Sulphur Dioxide
Environmental Effects Monitoring
for the Kitimat Modernization Project

2016 Annual Report

Prepared for:

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Summary of EEM Actions

The following tables summarize the EEM commitments for 2016, 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. Implement the monitoring network optimization according to the Terms of Reference drafted in 2015.	Collection and analysis of data from four analyzers, and comparison to model output. Air quality workshop was held in June. KPAC input was obtained on the network rationalization plus passive monitoring. A new multi-seasonal air quality study will be initiated in 2017 that will provide input to the network rationalization study in 2020.	Section 3.1
	If passive monitoring pilot shows good correlation with continuous monitors, then develop passive monitoring program to augment SO_2 analysers.	A passive monitoring network was designed for Kitimat and the Kitimat Valley. Passive monitoring was completed between July and October.	Section 3.1 Technical Memos P03, P04
Wet deposition	Maintain two rain chemistry stations (Haul Road and Lakelse Lake).	Continued operation of both stations.	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.	A continuous SO_2 monitor was purchased and will be installed in 2017. A methodology for estimating dry deposition was developed. Estimating dry deposition at both sites will occur in 2017.	Section 3.1
Human Health			
Atmospheric SO_2 concentrations	Increase accessibility of ambient air quality data to the community.	BC MOE was invited to give a presentation at the Kitimat air quality workshop on how to access the ambient air quality data. Weekly ambient SO_2 air quality monitoring reports were issued to concerned people who have signed up	Section 3.2

Topic	The commitment	What was done	Where to learn more
		for the reports. Weekly SO_2 reports are also posted on the Rio Tinto BC Works Facebook page.	
	Report on SO_2-associated predicted airway responses.	Rio Tinto requested that the informative indicator be removed from the report now that a key performance indicator (KPI) for health has been inserted into the SO_2 EEM program. The SO_2 Health KPI has been calculated for all three residential stations.	Section 3.2
Vegetation			
Vegetation survey	Visible injury survey, including sensitive species checklist.	Work was accomplished as planned. The inspection of vegetation was conducted August 29-September 2, 2016. The sensitive species checklist was used.	Section 3.3
	Continued vegetation sampling as described in Laurence (2010).	Vegetation sampling was accomplished as planned.	Section 3.3
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 August 29-September 2, 2016 by Stantec Consulting Ltd. One site was sampled in early October due to helicopter accessibility issues.	Section 3.3 Laurence (2017) Stantec (2017)
Terrestrial Ecosystems (Soils)			
Soil modelling	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).	Fifteen additional soil sites were sampled, and data were obtained from a further 22 sites.	Section 3.4 Technical Memos S02, S03, S05
Permanent soil plots	Chemical analysis of initial samples taken in 2015, re-visit sampling plots for bulk density sampling, and mapping of tree locations.	A reference long-term plot was established, additional soil bulk density sampling was done, and tree species were mapped out across all plots.	Section 3.4 Technical Memos S04, S06

Topic	The commitment	What was done	Where to learn more
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)			
Chemistry – water sampling	Annual water sampling and laboratory analysis, and data evaluation.	Completed. Continuation of intensive monitoring in three lakes and of annual water chemistry sampling of 14 lakes, including 7 sensitive lakes, 3 insensitive lakes, 3 control lakes, and Lakelse Lake. Weekly sampling of three additional lakes during fall sampling season	Section 3.5 Technical Memo W06 Bennet and Perrin (2017)
Fish sampling	Resample if the lake pH change reaches the threshold.	No fish sampling done.	
Episodic acidification	Implementation of episodic acidification study.	Maintained continuous pH monitoring in West Lake, End Lake, Little End Lake and Anderson Creek[1]. Episodic acidification work is continuing by Dr. Paul Weidman as an independent study from the EEM Program.	Section 3.5 Technical Memo W06
Amphibians	Provide support to existing local community groups who conduct annual amphibian monitoring. Conduct a literature review of potential effects of acidification on amphibians in the Kitimat Valley.	Terms of reference were drafted for reviewing the literature and available regional data to understand the potential risks to amphibians in the Kitimat Valley. The work is expected to be carried out in 2017.	Section 3.5 Technical Memo W06

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[1] A pH monitor was in place during 2016 but had calibration issues that resulted in the data being unusable.

Table of Contents

List of Figures

List of Tables

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.

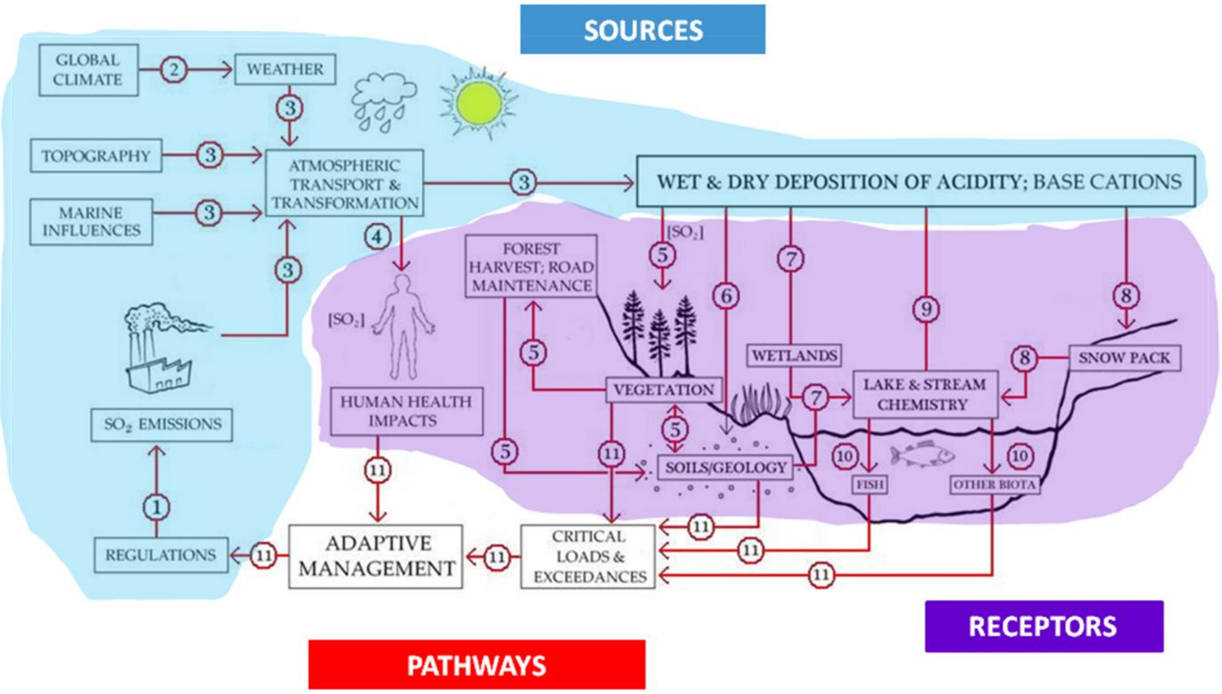


Figure 1. Source-Pathway-Receptor model of SO_2 emissions in the environment, showing linkages between sources and receptors. (Source: Figure 3.1-1 from ESSA et al. 2013)

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 2016 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 2017 will be prepared in the spring of 2018.

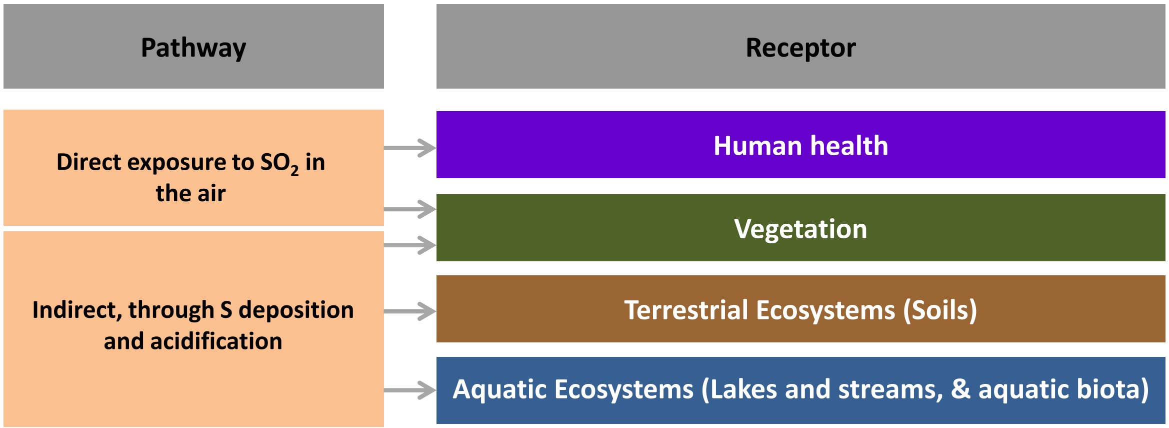


Figure 2. Framework for reporting on EEM activities.

2 Facility Production and Emissions

Metal production from the Kitimat smelter was higher in 2016 with the commissioning of all the new AP-4X pots. The last AP-4X pot was commissioned at the end of March. Over 2016, the modernized smelter was in a stabilization mode. Process stabilization is expected to continue into 2018. Despite not being at full steady-state condition, hot metal production reached 406 kt (Figure 3). During the 2016 stabilization period, emissions of SO_2 increased from the 8.3 t/d rate in 2015 to 27.8 t/d in 2016 (Figure 4).

