Environmental Effects Monitoring (EEM) Program
June 12, 2018 - Summary of 2017 EEM Annual Report

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RioTinto ESSA

Trinity Consultants RSI RISK SCIENCES INTERNATIONAL TRENT UNIVERSITY 1964–2014 LIMNOTEK

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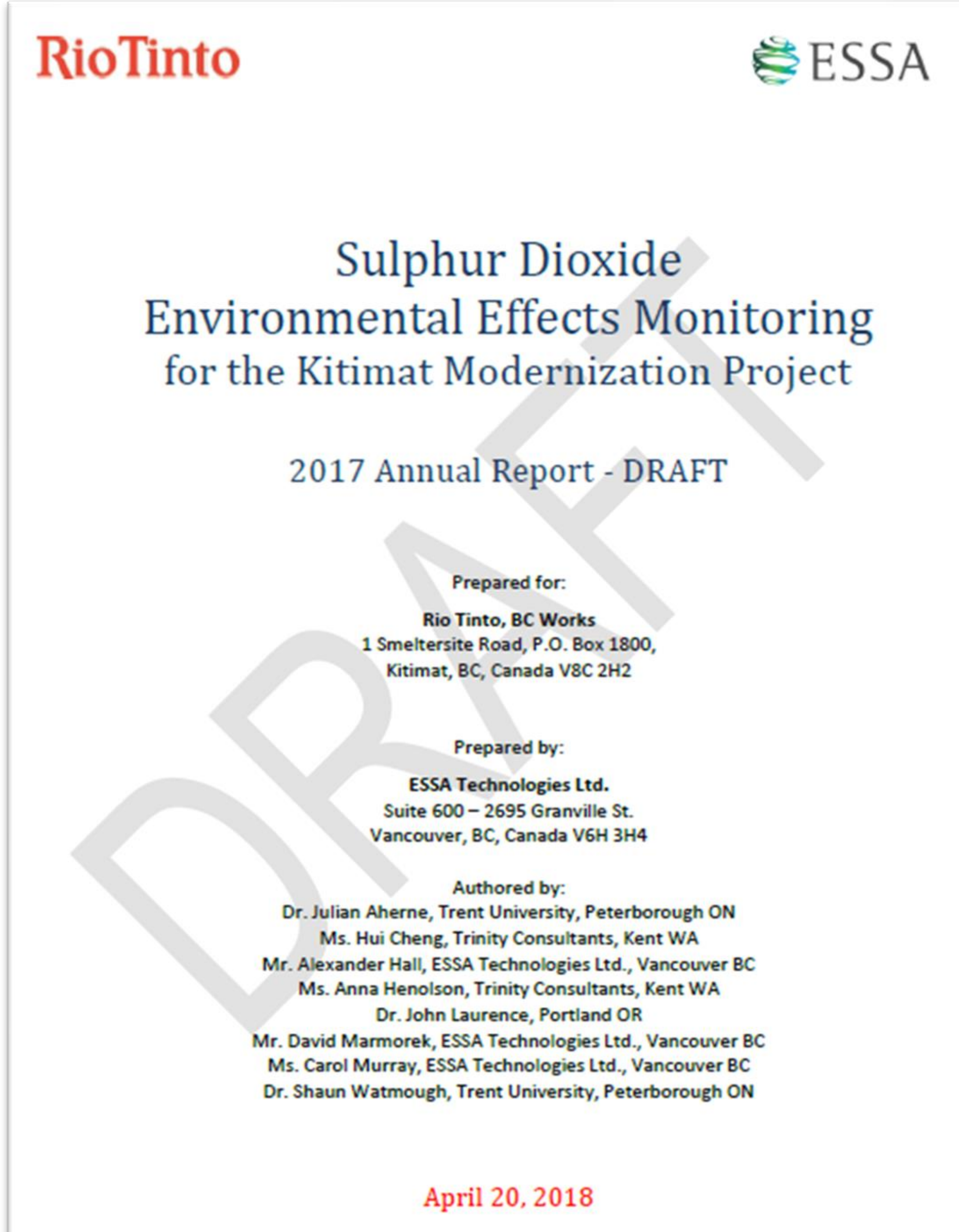

RioTinto ESSA

Sulphur Dioxide
Environmental Effects Monitoring
for the Kitimat Modernization Project

2017 Annual Report - DRAFT

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April 20, 2018

DRAFT

http://www.riotinto.com/canada/bcworks/reports-17826.aspx?tx=324,312

0. Definitions

AAQO – Ambient Air Quality Objective
ANC = Acid Neutralizing Capacity
Anion = Molecule with a negative charge, such as SO_4^{2-}
BC = Base Cations
Benthic sampling = sampling of organisms that live near or in the bottom of a waterbody
Cation = Molecule with a positive charge, such as Ca^{2+}
CEC = Cation Exchange Capacity
CL = Critical load
Cl = Chloride ion
D1HM = Daily 1 Hour Maximum, the highest 1 hour air quality SO2 concentration measured in a 24 hour day.
DOC = Dissolved Organic Carbon
EEM = SO2 Environmental Effects Monitoring program
HF = hydrogen fluoride
H_2S = hydrogen sulphide
KAA = Kitimat Airshed Assessment
KMP = Kitimat Modernization Project
PM2.5 = Particulate matter that is 2.5 microns in diameter and smaller
PM10 = Particulate matter that is 10 microns in diameter and smaller
SO_4^{2-} = sulphate ion ; SO_3^{-} = sulphite ion
STAR = 2013 SO2 Technical Assessment Report

Outline of Presentation

I. **Context and background**
   a. The STAR and EEM Program
   b. The 2017 EEM Annual Report
II. **What was done and learned in 2017**
   a. Atmospheric Pathways
   b. Human Health
   c. Vegetation
   d. Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)
   e. Terrestrial Ecosystems (Soils)
III. **Plans for 2018**
IV. **2019 Comprehensive Review**

I. Context and Background on the STAR and the EEM Program

I. Background – STAR and EEM

Step in Process	2011	2012	2013	2014	2015	2016	2017	2018	2019
STAR - predicted effects of KMP									
Design of EEM Program									
Implementation of EEM - actual effects of KMP									
Annual reports to MOE, Haisla, KPAC, public									
Required adjustments to monitoring or mitigation									
Comprehensive Review of EEM									

I. Background – STAR and EEM

EEM Plan, pg. 1

Purpose of EEM Program:

- answer questions that arose during the STAR
- monitor effects of SO_2
- consider changes to impact ratings, monitoring
- make decisions regarding need for mitigation

Results from STAR

Low	No impact or acceptable impact **(Vegetation)**
Moderate	Acceptable impact but in need of closer scrutiny **(Health, Soils, Water)**
High	Unacceptable impact; mitigation action **[No findings in this category]**
Critical	Extremely unacceptable impact; mitigation action needed **[No findings]**

I. Background – STAR and EEM

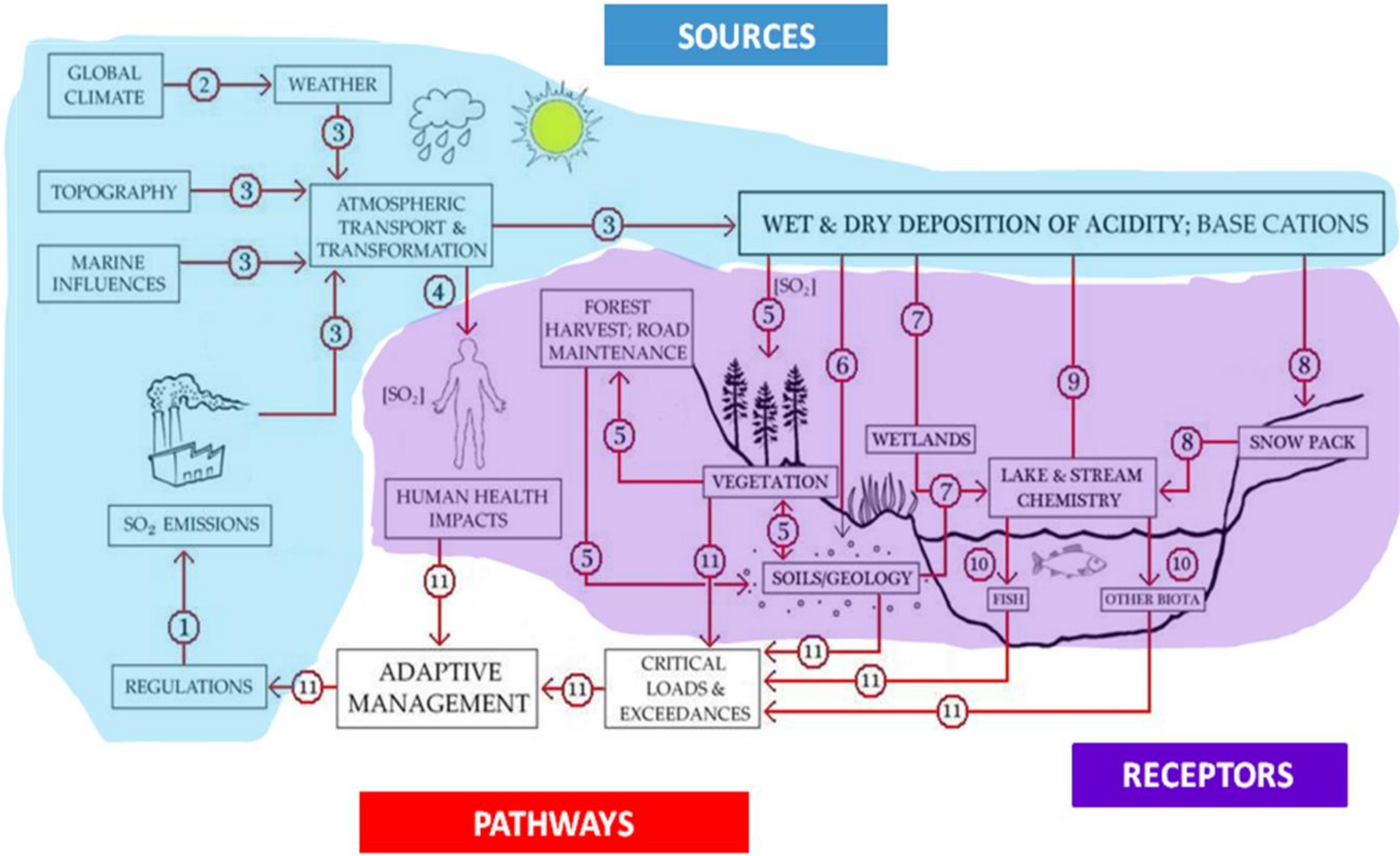
EEM Plan, pg. 1

Focus of EEM Plan

- EEM plan focuses on **first 6 years (2013-2018)**.
- What is learned during this period will be applied to **improve the EEM Program in 2019**.
- **More intensive monitoring** or **mitigation actions** may be undertaken at any time if thresholds are triggered.

I. Background – STAR and EEM

STAR



I. Background – EEM Annual Report

Structure of 2017 EEM Annual Report

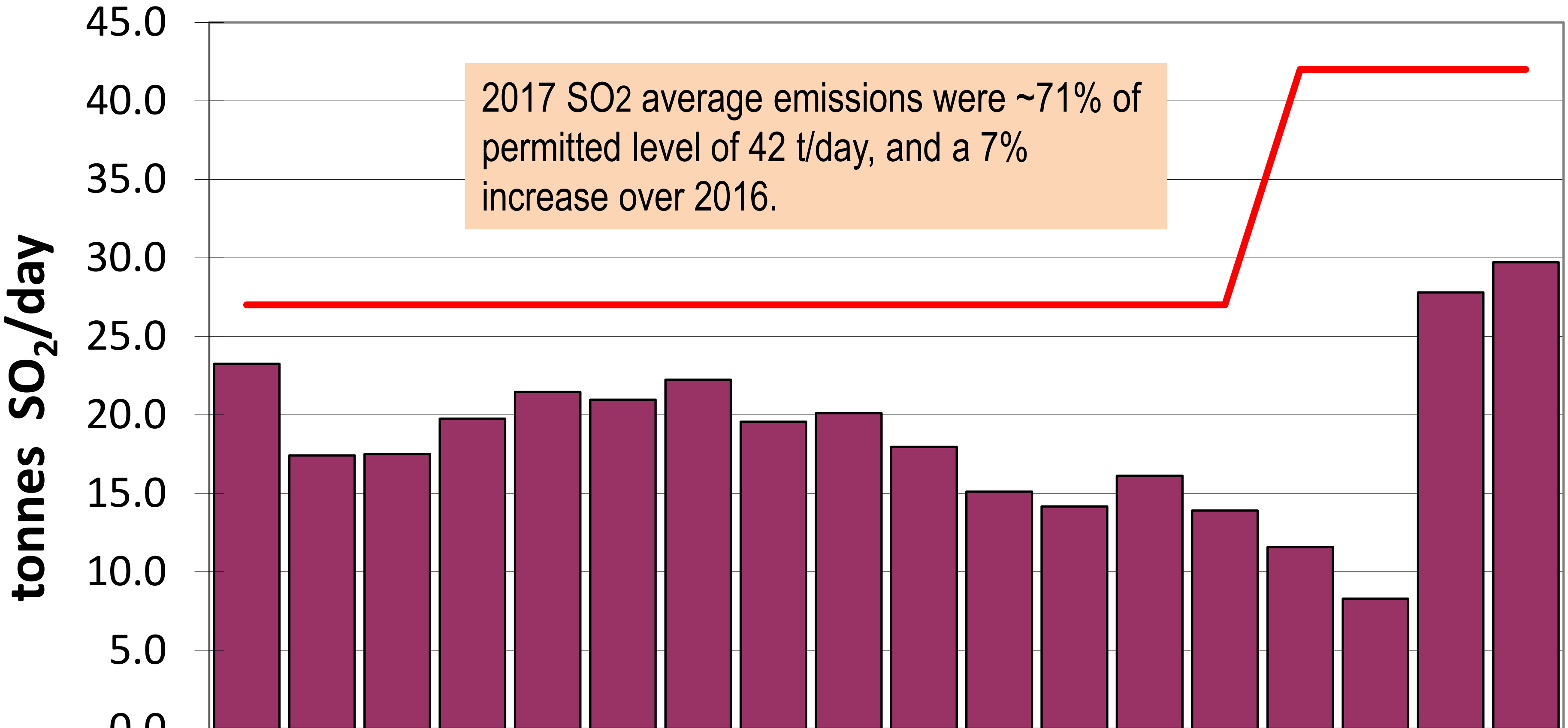
- Summary of EEM Actions
- Facility Emissions
- EEM Activities, by Receptor
- Reports Cited
  - STAR, EEM Plan, KAA, Laurence, Limnotek, Stantec
- EEM Technical Memos Cited
  - Passive Monitoring, Dry Deposition, Soils, Water, Filter Packs

II. What was done and learned in 2017 through the EEM Program

Facility Production and Emissions

2017 EEM Report, p. 3

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
Average	23.3	17.4	17.5	19.8	21.4	21.0	22.2	19.6	20.1	18.0	15.1	14.2	16.1	13.9	11.6	8.3	27.8	29.7
Limit	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	42.0	42.0	42.0	42.0

II-a. Atmospheric Pathways

2017 EEM Report, p. i

2017 EEM Actions

Topic	The commitment	What was done	Where to learn more
Atmospheric Pathways			
Atmospheric SO_2 concentration	Maintain existing four continuous SO2 analysers Compare to model output Implement the monitoring network optimization according to the Terms of Reference drafted in 2015 Initiate a new air quality study to provide input to the network rationalization study in 2020	Data were collected and analyzed from four analyzers, and compared to model output. Have begun network rationalization study and new air quality study in 2018	Section 3.1

II-a. Atmospheric Pathways

2017 EEM Report, p. i

2017 EEM Actions

Topic	The commitment	What was done	Where to learn more
Atmospheric Pathways			
Atmospheric SO_2 concentration	Continue the passive monitoring program	Passive samplers were deployed and analyzed in the Kitimat valley and urban area during 2017 (same sites as 2016).	Section 3.1 Tech P03, P04, P05
	Monitoring of particulate SO_4	Filter packs deployed during two campaigns at 3-4 stations	Tech F01

II-a. Atmospheric Pathways

2017 EEM Report, p. i

2017 EEM Actions

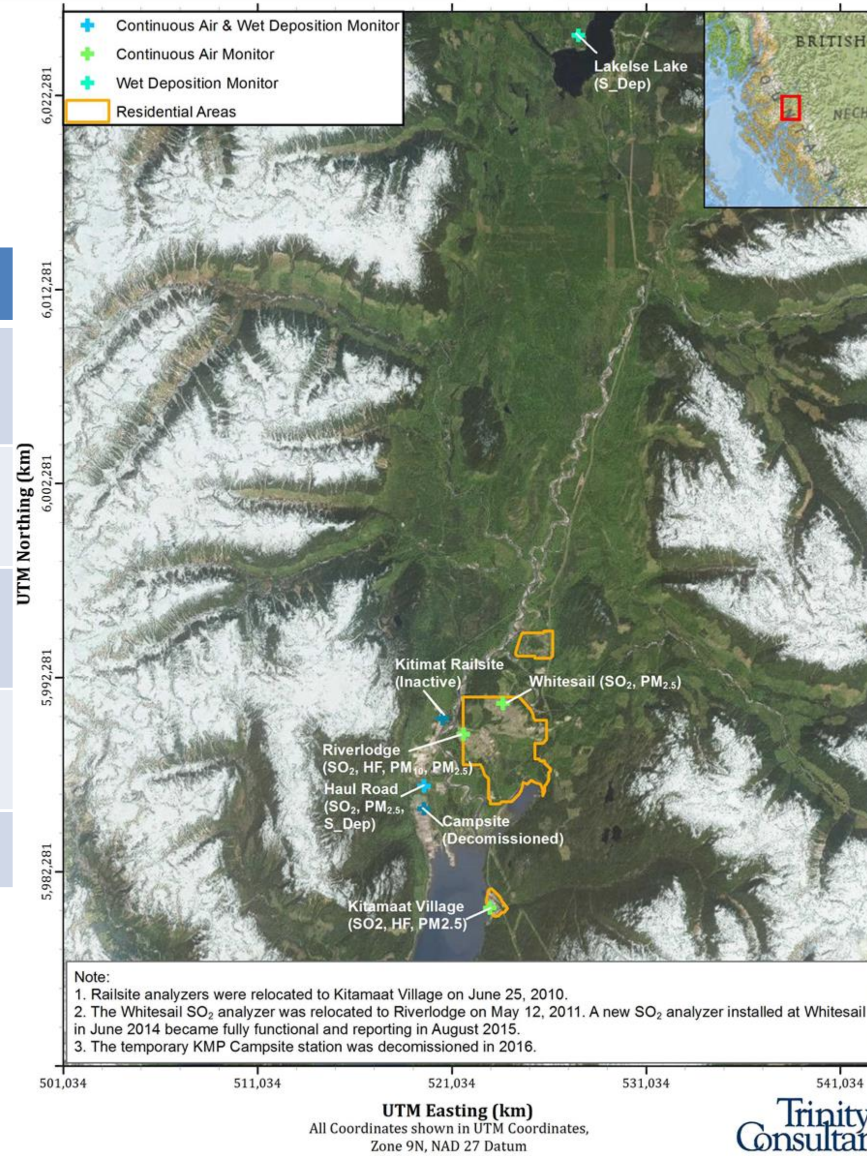
Topic	The commitment	What was done	Where to learn more
Atmospheric Pathways			
Wet deposition	Maintain two rain chemistry stations (Haul Road and Lakelse Lake)	Operation continued at both stations, and precipitation chemistry data for 2017 are included in this report.	Section 3.1
Dry deposition	Install a continuous SO2 monitor at Lakelse Lake station Estimate dry deposition at both the Haul Road and Lakelse Lake continuous SO2 monitor stations	An engineering project was scheduled to install an SO2 analyzer in summer 2018. Dry deposition was estimated at Haul Rd.	Section 3.1, D02

II-a. Atmospheric Pathways

2017 EEM Report, p. 5

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	



Trinity Consultants

II-a. Atmospheric Pathways

2017 EEM Report, p. 4

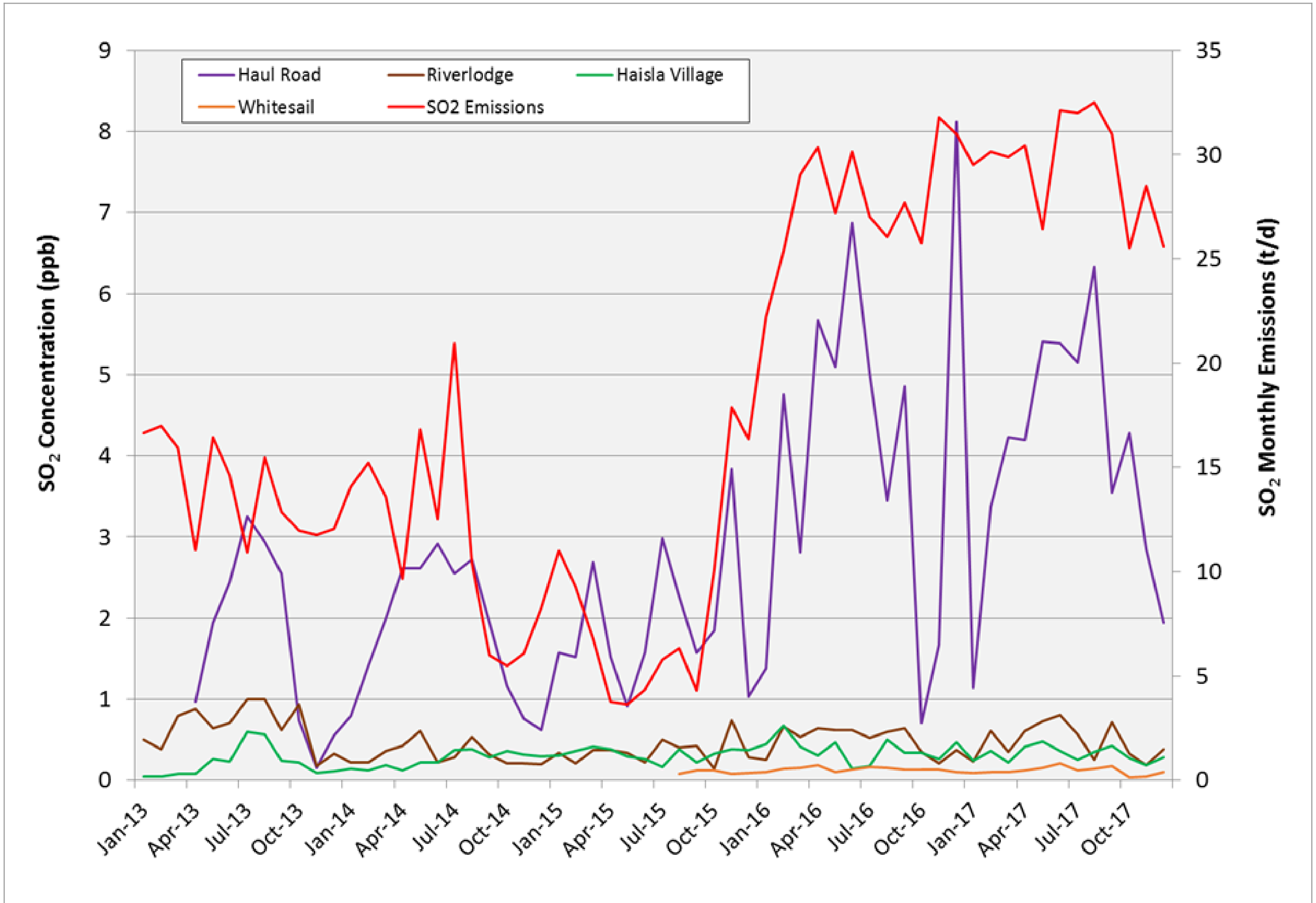
SO_2 Concentrations

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

II-a. Atmospheric Pathways

2017 EEM Report, p. 6

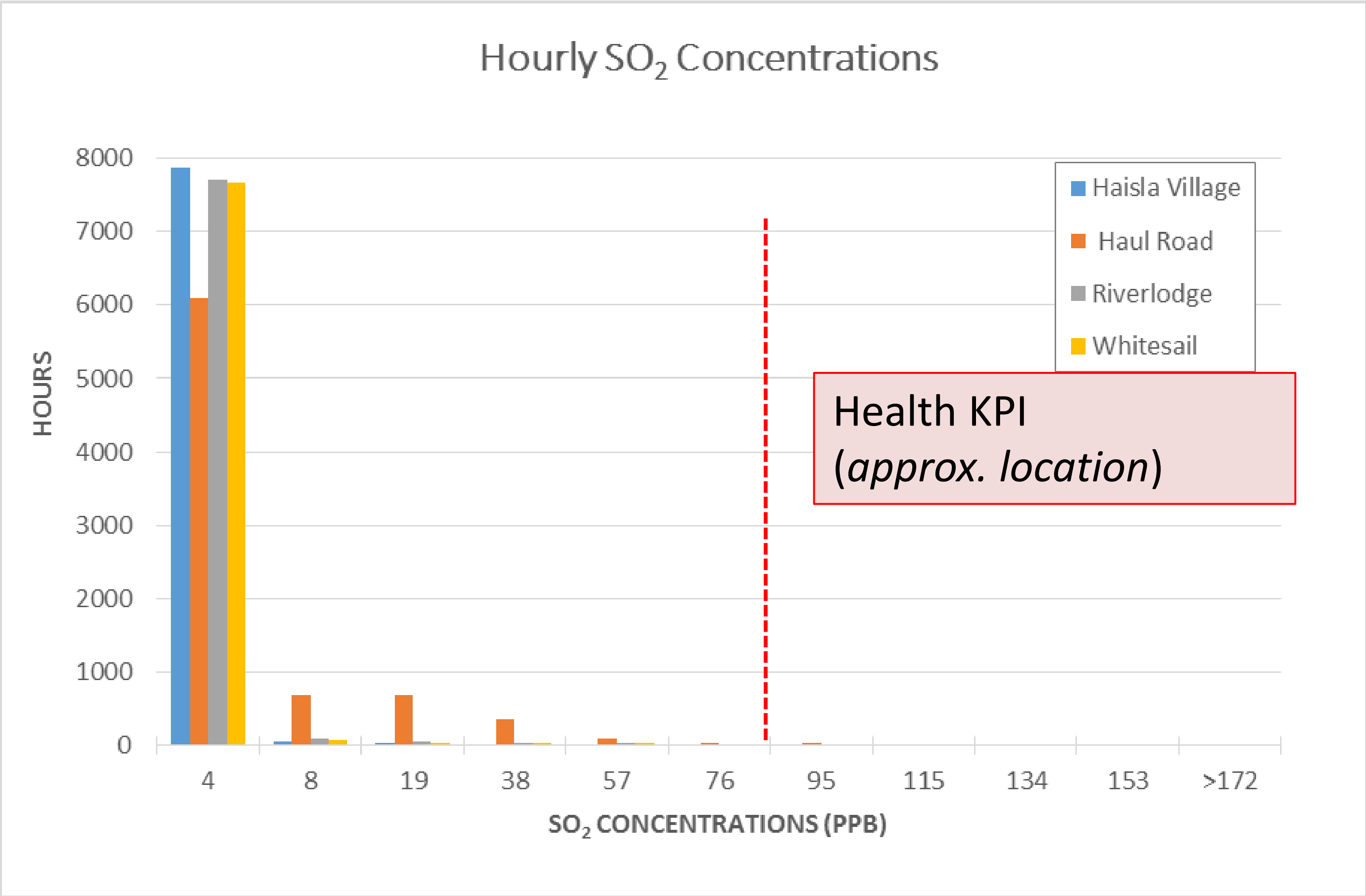
Monthly Avg. [SO_2] and Total SO_2 Emissions



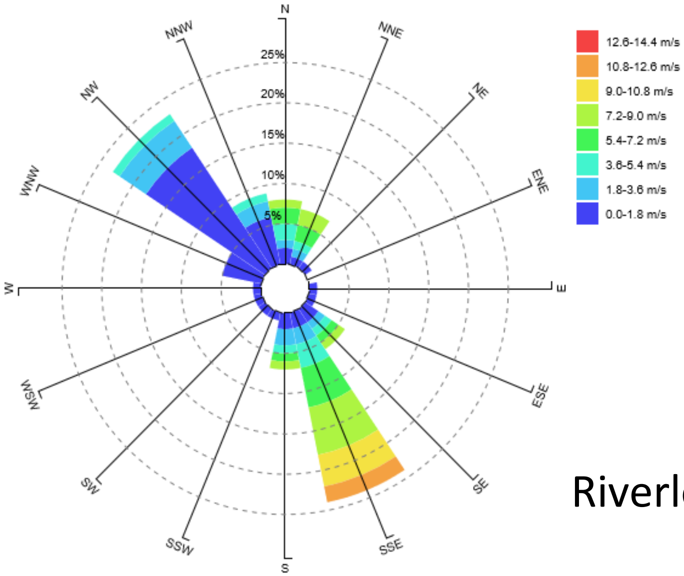
II-a. Atmospheric Pathways

2017 EEM Report, p. 7

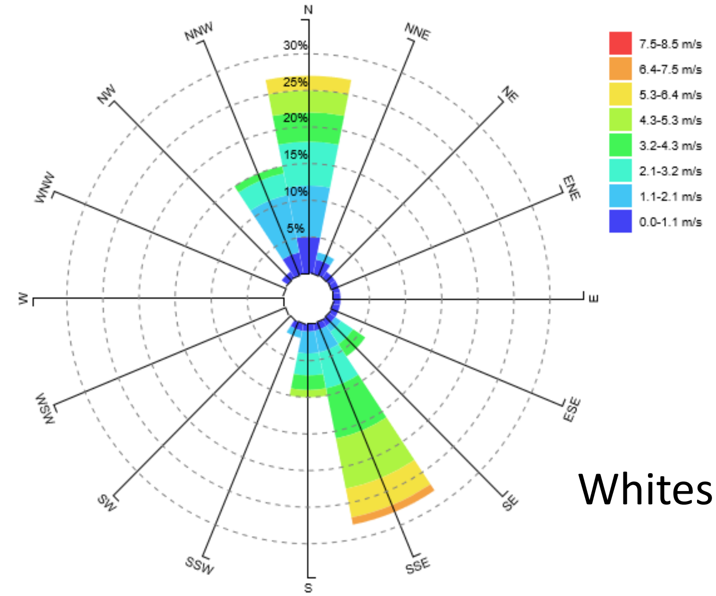
Hourly SO_2 Concentrations in 2017



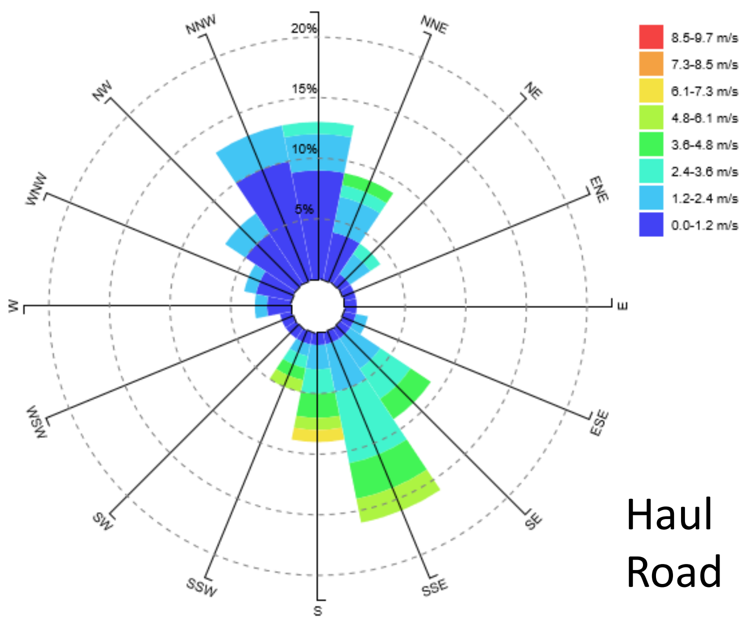
II-a. Atmospheric Pathways – Winds in 2017



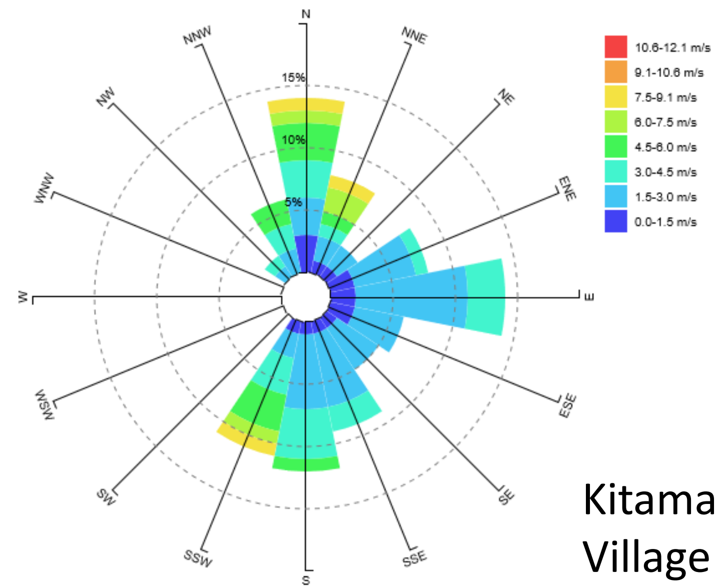
Riverlodge



Whitesail



Haul Road

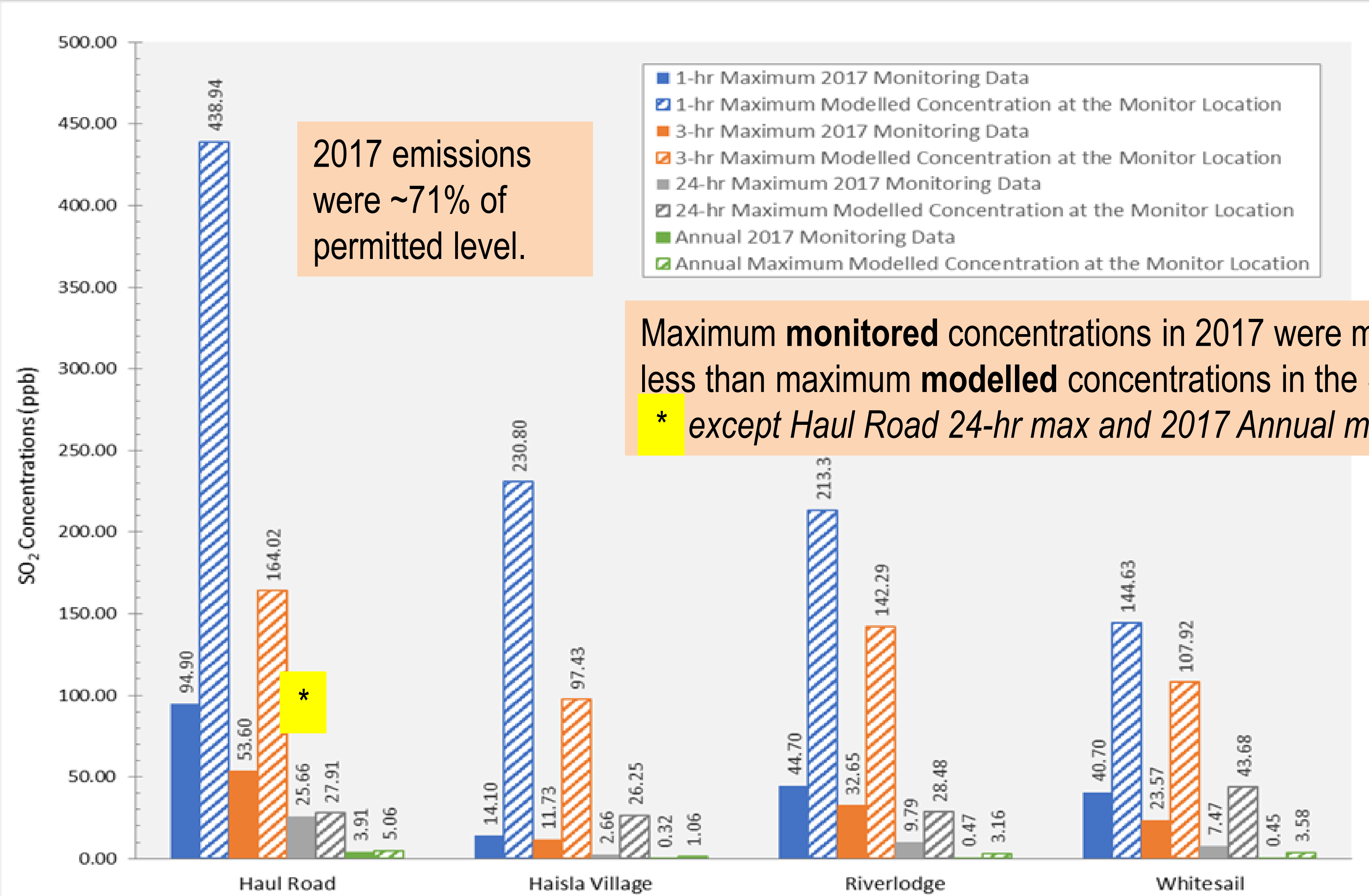


Kitamaat Village

II-a. Atmospheric Pathways

2017 EEM Report, p. 10

2017 SO_2 Concentrations – Monitored vs. Modelled



2017 emissions were ~71% of permitted level.

