Sulphur Dioxide Environmental Effects Monitoring
2018 Annual Report

RioTinto

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ESSA

Trinity Consultants

RSI
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LIMNOTEK

Outline of Presentation

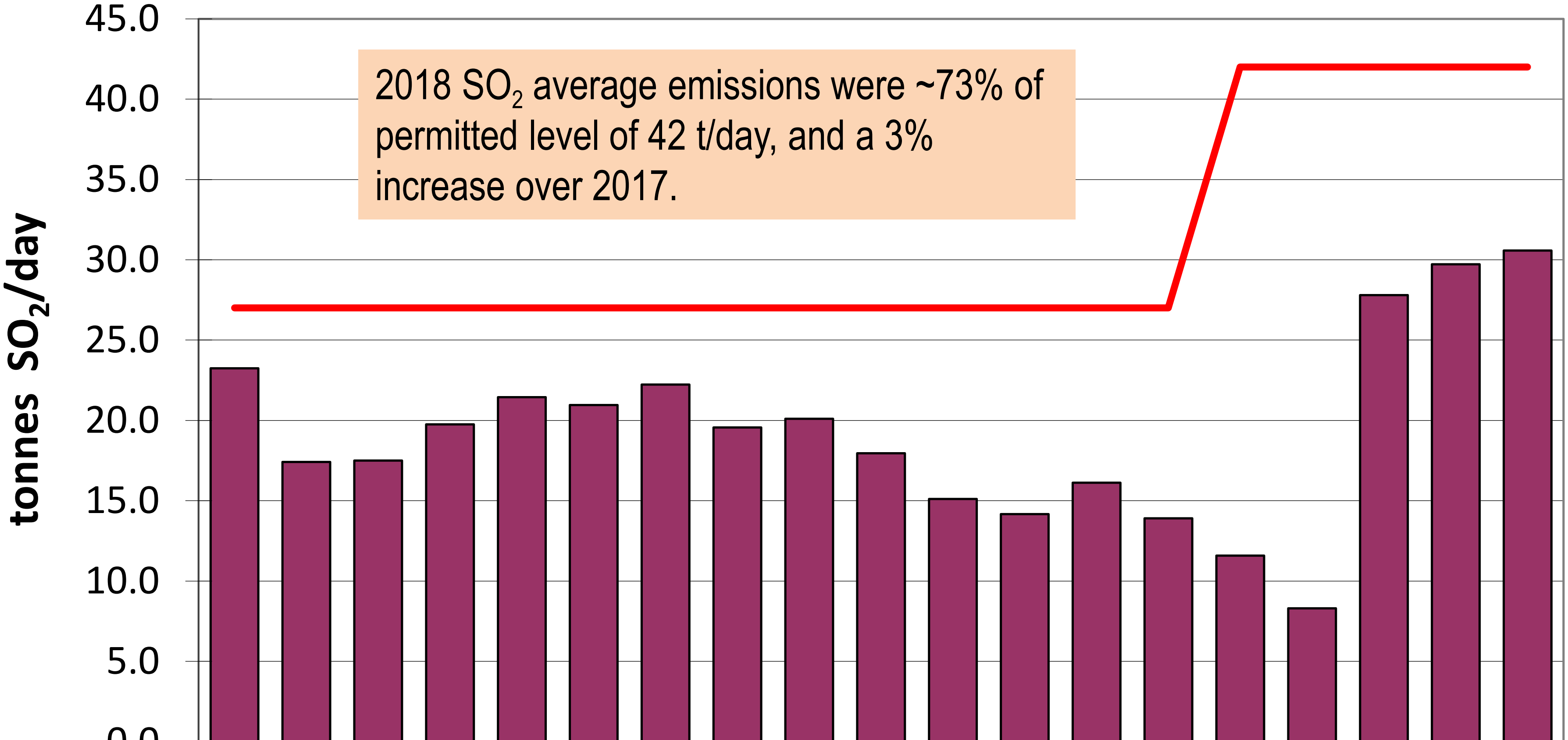
What we did and learned in 2018, and what's next

a. Atmospheric Pathways
b. Human Health
c. Vegetation
d. Terrestrial Ecosystems (Soils)
e. Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)

Facility Production and Emissions

Updated data from Rio Tinto

Average daily SO_2 emissions from Kitimat Smelter



	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
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	30.6
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	42.0

a. Atmospheric Pathways – *What We Did*

2018 EEM Actions [presented by Anna Henolson]

Topic	The commitment	What was done
Atmospheric Pathways		
Atmospheric SO_2 concentration	Maintain existing four continuous SO_2 analyzers 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. Conducted phase 1 network rationalization study. Phase 2 study based on 2016-2018 model data and multi-seasonal air quality study is underway.

a. Atmospheric Pathways – *What We Did*

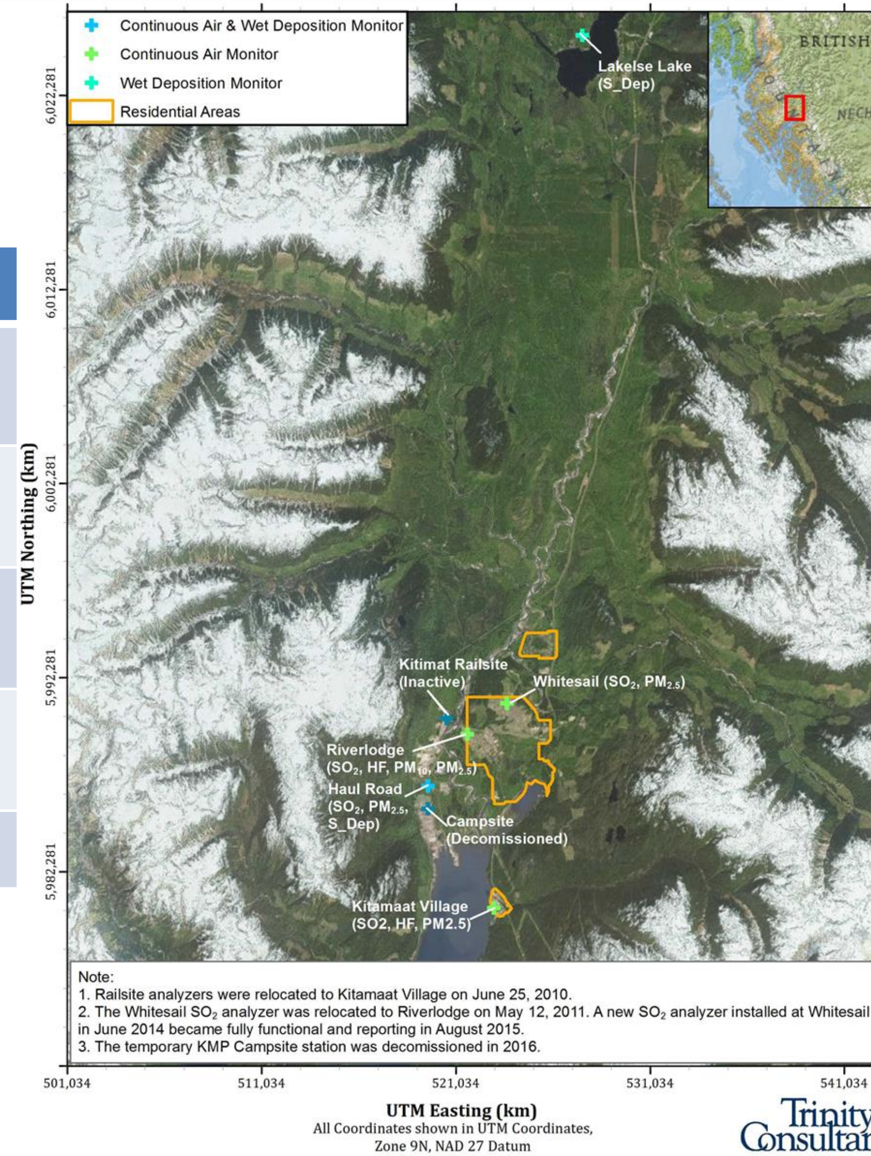
2018 EEM Actions [presented by Julian Aherne]

Topic	The commitment	What was done
Atmospheric Pathways		
Atmospheric SO_2 concentration	Continue the passive SO_2 monitoring program	Passive samplers were deployed in the Kitimat valley during June to October 2018
	Urban passive SO_2 monitoring program under 'Network Optimization'	Passive samplers being deployed for one year (2018–2019) in urban areas
	Monitor particulate SO_4	Filter packs deployed during two campaigns during February and June 2018 at 4–8 sites
	Wet deposition	Precipitation chemistry stations maintained at Haul Road and Lakelse Lake during 2018, with data provided by the NADP
	Dry deposition	Hourly dry velocities were modelled during 2015–2018 for two study areas: Kitimat and Terrace Airport

a. Atmospheric Pathways – *What We Did*

Monitoring Locations

Site	SO_2	HF	PM_{10}	$PM_{2.5}$	S_Dep	PAH
Haul Road (fenceline)	X			X	X	X
Riverlodge (lower Kitimat)	X	X	X	X		
Whitesail (upper Kitimat)	X			X		X
Kitamaat Village	X	X		X		X
Lakelse Lake	X				X	



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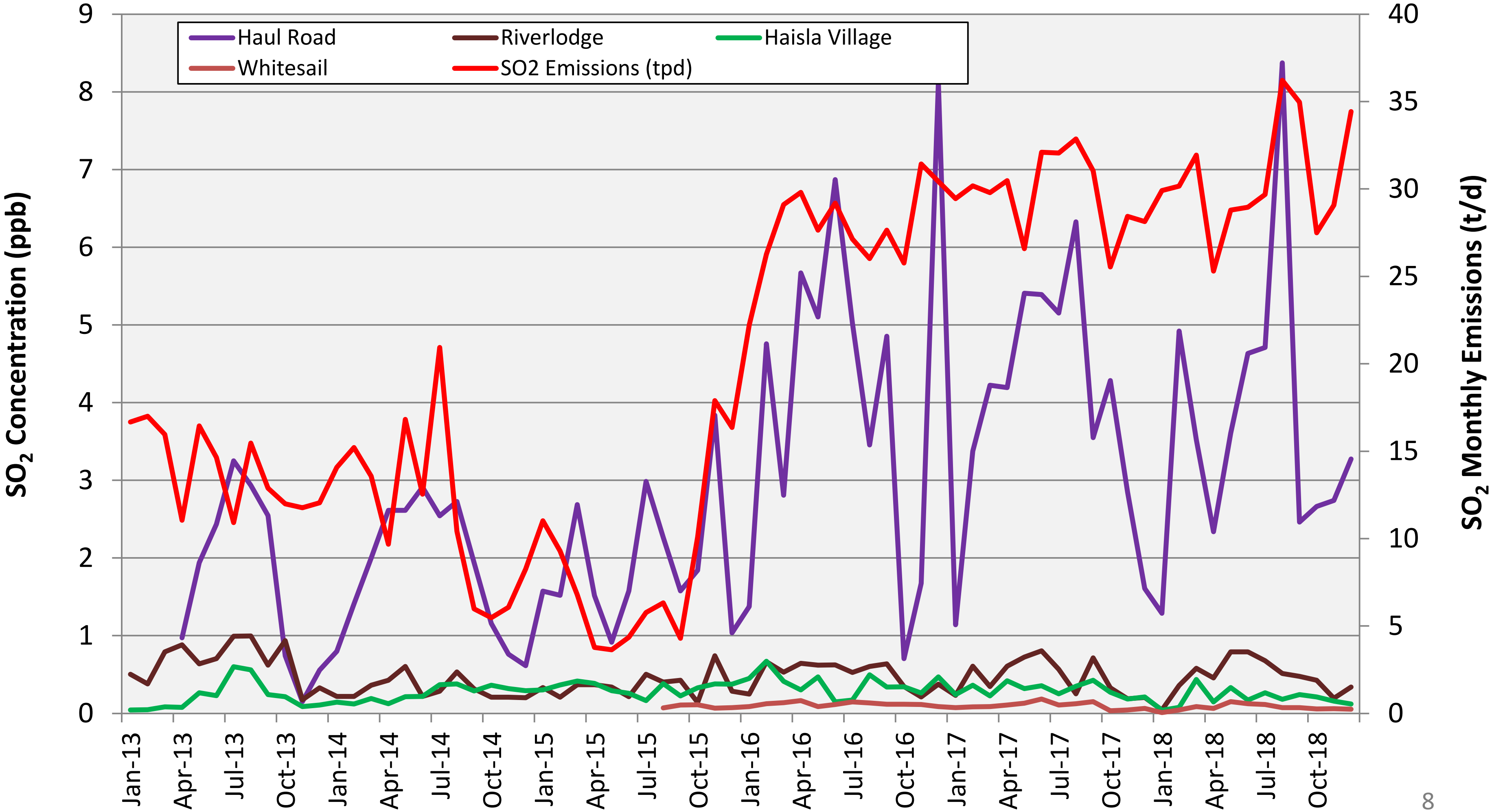
a. Atmospheric Pathways – *What We Did*

SO_2 Concentrations

- Four continuous analyzers
  - Haul Road, Riverlodge, Whitesail, Kitamaat Village
  - All passed BC MOE audits
  - All had >90% data capture
- Also installed Lakelse Lake analyzer in 2018
- Will have a mobile monitoring station in 2019
- Passive samplers provide other valuable data

