Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project

2017 Annual Report

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June 11, 2018

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Please cite this report as follows:

ESSA Technologies Ltd. 2018. Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project –2017 Annual Report. Prepared for Rio Tinto, BC Works, 31 pp.

Summary of EEM Actions

The following tables summarize the EEM commitments for 2017, 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 Compare to model output Implement the monitoring network optimization according to the Terms of Reference drafted in 2015 Initiate a new air quality study to provide input to the network rationalization study in 2020	Data were collected and analyzed from four analyzers, and compared to model output. Development of a multi-seasonal air quality study was begun, to inform the network optimization process and its ability to measure the human health KPI.	Section 3.1
	Continue the passive monitoring program	Passive samplers were deployed in the Kitimat valley and urban area during 2017.	Section 3.1 Technical Memos P03, P04, P05
Wet deposition	Maintain two rain chemistry stations (Haul Road and Lakelse Lake)	Operation continued at both stations, and precipitation chemistry data for 2017 are included in this report.	Section 3.1
Dry deposition	Install a continuous SO_2 monitor at Lakelse Lake station Estimate dry deposition at both the Haul Road and Lakelse Lake continuous SO_2 monitor stations	An engineering project was scheduled to install an SO_2 analyzer with a meteorological tower in September 2018. Deposition was estimated at Haul Rd.	Section 3.1 Technical Memos D02, F01
Human Health			
Atmospheric SO_2 concentrations	Report on the Health KPI	The SO_2 Health KPI has been calculated for all three residential stations.	Section 3.2
Vegetation			
Vegetation Survey	Per the EEM, the vegetation survey and inspection were not scheduled for 2017		
	Continued vegetation sampling as described in Laurence (2010)	Vegetation sampling was accomplished as planned.	Section 3.3

Topic	The commitment	What was done	Where to learn more
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	Western hemlock trees were sampled for S analysis from August 28-September 1, 2017 by Stantec Consulting Ltd. S analysis was conducted by Rio Tinto, Jonquière, Québec.	Section 3.3 Stantec (2018)
Terrestrial Ecosystems (Soils)			
Soil modelling	Re-do analysis for risk of CL exceedance, adding data from the new sites sampled in 2016	This work is scheduled for 2018.	Section 3.4
Permanent soil plots	Chemical analysis of the 2015 soil samples for the primary plots	These analyses were completed.	Section 3.4 Technical Memos S06, S07
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)			
Chemistry – water sampling	Annual water sampling and laboratory analysis, and data evaluation	This was completed. Intensive monitoring in 3 lakes continued, as did annual water chemistry sampling of 14 lakes, including 7 sensitive lakes, 3 insensitive lakes, 3 control lakes, and Lakelse Lake. There was weekly sampling of 6 of the 7 sensitive lakes during the fall sampling season; and vertical sampling of LAK028.	Section 3.5 Technical Memos W03, W06, W07 Bennet and Perrin (2018)
Fish sampling	Resample if the lake pH change reaches the threshold	Fish sampling was done in LAK028. No other fish sampling done.	Technical Memo W07 Bennet and Perrin (2018)
Episodic acidification	Implementation of episodic acidification study	Continuous pH monitoring was maintained in West Lake, End Lake, Little End Lake and Anderson Creek. Episodic acidification work is continuing by Dr. Paul Weidman as an independent study from the EEM Program.	Section 3.5 Technical Memo W07
Amphibians	Conduct a literature review of potential effects of acidification on amphibians in the Kitimat Valley	The literature review was conducted and is being finalized.	ESSA Technologies Ltd. (2017)

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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.

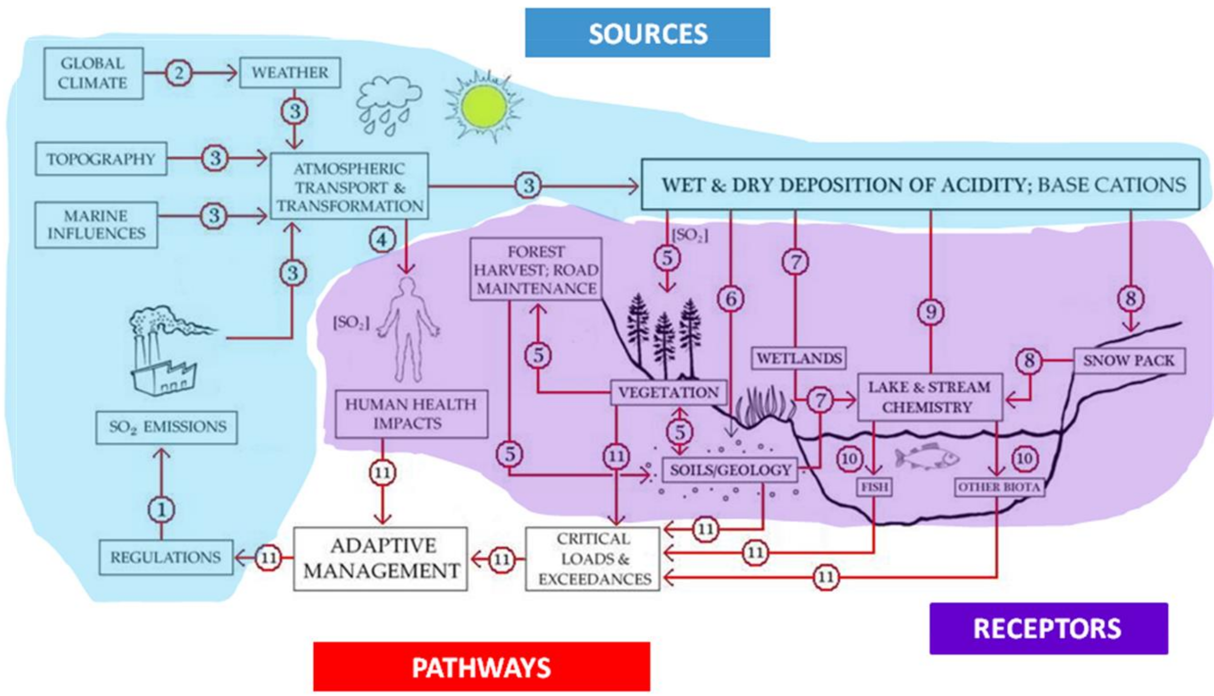


Figure 1. Source-Pathway-Receptor model of SO_2 emissions in the environment, showing linkages between sources and receptors. (Source: Figure 3.1-1 from ESSA et al. 2013)

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. 2014) 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 occurs on an annual basis. These reports 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 are 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 2017 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 2018 will be prepared in the spring of 2019.

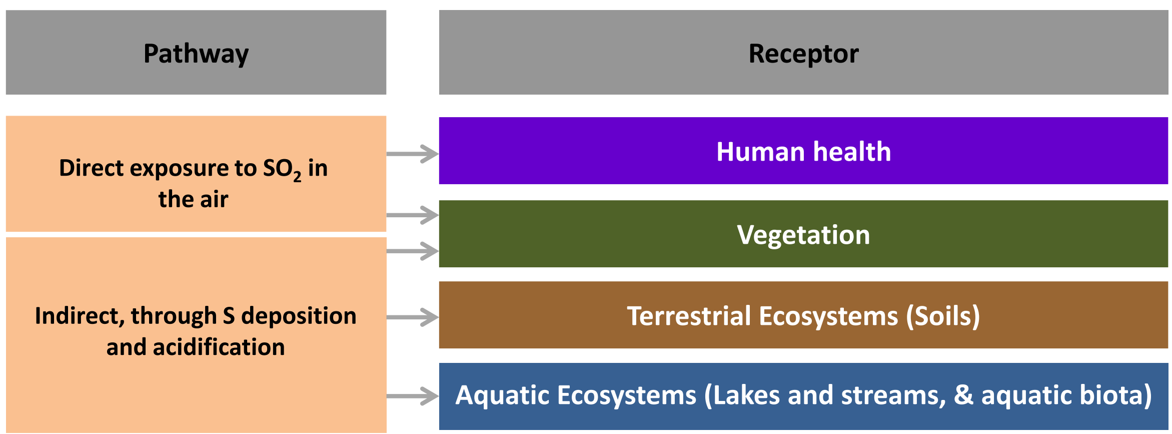
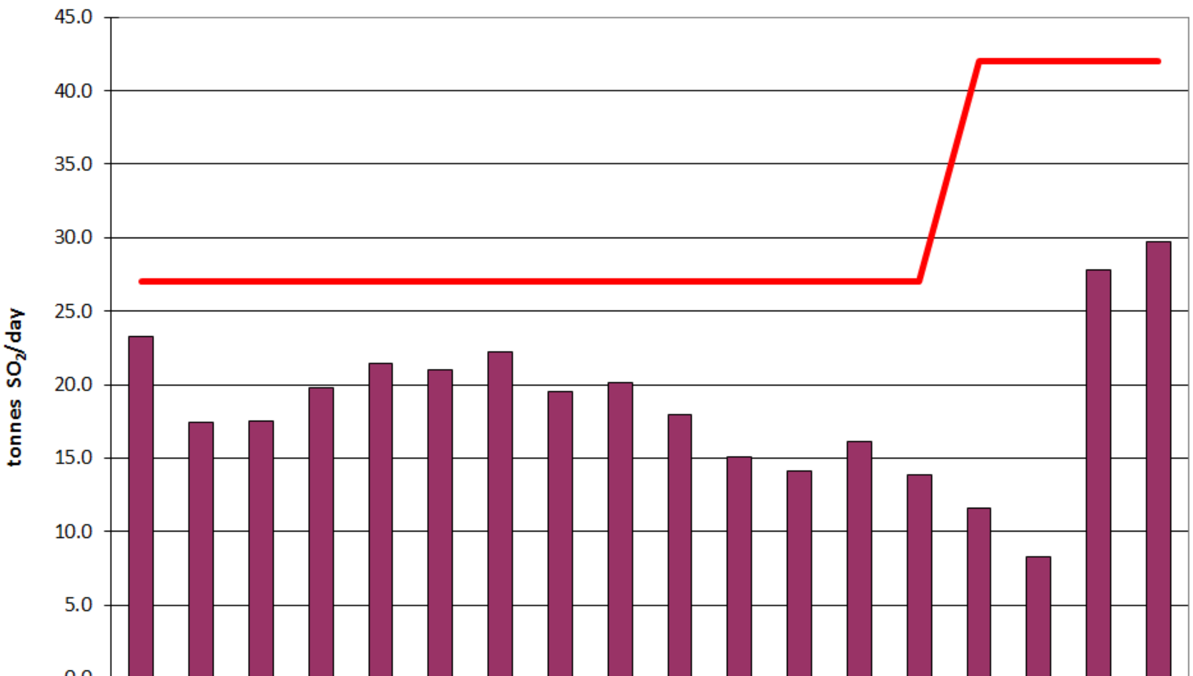


Figure 2. Framework for reporting on EEM activities.