Maximum **monitored** concentrations in 2017 were much less than maximum **modelled** concentrations in the STAR

* *except Haul Road 24-hr max and 2017 Annual max*

II-a. Atmospheric Pathways

2017 EEM Report, p. 8

2017 SO_2 Concentrations – Monitored vs. Modelled

- Residential areas
  - Short-term: maximum 2017 observations were up to 34% of maximum modelled predictions (1-hr, 3-hr, 24-hr)
  - Annual: 2017 observations were average (across 3 residential monitors) of 19% of modelled predictions

- Haul Road
  - 1-hr/3-hr: max. 2017 observation <50% of max. modelled predictions
  - 24-hr: maximum 2017 observation was 92% of max. modelled
  - Annual: 2017 observation was 70% of modelled prediction
  - Maximum observed concentrations <30% of max. modelled predictions at any other offsite location for any averaging period
  - Maximum observed SO_2 much closer to modelled (for annual and 24-hr time periods) at Haul Road than in residential areas

II-a. Atmospheric Pathways

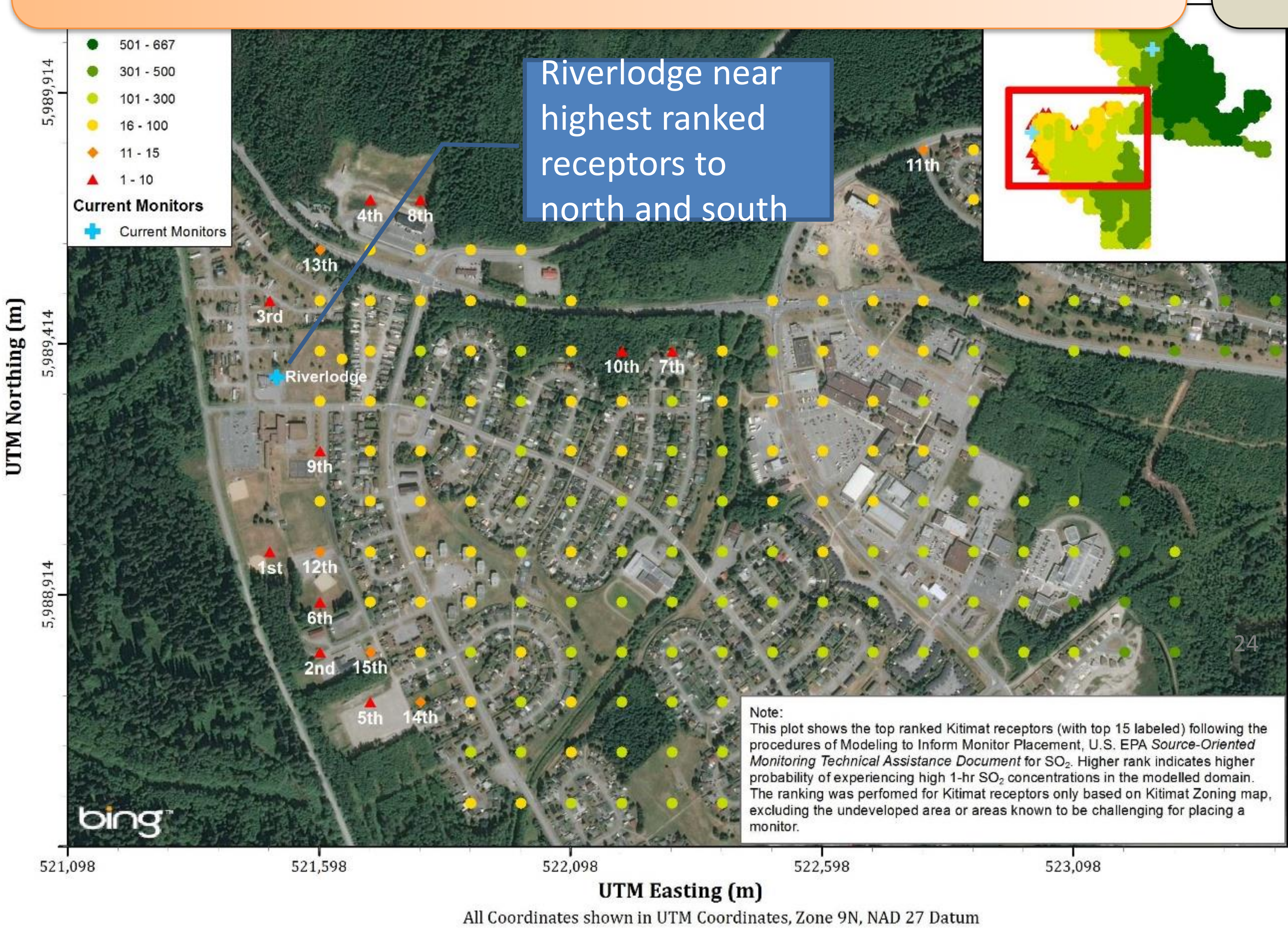
2017 EEM Report, p. 10

Network Optimization – Phase 1

- Network evaluation completed to meet SO2 EEM commitment, based on available data:
  - 2006, 08, 09 NoMM5 Model results
  - Post-KMP Monitoring data (continuous and passive sampling)
- Concludes Riverlodge & Kitamaat Village stations in good locations to continue to represent highest SO2 levels.

II-a. Atmospheric Pathways

2017 EEM Report, p. 10



II-a. Atmospheric Pathways

2017 EEM Report, p. 10

Second phase Network Optimization

- New dispersion modeling with 3 years post KMP meteorology
- Supported with actual air quality measurements in an Air quality study / exploratory monitoring using
  - Continuous monitors
  - Roaming station
  - Passive monitoring
- Draft Terms of Reference for network optimization being updated, to include:
  - air quality study
  - Comments from June 2016 air quality workshop
  - How study's exploratory monitoring will be used

II-a. Atmospheric Pathways

2017 EEM Report, p. 10

Passive Sampling Network – Atmospheric SO_2

- Previous pilot study recommended:
  - IVL passive SO_2 samplers with 1-month exposure period
- 2 networks of passive samplers redeployed in 2017
  - Following same protocol and locations as 2016
  - 20 sites in Kitimat Valley (established June 6)
    - primarily along Wedeene and Bish roads (plume path)
    - Included co-location with ambient (continuous monitoring) stations (Haul Road, Riverlodge, Whitesail[†])
  - 13 sites in urban and residential areas (established July 10)

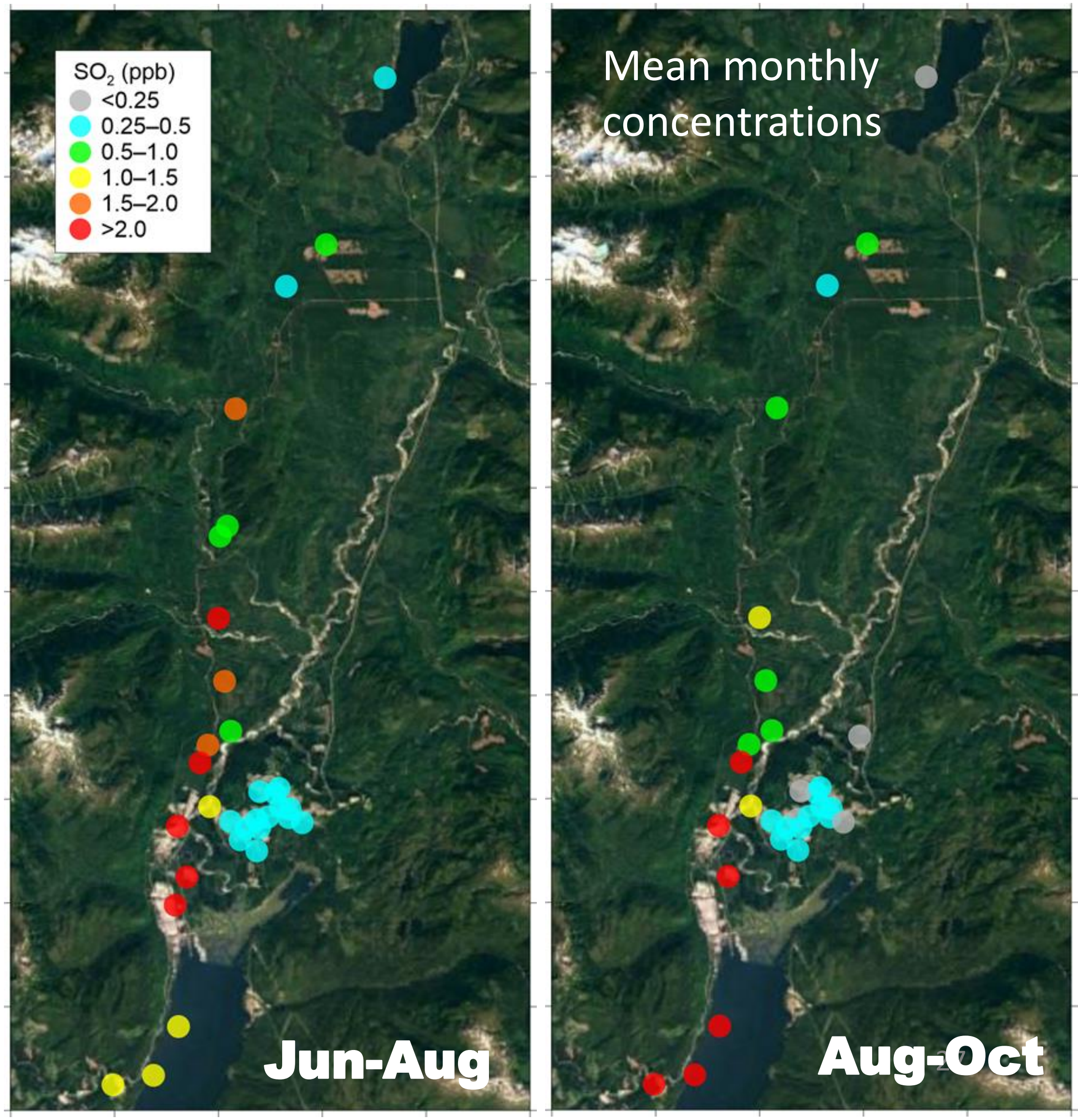
[†] *Whitesail sampler was deployed in July*

II-a. Atmospheric Pathways

2017 EEM Report, p. 11

SO_2 Passive Sampling Network

- 140 exposures across 2 networks
  - 3 one-month exposures within each network
  - 3rd deployment in Valley was 2-month
- Replicate samplers deployed >25% of time
- Elevated SO_2 along plume path
  - >4 ppb observed at Rifle Range in June-July
  - >6 ppb observed at Bish Road in Aug-Oct
- All monthly exposures in urban/residential network <0.5 ppb



II-a. Atmospheric Pathways

2018 Work Scope

2018 SO_2 Passive Sampling Urban Network

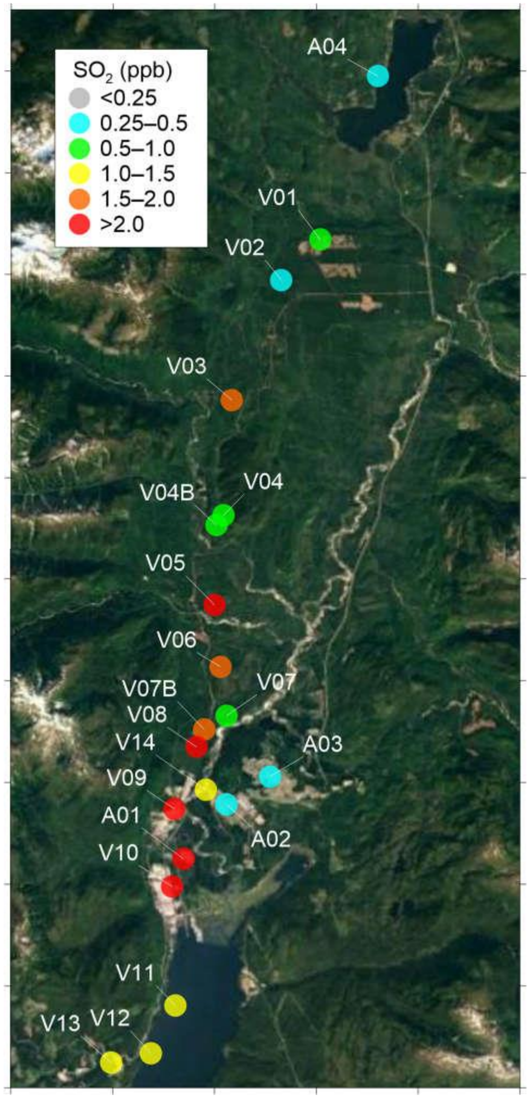
- Objectives:
  - assess the spatial and temporal variability of SO_2 in urban Kitimat
  - Support the AQM network optimization through identifying SO_2 ‘hot-spots’
- IVL passive SO_2 samplers
- 20+ sample sites, 20% duplicates.
- Consistent application of draft BC passive sampling guideline (2018).
- Monthly exposures over 12 months

II-a. Atmospheric Pathways

2018 Work Scope

2018 SO_2 Passive Sampling Valley Network

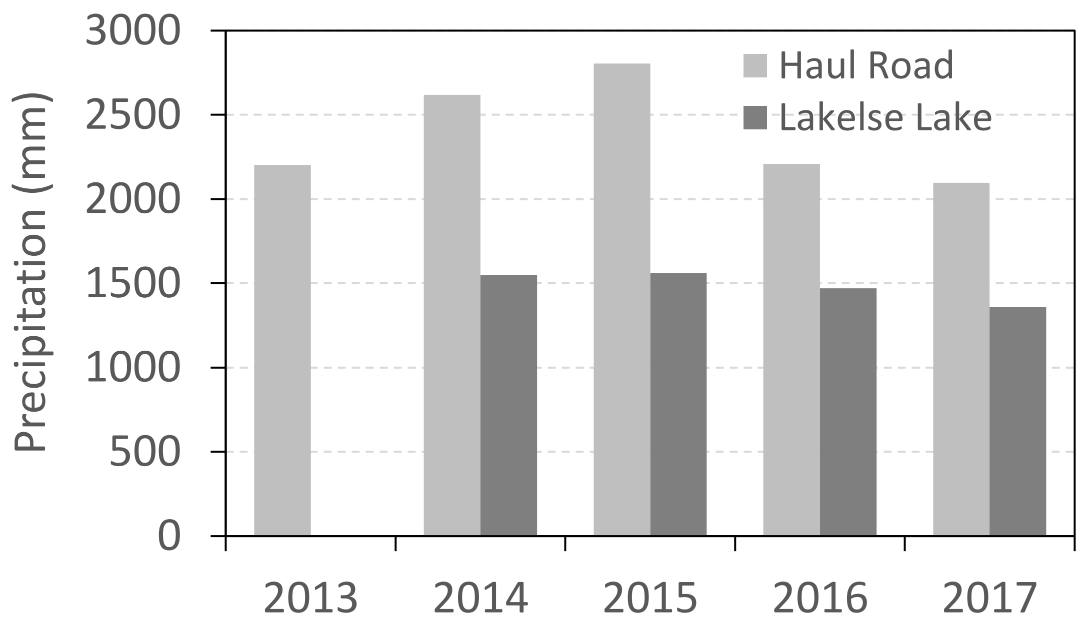
- Objectives:
  - assess the spatial and temporal variability of SO_2 in urban Kitimat
  - Support the AQM network optimization through identifying SO_2 'hot-spots'
- IVL passive SO_2 samplers
- 20 sample sites, 20% duplicates.
- Generally follows draft BC passive sampling guideline (2018).
- Monthly exposures June to October



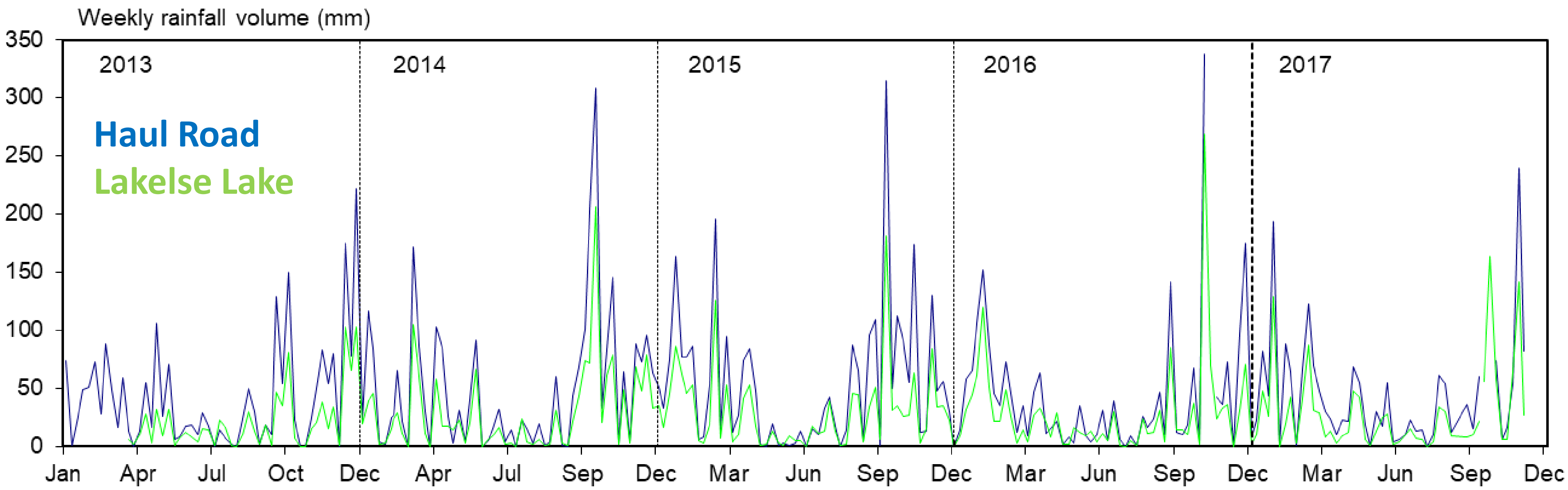
II-a. Atmospheric Pathways

2017 EEM Report, p. 13

Rainfall Volume



Source: NADP
nadp.sws.uiuc.edu



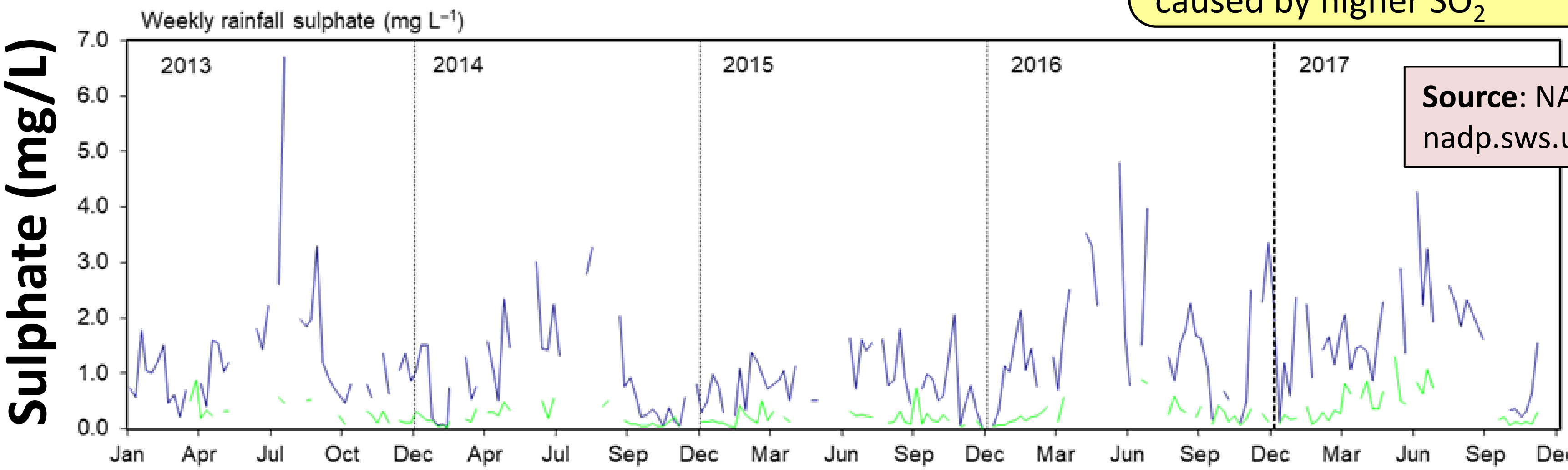
II-a. Atmospheric Pathways

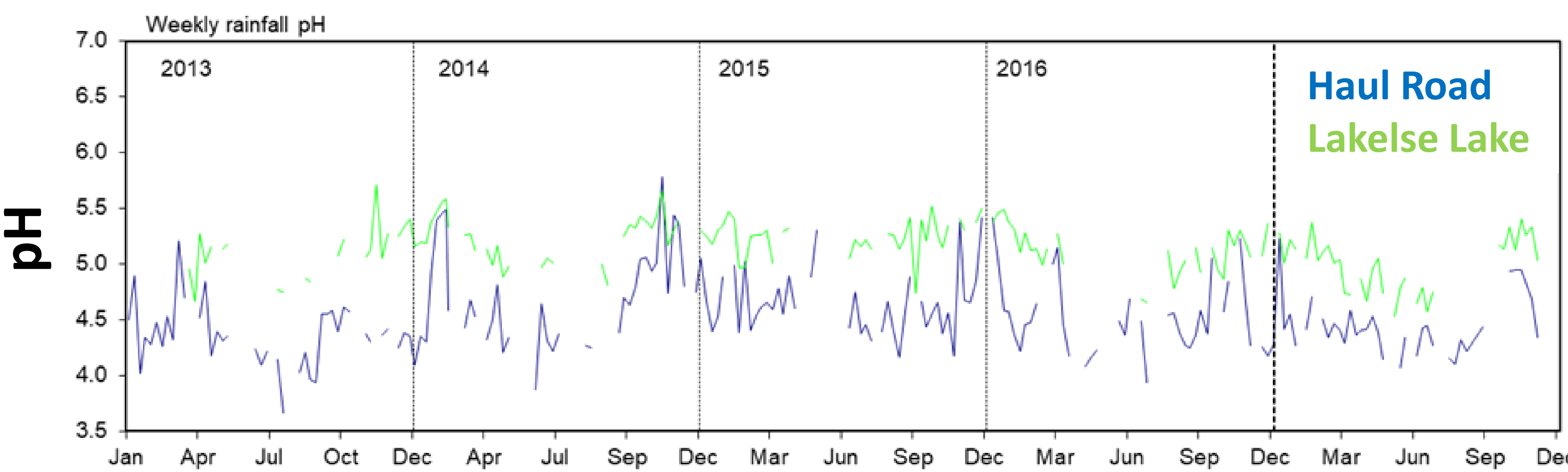
2017 EEM Report, p. 14

Wet Deposition – Precipitation Chemistry

Haul Road → higher sulphate and lower pH than at Lakelse Lake, caused by higher SO_2

Source: NADP
nadp.sws.uiuc.edu





II-a. Atmospheric Pathways

2017 EEM Report, p. 15

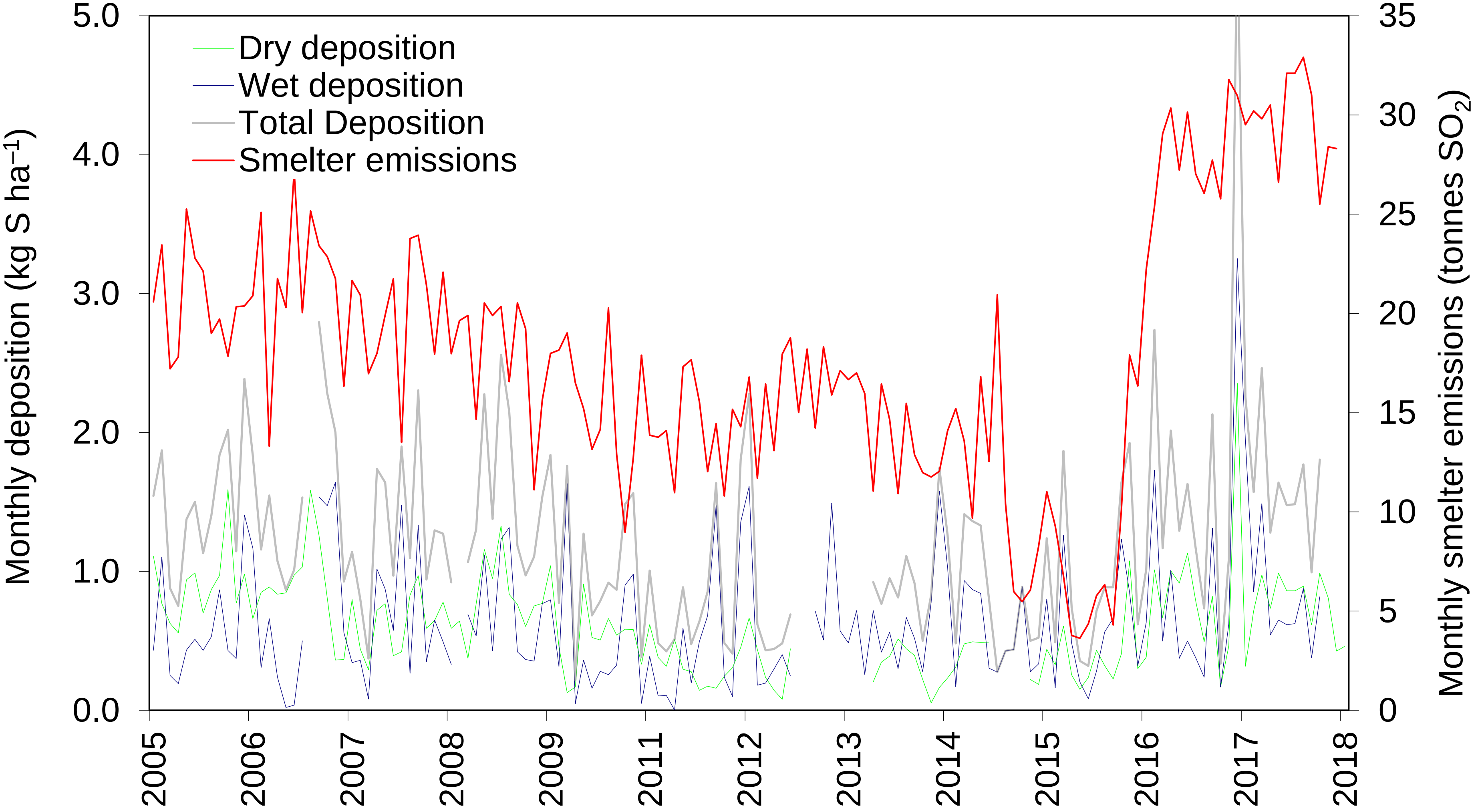
Dry Deposition

- Environment Canada model to estimate dry deposition (Zhang et al., 2003, 2014)
- Preliminary estimates of dry deposition at Haul Road calculated for 2005 to 2017

II-a. Atmospheric Pathways

2017 EEM Report, p. 15

Dry and Wet Deposition at Haul Road



II-b. Human Health

2017 EEM Report, p. i

2017 EEM Actions

Topic	The commitment	What was done	Where to learn more
Human Health			
Atmospheric SO_2 concentrations	Report on the Health KPI	The SO2 Health KPI has been calculated for all three residential stations.	Section 3.2

II-b. Human Health

2017 EEM Report, p. 16

Health Key Performance Indicator

- Province-wide interim SO_2 ambient air quality objective (AAQO) adopted December 15, 2016
- SO_2 AAQO to be used as Health KPI for EEM beginning in 2017

II-b. Human Health

2017 EEM Report, p. 16

Health Key Performance Indicator

- Threshold residential SO_2 ambient air concentration of 75 ppb
- Uses daily one-hour average maximum (D1HM)
- Three-year average of the X^{th} percentile (as below) of D1HM

Evaluation Year	Indicator	Threshold (SO_2)	Percentile	Evaluation Period
2017	D1HM	75 ppb	97.0	2015-2017
2018	D1HM	75 ppb	97.5	2016-2018
2019	D1HM	75 ppb	98.0	2017-2019
2020 onwards	D1HM	70 ppb	99.0	Previous 3 years

- Allowance of a one-time exceedance of 75 ppb threshold (up to max of 85 ppb) over the 3-year interim period

II-b. Human Health

2017 EEM Report, p. 16

Results for SO_2 Health KPI for 2017

- Health KPI started to apply in 2017

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

* Daily 1-hour average maximum

** The Whitesail 2017 health KPI calculation uses a 2-year average.

II-c. Vegetation

2017 EEM Report, p. i-ii

2017 EEM Actions

Topic	The commitment	What was done	Where to learn more
Vegetation			
Vegetation survey	Per the EEM, the vegetation survey and inspection were not scheduled for 2017		
	Continued vegetation sampling as described in Laurence (2010)	Vegetation sampling was accomplished as planned.	Section 3.3
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 Sulphur analysis from August 28-September 1, 2017 by Stantec Consulting Ltd. Sulphur analysis was conducted by Rio Tinto, Jonquière, Québec.	Section 3.3 Stantec (2018)

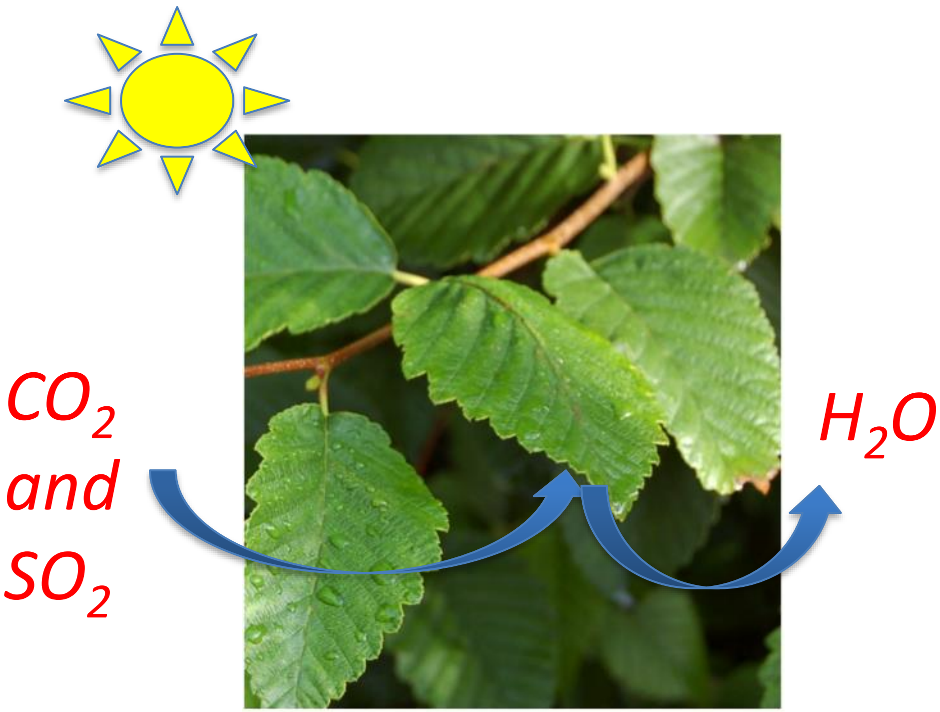
II-c. Vegetation

Background

- The vegetation monitoring and assessment program was initiated in 1970
- The program consists of 2 components and addresses both sulphur and fluoride
- Chemical Analysis Component—western hemlock is sampled every year and analyzed for S and F to provide an indicator of level of emissions taken up by plants
- Visual Assessment of Plant Health Component—every other year, a visual assessment of vegetation health is conducted and includes many species—not just western hemlock

II-c. Vegetation

Uptake of Air Pollutants by Plants



HF and SO_2 are taken up from the air along with CO_2, riding along as part of photosynthesis. It enters through stomata, small pores in leaves.