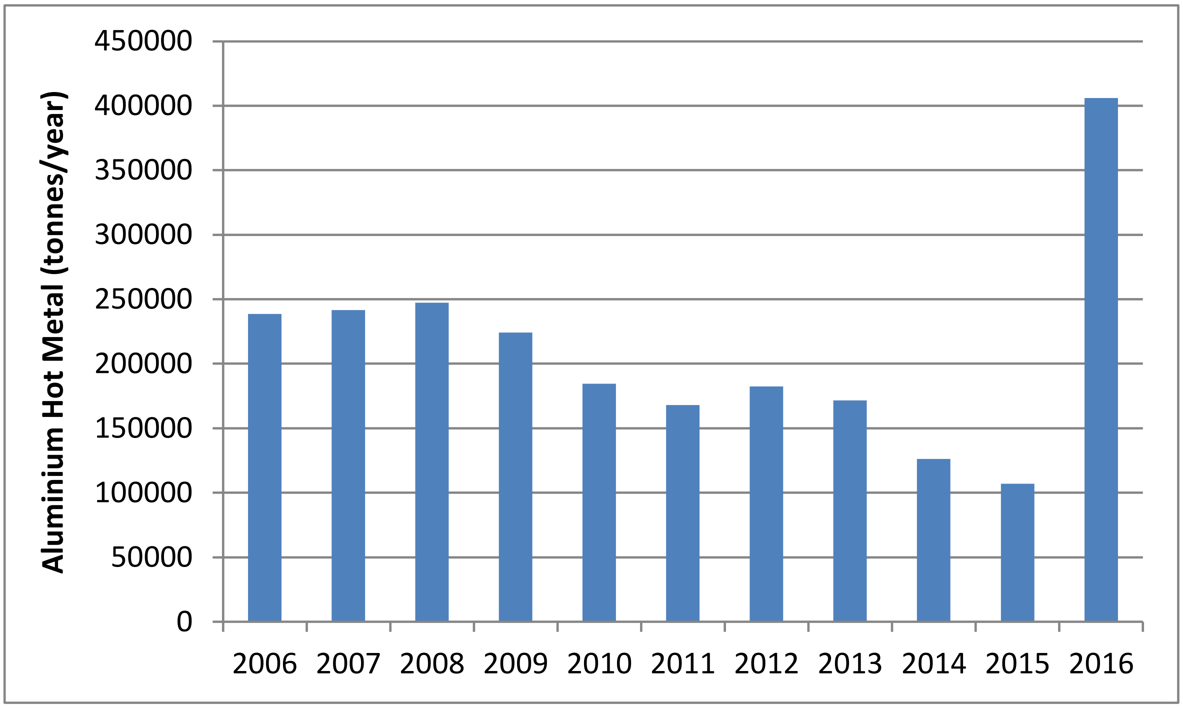
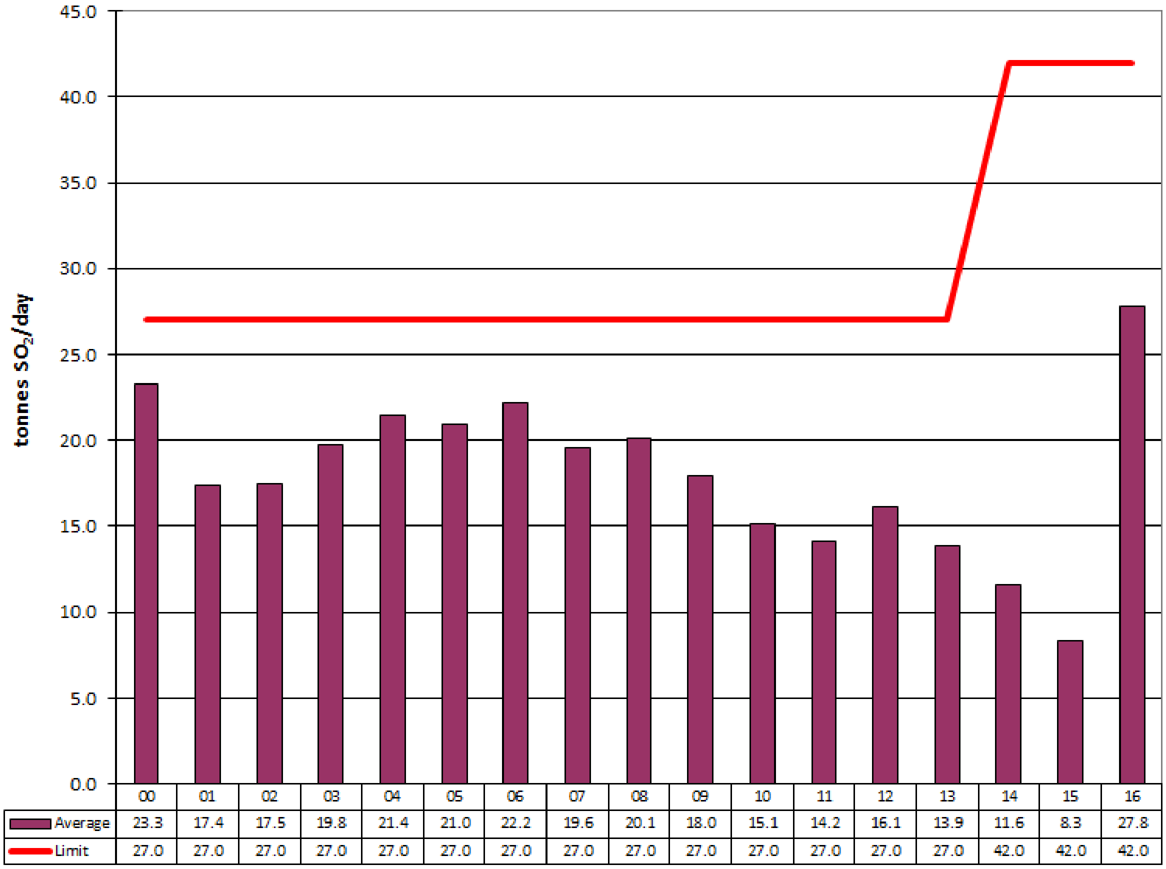


Figure 3. Annual hot metal production from the Kitimat smelter from 2006 to 2016. (Source: Rio Tinto)



	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
■ 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
▬ 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

Figure 4. Annual SO_2 emissions from the Kitimat smelter over the past 16 years. (Source: Rio Tinto)

3 EEM Activities

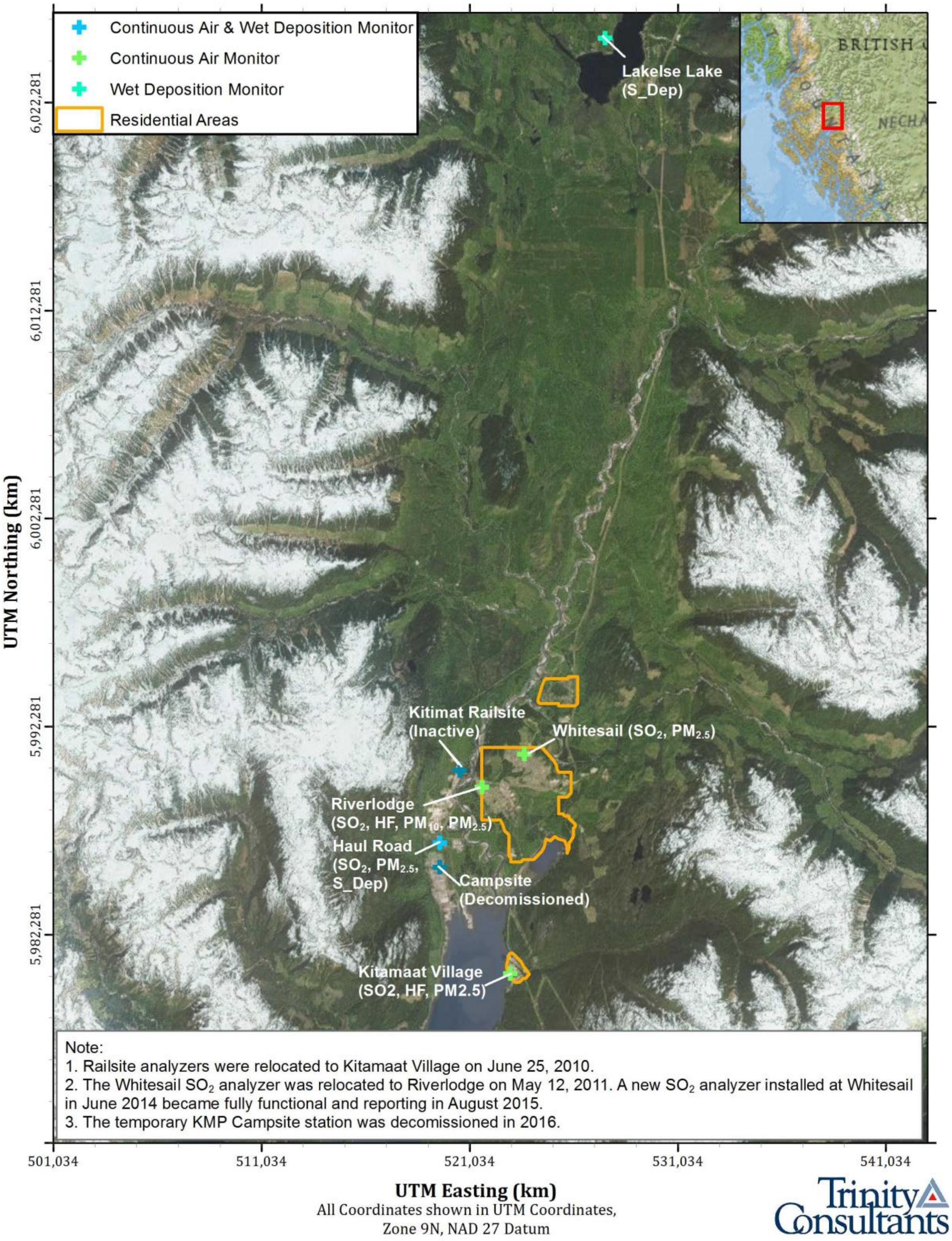
3.1 Atmospheric Pathways

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 5). All SO_2 analyzers passed BC MOE's audits and had greater than 90% data capture for SO_2 in 2016. 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 five continuous monitoring stations from 2013 through 2016, 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 7 shows a histogram depicting the relative frequency of hourly averaged concentrations of SO_2 at the Haul Road, Riverlodge and Kitamaat Village and KMP Camp sites. There is a relatively high frequency of low concentrations (below 4 ppb) and low frequency of higher concentrations.