2 Facility Emissions

SO_2 emissions have increased above pre-KMP emissions due to the commissioning of the smelter and full operation of the potline. During 2017 emissions of SO_2 increased from the 27.8 t/d rate in 2016 to 29.7 t/d in 2016 (Figure 3). 2017 SO_2 emissions remained below the 42 t/d permit limit.



	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17
Average	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	27.8	29.7
Limit	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	42.0	42.0

Figure 3. Annual SO_2 emissions from the Kitimat smelter from 2000 to 2017. (Source: Rio Tinto)

3 EEM Activities

3.1 Atmospheric Pathways

SO_2 Concentrations

SO_2 monitoring data were collected from four existing continuous analysers: Haul Road (fenceline), Riverlodge (lower Kitimat), Whitesail (upper Kitimat), and Kitamaat Village (Figure 4). Figure 5 shows wind roses for each of these locations. All SO_2 analyzers passed the ENV[1] audits and had greater than 90% data capture for SO_2 in 2017. The KMP Campsite station was decommissioned in the spring of 2016 due to the project's close and 3rd party development of the campsite lands.

Figure 6 shows the pattern of the monthly average SO_2 concentrations at the four continuous monitoring stations from 2013 through 2017, 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 two years.

Figure 7 shows a histogram depicting the relative frequency of hourly averaged concentrations of SO_2 at Haul Road, Riverlodge and Kitamaat Village and Whitesail. Low concentrations (below 4 ppb) occur most of the time (high frequency), and higher concentrations occur infrequently.

[1] BC Ministry of Environment and Climate Change Strategy, previously BC Ministry of Environment (MOE)

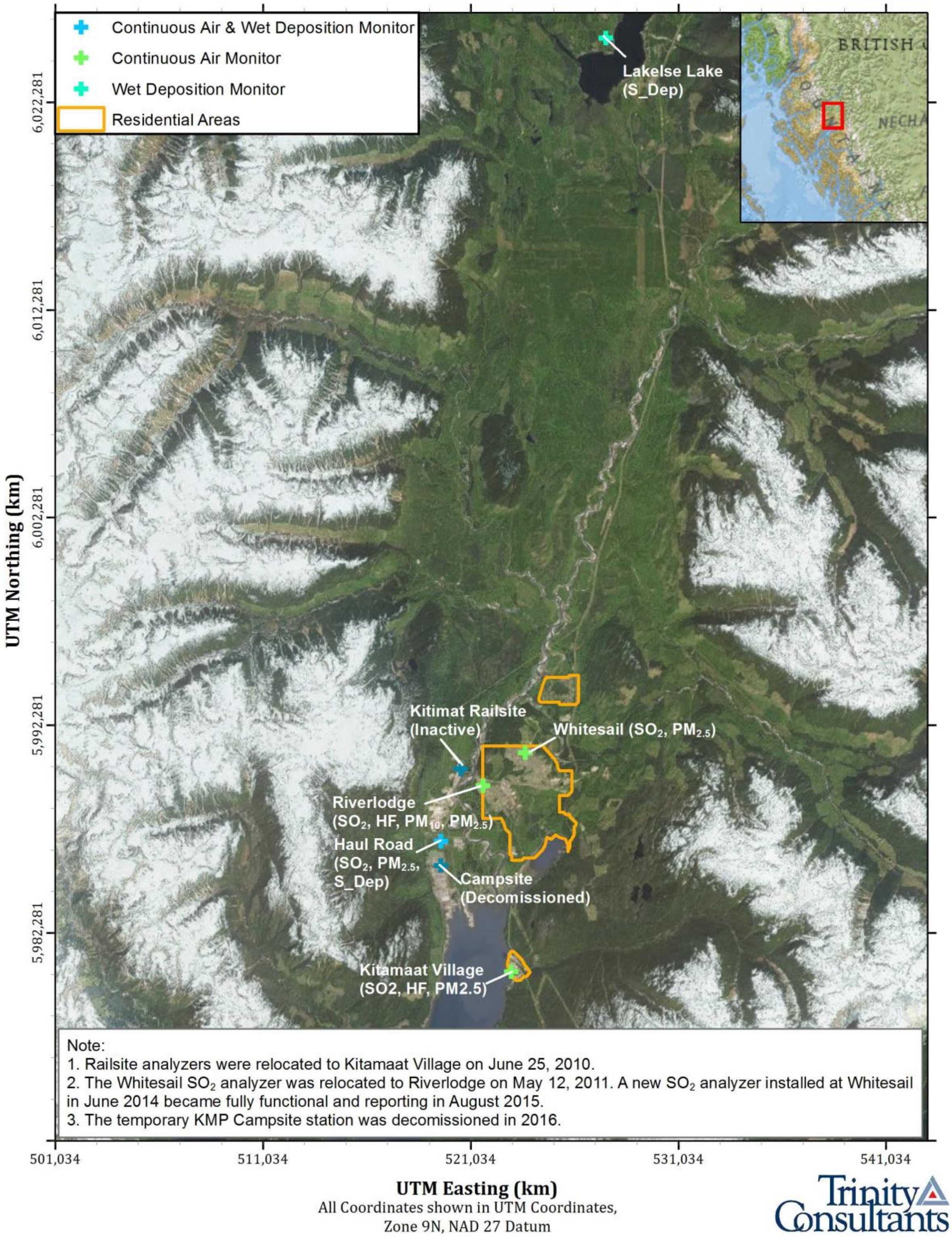


Figure 4. Locations of the four continuous SO_2 analysers (Haul Road, Whitesail, Riverlodge, Kitamaat Village).

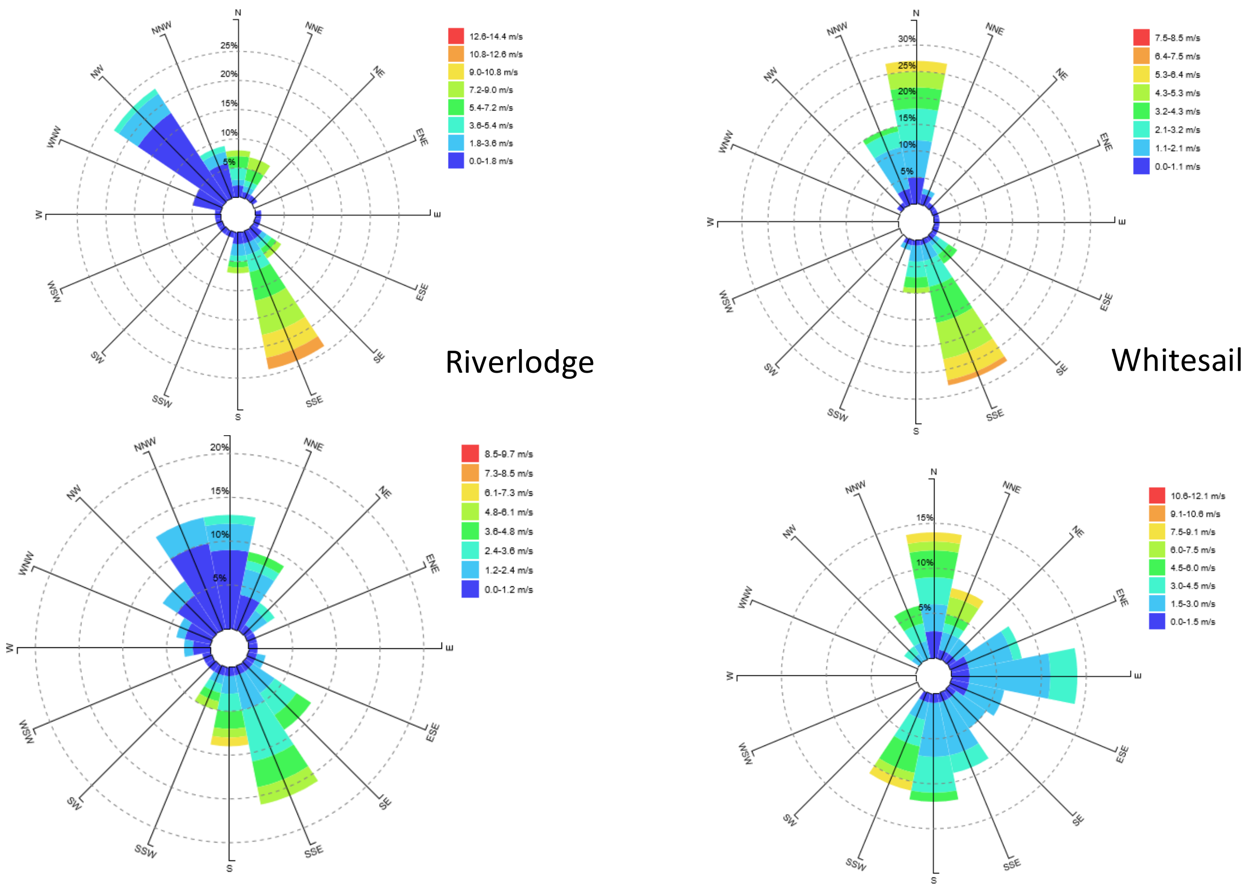


Figure 5. Wind roses for Riverlodge, Whitesail, Haul Road and Kitamaat Village, showing the frequency of winds blowing from particular directions at each location during 2017. The direction of the longest spoke shows the direction the wind blew from with the greatest frequency, and the different colours distinguish different wind speeds.

