



KMP SO₂ EEM Program – Technical Memo W06

Aquatic Ecosystems Actions and Analyses

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1 Introduction

This Technical Memo provides extended information on the data and analyses in support of the 2016 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 2016 Annual Report (ESSA et al. 2017).

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	2016
Steady state water modelling	<i>No work planned for 2016 on this task</i>
Chemistry: water body sampling	① Annual water sampling, laboratory analysis, and data evaluation. ② Continuation of intensive sampling to determine natural variability.
[SO ₄] _o ; F-factor	<i>No work planned for 2016 on this task</i>
Fish presence / absence sampling	③ Resample if lake pH change reaches threshold.
Episodic acidification	④ Implement study.
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; Perrin and Bennett 2015; Limnotek 2016; Bennett and Perrin 2017). 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)

2 Methods

2.1 Annual Monitoring Samples ①

2016 Annual Sampling

In 2016, 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). The sampling methodology is described in detail in

Limnotek’s technical report on the water quality monitoring (Bennett and Perrin 2017). Table 2-1 summarizes all of the EEM sites sampled during 2012-2016. Figure 2-1 shows a map of the lakes sampled in 2016.

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

Sample Site	Year of Sampling					Rationale for sampling
	2012	2013	2014	2015	2016	
	STAR	EEM	EEM	EEM	EEM	
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)				✓		
NC184		✓ ¹		✓	✓	Control lakes added to EEM in 2015
NC194		✓ ¹		✓	✓	
DCAS14A		✓ ¹		✓	✓	

¹ Sampled as part of the Kitimat Airshed Assessment (ESSA *et al.* 2014a)

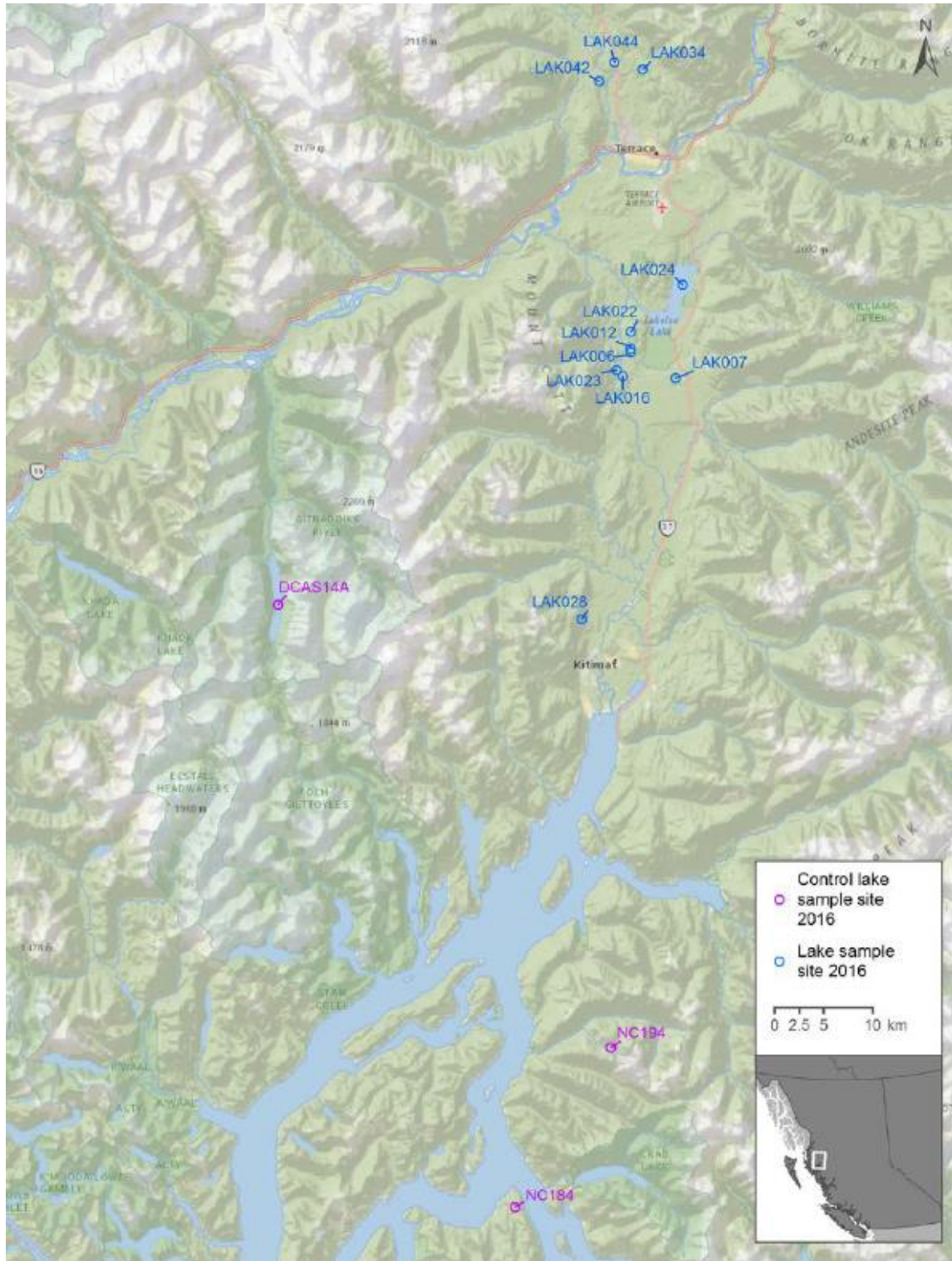


Figure 2-1: Location of the lakes that were sampled in 2016. The three control lakes are labelled with purple text (Source: Bennett and Perrin 2017).

