4.0	<4.0	45.7	<4.0
Dissolved Calcium (Ca)	mg/l		4.34	5.07	6.08	4.44	4.77	6.32
Dissolved Magnesium (Mg)	mg/l		0.434	0.524	0.698	0.581	0.544	0.727
Dissolved Hardness (CaCO3)	mg/l		12.6	14.8	18.1	16.2	14.2	18.8
pH			6.99	7.68	7.68	7.22	7.16	7.47
Dissolved Chloride (Cl)	mg/l		0.88	1.1	1.8	1.3	0.83	1.5
Dissolved Aluminum (Al)	mg/l	9.5	0.0242	0.0106	0.0105	0.0519	0.0518	0.0312
Dissolved Antimony (Sb)	mg/l		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Dissolved Arsenic (As)	mg/l	0.01	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dissolved Barium (Ba)	mg/l		0.0093	0.0110	0.0136	0.0114	0.0107	0.0134
Dissolved Beryllium (Be)	mg/l		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dissolved Bismuth (Bi)	mg/l		<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Boron (B)	mg/l		<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Dissolved Cadmium (Cd)	mg/l	0.005	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Dissolved Chromium (Cr)	mg/l		<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Cobalt (Co)	mg/l		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Dissolved Copper (Cu)	mg/l	1	0.00335	0.0004	0.00327	0.00561	0.00559	0.00399
Dissolved Iron (Fe)	mg/l	0.3	0.0339	0.0278	0.0592	0.0742	0.0705	0.11
Dissolved Lead (Pb)	mg/l	0.01	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Dissolved Lithium (Li)	mg/l		<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Dissolved Manganese (Mn)	mg/l	0.05	0.0049	<0.0010	0.0121	0.0024	0.0075	0.0151
Dissolved Mercury (Hg)	mg/l	0.001		<0.0020				
Dissolved Molybdenum (Mo)	mg/l	0.25	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Nickel (Ni)	mg/l		<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Selenium (Se)	mg/l	0.01	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dissolved Silicon (Si)	mg/l		1.64	1.71	2.09	2.26	1.84	2.79
Dissolved Silver (Ag)	mg/l		<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002
Dissolved Strontium (Sr)	mg/l		0.0260	0.0305	0.0370	0.0317	0.0282	0.0364
Dissolved Thallium (Tl)	mg/l		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Dissolved Tin (Sn)	mg/l		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Titanium (Ti)	mg/l		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Uranium (U)	mg/l		<0.0001	<0.0001	<0.0001	0.00011	0.00011	<0.0001
Dissolved Vanadium (V)	mg/l		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Zinc (Zn)	mg/l	5	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Zirconium (Zr)	mg/l		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dissolved Potassium (K)	mg/l		0.496	0.584	0.603	0.522	0.477	0.582
Dissolved Sodium (Na)	mg/l		0.974	1.48	2.06	1.24	1.12	1.93
Dissolved Sulphur (S)	mg/l		<3.0	<3.0	<3.0	<3.0	<3.0	<3.0

7.9 Aquatic Appendix I: Sensitivity Analyses with Alternative Baseline

7.9.1 Introduction

7.9.1.1 Purpose of Appendix

The aquatic analyses presented in the Comprehensive Review use the lake chemistry data for 2012 as the pre-KMP baseline. The purpose of this appendix is to present and discuss sensitivity analyses that we conducted using an alternate baseline based on the transition period of 2012-2014. The rationale for using 2012 alone for the pre-KMP baseline, along with acknowledgement of the inherent concerns of doing so, are presented in the main report (Section 7.3.2.2) and reiterated below. However, the reviewers of the draft Comprehensive Review expressed a strong interest in understanding the potential impacts that using an alternatively defined baseline could have on the reported results.

7.9.1.2 Structure of Appendix

This appendix includes the results of the sensitivity analyses as applied to three sets of analyses in the Comprehensive Review for which the definition of the baseline is relevant: the deterministic analyses of the empirical data (i.e., main report Section 7.3.1 and Aquatic Appendix A, the statistical analyses (i.e., main report Section 7.3.2.3 and Aquatic Appendix F), and the predicted future steady-state pH (main report Section 7.3.2.5 and Aquatic Appendix G).

For all three sets, the results of the sensitivity analyses using an alternative baseline are presented in this appendix only, which is briefly referenced in the main report.

7.9.1.3 Baselines

This section provides a brief summary of the history of baselines in the EEM Plan, Program and Comprehensive Report.

7.9.1.3.1 EEM Plan

In the EEM Plan, the aquatic KPI was defined based on observed changes in pH relative to the "mean baseline pH level measured pre-KMP". The EEM Plan also provided further details on how it was anticipated that the pre-KMP baseline should be defined:

> *"For water quality parameters which show statistically or biologically significant differences between summer 2012 and fall 2013/2014 values, the mean baseline pre-KMP values will be defined as the mean of the fall index samples in 2013 and 2014. For parameters which showed no statistically or biologically significant differences between summer 2012 and fall 2013 samples, the mean baseline pre-KMP values will be defined as the mean of summer 2012, fall 2013 and fall 2014 values."* (EEM Plan, Section 6.2.1, p. 36)

The EEM Annual Reports for 2015, 2016 and 2017 focused on reporting and interpreting inter-annual changes. These annual reports also reported the observed change over the period of record (i.e., 2012 to 201x) but did not explicitly examine pre-/post-KMP changes (due to the limited number of years of post-KMP data and deference to the upcoming Comprehensive Review).

7.9.1.3.2 EEM Program

The decision to use 2012 as the baseline emerged over several years during implementation of the EEM program, and completion of the Comprehensive Report. The statistical power analyses (EEM 2016 Technical Memo W04) sought to determine the ability to detect changes in lake chemistry, and therefore used all of the data available at that time (i.e., a 2012-14 baseline):

> *"The lake chemistry model starts with the baseline lake chemistry observations, adds a defined hypothetical KMP effect, and then adds assumed variability over a 20-year period. We defined the baseline conditions as the average of the observed values in 2012-2014. This period does not represent an ideal, stable baseline because KMP emissions were already declining during this period (and for several years previously), and therefore were lower than longer-term pre-KMP baseline conditions. Given the pre-KMP data available, alternate baselines could have included the average of 2013-2014 (i.e., only use fall samples) or just 2014 (i.e., the last year prior to KMP); however, both of these options would reduce the number of pre-KMP observations and decrease the power to detect changes in the primary metrics. We opted to utilize all of the pre-KMP data in defining the baseline."* (EEM 2016 Technical Memo W04, "Summary Report on Power Analyses", p. 9)

Over time, we realized that the period from 2012-2014 was better described as a *transition period* with the decommissioning of the old smelter, and not as a pre-KMP baseline. For the Comprehensive Report, we were faced with two less than ideal options: using a single observation from August 2012 as a pre-KMP baseline; and using observations from the 2012-2014 transition period with potential confounding from the decommissioning of the old smelter and its influences on lake chemistry. As described in Section 7.3.2.2 of the main report, we chose to use 2012 as the baseline for pH and Gran ANC. Using the 2012-2014 transition period as a baseline for pH and Gran ANC would have increased the risk of Type I error (a false positive) in testing for exceedances of thresholds for ΔpH and ΔANC. In general, the pH and Gran ANC of the EEM sensitive lakes increased during the 2012-2014 period as SO_2 emissions from the old smelter declined (Sections 7.6.2.1.2 and 7.6.2.1.3 of Aquatic Appendix F). Including pH and ANC observations from 2013 and 2014 in the estimates of mean pre-KMP pH and mean pre-KMP Gran ANC would increase those metrics to a level that is not representative of the pre-KMP period prior to and including 2012, and increase the risk of a false exceedance of the thresholds for changes in pH and Gran ANC. Changes in lake [SO_4] are an important part of the simplified and full evidentiary frameworks (main report Section 7.3.4.5). Using 2012-2014 as a baseline also could increase the risk of a false positive for detecting an increase in lake [SO_4], if a lake's [SO_4] decreased during 2013-3014 due to the decommissioning of the old smelter and reduced emissions of SO_2. Therefore, both the draft Comprehensive Report and the 2018 EEM Report used 2012 as a baseline for comparison.

In the following sections, we use the transition period from 2012-2014 as a baseline, either with unadjusted EEM thresholds (Section 7.9.2 and Analysis A in Section 7.9.3) or using adjusted thresholds that consider changes in lake chemistry between 2012 and 2014 (Analysis B in Section 7.9.3). As noted in Table 7.80:

- Analysis A may overestimate smelter impacts relative to the pre-KMP condition, as values of lake pH and Gran ANC, may have increased during 2012-14 due to the decommissioning of the old smelter and associated declines in SO_2 emissions. Since 2012-14 was a transition period rather than a pre-KMP period, Analysis A has a higher risk of false positives.

- Analysis B may under-estimate smelter impacts since it assumes that any increases in lake pH or Gran ANC from 2012 to 2014 were due to declining emissions during decommissioning of the old smelter, and adjusts pH and ANC thresholds accordingly. Analysis B therefore has a higher risk of false negatives.

7.9.2 Deterministic Analyses of Empirical Data

This section of the sensitivity analysis simply computes the mean values of pH, Gran ANC and SO_4 for each of the two alternative baselines: the 2012 pre-KMP year and the 2012-2014 transition period. We then calculate the average values of these parameters for the 2016-2018 post-KMP period, and the changes relative to each of the two alternative baselines. These comparisons do not apply any statistical methods. Statistical analyses are included in Section 7.9.3 of this appendix.

One caveat is that the lake-specific thresholds for ΔGran ANC were based on processing data from laboratory titrations at Trent University, to determine how much change in Gran ANC corresponded to a 0.3 unit change in pH from the 2012 pH. We did not go through the laborious process of estimating how much change in Gran ANC would correspond to a 0.3 unit change in pH from the mean pH during 2012-2014.

7.9.2.1 Changes in pH, Gran ANC and SO_4 against pre-KMP and transition period baselines

Table 7.76 demonstrates that comparing post-KMP values during 2016-2018 to the 2012-2014 baseline generates estimates of ΔpH and ΔANC that are more negative than using a 2012 baseline (e.g., LAK028 shows a -0.2 unit change in pH relative to the 2012-2014 baseline, and a 0.0 unit pH change relative to the 2012 baseline). This is to be expected given that 10 out of the 11 lakes had higher 2012-2014 mean values for pH than their estimates from 2012; the only exception was LAK007 for which the mean pH for 2012-2014 is the same as its 2012 value (8.0; Table 7.76). All 11 lakes had higher 2012-2014 mean values for Gran ANC than their 2012 value (Table 7.76). The control lakes are not included in Table 7.76 since the only pre-KMP measurement was for 2013, and it therefore is not possible to compare the two alternative baselines.

Eight of the 11 lakes had higher 2012-2014 mean values for SO_4 than their 2012 measurement. This general increase in SO_4 was not expected since average SO_2 emissions from the smelter declined from 16.1 tpd in 2012 to 11.6 tpd between 2012 and 2014. The pattern of changes in SO_4 suggested that there may have been some hydrologic changes across 2012-2014 (e.g., less precipitation could cause less dilution and higher concentrations of both SO_4 and Gran ANC, and higher pH values). We therefore explored the correlations between lake chemistry and levels of precipitation in the 2 months prior to lake sampling (Appendix I Section 7.9.3.5), and the effects of including precipitation (and lake sensitivity) on statistical analyses of a smelter effect (Appendix I Section 7.9.3.6).

