



KMP SO₂ EEM Program – Technical Memo W03

Aquatic Ecosystems Actions and Analyses

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Prepared for:

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

Prepared by:

ESSA Technologies Ltd.
Suite 600 – 2695 Granville St.
Vancouver, BC, Canada V6H 3H4
(Using data provided by Rio Tinto Alcan)

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1 Introduction

This Technical Memo provides extended information on the data and analyses in support of the 2015 requirements for the Aquatic Ecosystems component of the KMP SO₂ Environmental Effects Monitoring (EEM) program (ESSA et al. 2014b). These data and analyses thus provide the foundation for Section 3.5 in the 2015 EEM Annual Report (ESSA et al. 2016).

Table 1-1. Aquatic analyses as specified in the EEM Plan. Extracted from Table 16, Section 6.2.5, “Summary of Lakes, Streams and Aquatic Biota Actions, 2013-2018”. The numeric symbols (e.g., ①②③) are used to link sections of the present technical memo with the EEM requirements, and appear throughout this document.

Topic	2015
Steady state water modelling	-
Chemistry: water body sampling	① Annual water sampling, laboratory analysis, and data evaluation. ② Continuation of intensive sampling to determine natural variability.
[SO ₄] ₀ ; F-factor	-
Fish presence / absence sampling	③ Sampling of the 3 reference lakes. Resample if lake pH change reaches threshold.
Episodic acidification	④ Finalize study design.
Amphibians	⑤ Provide support to existing local community groups who conduct annual amphibian monitoring

This technical memo applies methods and approaches that have already been described in detail in other relevant documents. Most of the methods follow those employed in the SO₂ Technical Assessment Report (STAR) (ESSA et al. 2013) and the Kitimat Airshed Assessment (KAA) (ESSA et al. 2014a). Full details on the collection, processing and analysis of the water chemistry samples are reported in technical reports prepared by Limnotek for each year’s sampling (Perrin et al. 2013, 2015; Limnotek 2016). Wherever possible, the description of methods in this technical report refers to these reports instead of repeating information that is already well-documented elsewhere.

The following three documents (as described above) are listed here because they are referenced extensively throughout this technical memo, often without their full citation:

- The STAR (ESSA et al. 2013)
- The KAA (ESSA et al. 2014a)
- The EEM Plan (ESSA et al. 2014b)

Figure 1-1 provides a schematic diagram illustrating the relationship among the multiple documents associated with the surface water component of the EEM Program.

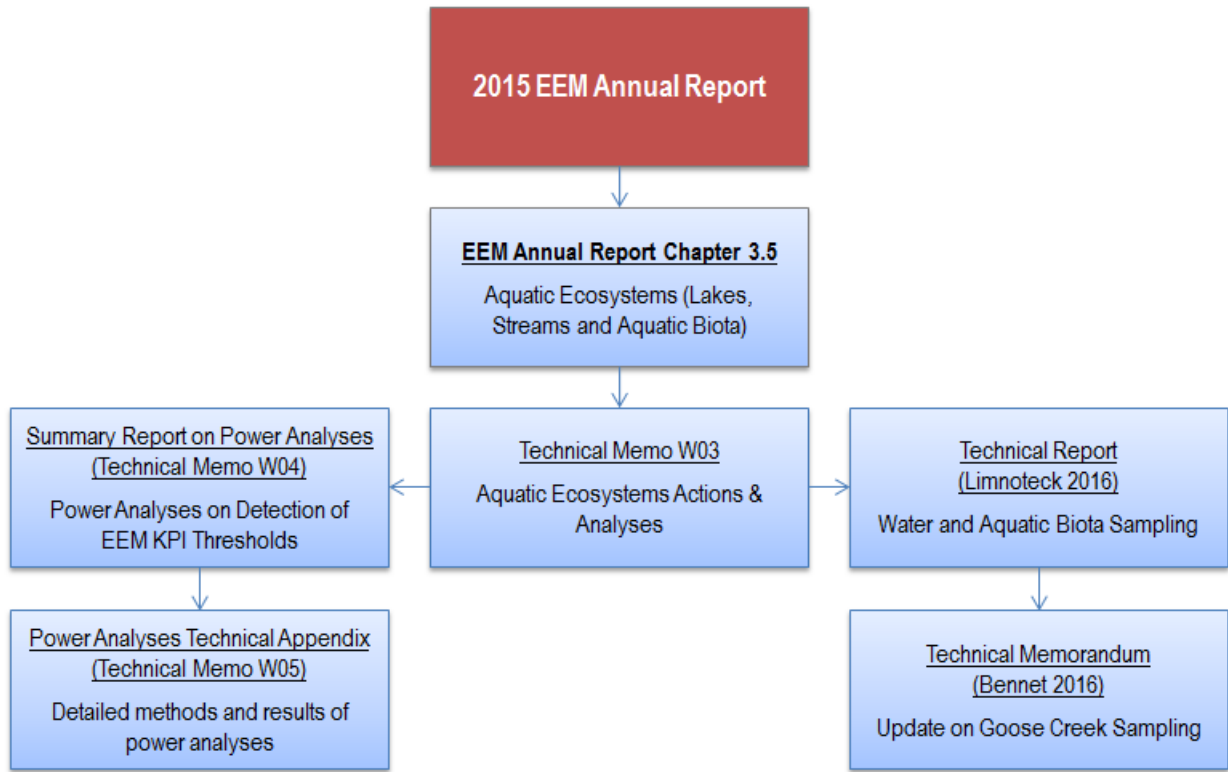


Figure 1-1. Relationship of the multiple technical reports and summaries associated with the aquatic ecosystem component of the EEM Program.

2 Methods

2.1 Annual Monitoring Samples ①

2015 Annual Sampling

In 2015, Limnotek sampled 14 lakes as part of the EEM long-term sampling plan. These lakes included the seven sensitive lakes and three less sensitive lakes identified in the EEM Plan, the high recreational value LAK024 (Lakelse Lake; added to the EEM in 2014), and three additional control lakes added to the EEM in 2015. The three control lakes (NC184, NC194 and DCAS14A) are all located outside of the KMP-influenced airshed and have baseline data for 2013 from sampling as part of the KAA (ESSA et al., 2014a). Sampling was also completed for two sites in the Goose Creek watershed (supplementing the six sites sampled in 2014), to assess whether those sites would be sensitive to increases in sulphur deposition. The sampling methodology is described in detail in Limnotek’s technical report on the water quality monitoring (Limnoteck 2016). Table 2-1 summarizes all of the EEM sites sampled during 2012-2015. Figure 2-1 shows a map of the lakes sampled in 2015.

Table 2-1. Summary of sites sampled within the EEM Program.

Sample Site	Year of Sampling				Rationale for sampling
	2012 During STAR	2013 EEM Program	2014 EEM Program	2015 EEM Program	
Lake 006	✓	✓	✓	✓	EEM sensitive lake
Lake 012	✓	✓	✓	✓	EEM sensitive lake
Lake 022	✓	✓	✓	✓	EEM sensitive lake
Lake 023	✓	✓	✓	✓	EEM sensitive lake
Lake 028	✓	✓	✓	✓	EEM sensitive lake
Lake 042	✓	✓	✓	✓	EEM sensitive lake
Lake 044	✓	✓	✓	✓	EEM sensitive lake
Lake 007	✓	✓	✓	✓	EEM less sensitive lake
Lake 016	✓	✓	✓	✓	EEM less sensitive lake
Lake 034	✓	✓	✓	✓	EEM less sensitive lake
Lake 024	✓		✓	✓	Added to the EEM long-term monitoring lake set due to public importance
MOE3		✓			Potentially sensitive lakes / streams not previously sampled
Cecil Creek 1		✓			
Cecil Creek 2		✓			
Cecil Creek 3		✓			
MOE6			✓		
Goose Creek 1			✓		
Goose Creek 2			✓		
Goose Creek 4			✓		
Goose Creek 5			✓		
Goose Creek 6			✓		
Goose Creek 7			✓		
GNT1 (Goose Creek)				✓	
GNT2 (Goose Creek)				✓	
		KAA Program			
NC184		✓		✓	Control lakes added to EEM in 2015
NC194		✓		✓	
DCAS14A		✓		✓	

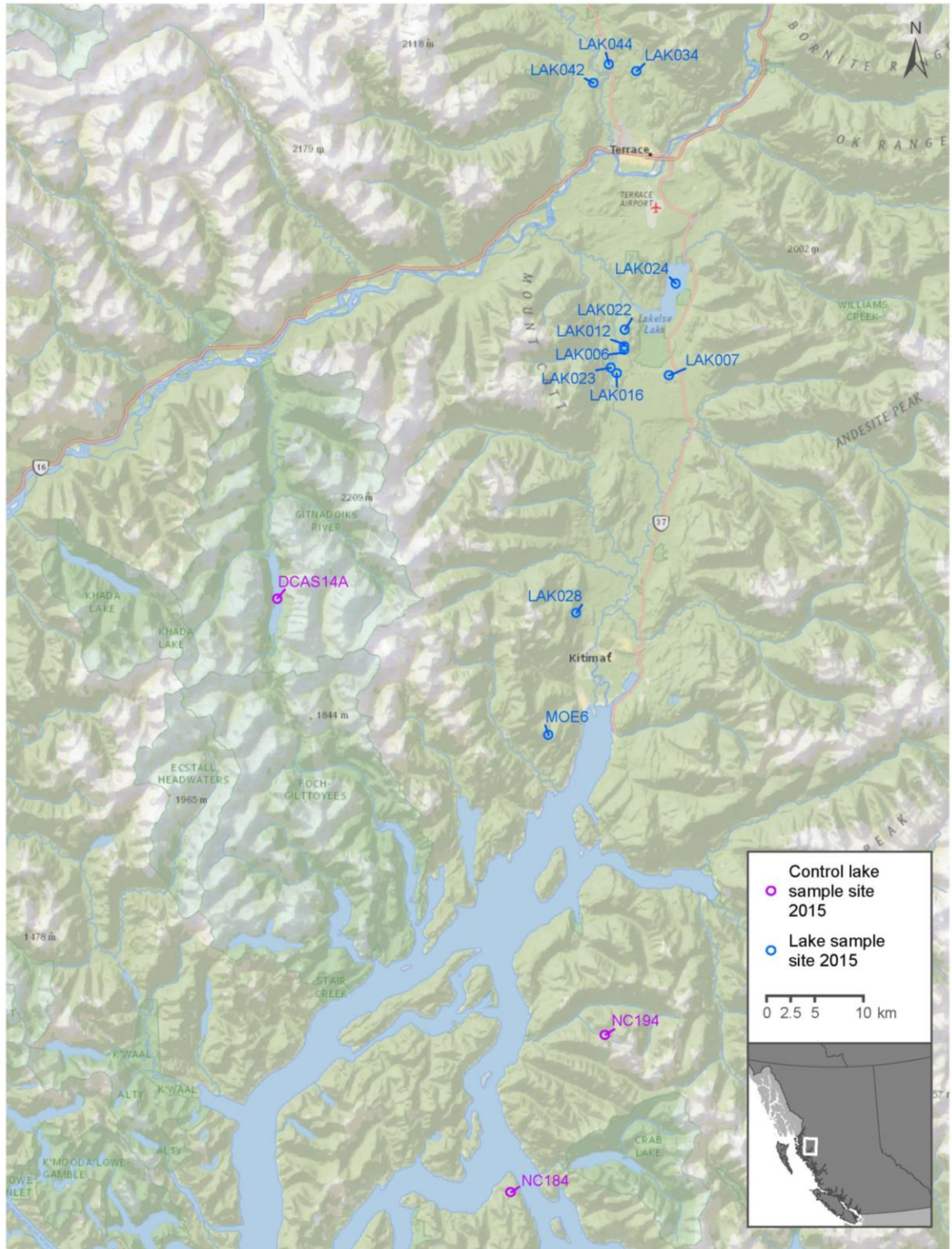


Figure 2-1: Location of the lakes that were sampled in 2015. The lake called MOE6 was not sampled in 2015. The three control lakes are labelled with purple text (Source: Limnotek 2016).

2.2 Intensive Monitoring of Three Lakes ②

Starting in 2014, intensive monitoring was initiated in three of the EEM lakes, End Lake (LAK006), Little End Lake (LAK012) and West Lake (LAK023). These three lakes were selected based on being accessible by road, thus making repeated visits much more feasible than for remote lakes requiring helicopter access. During the fall of 2014, the intensive monitoring included continuous pH monitors and multiple site visits to collect intra-season water samples for additional lab analyses and pH measurements. In 2015, the continuous pH monitors were deployed from mid-April until mid-November. During October 2015, three additional within-season water chemistry samples were taken at these three lakes, subsequent to annual sampling across all of the lakes (i.e., four samples for each of the intensively monitored lakes in 2015). This work was planned, implemented and documented by Limnotek. The methods and results for 2015 are reported in Limnotek (2016).

