Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project

2015 Annual Report

Prepared for:

Rio Tinto Alcan
1 Smeltersite Road, P.O. Box 1800,
Kitimat, BC, Canada V8C 2H2

Prepared by:

ESSA Technologies Ltd.
Suite 600 – 2695 Granville St.
Vancouver, BC, Canada V6H 3H4

Authored by:
Dr. Julian Aherne, Trent University, Peterborough ON
Mr. Alexander Hall, ESSA Technologies Ltd., Vancouver BC
Ms. Anna Henolson, Trinity Consultants, Kent WA
Ms. Hui Cheng, Trinity Consultants, Kent WA
Dr. John Laurence, Portland OR
Mr. David Marmorek, ESSA Technologies Ltd., Vancouver BC
Ms. Carol Murray, ESSA Technologies Ltd., Vancouver BC
Dr. Shaun Watmough, Trent University, Peterborough ON

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This report also cites work undertaken by:

Limnotek Research and Development Inc., Vancouver BC
Stantec Consulting Limited, Terrace, BC
Dr. Paul Weidman, Simon Fraser University, Vancouver BC

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Summary of EEM Actions

The following tables summarize the EEM commitments for 2015, what was done, and where to look for more information on each topic.

Topic	The commitment	What was done	Where to learn more
Atmospheric Pathways			
Atmospheric SO_2 concentration	Maintain existing four continuous SO_2 analysers. Assess and compare SO_2 concentrations at Haul Road with SO_2 concentrations at KMP Campsite. 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.	Collection and analysis of data from five analyzers, and comparison to model output. Drafted Terms of Reference for continuous monitoring network optimization.	Section 3.1
	Implement passive-diffusive SO_2 monitoring pilot program.	Conducted passive monitoring pilot.	Section 3.1 Technical Memos P01, P02, P03
Wet deposition	Maintain two rain chemistry stations (Haul Road and Lakelse Lake).	Continued operation of both stations.	Section 3.1
Dry deposition	Develop and apply the methods for estimating dry deposition using existing data, to see if this is a significant data gap. Install a continuous SO_2 monitor and Lakelse Lake station.	Developed method for estimating dry deposition. Deferred to 2016.	Section 3.1 Technical Memo D01
Human Health			
Atmospheric SO_2 concentrations	Increase accessibility of ambient air quality data to the community.	Planned for 2016. Link to MOE Air Quality Ratings added to RTA's website.	Section 3.2
	Report on SO_2-associated predicted airway responses.	Deferred to 2016 given low emissions in 2015.	Section 3.2
Vegetation			
Sulphur content in hemlock needles	Collection of hemlock needles near the end of the growing season from mid-August to mid-September, and analysis for sulphur content.	Vegetation survey, collection and analysis of hemlock needles, and field trip and presentation for the KPAC.	Section 3.3 Laurence (2015)

Topic	The commitment	What was done	Where to learn more
Terrestrial Ecosystems (Soils)			
Soil modelling	Develop weight-of-evidence approach for assessing whether change in CL exceedance (if predicted) is causally related to KMP.	Weight of evidence updated in 2015.	Section 3.4 Technical Memo S03
	Conduct additional soil sampling to fill data gaps (QD bedrock type in sensitive lake areas south of Lakelse Lake accessible by road; CA bedrock type near smelter; OG bedrock type in southwestern part of the region; and filling any important gaps for glaciofluvial landforms).	Collection of soil at supplemental sites postponed to 2016.	Section 3.4, sampling locations described in Technical Memo S02
Permanent soil plots	Establish plots in collaboration with BC MOE, and conduct initial soil sampling and analysis.	Sampling at long-term plots at Lakelse Lake and Kitimat Coho flats.	Section 3.4 Technical Memo S04
	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.	Weight of evidence developed.	Section 3.4 Technical Memo S04
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)			
Chemistry – water sampling	Annual water sampling and laboratory analysis, and data evaluation.	Completed. Additional sampling in Goose Creek watershed to assess sensitivity; and continuation of intensive monitoring in three lakes.	Section 3.5 Technical Memos W03, W04, W05 Limnotek (2016)
Fish sampling	Sample the three reference lakes. Resample if the lake pH change reaches the threshold.	Completed.	Section 3.5 Technical Memo W03 Limnotek (2016)
Episodic acidification	Finalize the study design for snow melt and fall storm episodic acidification in Anderson Creek near KMP (gauged stream).	Continuous pH monitoring at Anderson Creek. Completion of study design and preliminary sampling by Dr. Paul Weidman of Simon Fraser University.	Section 3.5 Technical Memo W03
Amphibians	Provide support to existing local community groups who conduct annual amphibian monitoring.	No action in 2015. Next steps will be revisited in 2016.	--

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1 Introduction

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 on human health, vegetation, terrestrial ecosystems, and aquatic ecosystems. Figure 1 shows a conceptual model of the pathways of potential effect that were considered in the technical assessment.

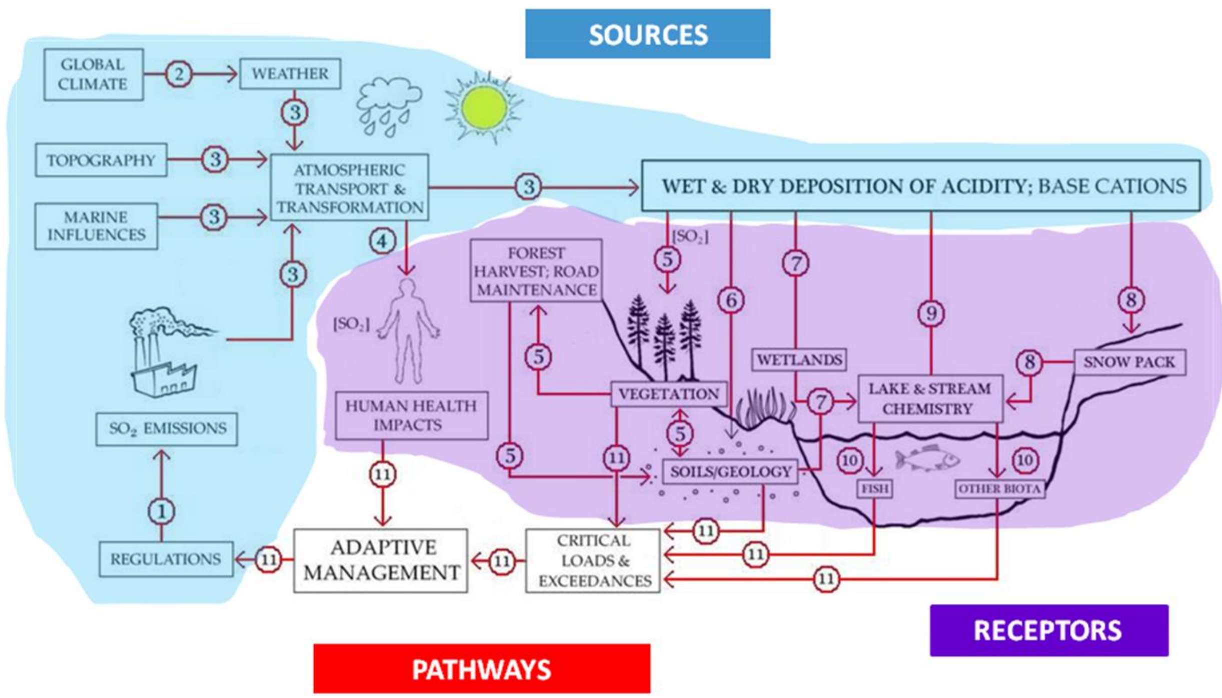


Figure 1. Source-Pathway-Receptor model of SO_2 emissions in the environment, showing linkages between sources and receptors. (Source: Figure 3.1-1 from ESSA et al. 2013)

A sulphur dioxide Environmental Effects Monitoring (EEM) Program was designed to answer questions that arose during the technical assessment, and to monitor effects of SO_2 from the modernized smelter on human health, vegetation, and terrestrial and aquatic ecosystems. Results from this 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 SO_2 emissions from the modernized smelter at full production capacity. An EEM Plan (ESSA et al. 2014a) that focuses on the first 6 years (2013-2018) of the EEM Program is currently underway. What is learned during this period will be applied to improve the Program in 2019. Other smelter 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.

SO_2 EEM reporting will occur on an annual basis. These reports will present a summary of EEM activity each year, and an overview of EEM activities that will be undertaken the following year. Details of the results from EEM activities will be documented in technical memoranda, allowing access to more in-depth technical information for the ECC, PAC, and anyone else who is interested. A comprehensive review will be conducted in 2019 to examine results from the SO_2 EEM Plan from 2013 to 2018. The review will inform the design of EEM activities after 2018, based on what has been learned during the first six years.

This document comprises the 2015 Annual Report under the SO_2 EEM Plan for KMP. It is organized into sections according to the SO_2 assessment framework illustrated in Figure 2.

The Annual Report for 2016 will be prepared in the spring of 2017.

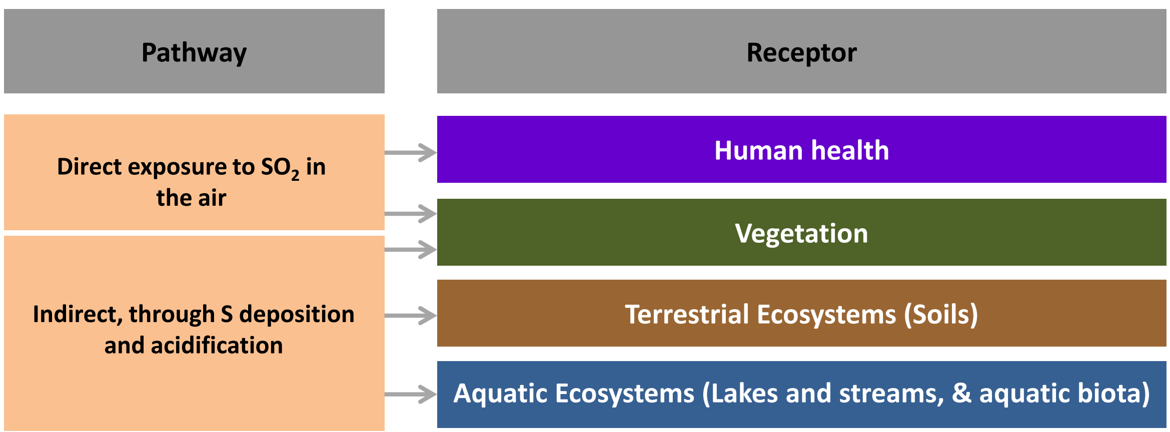


Figure 2. Framework for reporting on EEM activities.

2 Facility Production and Emissions

Metal production from the Kitimat smelter was lower in 2013, 2014 and 2015 than previous years (Figure 3), in preparation for the transition to the modernized smelter. The transition to the modernized AP40 technology occurred during 2015 (Figure 4). During this ramp-down and transition period, emissions of SO_2 decreased from an average of 15.1 tonnes per day in 2012 to 8.3 tonnes per day in 2015 (Figure 5). Emissions in 2015 were a combination of emissions from the original and the modernized technology.