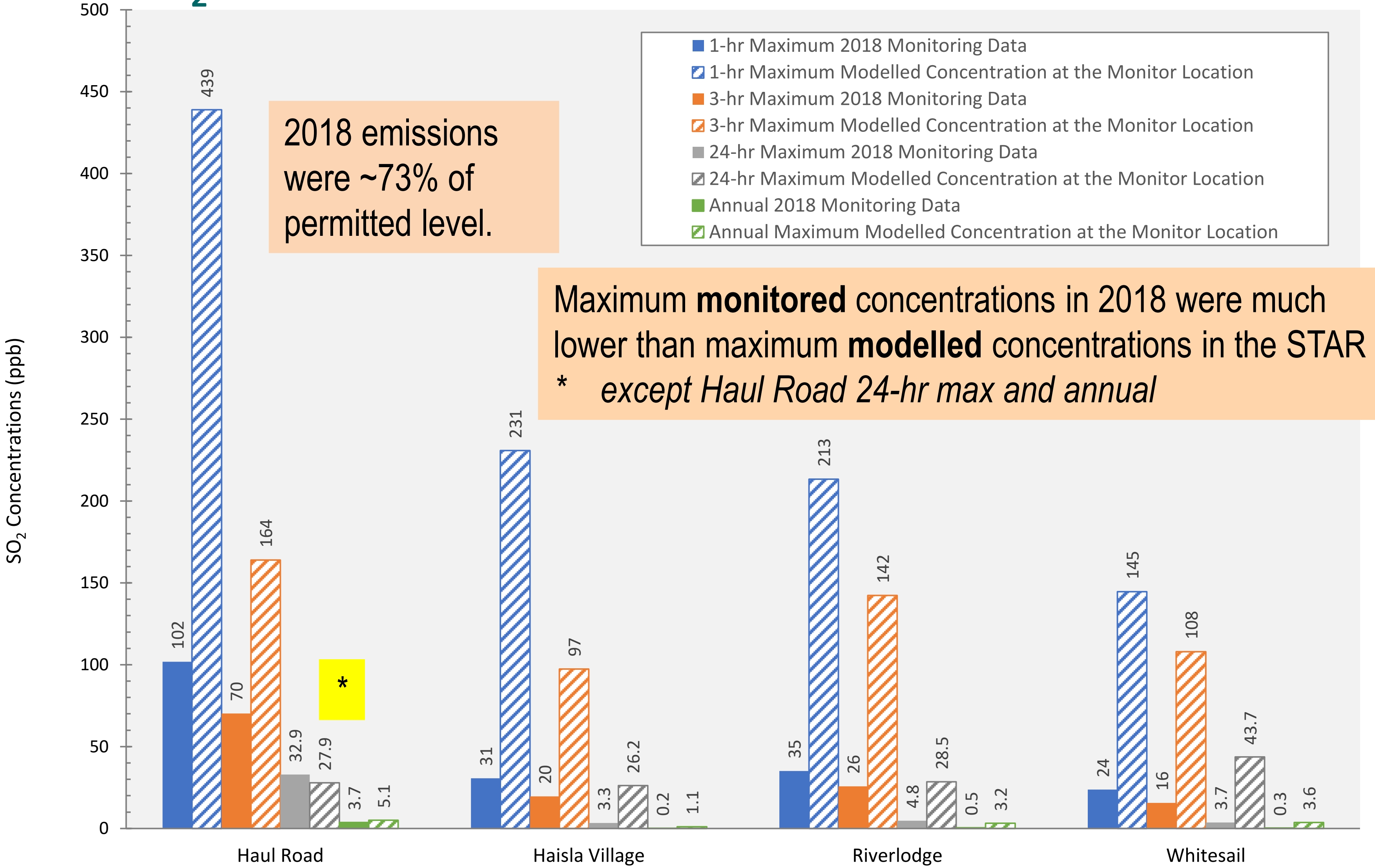
a. Atmospheric Pathways – *What We Learned*

Monthly Avg. [SO_2] and Total SO_2 Emissions



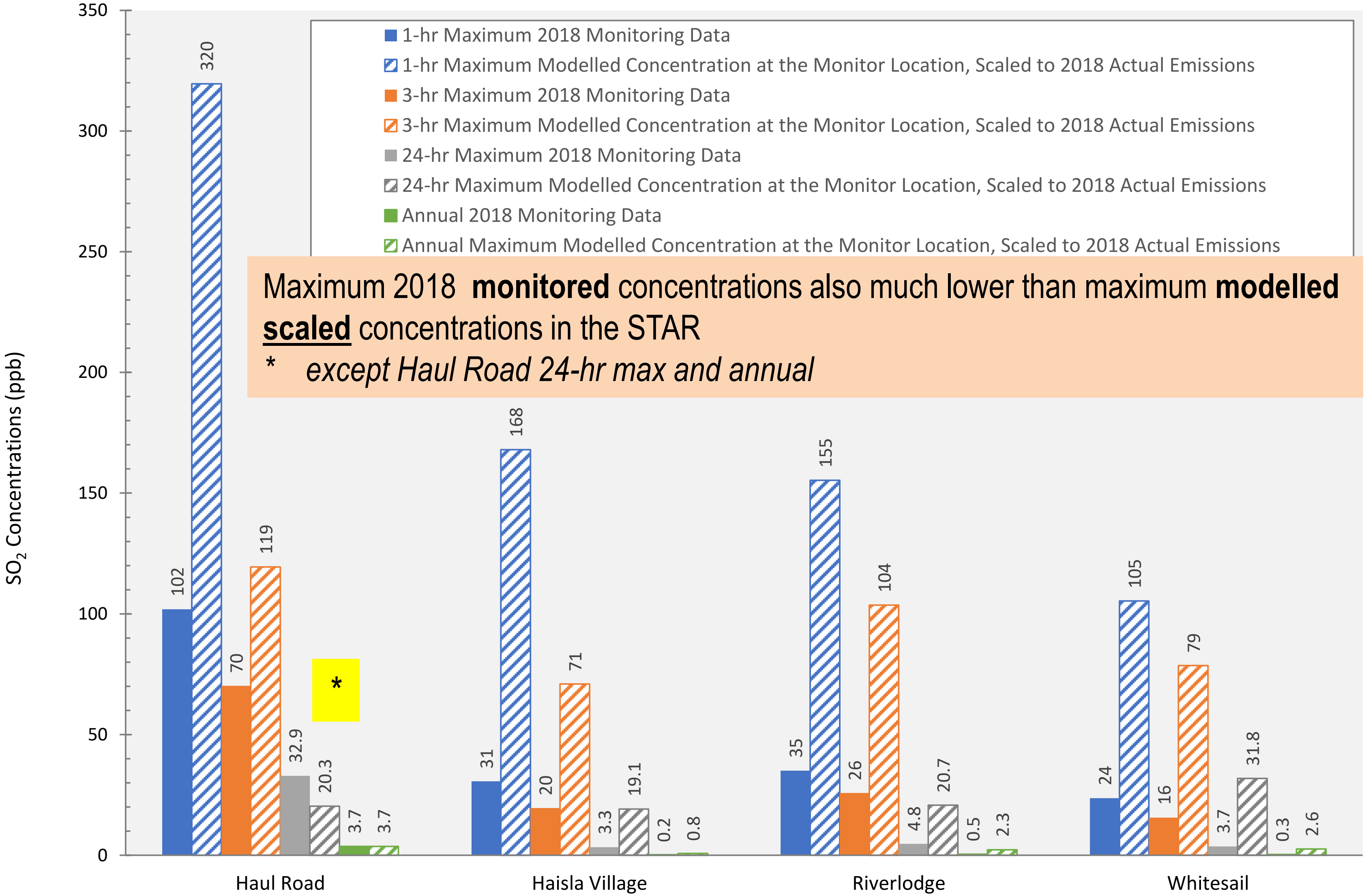
a. Atmospheric Pathways – *What We Learned*

2018 SO_2 Concentrations – Monitored vs. Modelled



a. Atmospheric Pathways – *What We Learned*

2018 SO_2 Concentrations – Monitored vs. Scaled (73%) Modelled



a. Atmospheric Pathways - *What We Learned*

2018 SO_2 Concentrations – Monitored vs. Modelled

- Residential areas
  - Short-term: max observed SO_2 < 20% of max modelled SO_2 (1-hr, 3-hr, 24-hr); 28% when adjusted to actual emission levels
  - Annual: observed SO_2 (across 3 residential monitors) averaged 14% of modelled predictions; 20% when adjusted to actual emission levels

- Haul Road
  - 1-hr/3-hr: max. 2018 observation <50% of max. modelled predictions
  - 24-hr: maximum 2018 observation was 118% of max. modelled
  - Annual: observed SO_2 was 73% of modelled prediction
  - Maximum observed SO_2 much closer to modelled (for annual and 24-hr time periods) at Haul Road than at residential areas

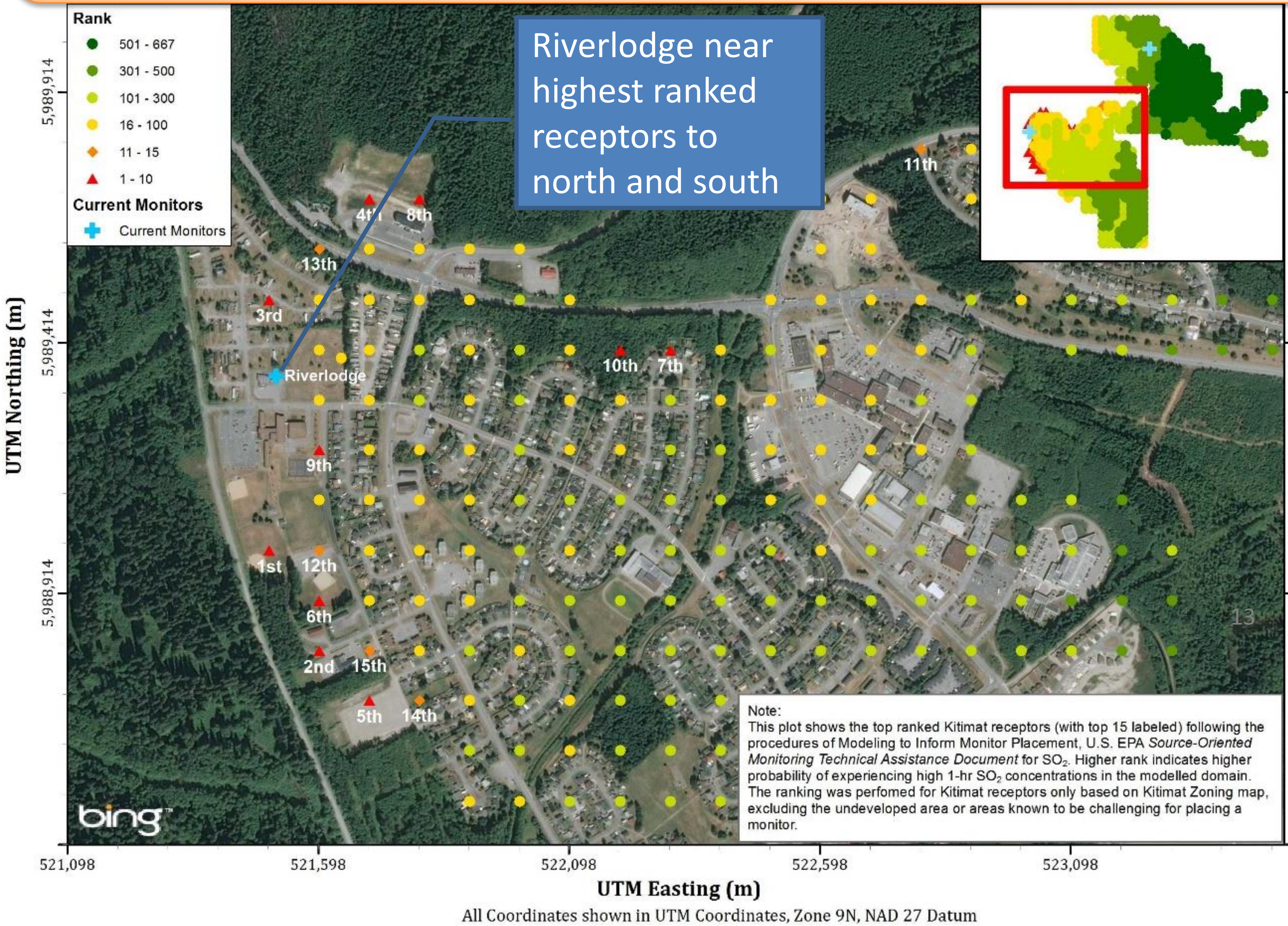
a. Atmospheric Pathways - *What We Learned*

Network Optimization – Phase 1

- Network evaluation completed to meet SO_2 EEM commitment, based on available data:
  - 2006, 08, 09 No MM5 Model results
  - Post-KMP Monitoring data (continuous and passive sampling)
- Concludes Riverlodge & Kitamaat Village stations in good locations to continue to represent highest SO_2 levels in respective areas

a. Atmospheric Pathways - *What We Learned*

Riverlodge near highest ranked receptors to north and south



a. Atmospheric Pathways - *What We Learned*

Second Phase Network Optimization

- New dispersion modeling with 3 years post-KMP meteorology
- Supported with actual air quality measurements in **multi-seasonal air quality study**
- Draft Terms of Reference for network optimization being updated (draft submitted April 12, 2019 to ENV), to include:
  - Multi-seasonal air quality study
  - Comments from June 2016 air quality workshop
  - How study's exploratory monitoring will be used

  * Will send Second Phase Network Optimization ToR to KPAC for review

a. Atmospheric Pathways - *What's Next*

Multi-Seasonal Air Quality Study

- Supports Phase 2 of Network Optimization
- Will include robust analysis of data from:
  - Existing continuous monitors
  - Exploratory monitoring
  - Roaming station
  - Passive monitoring
- Will send multi-seasonal air quality study design report to KPAC and ENV for review

New modelling and AQ study also support 2019 comprehensive review

a. Atmospheric Pathways – *What we did*

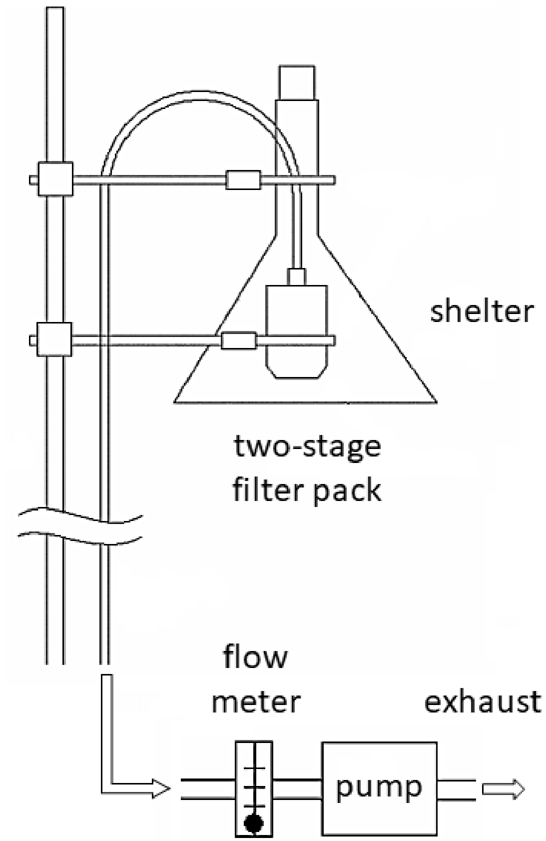
Passive Sampling Network – Atmospheric SO_2