If concentrations are great enough, the SO_3^{-} ion can be directly toxic. Otherwise, SO_2 supplies S to the plant for use in metabolism or is stored as SO_4^{2-}. If too much SO_4^{2-} accumulates, symptoms occur.

F^{-} moves in the transpiration stream to the margins or tips of leaves

S is an essential element and occurs at relatively high background concentrations—0.05 to 0.2% is not unusual.

F is not useful to plants and occurs in low concentrations in plant tissues—generally < 10-15 ppm

II-c. Vegetation

Visible Injury

Visible injury of sensitive species is used as an indicator of the magnitude and extent of the growing season exposure

Above: Mugo pine and alpine currant at the administration building in Kitimat in 2014

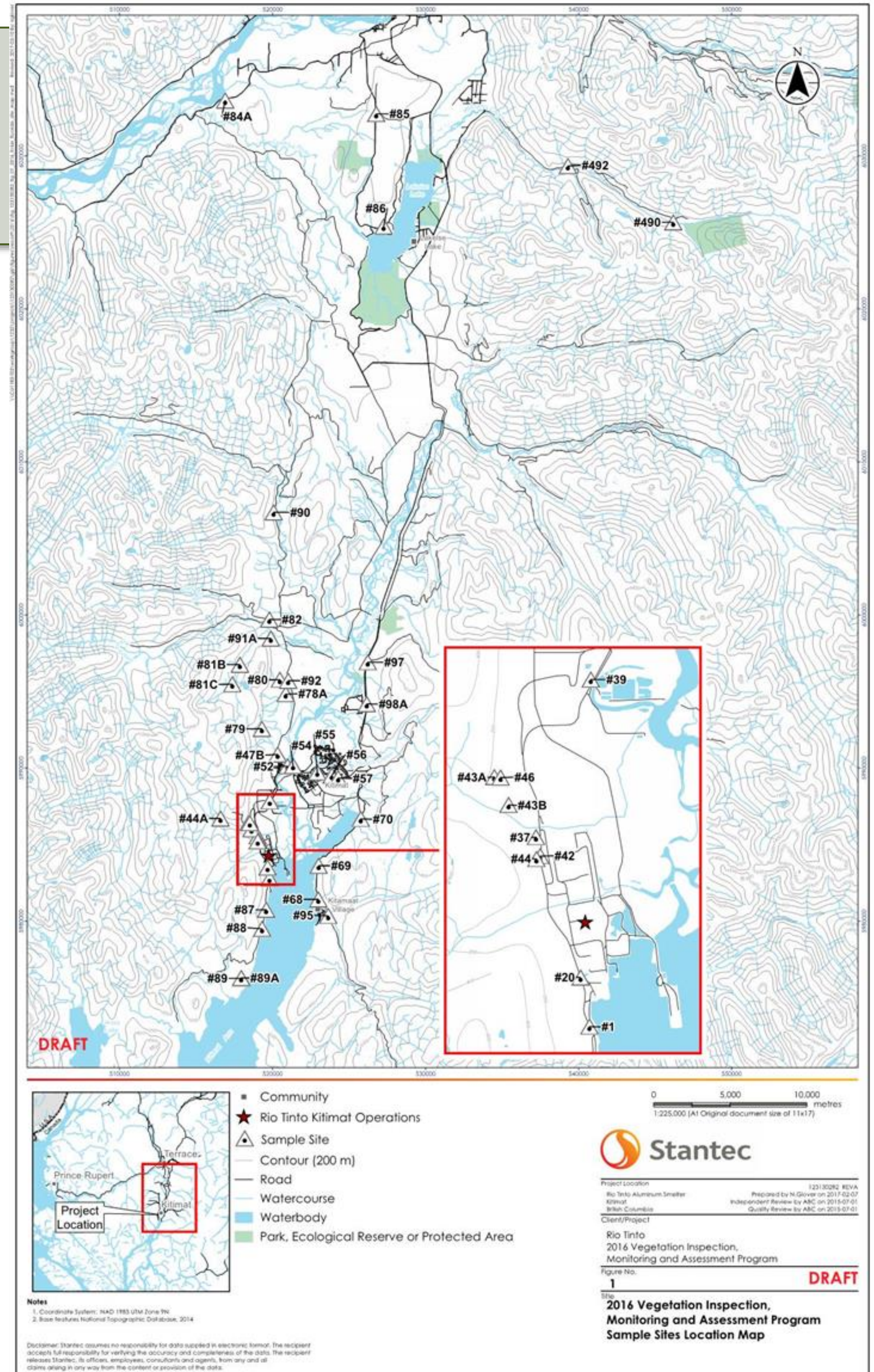
Left: Photo from near a coal-fired electricity generating facility in Indiana, USA. I have not observed SO_2 injury at Kitimat in my visits starting in 1999.

II-c. Vegetation

Vegetation Survey and Sampling

- Aug 28 – Sept 1, 2017
- Site and sample-tree assessment checklist implemented
- Sampling of western hemlock needles for lab analysis of S content

2017 EEM Report, p. 17



II-c. Vegetation
What was learned

2017 EEM Report, p. 27

Field Observations

- General condition of vegetation similar to condition reported previously
- Hemlock wooly adelgid persists at low intensity
- Trees at some sites showed chlorosis, but within expected levels based on site and time of year
- Other pest and pathogen activity generally at low level

II-c. Vegetation

What was learned

2017 EEM Report, p. 17

Sulphur Concentration in Hemlock Needles

- 2017 S concentration ranged from 0.05% to 0.14%
  - 2 sites added as reference sites, at request of MOE
  - All values within range of background concentrations reported in literature (including western hemlock)
  - Recall: 2015 was same as 2011, 2013, 2014
- Comparison of 2017 values to historic site averages (1998-2011)
  - Only 1 site exceeded historic mean (<1 SD)
- Comparison of 2017 values to 2015 values (low SO_2)
  - 22 sites with increases (8 sites >1 SD)
  - 15 sites with decreases
  - No sites had post-KMP means (2016, 2017) that exceeded historic mean
- EEM informative indicator was not exceeded

II-c. Vegetation
What was learned

Fluoride Concentration in Hemlock Needles

- 2017 F concentration ranged from 2 to 16 ppm
- Concentrations exceeded 10 ppm—historically considered background—at only 4 sites near the smelter
- All sites had concentrations below the 10 year mean
- Results are in line with what would be expected from a decrease of about 1/3 in F loadings.

II-c. Vegetation
What was learned—Analysis of F

Analytical Issues for F

- F is relatively difficult to analyze and there are few labs outside the industry who conduct the analysis
- For the past few years, anomalies appeared in F analysis
- For instance, starting in 2014, the number of sites with values below 10 and 20 ppm dropped by about half
- In 2015 when emissions were at a low, vegetation results increased over what they had been in the past.
- The RT lab discovered a problem with their analysis equipment
- RT Kitimat sponsored an inter-lab study, reanalyzing archived samples of western hemlock.

II-c. Vegetation
What was learned—Analysis of F

Inter-lab Study

- Archived samples of western hemlock submitted to 3 labs—RT in Jonquière, PQ, BC MOECCS in Victoria, and Aluminere Alouette in Sept-Îles, PQ
- Each lab analyzed the samples for F using their standard method. RT and BC MOECCS analyzed for S
- No differences were found in the results from the three labs. There is considerable variability in F results, comparable to that reported in previous inter-lab studies.
- The RT lab is assessing previous results to determine if the failure of a laboratory device resulted in artificially high results for 2014-2016.

II-d. Soils

2017 EEM Report, p. ii

2017 EEM Actions

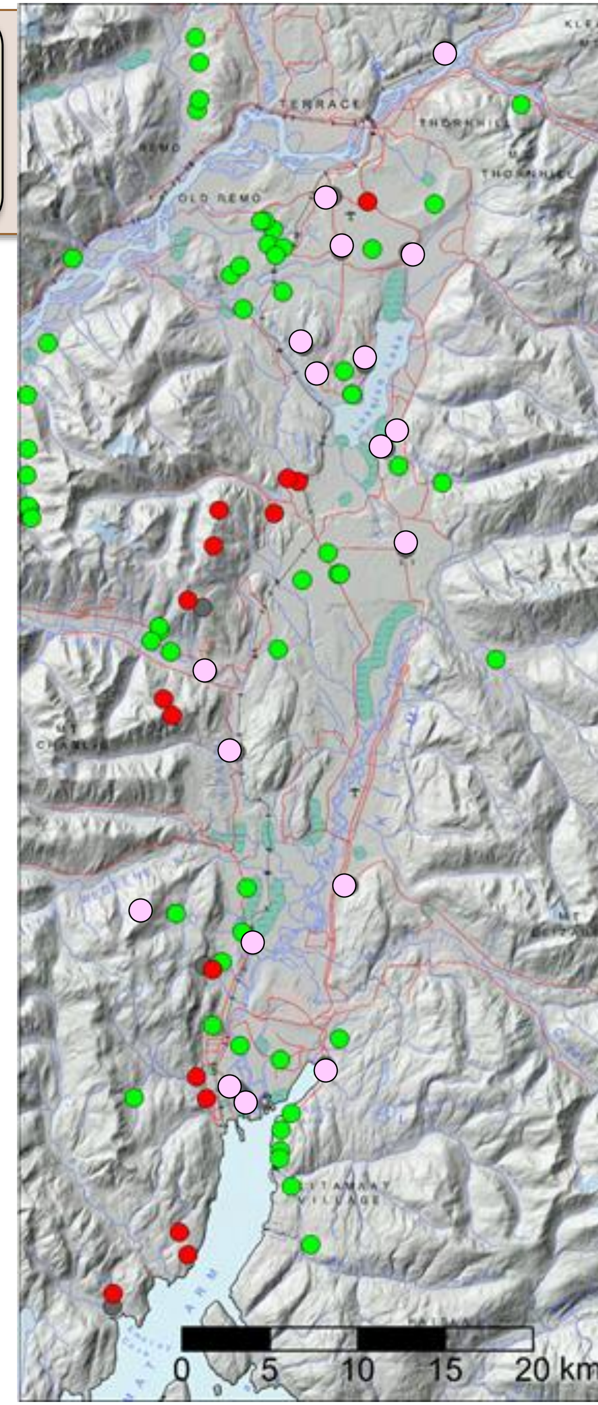
Topic	The commitment	What was done	Where to learn more
Terrestrial Ecosystems (Soils)			
Soil modelling	Re-do analysis for risk of CL exceedance, adding data from the new sites sampled in 2016	This work is scheduled for 2018.	Section 3.4
Permanent soil plots	Chemical analysis of the 2015 soil samples for the primary plots	These analyses were completed.	Section 3.4 Tech S06, S07

II-d. Soils

2016 EEM Report, p. 24

Soil Modelling

- Re-do analysis for risk of CL exceedance (adding new data)
  - Postponed to 2018
- Soil sampling sites
  - 2016 supplemental sites (n=15; red)
  - Previous soil samples (n=63; green)
  - LNG Canada soil samples (n=22; pink)
  - Total of 100 soil sampling sites



II-d. Soils – Permanent Plots

2017 EEM Report, p. 20

Permanent Soil Plots

Objective for 2017: Chemical analyses of composite soil samples for primary plots at Lakelse Lake and Coho Flats

- Soil samples collected during 2015 and 2016
  - 20 samples collected at 3 depths at each plot (120 total soil samples)

II-d. Soils – Permanent Plots

2017 EEM Report, p. 21

Analyses of Soil Samples

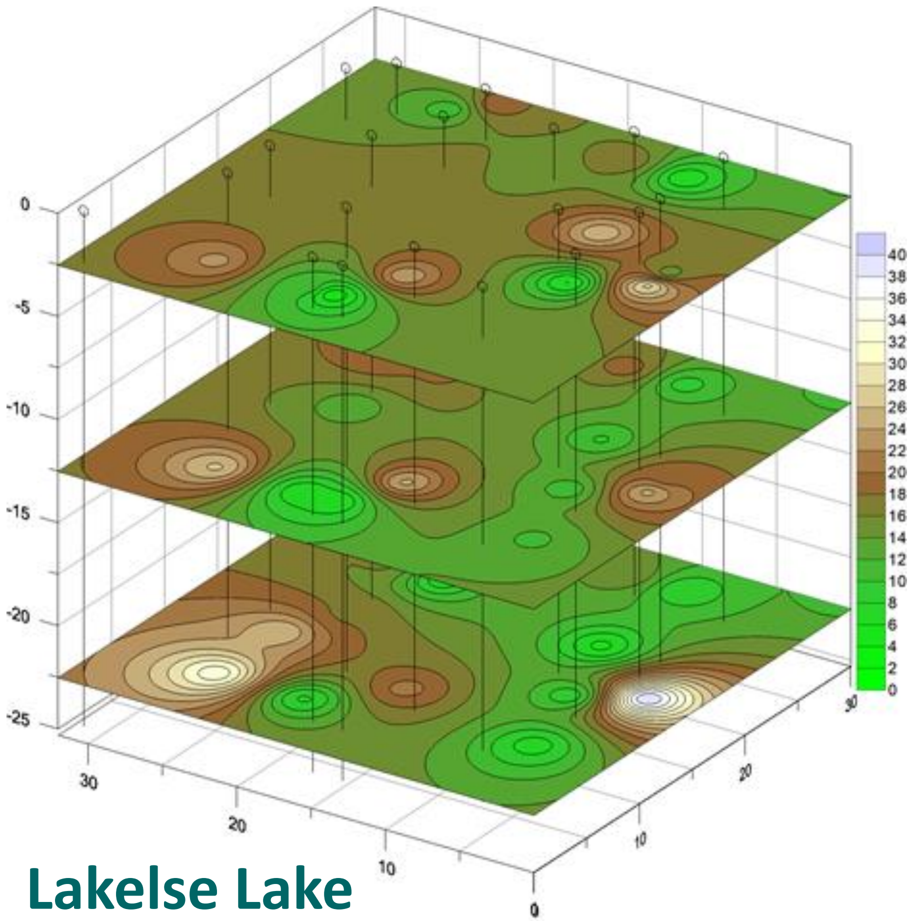
- Exchangeable cations
- Exchangeable acidity
- Base saturation
- Total cations or effective CEC (Cation Exchange Capacity)

II-d. Soils – Permanent Plots

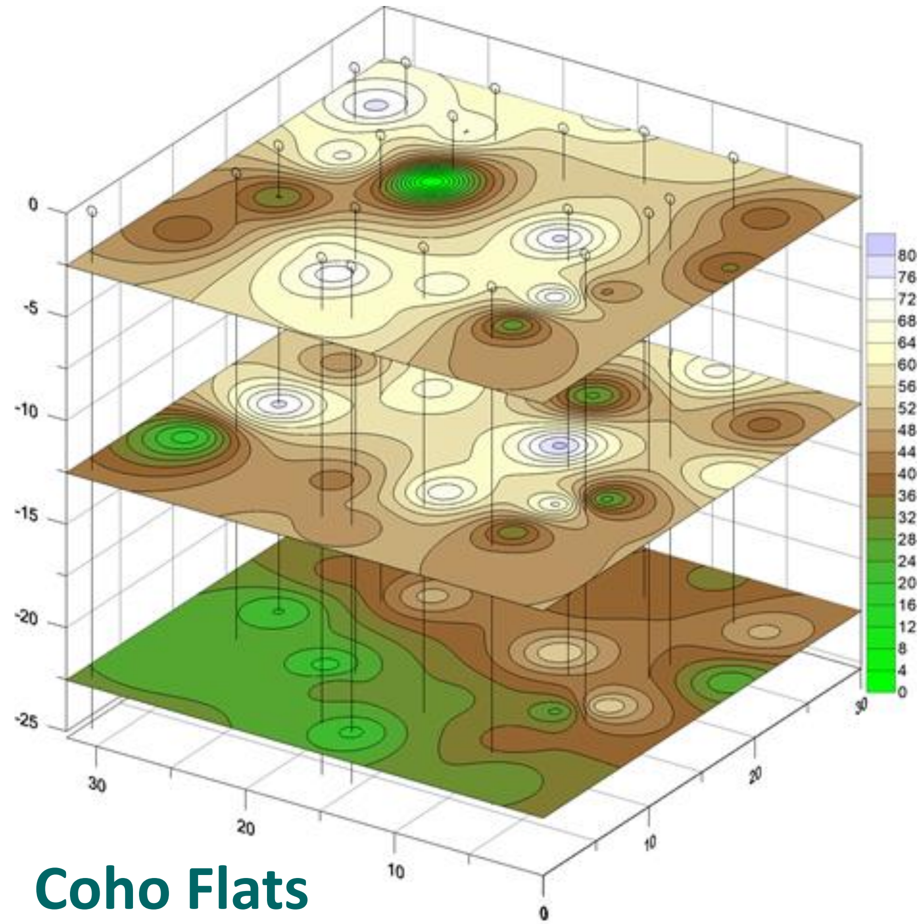
2017 EEM Report, p. 21

Soil Base Saturation

- Higher throughout all soil depths for Lakelse Lake



Lakelse Lake



Coho Flats

II-d. Soils – Permanent Plots

2017 EEM Report, p. 22

Soil Base Saturation

- Total cations (effective CEC) similar between plots
- Soils in Lakelse Lake has higher ability to neutralize acidic deposition than does Coho Flats

Soil Variable (meq/100g)	Coho Flats | Soil Depth (cm)			Lakelse Lake | Soil Depth (cm)		
	0–5	5–15	15–30	0–5	5–15	15–30
Cation Exchange Capacity	9.44	8.20	7.20	10.18	7.31	3.55
Base Saturation (%)	16.22	16.44	18.07	60.57	57.61	35.22

II-e. Freshwater – Overview

2017 EEM Report, p. iii

2017 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	This was completed. Intensive monitoring in 3 lakes continued, as did annual water chemistry sampling of 14 lakes, including 7 sensitive lakes, 3 insensitive lakes, 3 control lakes, and Lakelse Lake. There was weekly sampling of 6 of the 7 sensitive lakes during the fall sampling season; and vertical sampling of LAK028.	Section 3.5 Technical Memos W03, W06, W07 Bennet and Perrin (2018)
Fish sampling	Resample if the lake pH change reaches the threshold	Fish sampling was done in LAK028. No other fish sampling done.	Technical Memo W07 Bennet and Perrin (2018)

II-e. Freshwater – Overview

2017 EEM Report, p. iii

2017 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 West Lake, End Lake, Little End Lake and Anderson Creek. Episodic acidification work is continuing by Dr. Paul Weidman as an independent study from the EEM Program.	Section 3.5 Tech W07
Amphibians	Conduct a literature review of potential effects of acidification on amphibians in the Kitimat Valley	The literature review was conducted and is being finalized.	ESSA Technologies Ltd. (2017)

II-e. Freshwater – Overview

2017 EEM Report, p. 22; Tech Memo W07

Water Chemistry – Data Collection

- Annual monitoring samples for 11 EEM lakes
  - 7 sensitive, 3 less sensitive and Lakelse Lake
  - 3 control lakes (added to EEM Program in 2015)
- Intensive monitoring of sensitive EEM lakes
  - Multiple within-season (fall) samples collected for 6 lakes
  - Continuous monitoring of pH (spring through fall) for 3 lakes

II-e. Freshwater – Overview

2017 EEM Report, p. 22; Tech Memo W07

Lake	Group	Annual Sampling	Within-season Samples	Continuous pH monitoring
LAK006 (End Lake)	Sensitive	X	X	X
LAK012 (Little End Lake)	Sensitive	X	X	X
LAK022	Sensitive	X		
LAK023 (West Lake)	Sensitive	X	X	X
LAK028	Sensitive	X	X (from 2015)	
LAK042	Sensitive	X	X (from 2015)	
LAK044	Sensitive	X	X (from 2015)	
LAK007	Less sensitive	X		
LAK016	Less sensitive	X		
LAK024 (Lakelse Lake)	Less sensitive	X		
LAK034	Less sensitive	X		
DCAS014A	Control	X		
NC184	Control	X		
NC194	Control	X		

II-e. Freshwater – Overview

2017 EEM Report, p. 22 ; Tech Memo W07

Water Chemistry - Analyses

- Quality of water chemistry data
  - As per methods in STAR and KAA
  - Data of sufficient quality (results not presented)
- Inter-annual changes (2016 to 2017)
- Changes over observed record (2012-2017)

Other Freshwater Ecosystem Actions/Studies

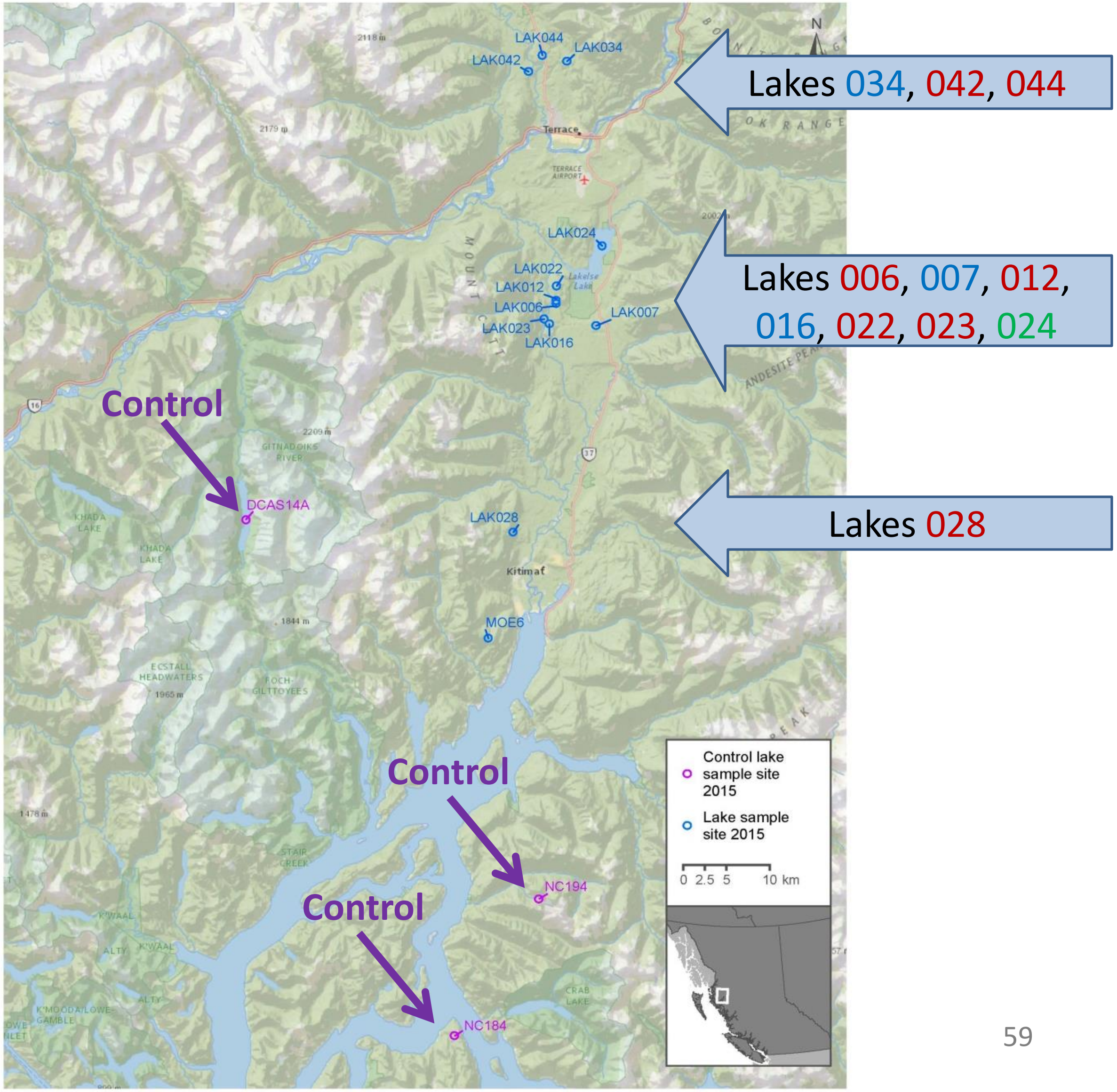
- Lake level monitoring in 3 lakes to better understand timing and magnitude of storm events
- LAK028 - fish sampling and water column chemistry
- Amphibians – literature of acidification impacts and potential pathways of effects

II-e. Freshwater – Methods/Results

Tech Memo W07

Lakes Sampled in 2017

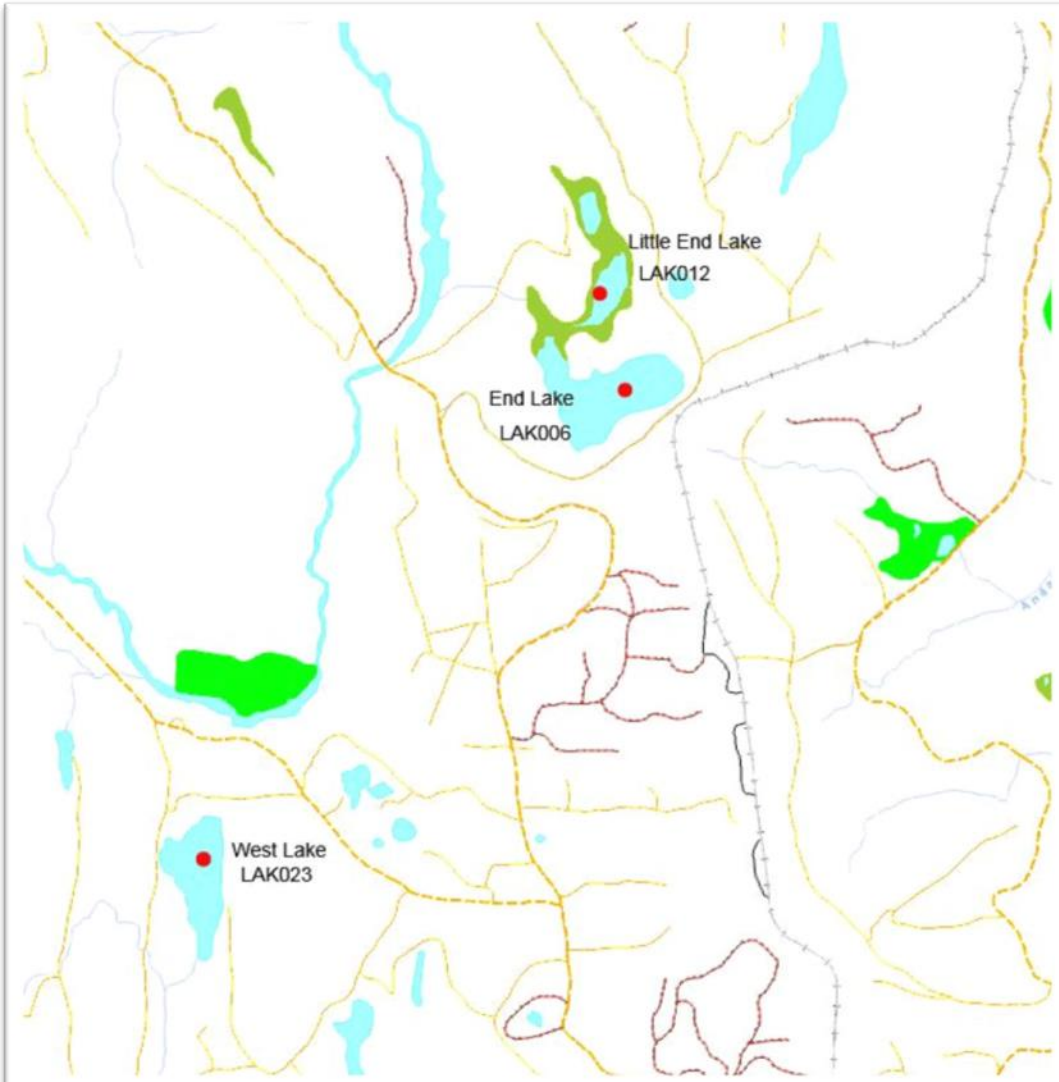
- 7 sensitive
- 3 less sensitive
- Lakelse Lake
- 3 controls (added in 2015)

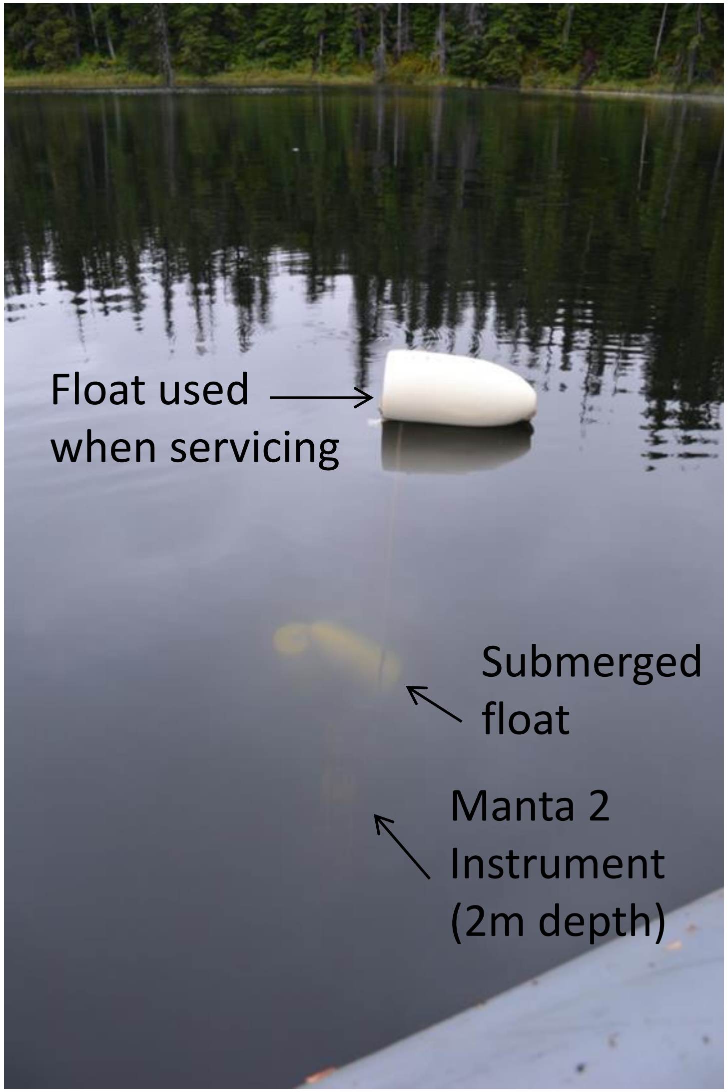


II-e. Freshwater – Methods

Limnotek;
Tech Memo W07

Intensive monitoring of 3 accessible lakes





II-e. Freshwater – Results
Overview of what was learned

2017 EEM Report, p. 23-27

- Notable changes observed in LAK028 (closest to KMP), which showed a large post-KMP increase in SO_4
- No concerns about long term changes in water chemistry in other lakes or acidic episodes
- Need more years of observations to have reliable estimates of post-KMP vs. pre-KMP (only 2 years post-KMP)
- Overall EEM program is working well; no need for any changes

II-e. Freshwater – Results

2017 EEM Report, p. 26; Tech Memo W07

Inter-annual Changes (2016 to 2017)

	pH (TU)	Gran ANC (μeq/L)	SO_4^* (μeq/L)
LAK006	0.0	1.1	2.5
LAK012	-0.1	-7.6	5.0
LAK022	0.0	-0.3	4.9
LAK023	-0.1	0.6	-2.6
LAK028	-0.2	-5.0	22.2
LAK042	-0.2	-11.7	3.5
LAK044	0.1	3.0	0.4
Total Lakes with Increase	**1**	**3**	**6**
Total Lakes with Decrease	**6**	**4**	**1**

LAK007	0.0	13.0	0.4
LAK016	0.1	-11.1	-1.8
LAK024	-0.1	-46.5	-4.3
LAK034	-0.1	-15.2	0.1
Total Lakes with Increase	**2**	**1**	**2**
Total Lakes with Decrease	**2**	**3**	**2**

Gran ANC = Acid Neutralizing Capacity

II-e. Freshwater – Results
What was learned

2017 EEM Report, p. 24; Tech Memo W07

Inter-annual Changes (2016 to 2017) – EEM Lakes

- **SO_4^{2-}:** ↑ in 6 of 7 sensitive lakes EEM lakes and 2 of 4 less sensitive lakes
- **ANC:** ↓ in 4 of 7 sensitive EEM lakes and 3 of 4 less sensitive lakes
- **ANC:** Direction of change consistent with ΔSO_4^{2-} for 4 of 7 sensitive lakes
  - Changes in ANC also potentially related to changes in base cations and/or DOC
- **pH:** ↓ in 4 of 7 sensitive EEM lakes
  - ↓ pH ≤ 0.2 pH (within range of measurement error)
  - 6 of 7 sensitive EEM lakes show pH 2017 > pH 2012
  - 5 of 7 sensitive lakes show $\Delta pH_{2012\text{-}2017}$ ±0.2 pH)
- **BC:** Variable – ↓ in 6 lakes, ↑ in 5 lakes
- **DOC:** ↓ in 9 of 11 lakes (reversal of 2016)
- **Cl:** ↓ in 9 of 11 lakes