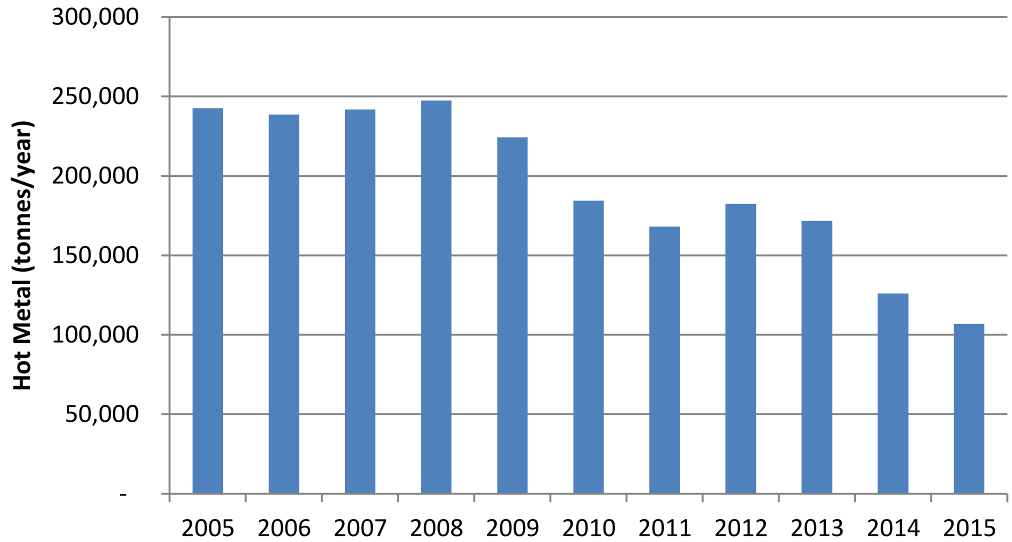


Figure 3. Annual hot metal production from the Kitimat smelter from 2005 to 2015. (Source: Rio Tinto Alcan)

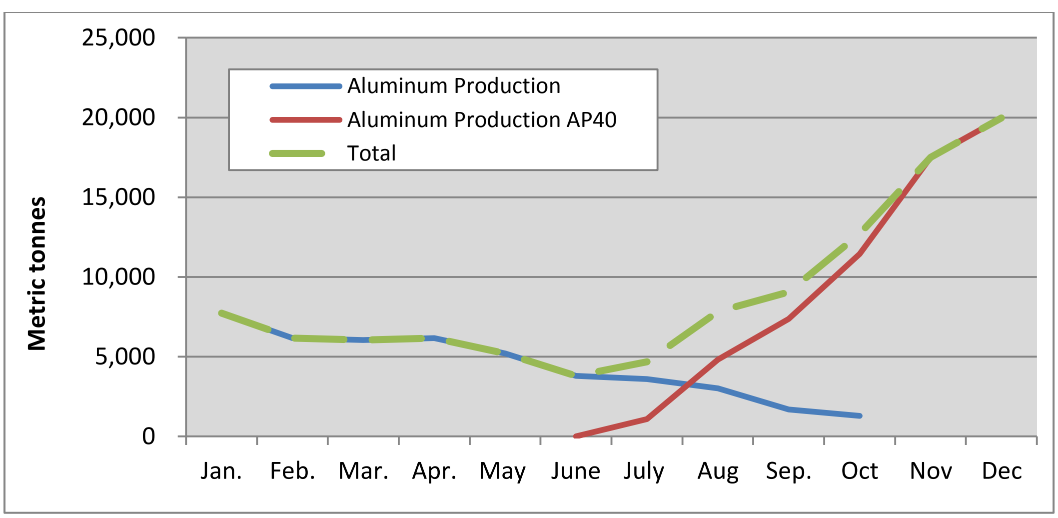
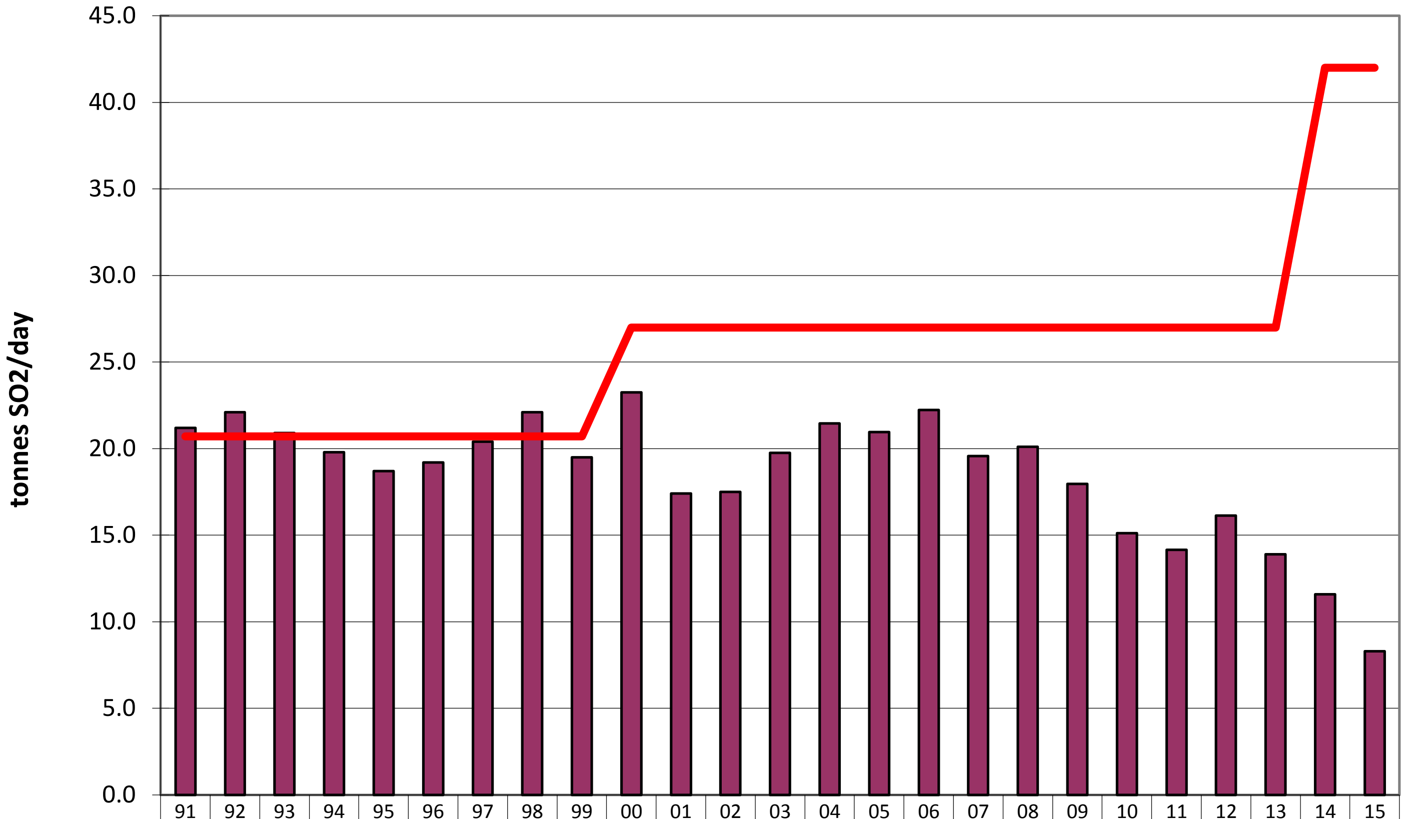


Figure 4. Monthly hot metal production for 2015 during the transition to the modernized technology. (Source: Rio Tinto Alcan)



	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Average	21.2	22.1	20.9	19.8	18.7	19.2	20.4	22.1	19.5	23.3	17.4	17.5	19.8	21.4	21.0	22.2	19.6	20.1	18.0	15.1	14.2	16.1	13.9	11.6	8.3
Limit	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	42.0	42.0

Figure 5. Annual SO_2 emissions from the Kitimat smelter over the past 15 years. (Source: Rio Tinto Alcan)

3 EEM Activities

3.1 Atmospheric Pathways

SO_2 Concentrations

SO_2 monitoring data were collected from five existing continuous analysers: Haul Road (fenceline), Riverlodge (lower Kitimat), Whitesail (upper Kitimat), Kitamaat Village and KMP Camp (Figure 6). There were technical issues with the communications equipment at the Whitesail station, and that station began recording data in August 2015. In 2015, SO_2 monitoring data from three stations required correction for a calibration gas issue.

Figure 7 shows the pattern of the monthly average SO_2 concentrations at the five continuous monitoring stations from 2013 through 2015, along with monthly SO_2 emissions over the same period. The continuous air quality monitoring stations record hourly observations of SO_2. They provide information on air quality in the area on an ongoing basis, and will provide important data for many EEM activities over the next three years.

Figure 8 shows a histogram depicting the relative frequency of hourly averaged concentrations of SO_2 at the Haul Road, Riverlodge, Kitamaat Village and KMP Camp. There is a relatively high frequency of low concentrations (below 10 $\mu g/m^3$) and low frequency of higher concentrations.

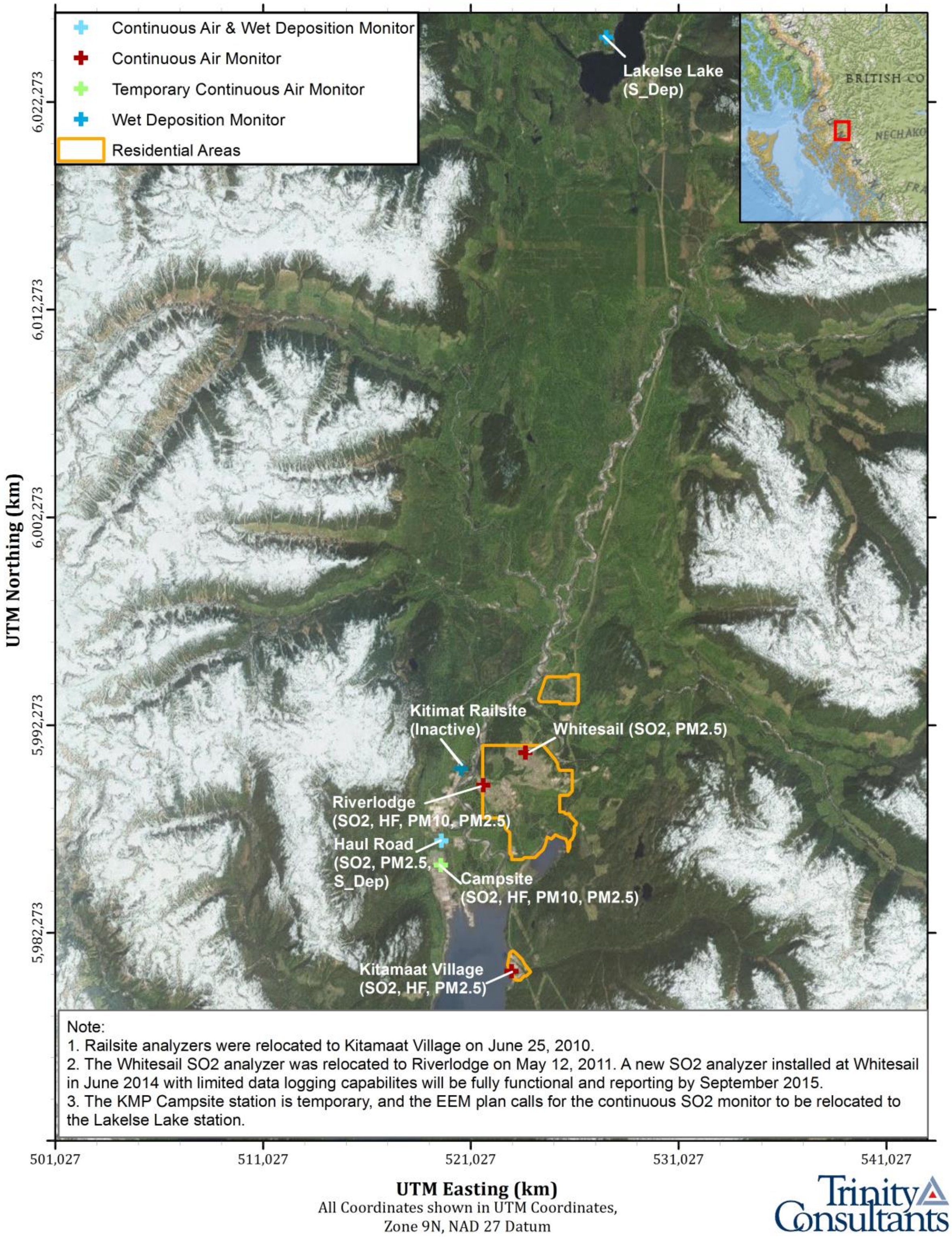


Figure 6. Locations of the four continuous SO_2 analysers (Haul Road, Whitesail, Riverlodge, Kitamaat Village) as well as the KMP Camp location.