2.3 Quality of Water Chemistry Data ①②

Sampling and laboratory quality control and quality assurance

The collection, handling, transport, and analyses of water quality samples were conducted with numerous quality checks, to ensure the highest quality data possible. Details on the methods for quality control and quality assurance for the water samples are described in Limnotek (2016).

Analyses of Charge Balance and Estimated vs. Measured Conductivity

In addition to the data quality control and assurance procedures applied during the sampling and subsequent laboratory analyses, we applied two additional methods to confirm the quality of the data input prior to their use for the analyses and modeling described in this technical memo. First, we assessed the charge balance for each site, and then examined the average charge balance across all sites within a particular data set (i.e., the EEM lakes were considered separately from the Goose Creek sites). Second, we compared the estimated conductivity based on ion concentrations for each site to the measured conductivity for that site, then examined average relative differences across all sites within a particular data set. These two tests integrate the cumulative errors in any of the measured parameters, therefore giving an indication of the overall quality of the entire data set.

Further details on the methods and rationale are described in greater detail in the STAR (ESSA et al. 2013, Section 8.6.3.2) and the KAA (ESSA et al. 2014a, Section 6.1.1.1).

pH measurements

Water quality samples taken in 2015 have multiple measures of pH, including a field measurement and two lab measurements (Trent University and ALS). As described in Section 2.2, three lakes also have additional measurements of pH, in particular from continuous meters. As described in the STAR, lab measurements of pH, rather than field measurements, have been used for the analyses of lake chemistry; lab pH measurements have lower variability, and therefore are more relevant to the detection of long term trends.

The 2012 data collected during the STAR included laboratory measurements of pH only from Trent University. Inter-annual comparisons of trends in pH have therefore been conducted using the Trent

pH results. Limnotek (2016) analyzed differences among the different methods of measuring pH for quality assurance purposes.

2.4 Inter-annual Changes

Observed Changes

The EEM Program now has four consecutive years of monitoring data with which to examine inter-annual changes in water chemistry parameters. We calculated the changes in major water chemistry attributes between subsequent years and across the entire period for 2012-2015¹.

Expected Changes and Application of the Evidentiary Framework

The EEM Evidentiary Framework (refer to Section 7.0 and Appendix H of the EEM Plan) provides a weight-of-evidence approach for assessing causality associated with observed changes in water chemistry. The general principles of the evidentiary framework are considered in Section 4.1, but we did not formally apply the framework because the 2015 annual emissions represent a transitional period from the old smelter to KMP, with average SO₂ emissions of only 8.3 tonnes / day, compared to 11.6 tonnes/day in 2014 (Figure 4). It will be more instructive to apply the evidentiary framework once KMP emissions have increased beyond levels observed in 2012-2015.

2.5 Fish Sampling ③

Limnotek conducted fish sampling in LAK006, LAK012, LAK023, and LAK044 in 2013. The goal of this work was to measure the presence/absence of fish in four of the seven sensitive lakes within the EEM Program. Under the EEM Plan, the fish populations in some of these lakes could potentially be resampled if it were determined that a lake's pH had declined by more than 0.3 pH units. In 2015, fish sampling was completed in the three less sensitive lakes: LAK007, LAK016, and LAK034. Details of the fish sampling methodologies for the two years are described in Limnotek's technical reports (Perrin et al. 2013, Section 2.9; Limnotek 2016, Section 2.8).

2.6 Goose Creek (non-EEM sites)

In 2014, six sites within the Goose Creek watershed (not formally part of the EEM Program) were sampled to assess their potential sensitivity. Sampling of these sites was conducted by Limnotek, as described by Bennett (2014). Further analyses of the water chemistry data were conducted in 2014 (ESSA Technologies 2015). In 2015, Limnotek collected samples from two additional sites on northern tributaries of Goose Creek, in a region of the watershed that had not been previously sampled. Full details of the sampling approach and methods are provided in Limnotek's technical report (Limnotek 2016) and a technical memorandum (Bennett 2016).

¹ As noted in the 2013/2014 EEM Annual Report (ESSA Technologies 2015), because sampling in 2012 was performed in August and the sampling in subsequent years was performed in October, the observed differences between 2012 and 2013 represent a mixed effect of both changes due to year and changes due to season. For this reason, the observed changes between 2012 and 2013 are harder to interpret than the changes between other sequential years.

2.7 Episodic Acidification Studies ④

The episodic acidification sub-component of the aquatic ecosystems component of the EEM Program is being addressed through two studies: continuous pH monitoring in Anderson Creek, and a research project conducted by Dr. Paul Weidman (School of Resource and Environmental Management & Department of Biology, Simon Fraser University) with supplemental funding provided by RTA.

Continuous pH Monitoring in Anderson Creek

On March 31, 2015, a Manta sampler was installed in Anderson Creek. The sampler has three pH sensors and a temperature probe, and the logging interval on the Manta was set to 30 minutes. The Manta was calibrated once every two weeks, and at the same time the pH of a grab sample of Anderson Creek water was measured using a WTW portable pH meter (same instrument that was used in the intensively sampled lakes). There was a data gap from April 15 to May 15 when the external battery pack was removed for use on a Manta installed in one of the intensively sampled lakes. Further details are provided in Limnotek's technical report (Limnotek 2016).

Research Project by Dr. Paul Weidman

The project title for this research is, "Impacts of industrial sulfur and nitrogen deposition and climate change on salmon stream habitat in the Kitimat watershed". Development of the study design was initiated in 2014 and finalized in 2015. Preliminary sampling activities were conducted in 2015. The following summary has been extracted from Dr. Weidman's project update (Appendix 3):

"The main objective of our project is to determine the cumulative effects of industrial atmospheric emissions of sulfur and nitrogen on salmon stream habitat under hotter and drier conditions due to climate change in the Kitimat watershed. Achieving this objective is critical to anticipating and managing the cumulative effects of industrial activities and climate change on north coastal salmon streams. Moreover, this project will help guide on-going fish habitat restoration projects that are being conducted by the Haisla Fisheries Commission in the Kitimat watershed.

In 2016, we propose to modify our sampling activities from 2015 in order to confirm our preliminary results and to map the potential impacts on salmonid habitat in the Kitimat and Lakelse watersheds from increased industrial emission of sulphur and nitrogen. We used data collected in 2015 to select 12 main project streams to continuing monitoring monthly throughout the entire year in 2016–2017. In this way, we are focusing our efforts on assessing and mapping habitat conditions in fewer streams than in 2015, but over the entire year in order to more efficiently conduct our fish habitat assessment. Streams selected in 2016 will represent the full range of habitat conditions that are relevant to our project. We also propose to measure the lethal and sub-lethal effects on juvenile salmonids of sulphur and nitrogen acid deposition and heat stress due to climate change. These rearing incubations will be conducted either at the Kitimat Hatchery and/or the Cultus Lake Salmon Laboratory."

2.8 Amphibian Monitoring ⑤

No actions were taken in 2015. Moving forward with the action to “provide support to existing local community groups who conduct annual amphibian monitoring” has been postponed and will be revisited next year.

2.9 Power Analyses

As part of the EEM Program in 2015, we conducted power analyses to assess our ability to correctly detect changes of interest in water chemistry in the sensitive lakes within the program. That is, we asked how confidently will the established monitoring program be able to identify lakes that have exceeded their ANC, SO₄²⁻, and/or pH thresholds?

The power analyses work is presented in its own summary report (Technical Memo W04), which describes the context, rationale, methods, results, and implications for the EEM Program. Further details on the methods and results are included in an additional technical appendix (Technical Memo W05) to that summary report.

To avoid unnecessary duplication, the methods, results and discussion are not repeated in the present report. However, the major recommendations have been included.

2.10 Water Residence Time for Lakes

An estimate of water residence time of all the lakes in the EEM Program was estimated based on a coarse approximation of lake volume. In 2015, bathymetric surveys were done by Limnotek (2016) on the three lakes with continuous monitoring (LAK006, LAK012, LAK023) in order to be able to generate a precise estimate of lake volume and therefore a more accurate estimate of the water residence time for each lake. Water residence time is relevant to understanding one of the possible factors contributing to variability (especially intra-annual variability) within individual lakes – that is, lakes with shorter water residence times would be expected to demonstrate higher variability in water chemistry. The full methods for the bathymetric survey and estimation of lake volume are described in Limnotek (2016).

Water residence time (or retention time) is calculated as:

$$\text{Retention time (years)} = \frac{\text{Lake volume (m}^3\text{)}}{\text{Annual outflow (m}^3\text{/year)}}$$

where annual outflow is estimated as: watershed area (m²) * mean annual runoff (m/yr), with mean annual runoff for the period from 1960 to 1990, as described in the STAR.

3 Results

3.1 Quality of Water Chemistry Data ①②

Sampling and laboratory quality control and quality assurance

The results of the sampling and laboratory quality control and quality assurance methods are presented in the associated Limnotek technical report (Limnotek 2016).

Charge Balance Check

The charge balance has been examined for each year of sampling. Table 3-1 shows four diagnostic metrics of the charge balance for the sample sets from 2012, 2013, 2014, 2015 and Goose Creek (2014 and 2015). The charge balance is better for the 2015 sampling data than it had been in 2013 or 2014. In all cases, the average charge balance represents an excess of anions relative to cations. The charge balance can be improved by adjusting the assumptions regarding the charge density of organic anions, which could change across different years (analyses not shown).

The charge balance for the lakes in the EEM Program (sensitive and less sensitive) in each of the four sampling years is shown graphically in Figure 3-1. The figure shows that the charge balance for 2015 demonstrates a markedly closer fit to the 1:1 line (i.e., cations = anions) than for 2013 or 2014. The relationships shown on the graph are heavily influenced by Lake 007 (not shown on the graph), which has cation and anion levels of an order of magnitude greater than the other lakes.

Table 3-1. Measures of the charge balance check for 2012 (STAR lakes), 2013 (EEM lakes, MOE3, Cecil Creek), 2014 (EEM lakes, MOE6), 2015 (EEM lakes and control lakes²), 2014-GS (Goose Creek), and 2015-GS (Goose Creek - GNT1, GNT2). Negative (red) values for “Average %Diff” and “Average Difference” indicate less total charge from cations than from anions.

Year	Number of Samples	Average %Diff	Average Abs (%Diff)	Average Difference (µeq/L)	Average Abs(Diff) (µeq/L)
2012	61	-0.7	2.6	-6.5	12.2
2013	14	-8.5	10.1	-28.2	42.8
2014	12	-5.0	5.2	-12.9	14.5
2015	13	-2.9	3.1	-16.6	17.3
Goose Creek sites					
2014-GC	6	-4.7	4.9	-30.4	32.6
2015-GC	2	-1.5	1.5	-25.6	25.6

² Only NC184 and NC194 are included. DCAS14A has been excluded from this summary because its charge balance is exceptionally poor and the underlying water chemistry data is currently being investigated.

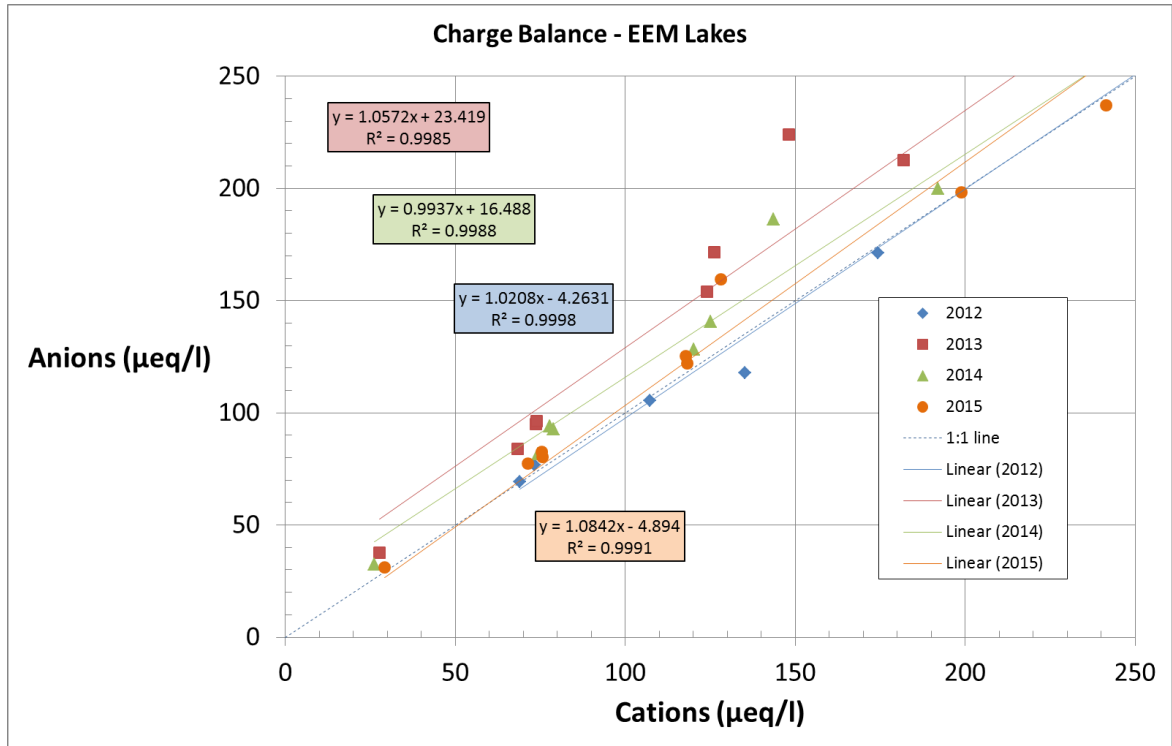


Figure 3-1. Analysis of charge balance for the EEM lakes, 2012-2015. The Y-axis is the sum of all major anions (negatively charged ions); the X-axis the sum of all major cations (positively charged ions).