Note:
1. Railsite analyzers were relocated to Kitamaat Village on June 25, 2010.
2. The Whitesail SO_2 analyzer was relocated to Riverlodge on May 12, 2011. A new SO_2 analyzer installed at Whitesail in June 2014 became fully functional and reporting in August 2015.
3. The temporary KMP Campsite station was decomissioned in 2016.

Figure 5. Locations of the four continuous SO_2 analysers (Haul Road, Whitesail, Riverlodge, Kitamaat Village).

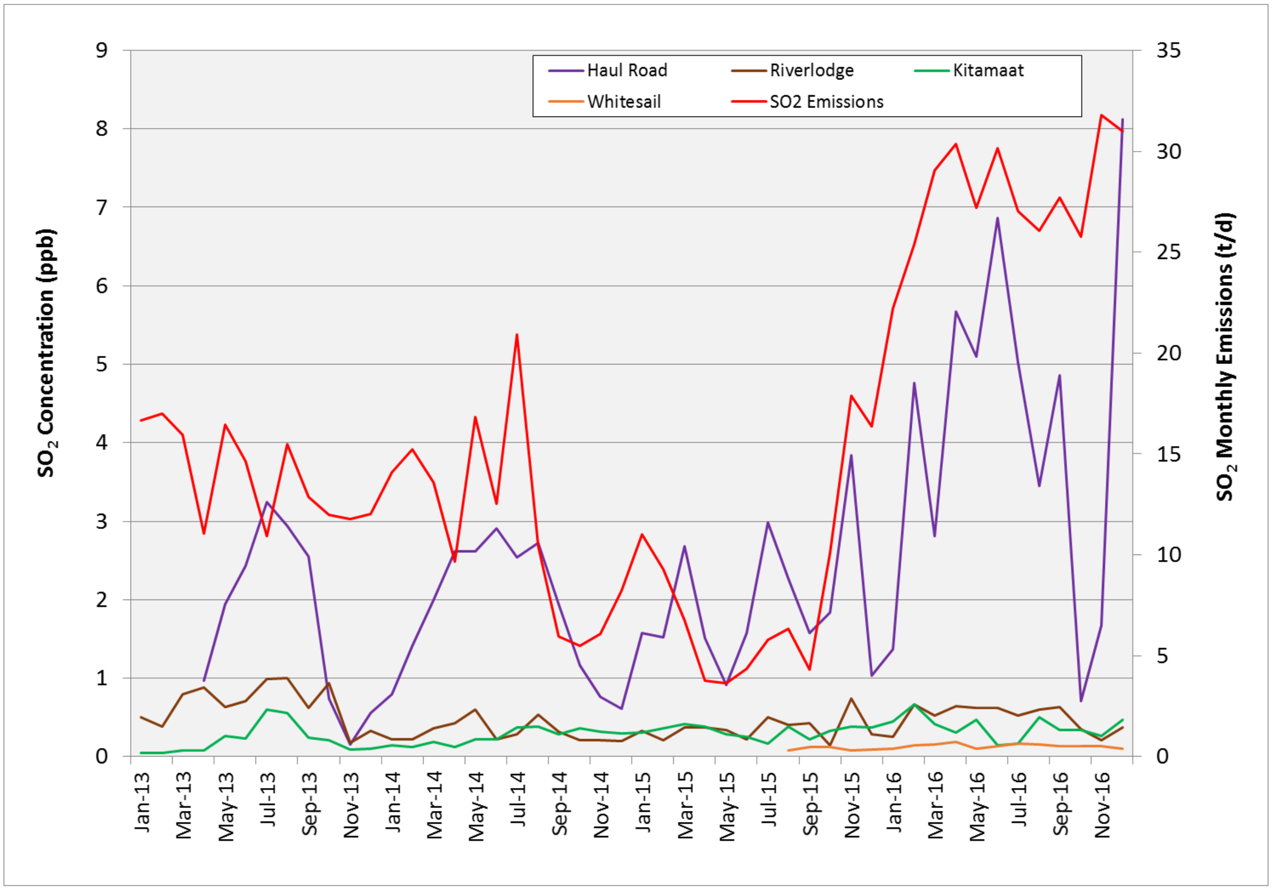


Figure 6. Monthly SO_2 emissions (red line) and monthly average ambient SO_2 concentrations at the four continuous monitoring stations (purple, brown, green and orange lines) for 2013 to 2016. (Source: Rio Tinto)

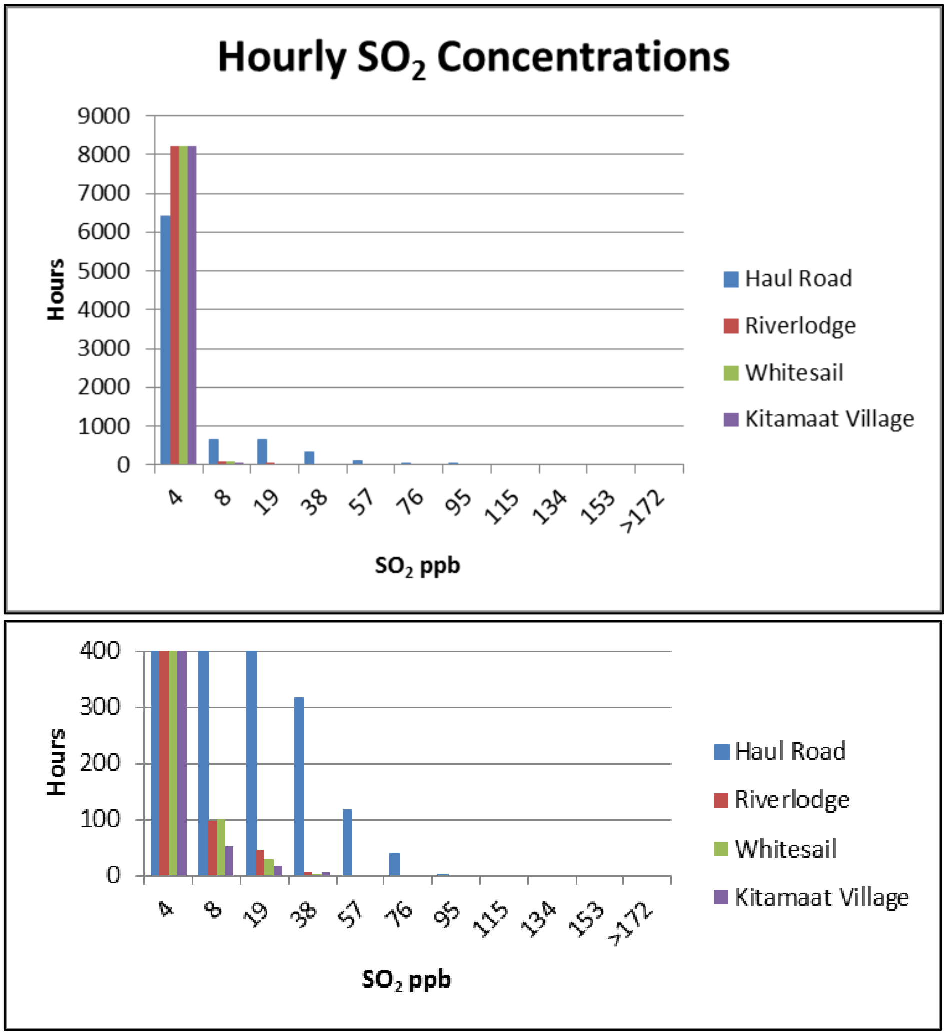


Figure 7. SO_2 hourly concentrations at the Haul Road, Riverlodge, Whitesail and Kitamaat Village continuous monitoring stations (top graph). The bottom graph zooms in on the subset of the data showing lower frequencies (400 hours and less) of higher concentrations. (Source: Rio Tinto)

Compare 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 2016 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 2016 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 for short-term averaging periods (1-hr and 3-hr), and at 83% of the maximum predicted concentration for the annual predicted concentrations. The maximum observed 24-hr average concentration was 25% higher than the maximum predicted concentration at Haul Road station. However, the maximum observed 24-hr average concentration at Haul Road was only 35% of the maximum predicted concentration at any offsite location. In residential areas, the maximum concentrations in 2016 were up to 26% 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 22% across the three residential monitors for the annual average. The 2016 emission rates (about 28 t/d) were 66% of the permitted level of 42 t/d. Put another way, the STAR predictions were based on 42 t/d, which is ~150% of the actual emissions in 2016. 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 1.5X higher than the observations. This is indeed the case in residential areas, as STAR predictions of maximum concentrations were about 4X the observations in residential areas. The notable exception are the 24-hr and annual concentrations at Haul Road. 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. 2016 Monitored Data Compared to Modelled Concentrations.

Monitor Location [1]	Averaging Period	2016 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	94.10	438.94	2006
Haul Road	3-hour	76.50	164.02	2006
Haul Road	24-hour	34.78	27.91	2008
Haul Road	Annual	4.22	5.06	2008
Kitamaat Village	1-hour	36.60	230.80	2009
Kitamaat Village	3-hour	15.47	97.43	2009
Kitamaat Village	24-hour	4.18	26.25	2009
Kitamaat Village	Annual	0.38	1.06	2009
Riverlodge	1-hour	31.80	213.34	2008
Riverlodge	3-hour	21.50	142.29	2008
Riverlodge	24-hour	9.39	28.48	2008
Riverlodge	Annual	0.50	3.16	2006
Whitesail	1-hour	37.00	144.63	2006
Whitesail	3-hour	19.50	107.92	2006
Whitesail	24-hour	4.16	43.68	2006
Whitesail	Annual	0.53	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 Haisla.