Table 7.77 compares the two estimates of ΔpH from the two baselines to the EEM threshold of 0.3 pH units. None of lakes show an exceedance of the pH threshold under either baseline. A similar conclusion is found for Gran ANC (Table 7.78). The only exception is for LAK034, where application of the 2012-2014 baseline results in an exceedance of the threshold for ΔGran ANC. As indicated in the footnote to Table 7.78, the decrease in Gran ANC in LAK034 cannot be associated with sulphur-driven acidification from the smelter because the concentration of SO_4

decreased to zero during the monitoring period. Table 7.79 shows that 9 of the 11 lakes generated the same direction of change in lake SO_4 under the two different baselines.

Table 7.76. Mean values of pH, Gran ANC and SO_4 for two different baselines (2012 and 2012-14), the 2016-2018 post-KMP period , the changes between these two periods, and the EEM thresholds.

	pH						Gran ANC (µeq/L)						SO_4^{2-*}(µeq/L)				
	Baseline		Post-KMP	ΔpH			Baseline		Post-KMP	ΔANC			Baseline		Post-KMP	ΔSO_4^{2-*}	
EEM sensitive lakes	2012	2012-14	2016-18	vs. 2012	vs. 2012-14	EEM Thresh old	2012	2012-14	2016-18	vs. 2012	vs. 2012-14	Thresh old †	2012	2012-14	2016-18	vs. 2012	vs. 2012-14
LAK006	5.8	6.0	6.0	0.2	0.0	-0.3	25.7	31.2	27.7	2.0	-3.5	-10.8	11.4	12.6	14.0	2.5	1.3
LAK012	5.6	6.0	6.2	0.5	0.2	-0.3	57.0	63.1	58.3	1.3	-4.8	-16.3	6.1	11.1	12.9	6.8	1.8
LAK022	5.9	6.1	6.1	0.1	0.0	-0.3	27.8	37.0	33.0	5.1	-4.1	-11.5	30.2	38.4	38.8	8.6	0.4
LAK023	5.7	5.9	5.9	0.2	0.1	-0.3	19.8	25.2	26.4	6.7	1.2	-10.5	19.0	20.7	12.3	-6.7	-8.4
LAK028	5.0	5.2	5.0	0.0	-0.2	-0.3	-4.0	7.8	-3.5	0.5	-11.3	-13.4	56.9	93.1	128.4	71.5	35.3
LAK042	4.7	5.1	5.2	0.5	0.1	-0.3	-20.4	4.4	5.6	26.1	1.3	-24.4	6.2	5.3	5.4	-0.8	0.1
LAK044	5.4	5.6	5.6	0.2	-0.1	-0.3	1.3	5.2	5.0	3.7	-0.2	-6.2	6.2	5.7	4.4	-1.9	-1.3
Total lakes with increase				7	4					7	2					4	5
Total lakes with decrease				0	3					0	5					3	2

EEM less sensitive lakes	2012	2012-14	2016-18	vs .2012	vs. 2012-14	EEM Thresh old	2012	2012-14	2016-18	vs. 2012	vs. 2012-14	Thresh old †	2012	2012-14	2016-18	vs. 2012	vs. 2012-14
LAK007	8.0	8.0	8.0	0.0	0.0	-0.3	1437.6	1448.5	1385.9	-51.6	-62.5	-50.6	51.4	49.6	47.0	-4.4	-2.6
LAK016	6.3	6.6	6.7	0.3	0.1	-0.3	68.7	90.4	89.8	21.1	-0.6	-25.6	39.0	48.0	44.5	5.4	-3.6
LAK024	7.1	7.4	7.5	0.4	0.1	-0.3	299.5	385.8	463.2	163.7	77.4	-60.4	24.8	31.0	38.9	14.1	7.9
LAK034	6.7	6.8	6.4	-0.3	-0.3	-0.3	99.4	171.6	139.6	40.2	-32.0	-22.0	24.1	26.4	0.1	-24.0	-26.3
Total lakes with increase				3	3					3	1					2	1
Total lakes with decrease				1	1					1	3					2	3

† The Gran ANC threshold was determined (based on analysis of the titration data) as the magnitude of change in Gran ANC equivalent to a 0.3 pH unit decline *from the 2012 pH value.*

Table 7.77. Comparisons of ΔpH versus 0.3 threshold for the 2012 and 2012-2014 baselines.

	pH								
	Baseline		Post-KMP	ΔpH			Observed post-KMP change in pH relative to threshold based on empirical data		
EEM sensitive lakes	2012	2012-14	2016-18	vs. 2012	vs. 2012-14	EEM Threshold	vs. 2012	vs. 2012-14	Does the alternate baseline change the conclusion for this metric?
LAK006	5.8	6.0	6.0	0.2	0.0	-0.3	Does not exceed threshold	Does not exceed threshold	No
LAK012	5.6	6.0	6.2	0.5	0.2	-0.3	Does not exceed threshold	Does not exceed threshold	No
LAK022	5.9	6.1	6.1	0.1	0.0	-0.3	Does not exceed threshold	Does not exceed threshold	No
LAK023	5.7	5.9	5.9	0.2	0.1	-0.3	Does not exceed threshold	Does not exceed threshold	No
LAK028	5.0	5.2	5.0	0.0	-0.2	-0.3	Does not exceed threshold	Does not exceed threshold	No
LAK042	4.7	5.1	5.2	0.5	0.1	-0.3	Does not exceed threshold	Does not exceed threshold	No
LAK044	5.4	5.6	5.6	0.2	-0.1	-0.3	Does not exceed threshold	Does not exceed threshold	No
Total lakes with increase				7	4				
Total lakes with decrease				0	3				

EEM less sensitive lakes	2012	2012-14	2016-18	vs .2012	vs. 2012-14	EEM Threshold	vs. 2012	vs. 2012-14	Does the alternate baseline change the conclusion for this metric?
LAK007	8.0	8.0	8.0	0.0	0.0	-0.3	Does not exceed threshold	Does not exceed threshold	No
LAK016	6.3	6.6	6.7	0.3	0.1	-0.3	Does not exceed threshold	Does not exceed threshold	No
LAK024	7.1	7.4	7.5	0.4	0.1	-0.3	Does not exceed threshold	Does not exceed threshold	No
LAK034	6.7	6.8	6.4	-0.3	-0.3	-0.3	Magnitude of change equivalent to threshold †	Magnitude of change equivalent to threshold †	No
Total lakes with increase				3	3				
Total lakes with decrease				1	1				

† The decrease in pH in LAK034 cannot be associated with sulphur-driven acidification from the smelter because the concentration of SO_4 decreased to zero during the monitoring period.

Table 7.78. Empirical comparisons of ΔGran ANC versus lake-specific thresholds for the 2012 and 2012-2014 baselines.

	Gran ANC (µeq/L)								
	Baseline		Post-KMP	ΔANC			Observed post-KMP change in Gran ANC relative to threshold based on empirical data		
EEM sensitive lakes	2012	2012-14	2016-18		vs. 2012-14	Threshold †	vs. 2012	vs. 2012-14	Does the alternate baseline change the conclusion for this metric?
LAK006	25.7	31.2	27.7	2.0	-3.5	-10.8	Does not exceed threshold	Does not exceed threshold	No
LAK012	57.0	63.1	58.3	1.3	-4.8	-16.3	Does not exceed threshold	Does not exceed threshold	No
LAK022	27.8	37.0	33.0	5.1	-4.1	-11.5	Does not exceed threshold	Does not exceed threshold	No
LAK023	19.8	25.2	26.4	6.7	1.2	-10.5	Does not exceed threshold	Does not exceed threshold	No
LAK028	-4.0	7.8	-3.5	0.5	-11.3	-13.4	Does not exceed threshold	Does not exceed threshold	No
LAK042	-20.4	4.4	5.6	26.1	1.3	-24.4	Does not exceed threshold	Does not exceed threshold	No
LAK044	1.3	5.2	5.0	3.7	-0.2	-6.2	Does not exceed threshold	Does not exceed threshold	No
Total lakes with increase				7	2				
Total lakes with decrease				0	5				

EEM less sensitive lakes	2012	2012-14	2016-18	vs. 2012	vs. 2012-14	Threshold †	vs. 2012	vs. 2012-14	Does the alternate baseline change the conclusion for this metric?
LAK007	1437.6	1448.5	1385.9	-51.6	-62.5	-50.6	Exceeds threshold	Exceeds threshold	No
LAK016	68.7	90.4	89.8	21.1	-0.6	-25.6	Does not exceed threshold	Does not exceed threshold	No
LAK024	299.5	385.8	463.2	163.7	77.4	-60.4	Does not exceed threshold	Does not exceed threshold	No
LAK034	99.4	171.6	139.6	40.2	-32.0	-22.0	Does not exceed threshold	Exceeds threshold	Yes*
Total lakes with increase				3	1				
Total lakes with decrease				1	3				

† The Gran ANC threshold was determined (based on analysis of the titration data) as the magnitude of change in Gran ANC equivalent to a 0.3 pH unit decline *from the 2012 pH value*.
* The decrease in Gran ANC in LAK034 cannot be associated with sulphur-driven acidification from the smelter because the concentration of SO_4 decreased to zero during the monitoring period.

Table 7.79. Comparisons of ΔSO_4 versus for the 2012 and 2012-2014 baselines.

	SO_4^{2-} (µeq/L)							
	Baseline		Post-KMP	ΔSO_4^{2-}		Observed post-KMP change in SO_4 based on empirical data		
EEM sensitive lakes	2012	2012-14	2016-18	vs. 2012	vs. 2012-14	vs. 2012	vs. 2012-14	Does the alternate baseline change the conclusion for this metric?
LAK006	11.4	12.6	14.0	2.5	1.3	SO_4 increased	SO_4 increased	No
LAK012	6.1	11.1	12.9	6.8	1.8	SO_4 increased	SO_4 increased	No
LAK022	30.2	38.4	38.8	8.6	0.4	SO_4 increased	SO_4 increased	No
LAK023	19.0	20.7	12.3	-6.7	-8.4	SO_4 decreased	SO_4 decreased	No
LAK028	56.9	93.1	128.4	71.5	35.3	SO_4 increased	SO_4 increased	No
LAK042	6.2	5.3	5.4	-0.8	0.1	SO_4 decreased	SO_4 increased	Yes (but difference is negligible)
LAK044	6.2	5.7	4.4	-1.9	-1.3	SO_4 decreased	SO_4 decreased	No
Total lakes with increase				4	5			
Total lakes with decrease				3	2			

EEM less sensitive lakes	2012	2012-14	2016-18	vs. 2012	vs. 2012-14	vs. 2012	vs. 2012-14	Does the alternate baseline change the conclusion for this metric?
LAK007	51.4	49.6	47.0	-4.4	-2.6	SO_4 decreased	SO_4 decreased	No
LAK016	39.0	48.0	44.5	5.4	-3.6	SO_4 increased	SO_4 decreased	Yes
LAK024	24.8	31.0	38.9	14.1	7.9	SO_4 increased	SO_4 increased	No
LAK034	24.1	26.4	0.1	-24.0	-26.3	SO_4 decreased	SO_4 decreased	No
Total lakes with increase				2	1			
Total lakes with decrease				2	3			

7.9.3 Statistical Analyses

Based on feedback from reviewers of the draft Comprehensive Report, we completed four sensitivity analyses of selected statistical analyses in Aquatic Appendix F, as described in Table 7.80. As explained at the end of Section 7.9.1, and in Table 7.80, we completed two analyses (A and B), which were designed to bracket the potential effects of the smelter on lake chemistry: Analysis A (2012-14 baseline, EEM thresholds) is more likely to over-estimate the effects of the smelter on lake chemistry, while Analysis B (2012-14 baseline, adjusted thresholds) is more likely to under-estimate these effects. The adjusted thresholds for ΔpH (Table 7.81) are 0.3 + (Mean $pH_{2012\text{-}14}$ – pH_{2012}). The adjusted thresholds for ΔGran ANC (Table 7.81) are the EEM lake-specific threshold + (Mean Gran $ANC_{2012\text{-}14}$ – $GranANC_{2012}$). Analyses A and B can be illustrated for LAK028, which had a pH of 5.0 in 2012, and a mean pH of 5.2 over 2012-14 (i.e., an increase of 0.2 pH units over the 2012 value). In applying analysis A to LAK028, we used a mean pH of 5.2 as the 2012-14 baseline, and the EEM threshold of 0.3 pH units. In applying analysis B to LAK028, we also used a mean pH of 5.2 as the 2012-14 baseline, but applied an adjusted EEM threshold of 0.5 pH units (i.e., the 0.3 unit threshold from the EEM Plan, plus the 0.2 pH unit difference between the 2012 measurement and the 2012-14 mean value).