Measured versus Estimated Conductivity

Measured and estimated conductivity were compared for each year of sampling. Table 3-2 shows two diagnostic metrics of the conductivity check for the sample sets from 2012, 2013, 2014, 2015 and Goose Creek (2014 and 2015). The 2015 Goose Creek data show a substantial difference between the measured and estimated conductivity, indicating a poor performance on this quality control; however, the charge balance for the two sites was very good. All of the other data sets demonstrate an acceptable relationship between measured and estimated conductivity. Estimated conductivity was lower than measured conductivity for the 2015 EEM lakes data, but higher for the Goose Creek sites.

The conductivity check for the EEM lakes (sensitive and less sensitive) in each of the four sampling years is shown graphically in Figure 3-2. The relationships shown on the graph are heavily influenced by Lake 007 (not shown on the graph), which has conductivity values of an order of magnitude greater than the other lakes.

Table 3-2. Measures of the conductivity check for 2012 (STAR lakes), 2013 (EEM lakes, MOE3, Cecil Creek), 2014 (EEM lakes, MOE6), 2015 (EEM lakes, control lakes³), 2014-GS (Goose Creek), and 2015-GS (Goose Creek - GNT1, GNT2). Positive values of “Average %Diff” indicate that the estimated conductivity was higher than the measured conductivity.

Year	Number of Samples	Average %Diff	Average Abs (%Diff)
2012	61	4.9	6.0
2013	14	6.8	10.5
2014	12	-5.1	6.4
2015	13	-3.0	6.1
Goose Creek sites			
2014-GC	6	3.4	3.4
2015-GC	2	19.9	19.9

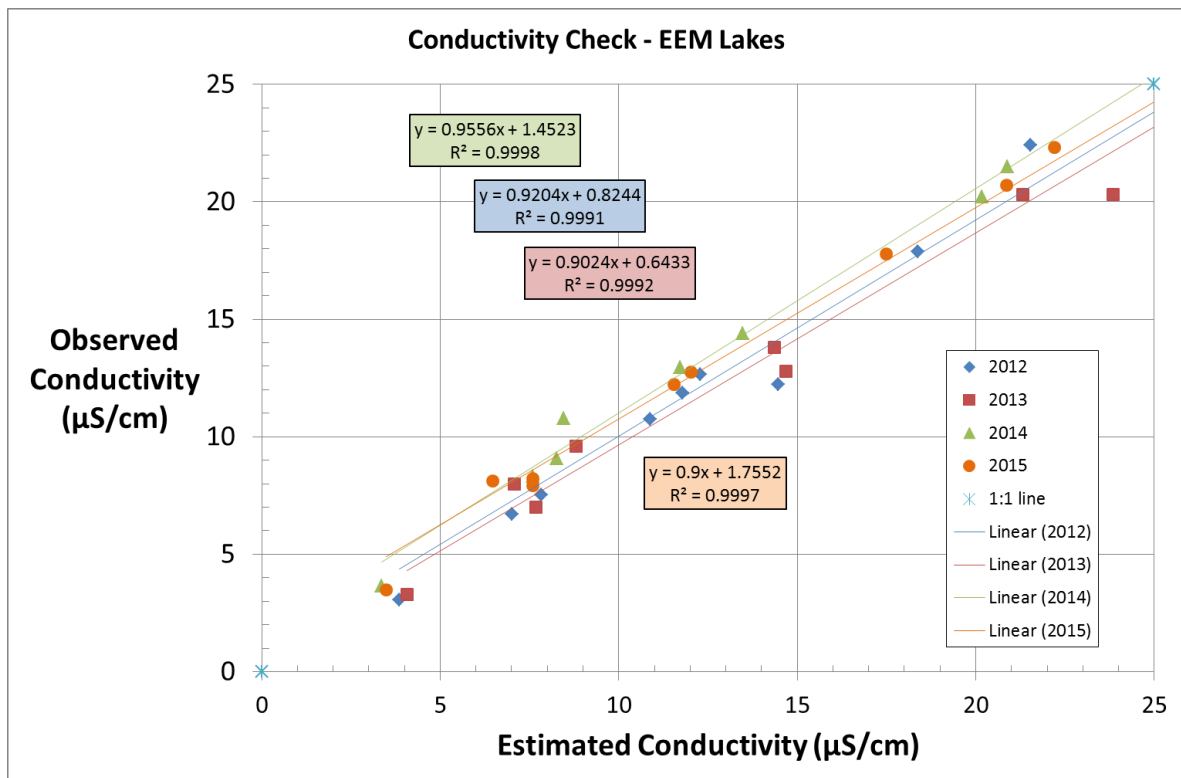


Figure 3-2. Conductivity check for the EEM lakes, 2012-2015. Estimated conductivity is based on laboratory measurements of the concentrations of all ions and literature values for the conductivity of each ion, which is compared to the conductivity observed in field measurements.

³ As per Table 3-1, only NC184 and NC194 are included. DCAS14A is excluded due to data concerns that are being currently explored.

pH measurements

Lab measurements of pH were made at two different labs in 2013, 2014 and 2015. Limnotek (2016) examined the differences in pH measurements for 2015 between the two labs and concluded that the difference was very small relative to the measurement error and not statistically significant. In previous years (see ESSA Technologies 2015), the values measured by ALS were observed to be consistently higher than those measured by Trent University. Both labs apply substantial quality control, quality assurance and equipment calibration procedures; therefore, it is not possible to conclude which lab's measurements are closer to the true pH value. However, the differences were substantially smaller in 2015. For the analyses presented in this technical memo, we used the Trent University measurements to be consistent with the data from the STAR. The 2012 samples were only analyzed by Trent University and not ALS.

3.2 Water Chemistry Results

EEM Lakes – Annual Water Chemistry Data ①

Appendix 1 reports the results of the annual water chemistry sampling for the EEM lakes from the sampling conducted in 2015 (with the data from 2012-2014 included for reference), for major water chemistry metrics (pH, DOC, Gran ANC, base cations, and major anions).

Non-EEM Sites – Water Chemistry Properties

Goose Creek

Goose Creek was the only non-EEM site sampled in 2015. Table 3-3 provides a summary of some of the key water chemistry properties from the 2015 Goose Creek sites, with 2014 Goose Creek sites included for reference.

Table 3-3. Select chemical properties of Goose Creek sites sampled during 2014 and 2015. The 2014 samples were also reported in the 2013/2014 EEM Annual Report. The * indicates that values are corrected for marine influence. Average values for the EEM sensitive lakes and EEM less sensitive lakes are included to provide some context for the values of the other sites.

Site	Sample Year	Gran ANC (µeq/L)	pH	SO ₄ * (µeq/L)	Cl (µeq/L)	F (µeq/L)	BC* (µeq/L)	DOC (mg/L)
Goose Creek 1	2014	93.2	6.4	128.9	18.3	27.6	274.9	6.3
Goose Creek 2	2014	82.5	6.3	139.4	16.6	28.0	251.2	5.6
Goose Creek 4	2014	41.1	5.5	112.1	18.9	42.2	210.1	14.7
Goose Creek 5	2014	332.6	6.7	188.2	18.6	22.4	601.0	4.5
Goose Creek 6	2014	284.9	7.4	185.2	15.2	18.1	488.9	4.5
Goose Creek 7	2014	283.4	6.9	167.6	14.1	12.2	458.0	4.2
GCNT1	2015	247.4	6.8	300.9	29.6	15.6	588.6	6.0
GCNT2	2015	254.6	6.8	620.8	16.6	18.4	872.4	4.6
Average of EEM sensitive lakes	2015	28.0	5.84	20.5	6.7	6.7	77.6	5.2
Average of EEM less sensitive lakes	2015	574.9	7.20	30.5	24.5	4.5	609.5	3.6

In the 2013/2014 EEM Annual report, Goose Creek sites 5, 6 and 7 (sampled in 2014) were described as having high pH, high ANC, very high SO₄²⁻ levels, very high F levels, and very high base cations. The two Goose Creek sites sampled in 2015 are similar or even higher than those sites across all of these metrics. GCNT 1 is markedly higher than those three sites for SO₄²⁻ and chloride. GCNT 2 is markedly higher than those sites for SO₄²⁻ and base cations. Notably, the SO₄²⁻ levels are multiple times higher than the levels observed in the other Goose Creek sites sampled in 2014, which were already significantly higher than all but one of the observations across the EEM lakes (i.e., LAK028 in 2013). Despite the high SO₄²⁻ levels, the base cation and ANC levels of sites GCNT 1 and GCNT 2 are indicative of very low sensitivity to acidification.

3.3 Intensive Monitoring of Three Lakes ⑤

Results from the continuous monitoring of pH in West Lake (LAK023), End Lake (LAK006), and Little End Lake (LAK012) are reported in the associated Technical Memo by Limnotek (2016). The Limnotek results for pH monitoring are summarized below in Table 3-4 and Table 3-5. Over the period of continuous monitoring (from April 13 to November 13, 2015), the pH varied by about 1.0 pH unit in End Lake and Little End Lake, and by about 0.8 pH units in West Lake. The mean pH in all three lakes remained very close to or above 6.0, the level used as a biological threshold for analyses of critical loads (see STAR and KAA reports).

The results from these lakes further confirm the results from the first year of continuous monitoring – i.e., that there is high variability in pH, substantially higher than originally expected. Understanding that natural intra-annual variation is very high was one of the primary reasons for conducting the power analyses (see Section 2.9 for brief description and reference to detailed documentation). The power analyses have now shown that continuous monitoring increases the power of the monitoring program to be able to correctly detect changes in pH that exceed the EEM KPI threshold of 0.3 pH units.

Table 3-4. Minimum, maximum, average and range of pH measurements taken every 30 minutes in each of End, Little End and West lakes in April to November 2015.

Lake	Sensor	Number of observations	Minimum pH	Maximum pH	Range of pH	Mean pH ± SD
End	pH1	9501	5.7	6.7	1.0	6.28 ± 0.16
End	pH2	9501	5.7	6.7	1.0	6.28 ± 0.16
End	pH3	9501	5.7	6.7	1.0	6.37 ± 0.15
Little End	pH1	8380	5.5	6.6	1.1	6.02 ± 0.21
Little End	pH2	8380	5.4	6.5	1.1	5.93 ± 0.20
Little End	pH3	8380	5.5	6.6	1.1	5.99 ± 0.20
West	pH1	10163	5.9	6.7	0.8	6.39 ± 0.15
West	pH2	10163	5.8	6.6	0.8	6.27 ± 0.14
West	pH3	10163	5.9	6.7	0.8	6.32 ± 0.14

Table 3-5. Mean (± standard deviation) pH of discrete samples collected on Oct 4, Oct 13, Oct 20, and Oct 27 at each of the three lakes.

Instrument or lab	Mean pH ± sd in October, 2015 (n=4)

	End Lake	Little End Lake	West Lake
WTW field pH meter	5.96 ± 0.29	5.79 ± 0.16	5.99 ± 0.39
Trent University	6.01 ± 0.13	5.95 ± 0.16	5.94 ± 0.12
ALS	6.42 ± 0.57	6.33 ± 0.30	6.22 ± 0.13
Manta sensors	6.19 ± 0.13	5.94 ± 0.12	6.24 ± 0.15
Instrument/lab effect (<i>P</i>)	0.245	0.014	0.185

3.4 Inter-annual Changes

Inter-annual changes in pH, Gran ANC, SO₄²⁻, DOC, sum of base cations, and chloride are shown in terms of absolute change in Table 3-6 and Table 3-7, and in terms of relative change in Table 3-8 and Table 3-9. Changes are shown for four time periods of comparison: 2012-2013, 2013-2014, 2014-2015, and 2012-2015. The sensitive EEM lakes and less sensitive EEM lakes are presented separately within each of the tables.