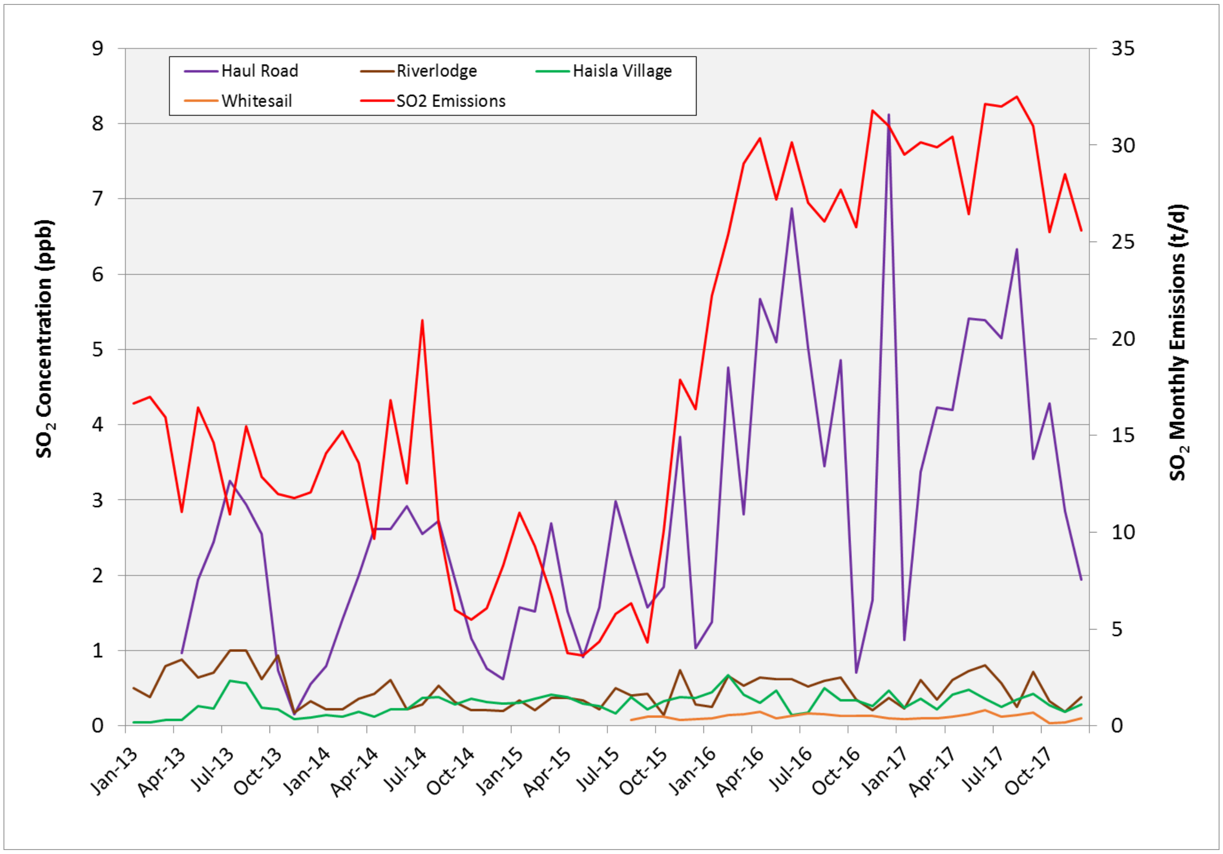


Figure 6. Monthly SO_2 emissions (red line) and monthly average ambient SO_2 concentrations at the four continuous monitoring stations (purple, brown, green and orange lines) for 2013 to 2017. (Source: Rio Tinto)

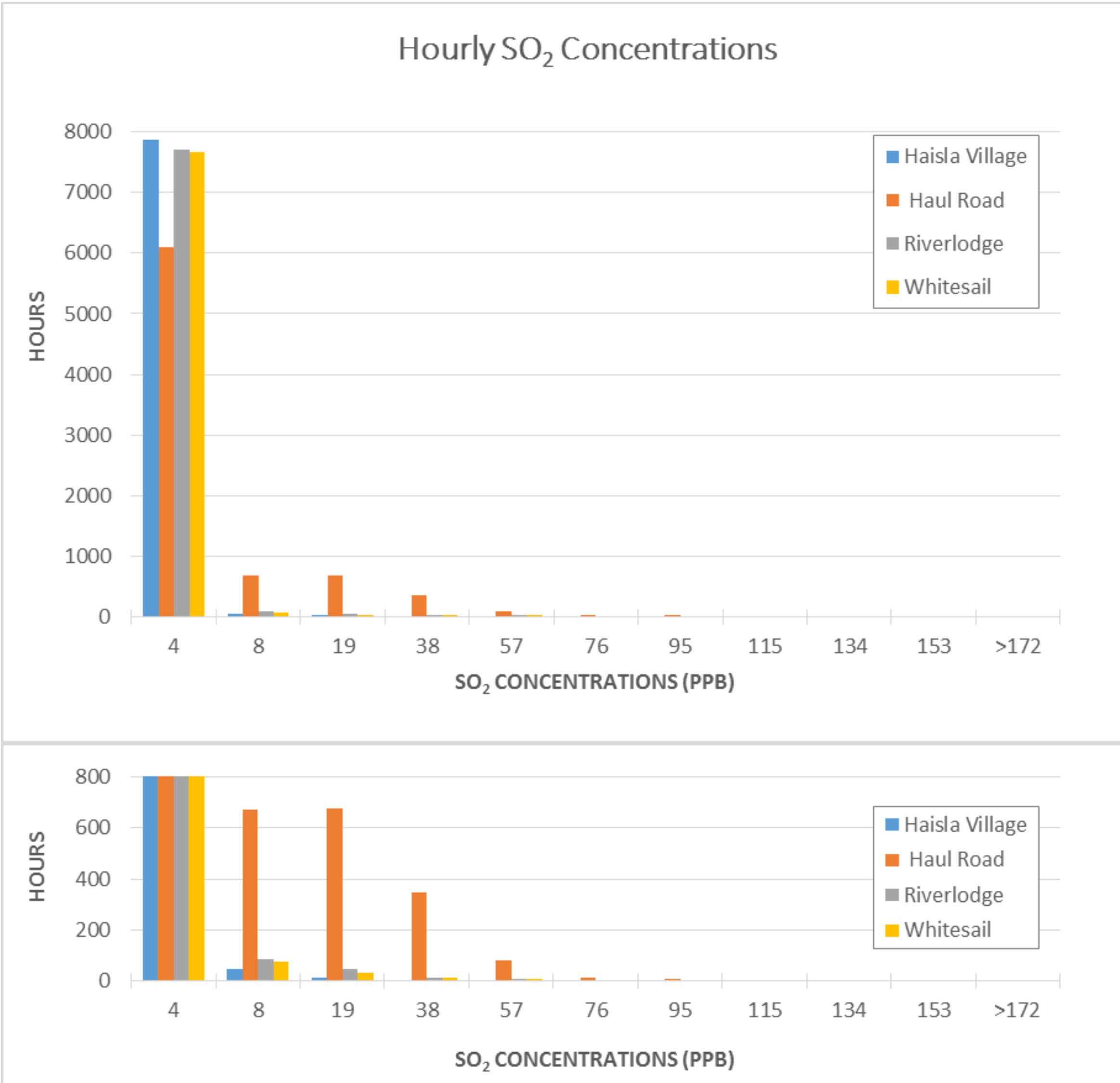


Figure 7. SO_2 hourly concentrations at the Haul Road, Riverlodge, Whitesail and Kitamaat Village continuous monitoring stations (top graph). The bottom graph zooms in on the subset of the data showing lower frequencies (800 hours and less) of higher concentrations. (Source: Rio Tinto)

Comparison to the Model Output

Monitoring data collected at the four monitor stations are compared to the air dispersion modelling results prepared for the STAR. Table 1 and Figure 8 show the comparison between maximum monitored concentrations in 2017 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 2017 are also compared to these maximum predicted concentrations.

As shown in Table 1, concentrations at the Haul Road offsite monitor were less than 50% of the maximum predicted concentrations (1-hr and 3-hr averaging periods), and at 92% and 77% of the maximum predicted concentrations for the 24-hour and annual predicted concentrations, respectively. Additionally, the maximum observed concentrations at Haul Road station are less than 30% of the maximum modeled concentration at any offsite location for any averaging period. In residential areas, the maximum concentrations in 2017 were up to 34% 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 19% across the three residential monitors for the annual average. The 2017 emission rates (about 29.5 t/d) were 70% of the permitted level of 42 t/d. Put another way, the STAR predictions were based on 42 t/d, which is 143% of the actual emissions in 2017. If maximum SO_2 concentrations were proportional to emissions (not always true as meteorology drives maximum concentrations) one would expect the model predictions of maximum concentrations to be at least 1.4 times higher than the observations. This is indeed the case in residential areas, as STAR predictions of maximum concentrations were about 5 times the observations in residential areas. The notable exceptions are the 24-hr and annual concentrations at Haul Road, which are only slightly higher than 2017 monitored concentrations. Overall, these comparisons support the discussion in the STAR that the predicted modelled concentrations in residential areas are conservative compared to measured concentrations.

Table 1. 2017 Monitored Data Compared to Modelled Concentrations.

Monitor Location [1]	Averaging Period	2017 Monitored Maximum Concentration (ppb) [2]	Maximum Modelled Concentration at the Monitor Location (ppb) [3]	Year of Maximum Modelled Concentration at the Monitor Location
Haul Road	1-hour	94.90	438.94	2006
Haul Road	3-hour	53.60	164.02	2006
Haul Road	24-hour	25.66	27.91	2008
Haul Road	Annual	3.91	5.06	2008
Kitamaat Village	1-hour	14.10	230.80	2009
Kitamaat Village	3-hour	11.73	97.43	2009
Kitamaat Village	24-hour	2.66	26.25	2009
Kitamaat Village	Annual	0.32	1.06	2009
Riverlodge	1-hour	44.70	213.34	2008
Riverlodge	3-hour	32.65	142.29	2008
Riverlodge	24-hour	9.79	28.48	2008
Riverlodge	Annual	0.47	3.16	2006
Whitesail	1-hour	40.70	144.63	2006
Whitesail	3-hour	23.57	107.92	2006
Whitesail	24-hour	7.47	43.68	2006
Whitesail	Annual	0.45	3.58	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 Kitamaat.

[2] 2017 monitored data are summarized here with the maximum value for each averaging period. The data completeness at Haul Road, Kitamaat Village, Riverlodge and Whitesail is 96%, 92%, 96% and 95%, respectively.. The monitoring data are in ppb.

[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 $\mu g/m^3$) for the 1 hour and 3 hour averaging periods, 1.2 ppb (3.1 $\mu g/m^3$) for the 24 hour averaging period, and 0.4 ppb (1.0 $\mu g/m^3$) for the annual averaging period (see STAR for details). The modelled concentrations are in $\mu g/m^3$ and are converted to ppb assuming standard condition per the BC Ambient Air Quality Objective (1 atmospheric pressure and 25 °C).