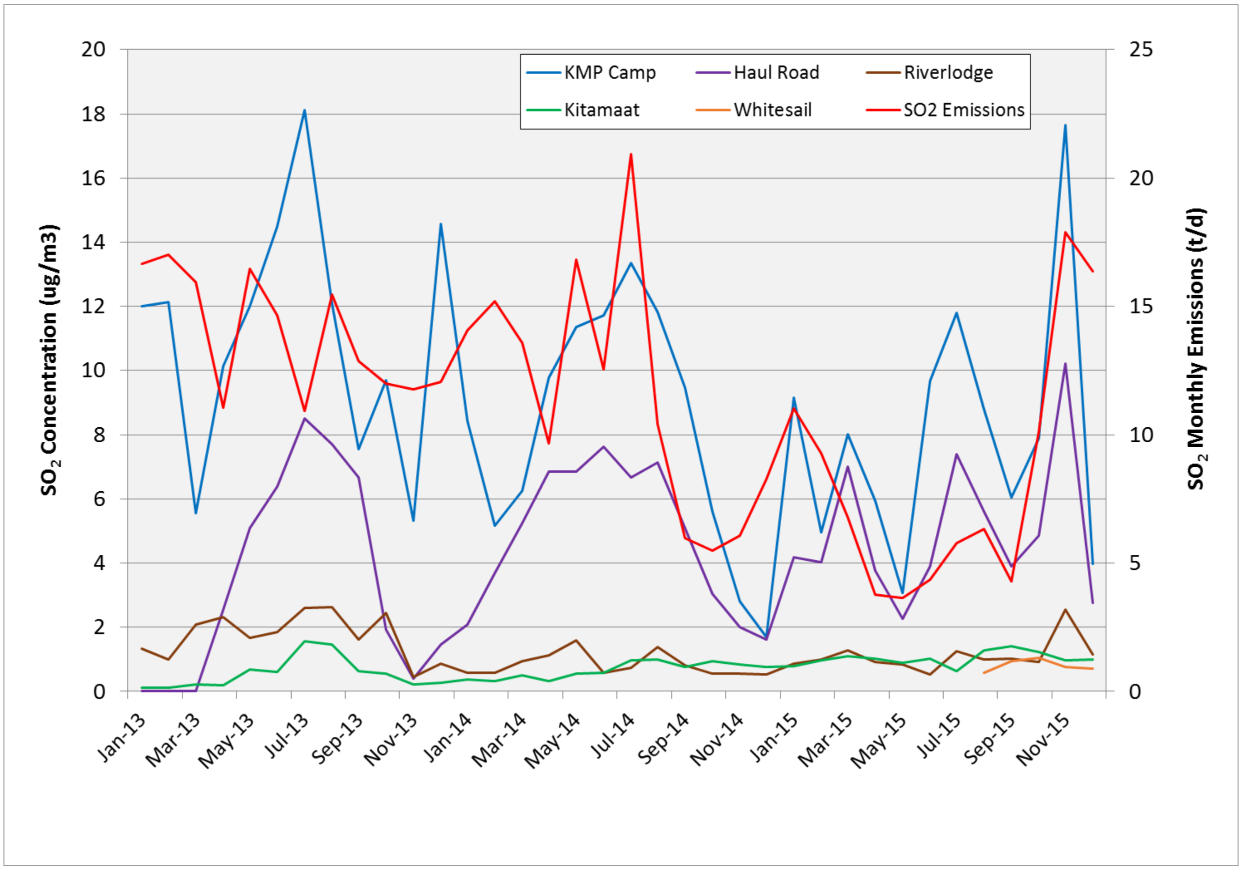


Figure 7. Monthly SO_2 emissions (red line) and monthly average ambient SO_2 concentrations at five continuous monitoring stations (blue, purple, brown, green and orange lines) for 2013 to 2015. (Source: Rio Tinto Alcan)

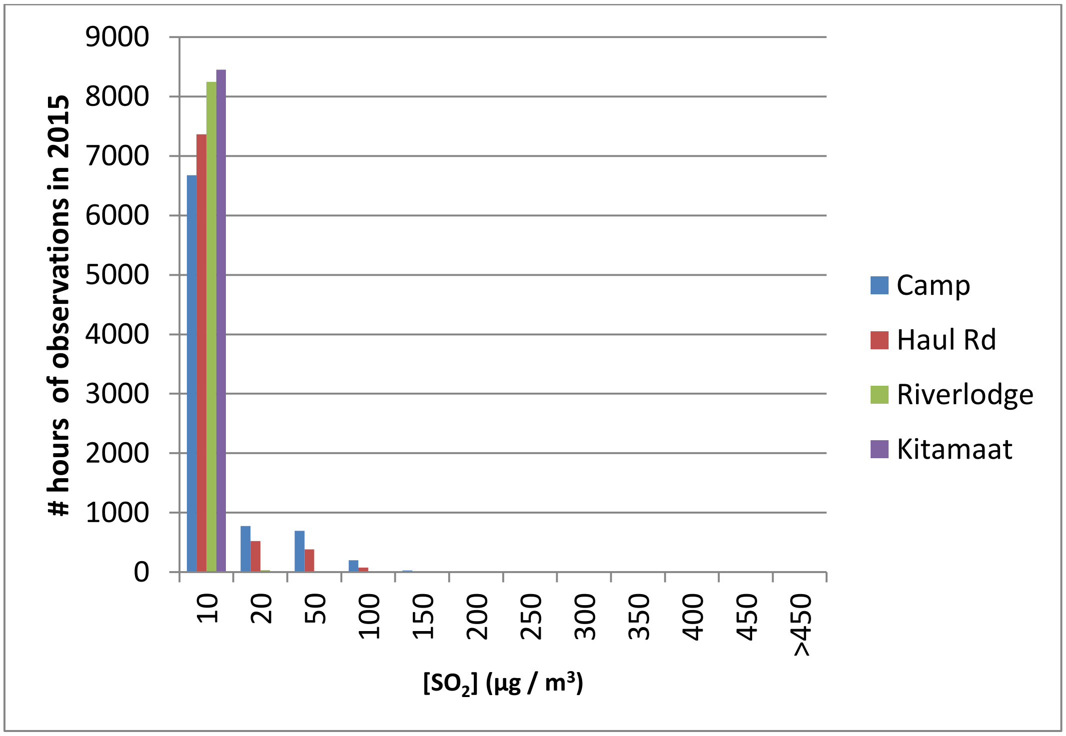


Figure 8. SO_2 hourly concentrations at the KMP Camp, Haul Road, Riverlodge and Kitamaat Village continuous monitoring stations. The first interval is 0 to 10 µg/m^3. (Source: Rio Tinto Alcan)

Compare to the Model Output

Monitoring data collected at the five monitor stations are compared to the air dispersion modelling results prepared for the STAR. Table 1 and Figure 9 show the comparison between maximum monitored concentrations in 2015 and the maximum predicted SO_2 concentrations from the air dispersion modelling analysis for 1-hour, 3-hour, 24-hour and annual averaging periods. Note that the predicted concentrations from air dispersion modelling analysis include background concentrations that were applied in the STAR. Additionally, the post-KMP maximum predicted concentrations at any offsite and residential receptors were the main driver for the EEM program for atmospheric pathways; therefore, the monitored concentrations in 2015 are also compared to these maximum predicted concentrations.

As shown in Table 1, the maximum monitored concentrations were up to 55% of the maximum predicted concentrations at any offsite monitor (excluding KMP Camp). The maximum concentrations in 2015 were up to 17% of the maximum predicted concentrations at monitors in residential areas (Kitamaat Village, Riverlodge and Whitesail) for short-term averaging periods (1-hr, 3-hr and 24-hr), and averaged 18% across the three residential monitors for the annual average. The 2015 emission rates were 20% of the permitted level of 42 t/d. These comparisons support the discussion in the STAR that the predicted modelled concentrations are conservative compared to measured concentrations.

Table 1. 2015 Monitored Data Compared to Modelled Concentrations.

Monitor Location [1]	Averaging Period	2015 Monitored Maximum Concentration (µg/m^3) [2]	Maximum Modelled Concentration at the Monitor Location (µg/m^3) [3]	Year of Maximum Modelled Concentration at the Monitor Location (µg/m^3) [3]
KMP Camp	1-hour	189.40	1,169.52	2009
KMP Camp	3-hour	144.84	491.83	2009
KMP Camp	24-hour	69.48	93.37	2008
KMP Camp	Annual	8.09	17.33	2008
Haul Road	1-hour	134.22	1,149.32	2006
Haul Road	3-hour	84.86	429.48	2006
Haul Road	24-hour	39.97	73.08	2008
Haul Road	Annual	5.19	13.25	2008
Kitamaat Village	1-hour	102.53	604.34	2009
Kitamaat Village	3-hour	60.36	255.10	2009
Kitamaat Village	24-hour	8.59	68.73	2009
Kitamaat Village	Annual	0.86	2.79	2009
Riverlodge	1-hour	55.13	558.62	2008
Riverlodge	3-hour	41.63	372.58	2008
Riverlodge	24-hour	10.76	74.58	2008
Riverlodge	Annual	0.98	8.28	2006
Whitesail	1-hour	20.24	378.70	2006
Whitesail	3-hour	12.38	282.58	2006
Whitesail	24-hour	2.99	114.38	2006
Whitesail	Annual	1.04	9.37	2006

[1] Haul Road monitor represents the fenceline location, Whitesail represents the residential location in upper Kitimat, Riverlodge represents the residential location in lower Kitimat, and Kitamaat Village location represents the residential location in Haisla. KMP Camp location is within RTA's property, and will be relocated to Lakelse Lake. The monitor data was based on MOE's BC Air Data Archive (downloaded on June 2, 2016) except for KMP Camp site, which was obtained from a website maintained by WSP, the firm who operates and maintains the station equipment and data.