[2] 2016 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 93%, 95%, 95% 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).

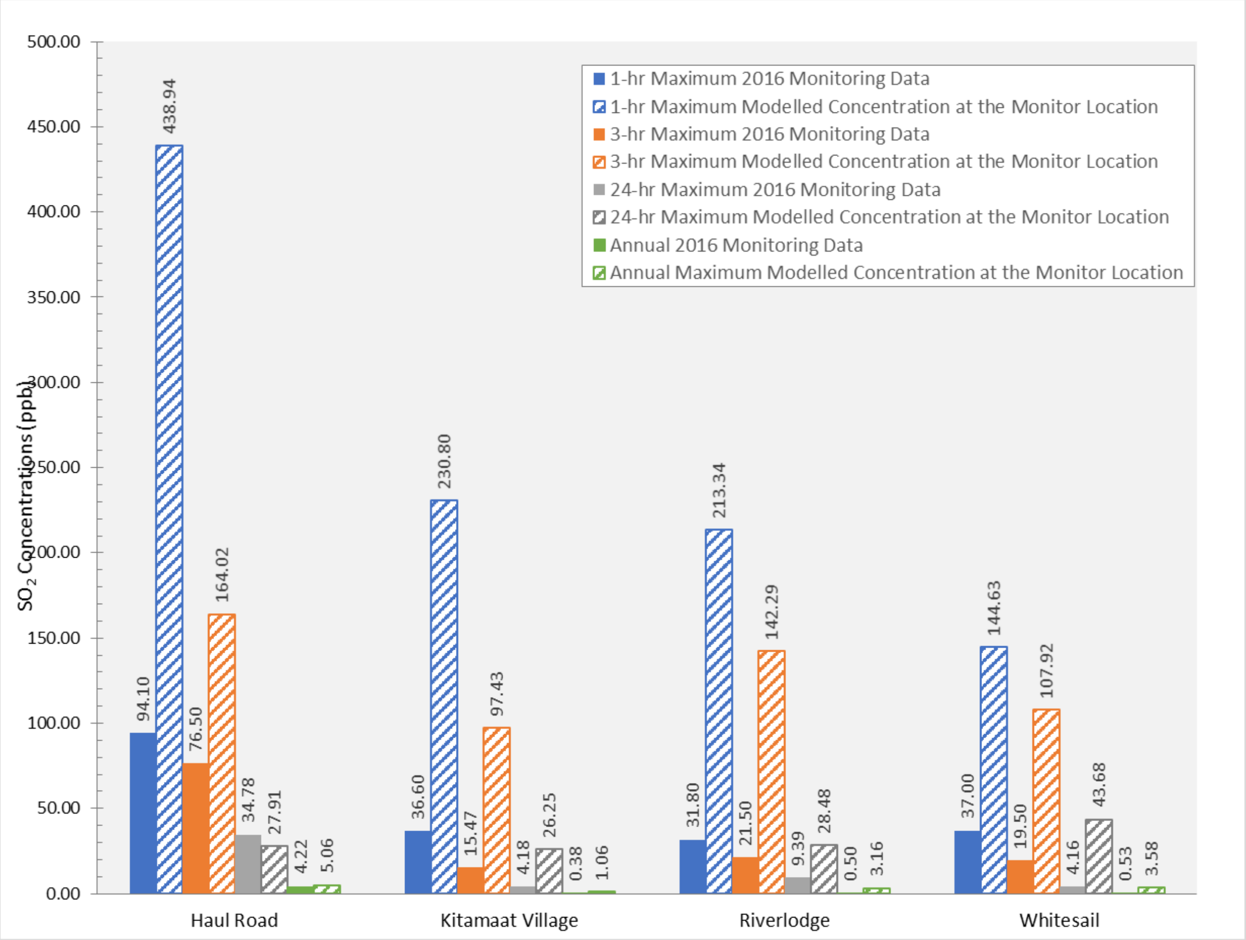


Figure 8. 2016 Monitored data compared to modelled concentrations. (Source: Rio Tinto)

Network Optimization

A two-day air quality workshop on “Optimization of the Ambient Air Quality Monitoring Network” was held on June 22-23 with the KPAC and representatives from the Northwest Hospital Advisory Board, Ministry of Health and BC MOE’s Clean Air Branch. The workshop covered the status of the Terrace – Kitimat air quality, how emissions are dispersed from the smelter, how air quality is monitored in Kitimat, and how to access air quality data from BC MOE. Additionally, input was sought from the workshop participants on the air station rationalization work and additional passive monitoring sites of interest (Tamburello and Alexander, 2016). The information from the workshop was used to help inform the passive monitoring network design by Trent University.

Questions have been raised over the seasonality aspects of Kitimat’s air quality. A three-year study will be conducted from 2017 to 2019. This study will be used to inform the rationalization project, which will be done in 2020.

Passive Sampling

Following on from the pilot study to evaluate the performance of passive diffusive SO_2 samplers (Technical Memo P03) a network of passive samplers was established in the Kitimat Valley during 2016. As recommended from the pilot study, the network employed IVL passive SO_2 samplers (URL: diffusivesampling.ivl.se) with an exposure period of one month (Technical Memo P04). The network was established on June 22–23, 2016 at 16 stations 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). On July 18, an additional site at Highway 37 and the Onion Lake Ski Trail was added to the network (Figure 9).

A second network was established during July 2016, following public consultation during the Kitimat Ambient Air Quality Monitoring Workshop, June 23–24, 2016 (Tamburello and Alexander 2016). The second network was established on July 18, with 15 stations located in urban and residential areas of Kitimat (Figure 9). During 2016, there were 110 sample exposures across both networks, with replicate samplers deployed during 30% of the time.

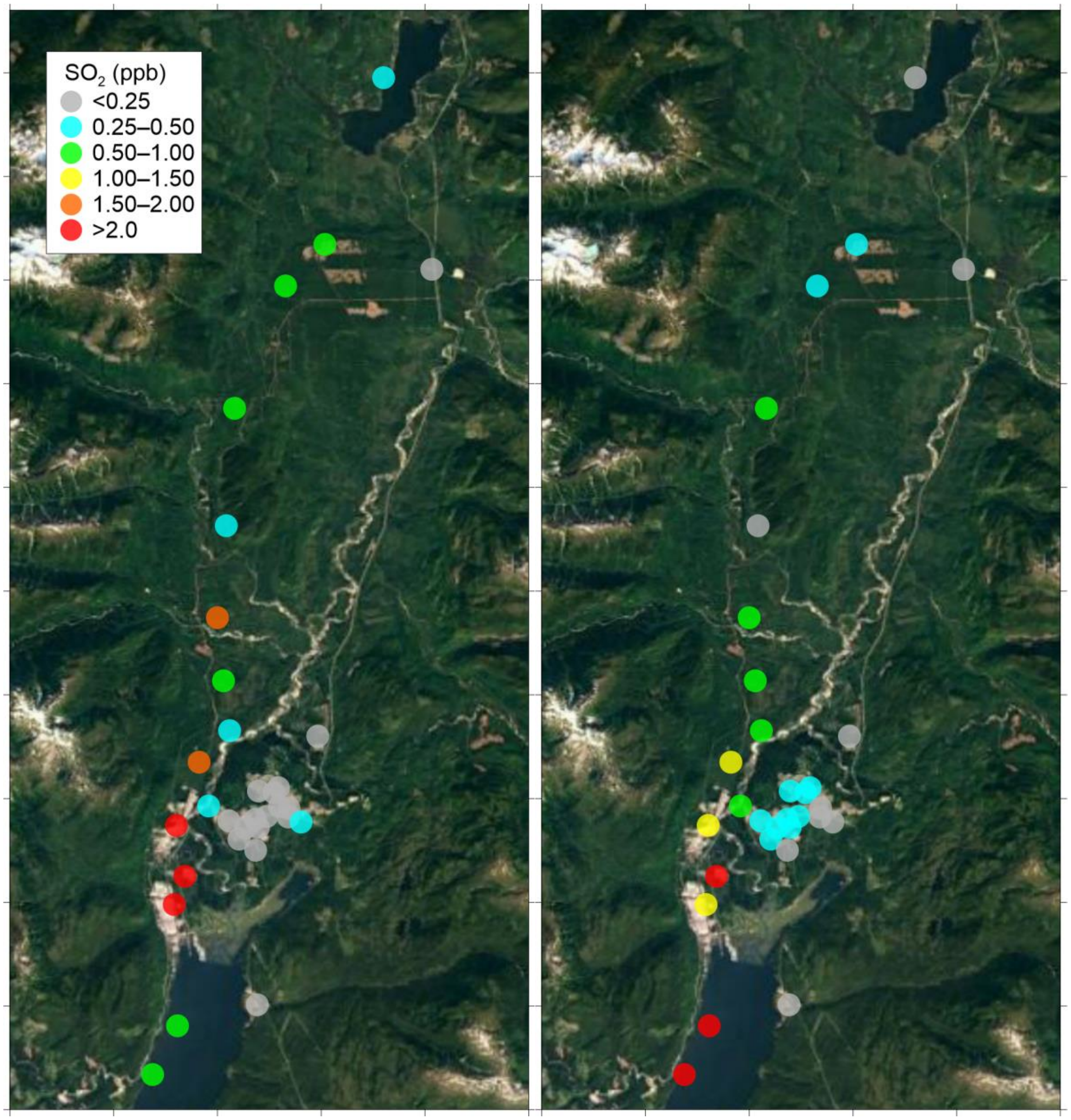


Figure 9. Average atmospheric sulphur dioxide (SO_2) concentration during June–August (left) and August–October (right) 2016 in the Kitimat Valley and urban passive diffusive monitoring networks. Note: monthly exposures under the Kitimat urban network started mid-July 2016. For further details on passive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

Four one-month exposures (June–October) were carried out under the valley network during 2016, and three one-month exposures (July–October) under the urban network. 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 Rife Range monitoring site during June-July 2016), and during August–October higher concentrations were observed south of Rio Tinto (concentrations >7 ppb were observed at Bish Road during September, 2016). In contrast, all monthly exposures under the urban network were consistently <0.5 ppb (Figure 9).