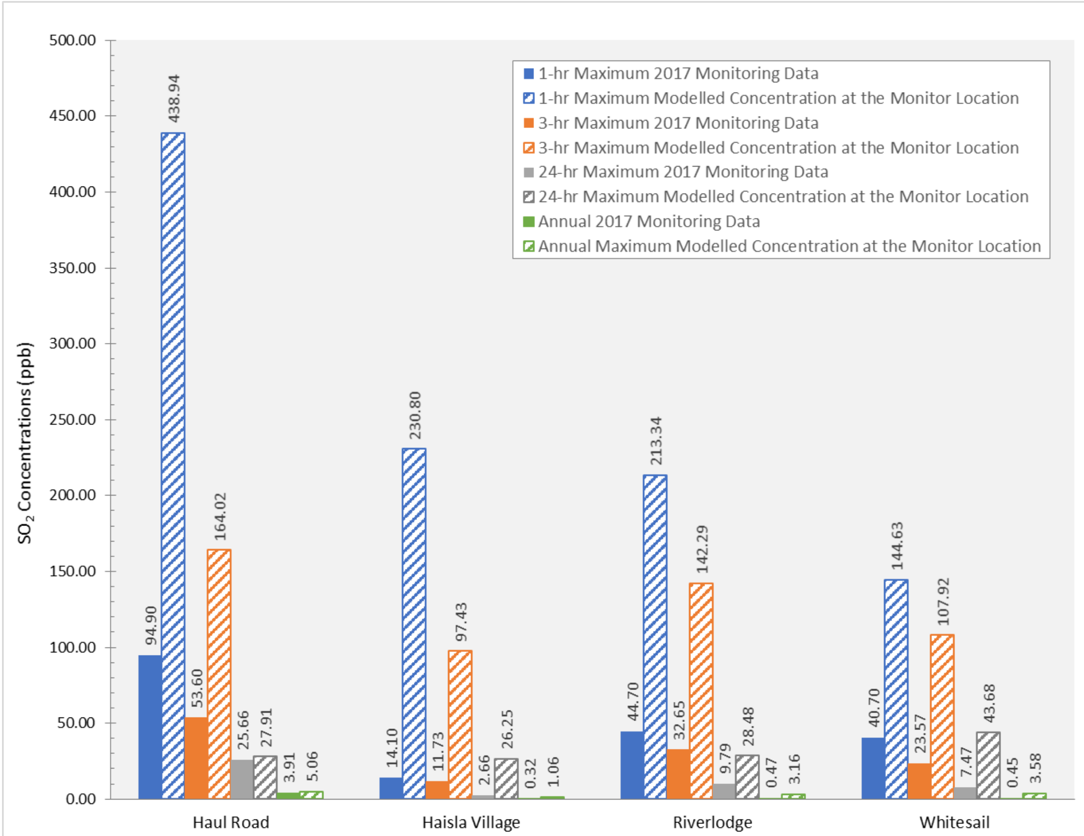


Figure 8. 2017 Monitored data compared to modelled concentrations. (Source: Rio Tinto)

Network Optimization

Rio Tinto is in the process of developing a multi-seasonal air quality study to better understand the seasonal patterns of ambient SO_2 concentrations and spatial distribution of SO_2 within residential areas of Kitimat. The multi-seasonal air quality study will inform the network optimization process and the network's ability to measure the health key performance indicators from the Kitimat Smelter. The draft Terms of Reference (ToR) for the SO_2 network optimization is being updated to include this multi-seasonal air quality study, along with the comments and responses from June 2016 workshop, and how the study's exploratory monitoring will be used.

Passive Sampling

The network of passive samplers was redeployed in the Kitimat Valley during 2017 (Technical Memo P05) following the same protocol and locations as in 2016 (Technical Memo P04), with the addition of a new location at the southern end of the network (Figure 9). As recommended from the pilot study (Technical Memo P03), the network employed IVL passive SO_2 samplers (URL: diffusivesampling.ivl.se) with an exposure period of one month. The network was established on June 06, 2017 at 20 sites (Figure 9) within the Kitimat Valley, primarily focused along the Wedeene and Bish roads to capture the plume path, and included co-location with three ambient (continuous monitoring) stations (Haul Road, Riverlodge and Whitesail). Note: Passive samplers at Whitesail were not deployed until July (exposure 2).

A second network in the urban and residential areas of Kitimat was established during July 2017, following the same protocol and locations as in 2016 (Technical Memo P04). The urban network was established on July 10, with 13 sites located in Kitimat (Figure 9). During 2017, there were 140 sample exposures across both networks, which included replicate samplers deployed >25% of the time.

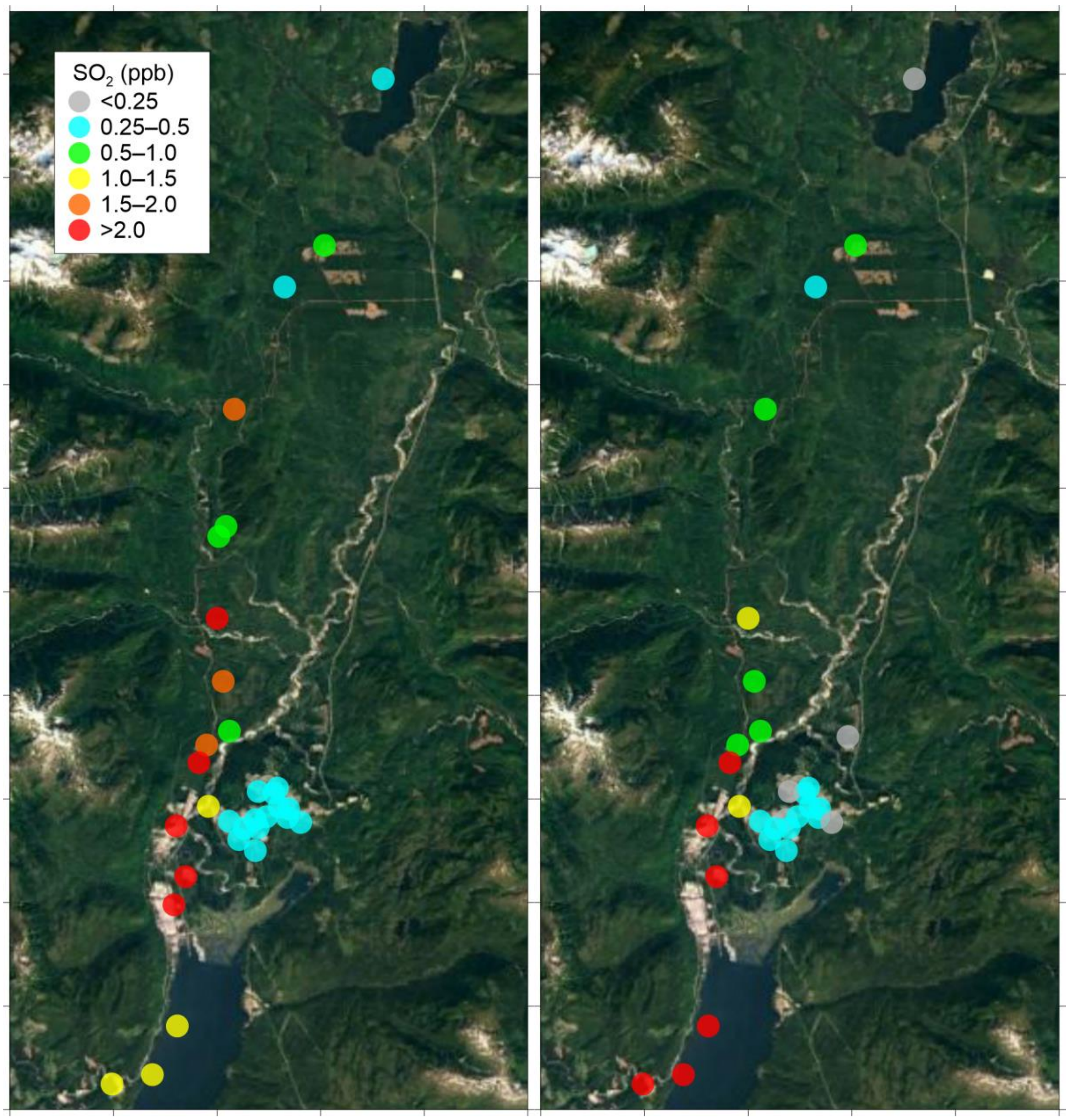


Figure 9. Average atmospheric sulphur dioxide (SO_2) concentration during June–August (left) and August–October (right) 2017 in the Kitimat Valley and urban passive diffusive monitoring networks. Note: monthly exposures under the Kitimat urban network started mid-July 2016. For further details on passive samplers see: IVL: www.diffusivesampling.ivl.se. (Source: Dr. Julian Aherne, Trent University)

Three deployments, with an approximate exposure time of one-month, were carried out under the valley network during June–October 2017, and three one-month exposures (July–October) under the urban network. The third deployment along the valley were exposed for two months (August 09–October 26), owing to limited site access following heavy rainfall. Similar to 2016 (Technical Memo P04), the observed data show elevated atmospheric SO_2 along the plume path (a transect of approximately 45 km (Figure 9); notably during June–August plume concentrations were high north the smelter (concentrations >4 ppb were observed at the Rifle Range monitoring site during June-July 2017), and during August–October higher concentrations were observed south of Rio Tinto (concentrations >6 ppb were observed at Bish Road during August–October, 2017). In contrast, all monthly exposures under the urban network were consistently <0.5 ppb (Figure 9).

The 2017 results (Technical Memo P05) are spatially and temporally consistent with the 2016 observations (Technical Memo P04), and further demonstrate the use of the passive samplers to map out the plume path along the Kitimat Valley; it is recommended that deployments continue during 2018 to further define the plume.

Wet Deposition

Figure 10 compares the amount of annual precipitation (mm) at the two precipitation chemistry monitoring stations during 2014 to 2017, and also compares annual precipitation at the Haul Road station from 2013 to 2017. Because the Lakelse Lake station was only in operation for part of 2013, data from that location are only shown for 2014 to 2017. Average annual precipitation volume was 2432 mm at Haul Road compared with 1485 mm at Lakelse Lake during the four-year period of 2014–2017.

Weekly precipitation volume (mm) at the two stations (operated by the NADP) during the same four-year period showed a higher weekly sulphate concentration (mg/L) and lower pH at Haul Road compared with Lakelse Lake (Figure 11). The higher SO_4 and lower pH in rainfall at Haul Road is caused by the higher atmospheric concentration of SO_2 at Haul Rd, as demonstrated by the passive samplers (Figure 9).