Table 7.80. Sensitivity analyses to explore effects of alternate baseline periods and additional covariates.

Analysis Code	Question Addressed	Methods / Assumptions	Interpretation
A	*How are conclusions on the % belief in changes in SO_4, Gran ANC and pH altered if the statistical analysis uses 2012-2014 as a baseline rather than 2012, and keeps the same thresholds for ΔpH and ΔGran ANC? (Section 7.9.3.1 to Section 7.9.3.4)*	Repeat the Bayesian analyses of chemical changes, using a 2012-2014 baseline with the same thresholds for ΔpH and ΔGran ANC (i.e., 0.3 pH units and corresponding threshold for ΔGran ANC).	Analysis A may overestimate smelter impacts relative to the pre-KMP condition, as values of lake pH and Gran ANC may have increased during 2012-14 due to the decommissioning of the old smelter and associated declines in SO_2 emissions. Since 2012-14 was a transition period rather than a pre-KMP period, Analysis A has a higher risk of false positives.
B	*How are conclusions on the % belief in changes in Gran ANC and pH altered if the statistical analysis uses 2012-2014 as a baseline rather than 2012, and the thresholds for pH and Gran ANC are adjusted?*	Repeat the Bayesian analyses of chemical changes, using a 2012-2014 baseline, and use larger thresholds for ΔpH and ΔGran ANC, based on the difference between the 2013-2014 mean value and the 2012 value.	Analysis B may under-estimate smelter impacts since it assumes that any increases in lake pH or Gran ANC from 2012 to 2014 were due to declining emissions during decommissioning of the old smelter, and adjusts pH and ANC thresholds accordingly. Analysis B therefore has a higher risk of false negatives.
C	*To what extent are changes in lake chemistry correlated with seasonal changes in precipitation? (Section 7.9.3.5)*	Linear regressions between pH, ANC, SO_4 and total precipitation in the 2 months prior to sampling[19]. Previous analyses in Appendix F (Section 7.6.2.2) looked at correlations over much shorter time periods (3 days and 14 days), to assess the effects of storm events.	If seasonal changes in precipitation affect water chemistry (e.g., lower values of SO_4, Gran ANC, and pH after relatively wet periods due to dilution effects), then precipitation should be used as a covariate in all statistical analyses.
D	*To what extent are the results of the Before-After-Control-Impact (BACI) analysis altered if precipitation and lake sensitivity are included as covariates? (Section 7.9.3.6)*	Include seasonal precipitation in the prior 2 months (analysis C) and each lake's F-factor in the statistical analysis. This BACI sensitivity analysis adds two covariates (seasonal precipitation and lake sensitivity) to the BACI analyses done previously.	If either of these covariates are statistically significant it indicates that lake chemistry is correlated with changes in that covariate, which might alter the evidence for a smelter effect in the BACI analysis.

[19] Computed by averaging the monthly precipitation at the Kitimat Townsite and Terrace monitoring stations for each month, and then summing those averages for the two months prior to sampling: June-July for August 2012 sampling; and August-Sept for 2013-2018 October sampling.

Table 7.81. EEM thresholds and adjusted thresholds for ΔpH and ΔGran ANC. See text for explanation of computation.

	pH				Gran ANC (µeq/L)			
	Baseline		ΔpH		Baseline		ΔANC	
EEM sensitive lakes	2012	2012-14	EEM Threshold	Adjusted Threshold	2012	2012-14	EEM Threshold	Adjusted Threshold
LAK006	5.8	6.0	-0.3	-0.52	25.7	31.2	-10.8	-16.3
LAK012	5.6	6.0	-0.3	-0.64	57.0	63.1	-16.3	-22.4
LAK022	5.9	6.1	-0.3	-0.49	27.8	37.0	-11.5	-20.7
LAK023	5.7	5.9	-0.3	-0.45	19.8	25.2	-10.5	-16.0
LAK028	5.0	5.2	-0.3	-0.5	-4.0	7.8	-13.4	-25.2
LAK042	4.7	5.1	-0.3	-0.7	-20.4	4.4	-24.4	-49.2
LAK044	5.4	5.6	-0.3	-0.5	1.3	5.2	-6.2	-10.2
EEM less sensitive lakes	2012	2012-14	EEM Threshold	Adjusted Threshold	2012	2012-14	EEM Threshold	Adjusted Threshold
LAK007	8.0	8.0	-0.3	-0.32	1437.6	1448.5	-50.6	-61.5
LAK016	6.3	6.6	-0.3	-0.57	68.7	90.4	-25.6	-47.4
LAK024	7.1	7.4	-0.3	-0.55	299.5	385.8	-60.4	-146.7
LAK034	6.7	6.8	-0.3	-0.34	99.4	171.6	-22.0	-94.2

7.9.3.1 Effects of alternative baseline on estimated ΔSO_4

We are interested if application of the alternative baseline changes the overall level of support for an increase in concentrations of lake SO_4, which is the first step in the evidentiary framework (Figure 7-10 in main report). A % belief greater than 80% is considered strong support, 20-80% is considered intermediate support, and less than 20% is considered weak support.

Including the transition period in the baseline (2012-2014; Analysis A from Table 7.80) *decreased* the % belief of a SO_4 increase in three of the sensitive lakes, from high (>80%) to intermediate (20-80%), and did not change the level of support for an increase in sulphate in the other four sensitive lakes. The overall conclusion is that there is *less* of an effect of SO_2 emissions on lake sulphate concentrations in the sensitive lakes (Figure 7.142). The statistical analysis reflects the fact that the mean concentration of SO_4 over 2012-14 was higher than the 2012 concentration in 4 of the 7 sensitive lakes (LAK006, LAK012, LAK022, LAK028), as shown in Table 7.76.

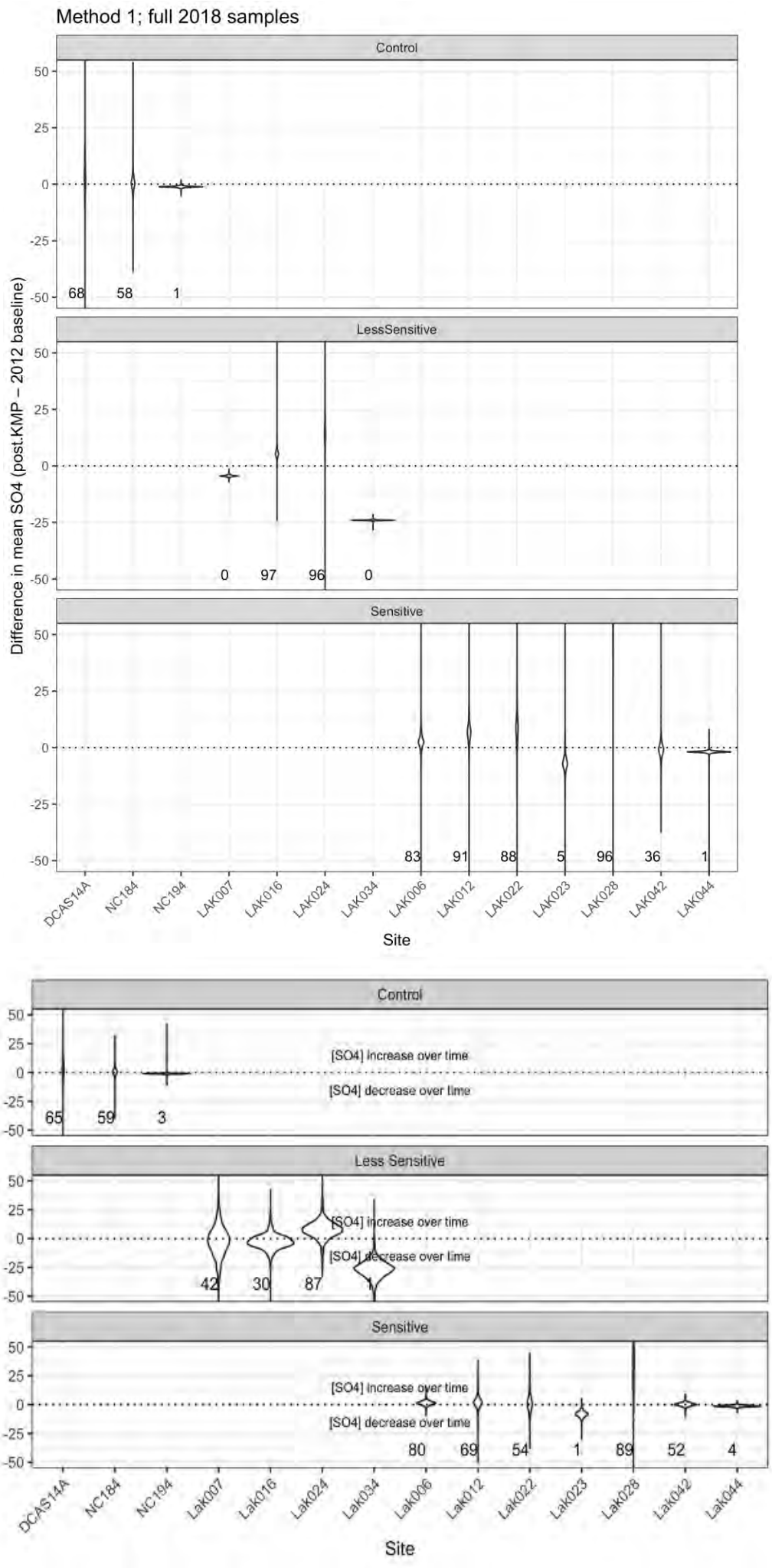


Figure 7.142. Percent belief in lake-specific change in sulphate given: 1) original baseline period of 2012 (upper figure; Figure 7.115, Aquatic Appendix F); and 2) an alternate baseline period of 2012-2014 (lower). The number at the base of each plot indicates the percent belief in an *increase* in sulphate.