Figure 3-3 and Figure 3-4 show the changes in the same water chemistry parameters graphically. These figures allow better visualization of the distribution and variability in the observed changes between 2014 and 2015. Although the tables show changes for other periods as well, these figures have only been included for the changes from 2014 to 2015. Changes from 2014 to 2015 in particular are examined in more detail, in the context of expected changes based on the Evidentiary Framework, in Section 4.1 in the Discussion.

Appendix 2 provides a detailed set of figures showing the inter-annual changes in major water chemistry metrics (Gran ANC, base cations, SO₄²⁻, chloride, pH and DOC) for each of the EEM lakes across the four years of annual monitoring (2012-2015).

Table 3-6. Inter-annual changes in pH, Gran ANC and SO₄²⁻ for EEM lakes, 2012-2015. The differences between subsequent years and across the full record of sampling are shown. The * indicates that the ionic concentrations have been corrected for marine influence. Numbers shown are the value in the later year minus the value in the earlier year.

		pH				Gran ANC (ueq/L)				SO ₄ * (µeq/L)			
From	To	2012	2013	2014	2012	2012	2013	2014	2012	2012	2013	2014	2012
		2013	2014	2015	2015	2013	2014	2015	2015	2013	2014	2015	2015
Lak006		0.4	0.1	-0.1	0.4	3.3	7.8	-5.4	5.7	3.0	-3.4	-0.3	-0.7
Lak012		0.6	0.0	-0.1	0.5	6.5	16.8	-9.6	13.7	5.2	-5.5	2.7	2.4
Lak022		0.2	0.1	-0.1	0.2	8.5	10.5	-11.3	7.7	16.9	-9.3	-5.3	2.3
Lak023		0.2	0.1	0.0	0.4	4.0	11.7	-8.2	7.6	5.0	-7.4	-3.6	-5.9
Lak028		0.2	0.1	-0.2	0.2	8.8	17.8	-11.8	14.8	71.2	-33.7	-23.3	14.2
Lak042		0.8	-0.4	0.3	0.7	41.4	-8.5	1.3	34.2	-0.5	-1.8	-0.2	-2.4
Lak044		0.3	0.1	0.0	0.4	7.3	-2.7	0.3	4.9	0.0	-1.6	-0.9	-2.5
Average (Sensitive lakes)		0.39	0.02	-0.02	0.39	11.4	7.6	-6.4	12.7	14.4	-8.9	-4.4	1.0
Lak007		0.0	0.1	-0.1	0.0	24.5	-16.4	119.9	128.1	15.1	-35.8	14.9	-5.8
Lak016		0.4	0.0	0.0	0.4	28.3	8.8	7.4	44.4	17.9	-8.7	-7.2	1.9
LAK024		¹	¹	-0.2	0.3	¹	¹	-29.1	143.5	¹	¹	-2.4	9.9
Lak034		0.1	-0.1	-0.1	-0.1	111.0	-5.4	-27.1	78.4	14.0	-21.1	-16.1	-23.2
Average (Less sensitive lakes)		0.15	0.02	-0.09	0.16	54.6	-4.3	17.8	98.6	15.7	-21.9	-2.7	-4.3

¹ LAK024 was not sampled in 2013, therefore change for 2012-13 and 2013-14 cannot be calculated.

Table 3-7. Inter-annual changes in DOC, base cations and chloride for EEM lakes, 2012-2015. The differences between subsequent years and across the full record of sampling are shown. DOC = dissolved organic carbon, ΣBC = sum of base cations (i.e., Mg, Ca, K, Na), Cl = chloride. The * indicates that the ionic concentrations have been corrected for marine influence. Numbers shown are the value in the later year minus the value in the earlier year.

		DOC (mg/L)				Σ BC* (µeq/L)				Cl (µeq/L)			
From	To	2012	2013	2014	2012	2012	2013	2014	2012	2012	2013	2014	2012
		2013	2014	2015	2015	2013	2014	2015	2015	2013	2014	2015	2015
LAK006		-0.4	0.2	0.1	-0.1	-3.0	8.7	1.8	7.5	2.9	-2.2	-0.6	0.2
LAK012		-0.4	0.3	-0.2	-0.3	-11.8	2.7	-1.6	-10.7	10.5	-8.5	0.0	2.1
LAK022		0.9	-0.6	0.6	1.0	11.0	4.9	-6.2	9.7	5.4	-3.3	-1.1	1.0
LAK023		-0.1	0.7	-0.5	0.1	-2.1	7.4	-3.0	2.3	3.0	-1.8	-0.3	0.9
LAK028		2.2	-1.1	2.2	3.2	48.4	4.4	-15.9	36.9	11.7	-6.7	-2.0	3.0
LAK042		-3.5	0.9	-2.3	-4.8	7.6	-5.3	3.7	5.9	1.6	4.1	-5.4	0.3
LAK044		-0.2	0.3	-0.2	-0.1	3.0	0.1	2.9	6.0	3.3	-2.9	0.0	0.3
Average (Sensitive lakes)		-0.2	0.1	0.0	-0.1	7.6	3.3	-2.6	8.2	5.5	-3.1	-1.9	1.1
LAK007		-0.5	0.6	-0.5	-0.4	-51.9	63.5	-7.8	3.8	11.7	-17.1	4.8	-0.6
LAK016		0.5	-0.2	0.3	0.6	0.8	13.7	7.8	22.3	6.0	-3.0	-0.6	2.4
LAK024		¹	¹	0.5	0.8	¹	¹	-2.8	167.6	¹	¹	-6.8	31.7
LAK034		0.1	2.4	0.5	3.0	56.0	8.6	-32.3	32.3	2.5	-1.8	-0.3	0.4
Average (Less sensitive lakes)		0.0	0.9	0.2	1.0	1.6	28.6	-8.7	56.5	6.7	-7.3	-0.7	8.5

¹ LAK024 was not sampled in 2013, therefore change for 2012-13 and 2013-14 cannot be calculated.

Table 3-8. Inter-annual changes (%) in pH, Gran ANC and SO₄²⁻ for EEM lakes, 2012-2015. The differences between subsequent years and across the full record of sampling are shown. The * indicates that the ionic concentrations have been corrected for marine influence. Numbers shown are the value in the later year minus the value in the earlier year.

		pH (TU)				Gran ANC (mg/L)				SO ₄ ^{2-*} (µeq/L)			
From	To	2012	2013	2014	2012	2012	2013	2014	2012	2012	2013	2014	2012
		2013	2014	2015	2015	2013	2014	2015	2015	2013	2014	2015	2015
LAK006		6%	1%	-1%	6%	13%	27%	-15%	22%	26%	-24%	-3%	-6%
LAK012		12%	0%	-1%	10%	11%	26%	-12%	24%	84%	-49%	47%	40%
LAK022		4%	2%	-2%	3%	31%	29%	-24%	28%	56%	-20%	-14%	8%
LAK023		4%	2%	1%	7%	20%	49%	-23%	38%	26%	-31%	-22%	-31%
LAK028		5%	2%	-4%	3%	¹	372%	-52%	¹	125%	-26%	-25%	25%
LAK042		17%	-6%	6%	15%	¹	-40%	10%	¹	-7%	-31%	-5%	-39%
LAK044		5%	2%	0%	7%	576%	-32%	6%	387%	0%	-26%	-19%	-40%
Average (Sensitive lakes)		7%	0%	-0.30%	7%	130%	20%	-16%	120%	44%	-29%	-6%	-6%
LAK007		-1%	2%	-1%	0%	2%	-1%	8%	9%	29%	-54%	49%	-11%
LAK016		6%	1%	0%	7%	41%	9%	7%	65%	46%	-15%	-15%	5%
LAK024		²	²	-3%	4%	²	²	-6%	48%	²	²	-7%	40%
LAK034		2%	-2%	-2%	-2%	112%	-3%	-13%	79%	58%	-55%	-95%	-96%
Average (Less sensitive lakes)		2%	0%	-1%	2%	52%	2%	-1%	50%	44%	-41%	-17%	-16%

¹ LAK028 and LAK042 had negative ANC values in 2012 and therefore the percentage change could not be properly calculated.

² LAK024 was not sampled in 2013, therefore change for 2012-13 and 2013-14 cannot be calculated.

Table 3-9. Inter-annual changes (%) in DOC, base cations and chloride for EEM lakes, 2012-2015. The differences between subsequent years and across the full record of sampling are shown. DOC = dissolved organic carbon, ΣBC = sum of base cations (e.g., Mg, Ca, K, Na), Cl = chloride. The * indicates that the ionic concentrations have been corrected for marine influence. Numbers shown are the value in the later year minus the value in the earlier year.

		DOC (mg/L)				Σ BC* (µeq/L)				Cl (µeq/L)			
From	To	2012	2013	2014	2015	2012	2013	2014	2015	2012	2013	2014	2015
Lak006		-10%	6%	2%	-3%	-5%	15%	3%	12%	51%	-25%	-9%	3%
Lak012		-9%	7%	-4%	-6%	-10%	2%	-1%	-9%	254%	-58%	0%	49%
Lak022		17%	-9%	11%	18%	11%	5%	-5%	10%	78%	-27%	-13%	14%
Lak023		-3%	18%	-10%	3%	-3%	12%	-4%	3%	67%	-24%	-5%	20%
Lak028		45%	-16%	36%	66%	66%	4%	-13%	51%	193%	-38%	-18%	49%
Lak042		-26%	9%	-21%	-37%	14%	-9%	7%	11%	26%	53%	-45%	6%
Lak044		-12%	17%	-11%	-7%	21%	1%	17%	43%	59%	-33%	0%	6%
Average (Sensitive lakes)		0%	5%	0%	5%	14%	4%	0%	17%	104%	-22%	-18%	21%
Lak007		-84%	610%	-65%	-59%	-3%	4%	-1%	0%	48%	-47%	25%	-3%
Lak016		14%	-4%	8%	17%	0%	8%	4%	13%	95%	-24%	-6%	38%
LAK024		¹	¹	30%	59%	¹	¹	-1%	49%	¹	¹	-10%	116%
Lak034		3%	51%	7%	66%	28%	3%	-12%	16%	42%	-21%	-4%	7%
Average (Less sensitive lakes)		-22%	219%	-5%	21%	8%	5%	-2%	20%	62%	-31%	1%	40%

¹ LAK024 was not sampled in 2013, therefore change for 2012-13 and 2013-14 cannot be calculated.

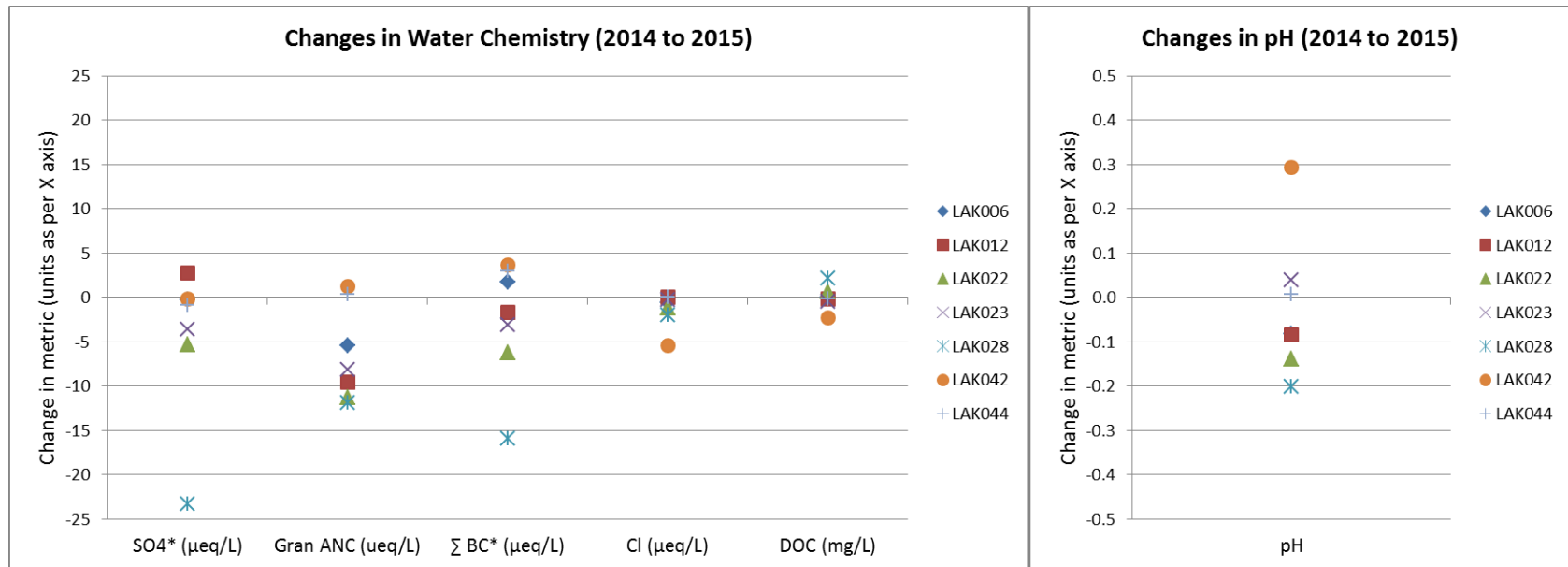


Figure 3-3: Changes in water chemistry parameters (left panel) and pH (right panel) across all of the sensitive EEM lakes, from 2014 to 2015. Values shown are 2015 value minus 2014 value.