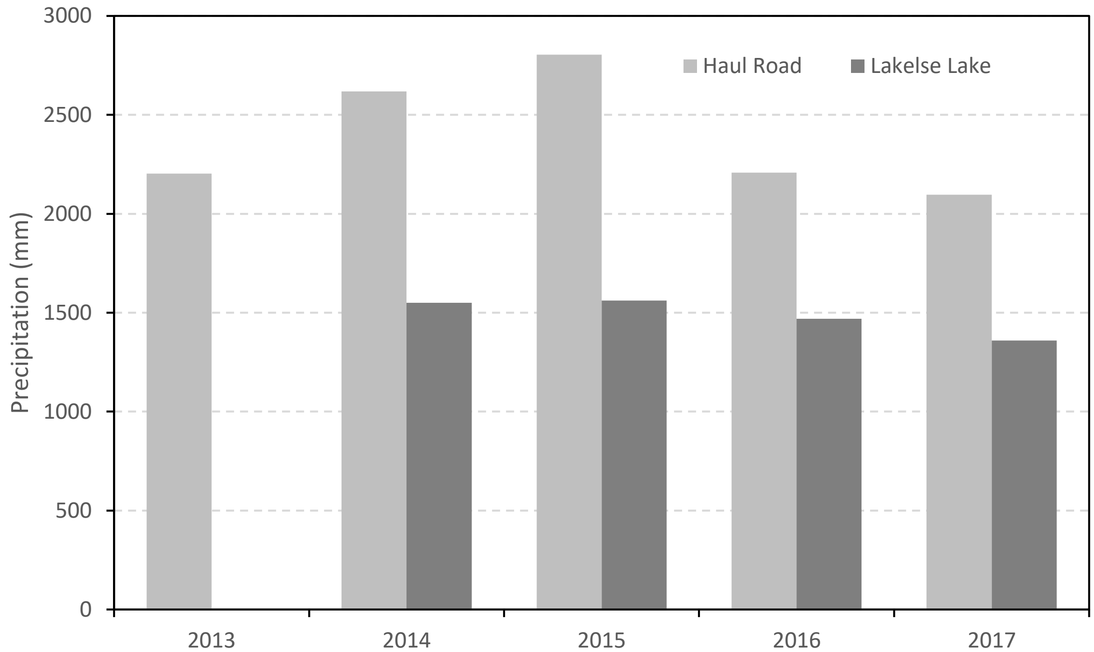


Figure 10. Annual precipitation volume (mm) from 2013 to 2017 at the Haul Road and Lakelse Lake precipitation chemistry monitoring stations (Source: NADP [URL: nadp.sws.uiuc.edu]). Note: Rainfall volume observations during 2017 are currently only available for the period up to December 5th. Due to gaps in the NAPD data for the fall of 2017, this graph is preliminary.

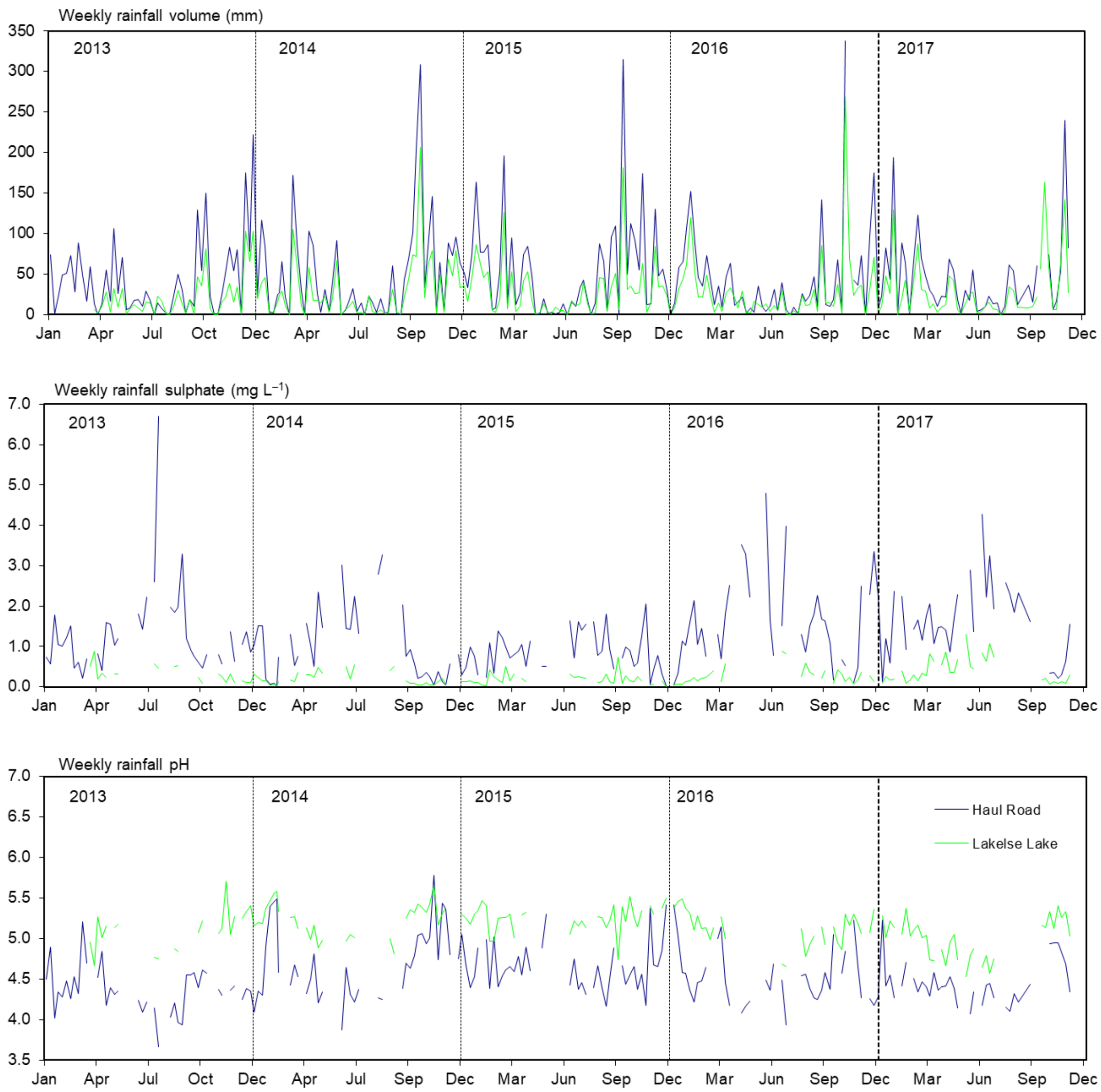


Figure 11. Weekly precipitation volume (mm) and chemistry (mg/L) at Haul Road (January 2013 to December 2017) and Lakelse Lake (April 2013–December 2017) showing inter-annual variation in precipitation volume (upper graph), sulphate concentration (middle graph) and precipitation pH (lower graph). Note: observations during the period 2013–2017 were revised using the most recent data obtained from NADP (URL: nadp.sws.uiuc.edu), which currently only includes data for the period up to December 5th, 2017. Due to gaps in the NADP data for the fall of 2017, this graph is preliminary.

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 (Technical Memo D02). The determination of dry deposition for SO_2 and particulate sulphate (Technical Memo F01) under the EEM Program is being 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 (which was obtained from Dr. Leming Zhang, Environment and Climate Change Canada), has been implemented for use within the Kitimat Valley, and is currently being used to estimate dry deposition based on data from the Terrace airport (Technical Memo D02); the required meteorological data will be obtained from the Prediction Services Operations West, Meteorological Services of Canada.

Preliminary estimates of dry deposition at the Haul Road NAPD monitoring station from 2005 to the end of 2017 (Figure 12) were determined following the approach used in the STAR (which used the same estimate of monthly deposition velocity from the big-leaf model; 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 chemistry, which may be partly responsible for the observed trends in wet deposition since fall 2012. Problems with the SO_2 data logger at Haul Road explain the gap in dry deposition estimates during the latter half of 2012 and first quarter of 2013. A sharp rise was seen in estimated dry deposition during December 2016 consistent with the higher SO_2 emissions (Figure 12).

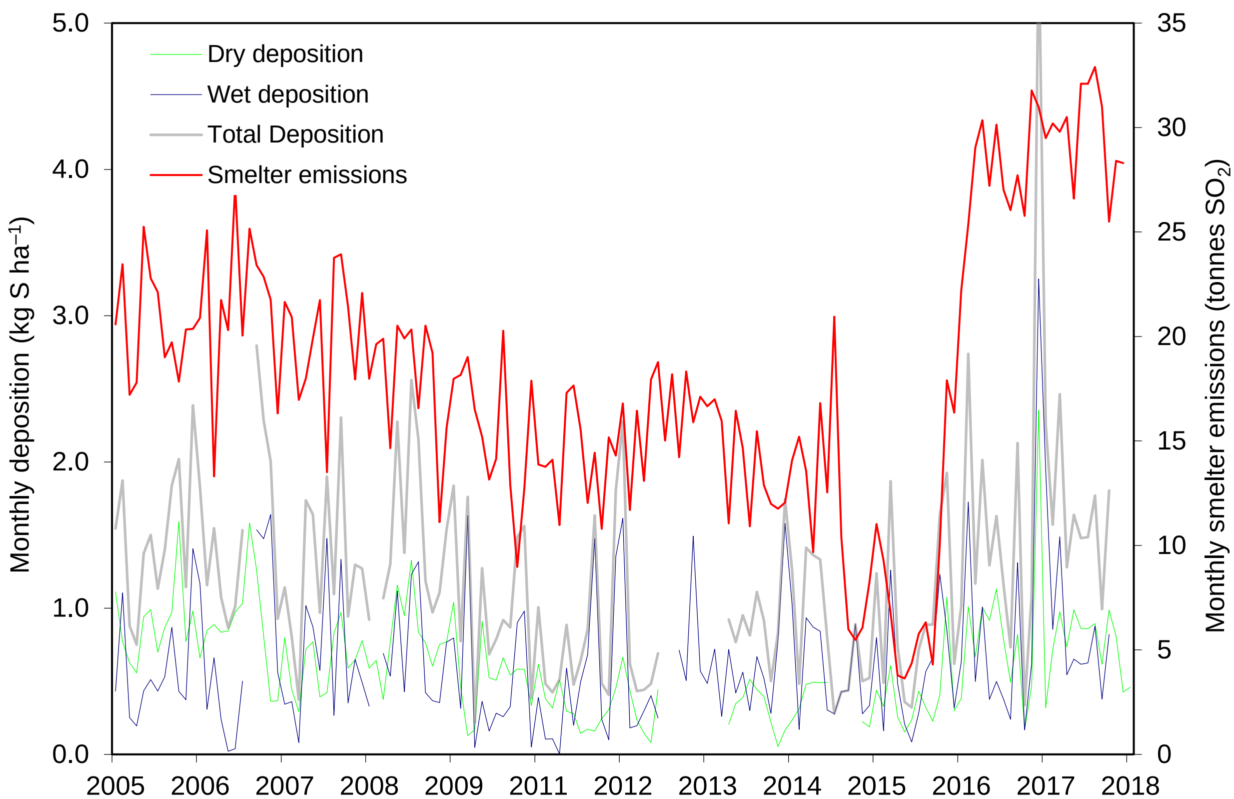


Figure 12. Long-term (2005–2017) monthly dry (green line) and wet (blue line) deposition of sulphur (kg S/ha), and smelter emissions of sulphur dioxide (red line; tonnes SO_2) at Haul Road. Due to gaps in the NAPD data for the fall of 2017, this graph is preliminary.