II-e. Freshwater – Results
What was learned

2017 EEM Report, p. 25; Tech Memo W07

Inter-annual Changes (2016 to 2017) – Control Lakes

- **SO_4^{2-}:** moderate changes (-16% to +10%); 2 lakes ±<1.0 μeq/L
- **ANC:** all 3 control lakes show decrease
- **Base cations:** 2 control lakes show decreases
- **Chloride:** decreased by 31-39% in all 3 control lakes

	pH (TU)	Gran ANC (μeq/L)	SO_4* (μeq/L)	Base Cations * (μeq/L)
DCAS14A	0.0	-6.5	-5.7	-10.7
NC184	-0.4	-17.5	-0.8	-19.1
NC194	0.1	-16.3	0.2	6.7
Total Lakes with Increase	**2**	**0**	**1**	**1**
Total Lakes with Decrease	**1**	**3**	**2**	**2**

II-e. Freshwater – Results

2017 EEM Report, p. 27; Tech Memo W07

Multi-year Changes (2012 to 2017)

- Provides indication of change across record
- Does NOT represent thorough evaluation

	pH (TU)	Gran ANC (µeq/L)	SO_4^* (µeq/L)
LAK006	0.2	2.3	2.9
LAK012	0.4	1.2	8.4
LAK022	0.1	6.3	8.8
LAK023	0.2	8.7	-8.9
LAK028	-0.2	-5.9	93.1
LAK042	0.5	22.7	0.6
LAK044	0.2	5.8	-1.7
Total Lakes with Increase	**6**	**6**	**5**
Total Lakes with Decrease	**1**	**1**	**2**

LAK007	0.0	-56.0	-4.3
LAK016	0.3	14.1	4.1
LAK024	0.3	117.2	10.0
LAK034	-0.3	37.1	-24.0
Total Lakes with Increase	**3**	**3**	**2**
Total Lakes with Decrease	**1**	**1**	**2**

Gran ANC = Acid Neutralizing Capacity

II-e. Freshwater – Results
What was learned

2017 EEM Report, p. 24; Tech Memo W07

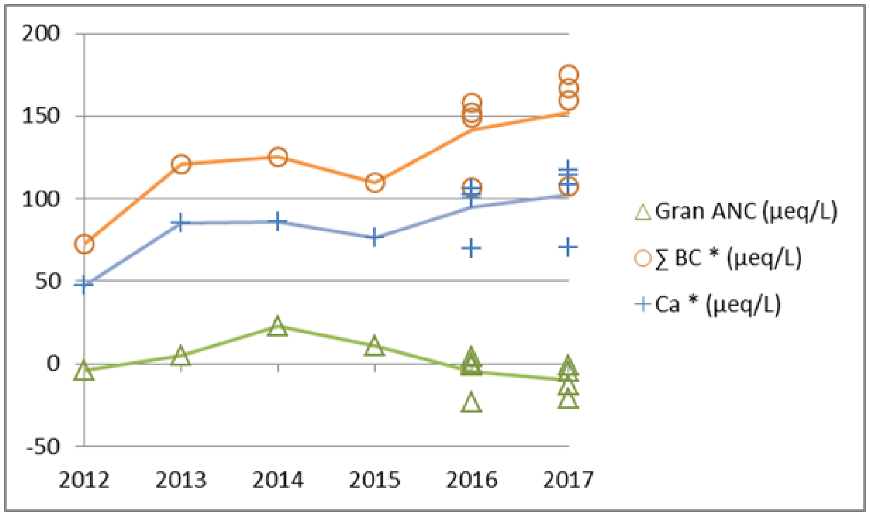
Annual Lake Chemistry Changes in LAK028

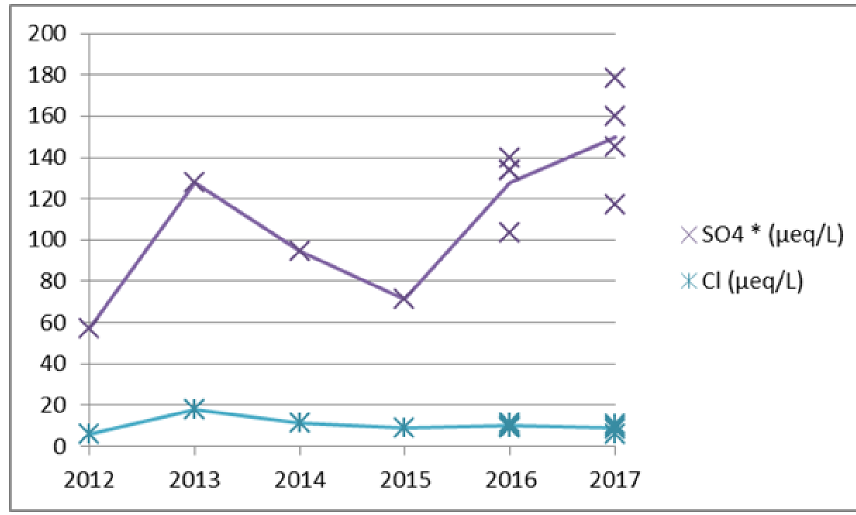
- Largest increase in SO_4^{2-} in 2017 (22.2 µeq/L)
  - consistent with closer proximity to the smelter than other EEM lakes
- Increase in base cations of 10.8 µeq/L,
  - Suggests that about half (49%) of the deposited acidity was neutralized by cation exchange in the watershed. STAR assumed 44%.
- Gran ANC declined by 5.0 µeq/L
  - Indicates that 78% of the sulphate-associated acidity deposited between 2016 and 2017 was neutralized, since Gran ANC only declined by 5 µeq/l, and [SO4] increased by 22 µeq/.
- Other neutralization processes besides cation exchange are apparently responsible

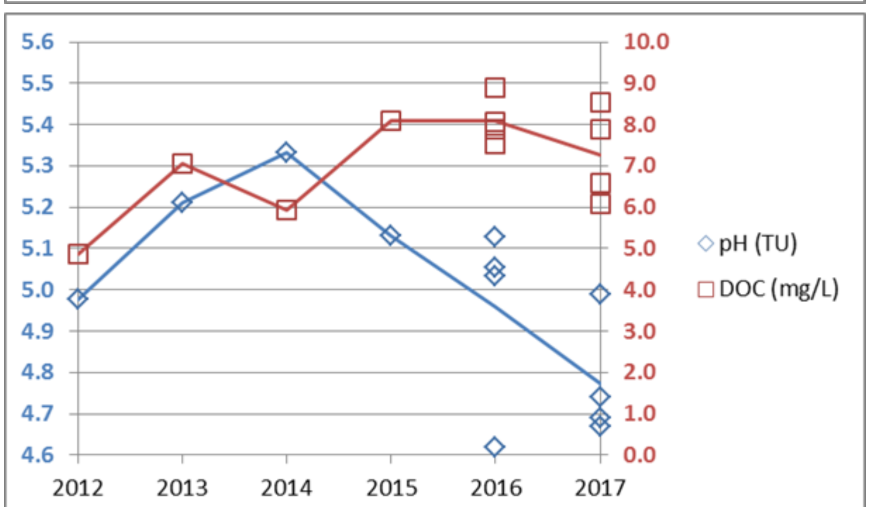
II-d. Freshwater – Results

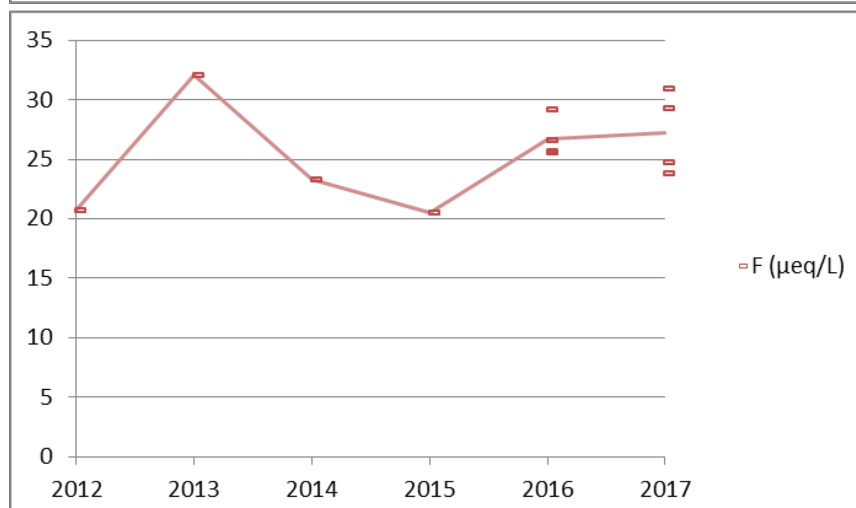
Tech Memo W07

Multi-year Lake Chemistry Changes in LAK028









II-d. Freshwater – Results

Tech Memo W07

Multi-year Lake Chemistry Changes in LAK028

	2012	2013	2014	2015	2016	2017	2012 to 2017	EEM thresholds Value	EEM thresholds Δ
pH	5.0	5.2	5.3	5.1	5.0	4.8	-0.2	4.7 [1]	-0.3 [1]
Gran ANC (μeq/L)	-4.0	4.8	22.6	10.8	-4.9	-9.9	-5.9	*-18.8* [2]	*-14.8* [2]
SO_4^{2-*} (μeq/L)	57.5	129.9	95.6	72.0	128.8	150.9	93.4	*n/a* [3]	*n/a* [3]

[1] pH is the Key Performance Indicator (KPI) in the EEM.

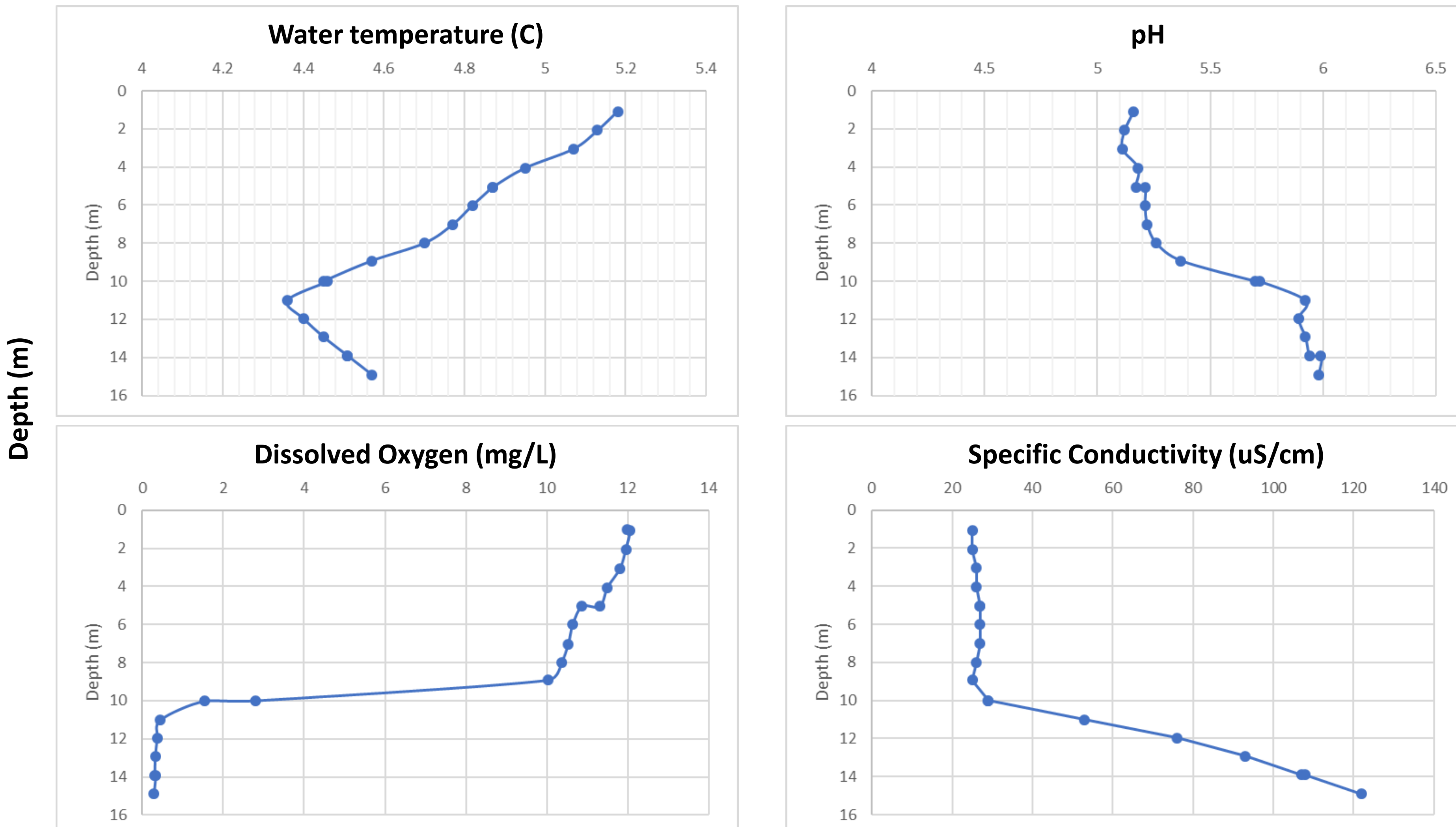
[2] Thresholds for Gran ANC have been calculated from lab titrations. Preliminary analyses indicate that a 0.3 pH unit change from 4.98 (2012 value) to 4.68 is equivalent to a -14.8 μeq/L (± 4.1 SE) change in Gran ANC in LAK029. Actual change has been less (-5.9 μeq/L).

[3] The appropriate thresholds for the EEM informative indicator of SO_4^{2-} will be calculated based on the Gran ANC thresholds (using the ESSA-DFO model) once we have developed the Gran ANC thresholds

II-d. Freshwater – Results

Bennett and Perrin (2018)

LAK028 – Water Column Chemistry



II-d. Freshwater – Results

Bennett and Perrin (2018)

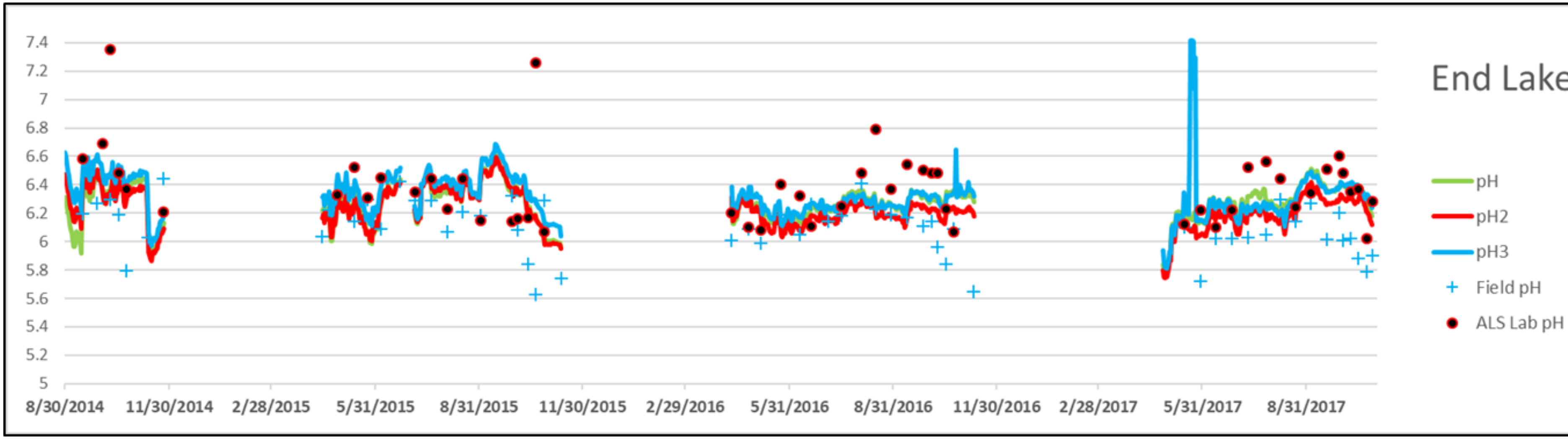
LAK028 – Water Column Chemistry

- Thermal/chemical conditions change significantly >9m
- Strongly suggests meromixis (surface & bottom don't mix)
  - Also implied by small area:depth ratio
- **Top layer**: temperature typical of region, high DO, conductivity & inorganic nitrogen typical of nutrient deficient lakes, pH at low end of tolerance
- **Bottom layer**: anoxic, higher pH, higher conductivity, warming thermocline, odour of H_2S, and other evidence of sulphur reducing green and/or purple bacteria

II-e. Freshwater – Results

Bennett and Perrin (2018)

Intensive Monitoring of 3 Lakes



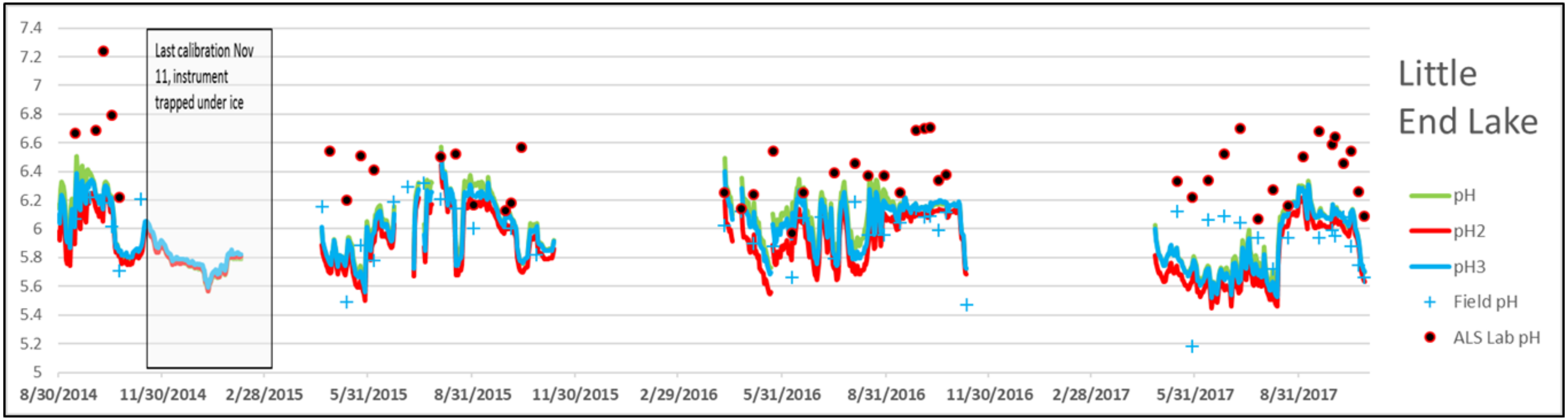
End Lake, Little End Lake, West Lake

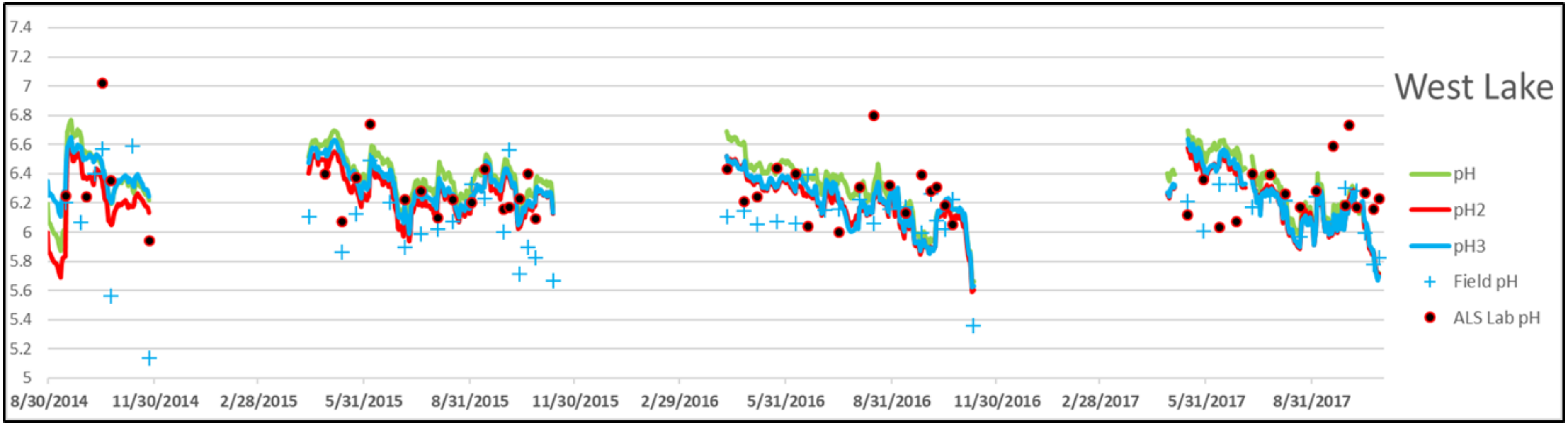
- pH monitored every 30 minutes (8,000 to 8,900 measurements in 2016)
- pH varied by 0.9 to 1.4* units over the sampling period (high variability)
- pH declined after storm on October 15th and 21st to 24th (especially in Little End Lake and West Lake)
- no obvious year to year changes; will provide valuable data in 2019 report
- West Lake shows higher pH early in the year

II-e. Freshwater – Results

Bennett and Perrin (2018)

Intensive Monitoring of 3 Lakes





II-e. Freshwater – Results
What was learned

2017 EEM Report, p. 25

Intensive Monitoring of EEM Lakes

- Reinforces previous conclusions:
  - maintain continuous monitoring and weekly fall samples for best understanding of natural variability
  - use Gran ANC in addition to pH as indicator of change
  - understand what's associated with pH declines; take water sample every 2 weeks (analyze if pH episode observed)
- Intensive data allows comparison of August vs. October (next slide)
- Can also assess effect of rainstorms on pH estimates

II-e. Freshwater – Results
What was learned

2017 EEM Report, p. 26

August vs. October Sampling

- August (STAR, 2012); October sampling for EEM
  - Concern about potential seasonal effect
  - Not possible to separate season vs. year effects with annual samples (e.g. Aug 2012 vs. Oct 2013)
- Can use continuous pH monitoring to examine August vs. October pH data
- Data show no consistent differences across lakes and years
  - Based on 3 lakes in 3 years (more data will be better)
  - Indication that August samples are not biased relative to October
  - Confirms validity of using 2012 as baseline
- Data indicate that rainstorms in October 2017 did not lead to a biased estimate of mean pH for October period

II-e. Freshwater – Results
What was learned

2017 EEM Report, p. 28

Implications for Comprehensive EEM Review in 2019

- Intensive monitoring continue to show high degree of variation in pH within each year
- Importance of probabilistic, statistical analyses to rigorously evaluate changes in water chemistry
  - i.e., probability that various magnitudes of change in pH and Gran ANC have occurred (post-KMP vs pre-KMP)
- Gran ANC is a more stable indicator than pH and has a higher statistical power to detect change

III. Plans for 2018

- **Actions and Activities**

Finalization of 2017 EEM Report

NOTE: Some of the prospective dates below are still being finalized

Component	Date
1st draft 2016 Annual EEM Report	April 20
EEM Technical Memos	April 20 & June 11
2018 EEM work plan	TBD
KPAC meeting re: draft report	June 12
KPAC feedback (comments / questions)	TBD
MOE feedback	TBD
Final 2017 Annual EEM Report	End of July

III-a. Atmospheric Pathways
2018 Actions & Activities

EEM Plan, p. 10
2017 EEM Report, p. 10-12

Atmospheric SO_2 – continuous analyzers

- Maintain 4 continuous SO_2 analyzers
- Compare to model output

Passive Sampling

- 2017 results spatially/temporally consistent with 2016 observations
- Recommended – continue deployments during 2018 and 2019 to further define the plume

Multi-season Air Quality Study

- Rio Tinto in process of developing study, to better understand:
  - season patterns of ambient SO_2 concentrations
  - Spatial distribution of SO_2 within residential areas of Kitimat

III-a. Atmospheric Pathways

2018 Actions & Activities

EEM Plan, p. 10

Wet Deposition – S, Base Cations, Chloride

- Maintain 2 rain chemistry stations (Haul Road, Lakelse Lake)
- In 2019 (comprehensive review), compare 2013-2018 data to model output, and assess number of rain chemistry stations

Dry Deposition

- Estimate dry deposition at both Haul Road and Lakelse Lake stations
- In 2019 (comprehensive review), compare 2013-2018 data to model output

III-b. Human Health
2018 Actions & Activities

2017 EEM Report, p. 16

Health KPI

- Continue to apply health KPI as defined
  - i.e., at end of 2018, percentile used will be 97.5th

III-c. Vegetation
2018 Actions & Activities

EEM Plan, p. 17

Vegetation Survey: Visible Injury

- Continued vegetation sampling as per Laurence (2010)

S Content in Hemlock Needles

- Sampling from mid-August to mid-September

III-d. Soils

2018 Actions & Activities

EEM Plan, p. 27
2017 EEM Report, pp. 20

Steady State Soil Modelling

- Re-analysis for risk of critical load exceedance (initially planned for 2017, shifted to 2018)

Review critical limit selection (Bc:Al ratio)

- Will be done in 2018
- Any changes in Bc:Al ratio will be incorporated into revised modelling in 2018

III-d. Soils

2018 Actions & Activities

EEM Plan, p. 27
2017 EEM Report, pp. 20

Long Term Monitoring

- Resampling (random design) of primary plots at Coho Flats and Lakelse Lake
- Analysis for exchange cations, exchangeable acidity, organic matter, pH

III-e. Freshwater

2018 Actions & Activities

2017 EEM Report, p. 27
Tech Memo W07

Recommendation: Maintain 2017 Sampling Plan for 2018

- Annual sampling of 7 sensitive lakes, 4 less sensitive lakes, and 3 control lakes consistent with what was done in 2016
- Continuous pH monitoring at 3 sensitive lakes as soon as lakes are safely accessible; archive a water sample when doing re-calibration of Mantas every 2 weeks
- 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

III-e. Freshwater
2018 Actions & Activities

2017 EEM Report, p. 27

Fish Sampling

- None scheduled (i.e., resampling if lake pH changes greater than KPI threshold)

Episodic Acidification

- Continuous monitoring of pH and lake levels in West Lake, End Lake and Little End Lake
- Continuous monitoring of pH in Anderson Creek
- Independent study is proceeding outside of EEM

LAK028

- Bathymetric analysis – more precise volume and estimates of residence time (to better estimate rate of change in lake chemistry)

III-e. Freshwater
2018 Actions & Activities

2017 EEM Report, p. 27

Goose Creek

- Re-sample eight tributaries (6 sampled in 2014 and 2 in 2015)
- Assess whether there have been significant changes

Benthic Organisms

- Sampling benthic organisms in Goose Creek and compare community composition to similar streams (i.e., RCA)

Activities to support 6-year Comprehensive Review

- Laboratory Gran ANC titrations used to estimate lake-specific ANC thresholds corresponding to pH decline of 0.3 pH units

IV. 6-Year Review in 2019

EEM Plan, p. 48

Comprehensive Review in 2019

- Integrated assessment of six years of SO_2 EEM monitoring.
- Summarizes the learnings over the six years of monitoring.
- Compares pre vs. post smelter modernization data.
- Provide recommendations for Post 2019 SO_2 EEM program.
- Report issued by October 31, 2019.
- Presentation to KPAC in November to December 2019.

IV. 6-Year Review in 2019

EEM Plan, p. 48

Comprehensive Review in 2019

- Work will start in 2018 on the comprehensive review:
  - Planning tasks and methods
  - Develop the framework / terms of reference for the 2019 review process
  - Initiate background / foundation work
  - Initiate pre-KMP summary & analysis

IV. 6-Year Review in 2019

NOTE: These dates are very preliminary

Component	Date
Analyses & draft Review	Jan – July 2019
Report compilation & editing	Aug – Oct 2019
Comprehensive Review report submission to BCMOE & KPAC	October 31st, 2019
KPAC review meeting	Dec 2019
BCMOE review workshop	Nov – Dec 2019
Report revisions	Jan 2020
Finalize review report	Feb – Mar 2020
Prepare EEM Plan for post-2019	Dec 2019 – Mar 2020

QUESTIONS?

EXTRA SLIDES!

ATMOSPHERIC PATHWAYS

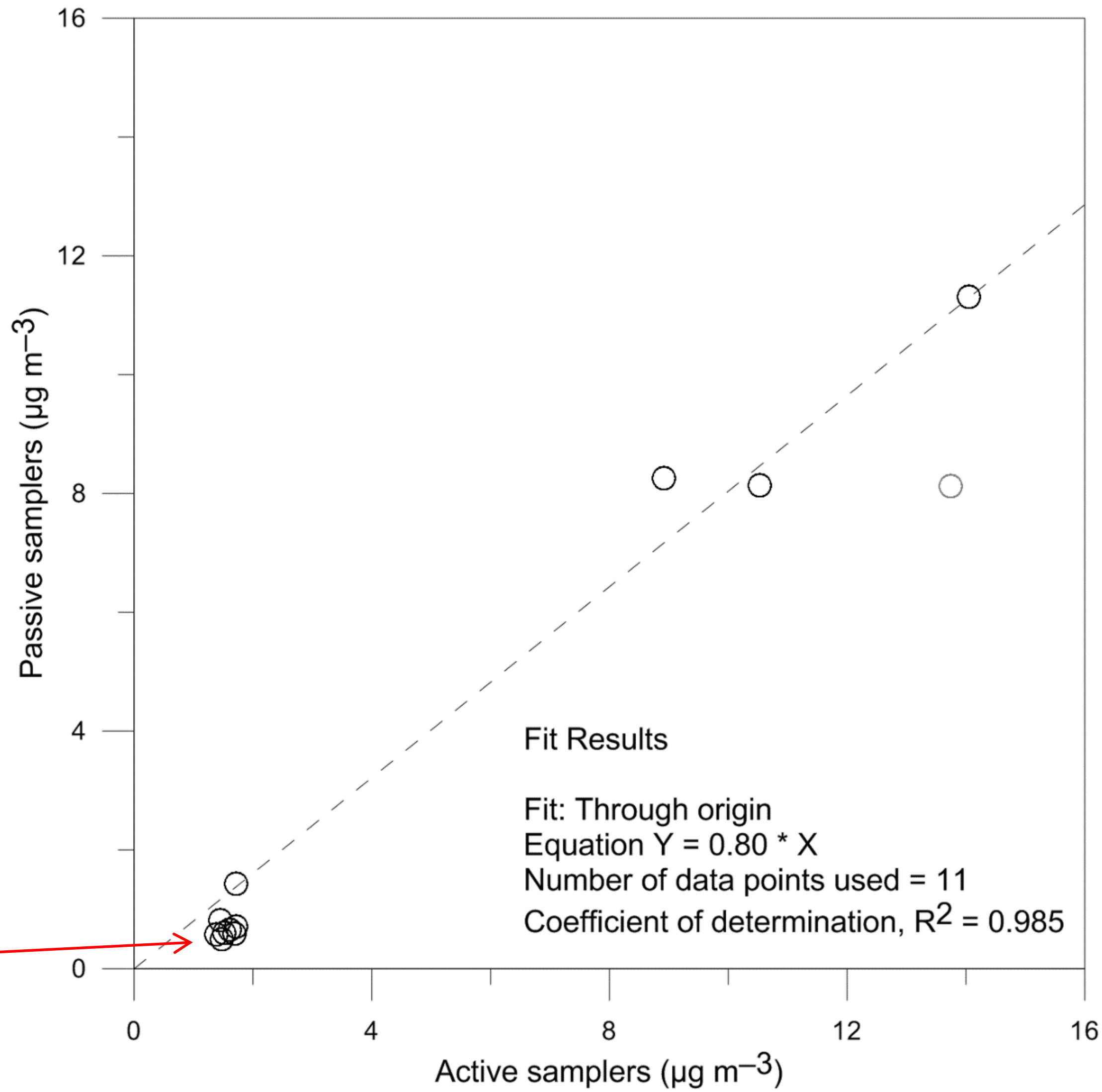
Slide from 2017

II-a. Atmospheric Pathways

2016 EEM Report, p. 16
Tech Memo P04

SO_2 Passive Sampling Network

- Generally good correlation between passive and intensive samplers
- Passive samplers underestimate low SO_2 concentrations (e.g. Whitesail)