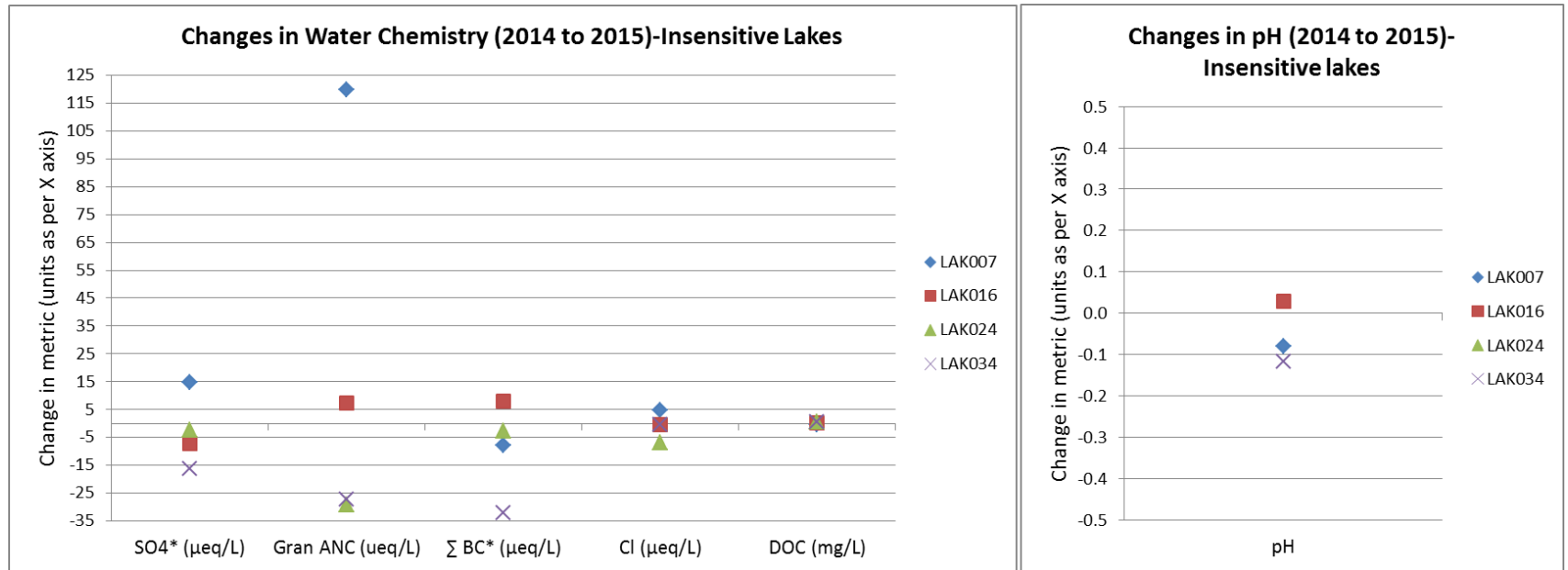


Figure 3-4: Changes in water chemistry parameters (left panel) and pH (right panel) across all of the less sensitive EEM lakes, from 2014 to 2015. Values shown are 2015 value minus 2014 value.

3.5 Fish Sampling ⑦

Fish were sampled from LAK007, LAK016, and LAK034 (less sensitive EEM lakes) in 2015. Limnotek (2016, Section 3.2) provide a detailed description of the fish sampling results. Fish presence was reported in all three lakes and the average values of fish population and biomass metrics were similar between these less sensitive lakes (2015 sampling) and the acid sensitive lakes (2013 sampling), although the variability in the metrics was higher for the less sensitive lakes.

The executive summary of Limnotek (2016) technical report provides a description of fish species distribution in the acid insensitive lakes sampled in 2015:

Six species were found in LAK007, three were found in LAK016, and two were found in LAK034. Coastal cutthroat trout (Oncorhynchus clarkii clarkii, CCT) were common in all three lakes. Both LAK007 and LAK016 had coastal cutthroat trout (Oncorhynchus clarkii clarkii, CCT), Coho salmon (Oncorhynchus kisutch, CO), and Dolly Varden char (Salvelinus malma, DV) whereas LAK034 only had CCT and Threespine Stickleback (Gasterosteus aculeatus, TSB). Large Coho of up to 355 mm in length were captured in LAK016. These large individuals resembled the residualized adult Coho captured in 2013 in West lake and are unique among common life histories of Coho salmon. The presence of these residualized Coho is attributed to periodic inaccessibility to and from waterbodies during certain hydrologic conditions that causes the adults to become “locked” into the lakes.

Limnotek (2016, p. v)

3.6 Episodic Acidification Studies ④

Continuous pH Monitoring in Anderson Creek

There were 199 days of continuous data. The three pH sensors on the Manta showed the same temporal changes, meaning there was no difference among the sensors in detecting ambient pH. There were however large differences in pH between the Manta and two other measurement methods. Results from the other measurement methods corresponded closely to each other, which suggests that the Manta data may not be correct. Further details are provided in Limnotek’s technical report (Limnotek 2016).

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As this project is being conducted by an external organization, the results from this work will be communicated separately as they become available.

3.7 Water Residence Time for Lakes

The bathymetric survey results and lake volume calculations for LAK006, LAK012 and LAK023 are presented in Limnotek (2016). Table 3-10 shows the updated volume calculations compared to the preliminary estimates, along with preliminary interpretation of the implications of these results.

Detailed results on the calculation of water residence time, including accounting for the uncertainty around the volume estimates, are currently not available but will be included in future reporting.

Further investigation of these results and their implications for interpretation and analysis of EEM monitoring data has not yet been completed, but will be incorporated in future analyses.

Table 3-10. Changes in the estimates of lake volume for LAK006, LAK012 and LAK023 along with potential implications for the EEM Program.

Lake	Preliminary estimates of Lake Volume in EEM Plan (m ³)	Precise estimates of Lake Volume (m ³)	Preliminary interpretation of implications
End Lake (LAK 006)	584,232	1,129,350	Lake volume and water residence time underestimated by ~50% in EEM report. Updated residence time is closer to 1.4 years (compared to 1.1 years). This might help to explain why LAK 006 has high power to detect Δ ANC and Δ SO ₄ ²⁻ , but does not explain why it has relatively low power to detect Δ pH.
Little End Lake (LAK 012)	80,538	94,455	Lake volume and water residence time underestimated by ~15% in EEM report; still very low water residence time (~0.1 years), which should cause high variability in water chemistry, as is observed for pH (very poor statistical power to detect Δ pH). However, statistical power to detect Δ ANC for LAK 012 is much better than for LAK 028 or LAK 042
West Lake (LAK 023)	182,857	185,064	Lake volume and water residence time very close to estimate in EEM report (underestimated by ~1.2% in EEM report).

4 Discussion

This section is divided based on two sets of sample sites: 1) the lakes representing the core of the EEM sampling program, and 2) other sample sites outside of the core EEM lakes that were included in 2015.

4.1 EEM Lakes

Application of the Evidentiary Framework

As noted in Section 2.4, the Evidentiary Framework has not been formally applied in the present EEM Annual Report because 2015 was a transitional period between the old smelter and KMP, with a decline in SO₂ emissions (Figure 4 in main report). However, we did consider the general principles of the evidentiary framework, which suggest that 2015 sulphate concentrations should decrease relative to 2014 (due to declining emissions of SO₂), and that ANC and pH levels should correspondingly increase, if all other constituents and hydrologic conditions remained unchanged. As noted in the EEM Evidentiary Framework, changes in base cations, nitrate or DOC can help to explain observed changes in ANC and pH.

Inter-annual Changes in Lake Chemistry, 2014-2015

Some of the main patterns observed in the changes in lake chemistry between 2014 and 2015:

Sulphate

- 6 of 7 sensitive lakes and 3 of 4 less sensitive lakes showed decreases in SO₄²⁻, which is generally consistent with the decrease in SO₂ emissions and expectations from the evidentiary framework.
 - 5 of these lakes showed decreases of 10-30%
 - LAK034 decreased by 95%
- Two lakes (LAK012 and LAK007) showed increases in SO₄²⁻ of almost 50%. It's not clear why this occurred in only 2 of the 11 monitored lakes, particularly since both LAK012 and LAK007 showed the expected decreases in SO₄²⁻ between 2013 and 2014 (Table 3-6). Watmough et al. (2005) cite a number of studies describing multiple mechanisms by which watersheds can potentially release sulphate: "Possible (and not mutually exclusive) internal sources, include release from wetland areas within catchments, desorption in response to declining SO₄ concentrations in deposition, weathering of S minerals and mineralisation of organic S in soil."

ANC

- For the sensitive lakes, increases in ANC would be expected (based on the evidentiary framework) to accompany decreases in SO₂ emissions and SO₄²⁻ concentrations.
 - This expected pattern was only observed in 2 of 7 sensitive lakes (LAK 042 and LAK 044); both of these lakes also showed increases in total base cations (Table 3-6, Table 3-7). DOC declined by 2.3 mg/l in LAK 042, and that change likely contributed to the observed increase in ANC in LAK 042 through a decrease in organic acids.
 - In the other 5 sensitive lakes ANC decreased (including some significant decreases of 23%, 24%, and 52%) accompanying decreases in SO₄²⁻, contrary to expectations. Base cations also declined in 4 of these 5 lakes, and likely contributed to the decline in ANC (Table 3-6, Table 3-7). However, since the magnitude of decrease in base cations was less than the magnitude of ANC decline in 3 of these 4 lakes, decreases in base cations are not sufficient to explain all of the ANC declines in these lakes. An increase in DOC of 2.2 mg/l in LAK028 (Table 3-7) might have also contributed to the ANC decline in that lake.
- For the less sensitive lakes, changes in ANC would be expected to be independent of changes in SO₄²⁻ as well as being relatively small
 - Two lakes showed increases in ANC (LAK 007 and LAK 016) and two lakes showed decreases (LAK 024 and LAK 034)
 - Both of the lakes which showed decreases in ANC also showed decreased in total base cations (Table 3-6, Table 3-7), though the magnitudes of change were only comparable in LAK 034.
 - Only 1 of 4 less sensitive lakes demonstrated inverse changes in ANC and SO₄²⁻
 - Changes in ANC were within the range 8-13%, even for the two lakes with substantial changes in SO₄²⁻

pH

- For all of the lakes, changes in pH would be expected to be in the same direction as changes in ANC, as per the relationship defined by the pH-alkalinity titration curve (though the magnitude of the pH change would depend on the specific location along the curve)
 - 6 of 7 sensitive lakes demonstrate this expected pattern, including 4 lakes with decreases and 2 lakes with increases in the two metrics

- 3 of 4 less sensitive lakes demonstrate this expected pattern, including 2 lakes with decreases and 1 lake with increases in the two metrics
- However, the two lakes that do not follow this pattern had only small changes in pH (+0.0 for LAK023, -0.1 for LAK007)
- pH decreased for 4 of 7 sensitive lakes and 3 of 4 less sensitive lakes

Other metrics

- 5 of 11 EEM lakes decreased in DOC
- 7 of 11 EEM lakes decreased in total base cations
- 10 of 11 EEM lakes decreased (8) or remained the same (2) in chloride.
- The above pattern would be consistent with greater amounts of precipitation in 2015 compared to 2014, which would result in greater dilution of both base cations and chloride. However, precipitation data (Figure 9 in main report) indicate that while there was a slight increase in precipitation at the KMP Campsite location, there was no increase in precipitation at the Lakelse Lake site (in fact a slight decrease).

4.2 Non-EEM Sites

Goose Creek

Goose Creek was sampled at two additional sites in 2015, to supplement the six sites sampled in 2014. Lake chemistry has been assessed for Goose Creek, but not critical loads.

The two new sites show definite influence of the smelter emissions, due to their very high levels of both SO₄²⁻ (much higher than any other observations) and F. However, based on their high pH, high ANC and very high base cations, these sites appear to be insensitive to potential acidification.