3.2 Human Health

A province-wide interim SO_2 ambient air quality objective (AAQO) was adopted on December 15, 2016, and became the Health KPI of the SO_2 EEM Program starting in 2017. The SO_2 Health KPI is a threshold for residential SO_2 ambient air concentration of 75 ppb and is evaluated through the following protocol:

- At the end of 2017: Three-year average of the 97th percentile of the daily one-hour average maximum (D1HM) for 2015 – 2017.
- At the end of 2018: Three-year average of the 97.5th percentile of the D1HM for 2016 – 2018,
- At the end of 2019: Three-year average of the 98th percentile of the D1HM for 2017 – 2019, and
- At the end of 2020 and the end of each subsequent year: Three-year average of the 99th percentile of the D1HM for that year and the two preceding consecutive years.

There is an allowance of a one-time exceedance of the 75 ppb threshold to a maximum concentration of 85 ppb, over the three-year interim period.

A draft guidance document for determining adherence to the protocol has been prepared, and is being reviewed by the BC Ministry of Environment.

Table 2 provides the KPI results for 2017, using the 3-year average of the 97th percentile of the D1HM for 2015 – 2017.

Table 2. Calculation method and results for the SO_2 Health KPI in 2017.*

Station	97th percentile D1HM** SO_2 (ppb)			SO_2 Health KPI (ppb) (3-year average of 97th percentile D1HM**)	KPI Attainment / Non-Attainment
	2017	2016	2015		
Riverlodge	15.5	12.9	6.3	11.6	Attainment
Whitesail***	12.1	11.0		11.6	
Kitamaat Village	6.1	8.4	3.0	5.8	Attainment

* Data for this table were extracted from the Envista database of the BC Ministry of Environment on January 19, 2018.
** Daily 1-hour average maximum
*** The Whitesail 2017 health KPI calculation uses a 2-year average.

3.3 Vegetation

Vegetation Survey and Sampling

Sampling of western hemlock (*Tsuga heterophylla*) foliage was conducted by personnel from Stantec Consulting Ltd., Terrace, BC, from August 28 to September 1, 2017. Western hemlock foliage was collected for analysis of sulphur (S) content at the established sampling locations (Figure 13). Under the EEM Program, a survey and inspection of vegetation is conducted biennially and was not conducted in 2017.

In 2017, a site and sample-tree assessment checklist was implemented to document conditions at the time of sampling. Use of the checklist resulted in increased observations of site characteristics and sample tree condition. Details of site conditions may be found in the 2017 Vegetation Program Annual Report (Stantec 2018).

Based on field observations by the Stantec sampling crew, the general condition of vegetation in the area is similar to what has been reported in the past. Hemlock woolly adelgid persists in the area at low intensity. The number of sites where signs of infestation were observed (14) is greater than in the past, perhaps due to the implementation of the site and sample-tree assessment checklist. The infestation is not affecting the integrity of sampling sites or individual sample trees.

Trees at a number of sites show some level of chlorosis (yellowing), but the levels observed are within those characteristic of the site and time of year. Chlorosis is a general symptom that may be associated with natural processes such as senescence, as well as stress due to site conditions (soil, water, etc.), pests and pathogens, or other stress factors including air pollution. The cause of the chlorosis was not determined. Other pest and pathogen activity is generally at a low level. A pocket of hemlock looper infestation was observed by the sampling crew in the Williams Creek drainage where reference sites are located. The infestation is in older, mature western hemlock and not affecting the sampling sites or sampled trees. Senescence in understory plants, typical for the time of year and site conditions, was observed throughout the area, as it has been in the past.

Analysis of western hemlock foliage for S was conducted by the Rio Tinto laboratory in Jonquière, Québec. The S concentration in western hemlock foliage ranged from 0.05% at site 54 to 0.14% at site 87 and 0.12% at sites 43A, 44, 78A, and 80. Only 1 site (80) exceeded its historic mean value (but not by more than 1 standard deviation) in S concentration used in the EEM Program[2] (1998-2011), thus the informative indicator was not exceeded. All S concentrations measured are within the range of background concentrations reported in the scientific literature, including in western hemlock in BC (Kayahara et al. 1995; Linzon et al. 1979; Reimann et al. 2003). Sites 490 and 492, added in 2016 at the request of ENV as reference sites, had S concentrations of 0.06% at both sites, well within background S concentrations reported in the literature.

In 2015, the loading of SO_2 was substantially reduced due to the modernization project. Comparing 2017 to 2015, when S loadings were very low, trees at 22 sites had an increase in

[2] The historic mean is defined as 1998-2011 in STAR Volume II, ` 9.2.1 (ESSA 2013). In the EEM Program the historic mean is defined as 1989-2011. That is a typographical error; the correct averaging period is 1998-2011.

S concentration, but only 8 (56A, 68, 69, 70, 78A, 80, 81B, and 82) exceeded the 2015 value by more than 1 standard deviation. Fifteen sites had S concentrations in foliage at or below the 2015 level.

When comparing two years of results post-KMP (2016 and 2017), no site had a post-KMP mean that exceeded the historic mean.

Additional information, including the results of the chemical analysis for each site, can be found in the 2017 Vegetation Program Annual Report (Stantec 2018).

The results of the vegetation sampling and analysis of western hemlock needles do not indicate a need for increased action under the EEM Program with regard to the health of vegetation. The informative indicator of 'S content in hemlock needles' does not surpass the threshold for increased monitoring (an increase of more than 1 standard deviation from the pre-KMP baseline data in 20% of the sites for 3 consecutive years, causally related to KMP). No sites had an increase in S content of more than 1 standard deviation from the STAR historic baseline concentration (1998-2011).

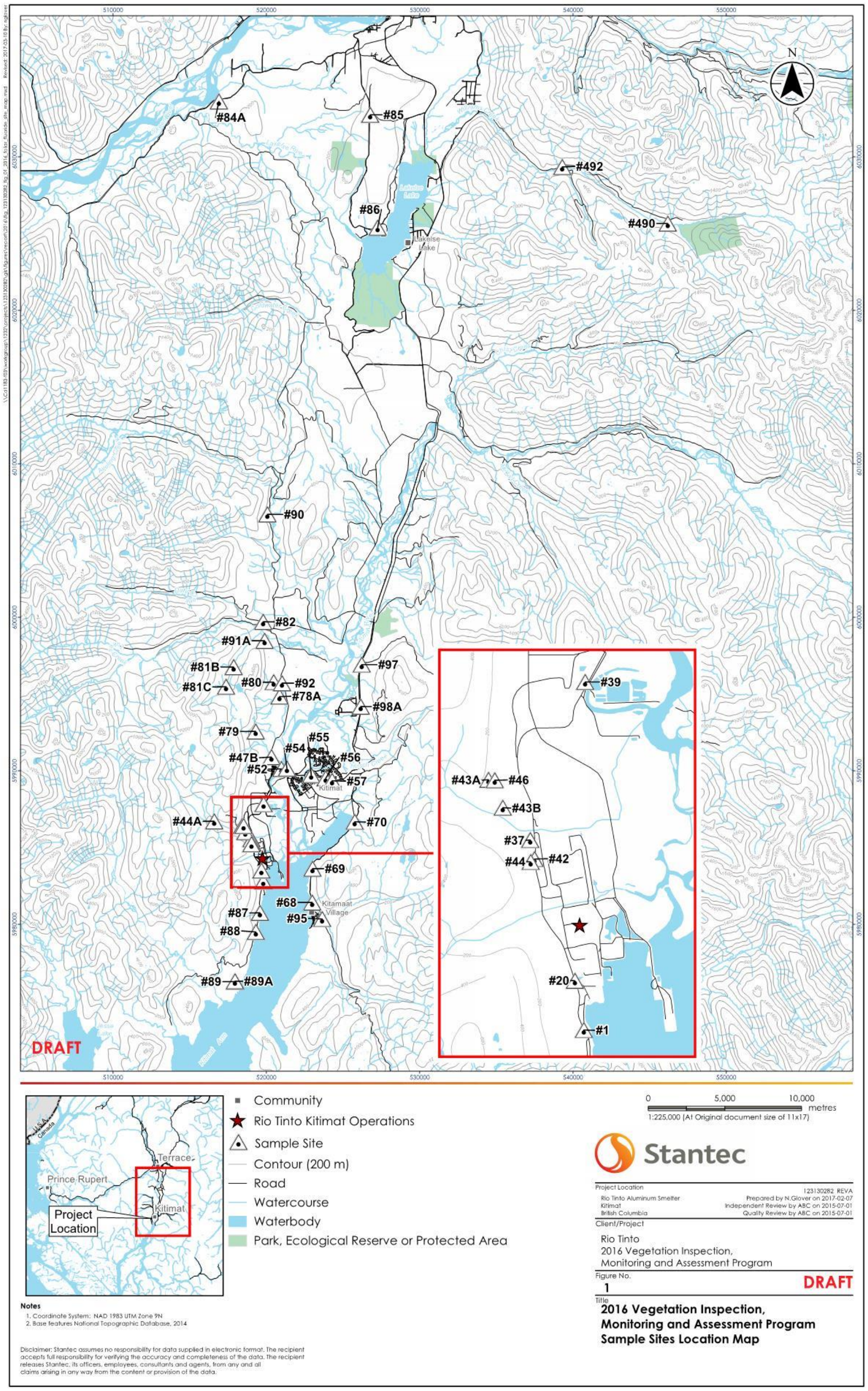


Figure 13. Location of vegetation sampling (denoted by triangles). (Source: Stantec 2017 [*map is currently the 2016 version; it will be updated for the final 2017 EEM Report, by which time the Stantec 2017 report should be finalized and available*])

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. Critical loads of acidity for (upland) forest soils are scheduled to be revised during 2018 to support the KPI of 'critical load exceedance risk'.

Permanent Soil Plots

During 2015 and 2016, long-term soil monitoring plots (primary and secondary plots) were established at Lakelse Lake and Coho Flats, Kitimat Valley, and at Kemano (reference plot); in addition, soil and bulk density samples were collected from all plots (Figure 14).

The long-term soil monitoring plots will address the KPI of 'observed change in base cation pool over time' through sampling and analysis of soils for base cations every five years (next sampling is scheduled for 2018, three years after the initial soil sampling). The objective during 2017 was the chemical analysis of the composite soil samples at the primary plots at Lakelse Lake and Coho Flats (Technical Memo S07); there are 20 soils samples, collected from three depths at each plot; a total of 120 soil samples. Soils were analysed for exchangeable cations (which includes calcium, magnesium and potassium) and exchangeable acidity.