[2] 2015 monitored data are summarized here with the maximum value for each averaging period. Note that the data completeness at Whitesail was 37% in 2015, due to technical issues with the station's communications equipment. The monitor data for Haul Road, Riverlodge and Whitesail was corrected by BCMOE (Envista data updated) due to a technical issue with the SO2 analyzer (different calibration span gas had been used). The correction factor supplied by WSP to BCMOE was 1.075, applied March 18 - October 1 for Riverlodge and Haul Road, and May 4 - October 1 for Whitesail.

[3] The modelled concentrations presented in this column are the maximum at the specified monitor location over 2006, 2008 and 2009, including a background concentration corresponding to the appropriate averaging period. Background concentrations are 1.5 ppb (3.9 µg/m^3) for the 1 hour and 3 hour averaging periods, 1.2 ppb (3.1 µg/m^3) for the 24 hour averaging period, and 0.4 ppb (1.0 µg/m^3) for the annual averaging period (see STAR for details).

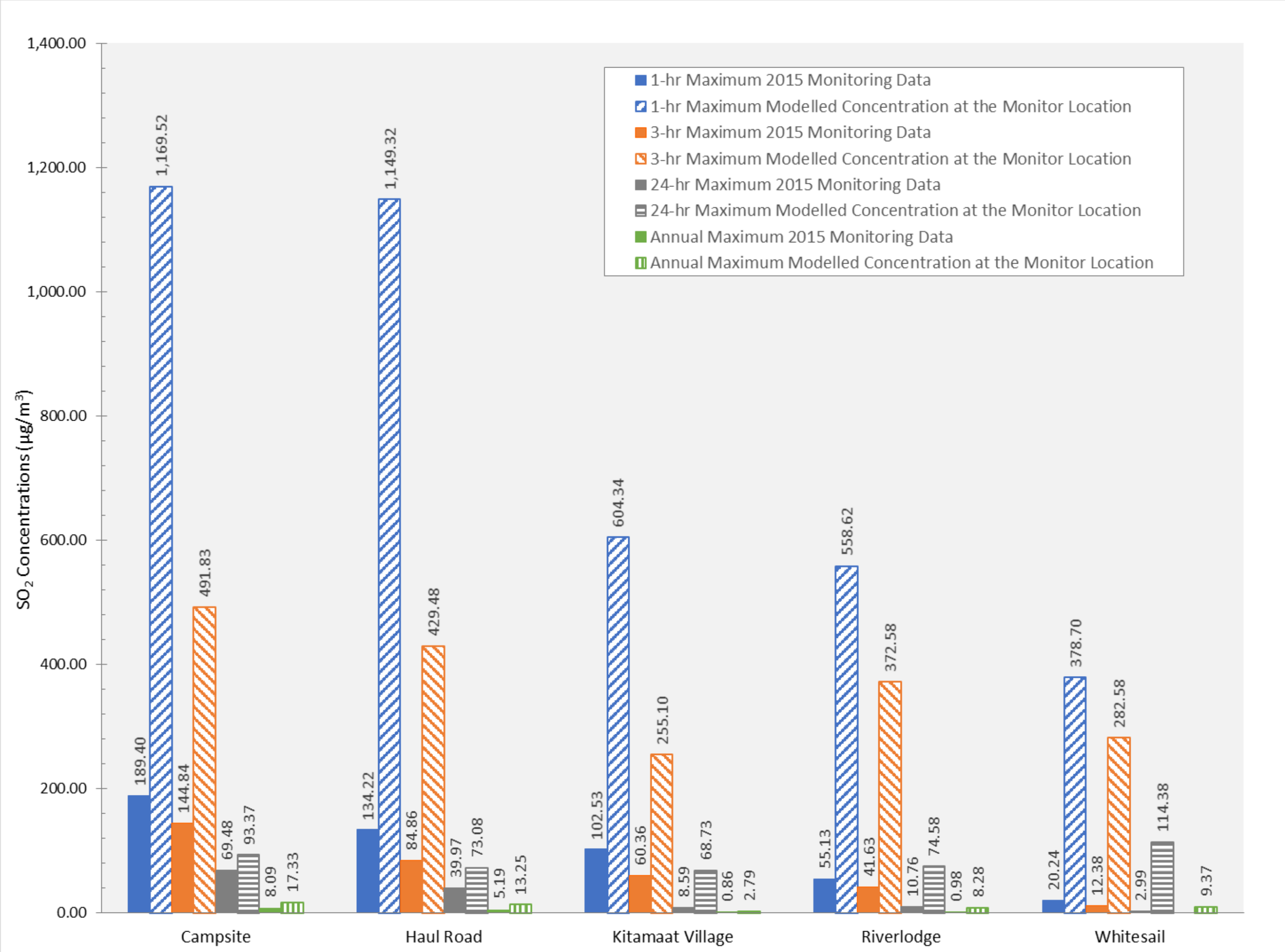


Figure 9. 2015 Monitored data compared to modelled concentrations. Annual monitored data for Whitesail are not shown because it was not in operation for the first part of the year.

Network Optimization

The draft Terms of Reference for the monitoring network optimization was resubmitted to BC MOE on December 3, 2015. BC MOE and Northern Health provided comments on the draft Terms of Reference on January 29, 2016. RTA has scheduled an air workshop to discuss the Terms of Reference and the network for June 22-23, 2016, titled *Air Quality Monitoring and the Optimization of the Kitimat AQM Network.* The Northern Health Authority, Haisla, Kitsumkalum, Kitselas, KPAC and MOE will be invited to this workshop.

After the workshop, Trinity and RTA will finalize the Terms of Reference in consultation with BC MOE and other stakeholders. Trinity will conduct the network optimization analysis over two to three months following the finalization of the Terms of Reference.

Passive Sampling

During 2011 and 2012, Rio Tinto Alcan operated a network of passive samplers to provide empirical observations of atmospheric SO_2 concentrations. Sampling and analysis issues led to a review of passive sampling program (Technical Memo P01), and a decision to pilot a different type of passive sampler (Technical Memo P02; replacing Radiello triethanolamine passive samplers with potassium or sodium carbonate based samplers).

The pilot study to evaluate the performance of passive diffusive SO_2 samplers against active continuous measurements was carried out between 24 July and 16 October 2015. Two commercial samplers (IVL and AGAT; Figure 10) were exposed at three monitoring stations (Figure 11) 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.

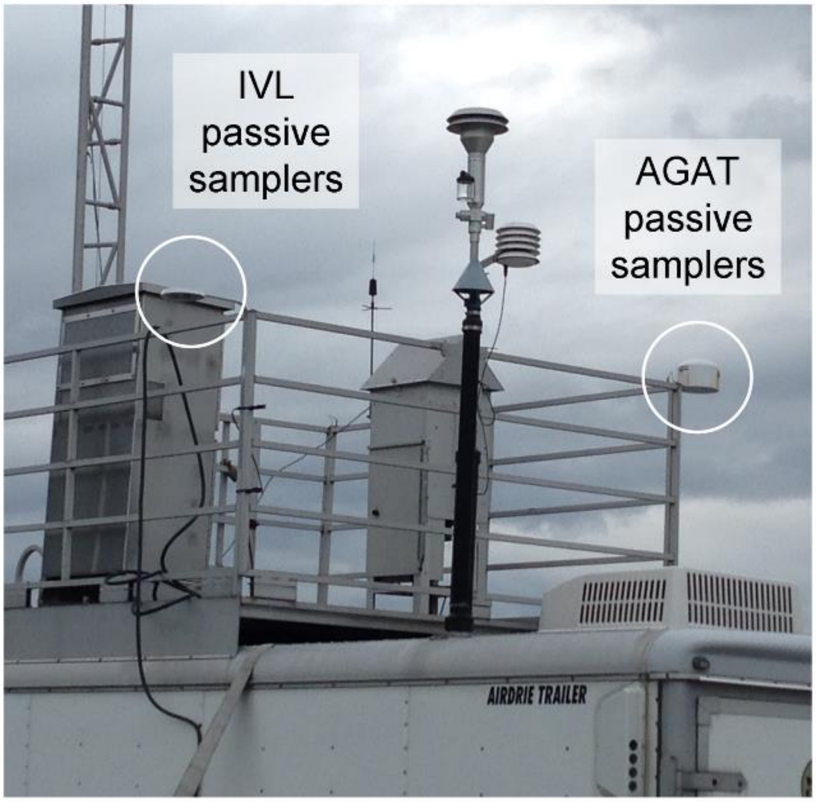


Figure 10. Deployment of passive diffusive samplers (obtained from IVL and AGAT) at continuous sulphur dioxide monitoring station. (Source: Dr. Julian Aherne, Trent University)

Further details on the passive samplers can be obtained from www.diffusivesampling.ivl.se for IVL samplers, and from www.agatlabs.com/energy/air-quality-monitoring/passive-monitoring.cfm for AGAT samplers.

There was a strong linear relationship between passive samplers and continuous measurements across the three monitoring stations (e.g., R^2 = 0.99 for IVL samplers; see Figure 12). Further, passive samplers performed equally during two-week and four-week exposures. However, the AGAT samplers were reported as below the detection limit at Riverlodge during September and October (two-week n = 3, and four-week n = 2), suggesting that they are not suited to measuring low background concentrations compared with the IVL samplers (all samplers reported concentrations above detection during the same exposure periods). The results of the study indicate that passive diffusive samplers (using a potassium or sodium carbonate membrane) can provide reliable measurements of atmospheric SO_2 to assess spatial and temporal changes in the Kitimat Valley (Technical Memo P03).