7.9.3.2 Effects of alternative baseline on estimated ΔpH

The purpose of this analysis is to determine if there is a change in the level of support for a decline of beyond the KPI threshold of 0.3 pH units (Analysis A), or an adjusted threshold (Analysis B), when using the transition period baseline (2012-2014).

Using the transition period baseline (2012-2014; Analysis A) there is an ***increase*** in the % belief (from 10% to 20%, still considered 'low') that pH declined by 0.3 pH units in LAK028. Though there are 1-5% changes in the % belief in eight of the other lakes, and one larger change (31% in LAK034) these shifts do not affect the category of support (i.e., low < 20%, intermediate 20-80%, high > 80%) for a 0.3 pH decline (Figure 7.143).

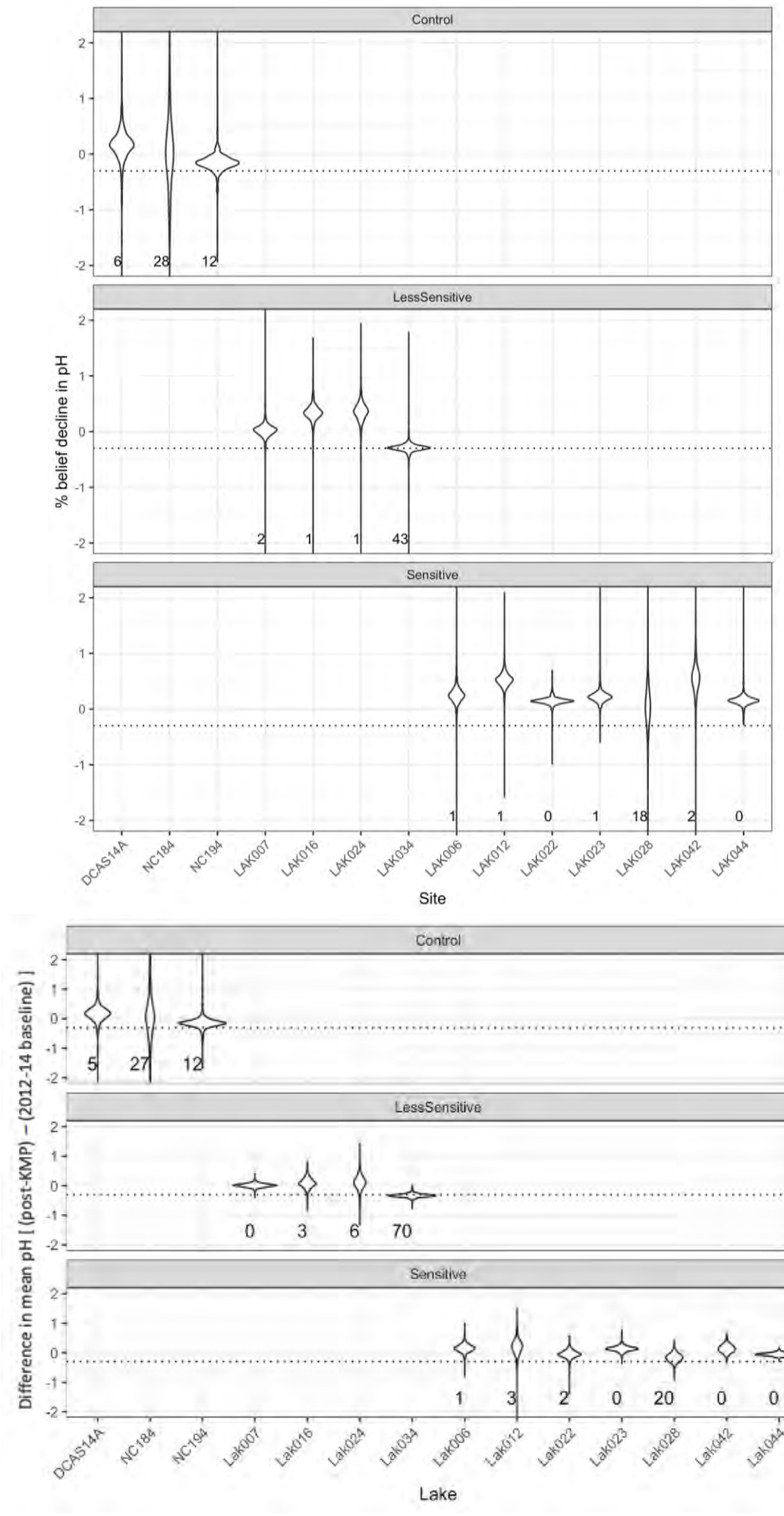


Figure 7.143. Percent belief in lake-specific ΔpH > 0.3 given: 1) original baseline period of 2012 (upper figure; Figure 7.127, Aquatic Appendix F); and 2) alternate baseline period of 2012-2014 (lower figure). The number at the base of each plot indicates the percent belief in a decline in pH greater than the threshold of 0.3 pH units.

When considering the adjusted threshold in addition to the transition baseline (Analysis B), there is generally a *decrease* in the % belief that pH has declined beyond the threshold (Figure 7.144).

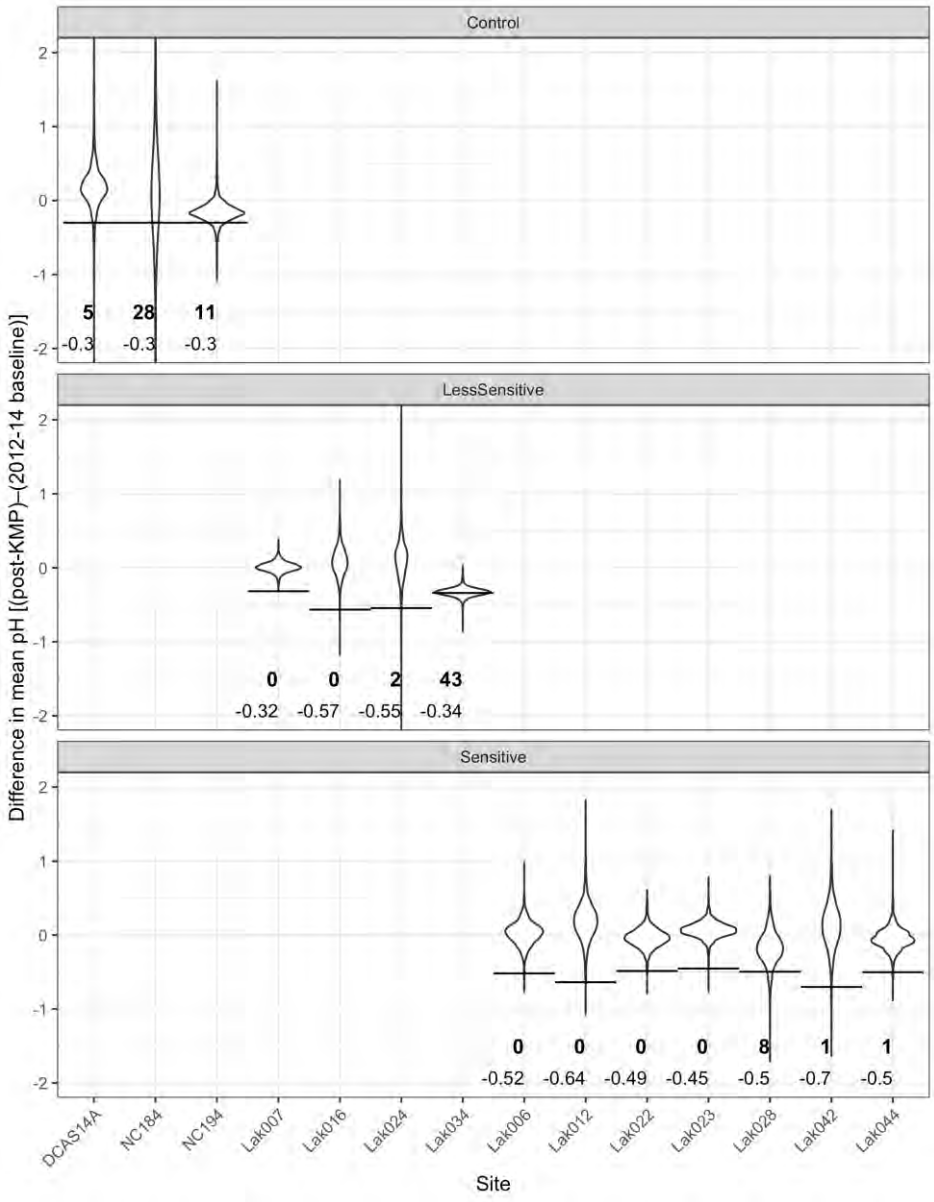


Figure 7.144. Percent belief in lake-specific decline in pH beyond the adjusted threshold using the alternate baseline period of 2012-2014. The % belief value is shown in bold and the value of the adjusted threshold for each lake is shown below the bolded value. Values for percent belief can be compared to the top graph in Figure 7.143.

7.9.3.3 Effects of alternative baseline on estimated ΔANC

The purpose of this analysis is to determine if there is a change in the level of support for a decline in Gran ANC beyond the lake-specific thresholds (Analysis A), or adjusted thresholds (Analysis B), when using the transition period baseline (2012-2014).

LAK028 is the only sensitive lake that showed an ***increase*** in the category of % belief (from 2% to 33%, low to intermediate level of support) that Gran ANC declined beyond the KPI threshold when using the alternate 2012-2014 baseline (Analysis A in Table 7.80). All other sensitive lakes showed the essentially same % belief (Figure 7.145).

The four less sensitive lakes all showed increases in the % belief that Gran ANC declined beyond the KPI threshold (Figure 7.145). Two of these increases were small (LAK016 (5%) and LAK024 (8%)), one was moderate (LAK034 (59%)), and one was large (LAK007 (76%)). The shift in % belief in LAK034 was large enough to change the level of support for exceedance of the ANC threshold from low to intermediate, and to moderate for LAK007, though as discussed previously the declines in lake pH and ANC in LAK034 were unrelated to the smelter, as lake [SO_4] declined relative to both the 2012 and 2012-14 baselines (Table 7.76).