Figure 14. Location of the long-term soil monitoring plots at Lakelse Lake and Coho Flats in the Kitimat Valley, and the 'background' or 'reference' plot at Kemano. Note: primary and secondary [backup] plots were established at all three locations.

All soil samples (collected during 2015 and 2016) were air dried, sieved to < 2 mm and analysed for pH, organic matter content, and bulk density. In addition, tree species were mapped for all plots (Technical Memo S06). During 2017, the soil samples at the primary plots were analyzed for exchangeable cations 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 and analyzed by ICP–OES for exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Fe^{3+} and Mn^{2+}). In addition, all soils were analyzed for exchangeable acidity using a potassium chloride (KCl) extraction; 5 g of soil was mixed with 25 ml of KCl, and the solution was extracted using vacuum filtration. The KCl extractant (135 mL) was titrated with sodium hydroxide (NaOH) to determine exchange acidity ($H^+ + Al^{3+}$). The KCl extractant (15 mL) was also analyzed by ICP–OES to determine exchangeable aluminum (Al^{3+}). Base saturation (%) was estimated as the percentage of base cations (calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+)) within total cations; total cations, also known as Cation Exchange Capacity (CEC), was estimated as the sum of all cations and exchangeable acidity (which is the sum of exchangeable aluminium (Al^{3+}) and hydrogen (H^+)), this is technically termed effective CEC.

Average base saturation (%) at Lakelse Lake was 47%, which is notably higher compared with 16% at Coho Flats. The base saturation was higher throughout all soil depths at Lakelse Lake, especially the 0–5 cm and 5–15 cm soil depths (Figure 15). While total cations (effective CEC) was similar between plots (Table 3), the soils in Lakelse Lake were dominated by base cations (average 4.0 meq/100g) compared with Coho Flats (average 1.4 meq/100g).

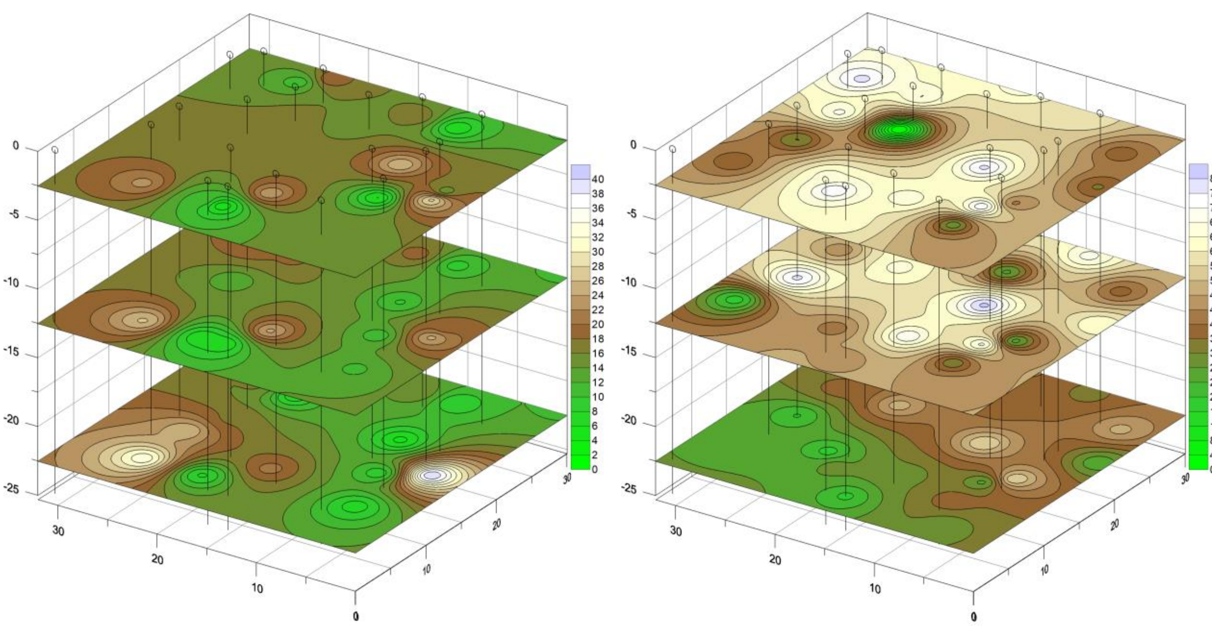


Figure 15. Three-dimensional representation of soil base saturation (%) in the 0–5 cm, 5–15 cm, and 15–30 cm (mineral) soil depths at the primary long-term soil monitoring plots at Coho Flats (left) and Lakelse Lake (right). The vertical lines indicate the location of the soil sampling pits (n = 20 per plot, with soil sampling at three depths). Note the differences in saturation scales between plots.

Table 3. Average soil chemistry data (n = 20 per soil depth) for the primary long-term soil monitoring plots at Coho Flats, and Lakelse Lake.

Soil Variable (meq/100g)	Coho Flats | Soil Depth (cm)			Lakelse Lake | Soil Depth (cm)		
	0–5	5–15	15–30	0–5	5–15	15–30
Exchangeable Ca2+	1.09	0.92	0.97	4.37	2.79	0.88
Exchangeable Mg2+	0.32	0.30	0.24	1.67	1.37	0.26
Exchangeable K+	0.13	0.13	0.10	0.13	0.05	0.11
Exchangeable Fe3+	0.06	0.07	0.07	0.14	0.12	0.03
Exchangeable Mn2+	0.01	0.02	0.01	0.20	0.12	0.03
Exchangeable Acidity	7.84	6.77	5.82	3.68	2.86	2.24
Exchangeable Base Cations$	1.53	1.35	1.30	6.17	4.21	1.25
Cation Exchange Capacity$	9.44	8.20	7.20	10.18	7.31	3.55
Base Saturation (%)	16.22	16.44	18.07	60.57	57.61	35.22

[$] Exchangeable Base Cations was estimated as the sum of calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^{+}); Cation Exchange Capacity (CEC) was estimated as the sum of all cations and Exchangeable Acidity (which is the sum of exchangeable aluminium (Al^{3+}) and hydrogen (H^{+})), this is also known as effective CEC.

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 (W07). Each action, learning/conclusion, and/or next step is presented as a short bullet. The Technical Memo provides extensive details on the methods and results that support these statements.

Actions Taken in 2017

- We completed 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 (Bennett and Perrin 2018). Lakes included in the EEM Program, plus Lakelse Lake (sampled due to its public importance), are collectively referred to as "EEM lakes".
- We examined inter-annual changes in water chemistry between 2016 and 2017 (Table 4).
- We intensively monitored pH in the three accessible sensitive EEM lakes for the fourth year, tracking within-year fluctuations including episodic changes. Intensive monitoring included the implementation of continuous pH monitors and multiple within-season samples collected for field and lab analyses of pH and all chemical parameters included in the annual sampling. In 2017 (as in 2015 and 2016), continuous monitoring of pH began in the spring and was continued through the summer and fall.
- Within-season sampling was expanded in 2016 beyond the three easily accessible EEM lakes (LAK006, LAK012, LAK023) to three additional EEM lakes (LAK028, LAK042, LAK044), based on the recommendations put forth in the 2015 EEM Annual Report to improve estimates of within-season variability. These six lakes were each sampled a total of 4 times from late September through October.

- We again sampled the three control lakes that were added to the EEM Program in 2015. 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.
- A Manta Sonde (continuous pH monitor) was installed in Anderson creek for from July 12 to August 16 for comparison to data collected by Rio Tinto from their permanently installed Foxboro pH logger. This comparison was part of quality assurance testing of instruments. Difficulties in consistently measuring pH in Anderson Creek in past years were discussed in previous Annual Reports. Rio Tinto monitored pH and flow in Anderson Creek from May through October.
- Lake levels were monitored in End Lake, Little End Lake, and West Lake (as they were in 2016) 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). These data can be used to assess what chemical changes are associated with storm events.
- Amphibian monitoring. A literature review of acidification impacts on amphibians and potential pathways of effects was conducted in 2017, and is being finalized (ESSA Technologies Ltd. 2017).

Knowledge Gained from Actions taken in 2017

- Inter-annual changes in water chemistry properties:
    - Changes in pH, ANC and SO_4^{2-} for 2016-2017, based on the annual samples, are shown in Table 4.
    - Summary of observed changes between 2016 and 2017:
        - Increases in SO_4^{2-} concentration, which would be consistent with the 6.8% increase in SO_2 emissions, were observed in 6 of 7 sensitive EEM lakes and 2 of 4 less sensitive lakes
        - 3 lakes showed decreases in SO_4^{2-}
        - ANC decreased in 4 of 7 sensitive EEM lakes and 3 of 4 less sensitive EEM lakes
        - 4 of 7 sensitive EEM lakes showed a change in ANC consistent with their observed change in SO_4^{2-}
            - 2 sensitive lakes increased in ANC and SO_4^{2-}
            - LAK023 showed an increase in ANC, consistent with the observed but unexpected decrease in SO_4^{2-}
            - LAK042 showed a prominent decrease in ANC that could not be explained by the increase in SO_4^{2-} alone and was likely partly due to the increase in DOC
            - LAK028 again showed the largest increase in SO_4^{2-} (22.2 μeq/L) which is consistent with its much closer proximity to the smelter than other EEM lakes. LAK028 also showed an increase in base cations of 10.8 μeq/L, suggesting that about 49% of the

deposited acidity was neutralized by cation exchange in the watershed. Overall, 78% of the sulphate-associated acidity deposited between 2016 and 2017 was neutralized, since Gran ANC only declined by 4.97 μeq/L. Other neutralization processes besides cation exchange are apparently responsible.