The 2016 results demonstrate the ability of the passive samplers to map out the plume path along the Kitimat Valley; it is recommended that deployments during 2017 attempt to further define the width and extent of the plume.

Wet Deposition

Figure 10 compares the amount of annual precipitation (mm) at the two precipitation chemistry monitoring stations during 2014 to 2016, and also compares annual precipitation at the Haul Road station from 2013 to 2016. Because the Lakelse Lake station was only in operation for part of 2013, data from that location are only shown for 2014 to 2016. 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 most likely reason for higher SO_4 and lower pH at Haul Road is that the concentration of SO_2 is higher at Haul Rd than at Lakelse Lake.

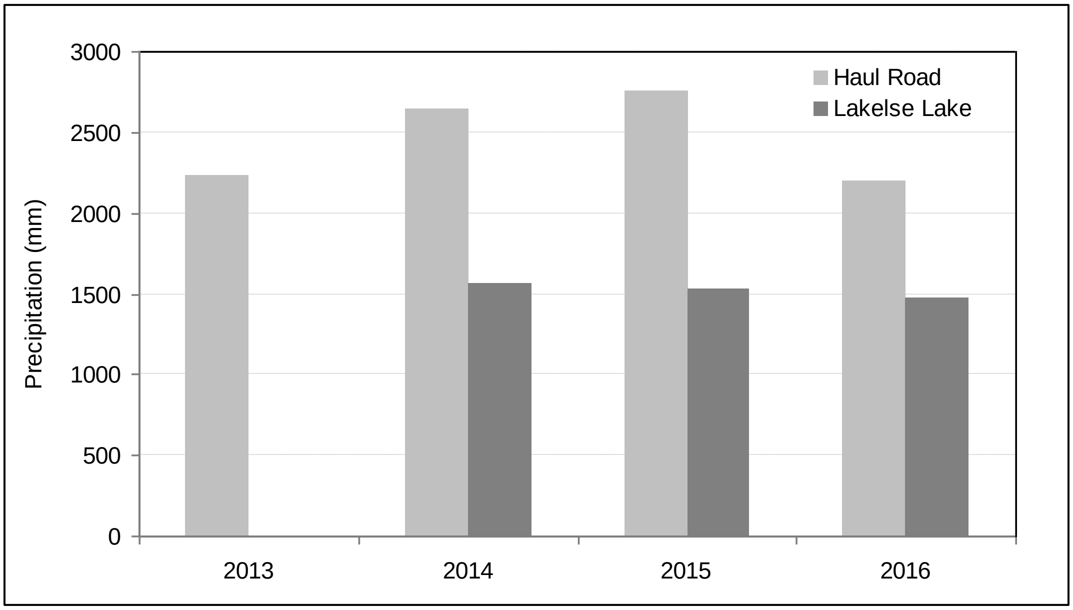


Figure 10. Annual precipitation volume (mm) from 2013 to 2016 at the Haul Road and Lakelse Lake precipitation chemistry monitoring stations (Source: NADP [URL: nadp.sws.uiuc.edu]).

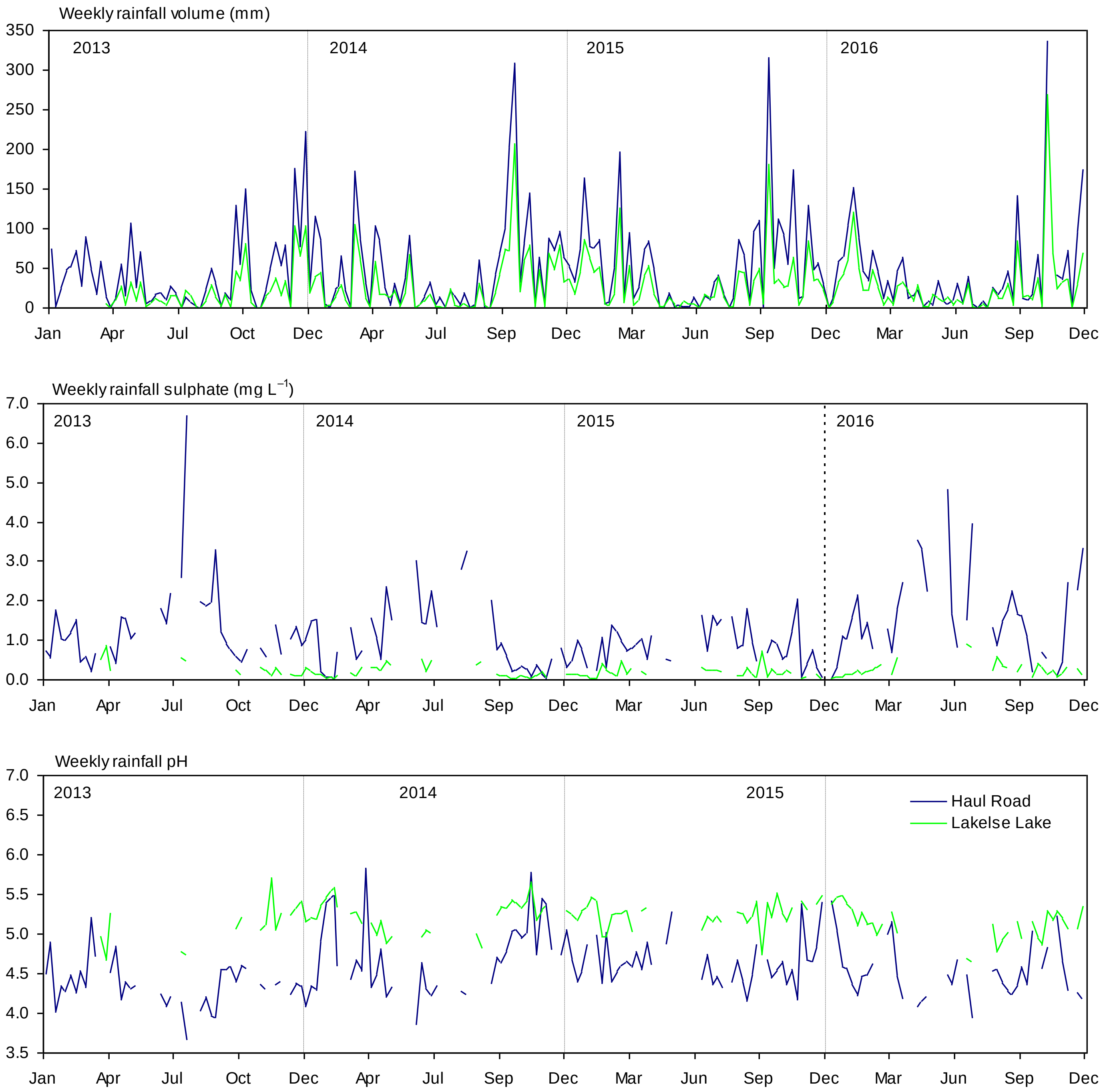


Figure 11. Weekly precipitation volume (mm) and chemistry (mg/L) at Haul Road (January 2013 to December 2016) and Lakelse Lake (April 2013–December 2016) showing inter-annual variation in precipitation volume (upper graph), sulphate concentration (middle graph) and precipitation pH (lower graph). Note: observations during the period 2013–2016 were revised using recent data obtained from NADP (URL: nadp.sws.uiuc.edu).

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 SO_2 and particulate sulphate (obtained from passive and active measurements) under the EEM Program 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 2017 to estimate dry deposition. Application of the dry deposition model was intended to occur in 2016, but will be done in to 2017 to accommodate acquisition of the required meteorological data from Prediction Services Operations West, Meteorological Services of Canada.

Preliminary estimates of dry deposition at Haul Road NAPD monitoring station from 2005 to the end of 2016 (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 high SO_2 emissions (Figure 12).