Slide from 2017

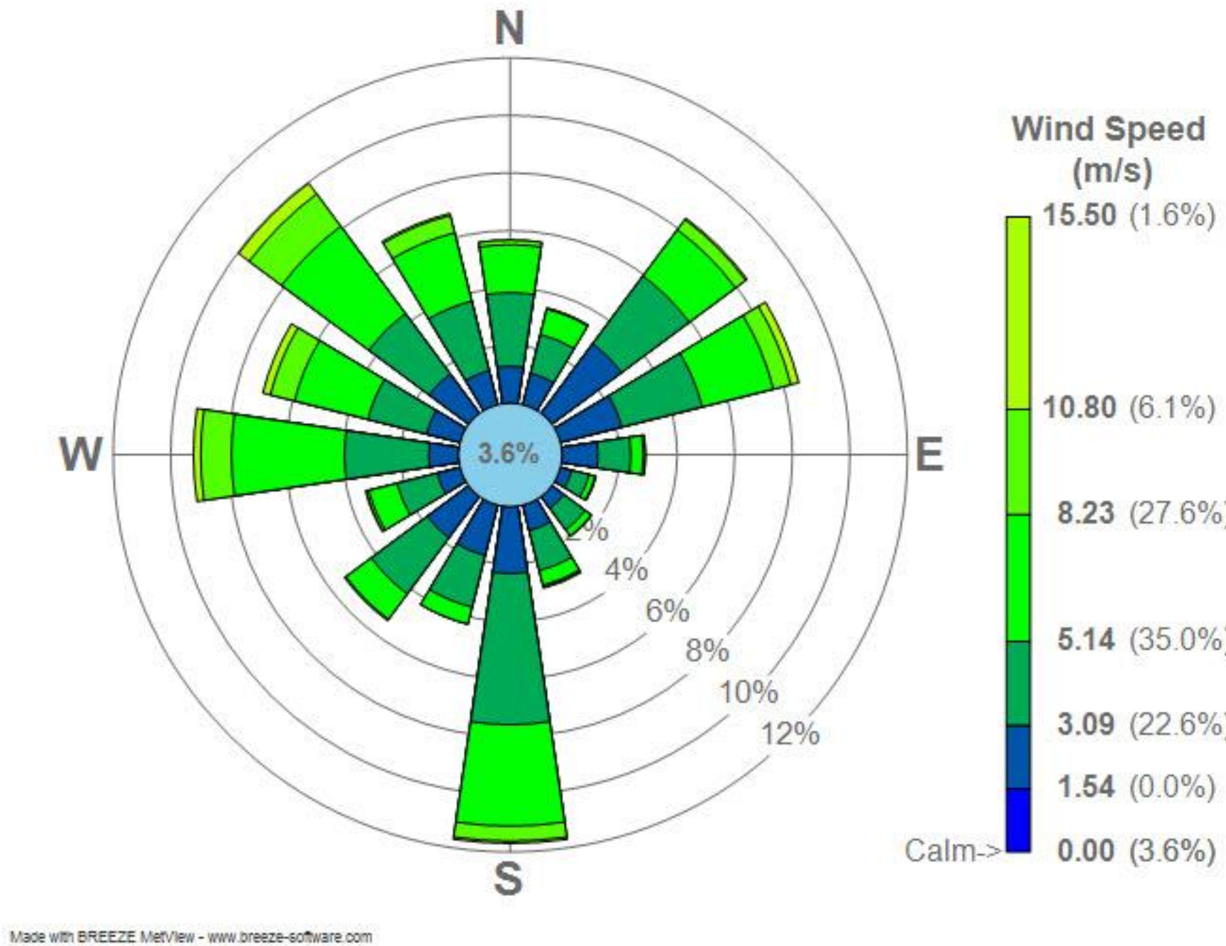
II-a. Atmospheric Pathways

Tech Memo P04

Predominant winds in 2016

Slide from 2017

Wind Roses



- Each "spoke" represents the direction *from which* the wind is blowing
- Shows the frequency of winds from different directions (length of each spoke)
- Shows the frequency of winds of different speeds from each direction (colour-coded bands)

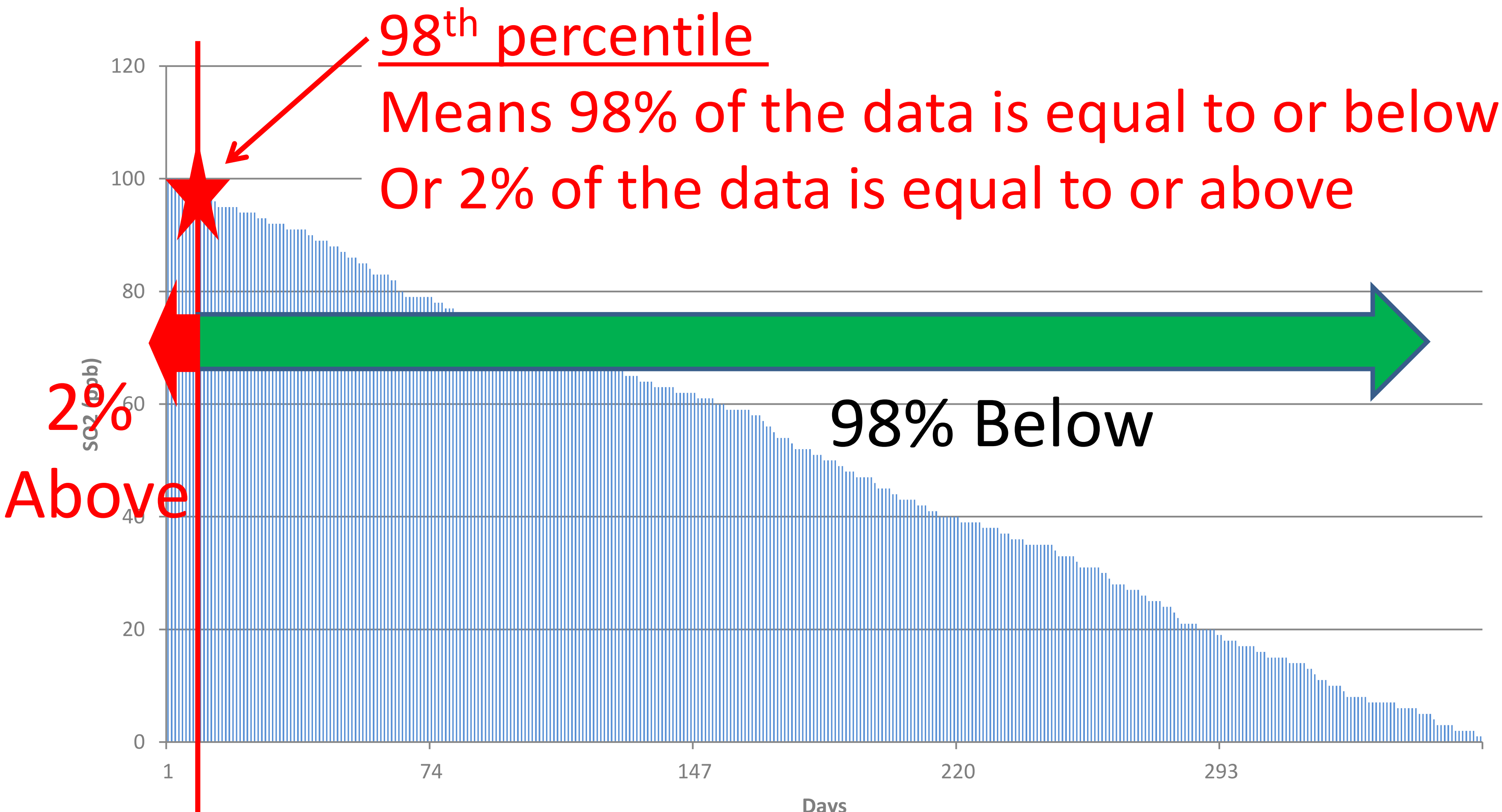
HUMAN HEALTH

Slide from 2017

II-b. Human Health

Health KPI - Calculation

What is a Percentile ?



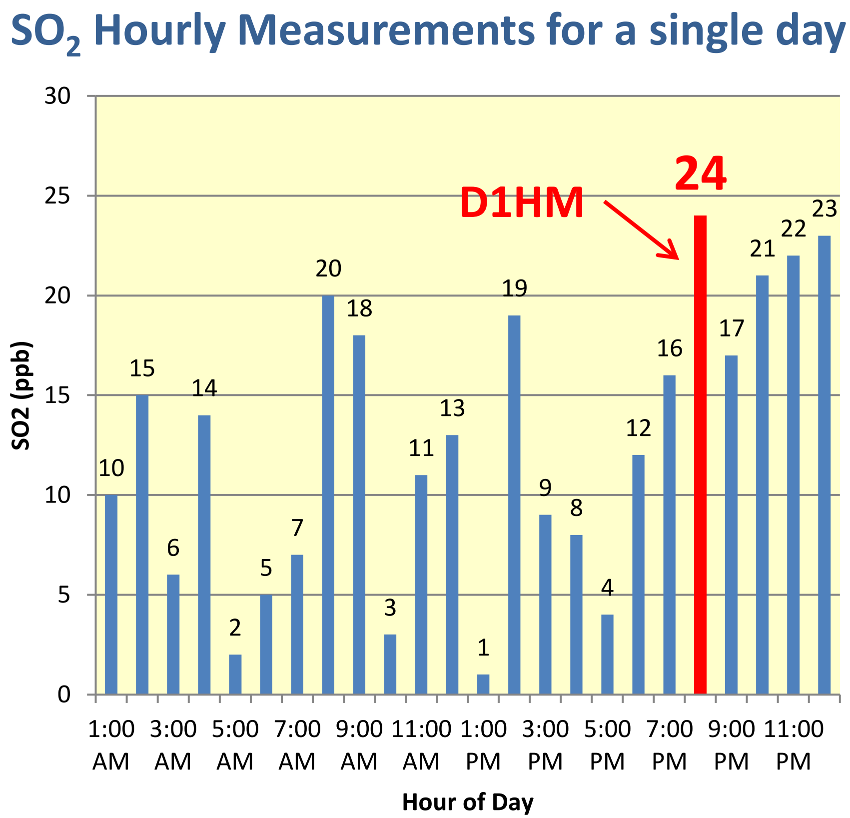
Slide from 2017

II-b. Human Health

Health KPI - Calculation

Step 1 – Sort the D1HM for the past year

- Sort the D1HM values for the entire year, and rank them from largest to smallest



The Daily 1 Hour Average Maximum (D1HM) is the highest 1 hour peak SO_2 concentration that is measured over a 24 hour day.

For each day of the calendar year, the D1HM is selected for a total of 365 values (observations).

Slide from 2017

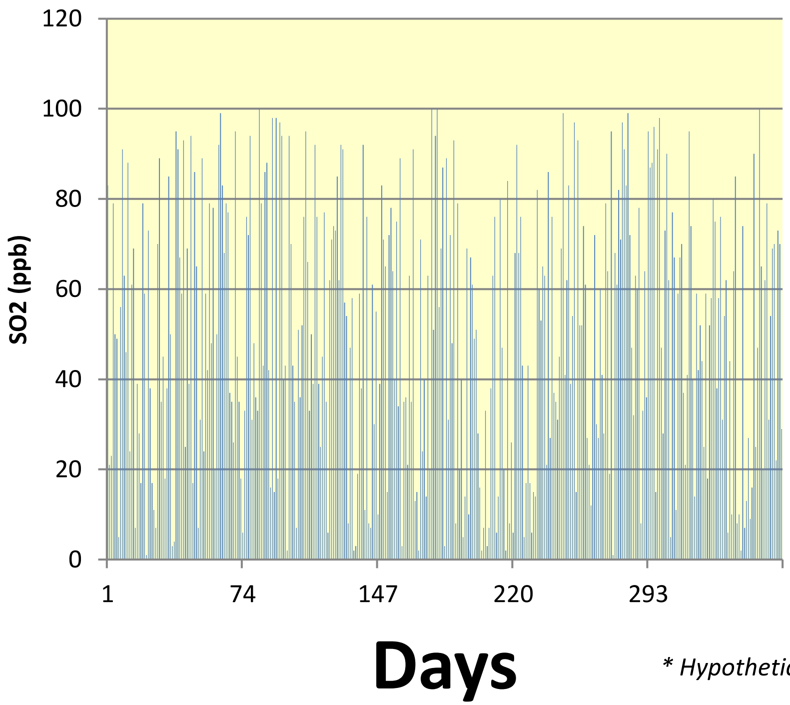
II-b. Human Health

Health KPI - Calculation

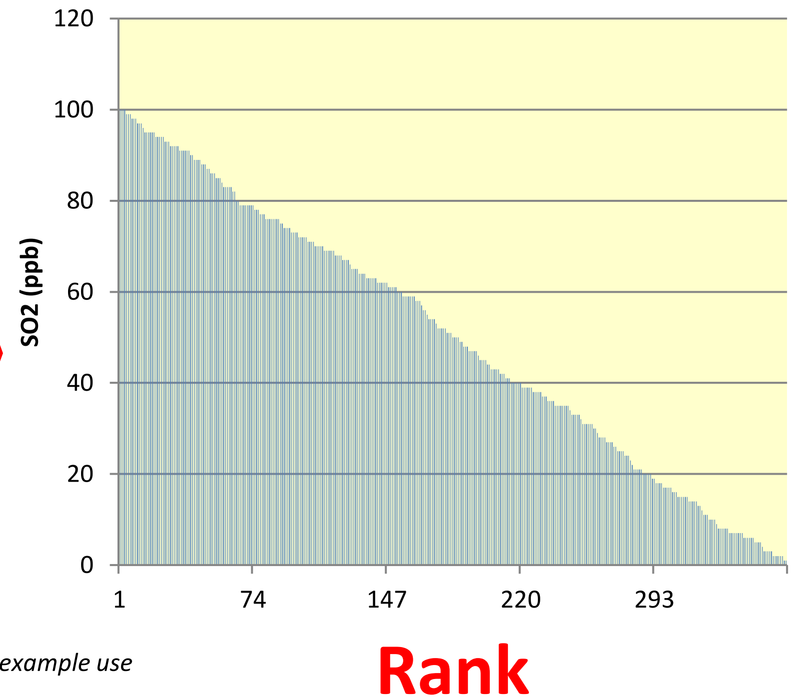
Step 1 (continued)

- Sort the D1HM values for the entire year, and rank them from largest to smallest

SO2 Daily 1 Hour Maximum Values for a Calendar Year*



Sorted and Ranked SO2 Daily 1 Hour Maximum Values*



** Hypothetical data for example use*

Slide from 2017

II-b. Human Health

Health KPI - Calculation

Step 2 – Determine the percentile position (I)

- I = Percentile x Total D1HM observations
- I = P x N

Example :

P = 98%

N = 365 observations

I = 0.98 x 365 = 357.7

II-b. Human Health

Health KPI - Calculation

Slide from 2017

Step 3 – Truncate the position to an integer

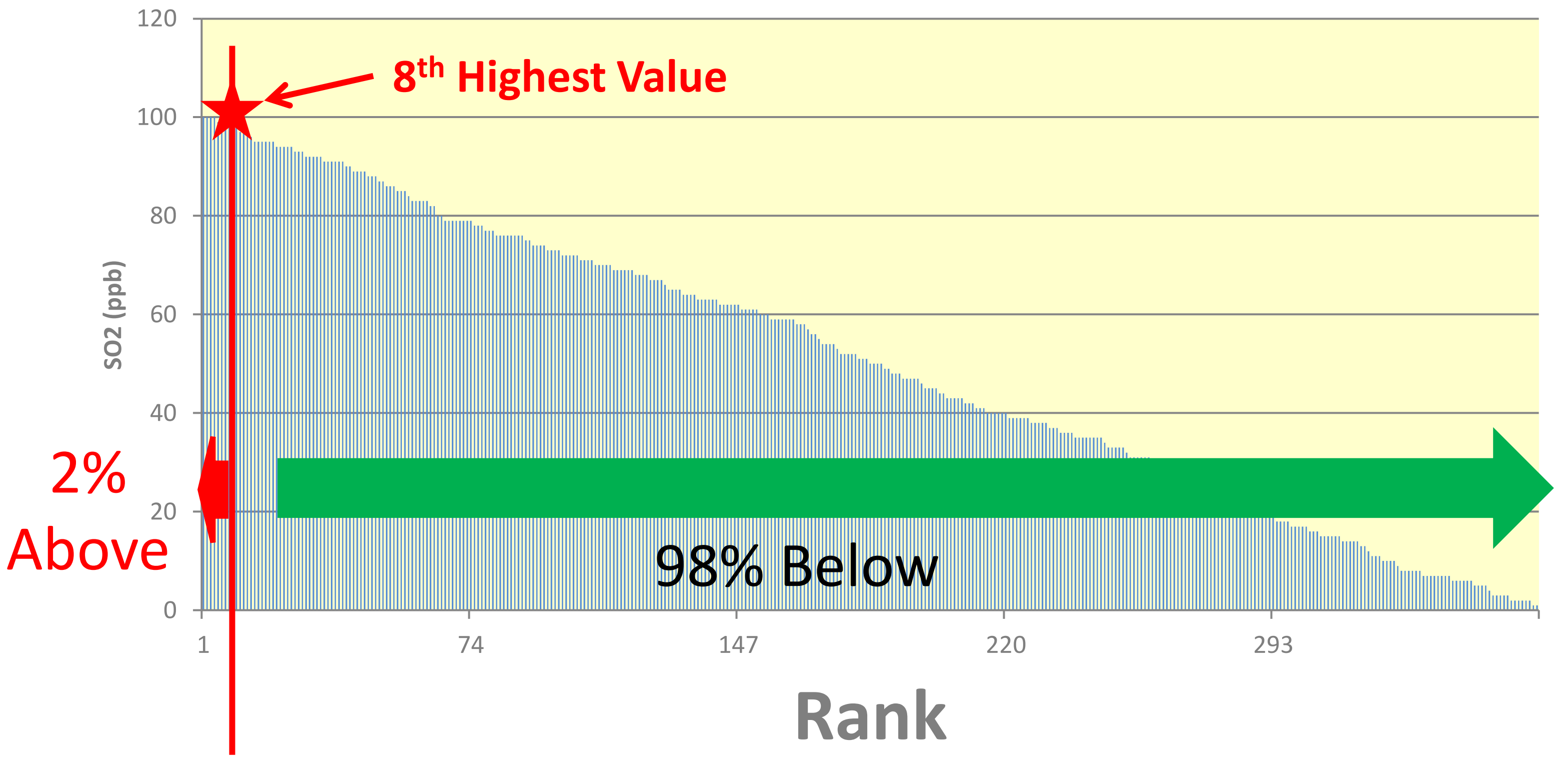
- e.g. I = 357.7 → 357

Slide from 2017

II-b. Human Health
Health KPI - Calculation

Step 4 – Determine the highest D1HM rank

- Highest D1HM = Total Observations - Position
- E.g., Highest D1HM = 365 – 357 = 8 = 8th highest value



Slide from 2017

III-b. Human Health

Health KPI - Calculation

Step 5 – Select the D1HM value from the Highest D1HM rank

- Return to sorted table of annual D1HM values
- Selected the Highest D1HM (e.g., the 8^{th} highest value)
- This value is the 98^{th} percentile D1HM value for this year

Step 6 – Determine the H1DM percentile value for the previous 2 years

- Repeat the percentile calculation process (Steps 1 to 5) for each of the previous two years

Slide from 2017

III-b. Human Health

Health KPI - Calculation

Hypothetical Example (assumes full data capture)

Rank	SO_2 D1HM (ppb) 2017	SO_2 D1HM (ppb) 2018	SO_2 D1HM (ppb) 2019
1st highest	40.8	43.4	31.8
2nd highest	33.4	33.8	25.4
3rd highest	29.1	31.5	24.1
4th highest	28.4	28.5	22.1
5th highest	28.2	28.1	17.5
6th highest	26.7	27.1	15.4
7th highest	26.5	21.4	14.5
8th highest	25.6	21.2	14.4
9th highest	22.3	20.4	14.3
10th highest	21.9	19.9	13.8
…	…	…	….
365 (lowest)	0.2	0.1	0.1

Slide from 2017

II-b. Human Health

Health KPI - Calculation

Step 7 – Calculate the 3-year average

- Calculate the average of the H1DM percentile values for each of the three years

Year	98^{th} Percentile (ppb)
2019	14.4
2018	25.6
2017	21.2

- Hypothetical example…
  - SO_2 Health KPI = [14.4 + 25.6 + 21.2]/3
  - **SO_2 Health KPI = 20.4 ppb**

Slide from 2017

II-b. Human Health

Health KPI - Calculation

Determination of Attainment of the SO_2 KPI

- The attainment threshold of the SO_2 Health KPI is 75 ppb
- For each residential station (Kitimat & Kitamaat Village) in each 3 year averaging period, the Health KPI “attained” if the KPI <75 ppb
- There is an allowance for one year between 2017 and 2019 for the SO_2 Health KPI to be in attainment when the KPI is above 75 ppb to a maximum of 85 ppb.

FRESHWATER

II-d. Freshwater – Results

Bennett and Perrin (2018) Tech Memo W07

Intensive Monitoring of 3 Lakes

- pH measurements taken every 30 min

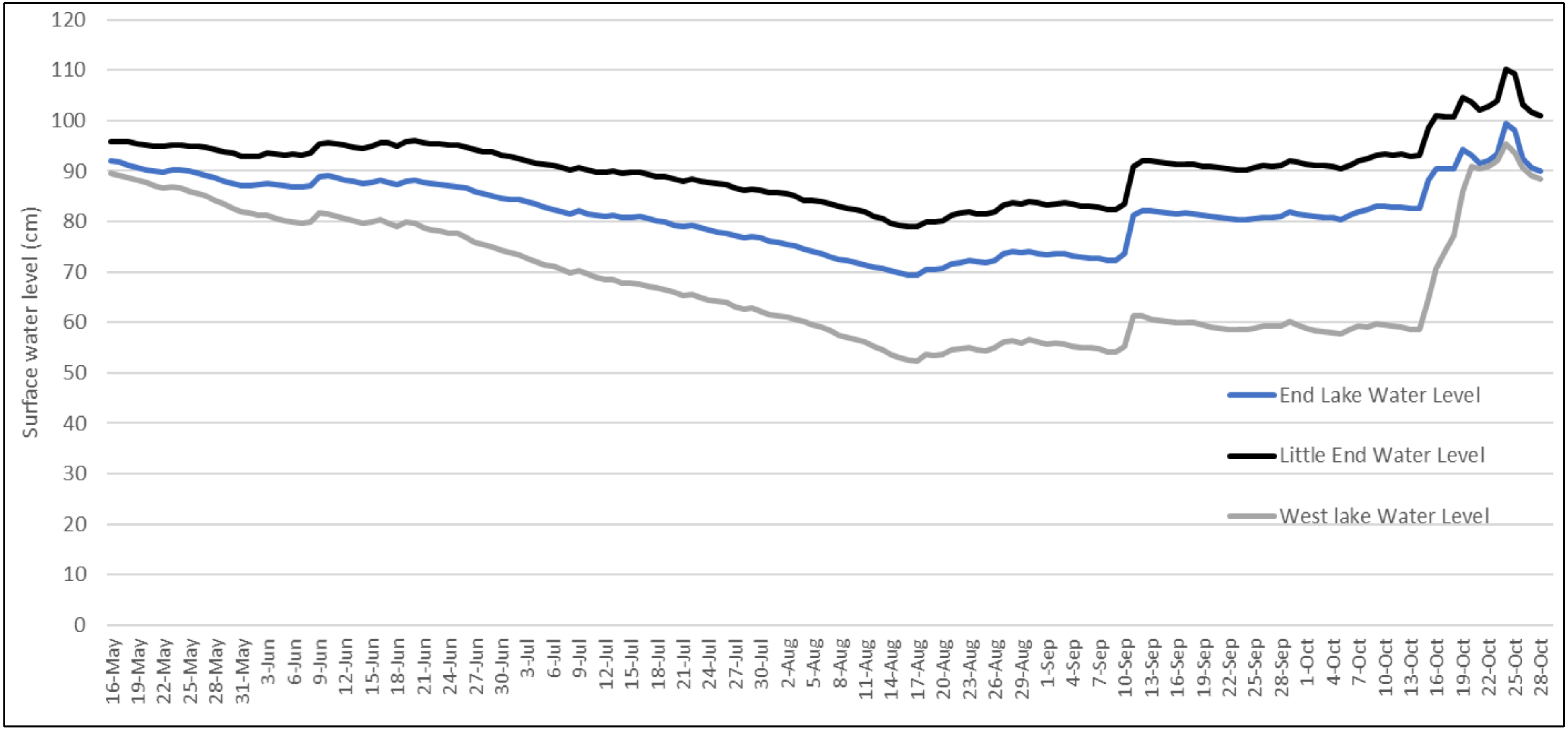
Lake	Sensor	Number of observations	Minimum pH	Maximum pH	Range of pH	Mean pH ± SD
End	pH1	8815	5.6	6.6	1.0	6.3 ± 0.1
End	pH2	8815	5.6	6.5	0.9	6.2 ± 0.1
End	pH3	8815	5.6	7.5	1.9	6.3 ± 0.2
Little End	pH1	8862	5.0	6.4	1.4	5.9 ± 0.2
Little End	pH2	8862	5.3	6.3	1.0	5.8 ± 0.2
Little End	pH3	8862	5.1	6.4	1.3	5.9 ± 0.2
West	pH1	8010	5.7	6.9	1.2	6.3 ± 0.2
West	pH2	8010	5.6	6.8	1.2	6.2 ± 0.2
West	pH3	8010	5.7	6.9	1.3	6.2 ± 0.2

II-d. Freshwater – Results

Bennett and Perrin (2018)

Lake Levels

- Mean daily surface water level (30-min measurements)



Atmospheric wet sulphate deposition and lakewater chemistry

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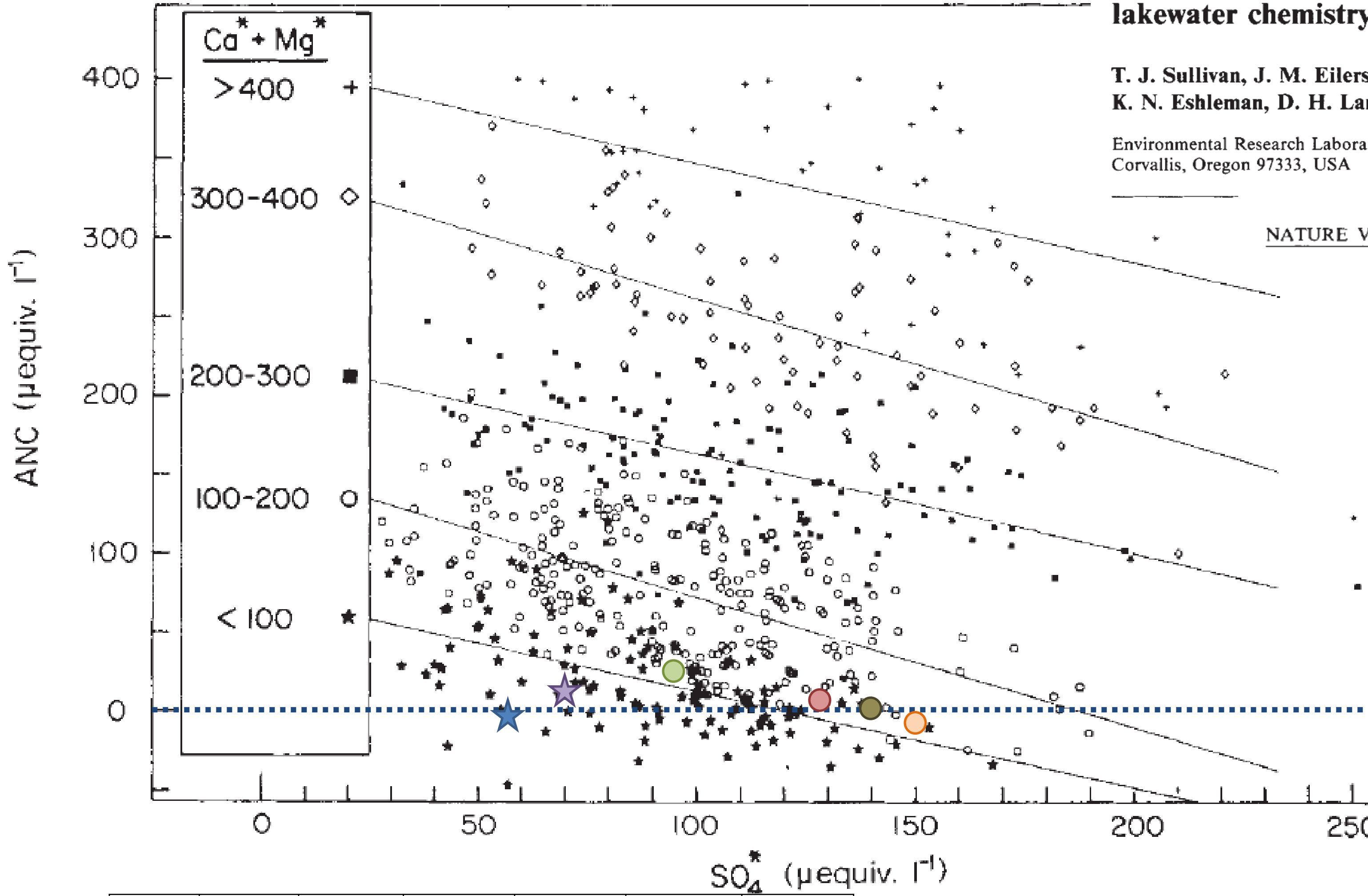
Environmental Research Laboratory—Corvallis, 200 SW 35th Street, Corvallis, Oregon 97333, USA

NATURE VOL. 331 18 FEBRUARY 1988



Lake 028 is similar to acid-sensitive lakes in NE U.S. which have been acidified by SO4, but has lower ANC due to organic acids. ANC has dropped since 2014.

Year	SO4 * (μeq/L)	Ca * (μeq/L)	Mg * (μeq/L)	Ca*+Mg*	∑ BC * (μeq/L)	Gran ANC
2012	56.90	47.54	9.50	57.05	72.91	-3.98
2013	128.12	85.11	18.27	103.38	121.31	4.80
2014	94.43	85.92	17.74	103.66	125.71	22.64
2015	71.11	76.52	15.66	92.17	109.83	10.79
2016	139.81	105.96	27.67	133.63	158.00	0.22
2017	149.99	102.48	26.49	128.97	152.41	-9.89

Fig. 2 Measured ANC plotted against non-marine sulphate for northeastern lakes having ANC ≤ 400 μequiv. l^{-1}. Lakes are stratified according to [Ca* + Mg*], and 15 lakes having $SO_4^* > 250$ μequiv. l^{-1} were deleted. Best-fit linear regression lines are provided to indicate relative slope, but regression equations are not provided because they should not be used for predictive purposes.

than ANC *per se.* [Ca* + Mg*] provides a better estimate of original lake susceptibility to acidic deposition effects than does ANC for low-base-cation lakes[10]. We therefore stratified north-eastern lakes into five [Ca* + Mg*] strata. A statistically significant ($P < 0.001$) negative relationship was found between lake [SO_4^*] and ANC within each of the four lowest [Ca* + Mg*] strata (Fig. 2). Multiple regression analysis of measured ANC as a function of [Ca*], [Mg*], and [SO_4^*] yielded the following equation for lakes in the north-east:

$$\text{ANC} = 23.86 + 1.02[\text{Ca}^*] + 0.94[\text{Mg}^*] - 0.96[\text{SO}_4^*] \quad (R^2 = 0.98,\ n = 759) \qquad (2)$$

Subregionally, results yielded comparable parameter estimates, with R^2 ranging from 0.91 (southern New England) to 0.99 (Adirondacks and central New England). The observed good fit reconfirmed our charge-balance definition of ANC presented in equation (1) (ignoring Na^+, K^+, NO_3^-, Cl^-, A_s^- and marine inputs of Ca^{2+}, Mg^{2+} and SO_4^{2-}). These results are illustrative of the negative relationship between [SO_4^*] and ANC in north-eastern lakes, when [Ca*] and [Mg*] are also taken into account.

Recognizing the inherent limitations of interregional comparisons because of differences in physical characteristics and deposition history, the data in Table 1 suggest that acidic north-eastern lakes >4 ha would likely not be acidic in the absence of SO_4^*. This contention can be further examined on the basis of the SO_4^*/C_B^* ion ratio in acidic NLS lakes. From the charge balance definition of ANC (equation (1)), it follows that if SO_4^* exceeds C_B^*, then lakewater will be acidic. Of the northeastern lakes measured as acidic (population estimate, $N = 326$), 85% also had a ratio of $SO_4^*/C_B^* > 1$. This suggests that these lakes are now acidic due to SO_4^*.

It is evident that most northeastern lakes that now have ANC ≤ 0 μequiv. l^{-1} are acidic because of SO_4^*. It is not clear, however, whether some of these lakes may previously have been acidic from another source, such as organic acids[14,15]. But available data from low-deposition areas in North America (Table 1) suggest that, for the lakes considered (that is, those generally >4 ha), temperate North American lakes are not acidic in the absence of anthropogenic sulphate. Palaeolimnological investigations of diatom remains in lake sediments have suggested that many northeastern lakes were acidic in pre-industrial times, but these have almost exclusively been small lakes (<10 ha)[16].

We should be able to compare predicted ANC for Lake 028 with actual ANC in Lake 028. We could also do this for the other lakes in the EEM program. Deviations from regression are likely related to DOC.

We can look at this ratio for Lake 028 and other lakes

Lake 028

Year	SO4 * (µeq/L)	Ca * (µeq/L)	Mg * (µeq/L)	Ca*+Mg*	∑ BC * (µeq/L)	Gran ANC	SO4 * / ∑ BC *	pH
2012	56.90	47.54	9.50	57.05	72.91	-3.98	0.78	4.98
2013	128.12	85.11	18.27	103.38	121.31	4.80	1.06	5.21
2014	94.43	85.92	17.74	103.66	125.71	22.64	0.75	5.33
2015	71.11	76.52	15.66	92.17	109.83	10.79	0.65	5.13
2016	127.79	94.69	23.75	118.45	141.59	-4.93	0.90	4.96
2017	149.99	102.48	26.49	128.97	152.41	-9.89	0.98	4.77

Ratio was < 1 in all years except for 2013. Base cations are increasing as sulphate increases.