- Changes in ANC could also be partially related to changes in total base cations or organic anions in some lakes
- pH decreased or remained unchanged in 6 of 7 sensitive EEM lakes, but these decreases were ≤ 0.2 pH units (i.e., within the limits for the accuracy of laboratory pH measurements)
    - 6 of 7 sensitive EEM lakes still show a net pH increase compared to pH measurements in 2012, though 4 of these values are ≤ 0.2 pH units (Table 5)
- pH decreased in two of the less sensitive EEM lakes and remained unchanged in another
- pH and ANC showed the same direction of change (as expected) for 6 of the 7 EEM lakes with ΔANC ≥ 2% and Δ pH ≥ 0.1
- Changes in base cations were variable across the EEM lakes (6 lakes decreased, 5 lakes increased)
- All but two of the EEM lakes showed decreases in DOC, a reversal of the pattern observed last year
- All but two of the EEM lakes showed decreases in chloride

- Changes in pH, ANC and SO_4^{2-} for 2012-2017, based on the annual samples, are shown in Table 5.
    - This table is included to provide an indication of the changes across the entire record, but is not meant to represent a thorough evaluation of the differences between the pre- and post-KMP periods
    - When the comprehensive review of the EEM is conducted in 2019, changes will be assessed using all of the data available at that time (i.e., 2012 to 2018)
- Observations for pH, ANC and SO_4^{2-} were also compared to values from 2012
    - From 2016 to 2017 in LAK028 pH decreased, ANC decreased and SO_4^{2-} increased
    - Technical Appendix W07 provides further exploration of the observed changes in LAK028. Previous data and analyses from the STAR and EEM program have consistently suggested that LAK028 has the highest potential risk of acidification due to KMP.
- Changes in the sampled lakes were generally consistent with expectations for 3 of the 7 sensitive lakes and all 4 of the less sensitive lakes
    - For sensitive lakes, expectations are based on the evidentiary framework, which is intended to identify patterns of change associated with the potential for an acidification effect driven by sulphate emissions – i.e., decreases in pH corresponding with both decreases in ANC and increases in SO_4^{2-} concentration, in the context of increased SO_2 emissions.
    - The less sensitive lakes are expected to show an increase in SO_4^{2-} concentrations with an increase in SO_2 emissions, but are not expected to experience any acidification effect – changes in ANC are expected to be relatively small and independent of changes in SO_4 concentration.

- Control lakes
  - The three control lakes showed changes in sulphate concentrations between 2016 and 2017 from -16% to +10%.
  - The directional changes in pH, base cations, DOC varied among control lakes
  - All three lakes had decreases in ANC, including two lakes with substantial decreases in ANC
  - Chloride decreased by 31-39% in all three control lakes
- The intensive monitoring of the three accessible EEM lakes continued to show that there is a high degree of variation in the continuous (half-hourly) pH within each year, but not in the mean annual pH. Over April to November 2017, pH varied by about 0.9 to 1.4 pH units, depending on the lake and pH sensor[3]. The mean pH values from all the sensors in End Lake and West Lake were the same in 2017 as they were in 2016, and therefore remained above pH 6.0, the level used as a biological threshold for analyses of critical loads (see STAR and KAA reports). The mean pH values for each of the sensors in Little End lake declined by 0.2 pH units, dropping below pH 6.0. These data reinforce the previously stated conclusions on the implications for the design of the EEM Program (i.e., previous Annual Reports):
  - 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. Since pH is highly variable, it is important to have within-season data on the additional metrics to better understand if and how lake chemistry is changing.
  - 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-}). ANC showed the strongest statistical power for detecting change, and efforts are underway to develop ANC thresholds that correspond to a 0.3 unit pH decline from lake-specific pH-ANC relationships derived from laboratory titrations.
  - August and October pH values were compared for the three lakes with continuous pH monitoring, in the three years in which such monitoring was active in August (2015, 2016, 2017). These data show that there is no consistent difference across lakes and years in the mean pH measured in August vs. the mean pH measured in October. This provides an indication that samples taken in August are not biased relative to samples taken in October in a particular year. This implies that the August 2012 data can be grouped together with the October samples taken in 2013 to 2017. However, although the additional data in 2017 supported the preliminary findings from last year, this analysis is still only based on three years of sampling and should be repeated in subsequent years to confirm the finding.
  - Continuous monitoring data indicated that pH tended to decline during large rainstorms, in both Anderson Creek and the three intensively monitored lakes. However, analyses of the pH measurements in the intensively monitored lakes indicate that there was little difference between the mean pH over May through October, the mean pH for the month of October, and the mean pH for just the four dates on which chemical measurements were taken in the fall. Despite a

[3] These values exclude sensor pH3 in End Lake. For that sensor, the range was 1.9 pH units but this reflects some extremely high readings that are suspected to be instrument errors.

very rainy fall, it does not appear that the mean pH estimated from four fall samples is biased relative to the overall mean pH for the May-October period.

- The high degree of intra-annual variation shown by the intensive monitoring (i.e., continuous monitoring of pH in three sensitive EEM lakes, and the multiple within-season sampling of water chemistry for six sensitive EEM lakes) demonstrates the importance of using probabilistic, statistical analyses to rigorously evaluate changes in water chemistry as part of the comprehensive EEM review in 2019.

Table 4. Changes in pH, ANC and SO_4^{2-} for EEM lakes, 2016 to 2017.

	pH (TU)	Gran ANC (ueq/L)	SO4* (µeq/L)
From	2016	2016	2016
To	2017	2017	2017
LAK006	0.0	1.1	2.5
LAK012	-0.1	-7.6	5.0
LAK022	0.0	-0.3	4.9
LAK023	-0.1	0.6	-2.6
LAK028	-0.2	-5.0	22.2
LAK042	-0.2	-11.7	3.5
LAK044	0.1	3.0	0.4
Total Lakes with Increase	**1**	**3**	**6**
Total Lakes with Decrease	**6**	**4**	**1**
LAK007	0.0	13.0	0.4
LAK016	0.1	-11.1	-1.8
LAK024	-0.1	-46.5	-4.3
LAK034	-0.1	-15.2	0.1
Total Lakes with Increase	**2**	**1**	**2**
Total Lakes with Decrease	**2**	**3**	**2**

* Refers to non-marine sulphate (total sulphate – marine derived sulphate). Marine-derived sulphate is based on chloride concentrations (assumed to be entirely marine) multiplied by 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.

Table 5. Changes in pH, ANC and SO_4^{2-} for EEM lakes, 2012 to 2017.

	pH (TU)	Gran ANC (ueq/L)	SO4* (µeq/L)
From	2012	2012	2012
To	2017	2017	2017
LAK006	0.2	2.3	2.9
LAK012	0.4	1.2	8.4
LAK022	0.1	6.3	8.8
LAK023	0.2	8.7	-8.9
LAK028	-0.2	-5.9	93.1
LAK042	0.5	22.7	0.6
LAK044	0.2	5.8	-1.7
Total Lakes with Increase	**6**	**6**	**5**
Total Lakes with Decrease	**1**	**1**	**2**
LAK007	0.0	-56.0	-4.3
LAK016	0.3	14.1	4.1
LAK024	0.3	117.2	10.0
LAK034	-0.3	37.1	-24.0
Total Lakes with Increase	**3**	**3**	**2**
Total Lakes with Decrease	**1**	**1**	**2**

* Refers to non-marine sulphate (total sulphate – marine derived sulphate). Marine-derived sulphate is based on chloride concentrations (assumed to be entirely marine) multiplied by 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 2018 sampling plan for water chemistry should follow the 2017 sampling plan. No additional changes are recommended at this time. Additional information on within-season variability in lake chemistry for LAK028, LAK042 and LAK044 (included in 2016 and 2017) will be valuable for analyzing trends over time, as will continued sampling of the control lakes, and the intensively monitored lakes.

The trends in LAK028 are of particular interest. The 2018 sampling of LAK028 will provide important additional information for assessing long term trends. LAK028 has very high year-to-year variability in both Gran ANC and pH. So far we only have two years with 4 samples during the fall index period (prior years had only one sample per year). We will have greater confidence in the apparent changes in water chemistry after collecting additional data in 2018 (i.e., another year with four samples in the fall index period), and thoroughly assessing all the data in the comprehensive 2019 report.

We recommend completing an analysis of the bathymetry of LAK028, as was done previously for End Lake, Little End Lake and West Lake. This will provide a more precise estimate of the volume of LAK028, from which we can derive more accurate estimates of the water residence time in LAK028, which will be helpful for modelling changes in its water chemistry over time.

We also recommend resampling the eight tributaries collectively called Goose Creek, six of which were sampled in 2014, and two of which were sampled in 2015. These tributaries of the Kitimat River are below the steep hill on which LAK028 is found, and are reportedly used for spawning by cutthroat trout. Resampling these tributaries will provide an indication if there have been any significant changes in the water chemistry of these streams since 2014-2015. One of these streams is acid sensitive (Goose Ck 4, Gran ANC < 50 μeq/L), two are moderately acid-sensitive (Goose Creek 1 and 2, Gran ANC < 100 μeq/L), and five are insensitive to acidification (Gran ANC > 200 μeq/L), as described in Technical Memos W03 and W06.

An option worthy of consideration in 2018 is to sample the benthic organisms in the Goose Creek tributaries, and compare their community composition to that expected from other streams in the region with similar attributes, using the Reference Condition Approach (RCA). RCA has been used across many parts of the province by the Ministry of Environment. The streams would be sampled at the end of summer during the period with the lowest flow.

Another option that we have considered is to sample the littoral benthos in LAK028, but we (ESSA and Limnotek) believe that sampling the Goose Creek tributaries would provide information of much greater value due to the potential use of these streams by cutthroat trout. LAK028 is inaccessible to fish due to high stream gradients, and the 2017 sampling found no fish there.

The primary future analyses of interest will be the 6-year comprehensive assessment in 2019. The EEM Plan (ESSA et al. 2014, pg. 32) recommended that laboratory Gran ANC titrations be used to estimate lake-specific ANC thresholds that correspond to a pH decline of 0.3, thereby taking into account the unique mix of organic anions found in each lake. Recent work by ESSA has demonstrated how past lab reports of Gran ANC titrations can be used to derive ANC thresholds. We have acquired the lab reports from all past lake samples from Trent University, and are in the process of estimating a lake-specific mean ANC threshold (and its variation) for each EEM lake. We will complete these analyses in 2018, and use these thresholds in the comprehensive 2019 report.

4 Cited Reports

Bennett, S. and C.J. Perrin. 2018. Rio Tinto Alcan Kitimat Modernization Project: Environmental Effects Monitoring of Lakes in 2017. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Alcan Ltd. 49 pp plus Appendices.

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5 Cited EEM Technical Memos

The numbering of Technical Memos continues from the numbers in the previous Annual Reports (for 2013-2014, and for 2015). Technical memos earlier in their numbering sequence from those listed below are cited in previous annual reports, and can be obtained from the Rio Tinto website.

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

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 D02. Atmospheric Sulphur Dioxide – Method for Estimating Dry Deposition: 2017 Update. (June 2018, Trent University)

Technical Memo F01. Atmospheric Sulphur – Filter Pack Measurements of Particulate Sulphate. (June 2018, Trent University)

Technical Memo S06. Long-term Soil Monitoring Plots – Plot Establishment (March 2017, Trent University)

Technical Memo S07. Long-term Soil Monitoring Plots – Laboratory Analysis (June 2018, Trent University)

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

Technical Memo W06. Aquatic Ecosystems Actions and Analyses (March 2017, ESSA Technologies Ltd.)

Technical Memo W07. Aquatic Ecosystems Actions and Analyses (April 2018, ESSA Technologies Ltd.)