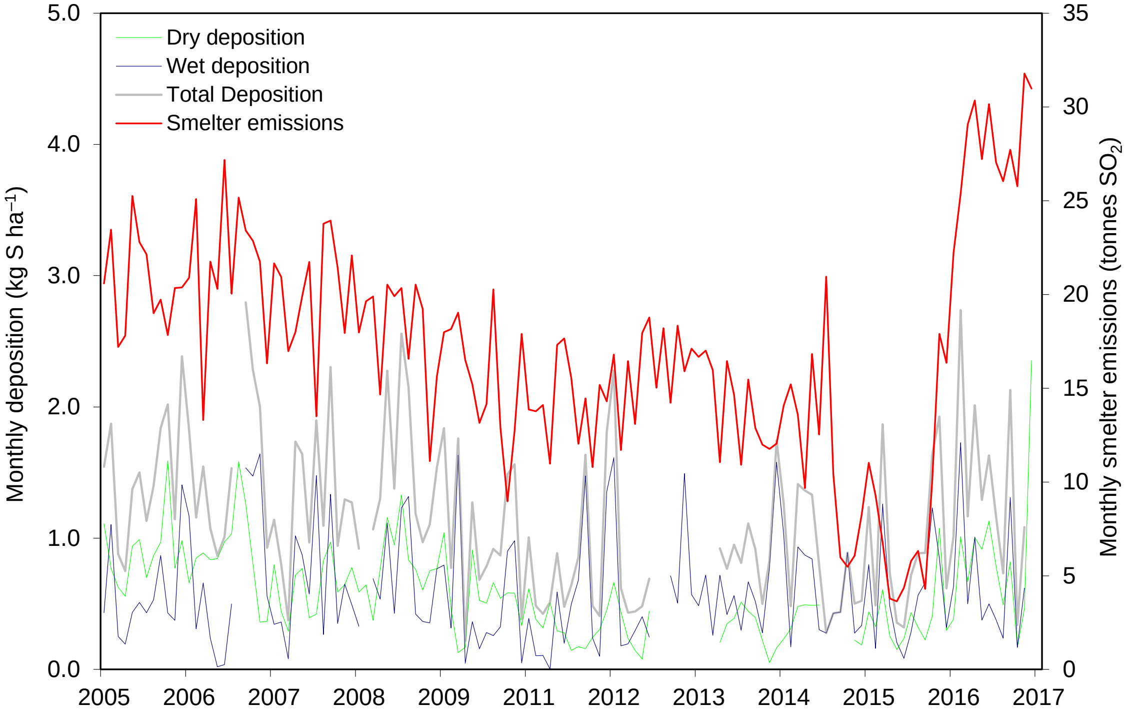


Figure 12. Long-term (2005–2016) monthly dry (green line) and wet (blue line) deposition of sulphur (kg S/ha), and smelter emissions of sulphur dioxide (red line; tonnes SO_2) at Haul Road.

3.2 Human Health

A province-wide interim SO_2 ambient air quality objective (AAQO) was adopted on December 15, 2016. This newly-adopted SO_2 AAQO will be 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 evaluated through the following protocol:

- At the end of 2017: Three-year average of 97th percentile of the maximum one-hour average SO_2 concentration measured in a 24 hr calendar day (D1HM) for 2015 – 2017
- At the end of 2018: Three-year average of 97.5th percentile of the D1HM for 2016 – 2018
- At the end of 2019: Three-year average of 98th percentile of the D1HM for 2017 – 2019
- At the end of 2020 and the end of each subsequent year: Three-year average of 99th percentile of the D1HM for that year and the two preceding 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.

Even though the SO_2 Health KPI will not apply to the SO_2 EEM Program until 2017, Table 2 provides an indication of how SO_2 concentrations in 2016 compare against the new KPI. For 2016, the calculations use the three-year average of the 97th percentile of the D1HM for 2014 – 2016.

Table 2. Calculation method and results for the SO_2 Health KPI in 2016.*

Station	97th percentile D1HM** SO_2 (ppb)			SO_2 Health KPI (ppb) (3-year average of 97th percentile D1HM**)	KPI Attainment / Non-Attainment
	2016	2015	2014		
Riverlodge	12.9	6.3	10.4	9.9	Attainment
Whitesail	11.3				
Kitamaat Village	8.4	7.8	4.3	6.8	Attainment

* Data for this table were extracted from the Envista database of the B.C. Ministry of Environment on January 31, 2017.

** Maximum one-hour average SO_2 concentration measured in a 24 hr calendar day

3.3 Vegetation

Vegetation Survey and Sampling

A visual inspection of vegetation in the vicinity of Rio Tinto was conducted from August 29-September 2, 2016. Sampling of western hemlock (*Tsuga heterophylla*) foliage was conducted by personnel from Stantec Consulting Ltd. concurrently with the inspection[2]. The inspection included a visual inspection of vegetation at established survey and sampling sites (Figure 13) for the symptoms of SO_2 injury, as well as other biotic and abiotic stresses that affect plants (i.e. diseases, insects, climate, physical disturbance, etc.). Western hemlock foliage was collected for analysis of sulphur (S) content at the same locations. Two additional inspection and sampling locations were added in 2016 at the request of BC MOE. Those sites, numbers 490 and 492, are located in the Williams Creek drainage, well outside the expected area of influence of Rio Tinto. A survey of residential areas in Kitimat and Kitamaat Village was conducted to document unusual conditions in ornamental vegetation if they existed.

No symptoms of visible injury due to SO_2 were observed at any site. No unusual conditions were observed in any of the residential areas visited. Residents of the area reported that the growing season started earlier than normal in 2016 and records from Environment Canada report growing season rainfall of about one-half the long-term mean, with August temperatures warmer than normal. Senescence seemed to be accelerated from what might be expected for the time of year in plants on dry, exposed sites throughout the area.

No significant insect infestations or disease outbreaks were observed in 2016. A minor infestation of hemlock woolly adelgid continues near Rio Tinto, but does not appear to extend south of Hospital Beach or north of the Service Centre. The incidence and severity is similar to that observed in 2015. Leaf rust (a fungal disease) of willow and poplar was observed at several locations throughout the area, but is not a concern at this time due to low incidence. More information on the inspection, including a list of plant species reported in the literature as being sensitive to SO_2 that were present at the 2016 inspection sites, can be found in the vegetation survey results report (Laurence 2016).

Foliar sulphur concentrations ranged from 0.05% at sites 54 and 57 to 0.13% at sites 44 and 44A. Compared to the historic site averages (calculated based on S concentrations from 1997-2014) foliar sulphur concentration in 2016 ranged from 0.01% greater (at Site 81C historic average=0.11% ± 0.03%) to 0.06% less (at Site 43B historic average=0.15% ± 0.04%). All other sites were at or below the historic average.

At sites furthest removed from the smelter—sites near Terrace (84, 85, and 86), the newly established sites (490 and 492), and site 95 near Kitamaat Village—S concentrations ranged from 0.06% TO 0.08%. S concentrations at the sites (except for 490 and 492 that were sampled for the first time in 2016) were at, or below historic averages, but within 1 standard deviation of the historic mean.

More information, including the results of the chemical analysis for each site, can be obtained in the 2016 Vegetation Inspection, Monitoring and Assessment Program report (Stantec 2017).

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[2] Site 44A, one of the sites accessed by helicopter, was not visited during the inspection due to safety concerns at the landing site. The landing site was subsequently improved and the sample was collected on October 11, 2016. No visual inspection was performed.

A meeting was held with available KPAC members and guests on September 1, 2016. Following a brief presentation and discussion of the inspection and sampling programme, a brief tour to inspect vegetation was conducted. Personnel from Stantec Consulting Ltd. demonstrated sampling and processing methodology.

The results of the vegetation inspection and sampling/analysis of western hemlock needles do not indicate a need for change based on the EEM plan with regard to the health of vegetation. No visible injury of SO_2 on vegetation was detected so the key performance indicator (KPI) of ‘visible vegetation injury caused by SO_2’ did not surpass the threshold for increased monitoring (or therefore, the threshold for facility-based mitigation). The indicators to be considered jointly with vegetation injury—atmospheric SO_2 concentrations, S content in hemlock needles, and atmospheric S deposition—support the conclusion that no change is warranted.

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 historic baseline concentration.

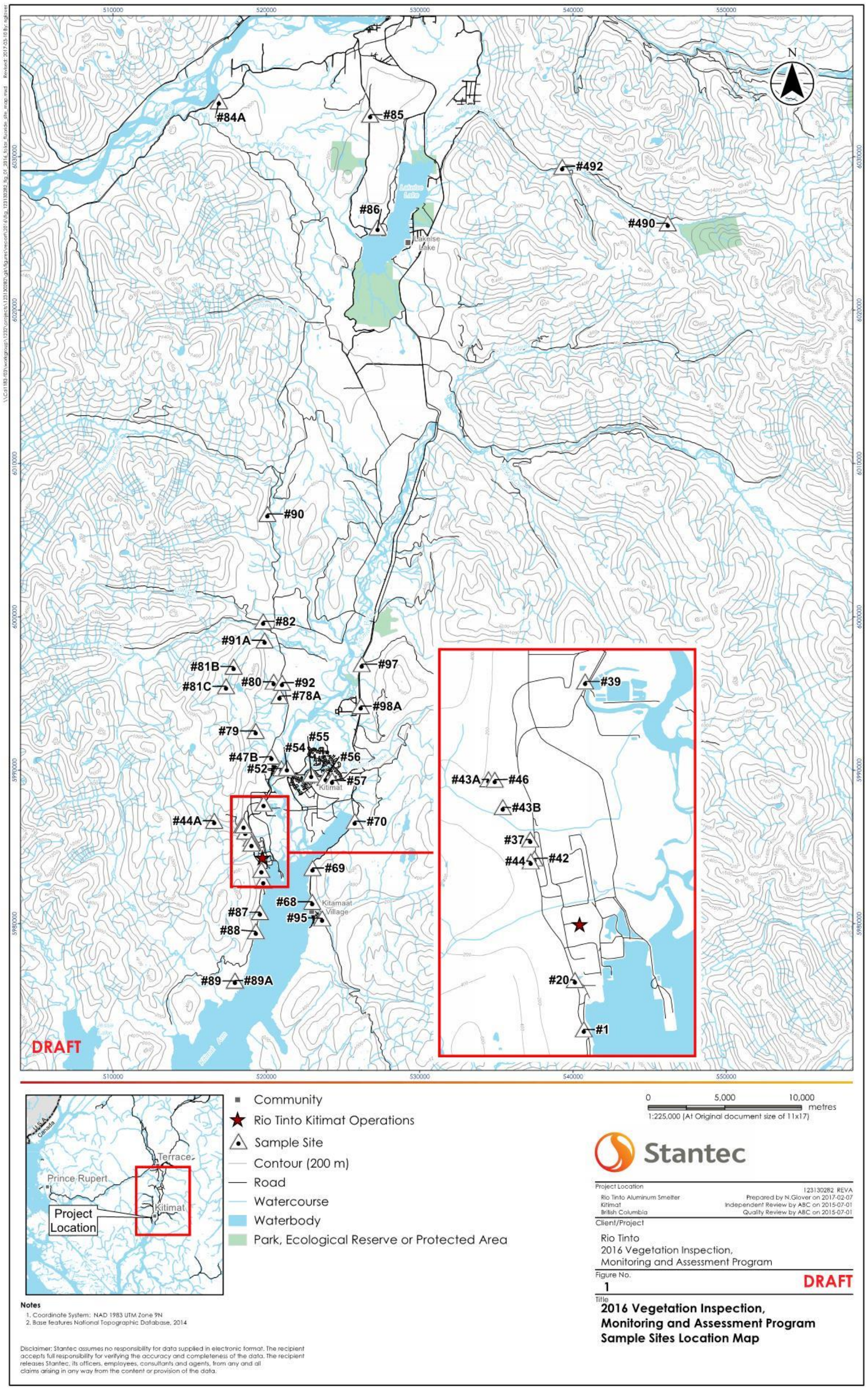

Figure 13. Location of vegetation sampling (denoted by triangles). (Source: Stantec 2017)