- Two networks of passive samplers deployed during 2018: Valley and Urban Kitimat
  - Following same protocols (and locations) as 2016 and 2017; IVL passive SO_2 samplers deployed monthly
  - 18 sites in Kitimat Valley (established June 11) primarily along Wedeene and Bish roads (plume path)
  - 20 sites in urban and residential areas (established June 12)
  - 4 ambient (continuous monitoring) stations included (Haul Road, Riverlodge, Whitesail and Lakelse Lakes)

a. Atmospheric Pathways – *What we did*

Filter Pack Sampling – Atmospheric Particulate SO_4^{2-}

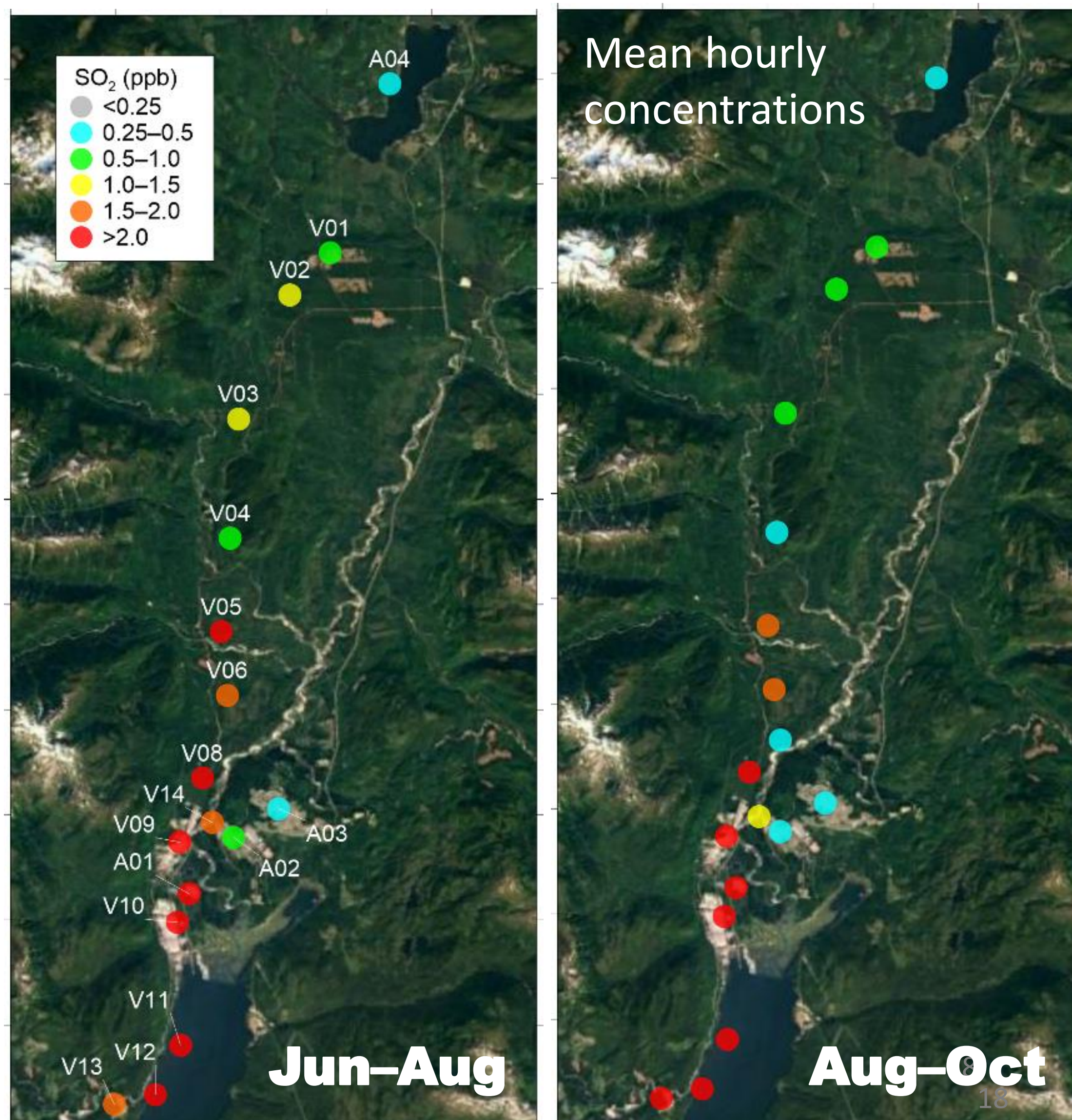
- Atmospheric SO_2 and pSO_4^{2-} measured using 2-stage filter pack during February and June 2018.
- deployed at Haul Road, Riverlodge, Whitesail, Lakelse Lake and Kitamaat monitoring stations and at four locations within the Kitimat valley
- > 60 exposures between the nine stations
- Will use data to assess amount of particulate sulphate (pSO_4^{2-}) in the region



a. Atmospheric Pathways – *What we learned*

Valley SO_2 Passive Sampling Network

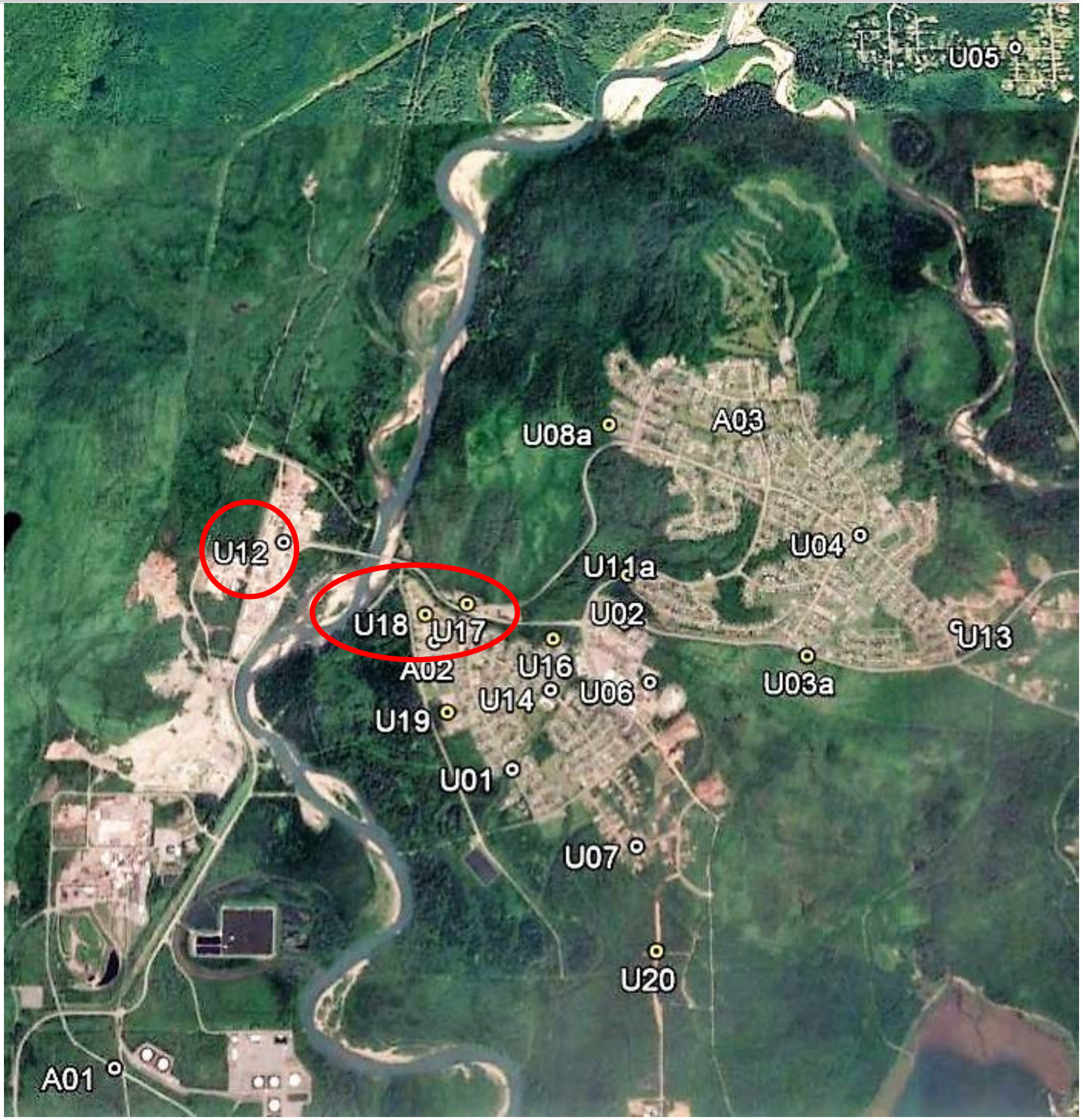
- 77 exposures
  - four one-month exposures
  - replicate samplers deployed >30% of time (average difference of 15%)
- Elevated SO_2 along plume path
  - >7.5 ppb observed at Rifle Range in June–July
  - >7.2 ppb observed at Bish Road in Sept–Oct
- Similar to 2017 and 2016, $[SO_2]$ higher to north of smelter during June–Aug.



a. Atmospheric Pathways – *What we learned*

Urban SO_2 Passive Sampling Network

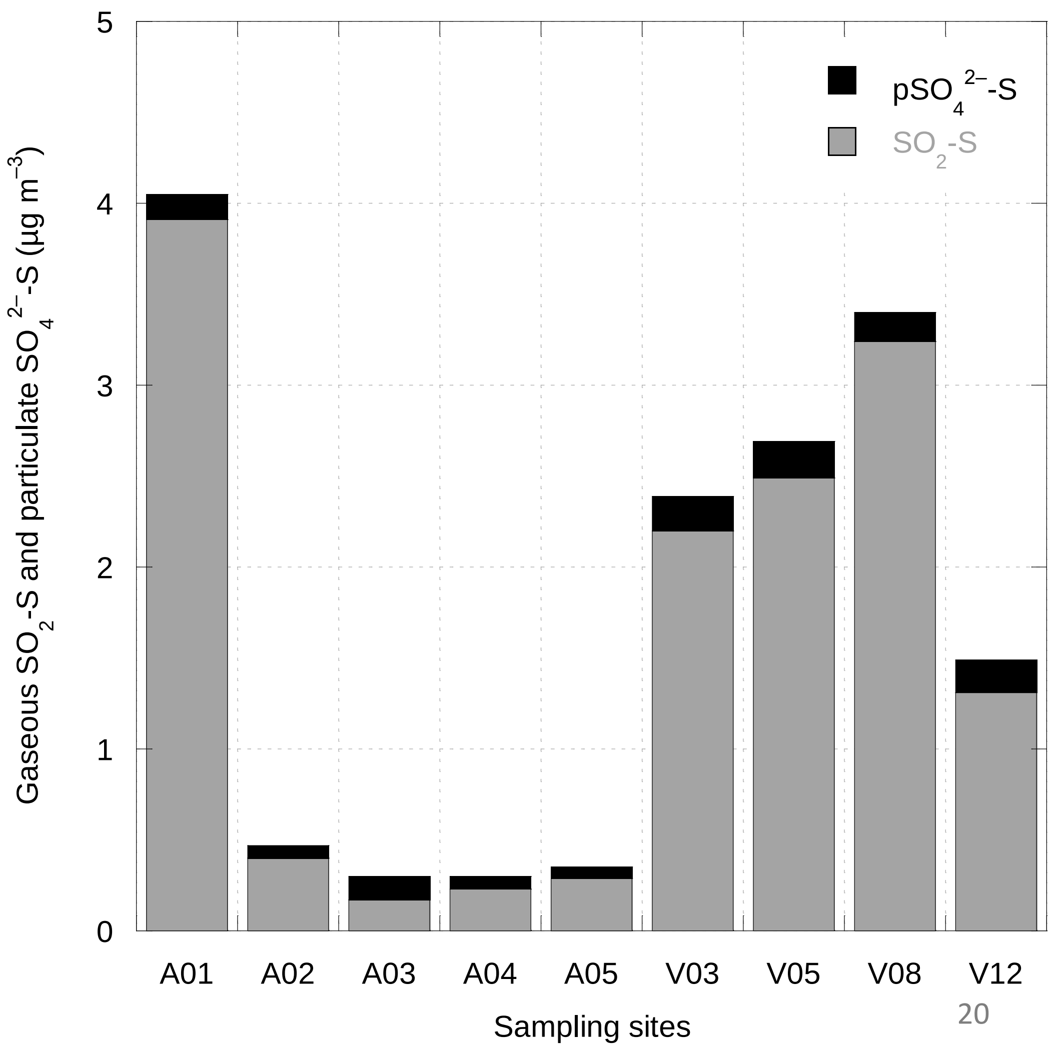
- Objectives: support network optimization; identify SO_2 'hot-spots'
- 20 sites established June 2018; will continue with monthly exposures through 2019.
- 8 new stations in 2017 (new addition or revised siting from 2016 location) following optimization (see next slide)
- During first four exposures (June to Oct 2018), all observations < 0.5 ppb except:
  - service centre (U12 0.9–1.5 ppb)
  - U17 and U18 (0.6 ppb during June–July 2018, sites close to Riverlodge A02)



a. Atmospheric Pathways – *What we learned*

Filter Pack Sampling – Atmospheric Particulate SO_4^{2-}

In general, particulate sulphate makes up < 10% of atmospheric concentrations of sulphur (particulate sulphate and gaseous sulphur dioxide)