Figure 11. Location of continuous sulphur dioxide monitoring stations with co-deployment of passive samplers during the 2015 pilot study. (Source: Dr. Julian Aherne, Trent University)

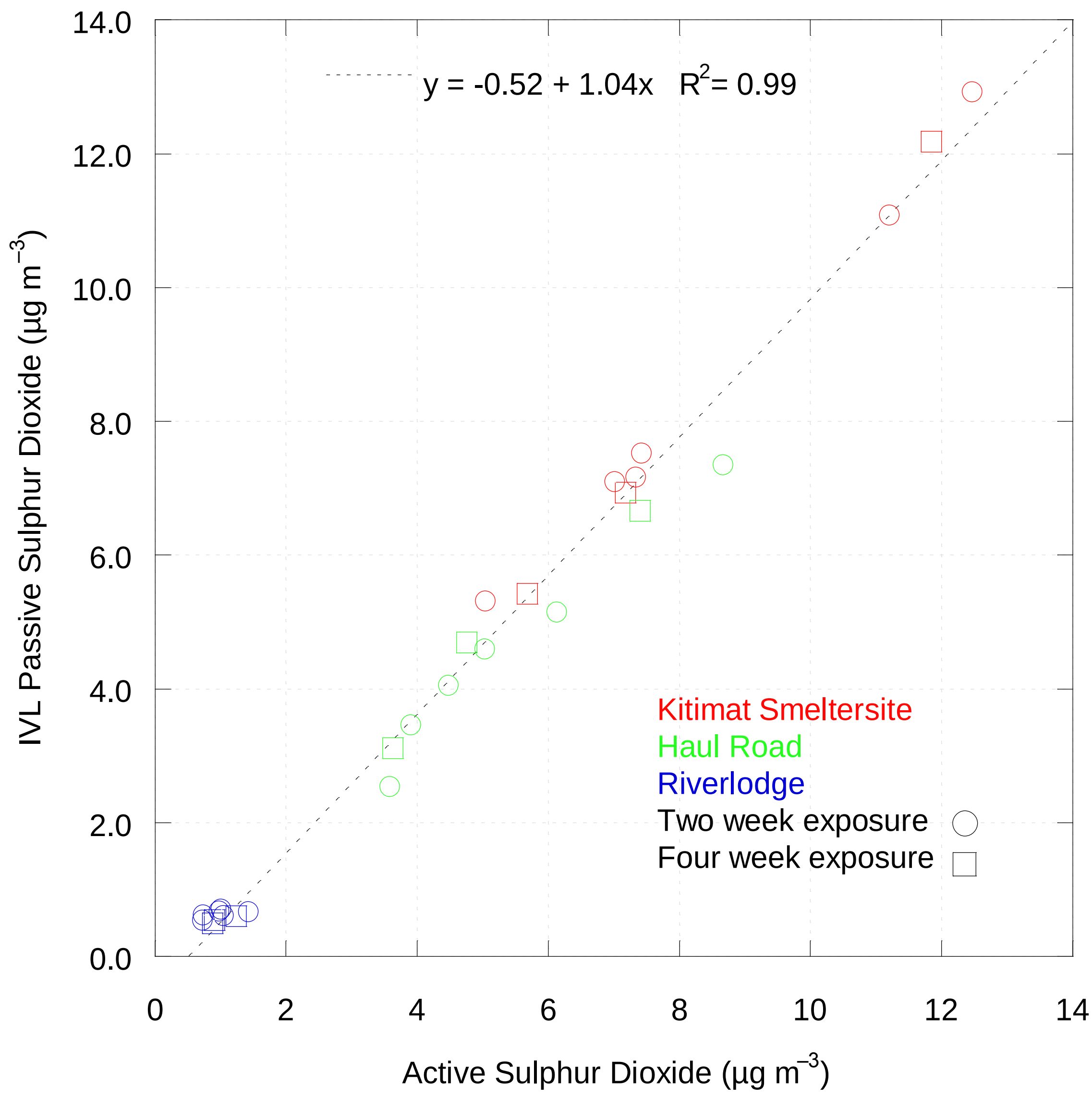


Figure 12. Comparison of IVL passive diffusive samplers for SO2 against continuous measurements at Kitimat Smeltersite (red), Haul Road (green) and Riverlodge (blue) during 24 July–16 October 2015. Passive samplers were deployed in duplicate at each station for two-week (open circle) and four-week (open square) exposures. (Source: Dr. Julian Aherne, Trent University)

Wet Deposition

Figure 13 compares the amount of annual precipitation at the two wet deposition monitoring stations during 2014 and 2015, and also compares annual precipitation at the Haul Rd. station from 2013 to 2015. Because the Lakelse Lake station was only in operation for part of 2013, data from that location are only shown for 2014 and 2015. Figure 14 compares weekly precipitation at the two stations for 2013, 2014 and 2015. Precipitation chemistry for both locations over the same three-year period is shown in Figure 15. Precipitation chemistry (operated by the NADP) during the same three-year period showed a higher weekly sulphate concentration (mg L^{-1}) and lower pH at Haul Road compared with Lakelse Lake (Figure 15).

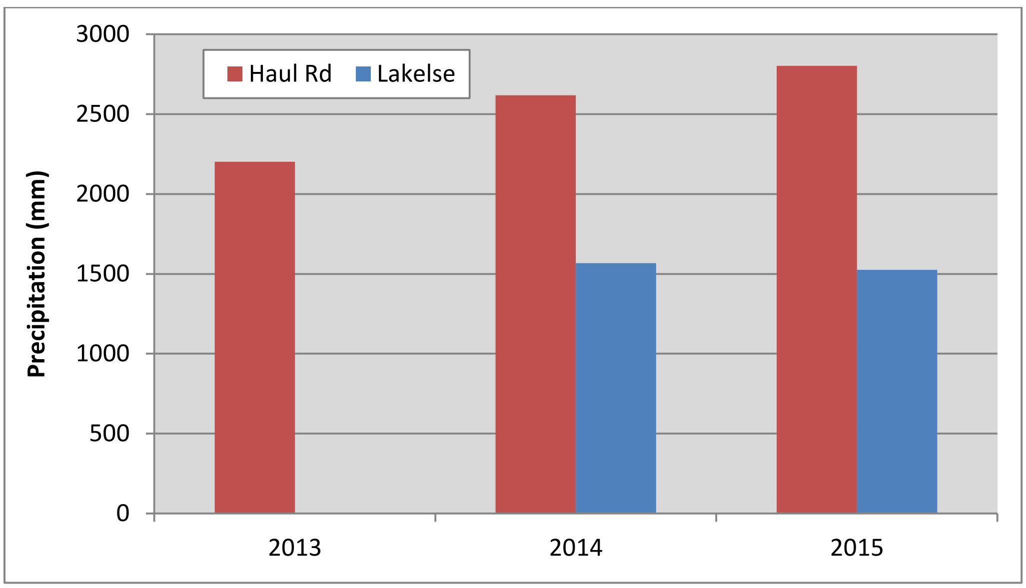


Figure 13. Annual precipitation from 2013 to 2015 at the Haul Road and Lakelse Lake wet deposition monitoring stations. (Source: Rio Tinto Alcan)

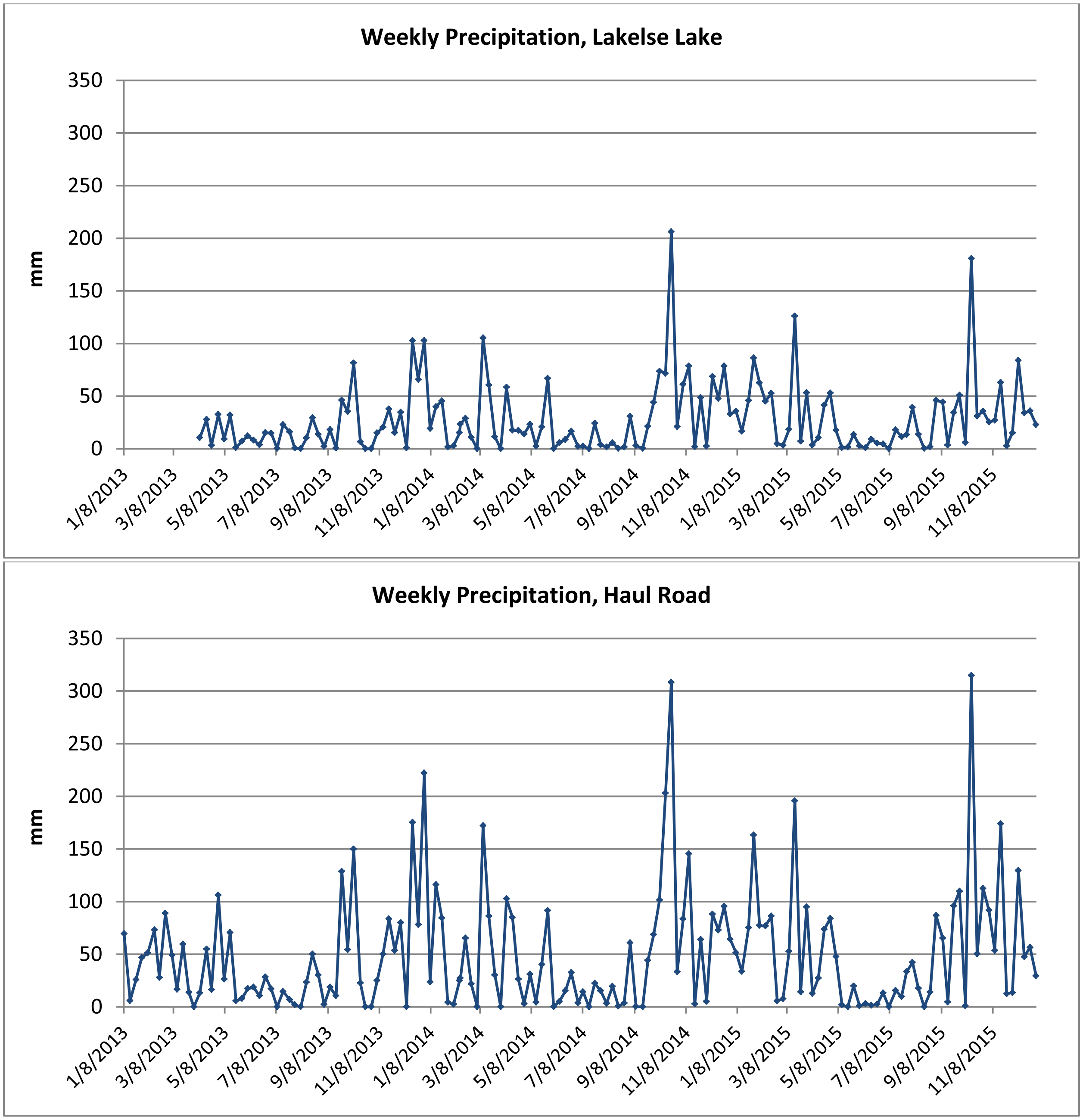


Figure 14. Weekly precipitation from April 2013 to December 2015 at the Lakelse Lake (upper graph) and from January 2013 to December 2015 at the Haul Road (lower graph) wet deposition monitoring stations. (Source: Rio Tinto Alcan)