Δ(BC)/Δ(SO4) = F= **0.49**
from 2016 to 2017

Lake 028 Summary from 2016 to 2017

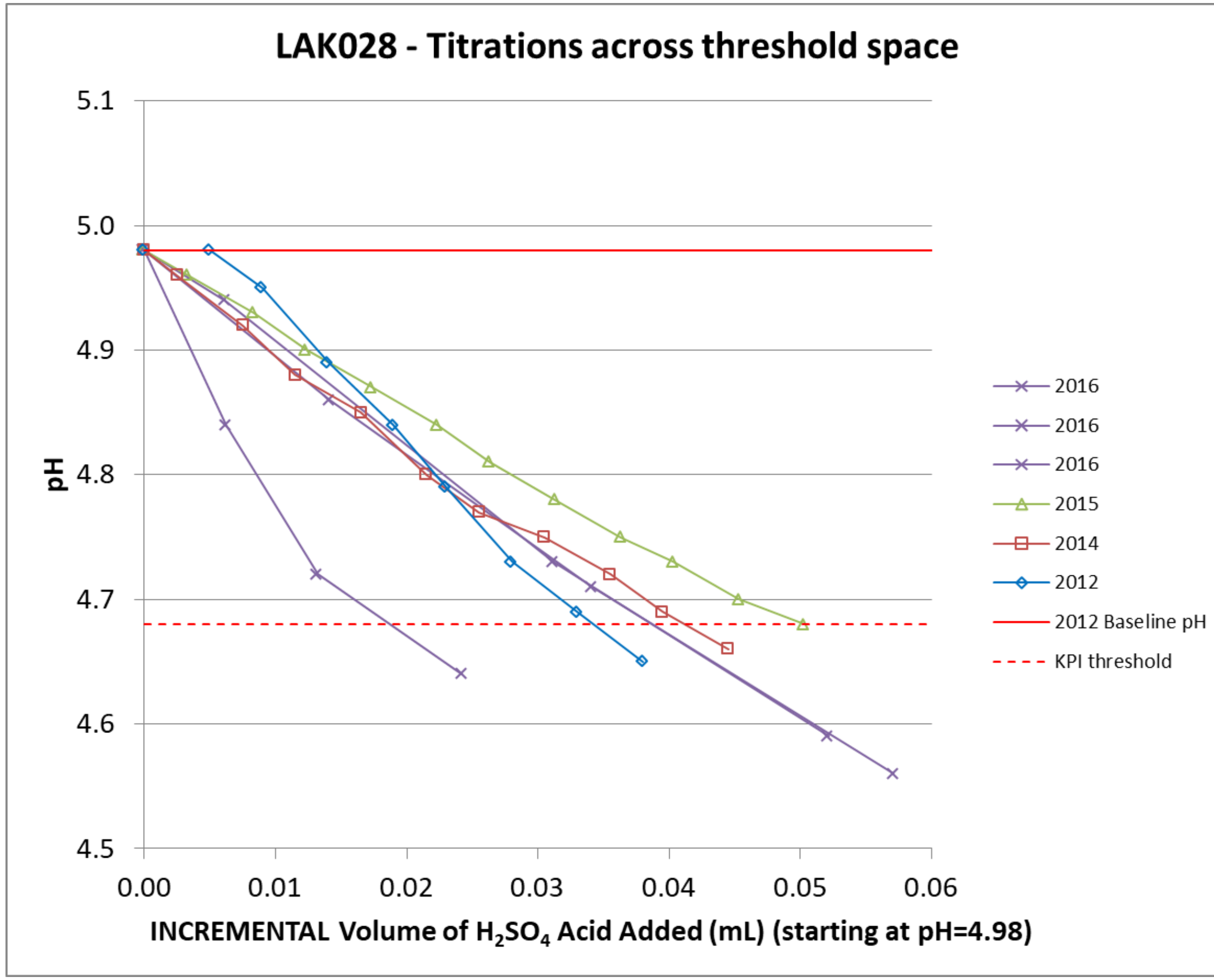
SO4* increased	78.88
Base cations increased	10.82
ANC declined	4.97

LAK028 – ANC Thresholds

ANC change (in µeq/L) associated with a pH decrease from 4.98 (2012 value) to 4.68 in LAK028			
2012	-13.6		
2014	-16.6		
2015	-20.0		
2016 (#1)	-7.6		
2016 (#2)	-15.4		
2016 (#3)	-15.4		
Median	-15.4		
Average	-14.8	± 4.1	SD

Actual change in Gran ANC in LAK028 = -5.9 µeq/L

Less than EEM threshold



II-d. Freshwater – Results
What was learned

Tech Memo W07

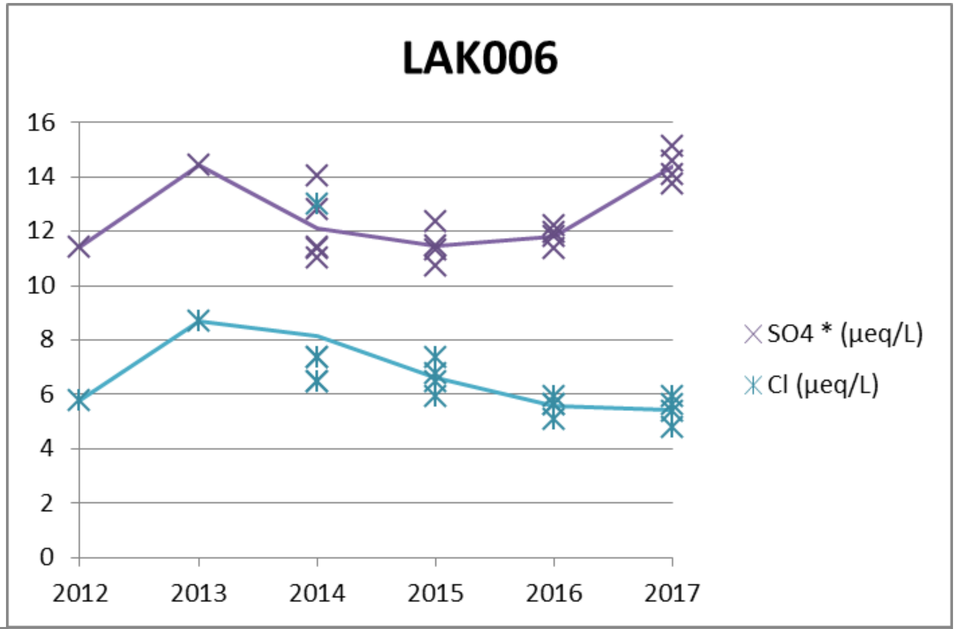
August vs. October Sampling show no consistent pattern

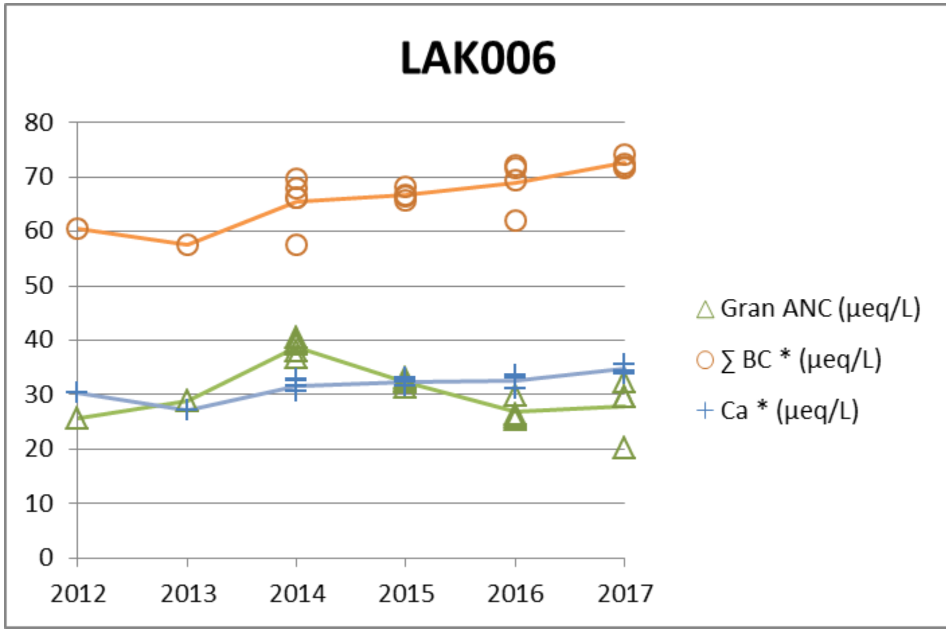
Year	Month	Lake								
		West Lake (LAK023)			End Lake (LAK006)			Little End (LAK012)		
		COUNT	MEAN pH	SD	COUNT	MEAN pH	SD	COUNT	MEAN pH	SD
2015	Aug	4455	6.2	0.1	4458	6.4	0.1	4101	6.2	0.2
	Oct	4455	6.3	0.1	4455	6.2	0.1	4458	5.9	0.1
	DIFF (Aug-Oct pH)	0			0.1			0.2		
2016	Aug	4452	6.2	0.1	4449	6.3	0.1	4452	6	0.2
	Oct	4455	6.1	0.1	4455	6.3	0.1	4245	6.2	0
	DIFF (Aug-Oct pH)	0.1			0			-0.2		
2017	Aug	4455	6.1	0.1	4314	6.3	0.1	4458	5.9	0.3
	Oct	3945	6.1	0.2	3948	6.3	0.1	3942	6	0.1
	DIFF (Aug-Oct pH)	0			-0.1			-0.1		
AVG. DIFF (Aug-Oct pH)		0.02								