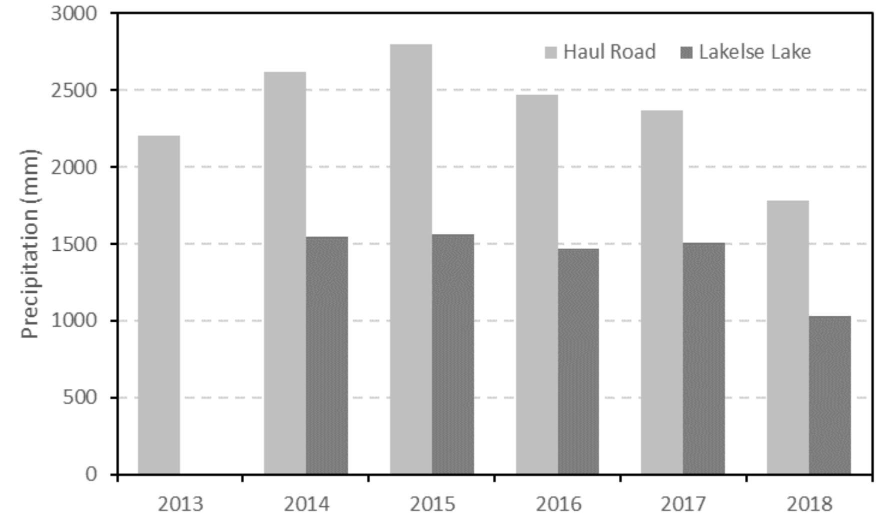


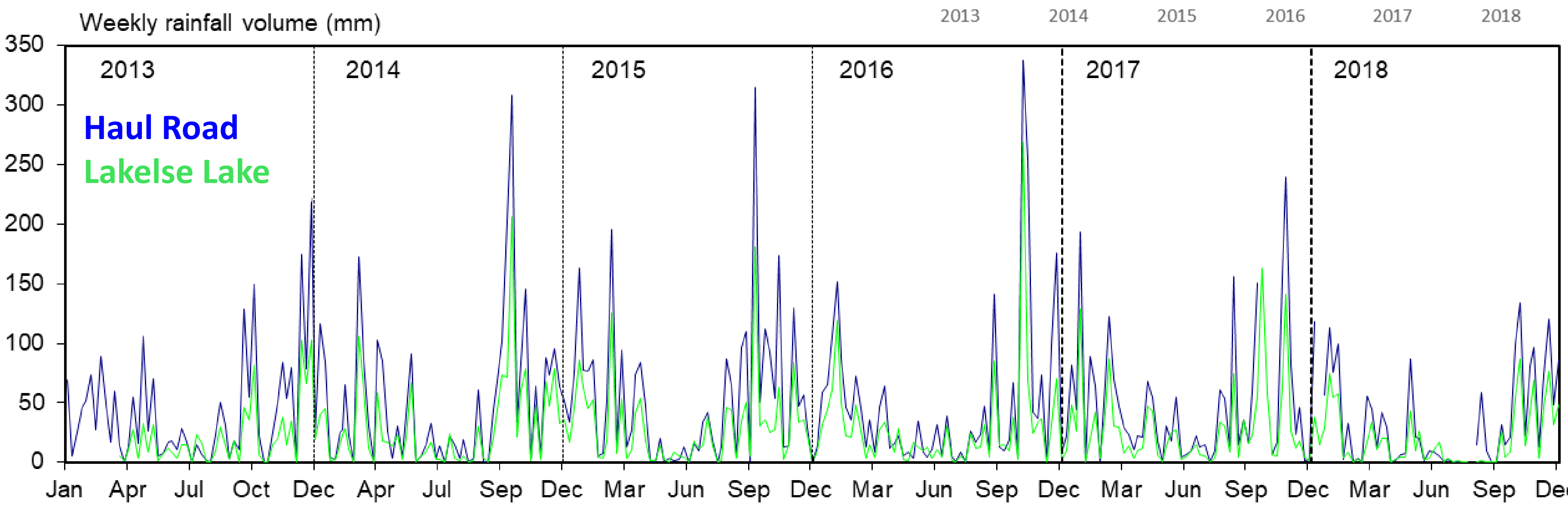
a. Atmospheric Pathways – *What we learned*

Rainfall Volume and Precipitation Chemistry

source: NADP nadp.slh.wisc.edu

- ~0.5m less precipitation at Lakelse Lake in 2018 vs. 2014-2017;
- ~1m decrease in precipitation at Haul Road over 2015-2018

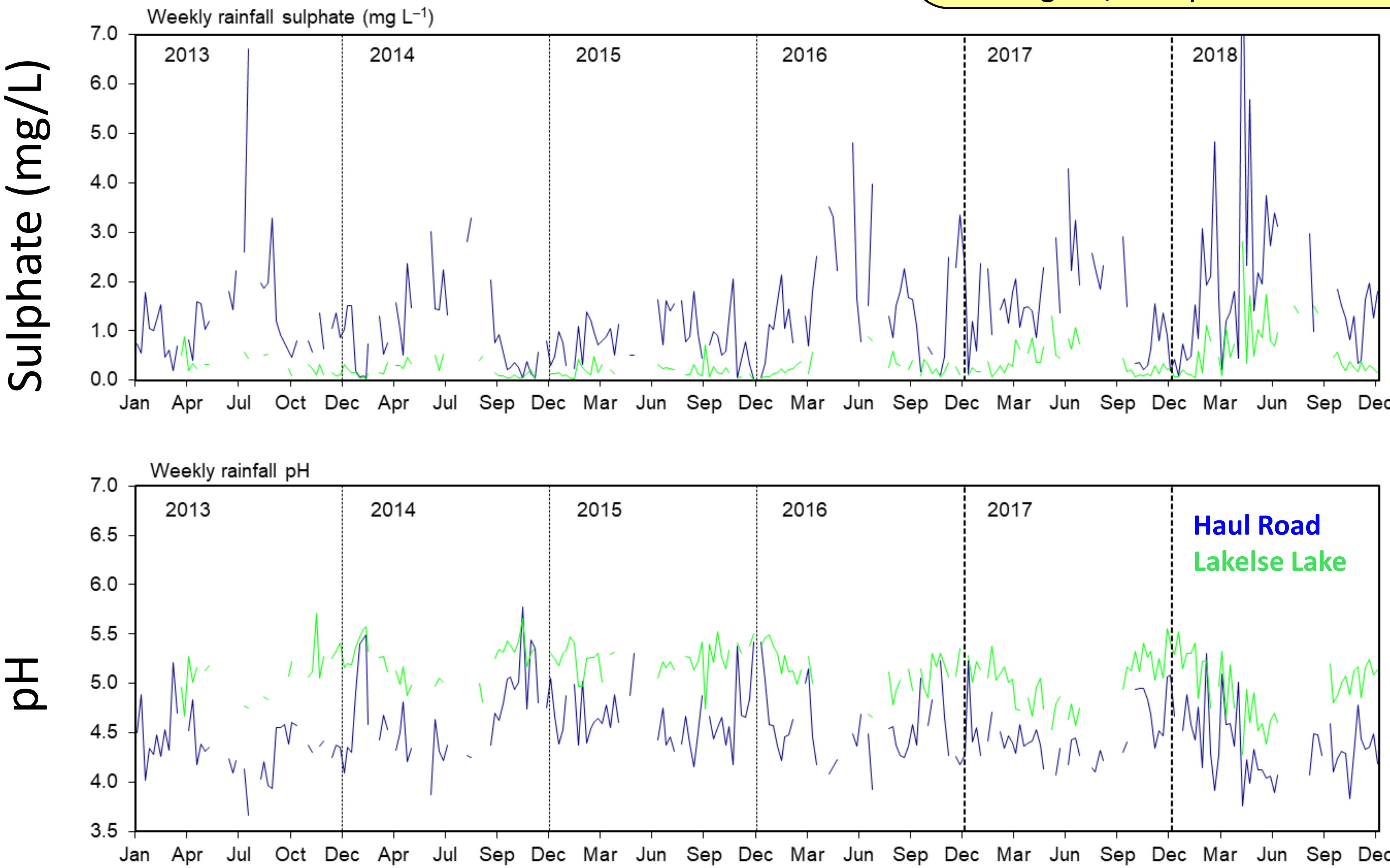




a. Atmospheric Pathways

Wet Deposition – Precipitation Chemistry

Haul Road → higher sulphate and lower pH than at Lakelse Lake, caused by higher SO_2. Note: preliminary data for 2018, awaiting QA/QC by NADP.



a. Atmospheric Pathways – *what we learned*

Estimating Dry Deposition

- Dry deposition depends on *concentration* and *deposition velocity*
- *Deposition velocity* depends on the characteristics of the gas or particle of interest, the receptor surface, and climate
- 'Big leaf' model widely used, compares well with (limited) measured results, high temporal resolution (hourly).
- Model requires hourly meteorological data; estimates deposition velocities for 31 gaseous species, and 3 particle size classes
- Dry deposition velocities modelled using meteorology from Terrace airport and Kitimat, combined with measured SO_2 (continuous and passive) and pSO_4^{2-} (filter pack) to estimate dry deposition

Zhang, Brook & Vet (2003). A revised parameterization for gaseous dry deposition in air-quality models. *Atmos. Chem. Phys.*, 3, 2067–2082.

a. Atmospheric Pathways – *what we learned*

Dry Deposition: inputs to calculate deposition velocity (V_d) over 2015–2018

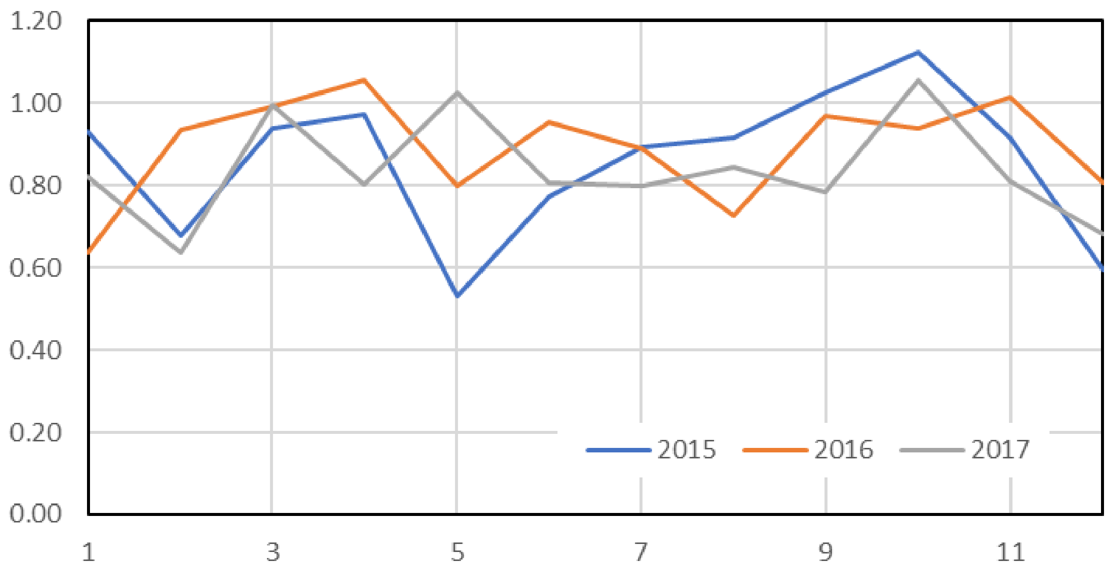
	Temper-ature	Wind speed	Relative humidity	Solar irradiance	Precipit-ation rate	Surface pressure	Snow depth	Cloud fraction
Kitimat	Rio Tinto hourly (NADP Haul Road)	Rio Tinto hourly (Whitesail or Haul Road)	Rio Tinto hourly (Whitesail	Modelled from max & min daily temp. using Hargreaves method	Rio Tinto hourly (NADP Haul Road)	Rio Tinto (Stantec data loggers). Terrace Airport	EC daily, applied to all hours	3-hourly Terrace A, infilled with average of nearest values
Terrace Airport	Terrace Airport hourly	Terrace Airport hourly	Terrace Airport hourly	Modelled from max & min daily temp. using Hargreaves method	Rio Tinto hourly (NADP Lakelse lakes) or Terrace PCC hourly data	Terrace Airport hourly	Terrace A & Terrace PCC daily snow depth, applied to all hours	3-hourly Terrace A, infilled with average of nearest values
Onion Lake*	Onion Lake hourly	Onion Lake hourly	Onion Lake hourly	Modelled from max & min daily temp. using Hargreaves method	Onion Lake hourly	Onion Lake hourly	Onion Lake hourly	3-hourly Terrace A, infilled with average of nearest values

* Only used for model testing, estimates of V_d are not being used for dry deposition

a. Atmospheric Pathways – *what we learned*

Dry Deposition: Deposition Velocity (V_d) at Terrace Airport

Species:	SO_2	H_2SO_4	NO_2	O_3	H_2O_2	HNO_3	HONO	HNO_4	NH_3
Average V_d (cm s^{-1})	0.85	1.10	0.48	0.56	1.16	3.22	1.72	2.60	0.93



Generally consistent patterns in SO_2 deposition velocity over 2015-2017, a bit more variation in 2015.

Average monthly V_d (cm s^{-1}) for SO_2 to coniferous forests during the period 2015–2017 (three years) at Terrace Airport

a. Atmospheric Pathways - *What's Next*

Topic	The commitment	What we plan to do in 2019	
Atmospheric Pathways			
Atmospheric SO_2 concentration	Continue the passive SO_2 monitoring program	Passive samplers will be deployed in the Kitimat valley during June to October 2019 (same sites as 2018)	.
	Continue the urban passive SO_2 monitoring program under 'Network Optimization'	Passive samplers being deployed in urban areas through out 2019 (same sites as 2018)	
	Wet deposition	Maintain two rain chemistry stations (Haul Road and Lakelse Lake)	.
	Dry deposition	Finalise dry deposition estimates at both the Haul Road and Lakelse Lake for the period 2015 to 2018	

b. Human Health – *What We Did*

- Province-wide interim SO_2 ambient air quality objective (AAQO) adopted Dec. 15, 2016; became the SO_2 Health KPI of EEM Program starting in 2017.
- From 2017 to 2019, 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 end of 2017**: 3-year average of 97^{th} percentile of the daily one-hour average maximum (D1HM) for 2015 – 2017.
  - **At end of 2018**: 3-year average of 97.5^{th} percentile of D1HM for 2016 – 2018,
  - **At end of 2019**: 3-year average of 98^{th} percentile of D1HM for 2017 – 2019, and
  - **At end of 2020 and the end of each subsequent year**: 3-year average of 99^{th} percentile of D1HM for that year and the two preceding consecutive years.
  - Allowance of a one-time exceedance of the 75 ppb threshold to a maximum concentration of 85 ppb, over the three-year interim period.
- After 2019: SO_2 Health KPI threshold reverts to SO_2 Canadian Ambient Air Quality Standards (CAAQS) - 70 ppb threshold using 99^{th} percentile of D1HM averaged over a three year period. The threshold is further reduced in 2025 to 65 ppb.

b. Human Health

What We Learned

Calculation method and results for the SO_2 Health KPI in 2018.*

Station	97.5th percentile D1HM** SO_2 (ppb)			SO_2 Health KPI (ppb)	KPI
	2018	2017	2016	(3-year average of 97.5th percentile D1HM**)	Attainment / Non-Attainment
Riverlodge	21.0	16.8	13.8	17.2	Attainment
Whitesail	15.6	12.7	12	13.4	Attainment
Kitamaat Village	10.1	6.4	8.6	8.4	Attainment

* Data for this table were extracted from the Envista database of the BC Ministry of Environment and Climate Change Strategy

** Daily 1-hour average maximum

c. Vegetation —*What We Did*

2018 SO_2 EEM Actions

Topic	The commitment	What was done	Where to learn more
Vegetation			
Vegetation survey	Conduct a visual inspection and assessment of vegetation	Inspection and assessment accomplished as planned	Stantec (2019)[1]
	Continue vegetation sampling as described in Laurence (2010)[2]	Vegetation sampling accomplished as planned.	Stantec (2019)[1]
Sulphur content in hemlock needles	Collect hemlock needles near end of growing season (mid-August to mid-September), and analyze for sulphur content	Western hemlock trees sampled for sulphur analysis from August 27-August 31, 2018 by Stantec. Sulphur analysis conducted by Rio Tinto, Jonquière, Québec.	Stantec (2019)[1]

[1]Stantec Consulting, Ltd. and J. Laurence. 2019. Vegetation Monitoring Report Annual Report 2018. Submitted to BC MOECCS March 29, 2019.