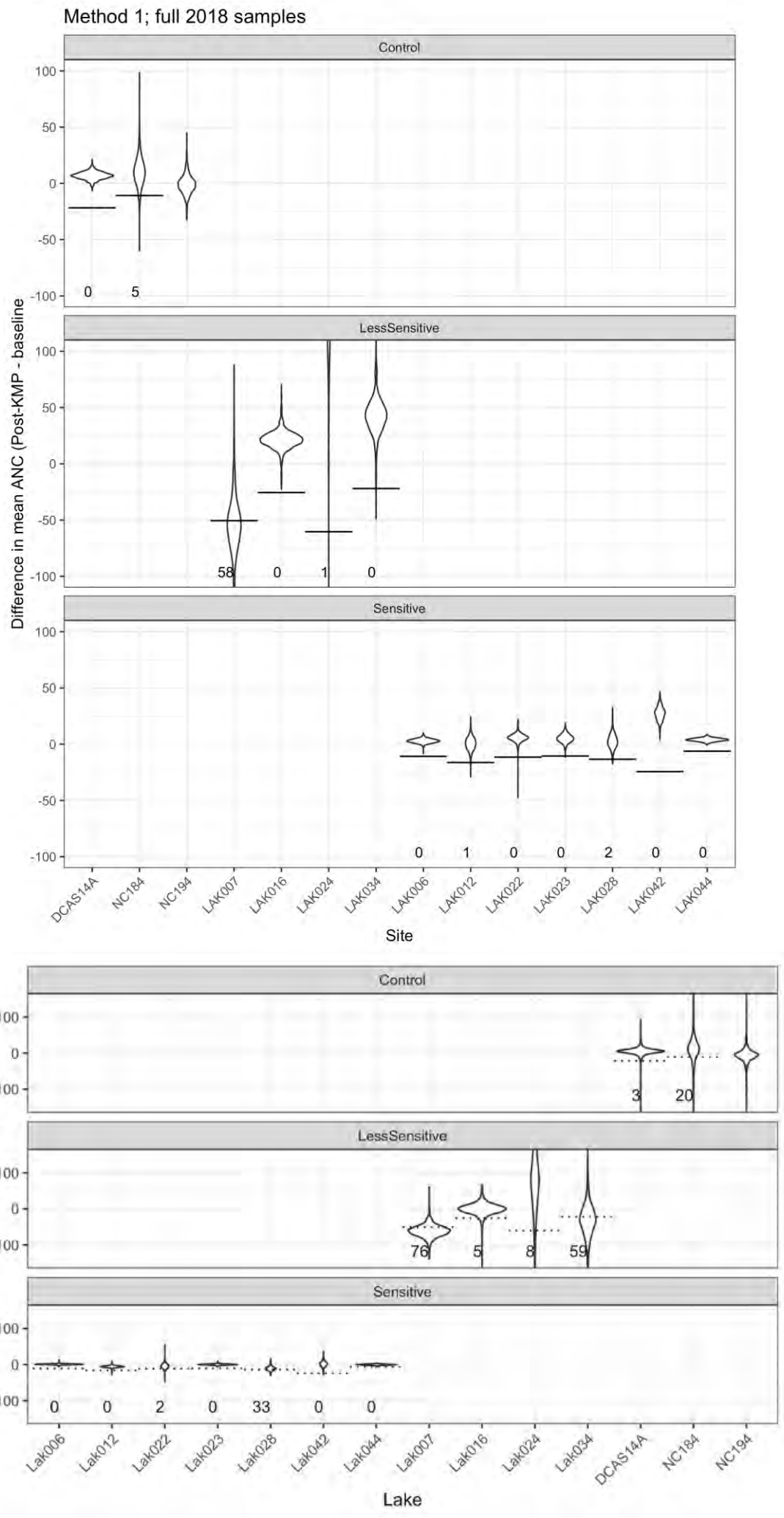


Figure 7.145. Percent belief in lake-specific decline in ANC beyond lake-specific threshold that corresponds to a change in pH of 0.3 pH units given: 1) baseline of 2012 (top graph, Figure 7.135, Aquatic Appendix F) or 2) alternate baseline period of 2012-2014 (Analysis A).

The thresholds of change in Gran ANC which correspond to a change in 0.3 pH units were based on laboratory titration curves using the 2012 data as the baseline. The titration data would have to be re-processed with the alternate baseline data to generate the appropriate thresholds for each lake with respect to a 2012-2014 baseline. This represents a significant amount of work and is not recommended at this time as it is unlikely to change the results of the sensitivity analysis. Instead, the adjusted thresholds for Analysis B simply modify the existing thresholds based on the difference between the mean Gran ANC in 2012-2014 and the 2012 value, as shown in Table 7.81. Using an adjusted Gran ANC threshold (Analysis B in Table 7.80) resulted in either a *decreased* or similar percent belief in an ANC change beyond the threshold relative to the original analysis for all lakes except the less sensitive LAK034 (which showed only a low level of support for exceeding its adjusted Gran ANC threshold).

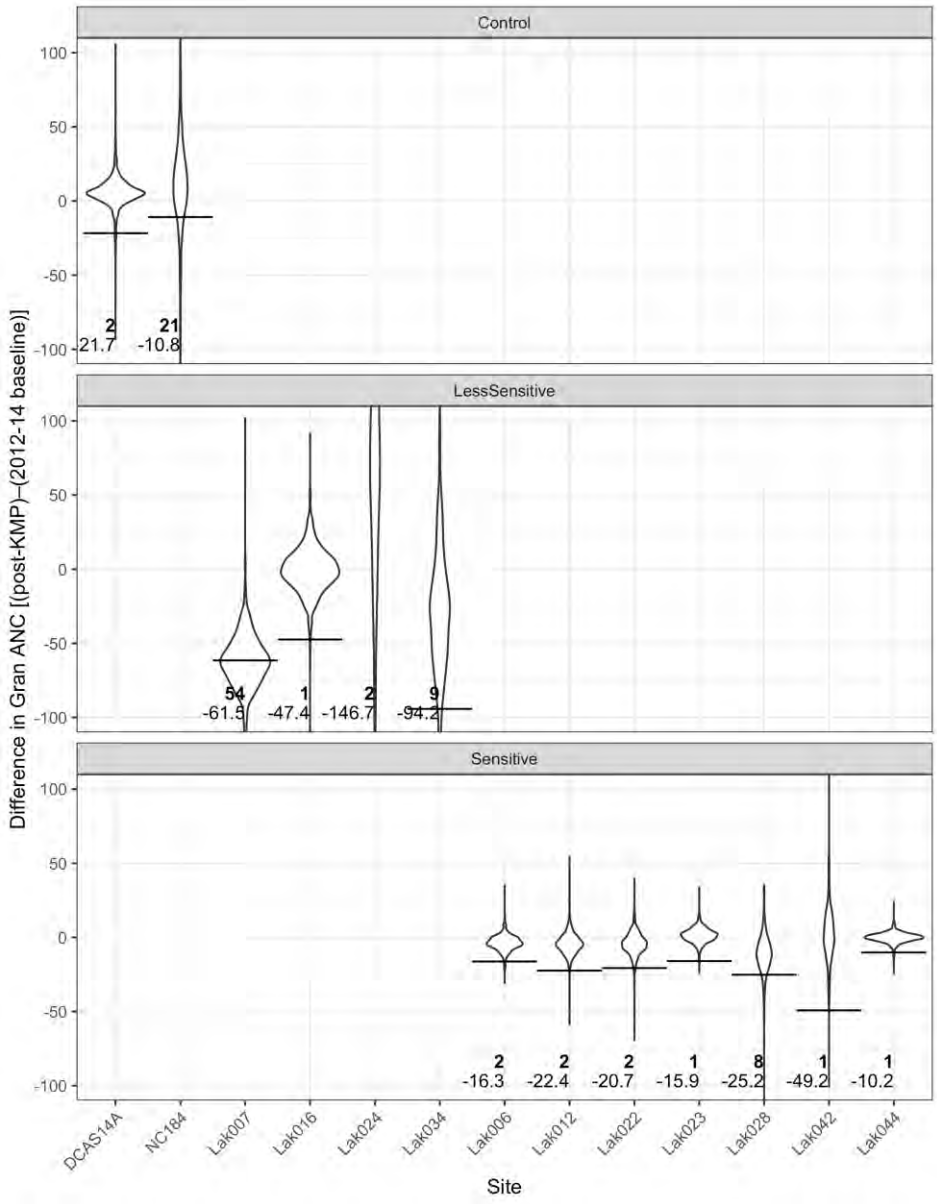


Figure 7.146. Percent belief in lake-specific decline in ANC beyond adjusted lake-specific threshold (Analysis B in Table 7.80). The % belief value is shown in bold and the adjusted ANC threshold for each lake is shown below the bolded value. This graph can be compared to the original analysis in the top graph of Figure 7.145.

7.9.3.4 Synthesis of Results for SO_4, ANC and pH

The simplified evidentiary framework (Figure 7-3 in main report) requires knowledge of the strength of evidence for *any* change in SO_4, pH and ANC, as well as evidence of whether or not the change in pH and Gran ANC has exceeded the EEM thresholds. Table 7.82 helps address the first question, while Table 7.83addresses the second question. Table 7.82 tabulates percent belief values for the 2012-14 baseline, summarizing analyses completed for this Appendix (violin plots exist, but have not been included to save space). Table 7.82 shows that application of the 2012-

2014 baseline increases the percent belief that there has been a decline in pH and ANC. The 2012-14 mean values of pH and ANC are higher than the 2012 values (possibly affected by the decommissioning of the old smelter), which increases the baseline value, and results in a higher % belief that values have declined from this higher baseline.

Table 7.82. Percent belief in pH and ANC decline > 0 with 2012 vs 2012-2014 baseline. These % belief statistics do not apply the EEM thresholds, but rather a threshold of 0. Percent belief values < 20% are shown in green, those from 20% to 80% are shown in yellow, and those > 80% are shown in bolded red.

	pH					Gran ANC (µeq/L)				
	Baseline		Post-KMP	ΔpH		Baseline		Post-KMP	ΔANC	
EEM sensitive lakes	2012	2012-14	2016-18	vs. 2012 [% belief in pH decline]	vs. 2012-14 [% belief in pH decline]	2012	2012-14	2016-18	vs. 2012 [% belief in ANC decline]	vs. 2012-14 [% belief in ANC decline]
LAK006	5.8	6.0	6.0	0.2 [1%]	0.0 [24%]	25.7	31.2	27.7	2.0 [0%]	-3.5 [6%]
LAK012	5.6	6.0	6.2	0.5 [1%]	0.2 [6%]	57.0	63.1	58.3	1.3 [1%]	-4.8 [46%]
LAK022	5.9	6.1	6.1	0.1 [0%]	0.0 [57%]	27.8	37.0	33.0	5.1 [0%]	-4.1 [6%]
LAK023	5.7	5.9	5.9	0.2 [1%]	0.1 [16%]	19.8	25.2	26.4	6.7 [0%]	1.2 [8%]
LAK028	5.0	5.2	5.0	0.0 [18%]	-0.2 73%]	-4.0	7.8	-3.5	0.5 [2%]	-11.3 [34%]
LAK042	4.7	5.1	5.2	0.5 [2%]	0.1 [10%]	-20.4	4.4	5.6	26.1 [0%]	1.3 [0%]
LAK044	5.4	5.6	5.6	0.2 [0%]	-0.1 [55%]	1.3	5.2	5.0	3.7 [0%]	-0.2 [0%]
EEM less sensitive lakes	2012	2012-14	2016-18	vs .2012	vs. 2012-14	2012	2012-14	2016-18	vs. 2012	vs. 2012-14
LAK007	8.0	8.0	8.0	0.0 [2%]	0.0 [64%]	1437.6	1448.5	1385.9	-51.6 [58%]	-62.5 [97%]
LAK016	6.3	6.6	6.7	0.3 [1%]	0.1 [24%]	68.7	90.4	89.8	21.1 [50%]	-0.6 [1%]
LAK024	7.1	7.4	7.5	0.4 1%]	0.1 [31%]	299.5	385.8	463.2	163.7 [1%]	77.4 [2%]
LAK034	6.7	6.8	6.4	-0.3 [43%]	-0.3 [100%]	99.4	171.6	139.6	40.2 [0%]	-32.0 [2%]

Table 7.83 shows that the sensitivity analyses using a baseline of 2012-2014 do not change the overall conclusions for any of the lakes. There is less evidence of a smelter effect on sulphate in three of the sensitive lakes (LAK006, LAK012 and LAK022). There is somewhat more evidence of a smelter effect on pH and ANC in LAK028 (though not sufficiently to change the previous conclusion, which acknowledged that pre-KMP conditions in LAK028 were potentially damaging to biota and have remained so in the post-KMP period).