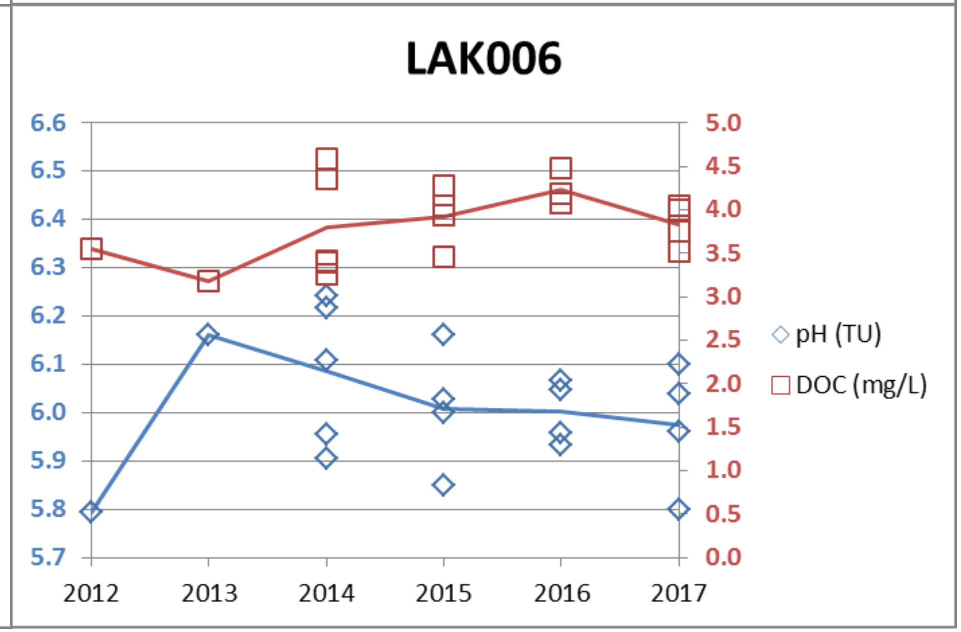
II-d. Freshwater – Results

Tech Memo W07

EEM Sensitive Lake LAK006



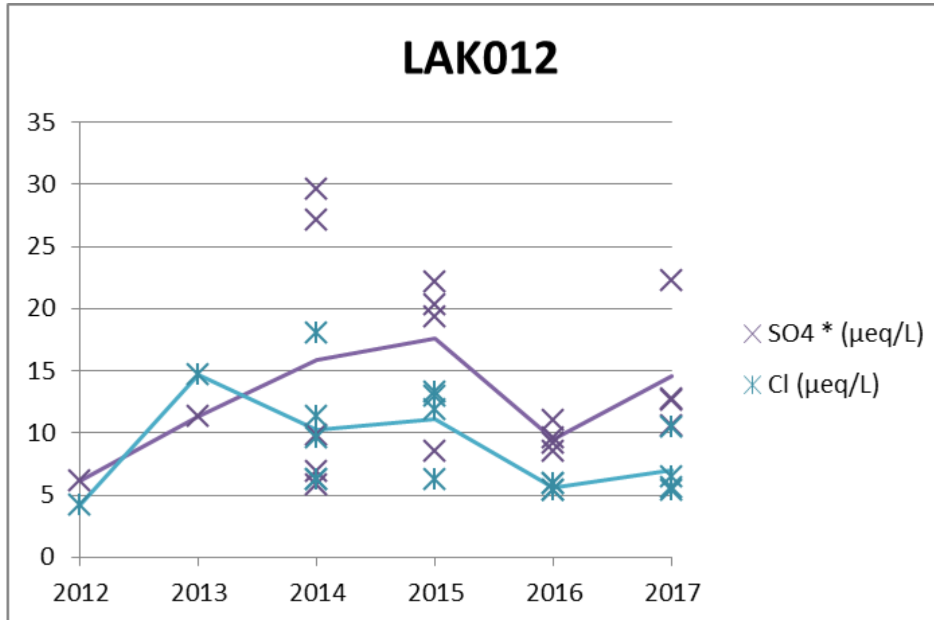


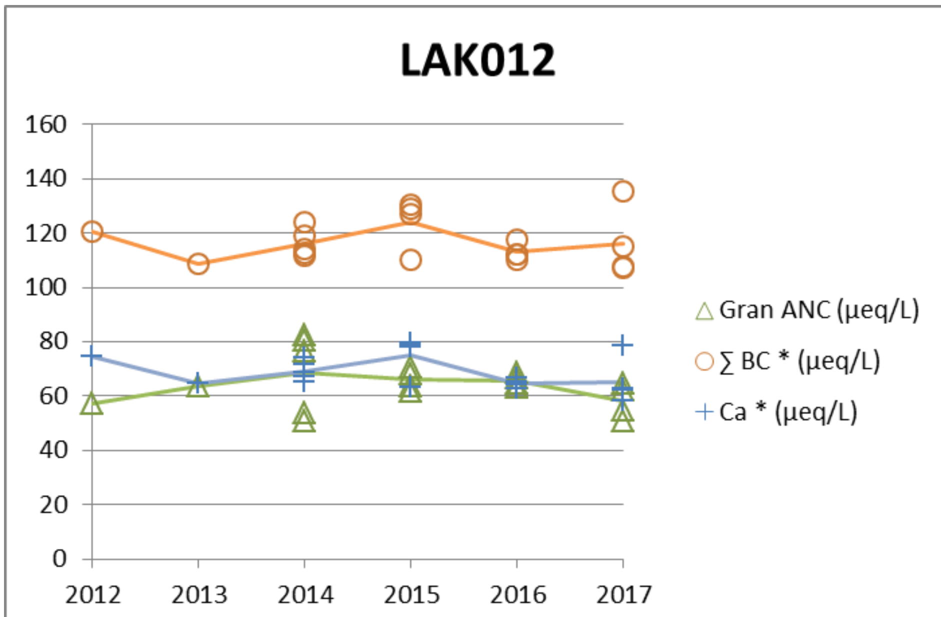


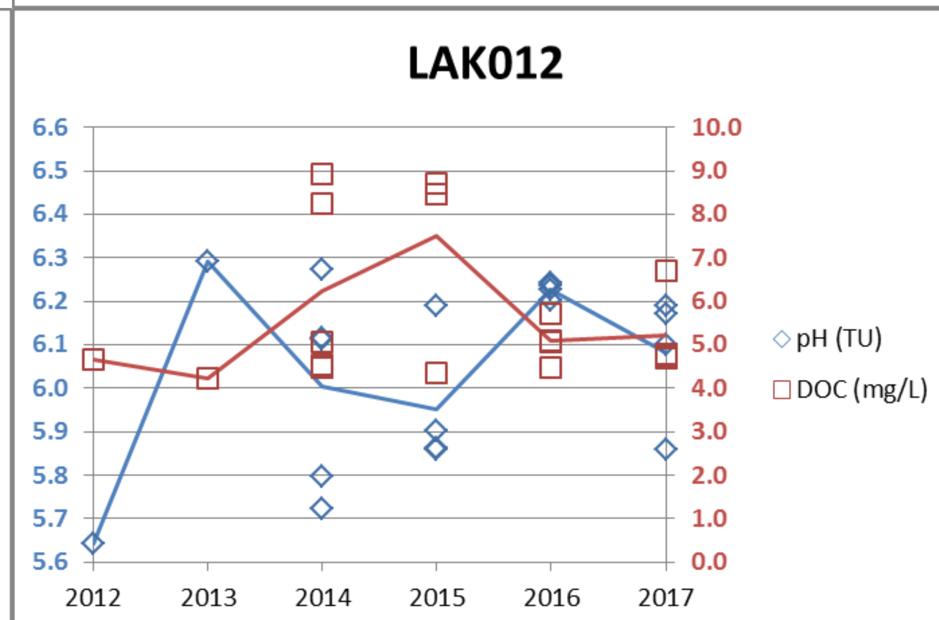
II-d. Freshwater – Results

Tech Memo W07

EEM Sensitive Lake LAK012



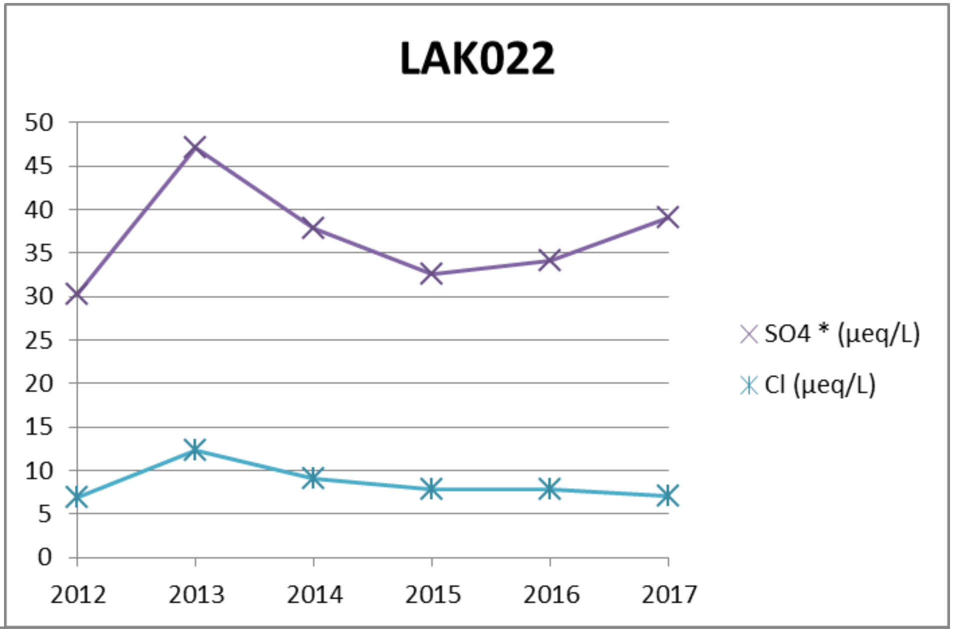


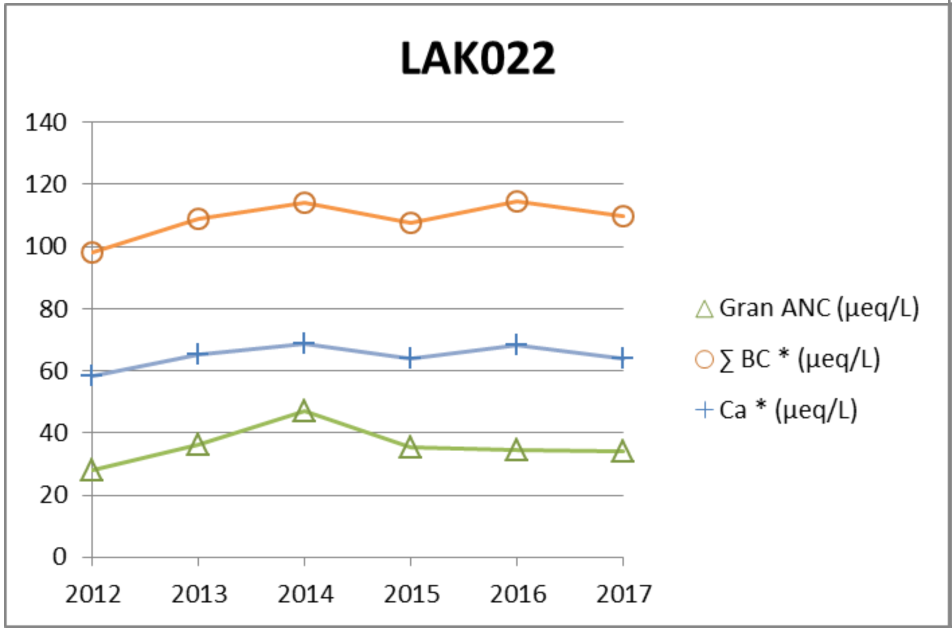


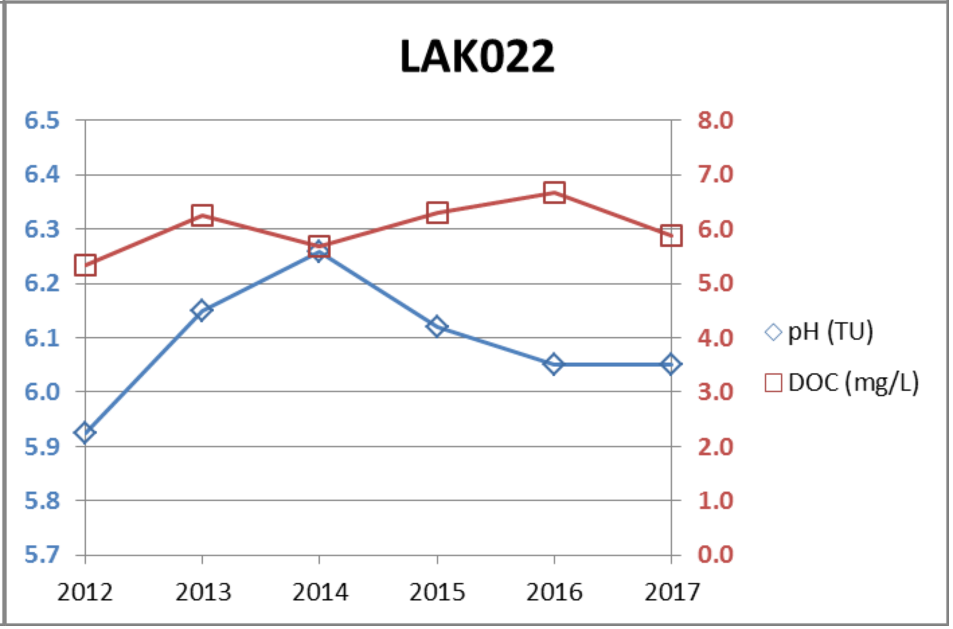
II-d. Freshwater – Results

Tech Memo W07

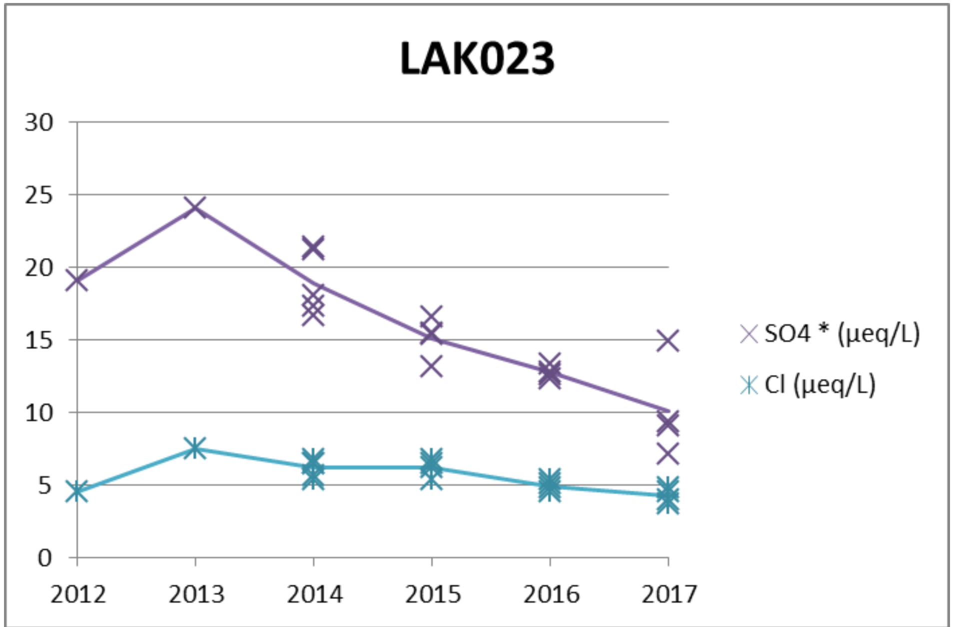
EEM Sensitive Lake LAK022

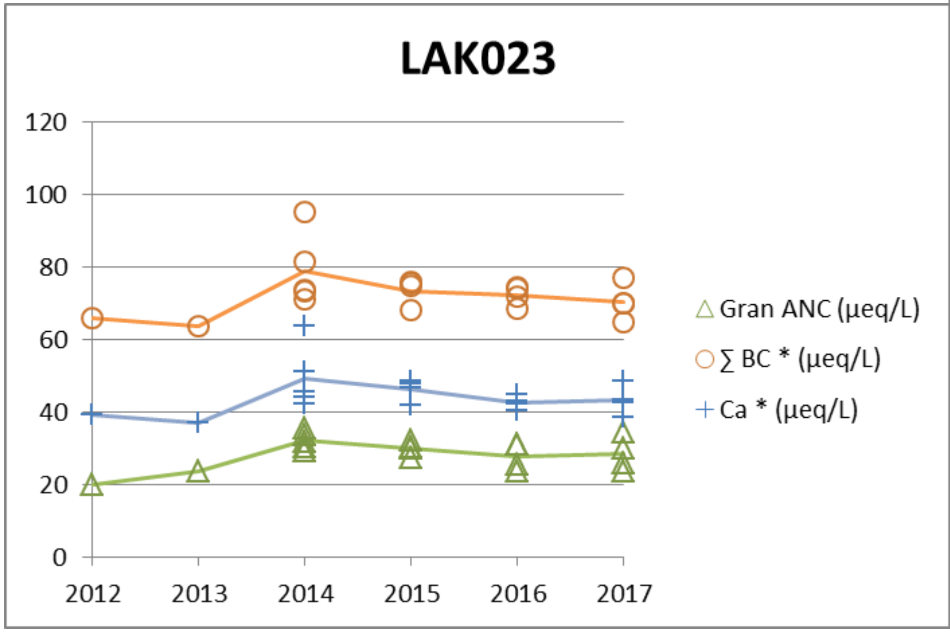


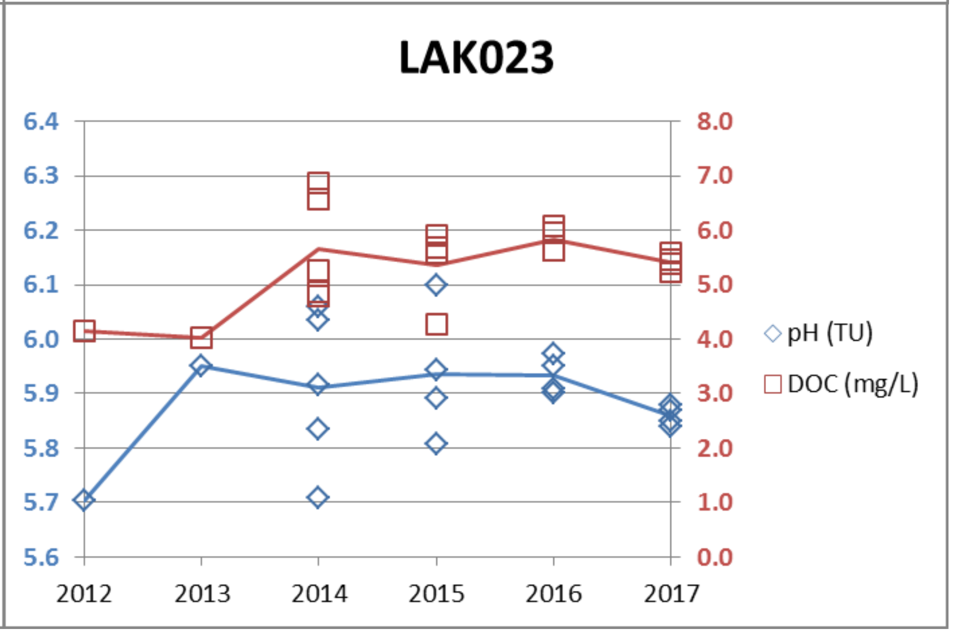




EEM Sensitive Lake LAK023



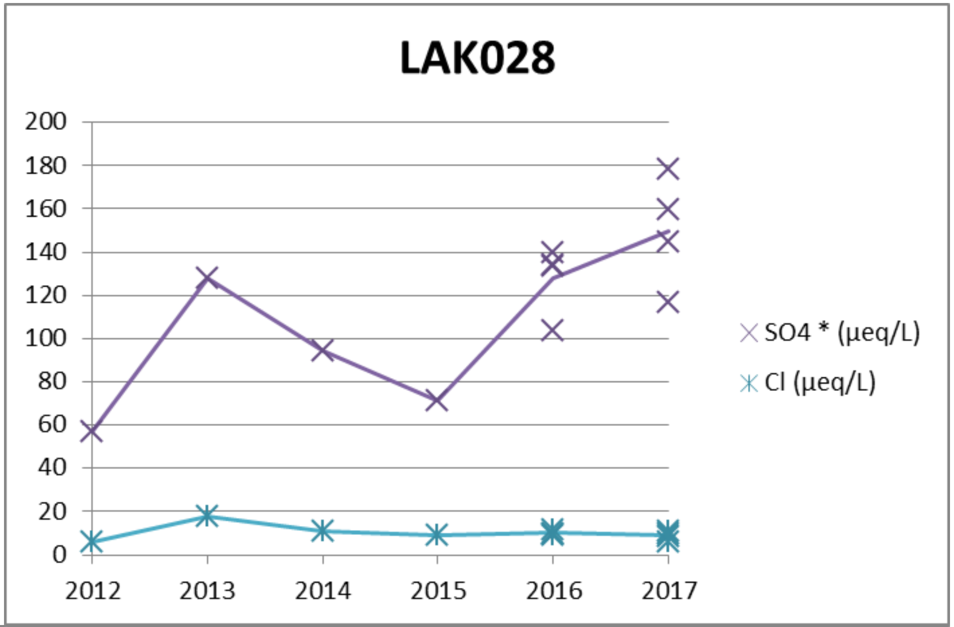


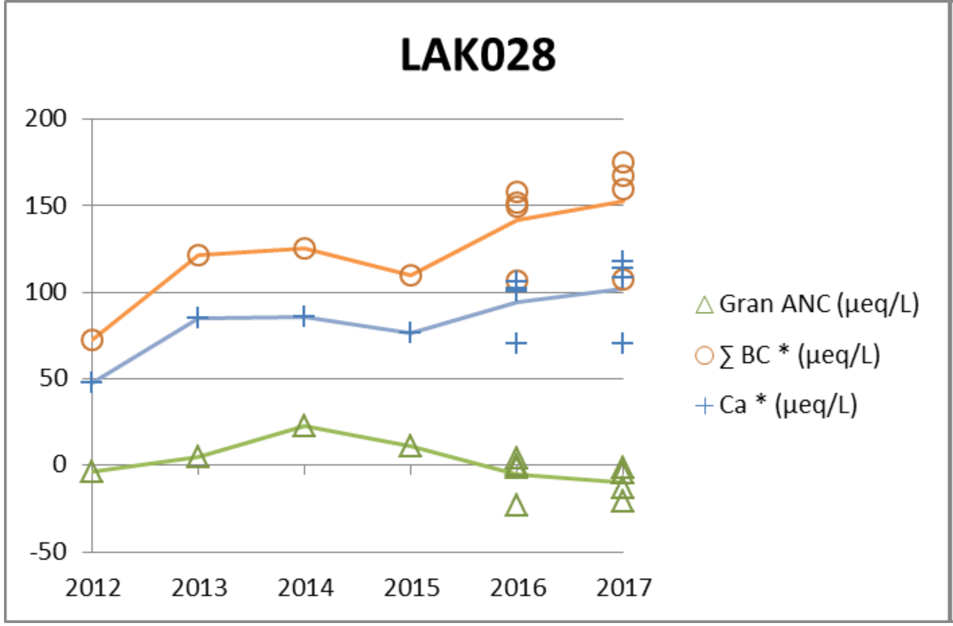


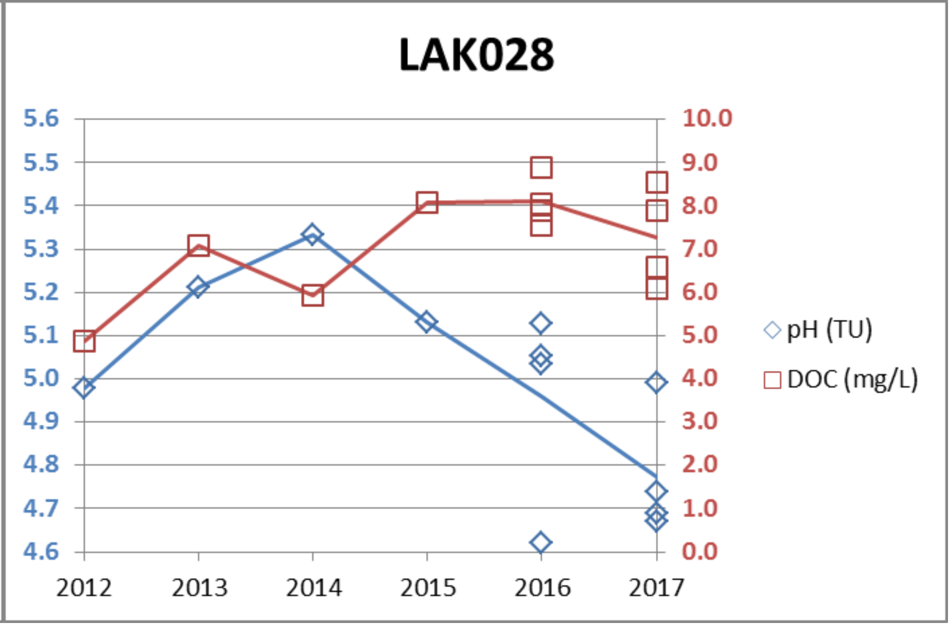
II-d. Freshwater – Results

Tech Memo W07

EEM Sensitive Lake LAK028



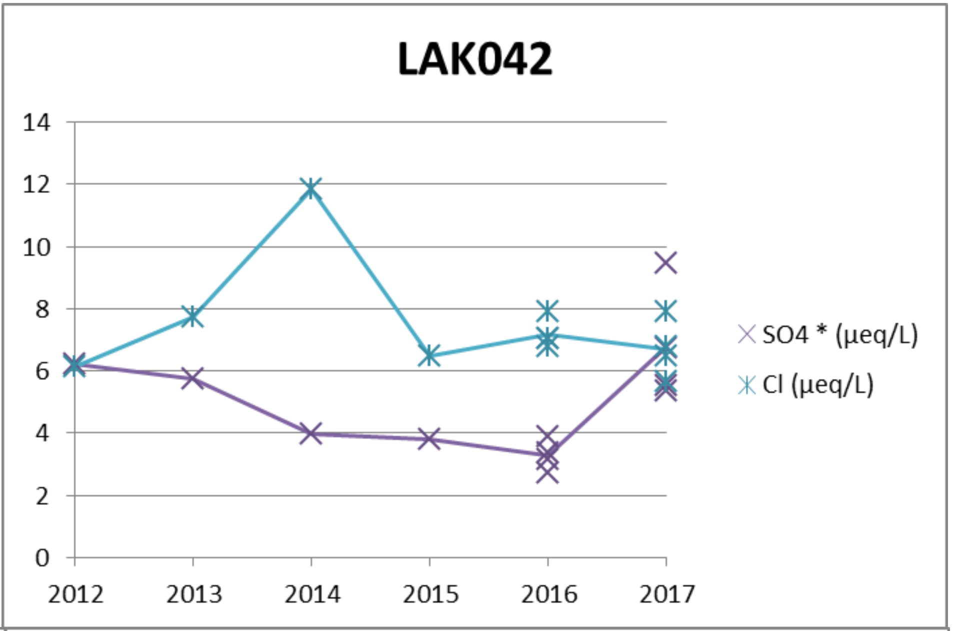


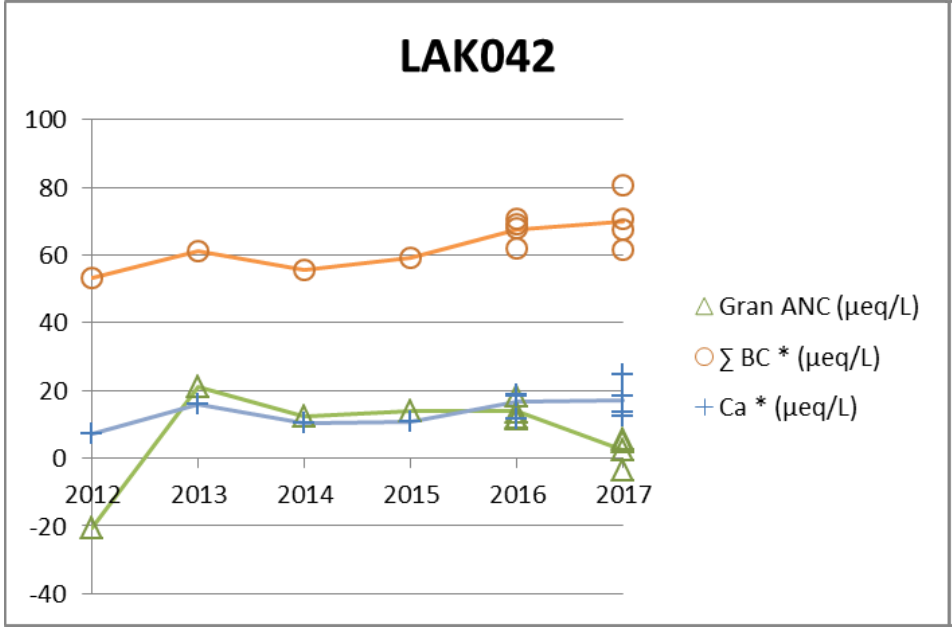


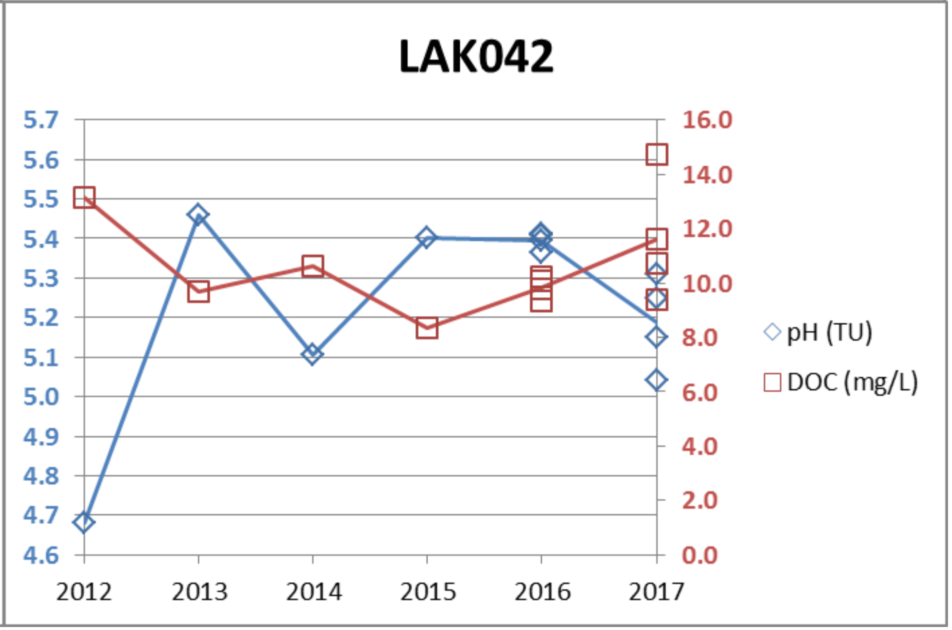
II-d. Freshwater – Results

Tech Memo W07

EEM Sensitive Lake LAK042



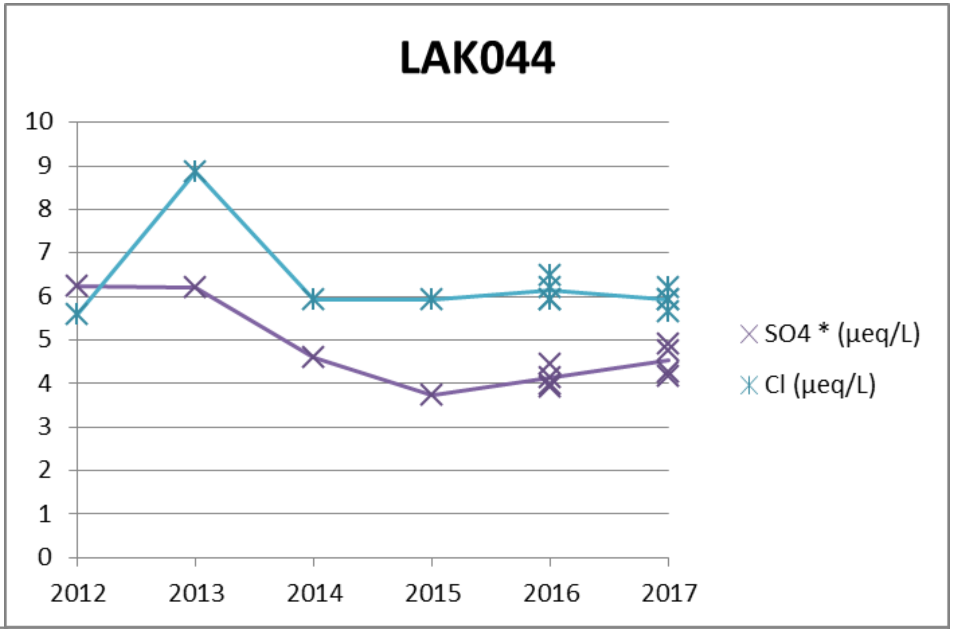


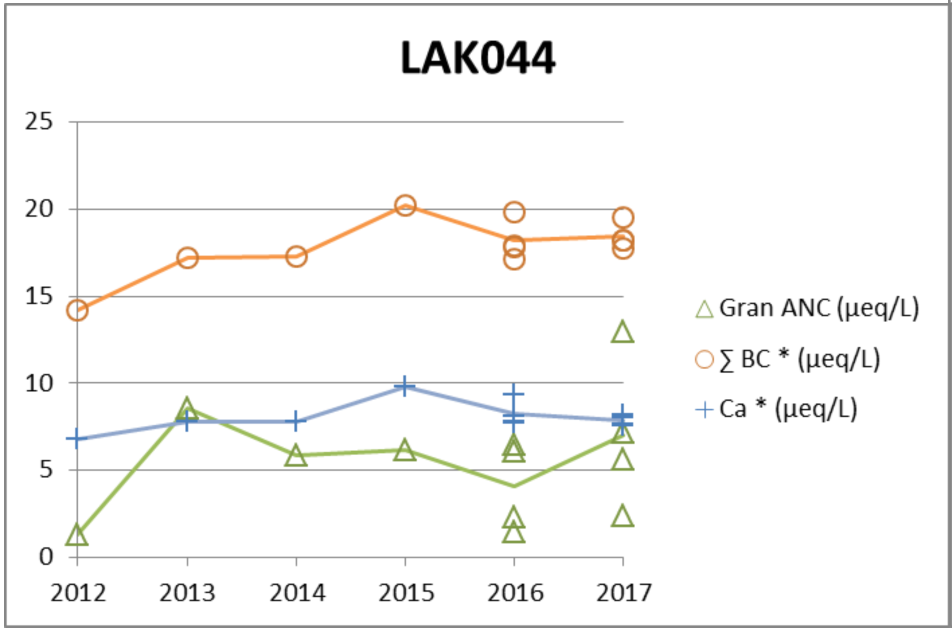


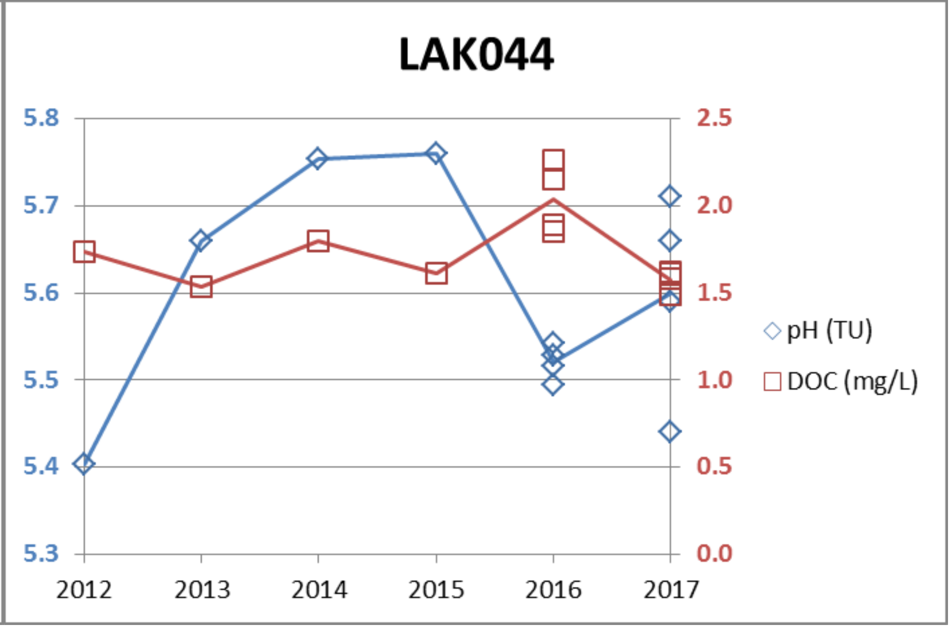
II-d. Freshwater – Results

Tech Memo W07

EEM Sensitive Lake LAK044



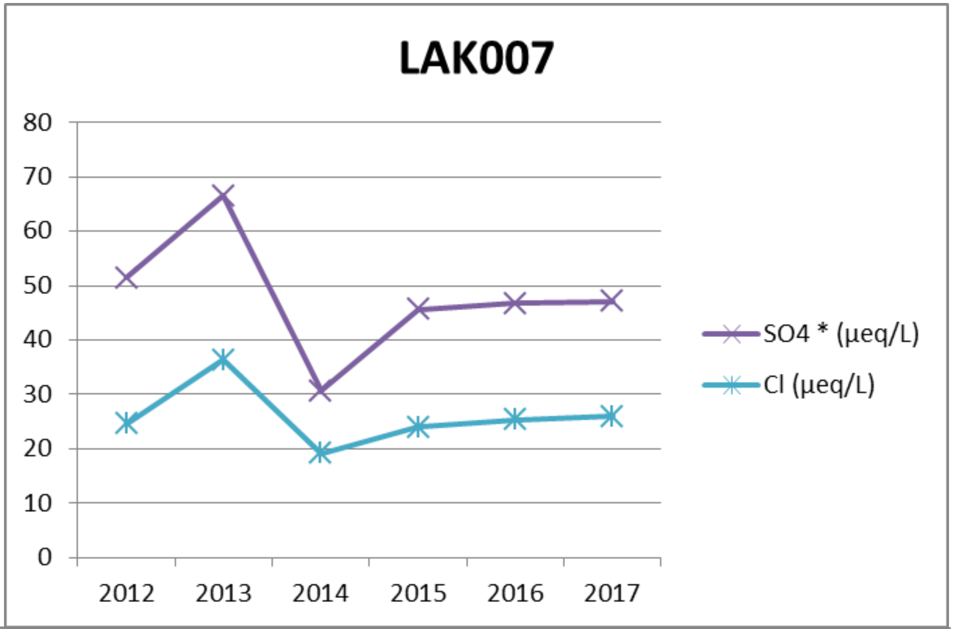


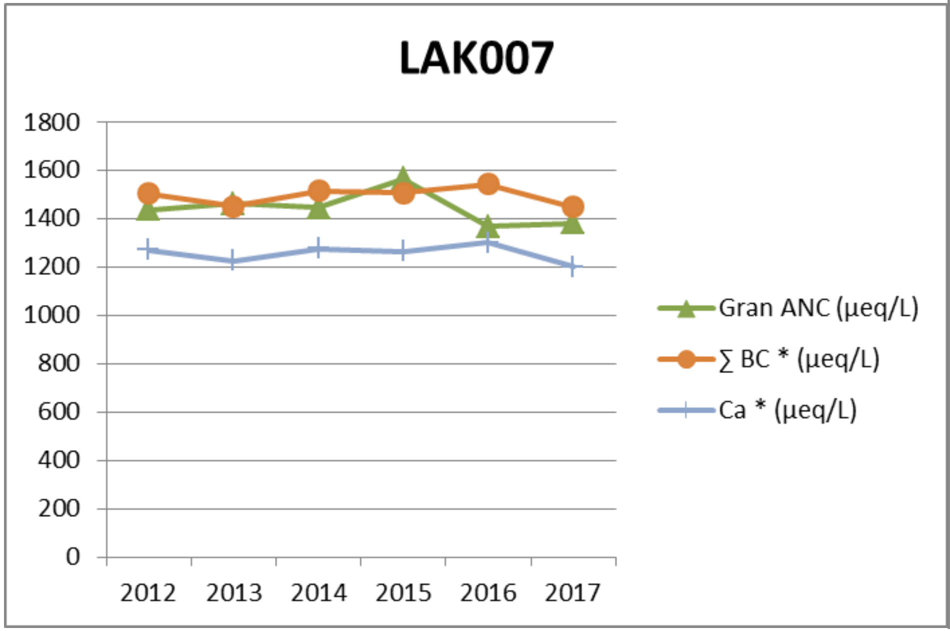


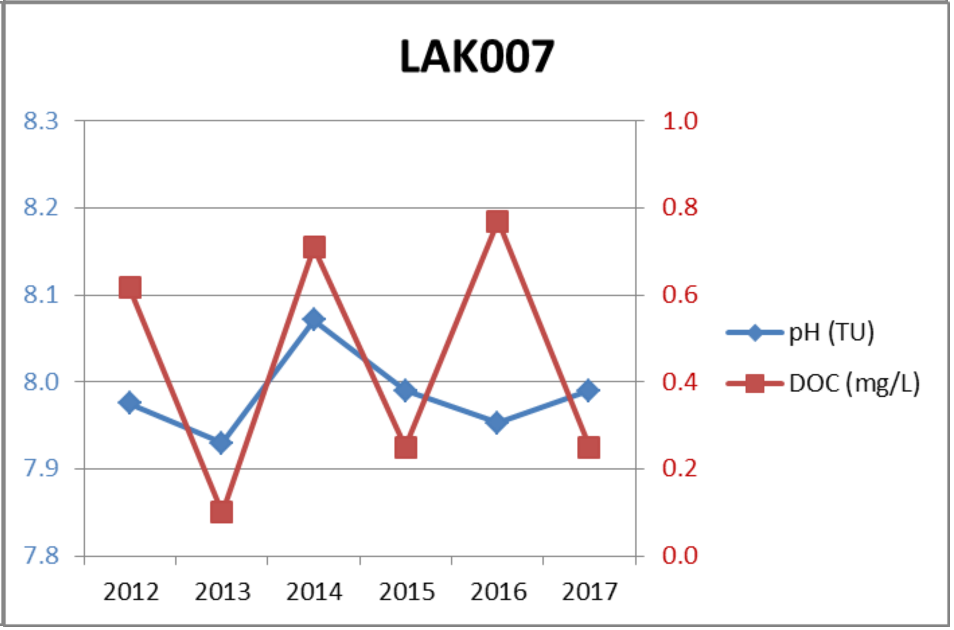
II-d. Freshwater – Results

Tech Memo W07

EEM Less Sensitive Lake LAK007



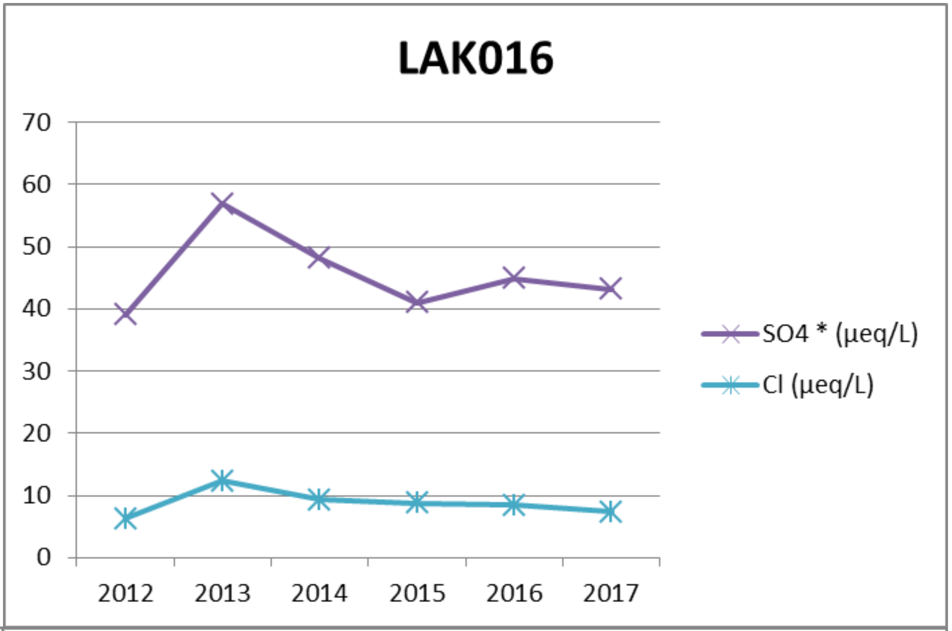


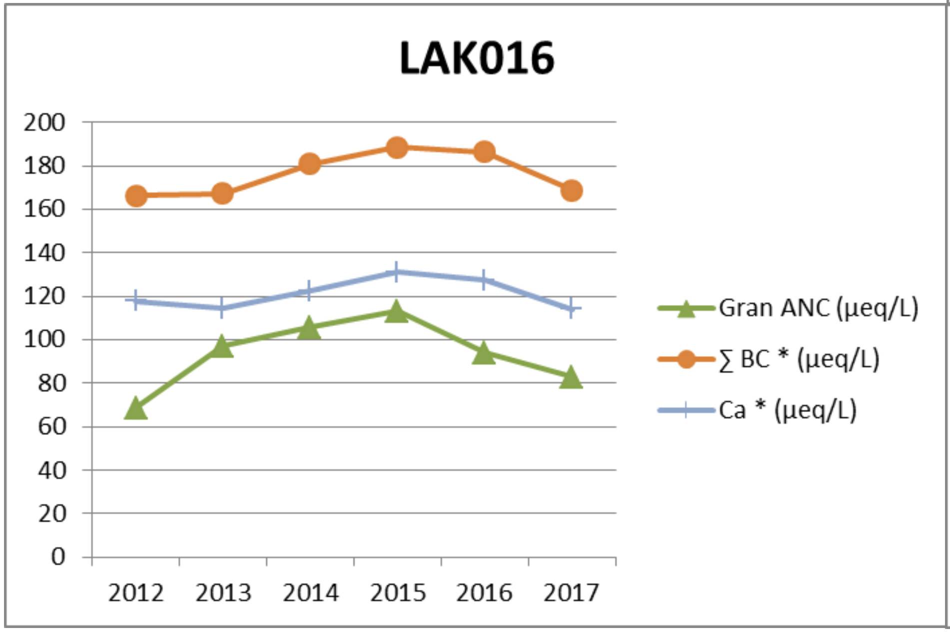


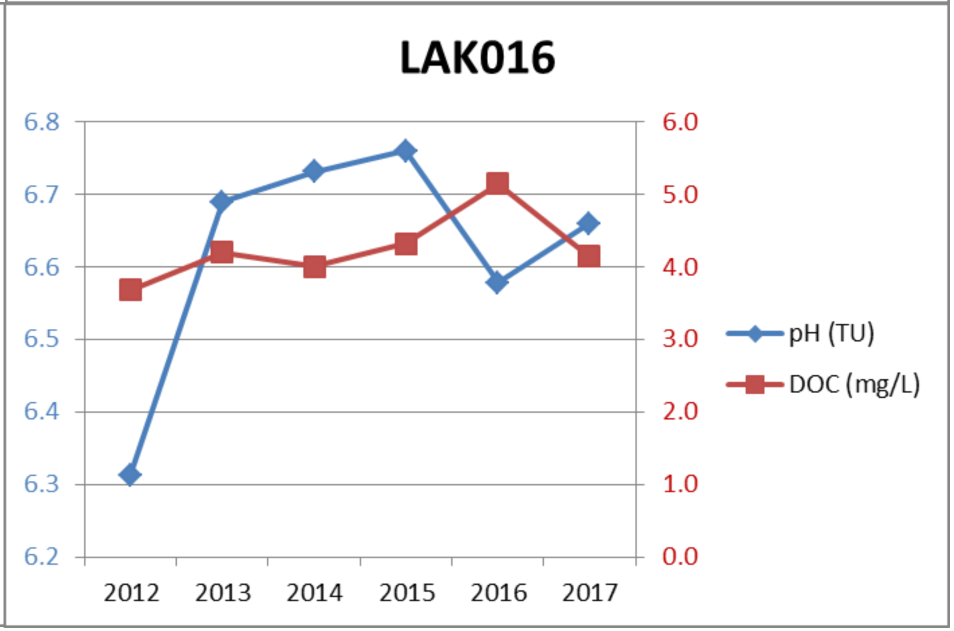
II-d. Freshwater – Results

Tech Memo
W07

EEM Less Sensitive Lake LAK016



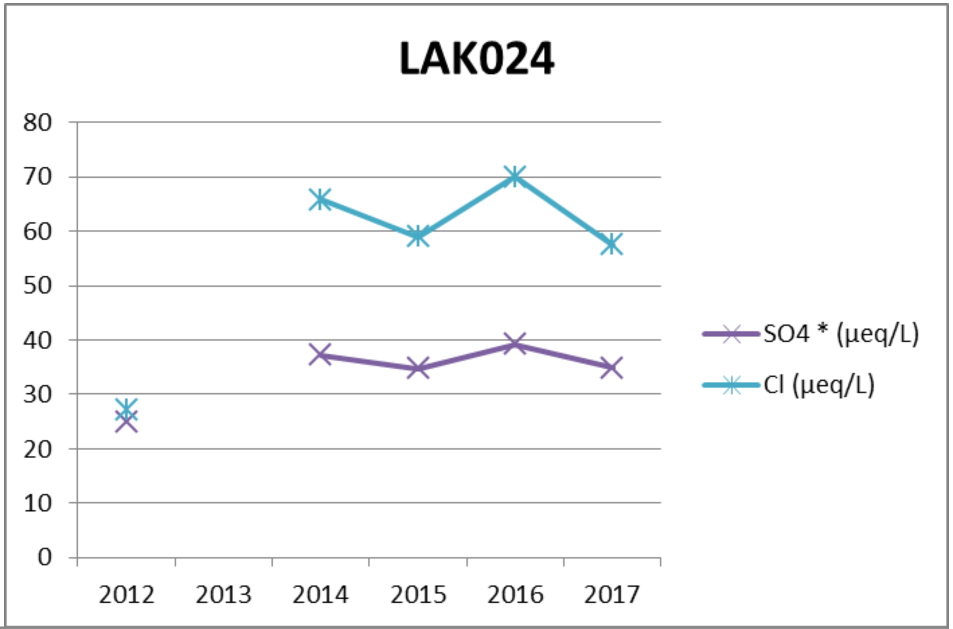


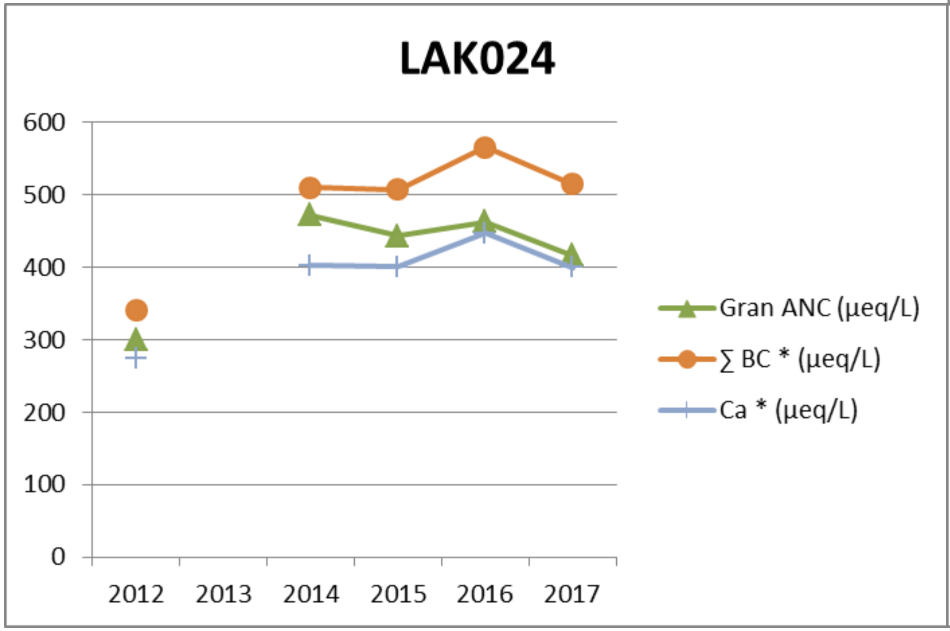


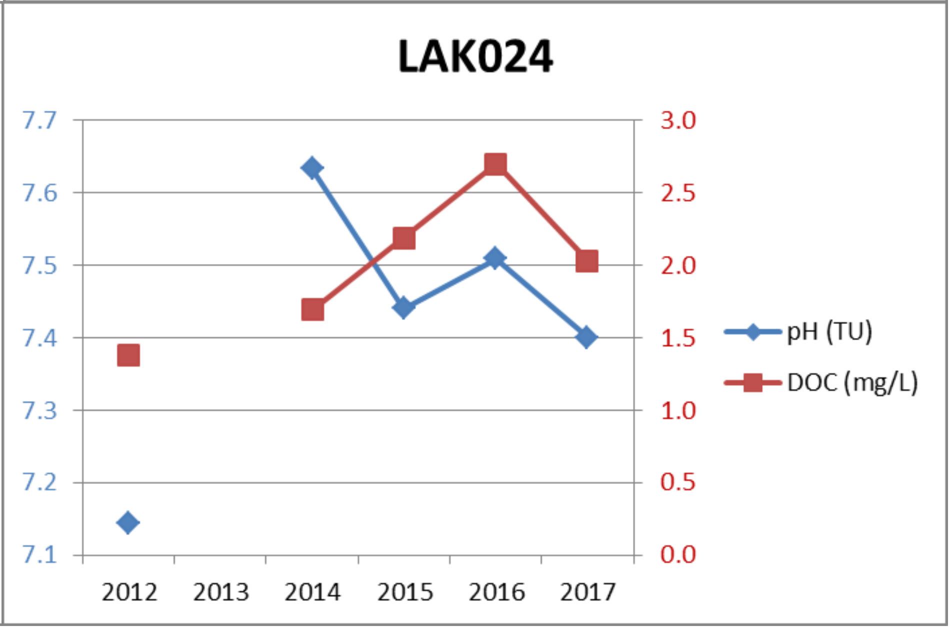
II-d. Freshwater – Results

Tech Memo W07

EEM Lake of High Public Value
LAK024



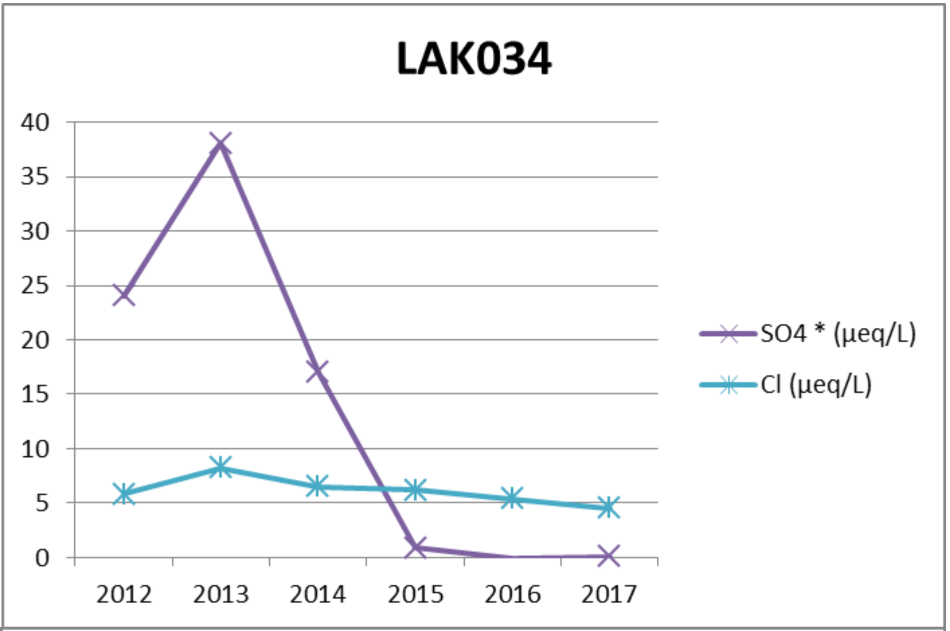


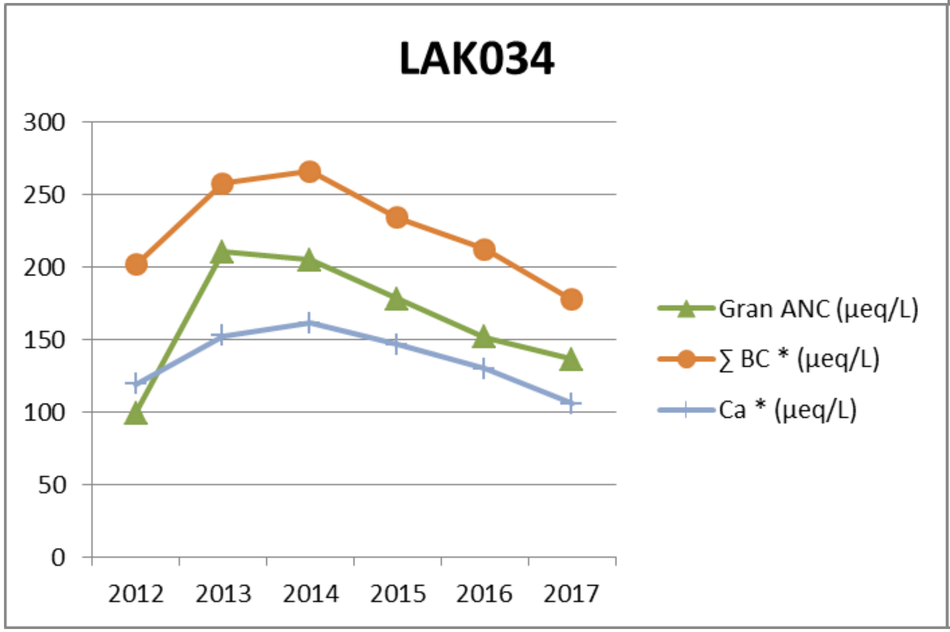


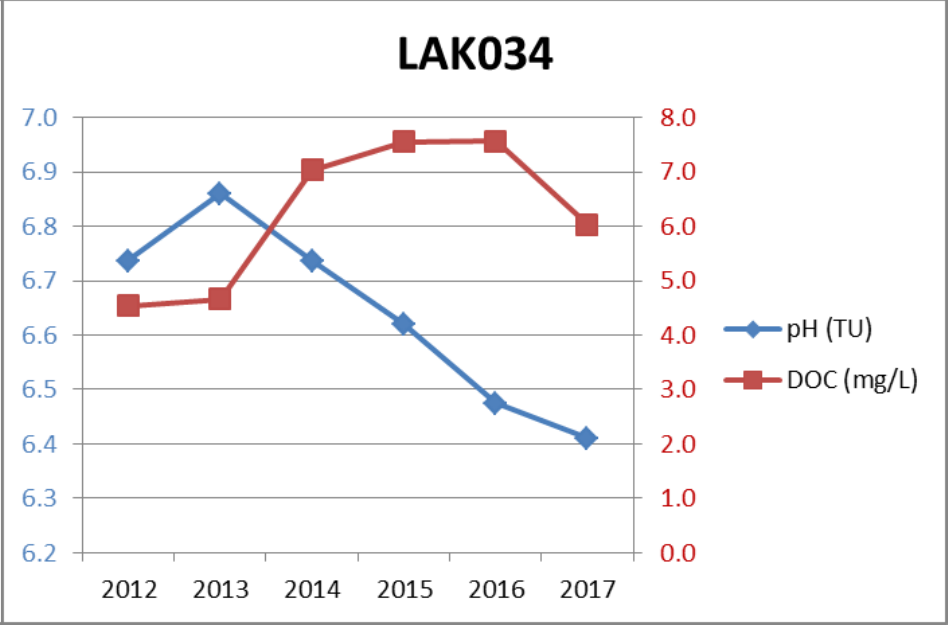
II-d. Freshwater – Results

Tech Memo W07

EEM Less Sensitive Lake LAK034



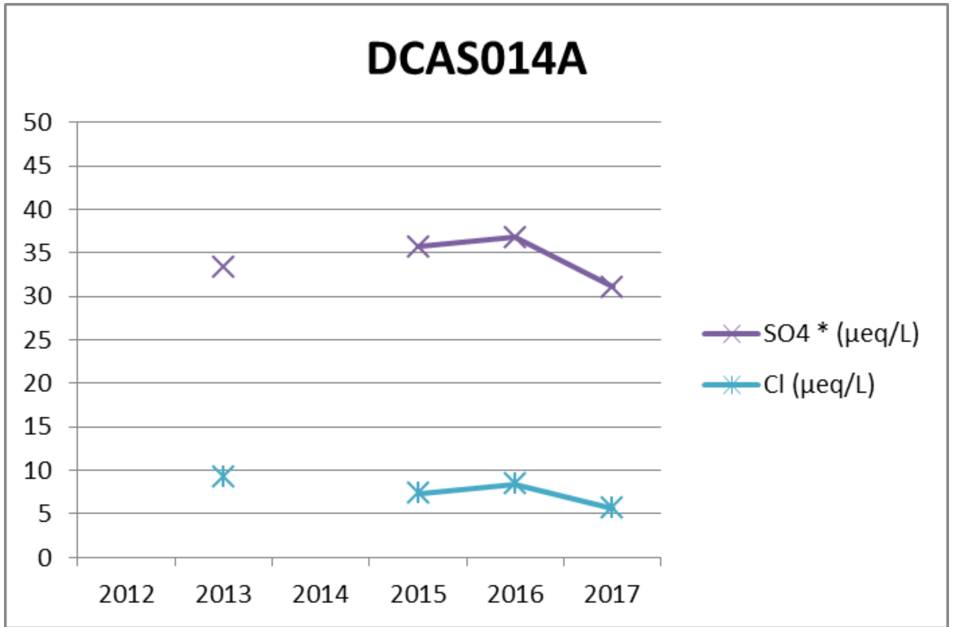


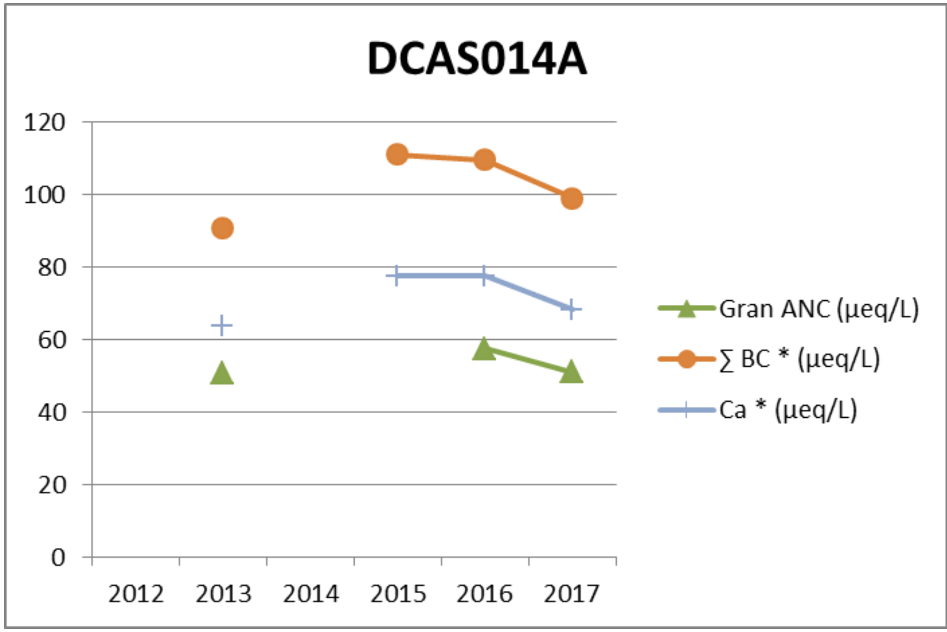


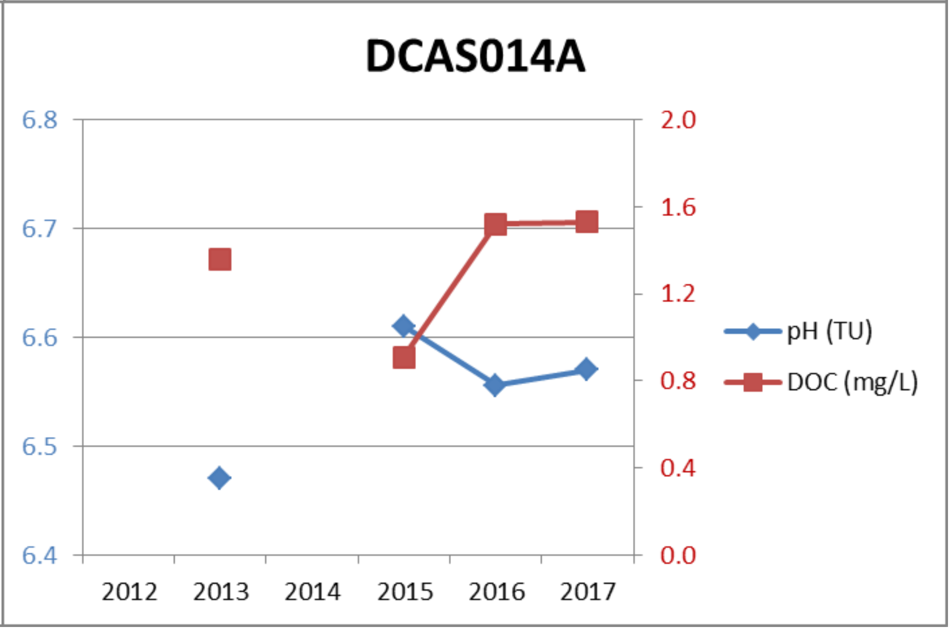
II-d. Freshwater – Results

Tech Memo W07

EEM Control Lake DCAS014A



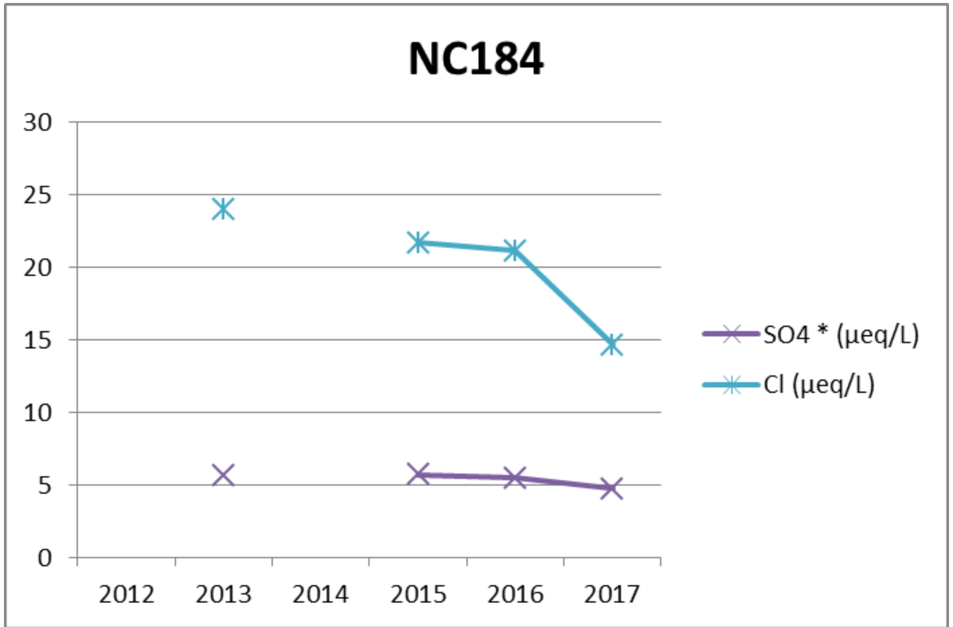


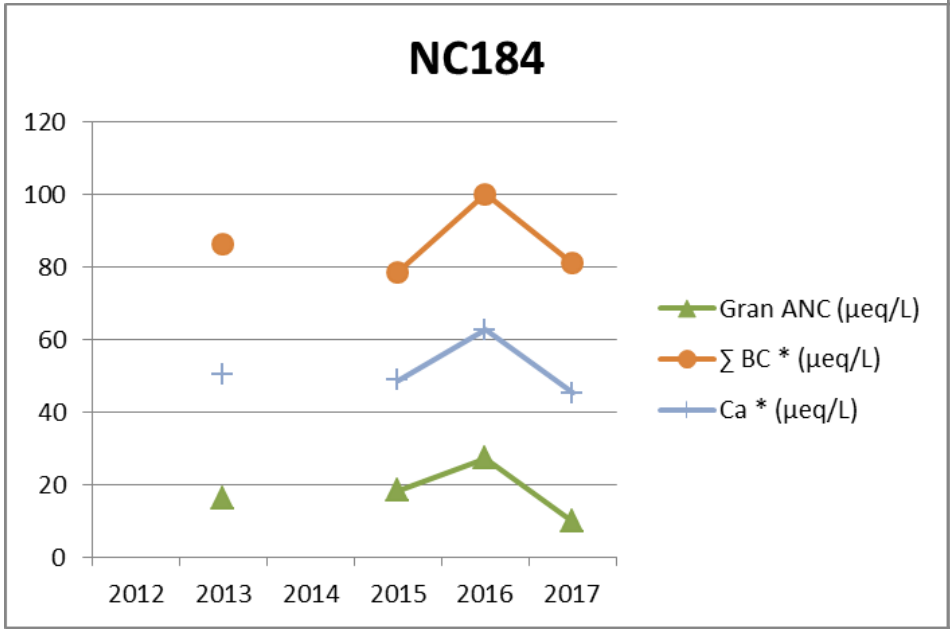


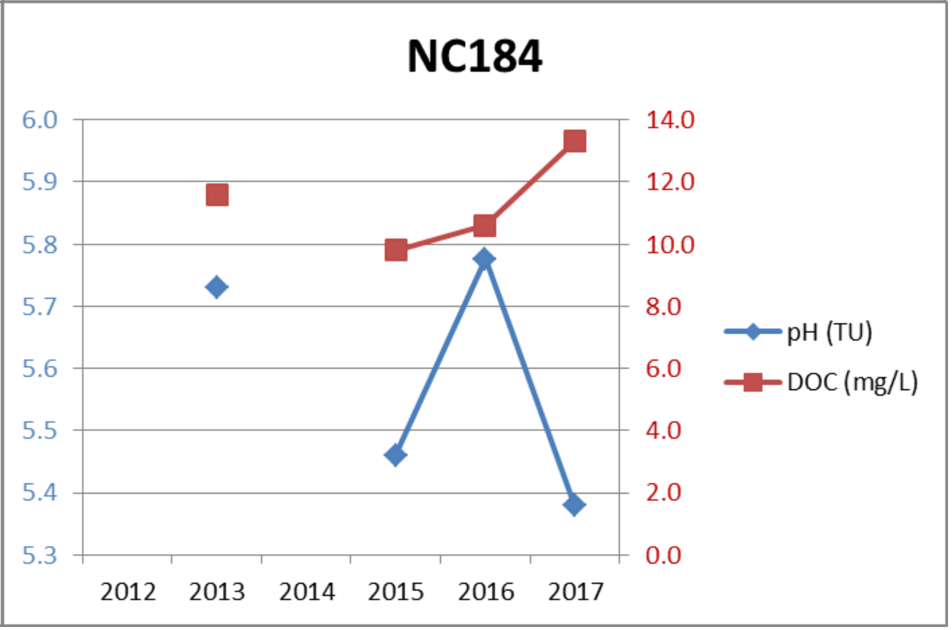
II-d. Freshwater – Results

Tech Memo W07

EEM Control Lake NC184



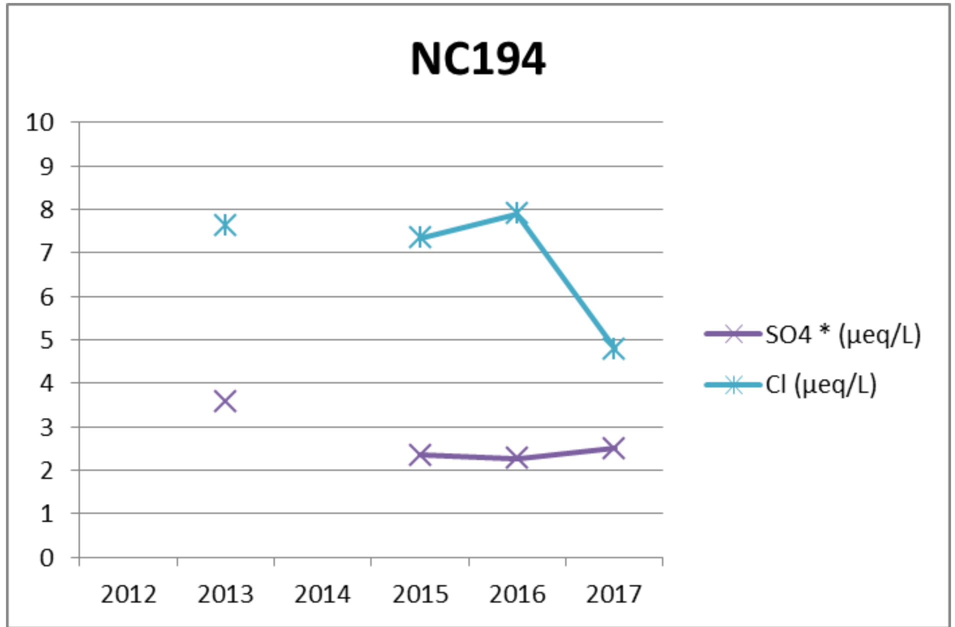


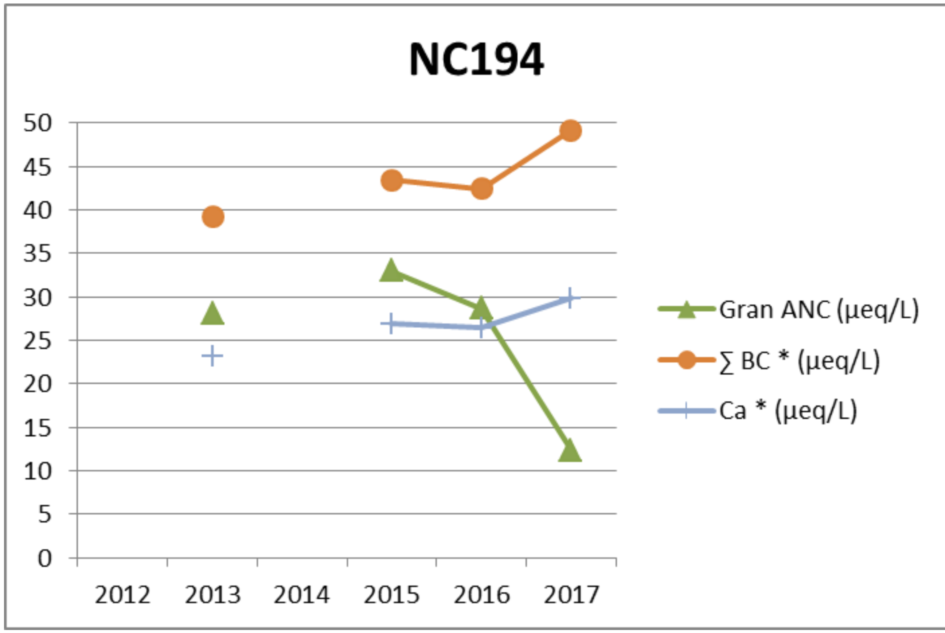


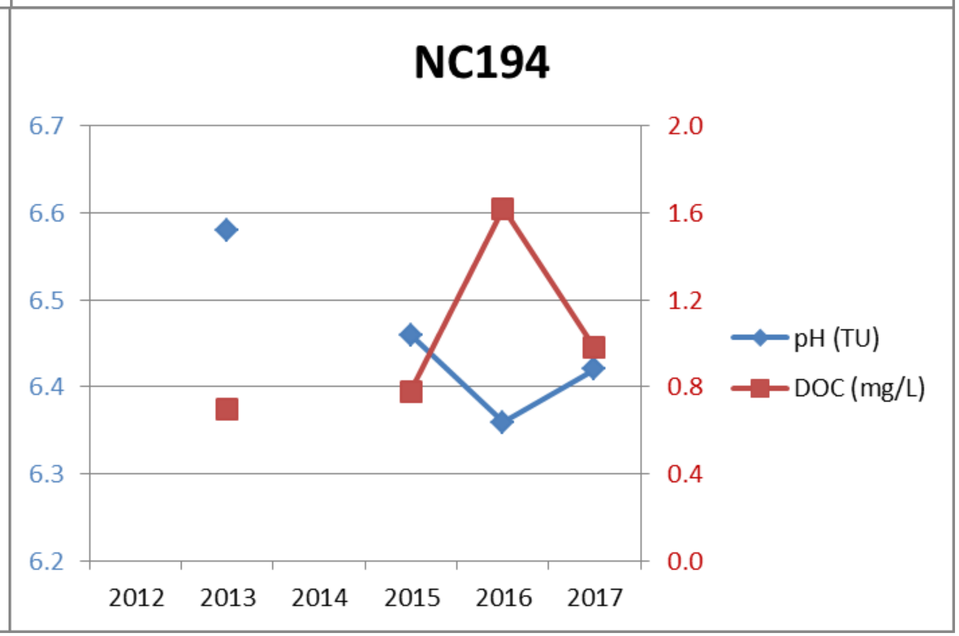
II-d. Freshwater – Results

Tech Memo W07

EEM Control Lake NC194







Power Analyses Slides (from 2016 KPAC ppt & Tech Memo)

Slide from 2016

II-d. Freshwater – Methods

Tech Memo W04

Power analyses

- Power analyses to assess our ability to correctly detect changes in sensitive EEM lakes, including:
  - How well can we detect changes in indicators?
  - How many years are needed to be confident?
  - What is the benefit of multiple samples within a year?
  - What is the benefit of monitoring control lakes?
  - What is the benefit of multiple metrics (pH, ANC, SO_4)?