[2] Laurence, J. A. 2010. A Review of the Vegetation Monitoring and Assessment Program in the Vicinity of the Rio Tinto Alcan British Columbia Operations at Kitimat, British Columbia. Report to Rio Tinto Alcan dated May 16, 2010.

c. Vegetation - *Background*

Visible Injury due to SO_2

- We don't know the SO_2 dose-response relationship for most plant species in the Kitimat area, **but**
- *Symptoms have not been observed on any species under previous deposition.*
- We use known sensitivities of similar species as a guide as to what to look for

Left: Injury to raspberry near a coal-fired electricity generating facility in Indiana, USA. Right: injury to elm caused by a chronic exposure to SO_2

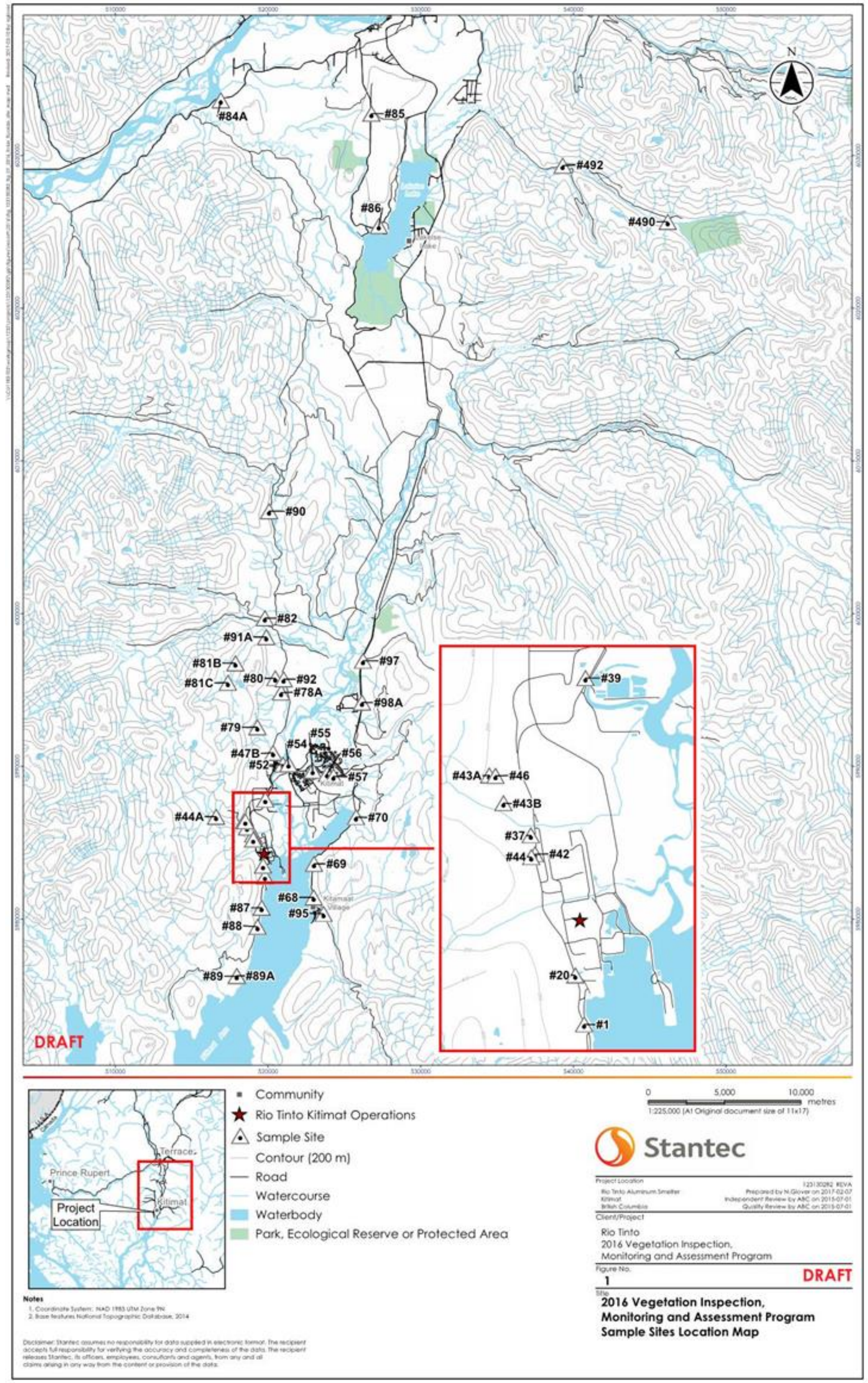
c. Vegetation - *Background*

- The SO_2 EEM established a Key Performance Indicator (KPI) and an Informative Indicator based on scientific literature, modeled deposition, and historical results of the vegetation program.
- KPI to trigger increased monitoring: **Visible Injury due to SO_2**
  - More than occasional symptoms of SO_2 injury outside of Rio Tinto Alcan Kitimat properties, causally related to KMP
- Informative Indicator to trigger increased monitoring: **S in needles of western hemlock**
  - An increase of more than 1 standard deviation (from pre-KMP baseline data, 1998-2011) in 20% of the sites for 3 consecutive years, causally related to KMP

c. Vegetation —*What We Did*

Vegetation Sampling

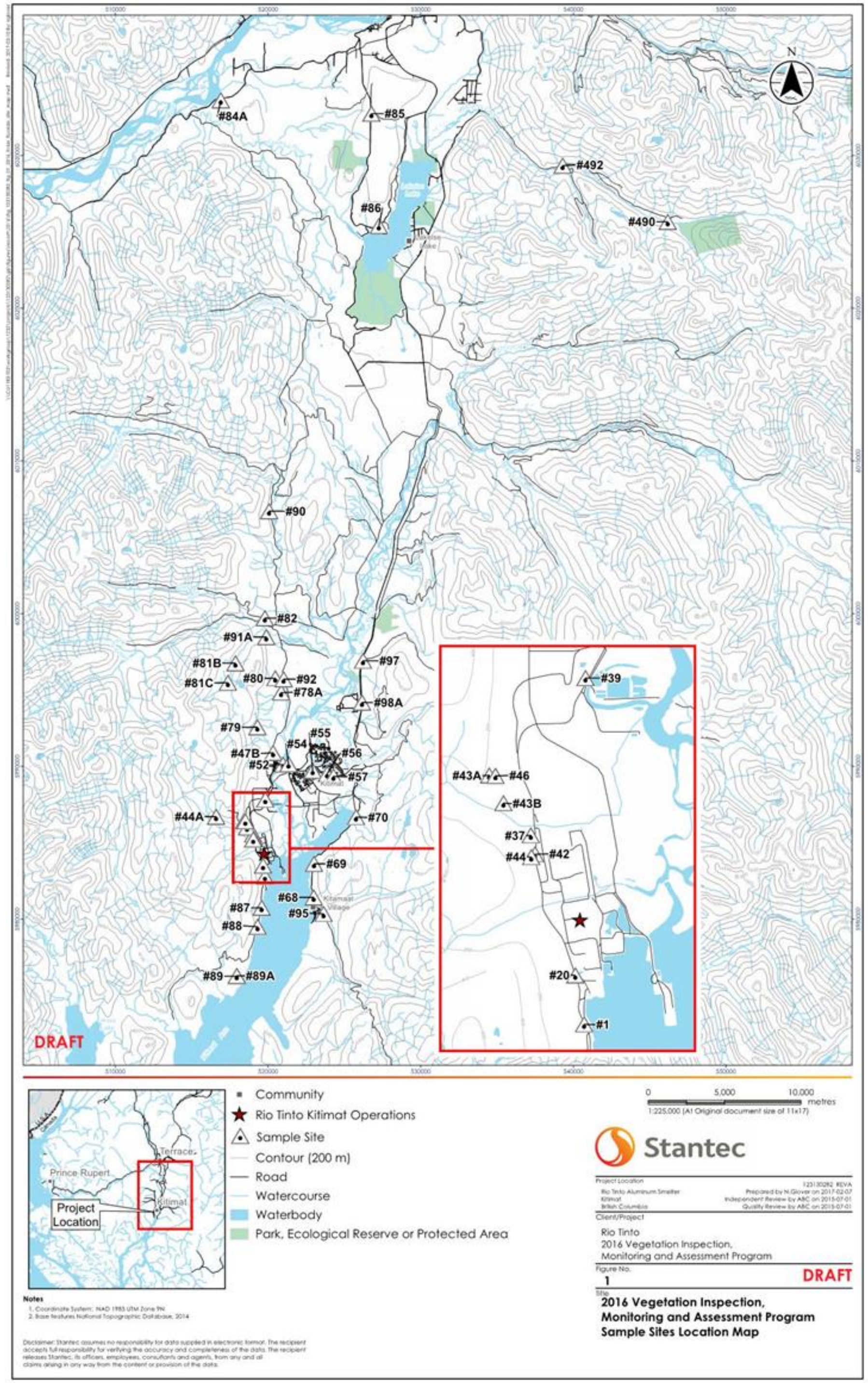
- Conducted Aug 27 – Aug 31, 2018
- Implemented site and sample-tree assessment checklist
- Sampled western hemlock needles at 40 sites for laboratory analysis of S and F content
- Samples analyzed by RT Laboratory in Jonquière, Québec.



c. Vegetation —*What We Did*

Vegetation Inspection

- Aug 27 – Aug 31, 2018
- Vegetation was inspected at 43 sites—40 sampling sites and 3 additional sites (Admin Building 272, Kitamaat Village, and Moore Creek Falls)
- Vegetation observed in Kitimat to assess general health of ornamental plantings
- Short field trip to demonstrate methods with members of KPAC, Haisla Nation, and the public



c. Vegetation - *What We Learned*

Field Observations

- General condition of vegetation was similar to the condition reported previously (pre- and post-KMP).
- Trees at some sites showed chlorosis, pests, and pathogens, but within expected levels based on site and time of year.
- Hemlock woolly adelgid persists at low intensity
  - Introduced accidently to BC in the 1920s. Not usually a problem on mature trees
  - Some signs (white tufts on the underside of branches) observed at 13 sites
  - Infestation less than 2% of the total tree and generally less than 1% of the sampled branch

c. Vegetation - *What We Learned*

Vegetation Inspection

– No symptoms of SO_2 or Fluoride exposure were observed at any site. ***The SO_2 EEM Key Performance Indicator related to vegetation injury due to SO_2 was not exceeded.***

– In 2018, condition of vegetation in inspection area near Rio Tinto BC Works (RTBCW) was similar to 2016 and reported by Stantec in 2017 (documented in Stantec annual reports and appendices).

– The major stress factor affecting vegetation in the area was dry weather. Pests and pathogens occurred at a normal level of incidence and severity.