Figure 7.147 compares the application of the simplified evidentiary framework in the main report (Figure 7-10) with the results from Analysis A (i.e., assuming a 2012-14 baseline and no change in thresholds). As noted in Table 7.80, Analysis A is more likely to over-estimate the impacts of the smelter, since the period from 2012 to 2014 was a transition period with decommissioning of the old smelter and not a representative pre-KMP period. In applying the simplified evidentiary framework, it is important to examine not only the % belief statistics in Table 7.81, but also the actual changes in mean values described in Section 7.9.2.1, and the time series of changes in Aquatic Appendix C. This is because the Bayesian analysis may in some cases show an intermediate or high % belief in a magnitude of change that is of no significance chemically or biologically, particularly for less sensitive lakes and control lakes with less frequent sampling. Issues like this are highlighted in some of the footnotes to Table 7.81.

The Bayesian analysis takes into account the variability in water chemistry measurements both within and between years, and computes the percent belief in a [SO_4] increase based on the entire distribution of estimates for changes in [SO_4] (as shown in Figure 7.142). There can sometimes be a considerable shift in the percent belief in an increase in [SO_4] for a very small change in the estimates of [SO_4] for each time period. For example, using the 2012 baseline, LAK007 had only a 1% belief in an increase in [SO_4], as shown in Table 7.84. The actual change in [SO_4] between 2012 and 2016-18 was a *decrease* of 4.4 µeq/L (Section 7.9.2.1, Table 7.76), and only 1% of the distribution of credible estimates for Δ[SO_4] was positive. When applying the 2012-14 baseline, LAK007 shows a 42% belief in an increase in [SO_4], because 42% of the distribution of credible estimates for Δ[SO_4] was positive. However, the actual change in mean values of [SO_4] between 2012-14 and 2016-18 was still a decrease, now of 2.6 µeq/L, a very small change (Section 7.9.2.1). Therefore, in the reapplication of the simplified evidentiary framework (Figure 7.147), LAK007 is still classified as a lake not showing evidence of an increase in [SO_4]. For the control lakes, which have only five years of observations (2013, 2015, 2016-18), we also take into account the fact that they are far outside the plume from the smelter.

Figure 7.147 shows that application of the 2012-14 baseline (relative to the 2012 baseline) results in little change in the first blue decision box *[Has lake [SO_4] increased since the pre-KMP period?]*. The only change relative to the draft Comprehensive Report is that LAK016 shows much less support for an increase in lake [SO_4] when the 2012-14 baseline is used, as compared to using the 2012 baseline (Table 7.83). At the second decision box *[Has lake pH or Gran ANC decreased since pre-KMP period?]*, there is stronger evidence for declines in pH and ANC relative to the 2012-14 baseline (lower figure) than occurred with the 2012 baseline, as evident in Table 7.82. Five sensitive lakes (lakes 006, 012, 022, 028 and 042) therefore proceed to the third blue decision box *[Is ΔpH or ΔGran ANC greater than the thresholds?]*. As shown in Table 7.83, none of these five sensitive lakes are likely to have exceeded the pH or Gran ANC thresholds. When compared to the 2012-14 baseline, LAK028 shows a 20% belief in exceeding the pH threshold, and a 33% belief of exceeding the Gran ANC threshold. Those would be considered low to low-intermediate levels of support.

Table 7.83. Results of sensitivity analyses on alternative baseline (2012-2014) compared to results with original baseline (2012), based on Method 1 of the Bayesian analysis. Values of % belief < 20% are coloured green, 20-80% yellow, and >80% red. Results of using the alternative baseline are shown in blue text, and in *italics* for alternative thresholds. Results for original baseline are in Table 7-10 of the main report and Table 7.71 of Aquatic Appendix F. *"[Same]"* in last column means that the sensitivity analysis has the same overall conclusion as the results in the draft comprehensive report with the original baseline.

LAKE	Changes in SO_4 (% belief in SO_4 increase / decrease from Bayesian analysis - Method 1 violin plot) [A. 2012-2014 baseline]	Changes in Gran ANC (% belief that ANC threshold exceeded, from Bayesian analysis - Method 1) [A. 2012-2014 baseline & original thresholds; *B. 2012-2014 & adjusted thresholds*]	Changes in pH (% belief pH threshold exceeded, from Bayesian analysis - Method 1) [A. 2012-2014 baseline & original thresholds; *B. 2012-2014 & adjusted thresholds*]	OVERALL INTERPRETATION for 2012 BASELINE *[OVERALL INTERPRETATION for 2012-2014 BASELINE]*
Sensitive Lakes				
LAK006	91% belief in increase [80%]	0% [0%; *2%*]	0% [1%; *0%*]	SO_4 increase *[weaker]*; no evidence of S-induced acidification *[Same]*
LAK012	99% belief in increase [69%]	8% [0%; *2%*]	0% [3%; *0%*]	SO_4 increase *[weaker evidence]*; no consistent evidence for S-induced acidification. *[Less evidence of smelter effect]*
LAK022	88% belief in increase [54%]	1% [2%; *2%*]	0% [2%; *0%*]	SO_4 increase *[weaker evidence]*; no evidence of S-induced acidification *[Less evidence of smelter effect]*
LAK023	1% belief in increase [1%]	13% [0%; *1%*]	0% [0%; *0%*]	SO_4 decrease; no evidence of S-induced acidification *[Same]*
LAK028	100% belief in increase [89%]	13% [33%; *8%*]	10% [20%; *8%*]	SO_4 increase; some evidence of S-induced acidification; low *[to intermediate]* belief in exceeding pH and ANC thresholds; conditions potentially damaging to biota pre-KMP and have remained so. *[Same]*
LAK042	32% belief in increase [52%]	1% [0%; *1%*]	0% [0%; *1%*]	No clear change in SO_4; no evidence of S-induced acidification *[Same]*
LAK044	0% belief in increase [4%]	18% [0%; *1%*]	0% [0%;*1%*]	SO_4 decrease; no evidence of S-induced acidification *[Same]*
Less Sensitive Lakes				
LAK007	1% belief in increase [42%][e]	53% [76%; 54%]	3% [0%; *0%*]	SO_4 decrease *[or no change]*; no evidence of S-induced acidification *[Same]*
LAK016	98% belief in increase [30%]	1% [5%; *1%*]	1% [3%; *0%*]	SO_4 increase; no evidence of S-induced acidification *[Same]*
LAK024	96% belief in increase [87%]	3% [8%; *2%*]	2% [6%; *2%*]	SO_4 increase; no evidence of S-induced acidification *[Same]*
LAK034	0% belief in increase [1%]	1% [59%; *9%*]	39% [b] [70%; *43%*]	SO_4 decrease; no evidence of S-induced acidification *[Same]*
Control Lakes				
DCAS14A	68% belief in increase[c] [65%]	4% [3%; *2%*]	5% [5%; *5%*]	No clear change in SO_4; no evidence of S-induced acidification *[Same]*
NC184	59% belief in increase [c] [59%]	19% [20%; *21%*]	26%[a] [27%; *28%*]	No clear change in SO_4; no evidence of S-induced acidification *[Same]*
NC194	1% belief in increase [3%]	TBD[d]	14% [a] [12%;*11%*]	SO_4 decrease; no evidence of S-induced acidification *[Same]*

[a] Mean pH in NC184 changed from ~5.7 (2013) to ~5.8 (2016-18); Mean pH in NC194 changed from ~6.6 (2013) to ~6.4 (2016-18).
[b] Not related to S deposition as lake SO_4 has declined in LAK034.
[c] Magnitude of increase in [SO_4] between 2013 and 2016-2018 is very small in NC184 (0.5 µeq/L) and DCAS14A (3 µeq/L); only 4 samples available for statistical analysis.
[d] Lake NC194 did not have a lab titration from which we could determine an ANC threshold. It had a 6 µeq/L ANC decline between 2013 and 2016-2018, but ANC decline not related to SO_4.
[e] LAK007 mean [SO_4] showed little change between 2012-14 (49.5 µeq/L) and 2016-18 (48.0 µeq/L).

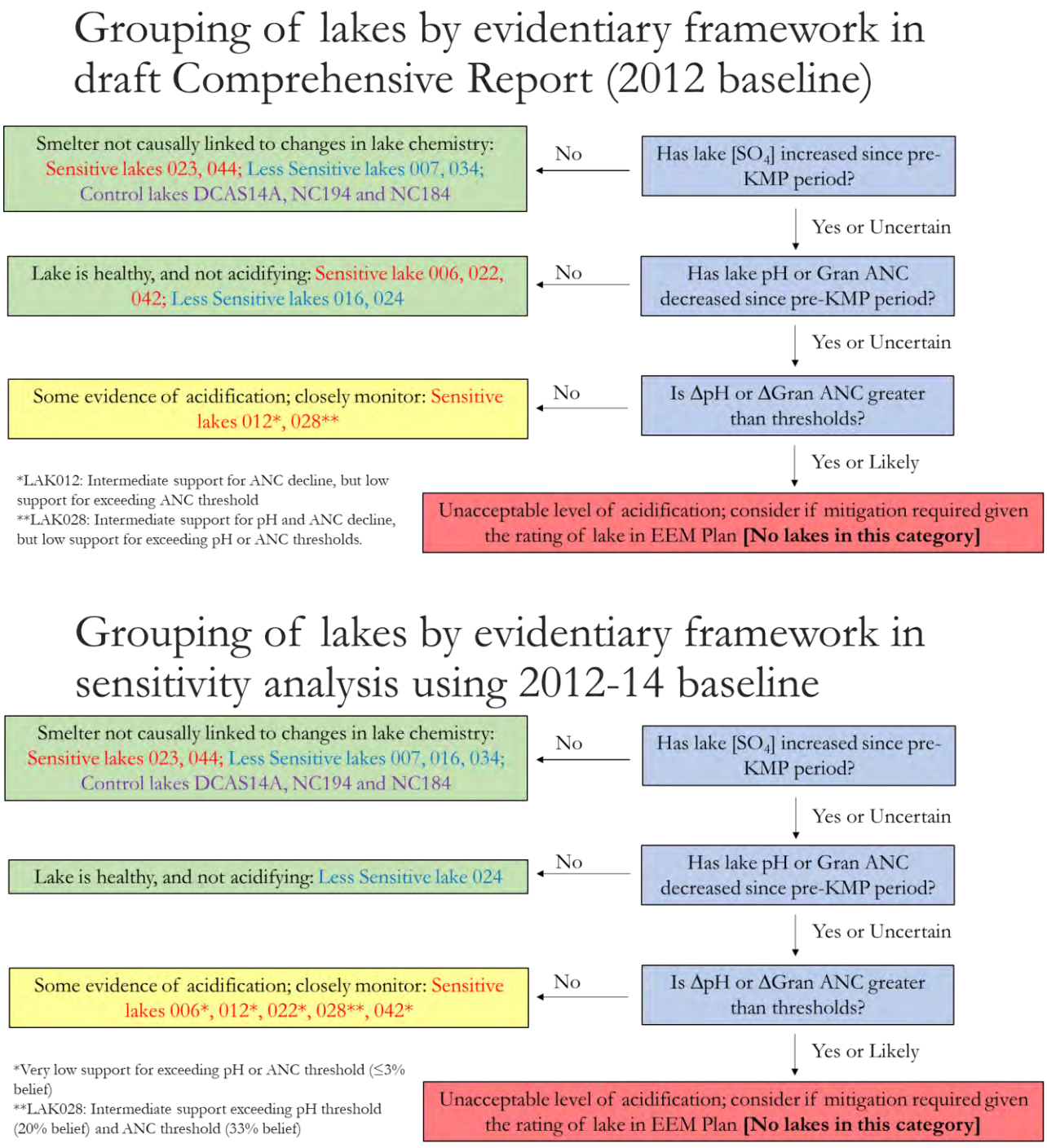


Figure 7.147. Original application of the evidentiary framework (main report Figure 7-10, top) and revised application based on the results using a 2012-2014 baseline (as shown in Table 7.81 of this appendix).