  - What is the effect of changing the threshold for detection?

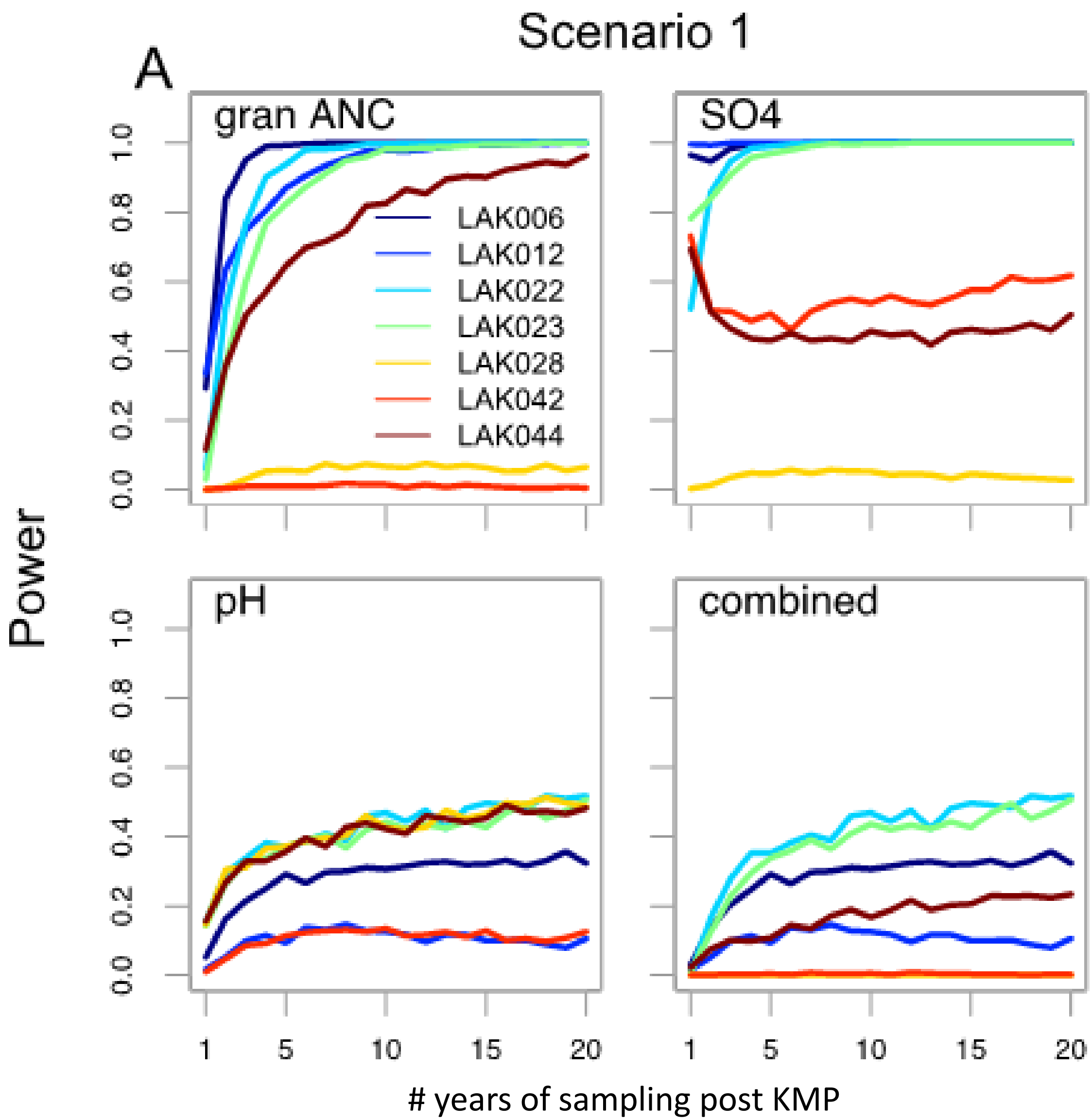
II-d. Freshwater – Results
What was learned

Slide from 2016

Tech Memo W04
Tech Memo W05

Power Analyses

- 5 of 7 lakes show adequate statistical power to detect changes in ANC from annual samples
- 2 lakes (028 and 042) have high variation in ANC, low power
- ANC a better indicator than pH
- Sharp changes in chemistry easier to detect than gradual changes
- Intensive sampling and control lakes improve ability to detect effects



Slide from 2016

II-d. Freshwater – Methods

Tech Memo
W04

Power analyses

- How well can we separate “signal” from “noise”?
- Power analyses are about determining the probability of correctly detecting:
  - a change in an **indicator**,
  - in terms of a particular **site** or **group of sites**,
  - of an explicit magnitude (**effect size**),
  - over a specified **period of time**,
  - relative to a defined **baseline**,
  - given the existing **variability** in the data.

II-d. Freshwater – Results

Slide from 2016

2015 EEM Report, p. 24
Tech Memo W04
Tech Memo W05

What was learned

Power Analyses – Base Case

- Power to detect ΔpH > KPI (- 0.3) is quite low; lower than ANC and SO_4^{2-}
- Power to detect ΔANC and ΔSO_4^{2-} is
  - High for 4 of 7 sensitive EEM lakes
  - Moderate for one metric and low/very low in the other for 2 of 7 lakes
  - Very low for both ANC and SO_4^{2-} for LAK028.
- Strong benefit of considering all three metrics (independently)
- Across all of the metrics, LAK022 and LAK023 consistently have among the highest power.
- LAK028 and LAK042 have very low power for ANC [why we've increased sampling of these lakes in October]
- LAK028 has very low power for SO_4^{2-} [due to high year to year changes in SO_4^{2}]
  - very close to smelter and sensitive to changes in both monthly emissions and wind patterns
- LAK012 and LAK042 have low power for pH.

SOILS

Slide from 2017

II-e. Soils – Permanent Plots

2016 EEM Report, p. 25; Tech S06

Permanent Soil Plots – Layout and Sampling Specifications

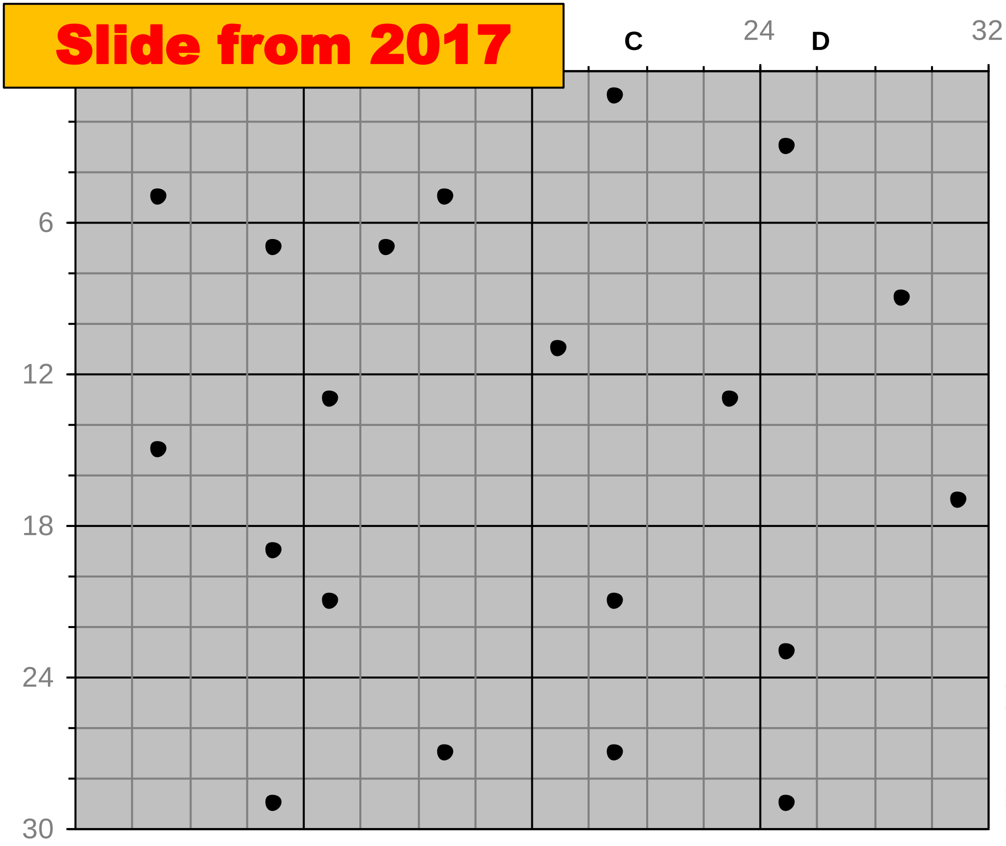
Plot layout:

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

Plot sampling:

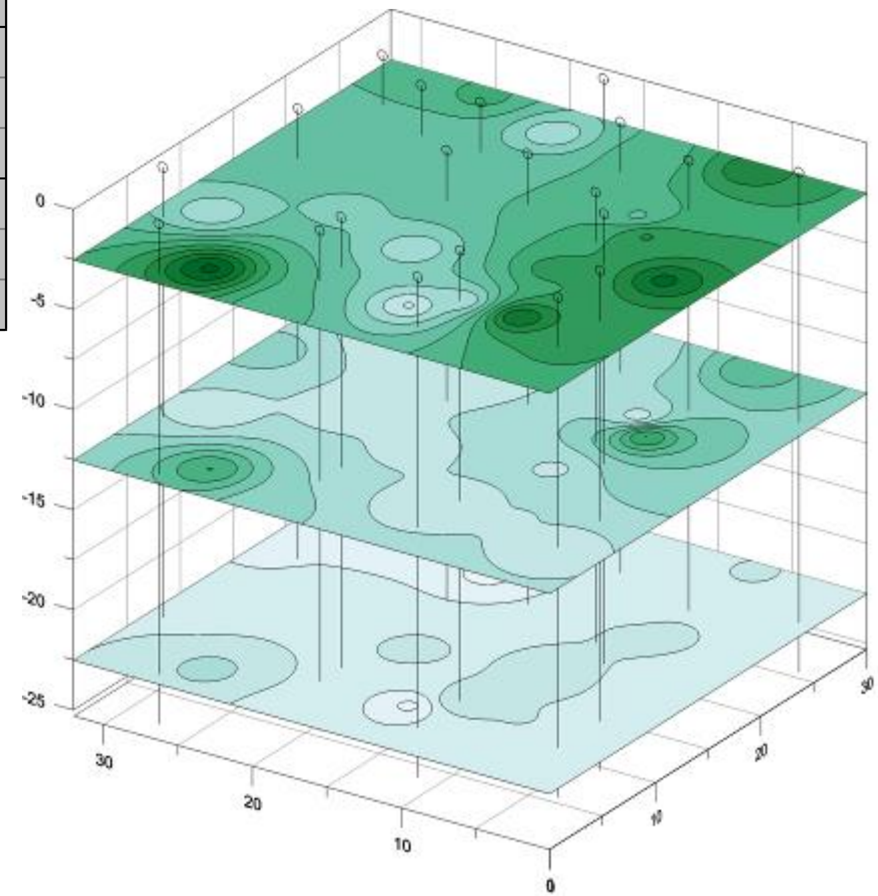
- Random selection of 1 grid in each subplot
- Each selected grid (representing sub-plot) sampled at 5 depths
- One grid sampled (per sub-plot) every 5 years

Slide from 2017



Bird's-eye view of plot grid layout:

- 32 m by 30 m, 20 subplots, 12 sampling grids.
- Dots are sampling sites at Lakelse Lake primary plot during 2015.



Three-dimensional representation of soil organic matter content (%) in the 0–5 cm, 5–15 cm, and 15–30 cm (mineral) soil depths at the primary permanent soil plot at Lakelse Lake. The vertical lines indicate the location of the soil sampling pits (n = 20 per plot.

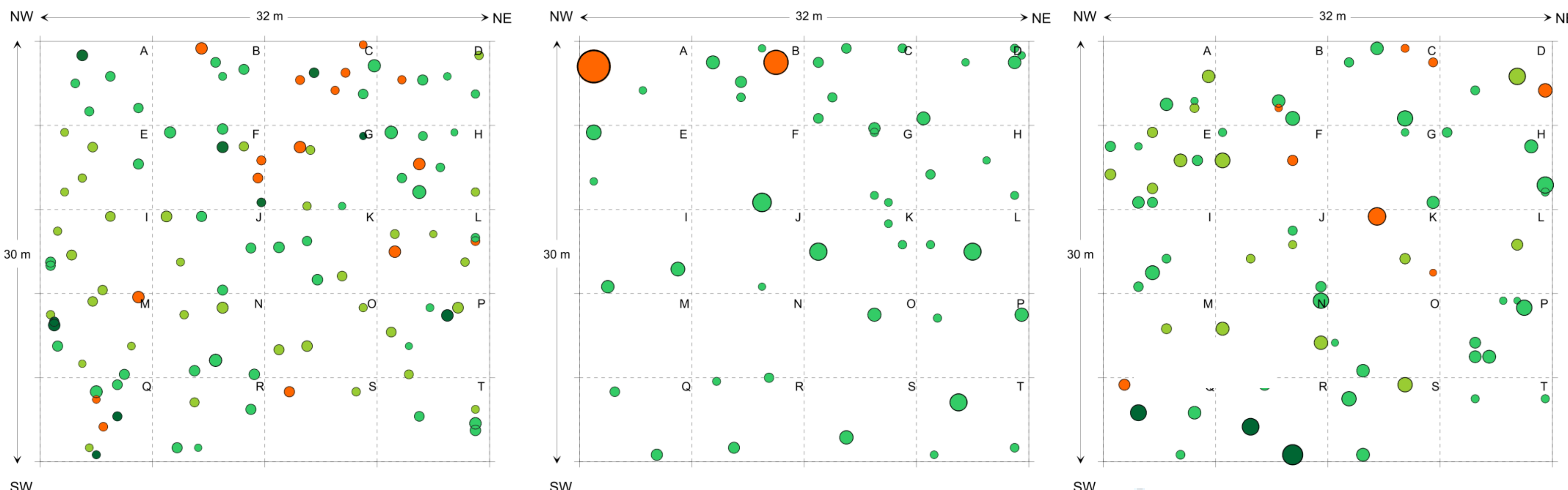
Slide from 2017

II-e. Soils – Permanent Plots

2016 EEM Report, p. 26; Tech Memo S06

Tree Mapping

Lakelse Lake Coho Flats Kemano



If there is a long-term change in exchangeable base cations it will be important to understand how biomass has changed. These data provide a baseline.