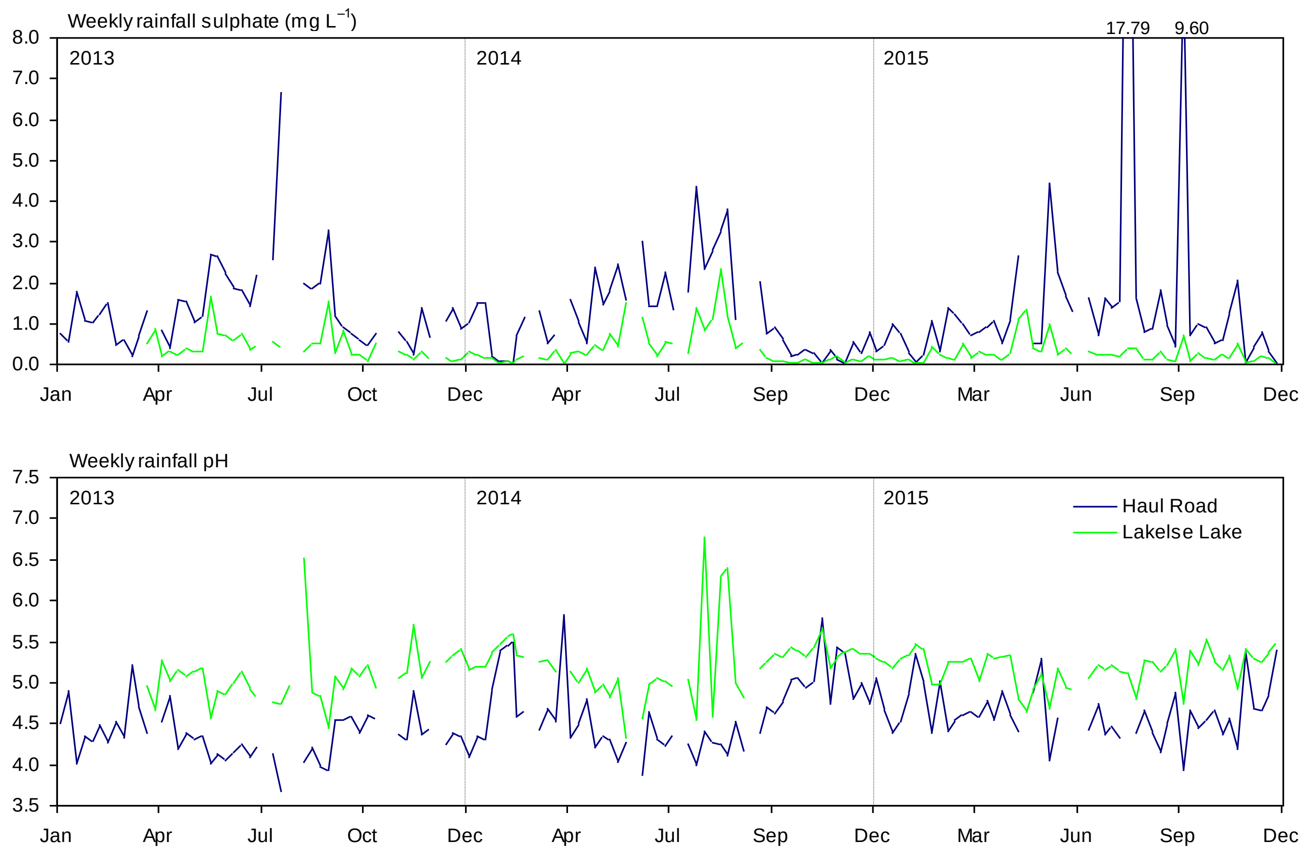


Figure 15. Weekly precipitation chemistry at Haul Road (January 2013–December 2015) and Lakelse Lake (April 2013–December 2015) showing inter-annual variation in sulphate concentration (mg L–1; upper graph) and precipitation pH (lower graph).
Note that high concentrations were observed twice during 2015. (Source: Rio Tinto Alcan)

Dry Deposition

The relative contribution of wet and dry deposition to total sulphur deposition requires the use of an inferential model to estimate dry deposition. The determination of dry deposition for sulphur dioxide and particulate sulphate (obtained from passive and continuous measurements) under the EEM will be estimated following Zhang et al. (2003, 2014). The big-leaf model (Zhang et al., 2003) requires several meteorological variables such as, surface temperature, wind speed, relative humidity, solar irradiance, precipitation, and surface pressure, and provides hourly or daily deposition velocity for SO_2 (dry deposition is estimated by multiplying air concentration with deposition velocity). The big-leaf model was recently obtained from Dr Leming Zhang (Environment Canada) and will be used during 2016 to estimate dry deposition (Technical Memo D01). Preliminary estimates of dry deposition at Haul Road monitoring station (operated by NADP) during the period 2005–2016, were determined following the approach used in the STAR (which used the same big-leaf model estimate long-term monthly deposition velocity; ESSA et al. 2013). The equipment at the Haul Road site was updated to the NADP standard during the fall of 2012, which explains the gap in wet deposition data during this period. The NADP equipment provides better estimates of precipitation, which may be partly responsible for the observed trends in wet deposition. The peak in estimated wet deposition during December 2013 is likely related to very high precipitation during that month (475.7 mm). Problems with the SO_2 data logger explain the gap in dry deposition estimates during the latter half of 2012 and first quarter of 2013.

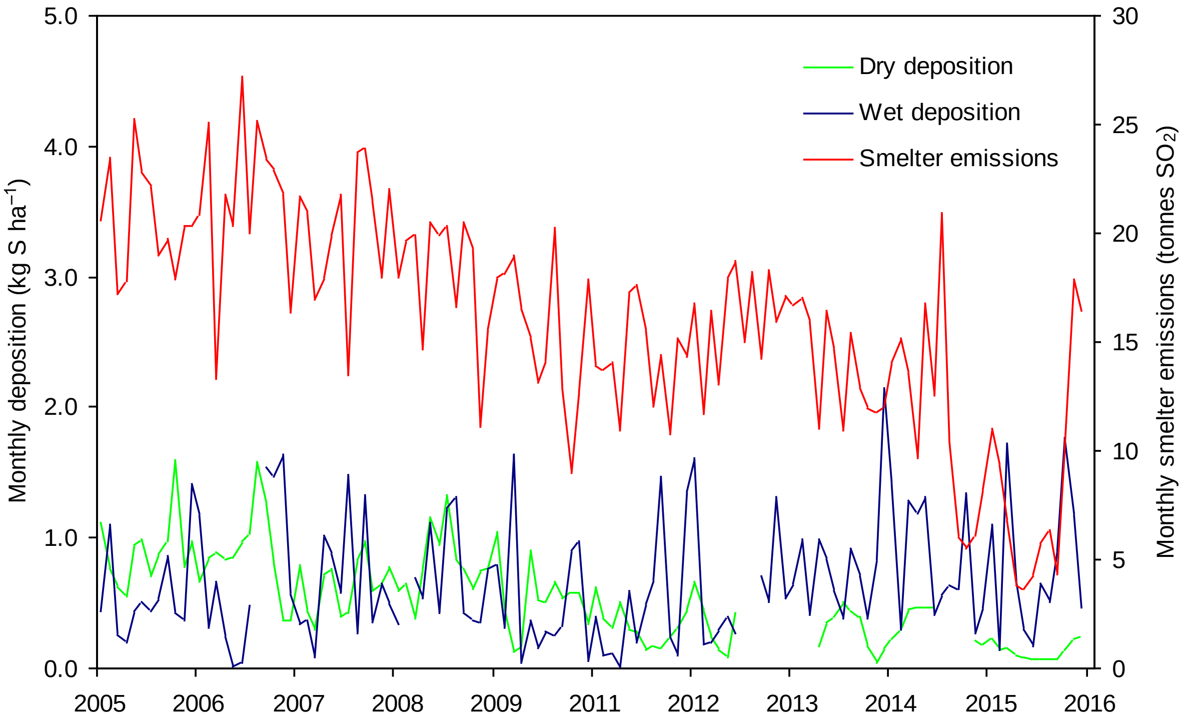


Figure 16. Long-term monthly dry (green line) and wet (blue line) deposition of sulphur (kg S/h–1), and smelter emissions of sulphur dioxide (red line; tonnes) at Haul Road. (Source: Dr. Julian Aherne, Trent University)

3.2 Human Health

As shown in Figure 5, emissions in 2015 were much lower than pre-KMP levels. Reporting on SO_2-associated predicted airway responses will occur in 2016.

3.3 Vegetation

Vegetation Survey and Sampling

Vegetation inspection and sampling occurred August 31 to September 4, 2015 and consisted of a visual survey for symptoms of SO_2 injury and other biotic and abiotic stresses that affect plants, and collection of hemlock needles for subsequent analysis for suphur content. The locations visited and sampled are shown in Figure 17.

As in 2014, no symptoms of visual injury due to SO_2 were observed, and no unusual conditions were observed in ornamental vegetation in Kitimat. A slight infestation of hemlock wooly adelgid on western hemlock was noted in the immediate vicinity of Rio Tinto (about 5 km north and south and only on the west side of Minette Bay), with the degree of infestation being reduced from that observed in 2014. There were otherwise no remarkable insect outbreaks, disease epidemics or other stress factors affecting vegetation. No unusual signs or symptoms were observed at the remote sites or on the east side of Minette Bay. More information, including a list of plant species reported in the literature as being sensitive to SO_2 that were present at the 2015 inspection sites, can be obtained in the vegetation survey results report (Laurence 2015).

Concentrations of sulphur in hemlock needles sampled in 2015 averaged 0.08%. This is the same average concentration found in 2011, 2013, and 2014 and is the lowest average recorded since the Vegetation Inspection and Monitoring Program began in 1970. Foliar sulphur concentrations in 2015 ranged from 0.05% (sites 57 and 85) to 0.14% (site 91A). More information can be obtained in the 2015 Vegetation Inspection, Monitoring and Assessment Program report (Stantec 2016).

Foliar sulphur concentrations remained about the same as reported in the last few years even though emissions decreased. Compared to 2014, in 2015, 22 sites were equal to or lower in concentration while 15 sites were higher in concentration. Only three sites—43B (decrease) and 46 and 91A (increase)—differed by more than one standard deviation from 2014. There did not appear to be a spatial pattern in the results. Only 1 site—91A—was greater than the historic mean (1997-2014). All values measured in 2015 fell within the range reported in the literature to be normal for leaves of plants.

A presentation and subsequent field trip was held for KPAC members on September 2, led by Dr. John Laurence. The event was well-attended, and participants learned about the history of the vegetation program in Kitimat, how SO_2 is taken up by vegetation, typical symptoms of SO_2 injury, and the results of the vegetation inspection survey from the previous year (2014). Attendees were also briefed on preliminary results of the 2015 inspection.

The results of the inspection and sampling do not indicate the need for a change based on the EEM plan with regard to the health of vegetation. Neither the Key Performance Indicator of Visual Injury of Vegetation Caused by SO_2 nor the Informative Indicator of S Content in Hemlock Needles surpassed the threshold for increased monitoring.