7.9.3.5 Correlations with 2-month precipitation

Lakes were analyzed by linear regression individually and all together for correlations between response variables (SO_4, pH, Gran ANC) and the cumulative precipitation over the 2-month period prior to sampling (i.e., June plus July for the August 2012 sampling, and August plus September for the October sampling in 2013-2018); see Table 7.84. No significant correlations (at alpha value of 0.01) were detected for any of the response variables whether lakes were analyzed individually or combined (Table 7.85, Figure 7.148, Figure 7.149, Figure 7.150), despite approximately a 4-fold variation in seasonal precipitation.

Table 7.84. Estimated values for seasonal precipitation.

Year	2 Months Included in Average	Total Precipitation over these 2 months (mm)
2012	July, August	122
2013	August, September	159
2014	August, September	121
2015	August, September	303
2016	August, September	280
2017	August, September	242
2018	August, September	69

Table 7.85. Results of the linear regression analyses between response variables (SO_4, pH, Gran ANC) and the cumulative amount of precipitation in the 2 months prior to sampling. No significant correlations were detected at p<0.01. Results for all lakes combined are bolded.

Lake	Response	Estimate	Std. Error	P.value	Adj-R2
Lak006	SO_4	-0.003	0.007	0.701	-0.162
Lak007	SO_4	-0.001	0.040	0.990	-0.200
Lak012	SO_4	0.008	0.015	0.616	-0.135
Lak016	SO_4	-0.013	0.022	0.567	-0.116
Lak022	SO_4	-0.013	0.022	0.572	-0.118
Lak023	SO_4	-0.024	0.014	0.150	0.239
Lak024	SO_4	-0.002	0.024	0.945	-0.248
Lak028	SO_4	0.121	0.115	0.341	0.017
Lak034	SO_4	-0.063	0.051	0.277	0.075
Lak042	SO_4	-0.002	0.005	0.740	-0.171
Lak044	SO_4	-0.004	0.003	0.292	0.061
DCAS14A	SO_4	-0.022	0.012	0.162	0.375
NC184	SO_4	-0.010	0.003	0.057	0.670
NC194	SO_4	-0.002	0.002	0.421	-0.034
COMBINED	**SO_4**	**-0.007**	**0.028**	**0.797**	**-0.010**
Lak006	pH	0.000	0.000	0.631	-0.140
Lak007	pH	0.000	0.000	0.338	0.020
Lak012	pH	0.000	0.001	0.775	-0.179

Lake	Response	Estimate	Std. Error	P.value	Adj-R2
Lak016	pH	0.000	0.001	0.750	-0.173
Lak022	pH	0.000	0.000	0.714	-0.165
Lak023	pH	0.000	0.000	0.897	-0.196
Lak024	pH	0.000	0.001	0.795	-0.226
Lak028	pH	-0.001	0.001	0.055	0.465
Lak034	pH	-0.001	0.001	0.288	0.065
Lak042	pH	0.001	0.001	0.301	0.052
DCAS14A	pH	0.000	0.001	0.406	-0.018
Lak044	pH	0.000	0.000	0.672	-0.153
NC184	pH	-0.002	0.001	0.033	0.766
NC194	pH	0.000	0.000	0.221	0.256
COMBINED	**pH**	**0.000**	**0.001**	**0.798**	**-0.010**
Lak006	ANC	-0.006	0.017	0.741	-0.171
Lak007	ANC	-0.005	0.251	0.985	-0.200
Lak012	ANC	0.016	0.023	0.532	-0.101
Lak016	ANC	0.012	0.056	0.838	-0.189
Lak022	ANC	0.000	0.023	0.986	-0.200
Lak023	ANC	0.018	0.015	0.268	0.084
Lak024	ANC	-0.031	0.288	0.919	-0.246
Lak028	ANC	-0.042	0.038	0.312	0.042
Lak034	ANC	-0.002	0.156	0.991	-0.200
Lak042	ANC	0.029	0.051	0.592	-0.126
Lak044	ANC	0.008	0.009	0.408	-0.032
DCAS14A	ANC	0.925	1.819	0.646	-0.227
NC184	ANC	-0.081	0.039	0.130	0.452
NC194	ANC	-0.026	0.033	0.490	-0.107
COMBINED	**ANC**	**0.015**	**0.374**	**0.969**	**-0.011**

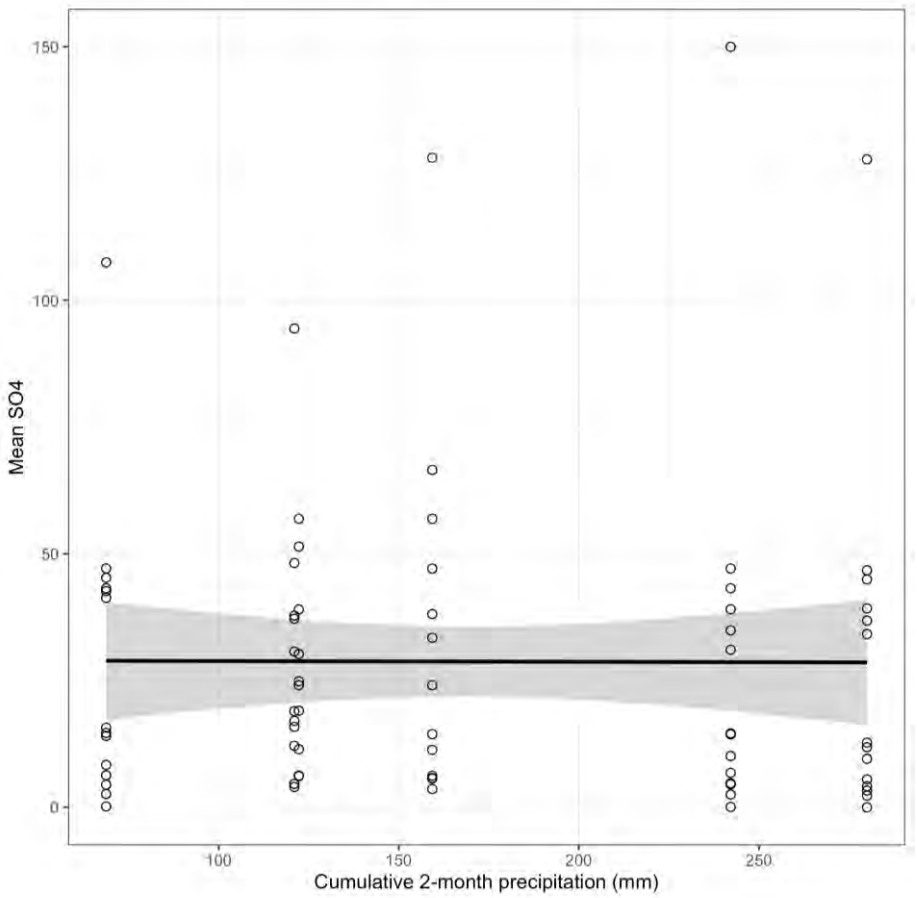


Figure 7.148. Linear regression with annual mean SO_4 and 2-month precipitation for all lakes. The grey shaded area is the 95% confidence interval.

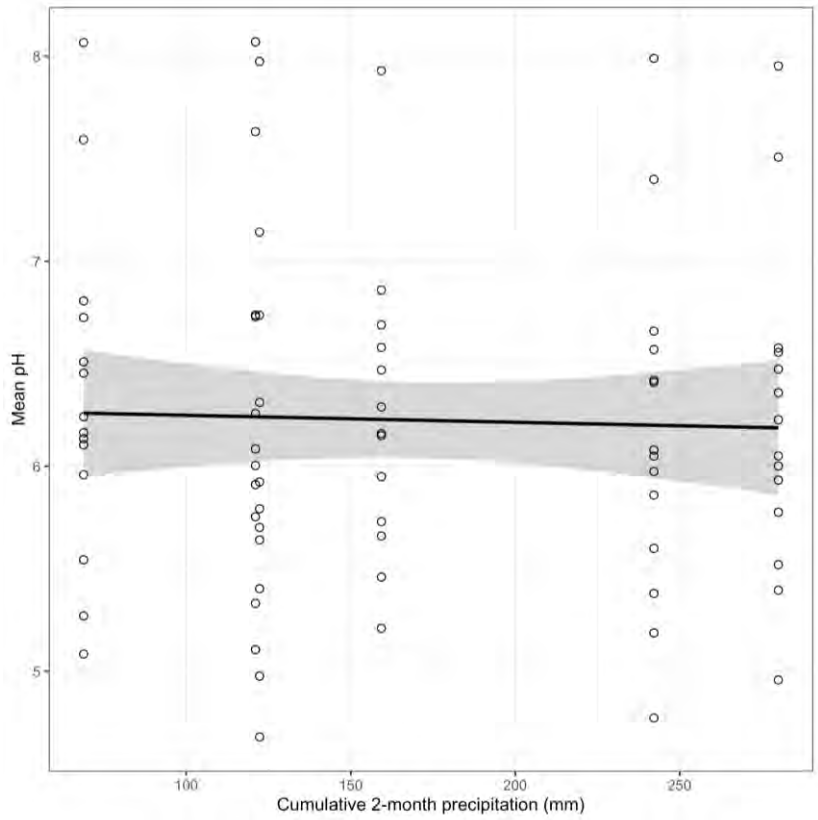


Figure 7.149. Linear regression with annual mean pH and 2-month precipitation for all lakes. The grey shaded area is the 95% confidence interval.