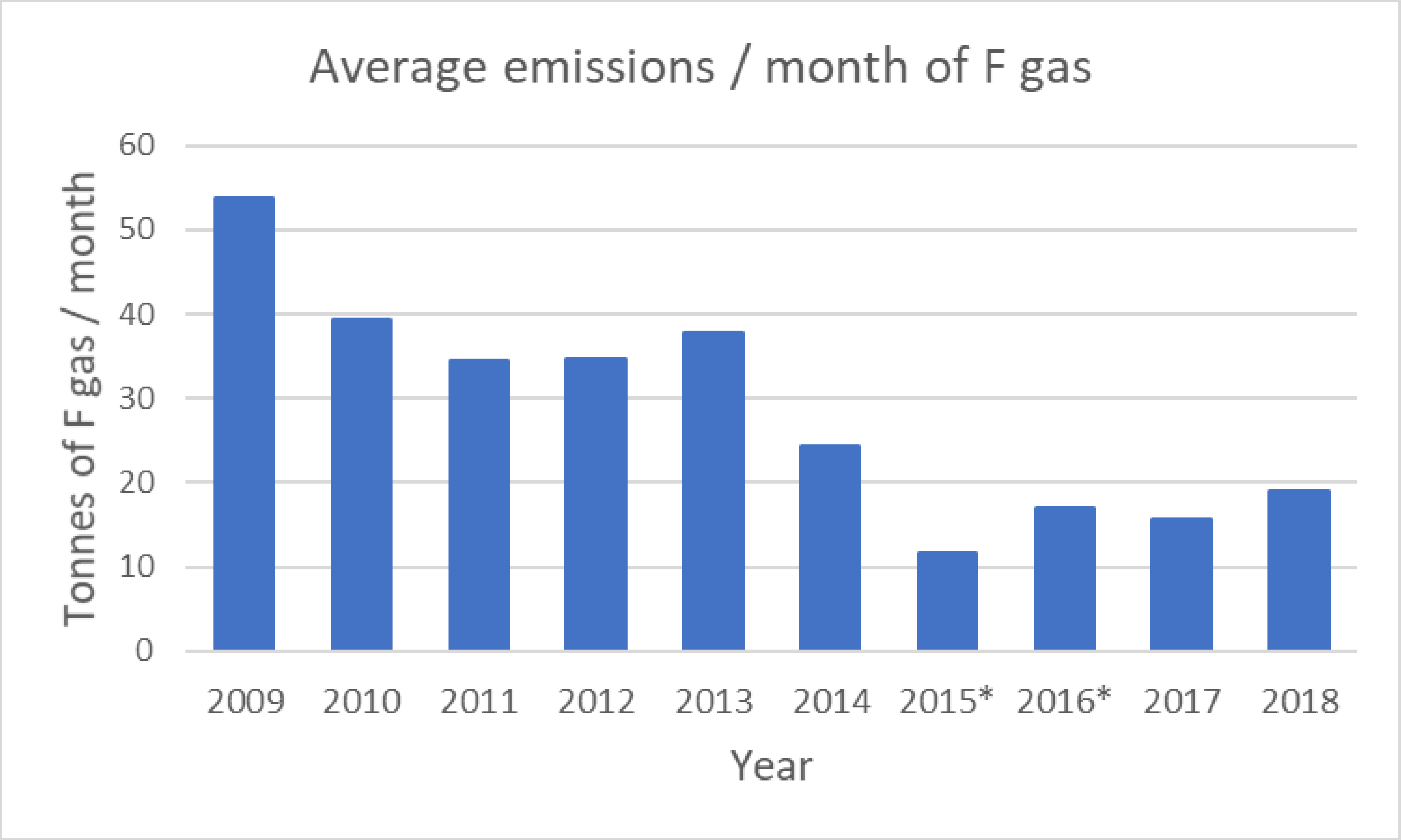
c. Vegetation - *What We Learned*

Sulphur Concentration in Hemlock Needles

- *SO_2 EEM informative indicator was not exceeded*
- 2018 S concentrations ranged from 0.06% to 0.12%--within reported background
- Comparison of 2018 values to SO_2 EEM baseline (1998-2011)
  - 3 sites (81C, 89A & 90) exceeded historic baseline (1998-2011) mean by <0.02% (<1 SD above historic baseline); precision of analytical technique is ±0.01%.
- Comparison of 2018 values to 2015 values (very low emissions of SO_2 – 8.3 tpd)
  - 25 sites with increases (0.01%-0.05%)
  - 13 sites with decreases or no change (0.00 to -0.05%)
- Comparison of Post-KMP (2016-2018) to 2015 values (very low SO_2 emissions)
  - 22 sites increased (0.01 to 0.04%); (<1 SD above historic baseline)
  - 16 sites stayed the same or decreased (0.00% to -0.04%)
- Comparison of Post-KMP (2016-2018) to SO_2 EEM baseline (1998-2011)
  - 1 site (89A) had a post-KMP mean (2016-2018) that exceeded SO_2 EEM baseline (1998-2011) but by less than 1 SD

c. Vegetation - *Background*

Changes in emissions of Fluoride over time



* Partial monitoring of F emissions during KMP transition (10 months in 2015, 4 months in 2016)

c. Vegetation - *What We Learned*

Fluoride Concentration in Hemlock Needles

- Post-KMP (2016-2018) vs. Mean for 2009-2013 (pre-KMP; partial operation)
  - 24 sites showed decreased F
  - 14 sites showed increased F (by 0.3-4.4 ppm); 8 of the 14 were still below historical background level of 10 ppm.
- 2018 – results of F concentrations:
  - **Substantial improvement over historical concentrations**
  - **At 21 of 40 sites, F concentrations were ≤ 10 ppm (historical background); 32 sites had concentrations ≤ 15 ppm**
  - First analysis showed 7 sites greater than 30 ppm with a high of 130 ppm
  - Trees at 5 accessible sites in January were re-sampled and re-analyzed
  - Results of re-analysis show F at 19-36% of the original value
  - After re-analysis, concentrations ranged from 3 to 29 ppm
  - High F levels likely due to contamination, which would not affect plants
  - Dry summer conditions allowed dust to accumulate (1.7 mm of rain from July 20 to August 28 in 2018 vs >140mm in 2017). Fall and winter rains removed particulate.

c. Vegetation - *What's Next*

- Will do vegetation sampling and inspection in 2019
- RT will request a modification in sampling in 2019 to eliminate redundant plots
  - based on proximity of neighbouring plots and historical contribution to understanding dispersal of emissions.

c. Vegetation - *What's Next*

- Comprehensive Review of SO_2 EEM will address whether Key Performance Indicator and Informative Indicator are appropriate to assess potential effects on vegetation.
- Results from research since the STAR will be used to inform the analysis (e.g., could more sensitive indicators be used?).
- Results of vegetation program will be integrated with updated air modeling and soils analysis to assess risk levels in the original STAR analysis

d. Soils – *What We Did*

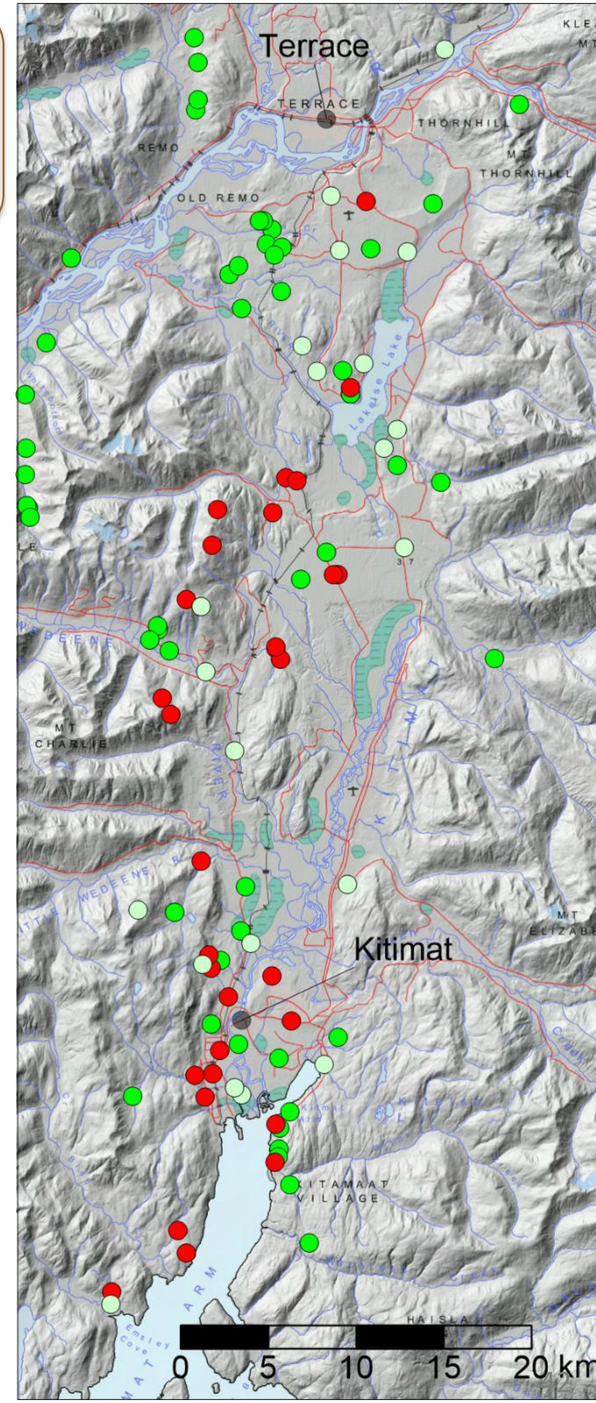
2018 EEM Actions

Topic	The commitment	What was done	
Terrestrial Ecosystems (Soils)			
Soil modelling	Re-do modelling and mapping of critical loads, adding data from the new sites	Completed soil analysis for all new 'regional' soil samples; total oxide content, Loss on Ignition (LOI) and Particle Size Analysis (PSA)	
Permanent soil plots	Resample and analyse soils for the primary plots	The primary plots at Coho Flats and Lakelse Lake were resampled during 2018	

d. Soils – Regional Mapping – *What we did*

Regional Soil Modelling

- Soil analysis for 'new' EEM sites finalized during 2018
- Modelling and mapping of base cation weathering rates and critical loads will be carried out during 2019
- Regional soil sampling sites
  - EEM sites (n=32; red)
  - Previous soil samples (n=58; STAR = 51, KAEEA = 7)
  - LNG Canada soil samples (n=21; light green)
  - Total of 111 sites with measurements of total oxide content for modelling of base cation weathering rate



d. Soils – Permanent Plots – *What we did*

Permanent Soil Plots

Primary plots at Coho Flats and Lakelse Lake were resampled during June 2018

- 20 samples collected at 3 depths at each plot (120 total soil samples)

d. Soils – Permanent Plots – *Background*

Layout and Sampling Specifications | Background

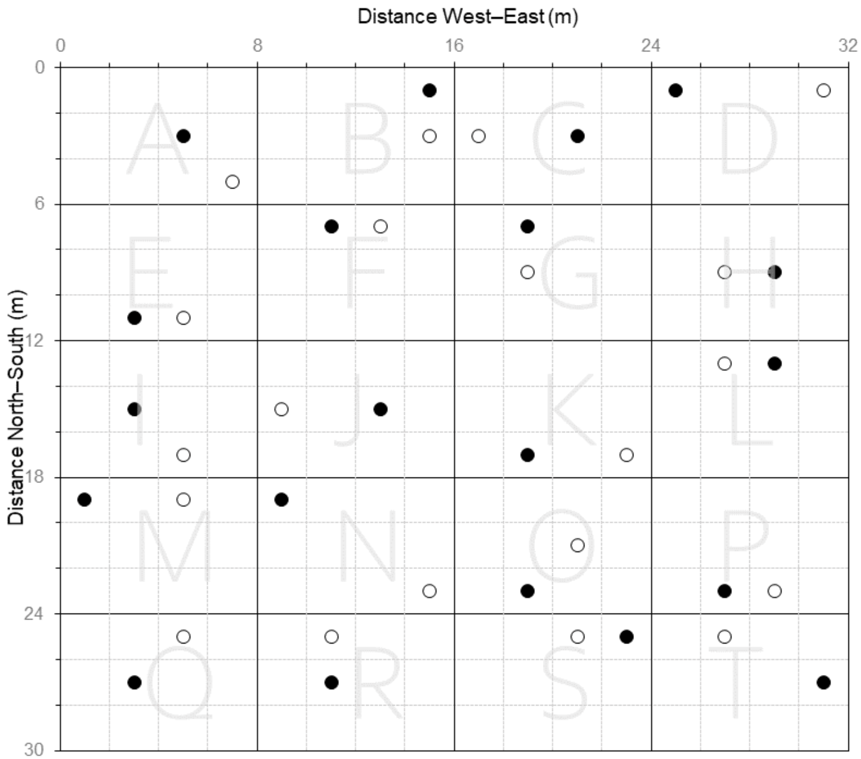
Plot layout:

- 6 plots (32 m × 30 m)
  - primary and secondary (backup) plots at each of the 3 study sites (Coho Flats, Lakelse Lake, Kemano)
- 1 plot has 20 sub-plots (6 m × 8 m)
- 1 sub-plot has 12 sampling grids (2 m × 2 m)

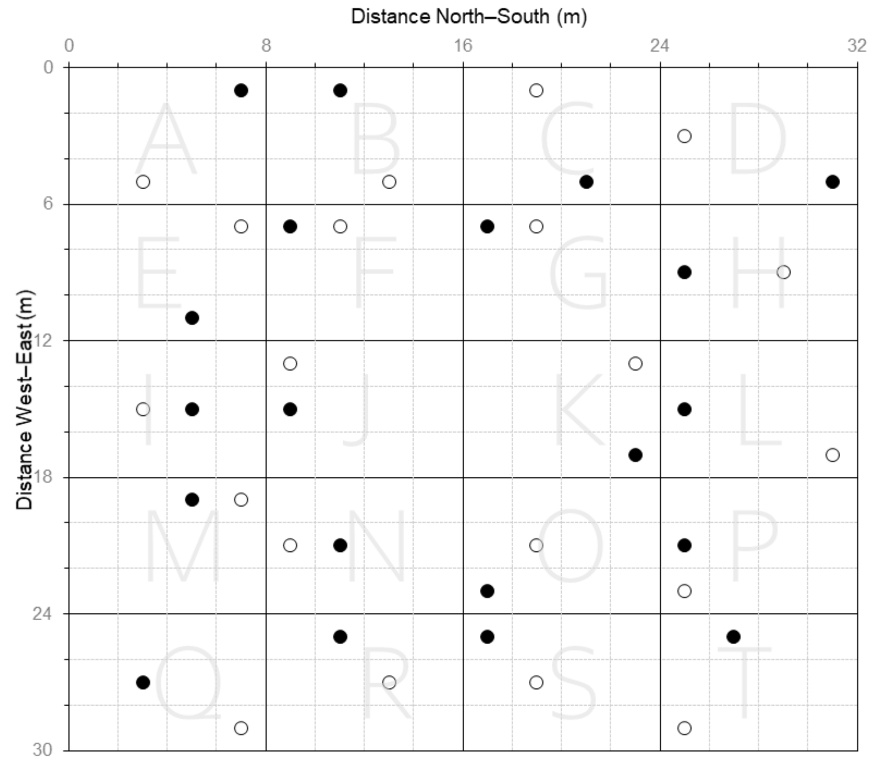
Plot sampling:

- random selection of 1 grid in each subplot
- each grid sampled at 3 depths for chemical analysis (i.e., total of 120 samples per plot)
- one grid sampled (per sub-plot) every 5 years

d. Soils – Permanent Plots - *Background*



Coho Flats Primary Plot



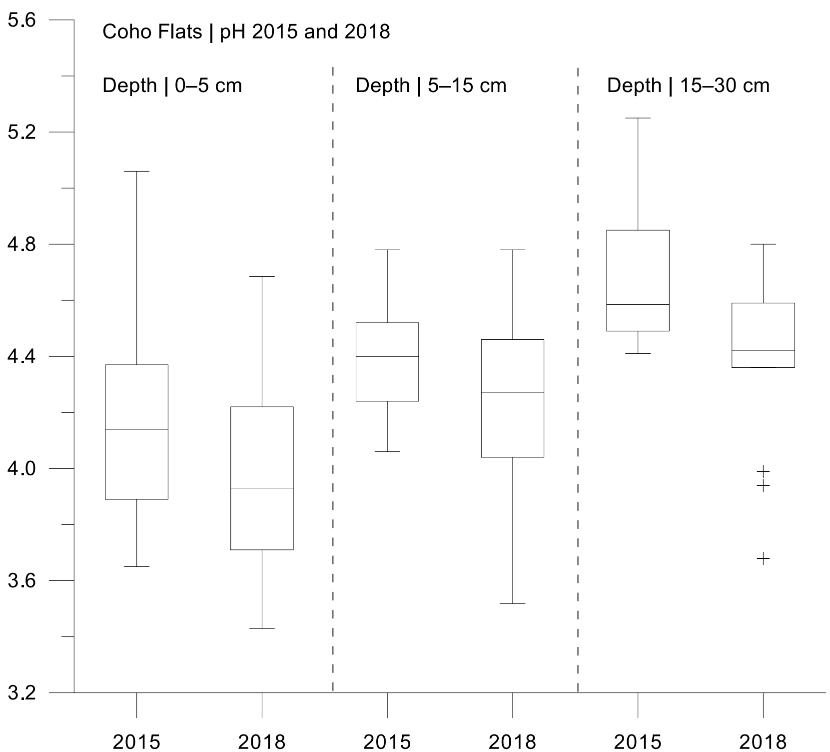
Lakelse Lake Primary Plot

Plot sampling:

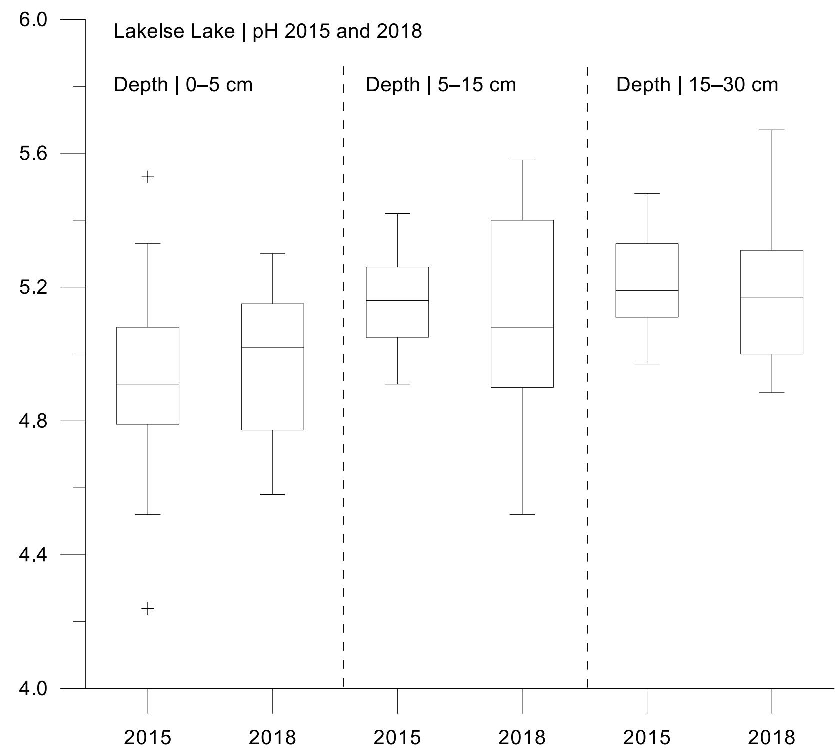
- Random selection of 1 grid in each subplot
- Each selected grid (representing sub-plot) sampled at 3 depths (i.e., total of 60 samplers per plot)

2015 ○
2018 ●

d. Soils – Permanent Plots - *What We Learned*



Coho Flats Primary Plot

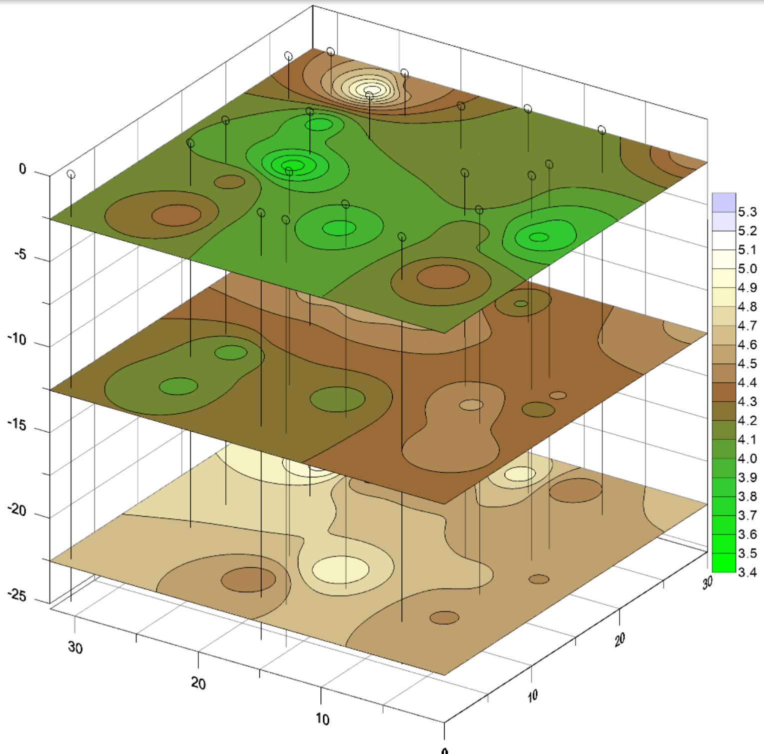


Lakelse Lake Primary Plot

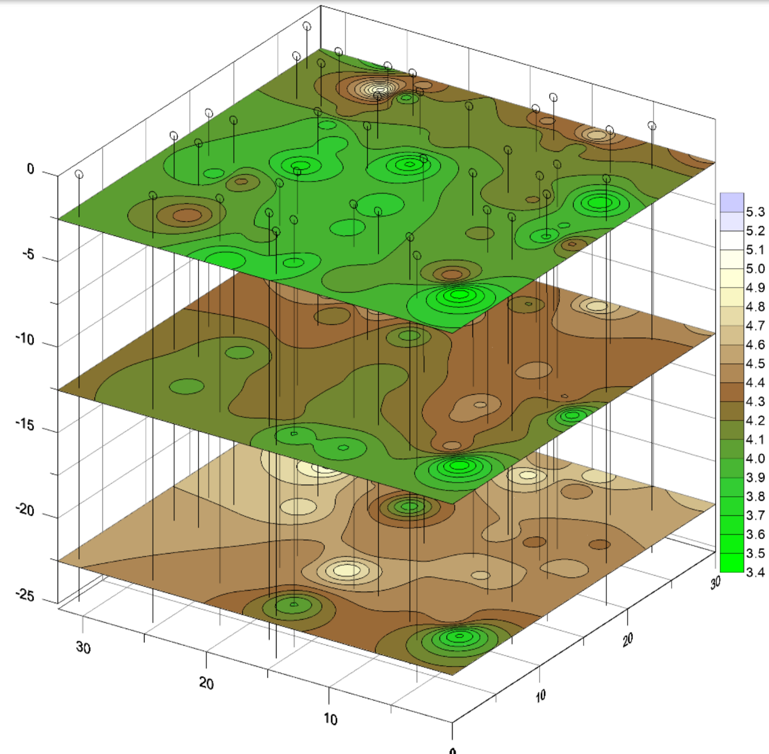
Preliminary Analysis: pH 2015 and 2018

- Box plot comparison of soil pH from 2015 and 2018 samples collected at three soil depths (0–5, 5–15 and 15–30 cm) at Coho Flats and Lakelse lake
- **There is no statistical difference between sampling periods (at each depth)**

d. Soils – Permanent Plots - *What We Learned*



Soil pH (n = 20 per depth)



Soil pH (n = 40 per depth)

Spatial variability: Coho Flats soil pH

- Left: spatial variability of soil pH using 2015 observations only
- Right: spatial variability of soil pH using 2015 and 2018 observations
- Improved description of variability in soil properties using all observations

d. Soils - *What's Next*

Topic	The commitment	What we plan to do in 2019
Terrestrial Ecosystems (Soils)		
Soil modelling	Re-do modelling and mapping of critical loads, adding data from the new sites	Re-do soil base cation weathering, mapping of soil properties and determination of critical loads for soils
Permanent soil plots	Analyse soils for the primary plots	The soil samples from the primary plots at Coho Flats and Lakelse Lake will be analyzed for exchangeable cations and acidity
Permanent soil plots	Measured and tagging of trees for the primary and secondary plots	All trees within the primary and secondary plots at Coho Flats and Lakelse Lake will be measured (DBH) and tagged for long-term identification

e. Freshwater – *What we did*

2018 EEM Actions

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	Annual water chemistry sampling of **10 EEM lakes** (including 7 sensitive and 3 insensitive lakes), **LAK024** (Lakelse Lake), and three control lakes (**DCAS14A**, **NC184**, **NC194**); done Sept 30. 2018. Within-season sampling (4X between Sept. 30 and Nov. 2) was done for 6 of the 7 sensitive lakes.	EEM 2017 Limnotek 2019
Fish sampling	Resample if the lake pH change reaches the threshold	No fish sampling was required in 2018, so no sampling was done.	EEM 2017 Limnotek 2019

e. Freshwater – Overview

2018 EEM Actions

Topic	The commitment	What was done	Where to learn more
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)			
Episodic acidification	Implementation of episodic acidification study	Continuous pH monitoring was maintained in the acid-sensitive West Lake (**LAK023**), End Lake (**LAK006**) and Little End Lake (**LAK012**), and added to **LAK028**. Continuous monitoring of pH in Anderson Creek.	Limnotek 2019
Goose Creek	Re-sample 8 tributaries for water chemistry and sample 3 stream sites for benthic organisms	Water chemistry measurements were done in 7 stream sites (8^{th} was dry) from the Goose Creek network (draining from near LAK028). Potential stream sites were ranked for bioassessment but not sampled in 2018.	Limnotek 2019

e. Freshwater –*What we did*

2018 EEM Actions

Topic	The commitment	What was done	Where to learn more
Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)			
Bathymetry	Bathymetric analysis for LAK028 to better estimate lake volume and water residence time	A bathymetric survey of **LAK028** was conducted to assist with interpretation of lake biogeochemistry and later calculation of lake water residence time.	Limnotek 2019
Amphibians	Conduct a literature review of potential effects of acidification on amphibians in the Kitimat Valley	The literature review was reviewed and finalized by August 2018.	ESSA 2018

e. Freshwater – *What we learned*

EEM 2018 results

Results (2012-2018)

- Shows change across period of record.
- Is NOT a thorough statistical evaluation of changes in water chemistry.
- Statistical evaluation included in CR (e.g., changes in EEM lakes vs. control lakes).
- ***Preliminary conclusion:* No lakes show exceedance of KPI**

	pH (TU)	Gran ANC (µeq/L)	SO4* (µeq/L)	DOC (mg/L)	∑ BC* (µeq/L)	Cl (µeq/L)	Ca* (µeq/L)	KPI exceeded
LAK006	0.3	2.6	4.3	0.2	14.5	0.3	5.9	No
LAK012	0.5	-6.1	8.5	0.0	-15.4	2.1	-16.3	No
LAK022	0.2	2.5	13.0	0.3	21.8	0.4	14.0	No
LAK023	0.3	3.2	-5.0	1.5	9.6	0.4	6.5	No
LAK028	0.3	8.2	50.6	-0.5	43.1	0.5	28.8	No
LAK042	0.4	21.0	0.1	-2.6	3.4	0.0	1.4	No
LAK044	0.1	2.7	-1.8	0.1	3.5	0.8	1.5	No
Total ↑	**7**	**6**	**5**	**4**	**6**	**6**	**6**	
Total ↓	**0**	**1**	**2**	**3**	**1**	**1**	**1**	
LAK007	0.1	-30.0	-4.3	-0.4	-13.1	3.3	-20.7	No
LAK016	0.4	24.1	6.2	0.9	17.2	1.0	10.8	No
LAK024	0.5	210.4	17.8	0.2	255.7	50.0	199.5	No
LAK034	-0.3	31.2	-23.9	0.6	-18.0	-2.1	-6.2	No
Total ↑	**3**	**3**	**2**	**3**	**2**	**3**	**2**	
Total ↓	**1**	**1**	**2**	**1**	**2**	**1**	**2**	
DCAS14A	0.3	8.8	7.9	-0.4	29.8	-1.9	21.7	
NC184	0.5	27.8	2.7	-4.6	17.2	-7.3	17.2	
NC194	-0.1	-1.9	-1.0	-0.5	6.6	-2.5	5.1	
Total ↑	**2**	**2**	**2**	**0**	**3**	**0**	**3**	
Total ↓	**1**	**1**	**1**	**3**	**0**	**3**	**0**	

e. Freshwater – *What we learned*

- **No lakes have exceeded the KPI threshold**
- Over 2012-2018, no lakes are showing strong, consistent evidence of smelter-driven acidification (i.e., ↓ pH and ↓ANC associated with ↑ SO_4)
- Some acidification observed in LAK028 from 2015 to 2017 (closest to smelter with greatest changes in sulphate), but changes over 2012-2018 do not indicate concerns (pH and ANC above 2012 baseline)
- No concerns about long term changes in water chemistry in other lakes
- Need more years of observations to have reliable estimates of post-KMP vs. pre-KMP (only 3 years post-KMP)
  - Intra- and inter-annual variability is high
- Overall EEM program is working well; no need for any changes

e. Freshwater – *What we learned*

EEM 2018 results

2012-2018 Lake Chemistry Changes in LAK028

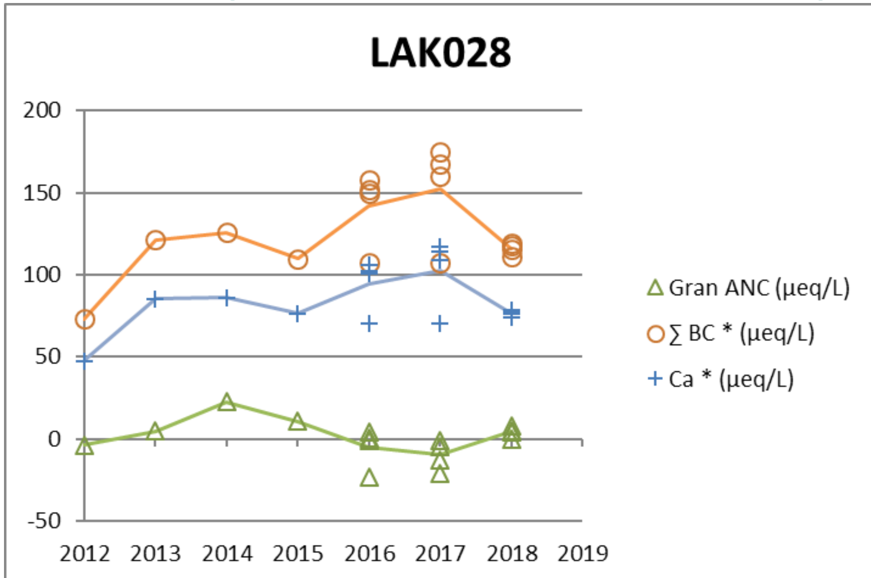
- Changes in $\mathbf{SO_4^{2-}}$ (μeq/L)
  - In the 2012-2018 period, overall increase of 50.6 μeq/L
- Increase in **base cations** of 43.1 μeq/L
  - Suggests that most (85%) of the deposited acidity was neutralized by cation exchange in the watershed. STAR assumed 44%.
- Gran **ANC** has increased by 8.2 μeq/L
- **pH** has increased by 0.3 units since 2012; 0.5 unit increase from 2017 to 2018 may relate to ↓ in both SO_4^{2-} and DOC