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 2017 to support the KPI of ‘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) and the Kitimat Airshed Emissions Effect Assessment (ESSA et al., 2014). Details are provided in Technical Memo S03. During summer 2016, supplemental soil sampling sites (n = 15; red filled-circles in Figure 14) were sampled to address critical uncertainties and data gaps identified under the STAR (ESSA et al., 2013; Technical Memo S02). Soil data for the determination and mapping of soil base cation weathering rates (a key determinant of critical loads) is available from 100 sites within the Kitimat Valley (Technical Memo S05), composed of soil samples physically collected from 78 sites during 2012–2017, following a consistent sampling and analysis protocol as described under the STAR (ESSA et al., 2013), and data for 22 sites obtained from LNG Canada (Technical Memo S05).). In general, soil sampling sites were randomly selected (see ESSA et al., 2013), rather than focused at existing vegetation plots. However, the soil data will be used to map soil information across the Kitimat (as described in Technical Memo S05).

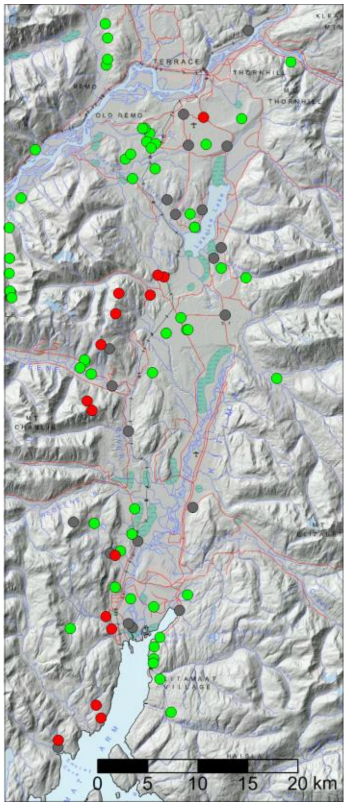

Figure 14. Location of soil sampling sites (n = 100) with observations of total element data for determination of soil base cation weathering rates within the Kitimat Valley. Soil samples were collected from 78 sites (green and red circles) during the period 2012–2017 (red circles n = 15, were collected during summer 2016); in addition soil data for another 22 sites (grey circles) were obtained from LNG Canada.

Permanent Soil Plots

During June–July 2016, the ‘background’ or ‘reference’ long-term soil monitoring plot was established at Kemano (latitude: 53.53032, longitude: –127.97384); in addition soil bulk density sampling and tree mapping were carried out at Lakelse Lake and Coho Flats, Kitimat Valley (Figure 15). 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). The primary objectives during 2016 were to: 1) establish the reference plot at Kemano (i.e., select locations and lay out the plot design), 2) to collect soil samples from each plot for bulk density determination, and 3) to map out tree species across all plots. At each location (Lakelse lake, Coho Flats and Kemano), primary and secondary (backup) plots have been established, and soils have been sampled for chemical analysis and bulk density (Technical Memo S06). Each plot (n = 6) 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 was 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 (yielding a total of 100 soil samples from each plot, ~600 soil samples in total sampled during 2015 and 2016). Every five years one grid will be randomly sampled, making a total of twelve sampling campaigns (for further details see Technical Memo S04).

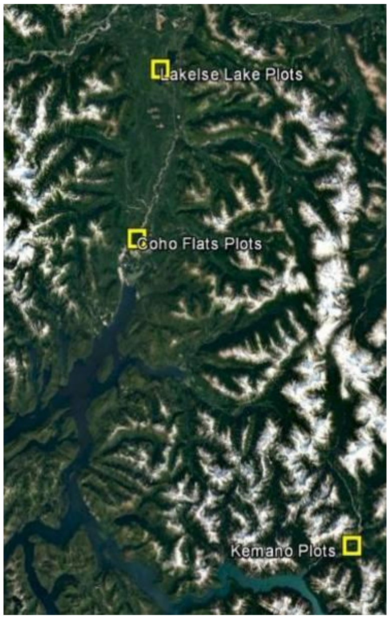

Figure 15. Location of the long-term soil monitoring plots at Lakelse Lake and Coho Flats in the Kitimat Valley, and the ‘background’ or ‘reference’ plot at Kemano. Note: primary and secondary [backup] plots were established at all three locations.

All soil samples (collected during 2015 and 2016) have been dried, sieved to < 2 mm and analysed for pH, organic matter content, and bulk density. In addition, tree species has been mapped for all plots (Figure 16). All primary plots are dominated by Western Hemlock (61% of plot DBH at Kemano, 44% at Lakelse Lake and 96% at Coho Flats; Figure 16). The total number of trees (> 10 cm DBH) on the primary plots were: 47 (Coho Flats), 69 (Kemano) and 108 (Lakelse Lake). During 2017, the soil samples at the primary plots will be analyzed for exchangeable base cations, exchangeable acidity, and all soils (from the primary and secondary plots) will be archived.

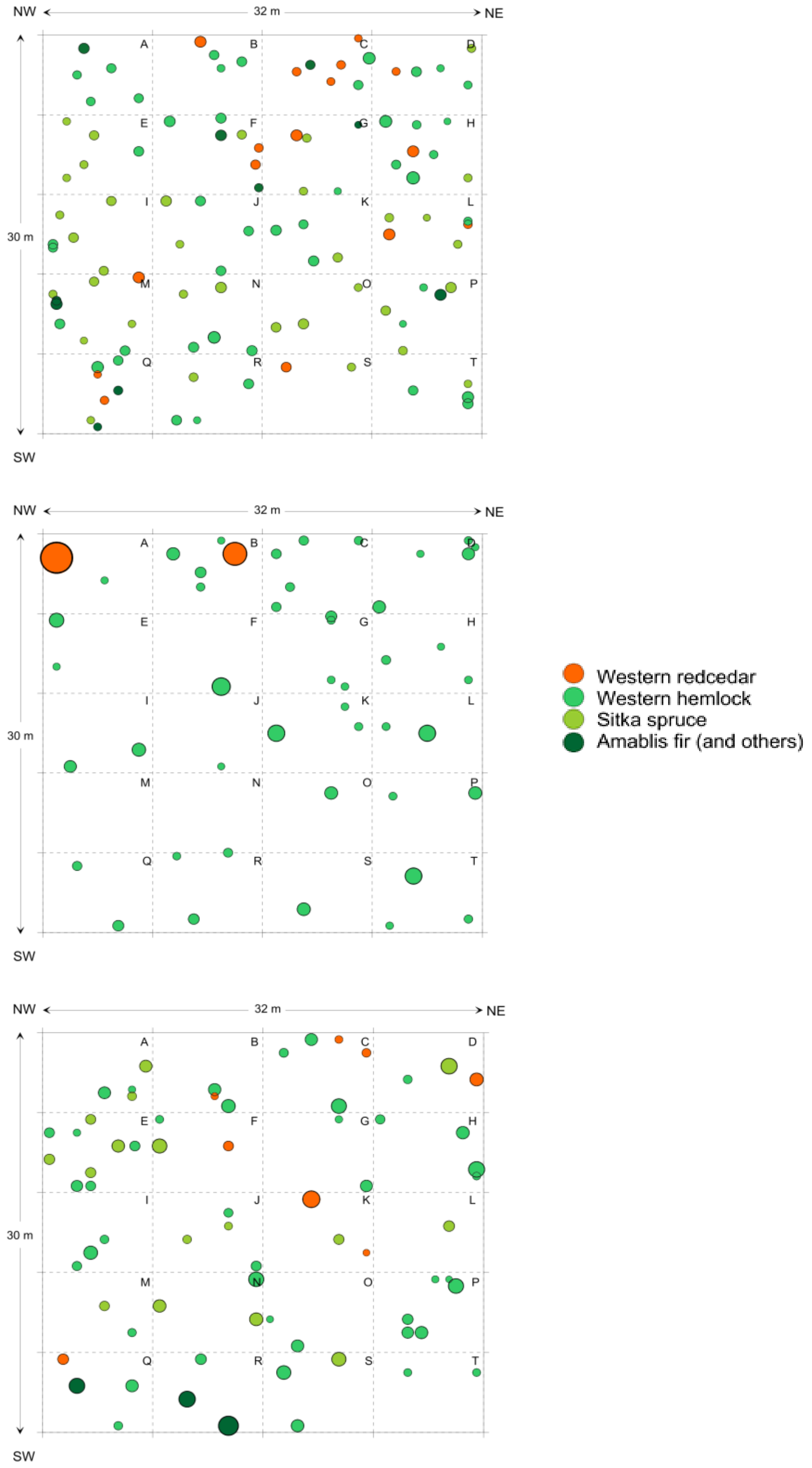

Figure 16. Layout of the primary long-term soil monitoring plots at Lakelse Lake (upper), Coho Flats Trail (middle), and Kemano (lower) showing the location and size of each tree species.