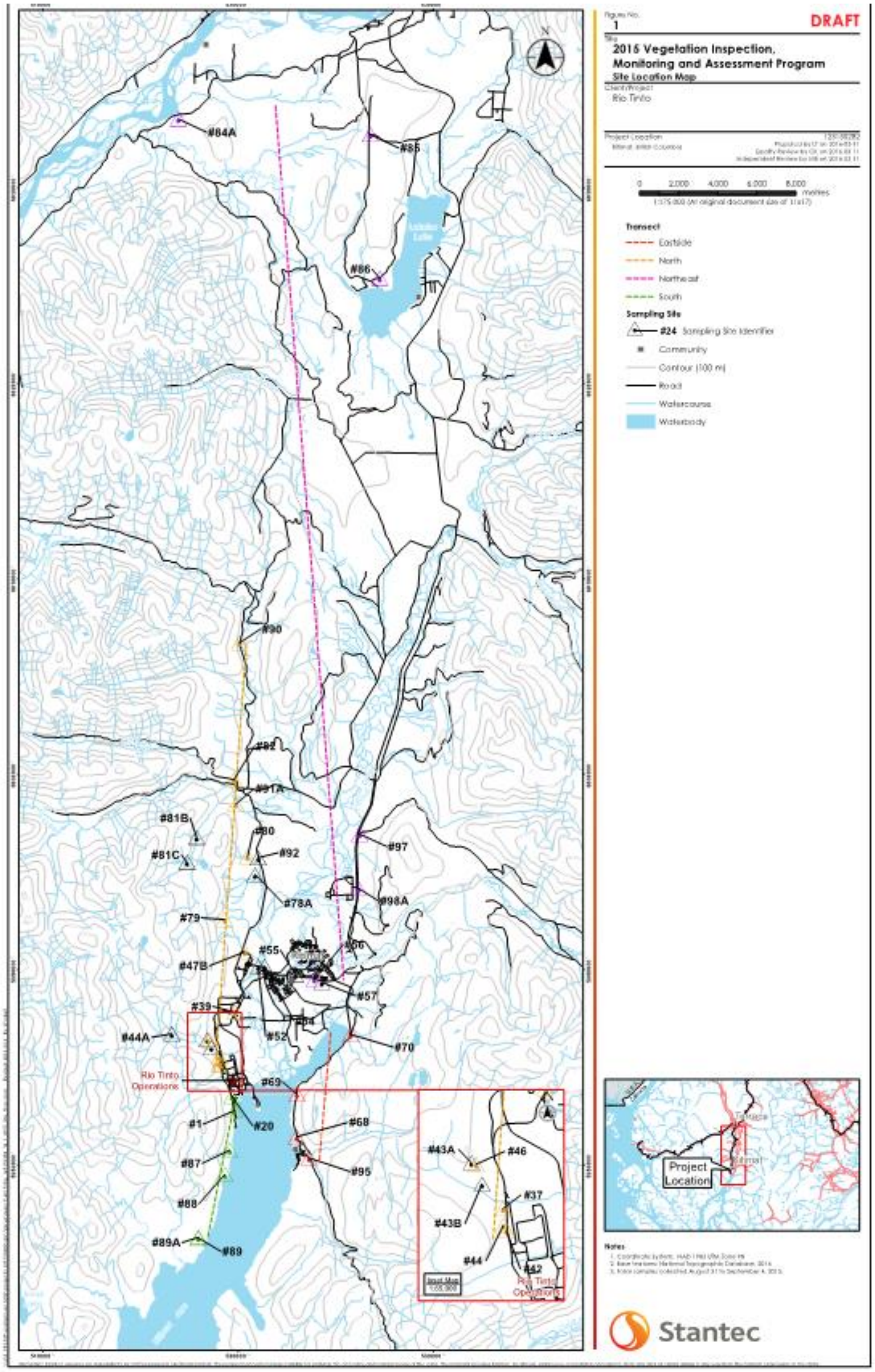


Figure 17. Location of vegetation sampling (denoted by triangles). (Source: Stantec 2016)

3.4 Terrestrial Ecosystems (Soils)

Soil Modelling

The soils component of the EEM program includes two key performance indictors (KPIs): critical load exceedance risk and observed change in base cation pool over time. The first KPI, critical loads of acidity for (upland) forest soils will be revised during 2017 to support the KPI 'critical load exceedance risk'. Revised modelling and mapping of terrestrial critical loads will incorporate additional (new) observational data, improved regionalisation methods and updated model parameters as recommended under the STAR (ESSA et al., 2013) or following the Kitimat Airshed Emissions Effect Assessment (ESSA et al., 2014). Details are provided in a separate Technical Memo (Technical Memo S03, which is an update of Technical Memo S01). During 2016, supplemental soil sampling sites will be sampled to address critical uncertainties and data gaps identified under the STAR (ESSA et al., 2013). A list of potential plots have been selected; it is recommended that at least 12 plots are sampled.

Permanent Soil Plots

During October–December 2015, long-term soil monitoring plots were established at Lakelse Lake and at Coho Flats, Kitimat (Figure 18, Figure 19). The long-term soil monitoring plots will address the KPI: 'observed change in base cation pool over time' through sampling and analysis of soils for base cations every five years. The primary objective during 2015 was to establish the plots (i.e., select locations and layout plot design) and to carry out the initial collection and processing (i.e., drying and sieving) of soil samples. Chemical analysis will be carried out during 2016. At each location (Lakelse lake and Coho Flats), primary and secondary (backup) plots were established, and soils were sampled for chemical analysis. Each plot (n = 4) is 32 m by 30 m in size and composed of twenty 6 m by 8 m sub-plots (lettered A to T; the A sub-plot is oriented to the north-west corner of each plots). Each sub-plot is further divided into twelve 2 m by 2 m sampling grids (numbered 1 to 12); one grid was randomly sampled from each sub-plot at five depths: litter-fibric (LF), humic (H), and 0–5 cm, 5–15 cm, and 15–30 cm depths in the mineral soil. Every five years one grid will be randomly sampled, making a total of twelve sampling campaigns (for further details see Technical Memo S04).

Soil samples from the first (2015) sampling campaign have been dried, sieved to < 2 mm and analysed for pH and organic matter content (Figure 20). There is a noticeable difference in organic matter content between depths (i.e., there is a statistically significant decrease in organic matter between the 0–5 cm and the lower depths at Lakelse Lake) but not between primary and secondary plots (i.e., there is no statistical difference between the 0–5 cm at Lakelse Lake primary compared with the same depth in Lakelse Lake secondary). During 2016, the soil samples at the primary plots will be analyzed for exchangeable base cations, exchangeable acidity, and all remaining soil (from the primary and secondary plots) will be archived. The sampling plots will be re-visited for bulk density sampling, and mapping of tree locations. In addition, a background (control) plot will be established at Kemano, far from the smelter emissions.

Figure 18. Location of long-term soil monitoring plots (primary and secondary [backup] plots) at Lakelse Lake and Coho Flats, Kitimat Valley.

Figure 19. The long-term soil monitoring plots at Lakelse Lake are located beside the NADP monitoring station (A), in a western Hemlock stand (primary plot is shown in B), and east of the Coho Flats Trail, Kitimat (primary plots is shown in C). (Source: Dr. Julian Aherne, Trent University)

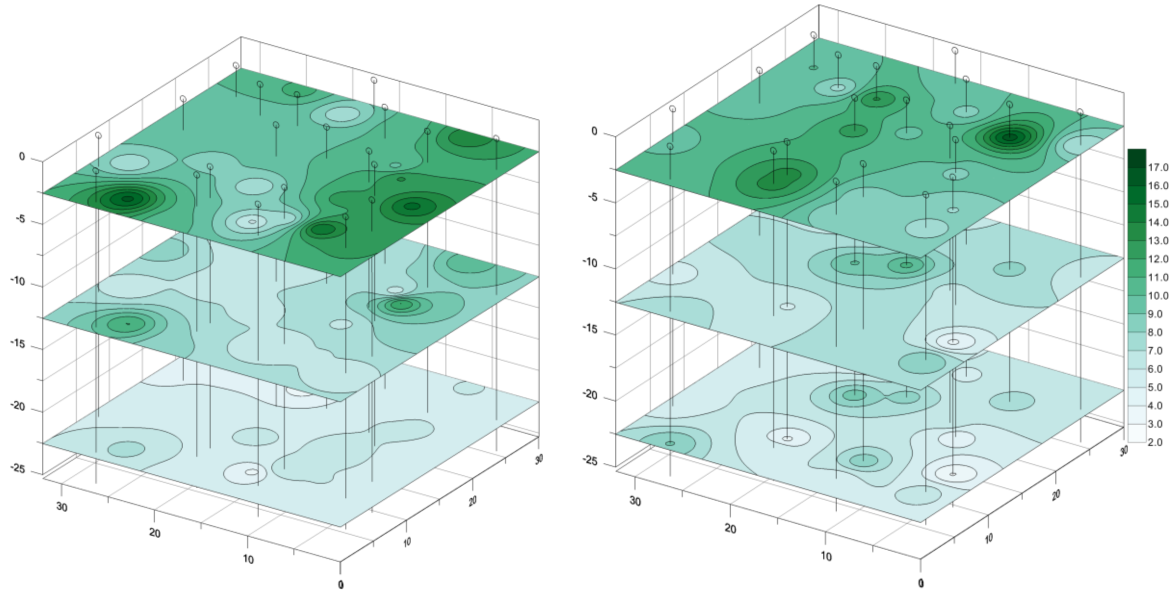


Figure 20. Three-dimensional representation of soil organic matter content (%) in the 0–5 cm, 5–15 cm, and 15–30 cm soil depths at the primary (left) and secondary (right) permanent soil plots at Lakelse Lake. The vertical lines indicate the location of the soil sampling pits (n = 20 per plot). (Source: Dr. Julian Aherne, Trent University)

3.5 Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)

The following three sub-sections contain a condensed summary of the work described in a separate Aquatic Ecosystems Actions and Analyses Technical Memo, focusing on the actions that were performed, the knowledge gained from conducting those actions, and the recommended next steps to take as a result of those learnings. Each action, learning/conclusion, and next step is presented as a short bullet. The Aquatic Ecosystems Actions and Analyses Technical Memo (Technical Memo W03) provides extensive details on the methods and results that support these statements.

Actions Taken in 2015

- Annual sampling and lab analyses of water chemistry for the seven sensitive lakes in the EEM Program, three less sensitive lakes in the EEM Program, and Lakelse Lake, sampled due to its public importance (Limnotek 2016). (Lakes included in the EEM Program are referred to as “EEM lakes”.)
- Examination of inter-annual changes in water chemistry between 2014 and 2015.
- Sampling of two additional sites within the Goose Creek watershed (i.e., non-EEM sites), 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.
- Intensive monitoring of pH in the three accessible sensitive EEM lakes for the second year. Monitoring included the implementation of continuous pH monitors and multiple within-season samples collected for field and lab analyses of pH. In 2015, continuous monitoring of pH began in the spring and was continued through the summer and fall.
- Power analyses were conducted to assess our ability to correctly detect changes of interest in water chemistry in the sensitive EEM lakes. That is, we asked how confidently will the established monitoring program be able to identify lakes that have exceeded their ANC, SO_4^{2-}, and/or pH thresholds?
- Three control lakes were added to the EEM Program. The control lakes are generally similar to the sensitive EEM lakes (i.e., low ANC and comparable annual runoff) but located well outside the KMP deposition zone and therefore predicted to receive very low levels of acidic deposition. The control lakes will provide multiple benefits: 1) improving our estimates of natural variability, 2) improving our understanding of common, regional trends independent of potential KMP effects, and 3) improving our ability to detect potential KMP effects in the sensitive EEM lakes.
- Continuous monitoring of stream pH was continued in Anderson Creek.
- The study design for the research project on episodic acidification was finalized in 2015. This project is being conducted by Dr. Paul Weidman (SFU) with supplemental funding from RTA as part of the EEM. Preliminary sampling activities were conducted in 2015 (Appendix 3 of Technical Memo W03). Preliminary results will be reported separately as they become available.
- Bathymetric surveys were performed on three lakes (LAK006, LAK012 and LAK023) in order to acquire more precise estimates of water volume to better estimate water residence time. Water residence time is expected to be a factor that influences water chemistry variability in lakes.
- Rio Tinto Alcan had preliminary discussions with the Center for Conservation Education and Sustainability at the Smithsonian Conservation Biology Institute with regards to providing additional support for existing amphibian monitoring. No further actions were taken in 2015 but these discussions will be revisited next year.

Knowledge Gained from Actions taken in 2015

- Inter-annual changes in water chemistry properties:
  - Summary of observed changes between 2014 and 2015:
    - SO_4^{2-} concentration decreased in almost all of the EEM lakes, consistent with a decrease in total emissions of SO_2 from 2014 to 2015.
    - ANC decreased in most of the sensitive EEM lakes.
    - Less than half of the sensitive EEM lakes showed a change in ANC consistent with their observed change in SO_4^{2-}. Declines in ANC appeared to be partially related to declines in total base cations in some of the lakes.