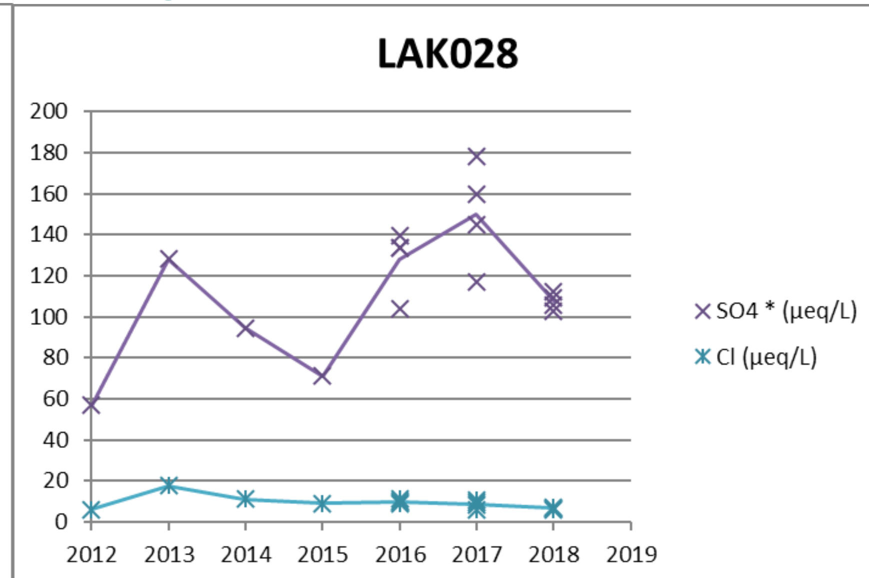
	Change from 2012 to 2018		
Lake	**pH (TU)**	**Gran ANC (μeq/L)**	**SO4* (μeq/L)**
LAK028	0.3	8.2	50.6

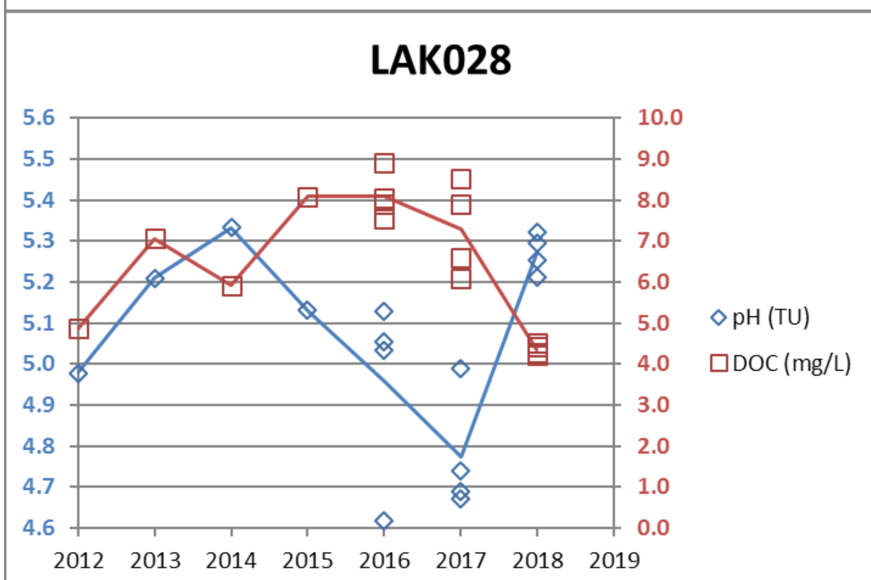
e. Freshwater – *What we learned*

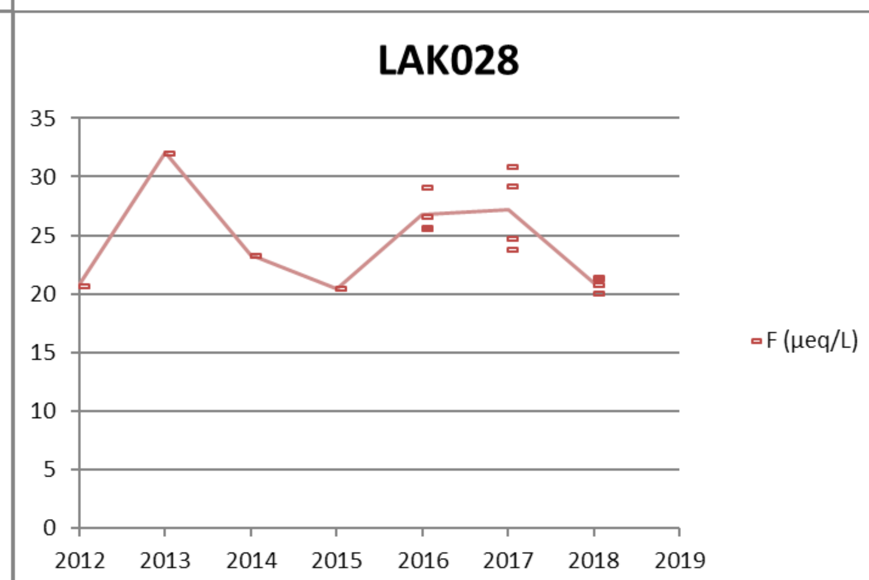
EEM 2018 results

Multi-year Lake Chemistry Changes in LAK028









e. Freshwater – *What we learned*

2018 EEM results

Goose Creek Stream sites sampled in 2018

Site	Gran ANC (µeq/L)	pH	SO4* (µeq/L)	Cl (µeq/L)	F (µeq/L)	BC* (µeq/L)	DOC (mg/L)
GCNT1	484.0	7.3	836.0	29.3	11.5	1391.7	2.5
GCNT2	568.5	7.5	1648.8	21.2	14.6	2144.2	1.6
GC2 us	363.9	7.2	806.1	16.6	23.5	1147.4	1.3
GC3	388.1	6.9	802.1	14.7	24.5	1037.2	2.7
GC5	565.0	6.6	414.6	16.9	14.2	971.3	1.5
GC6	626.0	7.5	492.4	9.6	13.8	1133.8	1.2
GC8	425.1	7.6	350.9	8.7	4.1	771.9	3.0

Average of Goose Creek sites	488.7	7.2	764.4	16.7	15.2	1228.2	2.0

Goose Creek sites are not sensitive to acidification (high ANC and BC)

Average of EEM sensitive lakes	*20.2*	*5.8*	*29.4*	*6.2*	*6.4*	*80.9*	*5.2*
Average of EEM less sensitive lakes	*535.2*	*7.2*	*33.8*	*29.1*	*4.2*	*613.4*	*2.9*

e. Freshwater – *What We Learned*

Limnotek 2019

Instrument effects on pH measurements

Testing of instrument effects from three sets of data:

1. Samples collected from all lakes, Sept 30 (WTW field meter, Trent lab, ALS lab)
2. Frequent samples from LAK006, LAK012, LAK023, and LAK028 (WTW field meter, Manta, Trent lab, ALS lab)
3. Sampling in Anderson Creek during Aug-Nov (WTW, Foxboro, Manta)

Instrument comparisons showed:

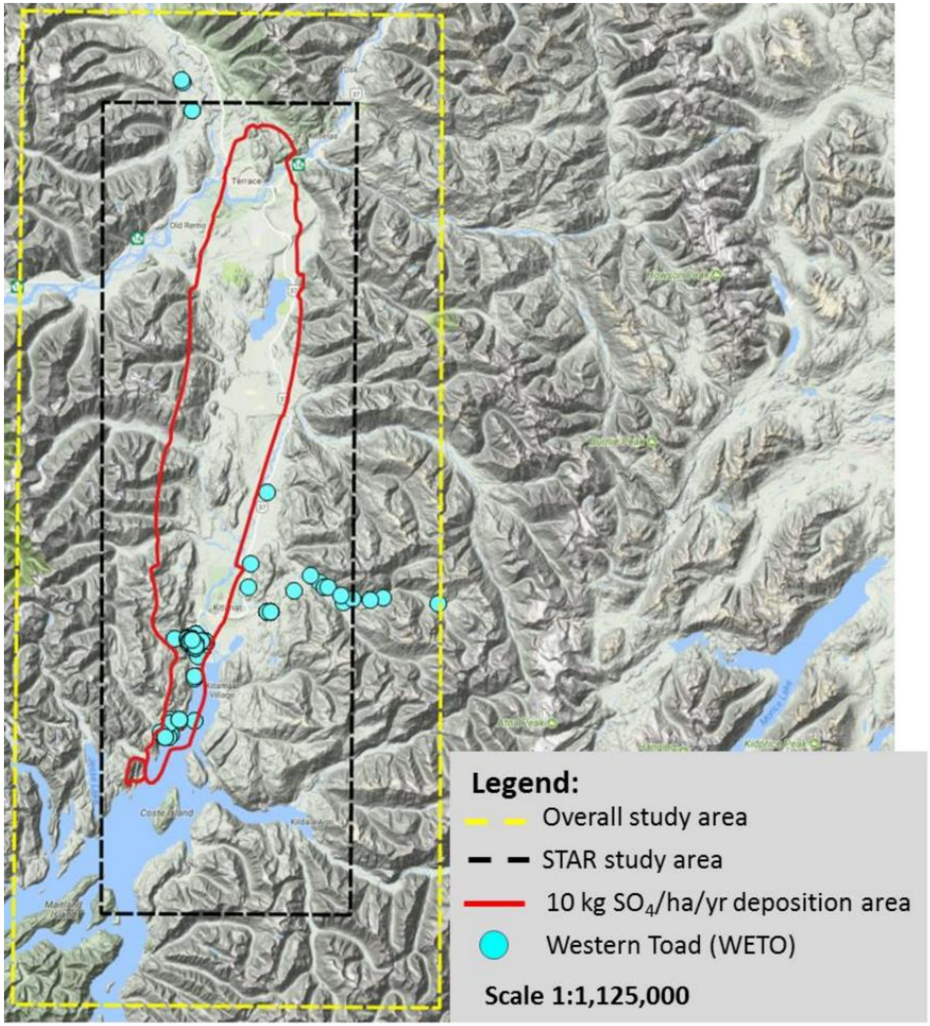
1. ALS pH differ from the WTW field meter and Trent lab – statistically significant but within instrument specifications (±0.2 pH)
2. Clear instrument effect for the 4 lakes with frequent measurements, exceeding instrument specifications
   - No difference between WTW and Trent (despite largest difference in time lag)
   - ALS and Manta similar, but significantly higher than WTW and Trent
   - Hypothesis – ALS and Manta do not allow sufficient time required for stabilization of measurements in low conductivity water
3. No statistical differences among instruments for Anderson Creek (Manta is newest)

e. Freshwater – *What We Learned*

ESSA 2017

Literature Review on Acidification Risk to Amphibians

- At least **7 amphibian species** occur within the overall study area.
- 6 require aquatic breeding habitats in low-lying areas (within the isopleth of 10 kg/ha/yr)
- 6 amphibian species have been observed within the zone of highest deposition close to the smelter
- Suggests tolerance to historic and current levels of deposition and their effects on soils and aquatic environments.



e. Freshwater – *What We Learned*

ESSA 2017

Literature Review on Acidification Risk to Amphibians

Two main **knowledge gaps** were identified:

- Acid sensitivity of the smaller ponds (< 1 ha) and wetlands occupied by amphibians in the Kitimat area is unknown.
- Uncertainty in sensitivity to acidification of 5 local amphibians; sensitivity known only for 2 species: Wood Frog and Western Toad.

Species *		Conservation status	General breeding habitat	Observation locations**		
Common name (*Scientific name*)		BC List (SARA Status)		10 kg SO_4/ha/yr deposition area	STAR study area	Overall study area
Coastal Tailed Frog (*Ascaphus truei*)		Yellow (*Special Concern*)	Lotic (stream)	49 (25%)	98 (50%)	198
Northwestern Salamander (*Ambystoma gracile*)		Yellow	Lentic (lake, wetland, pond)	3,690 (99.8%)	3,693 (99.9%)	3,696
Long-Toed Salamander (*Ambystoma macrodactylum*)		Yellow	Lentic (lake, wetland, pond)	291 (100%)	291 (100%)	291
Western Toad (*Anaxyrus boreas*)		Yellow (*Special Concern*)	Lentic (lake, wetland, pond)	1,490 (96.6%)	1,537 (99.6%)	1,543

e. Freshwater - *What's Next*

EEM 2018 recommend.

Recommendations: Maintain 2018 Sampling Plan for 2019

- Annual sampling of 7 sensitive lakes, 4 less sensitive lakes, and 3 control lakes consistent with 2016-2018
- Continue to investigate best path forward for continuous pH monitoring at 4 sensitive lakes
  - See recommendations on following slide
- Within-season samples for 6 of 7 sensitive lakes
  - Better ability to detect both long term changes and episodic events
- Continue to examine changes in pH, Gran ANC, SO_4, base cations and DOC
- Add continuous temperature monitoring along a vertical profile in LAK028

e. Freshwater, ***What's Next***

2019 Actions & Activities

Limnotek 2019

Recommendations on pH Measurement / Instruments

Recommendation 1: Determine the minimum time for stable pH measurements.

Recommendation 2: Do not use Manta measurements to interpret variability or trend in pH.

Recommendation 3: Use WTW field pH and Trent lab pH measurements for estimates of trends in pH.

Recommendation 4: Explore changing Manta factoring settings for stabilization from 5 sec seconds to >10 min. Then test for pH drift.

Recommendation 5: If Manta probes used in 2019, replace electrodes (in their final year of effective life, as indicated by the manufacturer).

QUESTIONS?

RioTinto

John Laurence
Plant Pathologist

ESSA

Trinity Consultants

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