5 Recommendations

5.1 Recommendations regarding EEM lakes

The rationale for these recommendations is primarily supported by the power analyses. Please refer to the summary report (Technical Memo W04) and technical appendix (Technical Memo W05) on the power analyses for further details on these recommendations, as well as additional recommendations that are more specific to the power analyses and future analyses of the monitoring data.

- Maintain the continuous monitoring of pH at the three accessible lakes
- Collect water chemistry samples for lab analyses from the three lakes with continuous pH monitors four times during the fall sampling period
- Continue to use multiple metrics to assess potential KMP effect (i.e., ANC, SO₄²⁻ and pH)
- Continue collecting annual water chemistry samples from the three control lakes that were added to the EEM
- Wait until having collected 5 years of post-KMP monitoring data before drawing conclusions about potential changes to lake chemistry, due to the predicted low power and higher false positives (for some scenarios) in the first few years of post-KMP monitoring.

At a minimum, wait until the end of the initial phase of the EEM program (3 years of post-KMP monitoring data).

- Consider using Gran ANC as the primary indicator of KMP induced change in lake chemistry. Gran ANC had a higher power to detect true changes than pH but lower false positive rate than SO₄²⁻.
- Explore the feasibility of increasing the number of samples for lakes with low power to correctly detect whether the EEM KPI thresholds have been exceeded (in order of priority, with metrics with low power indicated):
 - LAK042 (pH, ANC)
 - LAK028 (ANC, SO₄²⁻)
 - LAK044 (ANC, SO₄²⁻)

5.2 Recommendations regarding non-EEM sites

- No additional activities recommended for non-EEM sites at this time.

6 References Cited

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7 Cited EEM Technical Memos

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

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

Appendix 1: Water Chemistry Data from Annual Sampling, 2012-2014

The table below shows the sample results for each of the EEM lakes from annual monitoring conducted in 2012, 2013, 2014 and 2015, including pH, dissolved organic carbon (DOC), Gran ANC, and the concentration of major anions and cations, as well as the sum of all base cations (BC). In 2013-2015, the pH of the water samples was measured by two different laboratories (Trent University and ALS).

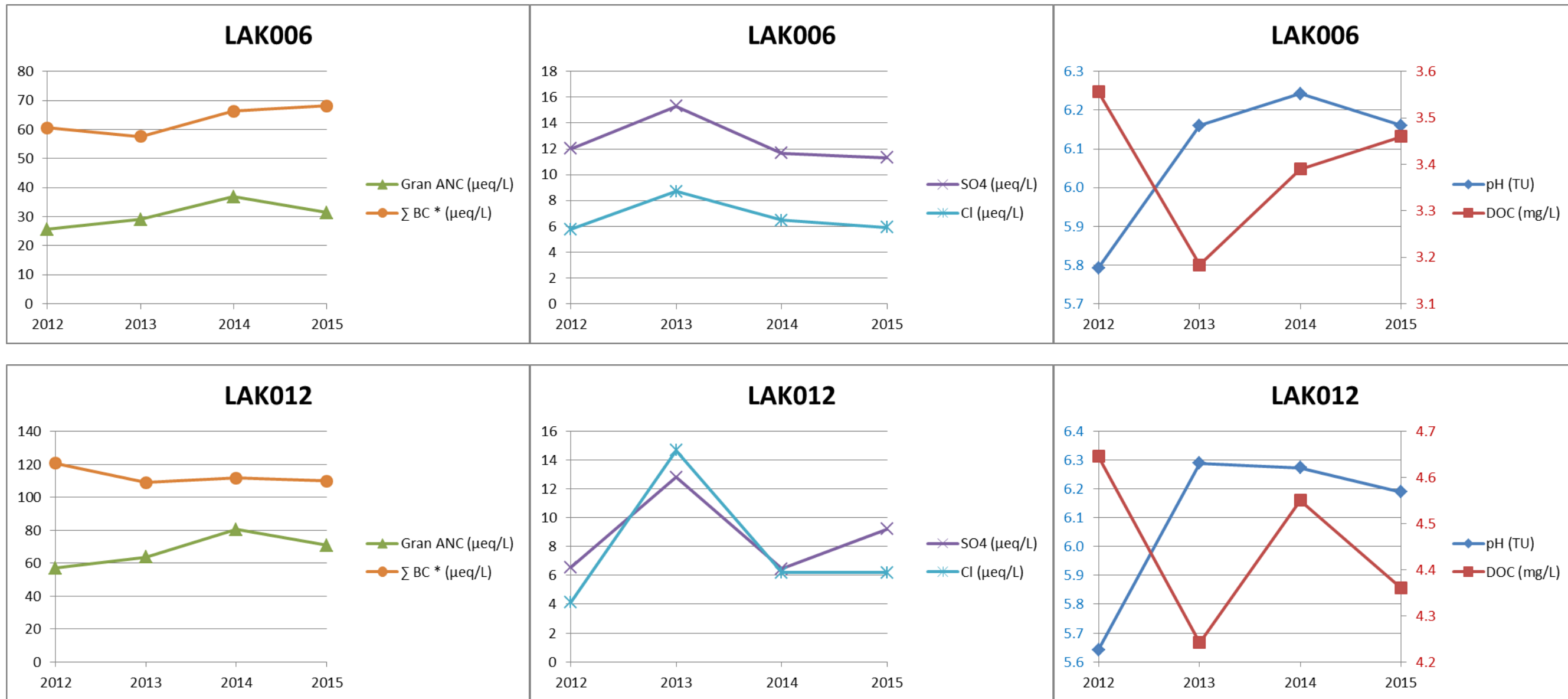
Lake	Year	Lab pH (Trent)	Lab pH (ALS)	DOC (mg/L)	Gran ANC (µeq/L)	SO ₄ (µeq/L)	Cl (µeq/L)	F (µeq/L)	Ca (µeq/L)	Mg (µeq/L)	K (µeq/L)	Na (µeq/L)	Σ BC (µeq/L)
LAK006	2012	5.8		3.6	25.7	12.0	5.8	4.5	30.5	13.6	3.0	19.8	67.0
LAK007	2012	8.0		0.6	1437.6	53.9	24.6	2.8	1273.1	161.8	19.8	76.5	1531.2
LAK012	2012	5.6		4.6	57.0	6.6	4.2	5.0	74.7	21.6	5.3	23.6	125.2
LAK016	2012	6.3		3.7	68.7	39.7	6.3	7.8	117.9	21.8	7.4	26.2	173.3
LAK022	2012	5.9		5.3	27.8	30.9	6.9	6.1	58.4	17.4	3.3	26.7	105.8
LAK023	2012	5.7		4.2	19.8	19.5	4.5	5.6	39.6	12.9	3.7	14.7	70.9
LAK024	2012	7.1		1.4	299.5	27.6	27.3	1.6	274.2	38.4	4.7	53.0	370.3
LAK028	2012	5.0		4.9	-4.0	57.5	6.1	20.7	47.8	10.7	3.2	18.0	79.6
LAK034	2012	6.7		4.5	99.4	24.7	5.8	5.8	119.5	32.8	5.9	49.9	208.1
LAK042	2012	4.7		13.2	-20.4	6.8	6.1	3.2	7.6	23.9	3.2	25.5	60.2
LAK044	2012	5.4		1.7	1.3	6.8	5.6	2.9	7.0	4.3	4.2	4.8	20.4
LAK006	2013	6.2	6.1	3.2	29.0	15.3	8.7	5.6	27.4	14.7	5.4	19.7	67.2
LAK007	2013	7.9	8.1	0.1	1462.1	70.3	36.3	3.7	1227.3	163.7	22.6	78.8	1492.4
LAK012	2013	6.3	6.1	4.2	63.5	12.8	14.7	8.2	65.4	23.2	9.5	27.2	125.2
LAK016	2013	6.7	7.2	4.2	96.9	58.2	12.3	11.5	114.9	26.3	11.4	28.1	180.8
LAK022	2013	6.2	6.1	6.2	36.4	48.3	12.4	8.7	65.6	21.7	6.2	29.4	122.8
LAK023	2013	6.0	6.0	4.0	23.8	24.8	7.5	7.4	37.4	14.8	5.3	14.7	72.2
LAK028	2013	5.2	5.5	7.1	4.8	129.9	17.7	32.0	85.8	21.8	5.3	28.2	141.0
LAK034	2013	6.9	7.4	4.7	210.4	39.0	8.2	10.0	153.0	43.3	9.3	61.2	266.9
LAK042	2013	5.5	5.4	9.7	21.0	6.5	7.7	3.2	16.3	23.8	3.6	25.9	69.6
LAK044	2013	5.7	6.0	1.5	8.6	7.1	8.9	3.8	8.1	5.3	6.0	5.6	25.1
LAK006	2014	6.2	6.7	3.4	36.8	11.7	6.5	5.1	31.8	15.9	4.3	21.5	73.5
LAK007	2014	8.1	8.0	0.7	1445.7	32.7	19.2	1.9	1277.5	160.5	20.6	78.3	1536.9
LAK012	2014	6.3	6.7	4.6	80.3	6.5	6.2	5.7	65.4	21.4	6.2	25.5	118.5
LAK016	2014	6.7	6.7	4.0	105.7	49.1	9.3	9.5	122.8	26.8	10.2	31.3	191.1
LAK022	2014	6.3	6.4	5.7	46.9	38.7	9.0	6.9	68.9	20.7	5.3	29.1	124.1
LAK023	2014	6.1	6.2	4.8	35.5	17.3	5.6	6.7	42.4	15.6	3.9	15.6	77.5
LAK024	2014	7.6	7.5	1.7	472.1	43.9	65.7	2.3	404.7	63.1	9.0	106.6	583.4
LAK028	2014	5.3	5.7	5.9	22.6	95.6	11.0	23.3	86.3	19.9	4.6	27.1	137.9
LAK034	2014	6.7	7.0	7.0	205.0	17.7	6.5	7.7	161.7	44.8	9.5	57.4	273.5
LAK042	2014	5.1	5.4	10.6	12.5	5.2	11.8	2.6	10.9	25.9	3.9	28.1	68.8
LAK044	2014	5.8	5.6	1.8	5.9	5.2	5.9	2.8	8.0	5.1	5.4	5.5	23.9