        - The magnitude of the changes in ANC was generally lower in the less sensitive EEM lakes (as expected).
        - pH decreased in half of the sensitive EEM lakes.
        - pH decreased in most of the less sensitive EEM lakes.
        - pH and ANC showed the same direction of change (as expected) for almost all of the EEM lakes.
        - Changes in DOC and base cations were variable across the EEM lakes.
        - Chloride decreased or remained the same in almost all of the EEM lakes.
    - Changes in pH, ANC and SO_4^{2-} for 2014-2015 are shown in Table 2 and Figure 21.

- The preliminary assessment of the Goose Creek sites suggests that the sites are insensitive to potential increases in acid deposition.

- The intensive monitoring of the three accessible EEM lakes continued to show that there is high variability in pH, including in the spring and summer seasons in addition to the fall. Over the period from April 13 to November 13, 2015, the range of pH readings in End Lake and Little End Lake was about 1.0 pH units, and about 0.8 pH units in West Lake. Average pH levels remained very close to or above 6.0, the threshold for biological effects used for critical load analyses in the STAR and KAA. These data reinforce the previously stated (i.e., 2013/2014 EEM Annual Report) conclusions on the implications for the design of the EEM Program:
    - The need to maintain continuous monitoring of pH at these lakes, as well as frequent collection of samples for lab analyses to generate the best possible understanding of this natural variability.
    - The need to analyze the within-season samples for ANC and SO_4^{2-} in addition to pH.
    - The need to strengthen the EEM threshold for change in pH by evaluating the patterns of change in multiple primary metrics (pH, ANC and SO_4^{2-}).
    - The importance of power analyses (completed in 2015) to rigorously assess the ability to correctly identify changes in water chemistry given the high levels of variability.

- The power analyses have yielded a lot of valuable information:
    - The base case
        - On average, the power to detect changes in pH that exceed the KPI threshold is quite low and the lowest among the three primary metrics.
        - However, the power to detect changes in ANC and SO_4^{2-} is high for 4 of the 7 sensitive EEM lakes, indicating the benefit of using multiple metrics.
            - Two of the other lakes have moderate power in one of ANC or SO_4^{2-} and low to very low power in the other.
            - One lake has very low power for both ANC and SO_4^{2-} (LAK028).
        - 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.
        - Across all of the metrics, LAK022 and LAK023 consistently have among the highest power.
        - LAK028 and LAK042 have very low power for ANC.

        - LAK028 has very low power for SO_4^{2-}.
        - LAK012 and LAK042 have low power for pH.
    - If the lake chemistry variability of the lakes is actually lower than has been observed since 2012, 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, 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, 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.
    - 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.
    - 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 <5 years of post-KMP observations were analyzed.
- The implications of the revised estimates of water residence time have not yet been fully explored.

Table 2. Changes in pH, ANC and SO_4^{2-} for EEM lakes, 2014 to 2015.

	pH	Gran ANC (µeq/L)	SO_4^{2-} * (µeq/L)
From	2014	2014	2014
To	2015	2015	2015
LAK006	-0.1	-5.4	-0.3
LAK012	-0.1	-9.6	2.7
LAK022	-0.1	-11.3	-5.3
LAK023	0.0	-8.2	-3.6
LAK028	-0.2	-11.8	-23.3
LAK042	0.3	1.3	-0.2
LAK044	0.0	0.3	-0.9
Average (Sensitive lakes)	**-0.02**	**-6.4**	**-4.4**

	pH	Gran ANC (μeq/L)	SO_4^{2-} * (μeq/L)
From	2014	2014	2014
To	2015	2015	2015
LAK007	-0.1	119.9	14.9
LAK016	0.0	7.4	-7.2
LAK024	-0.2	-29.1	-2.4
LAK034	-0.1	-27.1	-16.1
Average (Less sensitive lakes)	**-0.09**	**17.8**	**-2.7**

* Refers to non-marine sulphate (total sulphate – marine derived sulphate). Marine-derived sulphate is based on chloride concentrations (assumed to be entirely marine) times the ratio of sulphate to chloride in seawater. This is explained further in ESSA et al. (2013) and equation 2.2 (page 2-11) of UNECE 2004.

Recommendations

The rationale for these recommendations is primarily supported by the work on the power analyses. Please refer to the Summary Report on Power Analyses (Technical Memo W04) and Power Analyses Technical Appendix (Technical Memo W05) on the power analyses for further details on these recommendations, as well as additional recommendations that are more specific to the power analyses and future analyses of the monitoring data.

- Maintain the continuous monitoring of pH at the three accessible lakes.
- Collect water chemistry samples for lab analyses from the three lakes with continuous pH monitors four times during the fall sampling period.
- Continue to use multiple metrics to assess the potential KMP effect (i.e., ANC, SO_4^{2-} and pH).
- Continue collecting annual water chemistry samples from the three control lakes that were added to the EEM.
- Wait until having collected 5 years of post-KMP monitoring data before drawing conclusions about potential changes to lake chemistry, due to the predicted low power and higher false positives (for some scenarios) in the first few years of post-KMP monitoring. At a minimum, wait until the end of the initial phase of the EEM Program (3 years of post-KMP monitoring data).
- Consider using Gran ANC as the primary indicator of KMP induced change in lake chemistry. Gran ANC had a higher power to detect true changes than pH but lower false positive rate than SO_4^2-.
- Explore the feasibility of increasing the number of samples for lakes with low power to correctly detect whether the EEM KPI thresholds have been exceeded (in order of priority, with metrics with low power indicated):
    - LAK042 (pH, ANC)
    - LAK028 (ANC, SO_4^{2-})
    - LAK044 (ANC, SO_4^{2-})

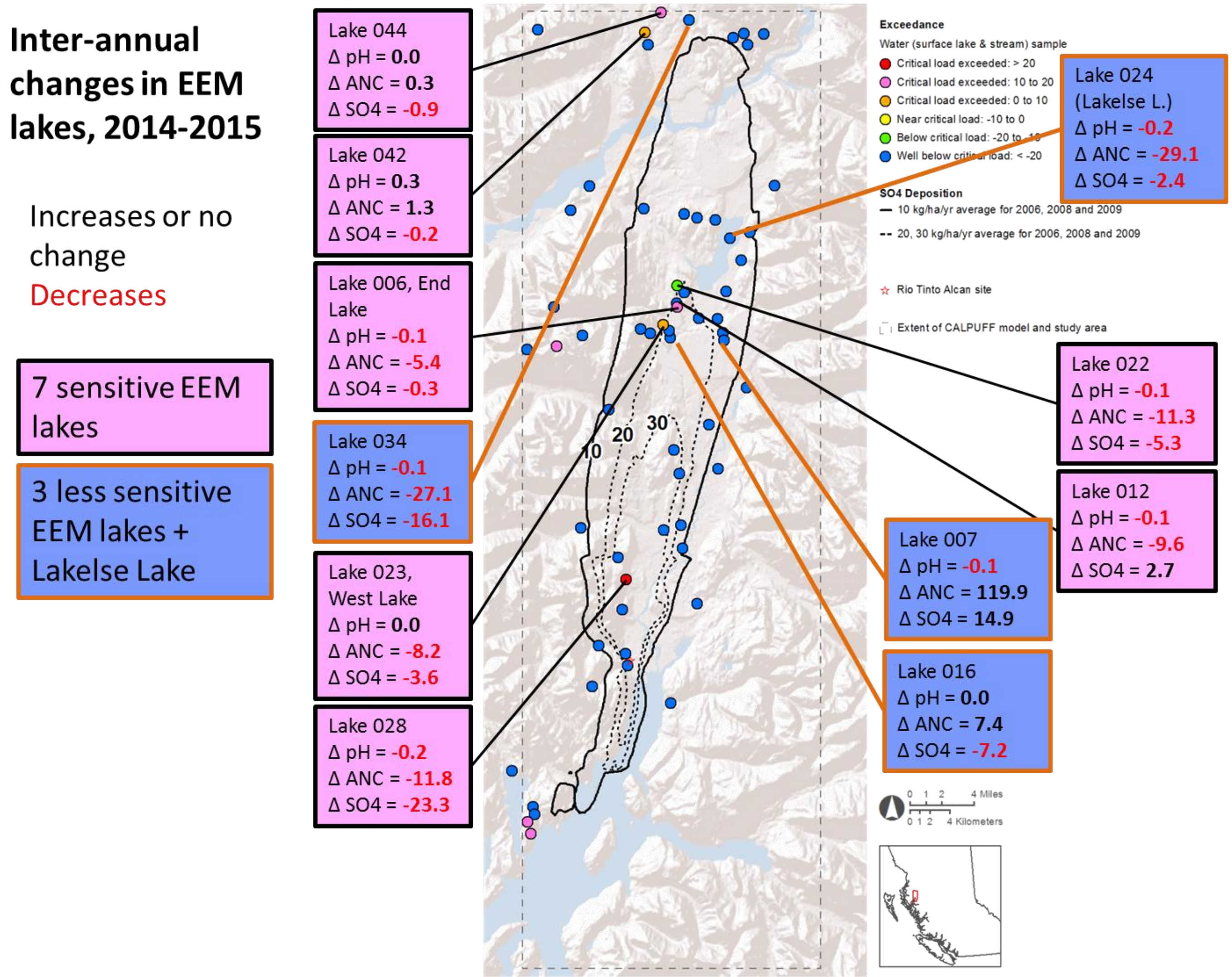


Figure 21. Map of EEM lakes, with inter-annual changes (2014-2015) in pH, ANC and SO_4^{2-}. Underlying map shows all STAR sample sites and calculated critical loads.

4 Cited Reports

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.

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Zhang L., and He Z., 2014. Technical Note: An empirical algorithm estimating dry deposition velocity of fine, coarse and giant particles. Atmos. Chem. Phys., 14, 3729–3737.

5 Cited EEM Technical Memos

The numbering of Technical Memos continues from the numbers in the previous Annual Report (for 2013-2014). The Technical Memos listed below are available in a separate 'KMP EEM 2015 Annual Report-Cited Technical Memos' package.

Technical Memo P01. Atmospheric Sulphur Dioxide – Passive Diffusive Sampler Network: 2011–2012 (March 2015, Trent University)

Technical Memo P02. Atmospheric Sulphur Dioxide – Passive Diffusive Sampler Network: Pilot Study (March 2015, Trent University)

Technical Memo P03. Atmospheric Sulphur Dioxide – Passive Diffusive Sampler Network: Pilot Study Results (September 2016, Trent University)

Technical Memo D01. Atmospheric Sulphur Dioxide – Method for Estimating Dry Deposition (September 2016, Trent University)

Technical Memo S02. Steady-State Soil Modelling - Supplemental Soil Sampling (March 2015, Trent University)

Technical Memo S03. Steady-State Soil Modelling - Revised Modelling and Mapping of Terrestrial Critical Loads Update (September 2016, Trent University)

Technical Memo S04. Long-term Soil Monitoring Plots – Plot Establishment (September 2016, Trent University)

Technical Memo W03. Aquatic Ecosystems Actions and Analyses (March 2016, ESSA Technologies Ltd.)

Technical Memo W04. Summary Report on Power Analyses (March 2016, ESSA Technologies Ltd.)

Technical Memo W05. Power Analyses Technical Appendix (March 2016, ESSA Technologies Ltd.)