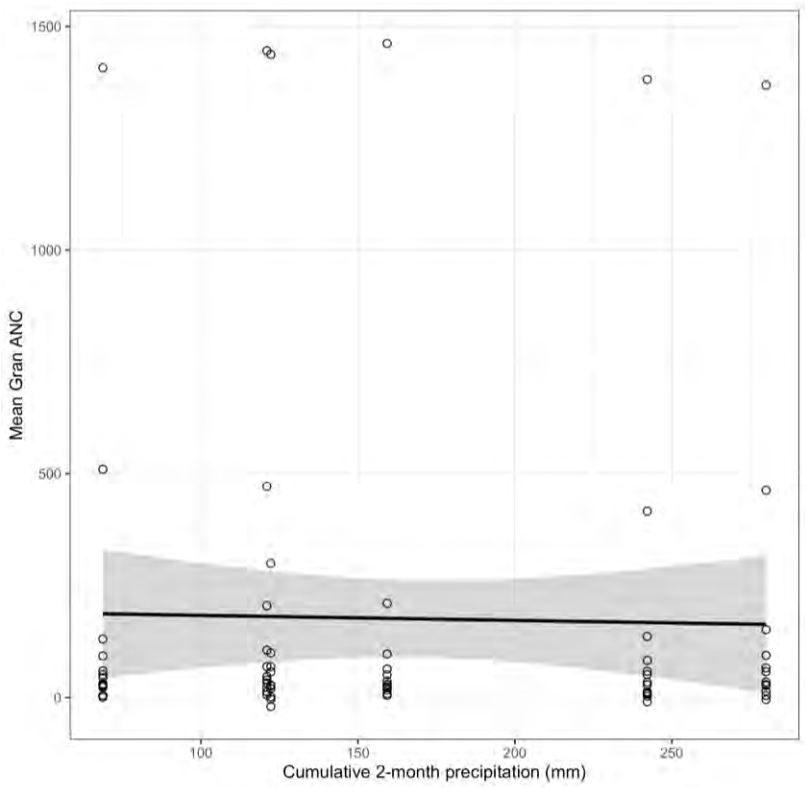


Figure 7.150. Linear regression with annual mean Gran ANC and 2-month precipitation for all lakes. The grey shaded area is the 95% confidence interval.

7.9.3.6 BACI with 2-month precipitation and F-Factor

A suite of three additional BACI analyses that use the 2012-2014 baseline were run for each response variable (SO_4, pH, Gran ANC) with all lakes combined. Each suite of models includes a model with just the BACI contrast, a model with the BACI contrast and the 2-month precipitation covariate, and a model with the BACI contrast, the 2-month precipitation and F-Factor covariates (in response to a reviewer's suggestion to include lake sensitivity). Compared to previous BACI analyses in Appendix F, these analyses add one or two additional covariates (seasonal precipitation and lake sensitivity). Annual average emissions were used as a covariate in the previous BACI analyses in Appendix F, but were removed since the BACI contrast is intended to test for a smelter effect; including emissions as a covariate is redundant. No significant BACI contrast, 2-month precipitation effect or significant F-Factor were identified for any of the response variables (Table 7.84).

Table 7.86. The results of the additional BACI analyses with the 2012-2014 baseline for each response variable (pH, ANC, SO_4). No significant BACI contrast, or effect of precipitation or F-Factor was identified in any analysis. Models 1, 4, and 7 include the BACI contrast as well as the 2-month precipitation and F-Factor covariates. Models 2, 5, and 8 include the BACI contrast and only the 2-month precipitation covariate. Models 3, 6, and 9 only include the BACI contrast.

Model No.	term	Response	estimate	SE	p.value	Precip	F.Factor
1	baci	pH	0.075	0.109	0.496	Yes	Yes
1	PRECIP	pH	0.000	0.001	0.720	Yes	Yes
1	F.FACTOR	pH	-0.221	1.147	0.854	Yes	Yes
2	baci	pH	0.146	0.093	0.120	Yes	No
3	baci	pH	0.144	0.093	0.126	No	No
4	baci	ANC	7.309	4.969	0.144	Yes	Yes
4	PRECIP	ANC	0.000	0.030	0.998	Yes	Yes
4	F.FACTOR	ANC	50.840	45.800	0.309	Yes	Yes
5	baci	ANC	8.238	4.208	0.053	Yes	No
6	baci	ANC	8.190	4.199	0.054	No	No
7	baci	SO_4	0.595	8.345	0.943	Yes	Yes
7	PRECIP	SO_4	0.017	0.022	0.516	Yes	Yes
7	F.FACTOR	SO_4	133.345	82.442	0.157	Yes	Yes
8	baci	SO_4	1.704	7.085	0.810	Yes	No
9	baci	SO_4	1.184	7.004	0.866	No	No

7.9.4 Steady State Future pH

7.9.4.1 Future pH

Average pH levels over the 2012-2014 period were consistently higher than 2012 pH levels (first two columns under Empirical Observations in Table 7.87). Post-KMP mean pH levels (third column under Empirical Observations) have remained equal to, or higher than, the 2012-2014 mean values in nine of the eleven lakes. The two exceptions are LAK028 (decline of 0.2 pH units relative to the 2012-14 mean, see Table 7.83 for more detailed analysis) and LAK034 (decline of 0.4 pH units, unrelated to the smelter, as SO_4 concentrations have declined, see Table 7.83). The next part of Table 7.87 lists the predicted steady state pH (pH_∞), and the predicted change in pH from 2012 levels, under an emission scenario of 42 tpd, as reported in the STAR. In the STAR, all of the sensitive lakes were predicted to have a pH decline of 0.1 pH units or more (which is what led to their inclusion in the EEM program). Revised predictions of steady state pH included in Table 7-11 of the Comprehensive Report ("NEW: Best Prediction" in Table 7.87) are considerably higher that the predictions in the STAR, for several reasons (i.e., emissions have been ~30 tpd, not 42 tpd; most lakes have shown less change in SO_4 than predicted even after accounting for lower emissions; and lakes with evidence of SO_4 change have been less acid-sensitive than

predicted). When expressed relative to the 2012-14 baseline ("ΔpH (2012-14)"), the predicted ΔpH is less positive (or more negative) compared to being expressed relative to the 2012 baseline.

Table 7.87. Predicted change in steady state pH relative to both a 2012 baseline and a 2012-2014 baseline. Revision of Table 7.83 in this appendix, and the pH component of Table 7-11 in the main report.

Lake	Empirical Observations			ORIGINAL: STAR predictions		NEW: Best Prediction			Effect of Alternate Baseline on Predicted Steady-state pH
	2012 pH	2012-14 pH	Post-KMP pH	pH_∞	Δ pH (2012)	pH_∞	Δ pH (2012)	Δ pH (2012-14)	
EEM Sensitive Lakes									
LAK006	5.8	6.0	6.0	5.3	-0.5	6.0	0.2	0.0	Predicted increase decreases to zero
LAK012	5.6	6.0	6.2	5.5	-0.1	6.1	0.5	0.2	Predicted increase declines from 0.5 to 0.2
LAK022	5.9	6.1	6.1	5.5	-0.4	6.0	0.1	-0.1	Small increase becomes small decrease
LAK023	5.7	5.9	5.9	5.2	-0.5	5.9	0.2	0.0	Predicted increase decreases to zero
LAK028	5.0	5.2	5.0	4.6	-0.4	4.8	-0.2	-0.4	Predicted decrease exceeds threshold
LAK042	4.7	5.1	5.2	4.5	-0.2	5.2	0.5	0.1	Predicted increase declines from 0.5 to 0.1
LAK044	5.4	5.6	5.6	4.9	-0.5	5.5	0.1	-0.1	Small increase becomes small decrease
EEM Less Sensitive Lakes									
LAK007	8.0	8.0	8.0	8.0	0.0	8.0	0.0	0.0	No change
LAK016	6.3	6.6	6.7	6.2	-0.1	6.6	0.3	0.1	Predicted increase declines from 0.3 to 0.1
LAK024	7.1	7.4	7.5	7.1	0.0	7.5	0.4	0.1	Predicted increase declines from 0.4 to 0.1
LAK034	6.7	6.8	6.4	6.7	0.0	6.4	-0.3	-0.3	Negligible change (-0.29 vs. -0.33).

*Not related to S deposition as lake SO_4 has declined in LAK034

7.9.4.2 Future ANC

Average Gran ANC levels over the 2012-2014 period were consistently higher than 2012 pH levels (first two columns under Empirical Observations in Table 7.87). Post KMP mean Gran ANC levels (third column under Empirical Observations) have remained higher than the 2012-2014 mean values in three lakes, decreased relative to the 2012-2014 mean in five lakes, and have shown no change (< 1 µeq/l) in two lakes; see Table 7.83 for a more detailed analysis. The next part of Table 7.87 lists the predicted steady state Gran ANC (Gran ANC_∞), and the predicted change in Gran ANC relative to both 2012 levels and the mean ANC from 2012-2014, under an emission scenario of 42 tpd. When expressed relative to the 2012-14 baseline ("ΔGran ANC (2012-14)"), the predicted ΔGran ANC is less positive (or more negative) compared to being expressed relative to the 2012 baseline. Relative to the 2012-14 baseline, two lakes (LAK028 and LAK034) are predicted to eventually exceed their reference thresholds for changes in Gran ANC. As noted above, changes in the pH and Gran ANC of LAK034 are unrelated to the smelter.

Table 7.88. Predicted change in steady state Gran ANC relative to both a 2012 baseline and a 2012-2014 baseline. Revision of Table 7.84 in this appendix, and the ANC component of Table 7-11 in the main report.

	Empirical Observations of Gran ANC (µeq/L)			NEW prediction – with best inputs				Effect of Alternate Baseline on Predicted Steady-state pH
Lake	2012 Gran ANC	2012-14 Gran ANC	post-KMP Gran ANC (2016-2018)	Gran ANC∞	Δ Gran ANC (2012)	Δ Gran ANC (2012-14)	Δ Gran ANC (2012) Threshold †	
EEM Sensitive Lakes								
LAK006	25.7	31.2	27.7	24.7	-1.0	-6.5	-10.8	Larger decrease; still above reference threshold †
LAK012	57.0	63.1	58.3	56.0	-1.0	-7.1	-16.3	Larger decrease; still above reference threshold †
LAK022	27.8	37.0	33.0	30.4	2.6	-6.6	-11.5	Larger decrease; still above reference threshold †
LAK023	19.8	25.2	26.4	23.8	4.0	-1.4	-10.5	Larger decrease; still above reference threshold †
LAK028	-4.0	7.8	-3.5	-9.3	-5.3	-17.1	-13.4	Larger decrease, exceeds reference threshold †
LAK042	-20.4	4.4	5.6	4.2	24.6	-0.2	-24.4	Predicted increase decreases to approx. zero
LAK044	1.3	5.2	5.0	2.8	1.5	-2.5	-6.2	Larger decrease; still above reference threshold †
EEM Sensitive Lakes								
LAK007	1437.6	1448.5	1385.9	1385.9	-51.6	-62.5	-50.6	Larger decrease; still exceeds reference threshold †
LAK016	68.7	90.4	89.8	88.0	19.4	-2.4	-25.6	Predicted increase → small decrease; still above threshold †
LAK024	299.5	385.8	463.2	463.2	163.7	77.4	-60.4	Predicted increase decreases
LAK034	99.4	171.6	139.6	138.7	39.3	-32.9	-22.0	**Predicted increase → decrease; exceeds reference threshold †**

† The Gran ANC threshold was determined (based on analysis of the titration data) as the magnitude of change in Gran ANC equivalent to a 0.3 pH unit decline *from the 2012 pH value* and due to the non-linear relationship between pH and Gran ANC, this threshold does **not** necessarily represent a 0.3 pH unit decline *from the average 2012-14 pH value*. The Gran ANC threshold therefore only applies directly to the changes calculated from the 2012 baseline but is included for approximate reference.

7.10 Aquatic Appendix J: Cited References for Aquatic Receptor Chapter and Appendices

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