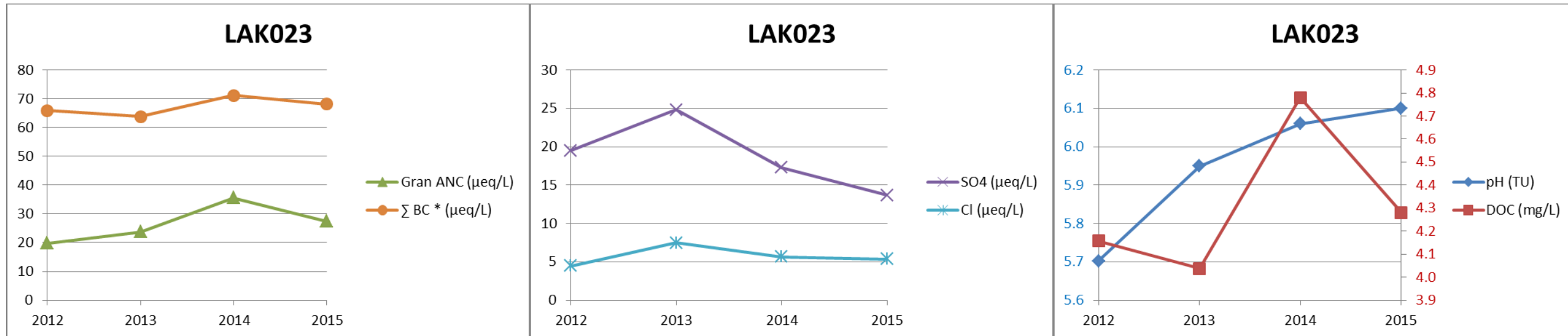
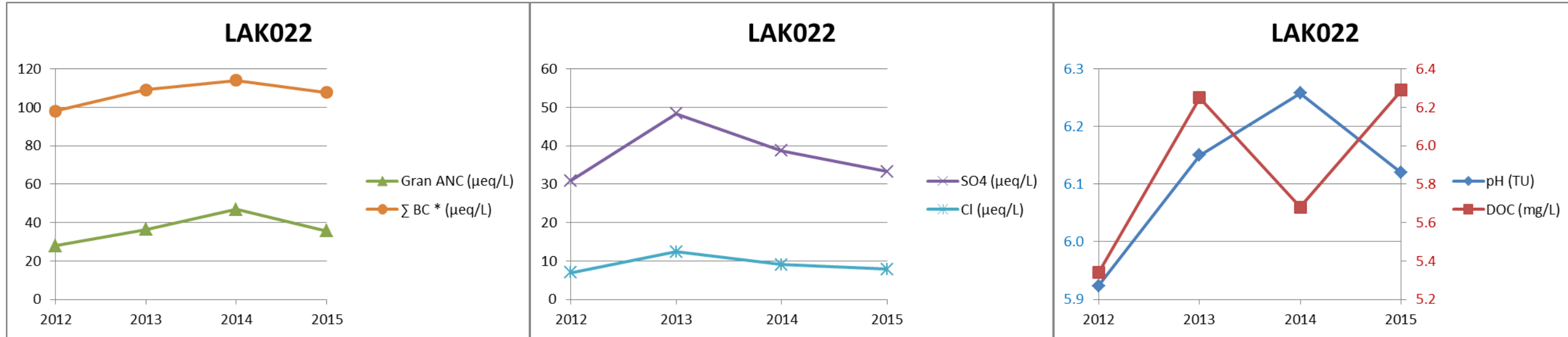
Lake	Year	Lab pH (Trent)	Lab pH (ALS)	DOC (mg/L)	Gran ANC (µeq/L)	SO ₄ (µeq/L)	Cl (µeq/L)	F (µeq/L)	Ca (µeq/L)	Mg (µeq/L)	K (µeq/L)	Na (µeq/L)	Σ BC (µeq/L)
Lak006	2015	6.2	6.2	3.5	31.4	11.3	5.9	4.7	32.7	16.3	4.0	21.7	74.7
Lak007	2015	8.0	7.9	0.3	1565.6	48.1	24.0	2.6	1267.5	166.2	21.5	79.2	1534.4
Lak012	2015	6.2	6.2	4.4	70.7	9.2	6.2	5.0	63.4	21.9	6.2	25.4	116.8
LAK016	2015	6.8	6.9	4.3	113.1	41.8	8.7	8.6	131.2	26.7	9.9	30.4	198.3
LAK022	2015	6.1	6.2	6.3	35.6	33.3	7.9	5.9	64.4	19.7	4.6	28.0	116.6
Lak023	2015	6.1	6.2	4.3	27.4	13.7	5.4	5.6	42.0	14.2	3.7	14.2	74.1
Lak024	2015	7.4	7.5	2.2	443.0	40.8	59.0	2.1	402.7	61.0	9.8	99.6	573.1
LAK028	2015	5.1	5.3	8.1	10.8	72.0	9.0	20.5	76.9	17.4	3.4	22.2	119.9
LAK034	2015	6.6	6.7	7.6	177.8	1.5	6.2	4.7	146.7	38.3	5.4	50.5	240.9
LAK042	2015	5.4	5.5	8.3	13.8	4.5	6.5	2.3	11.0	24.4	2.7	28.5	66.5
LAK044	2015	5.8	5.8	1.6	6.2	4.3	5.9	2.7	10.0	5.6	5.6	5.6	26.8

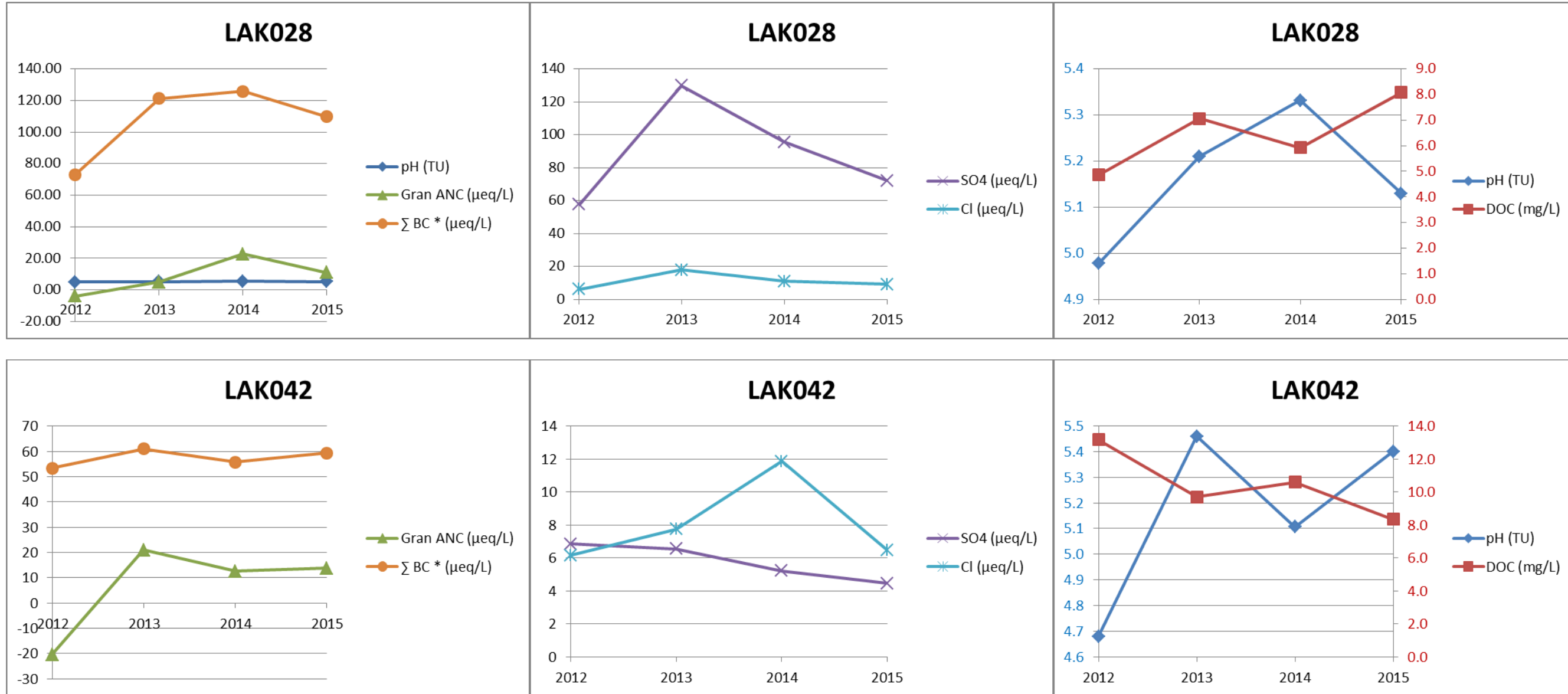
Appendix 2: Changes in Ion Concentrations from 2012 to 2015

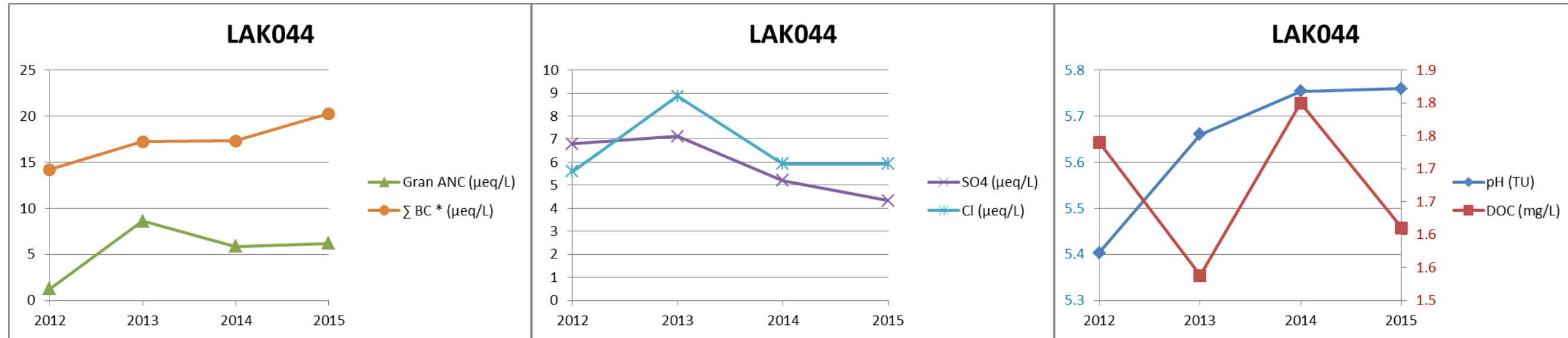
For each of the EEM lakes, the figures in this appendix show the inter-annual changes in six major water chemistry metrics from 2012 to 2015: Gran ANC and base cations (left panel), sulfate and chloride (centre panel), and pH and dissolved organic carbon (right panel). The selection of each pair of metrics is solely based on optimizing graphical representation across all metrics and lakes (i.e., metrics with somewhat similar numeric ranges are shown together). The right panel has two Y-axes, neither of which start at zero – be aware that this can make relatively minor changes appear to be much more substantial than they are. Due to large variation among the lakes for some of the metrics, the Y-axis is not consistent across the lakes, therefore extra caution is required for making comparisons among lakes with respect to the magnitude of changes. However, these graphs are especially useful for looking at the patterns of changes across the sampling record and determining whether similar patterns are observed across lakes and/or metrics.