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 (W06). 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 2016

- 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 2017). Lakes included in the EEM Program, plus Lakelse Lake (sampled due to its public importance), are collectively referred to as “EEM lakes”.
- Examination of inter-annual changes in water chemistry between 2015 and 2016 (**Error! eference source not found.**).
- Intensive monitoring of pH in the three accessible sensitive EEM lakes for the third 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 2016 (as in 2015), continuous monitoring of pH began in the spring and was continued through the summer and fall.
- Within-season sampling was expanded 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 during October and early November.
- The three control lakes that were added to the EEM Program in 2015 were sampled again in October 2016. 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 pH monitoring in Anderson Creek was unsuccessful. In response to problems with the Manta monitor data in 2015, the monitor was removed – in 2016 it was set up alongside the Manta monitor in West Lake to test for instrument issues (Limnotek 2016). Rio Tinto had an independent continuous pH monitor in place in Anderson Creek during 2016; however, the instrument was not properly re-calibrated through the season and therefore the data were unusable due to measurement drift. In 2017, a Manta monitor was installed in Anderson creek for 4 weeks in 2017 to validate the Rio Tinto data from their Foxboro instrument which was installed in Anderson Creek in July 2017.
- Lake levels were monitored in End Lake, Little End Lake, and West Lake to provide an accurate, local measure of the timing of storm events, so as to better explain observed variation in pH (monitored continuously) and other water quality parameters of interest monitored during October (particularly sulphate, nitrate, DOC, ANC, and base cations).

These data can be used in future years to assess what chemical changes are associated with storm events.

- Amphibian monitoring. No actions were taken in 2016. Moving forward with the action to "provide support to existing local community groups who conduct annual amphibian monitoring" had been postponed and is presently being revisited. A literature review of acidification impacts on amphibians and potential pathways of effects is currently planned for 2017.

Knowledge Gained from Actions taken in 2016

- Inter-annual changes in water chemistry properties:
    - Changes in pH, ANC and SO_4^{2-} for 2015-2016, based on the annual samples, are shown in **Error! Reference source not found.**
    - Summary of observed changes between 2015 and 2016:
        - Increases in SO_4^{2-} concentration, which would be consistent with an increase SO_2 emissions, were observed in 7 EEM lakes
        - 4 lakes showed decreases in SO_4^{2-}, although some of these changes were quite small
        - ANC decreased in 6 of 7 sensitive EEM lakes and 3 of 4 less sensitive EEM lakes
        - 5 of 7 sensitive EEM lakes showed a change in ANC consistent with their observed change in SO_4^{2-}
            - The two exceptions had only small decreases in ANC associated with decreases in SO_4^{2-}, which does not provide strong evidence of a truly contrary pattern
            - The significant increase in SO_4^{2-} in LAK028 (56.7 μeq/L) was associated with an increase in base cations of 31.8 μeq/L, suggesting that about 56% of the deposited acidity was neutralized by cation exchange in the watershed. Overall, 72% of the sulphate-associated acidity deposited between 2015 and 2016 was neutralized, since Gran ANC only declined by 15.8 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 in some of the 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)
            - All of the seven sensitive EEM lakes still show a net pH increase or no change compared to pH measurements in 2012, though 5 of these values are ≤ 0.2 pH units (**Error! Reference source not found.**)
        - 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 all of the EEM lakes with change in ANC greater than 1% (i.e., 9 of 11 lakes)
        - Changes in base cations were variable across the EEM lakes (5 lakes decreased, 6 lakes increased)
        - All but one of the EEM lakes showed increases in DOC

        - Changes in chloride were variable across the EEM lakes (5 lakes decreased, 5 lakes decreased, and 1 lake did not change)
    - Changes in pH, ANC and SO_4^{2-} for 2012-2016, based on the annual samples, are shown in **Error! Reference source not found.**
        - 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 against a baseline that uses all of the pre-KMP monitoring data (i.e., 2012, 2013, 2014) and not just the values from 2012
        - LAK028 has shown little change in Gran ANC since 2012 (-0.9 μeq/L). The increase in SO_4^{2-} over 2012-2016 (70.9 μeq/L) is balanced by an increase in base cations of 68.7 μeq/L.
    - 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 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 3 control lakes showed minimal changes (i.e., ± 4%) in sulphate concentrations between 2015 and 2016, which provides initial confirmation that they are outside the area of deposition (a critical criterion for their suitability as 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 the period from April 10 to November 10, 2016, the pH varied by about 1.1 pH units in End Lake and by about 1.3 pH units in both Little End Lake and West Lake. The mean pH in all three lakes remained at 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 conclusions on the implications for the design of the EEM Program (i.e., 2013/2014 and/or 2015 EEM 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.

  - August and October pH values were compared for the three lakes with continuous pH monitoring, in the two years in which such monitoring was active in August (2015, 2016). 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 a preliminary 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 samples taken in October 2013 and October 2014 as an estimate of pre-KMP conditions. However, this analysis is only based on two years of sampling and should be repeated in subsequent years to confirm the finding.
- 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.
- Technical Appendix W06 provides further exploration of the observed changes in LAK028. LAK028 is examined in particular because the data and analyses from the STAR and EEM program thus far have suggested that it has the highest potential risk of acidification due to KMP. Some of the observations include:
  - Sulphate and ANC levels for LAK028 are comparable to those acid-sensitive lakes, except that LAK028 has slightly lower ANC than many of those lakes due to organic acids.
  - Base cations are increasing as SO_4^{2-} increases, neutralizing much of the H+ associated with the sulphate.
  - Two methods estimate the proportion of deposited acidity that was neutralized between 2015 and 2016
    - The comparison of changes in Gran ANC with changes in SO_4^{2-} suggests that 72% of the deposited acidity was neutralized (by various processes)
    - The estimated F-factor suggests that 56% of deposited acidity was neutralized specifically through increases in base cations
- Our preliminary conclusion is that the acidity contributed by increases in SO_4^{2-} over 2012-2016 appears to have been balanced by increases in base cations (as well as possibly other mechanisms such as sulphate reduction), and increases in DOC do not appear to have resulted in any further acidification.

Table 3. Changes in pH, ANC and SO_4^{2-} for EEM lakes, 2012[3]-2016.

	pH	**Gran ANC (µeq/L)**	**SO_4^{2-} * (µeq/L)**
From	2012	2012	2012
To	2016	2016	2016
LAK006	0.2	1.2	0.4
LAK012	0.6	8.8	3.4
LAK022	0.1	6.6	4.0
LAK023	0.2	8.1	-6.3
LAK028	0.0	-0.9	70.9
LAK042	0.7	34.4	-2.9
LAK044	0.1	2.8	-2.1
Total Lakes with Increase	**6**	**6**	**4**
Total Lakes with Decrease	**1**	**1**	**3**

LAK007	0.0	-69.0	-4.7
LAK016	0.3	25.2	5.9
LAK024	0.4	163.6	14.4
LAK034	-0.3	52.2	-24.1
Total Lakes with Increase	**2**	**3**	**2**
Total Lakes with Decrease	**2**	**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.

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[3] Note: As described in the text, these values simply represent the observed change over the period of record, but not an evaluation of the difference between the pre- and post-KMP periods (i.e., future comprehensive analyses will use a pre-KMP baseline based on monitoring data from 2012-2014 rather than just 2012).

Table 4. Changes in pH, ANC and SO_4^{2-} for EEM lakes, 2015 to 2016.

	pH	**Gran ANC (µeq/L)**	**SO_4^{2-}* (µeq/L)**
From	2015	2015	2015
To	2016	2016	2016
LAK006	0.0	-5.5	0.4
LAK012	0.3	-0.1	-8.0
LAK022	-0.1	-1.1	1.7
LAK023	0.0	-2.1	-2.4
LAK028	-0.2	-15.7	56.7
LAK042	0.0	0.2	-0.5
LAK044	-0.2	-2.1	0.4
Total Lakes with Increase	**1**	**1**	**4**
Total Lakes with Decrease	**6**	**6**	**3**

LAK007	0.0	-197.0	1.1
LAK016	-0.2	-19.2	4.0
LAK024	0.1	20.1	4.5
LAK034	-0.1	-26.2	-0.9
Total Lakes with Increase	**1**	**1**	**3**
Total Lakes with Decrease	**3**	**3**	**1**

* 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 2017 sampling plan should follow the 2016 sampling plan. Changes that were implemented in 2016 were justified based on recommendations in the 2015 EEM Annual Report, which still hold. No additional changes are recommended at this time. Additional information on within-season variability in lake chemistry for LAK028, LAK042 and LAK044 will be valuable for analyzing trends over time, as will continued sampling of the control lakes, and the intensively monitored lakes.

Some of the reviews of this year's report have suggested some additional analyses that should be considered in future years. The primary analysis of interest will be comparisons (in the 2019 report) of observed changes in pH and ANC to the thresholds of interest. The EEM report (ESSA et al. 2014b, 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 recommend that the lab reports from all past lake samples be retrieved from Trent University in 2018, and used to estimate the mean ANC threshold (and its variation) for each EEM lake. Other secondary analyses suggested by the KPAC will also be explored in future years. In addition, we recommend an exploration of the potential role of sulphate reduction in LAK028, applying simple models from the literature based on estimated runoff, depth, watershed area and lake area.

4 Cited Reports

Bennett, S. and C.J. Perrin. 2017. Rio Tinto Alcan Kitimat Modernization Project: Environmental Effects Monitoring of Lakes in 2016. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Alcan Ltd. 40 pp plus Appendices.

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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 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 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 S05. Steady-State Soil Modelling – Supplemental Soil Sampling (March 2017, Trent University)

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

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