Sensitive Lakes

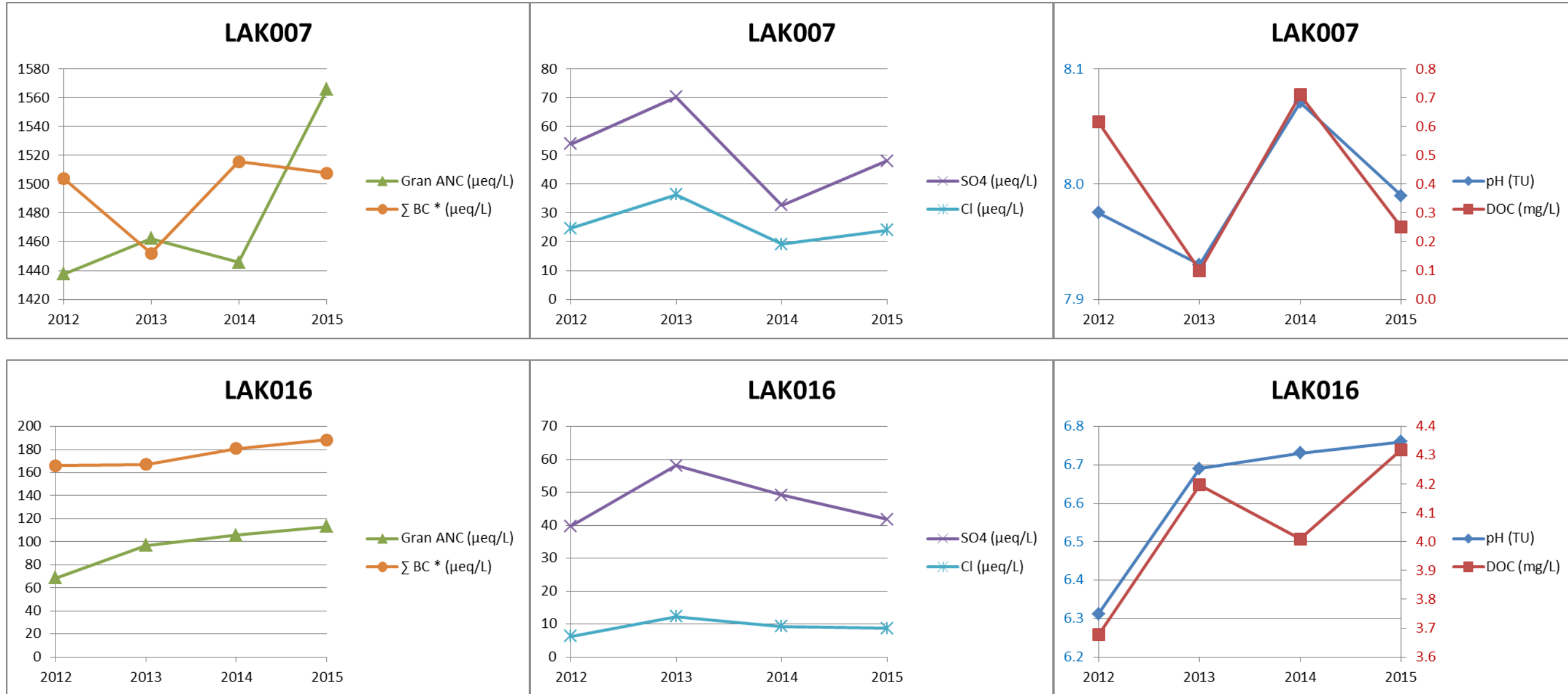


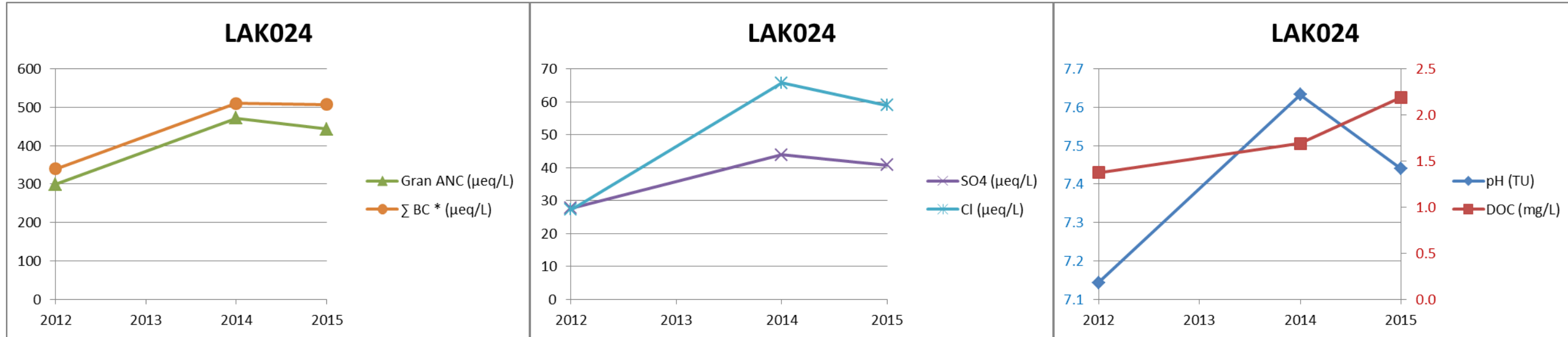




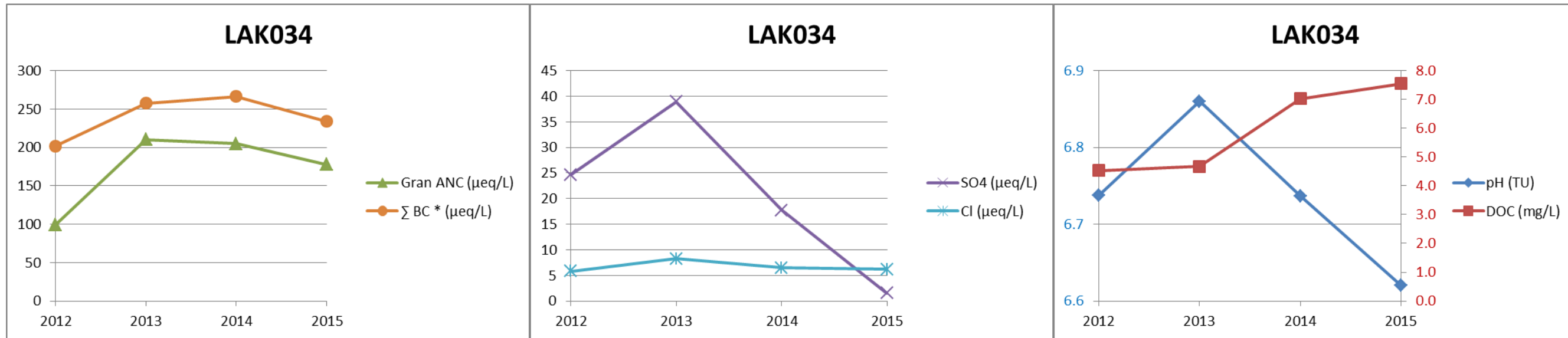


Less Sensitive Lakes





NOTE: Because LAK024 was not sampled in 2013, the implied trend between 2012 and 2014 may misrepresent the true pattern. For example, for most of the other lakes, SO₄²⁻ was highest in 2013, which could be the same for LAK024 but the lack of data point from 2013 masks that potential pattern.



Appendix 3: Project Update from Dr. Paul Weidman

Impacts of Industrial Sulfur and Nitrogen Deposition and Climate Change on Salmon Stream Habitat in the Kitimat Watershed

Paul Weidman, Ph.D. (Postdoctoral Fellow & Lead for Project #1) School of Resource and Environmental Management & Department of Biology, Simon Fraser University

15-March-2016

Brief Summary

The main objective of our project is to determine the cumulative effects of industrial atmospheric emissions of sulfur and nitrogen on salmon stream habitat under hotter and drier conditions due to climate change in the Kitimat watershed. Achieving this objective is critical to anticipating and managing the cumulative effects of industrial activities and climate change on north coastal salmon streams. Moreover, this project will help guide on-going fish habitat restoration projects that are being conducted by the Haisla Fisheries Commission in the Kitimat watershed.

In 2016, we propose to modify our sampling activities from 2015 in order to confirm our preliminary results and to map the potential impacts on salmonid habitat in the Kitimat and Lakelse watersheds from increased industrial emission of sulphur and nitrogen. We used data collected in 2015 to select 12 main project streams to continuing monitoring monthly throughout the entire year in 2016–2017. In this way, we are focusing our efforts on assessing and mapping habitat conditions in fewer streams than in 2015, but over the entire year in order to more efficiently conduct our fish habitat assessment. Streams selected in 2016 will represent the full range of habitat conditions that are relevant to our project. We also propose to measure the lethal and sub-lethal effects on juvenile salmonids of sulphur and nitrogen acid deposition and heat stress due to climate change. These rearing incubations will be conducted either at the Kitimat Hatchery and/or the Cultus Lake Salmon Laboratory.

Description of Activities

Part 1: Stream Water Quality

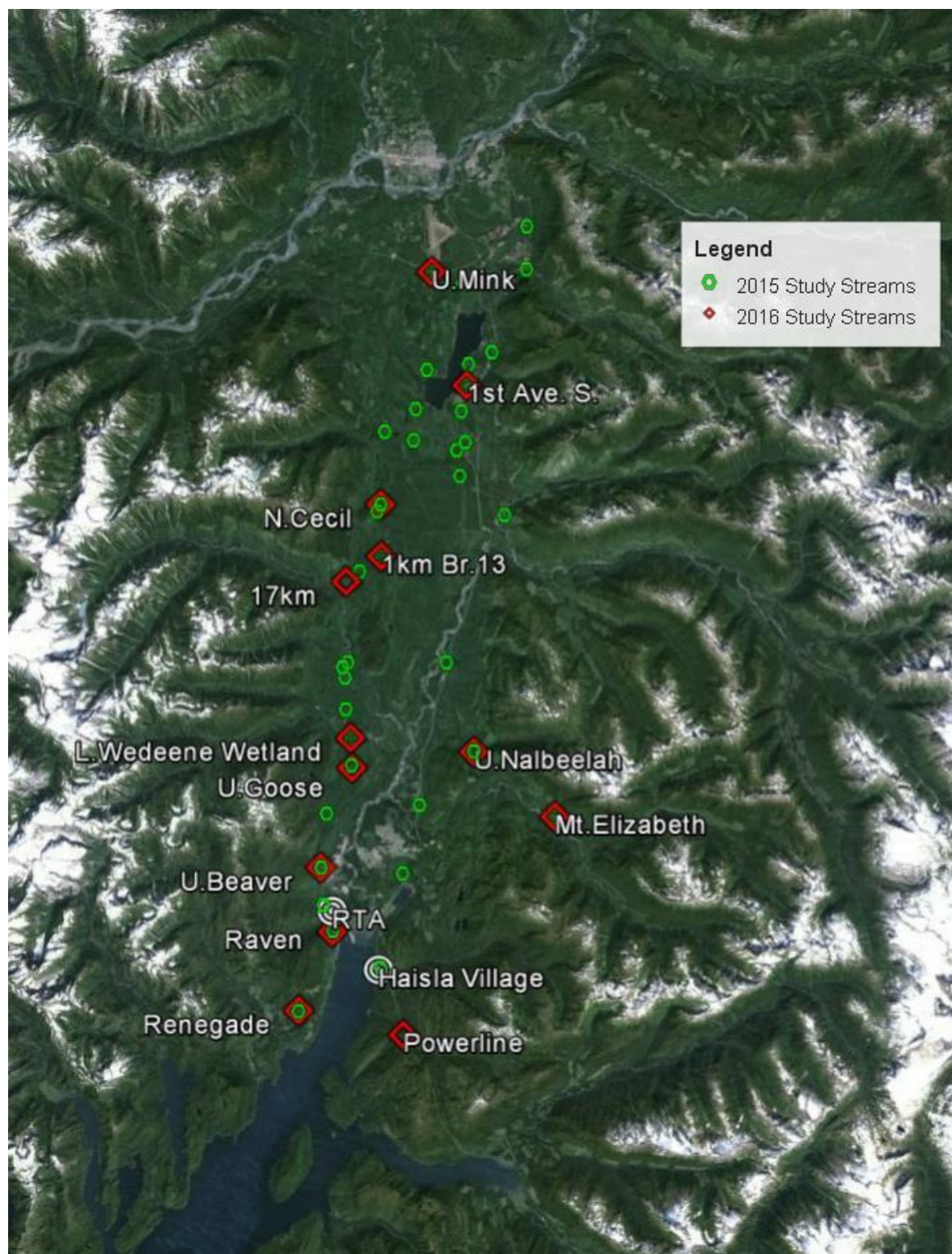
- Continue to survey water quality and water chemistry in 12 main project streams monthly throughout 2016 and 2017.
- Re-install and continue to monitor data loggers for pH, water temperature, and water depth throughout the year in order to determine the extent of episodic acidification in late fall, winter and early spring.
- Continue to sample benthic algae and benthic invertebrates as bioindicators of industrial impacts every four months.
- Re-assess the presence of all salmonid species in all 12 streams using a minnow traps and seine nets in summer.

Part 2: Fish Stress Rearing Incubations

- Collect live juvenile salmonids (coho, chum, chinook, and steelhead) from streams in the Kitimat watershed where these populations spawn and rear.
- Incubate juveniles in containers at either the Kitimat Hatchery and/or the Cultus Lake Salmon Laboratory (to be determined).
- Subject juveniles to a 2-week period of stress due to inorganic acid (sulphur, pH 5.0), organic acid (from wetlands, pH 5.0), and heat stress (20°C).
- Continue to incubate juveniles for 2 months and monitor survival.
- At the end of the 2-month incubation, sacrifice individuals and measure growth and sub-lethal stress response indicators, including ion concentration and enzyme activity in blood and gill tissue.

Table 1. Average Chemical Conditions among 37 Study Streams in the Kitimat Valley, June–November 2015, measured with a YSI ProDSS multi-parameter probe.

	Water Temperature (°C)	Turbidity (NTU)	Conductivity (µS/cm)	pH (<i>in situ</i>)	Dissolved Oxygen (%)	Sample size (#)
Mean	11.1	2.2	50	7.00	91	14
SD	3.6	8.1	29	0.37	14	6
Min	7.7	0.0	16	6.10	34	6
Max	27.2	43.7	147	7.55	105	21

Figure 1. Study Sites in 2015 and 2016.**Reports provided to DFO:**

- We will produce a peer-reviewed scientific publication that will summarize the historical and expected future impacts of industrial atmospheric sulphur and nitrogen emissions on salmon stream habitat in the Kitimat watershed.
- We will produce a peer-reviewed scientific publication that will summarize the cumulative impacts on salmonid survival as the result of expected changes in fish habitat due to industrial atmospheric sulphur and nitrogen emissions and warming due to climate change.
- We will share both of these scientific publications with our main project partners who are responsible for monitoring and regulating the impacts of industrial activities on fish populations and fish habitat in the region, including Fisheries and Oceans Canada and the BC Ministry of Environment.
- A public summary of findings from both these publications will be produced for the Haisla Nation Council and the general public.

First Nation Communities Involved:

- Haisla First Nation

Other Partners Involved:

- Dr. Paul Weidman (Postdoctoral Fellow and Lead for Project #1), Department of Biology & School of Resource and Environmental Management, Simon Fraser University, Burnaby
- Mr. Michael Jacobs (Fisheries Manager) & Ms. Brenda Bouzane (Fisheries Administrative Technician), Haisla Fisheries Commission, Haisla Nation Council, Kitimaat Village
- Mr. Mitch Drewes (Environmental Specialist), Hidden River Environmental Management Ltd., Terrace
- Dr. Daniel Selbie (Head), Cultus Lake Salmon Research Laboratory, Fisheries and Oceans Canada, Cultus Lake
- Dr. Jonathan Moore (Associate Professor), Department of Biology & School of Resource and Environmental Management, Simon Fraser University, Burnaby
- Mr. Markus Feldhoff (Hatchery Manager) & Mr. Vince Sealy (Hatchery Manager), Kitimat River Hatchery, Fisheries and Oceans Canada, Kitimat
- Mr. Erland MacIssac (Fisheries Biologist - retired), Cooperative Resource Management Institute, Fisheries and Oceans Canada, Simon Fraser University, Burnaby
- Mr. Patrick Williston (Environmental Impact Assessment Biologist), Ministry of Environment, Smithers