2.2 Intensive Monitoring of Three Lakes ②

Starting in 2014, intensive monitoring was implemented 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 in total for each of the intensively monitored lakes in 2015). In October 2016, this was repeated for the same three lakes (LAK006, LAK012 and LAK023) as well as being expanded to LAK028, LAK042 and LAK044. The three additional lakes were added in 2016 based on the recommendation in the 2015 EEM Annual Report to 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. The power analyses (see ESSA Technologies Ltd. 2016) demonstrated that the existing monitoring plan (i.e., annual samples only for these lakes) would have low power to detect changes in some of the primary metrics for water chemistry in LAK028 (for ANC, SO₄²⁻), LAK042 (for pH, ANC), or LAK044 (for ANC, SO₄²⁻). Additional sampling was conducted in 2016 to provide insight into the natural variability in pH, Gran ANC and SO₄²⁻ in these lakes near the time of the annual water sampling. Finally, lake levels were monitored in End Lake, Little End Lake, and West Lake to provide an accurate, local measure of the timing of storm events, so as to better explain observed variation in pH (monitored continuously) and other water quality parameters of interest monitored during October (particularly sulphate, nitrate, DOC, ANC, and base cations).

This work was planned, implemented and documented by Limnotek. The methods and results for 2016 are reported in Bennett and Perrin (2017).

For the lakes with more than one sample per year, the data from the multiple within-season samples have been used to determine mean annual values. In previous Annual Reports, only the sample taken on the first day of the monitoring season (i.e., the day(s) of sampling all lakes) was designated as the “annual sampling” value. Starting in this year’s Annual Report, the mean annual values are used for all years in which additional within-season samples were taken.

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 Bennett and Perrin (2017).

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. 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. 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 2016 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 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 pH measurements from Trent University. Limnotek (Bennett and Perrin 2017) analyzed differences among the different methods of measuring pH for quality assurance purposes, repeating similar comparisons conducted in previous years (Perrin and Bennett 2015, Limnotek 2016).

2.4 Inter-annual Changes

Observed Changes

The EEM Program now has five consecutive years of monitoring data with which to examine inter-annual changes in water chemistry parameters. The monitoring data from 2016 represents the first year of true post-KMP sampling. The years 2012 to 2014 were prior to the implementation of KMP and 2015 was a transition year that included decreases in production in preparation for the transition then ramping production as KMP was phased in during the year.

We calculated the changes in major water chemistry attributes between subsequent years and across the entire period for 2012-2016². However, the power analyses conducted and reported in the 2015 EEM Annual Report illustrated that the power to detect annual changes in pH, Gran ANC and SO₄ is very low due to high variability and/or measurement error. Therefore annual changes should be interpreted very cautiously.

² 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. However, to better understand this potential seasonal effect, We analyzed pH data from 2015 and 2016 for the 3 intensively monitored lakes to test if there were any consistent differences in mean August pH vs mean October pH.

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 principles of the framework are considered and applied in Section 4. More years of data will be required to achieve statistically reliable comparisons of pre-KMP and post-KMP conditions, as demonstrated by the statistical power analyses conducted in 2015.

2.5 Fish Sampling ③

No new fish sampling was conducted in 2016.

Limnotek conducted fish sampling in LAK006, LAK012, LAK023, and LAK044 in 2013 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 there were convincing evidence 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 previous technical reports (Perrin et al. 2013, Section 2.9; Limnotek 2016, Section 2.8).

2.6 Episodic Acidification Studies ④

Three studies are directly relevant to the episodic acidification sub-component of the aquatic ecosystems component of the EEM Program. First, the three intensively monitored lakes include continuous monitoring of pH during the ice free season. Second, there have been substantial efforts to establish a continuous pH monitoring station on Anderson Creek. In 2015, there was a Manta monitor installed by Limnotek, but the data collected suggested that the instrument may not have been functioning properly. Due to such concerns, the monitor was removed and set up alongside the Manta monitor in West Lake in 2016 to test for instrument issues (Limnotek 2016). Independently, Rio Tinto had a continuous pH monitor in place in Anderson Creek during 2016; however, the instrument was not properly re-calibrated through the season and therefore the data were unusable due to measurement drift. In 2017, a Manta monitor was installed in Anderson creek for 4 weeks in 2017 to validate the Rio Tinto data from their Foxboro instrument which was installed in Anderson Creek in July 2017. Third, Dr. Paul Weidman (School of Resource and Environmental Management & Department of Biology, Simon Fraser University) has been conducting a research project on episodic acidification and climate change. Dr. Weidman's research is highly relevant to the work of the EEM program although it is not a formal component of the EEM program. Rio Tinto will provide an update on Dr. Weidman's research once his report is publicly available.

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 summary provided in the 2015 EEM Annual Report:

“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.”

2.7 Amphibian Monitoring ⑤

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

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 technical report by Limnotek (Bennet and Perrin 2017). The laboratory data show high precision and accuracy, with no apparent problems. Measurements of pH from ALS were statistically significantly different from pH measurements in the field, and from pH measurements in the laboratory at Trent University, but these differences were still within the specified limits of ± 0.3 pH units for the equipment used by ALS.

Charge Balance Check

The charge balance has been examined for each year of sampling, based on the data from annual sampling event. Table 3-1 shows four diagnostic metrics of the charge balance for the annual sample sets from 2012 to 2016. The charge balance is better for the 2016 sampling data than it had been in during the previous three years.

The charge balance for the lakes in the EEM Program (sensitive and less sensitive), as sampled in 2016, is shown graphically in Figure 3-1. The linear trend line shown on the graph is 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, control lakes³), and 2016 (EEM lakes, control lakes). 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 ³	-2.9	3.1	-16.6	17.3
2016	14	-1.7	2.3	1.7	12.6

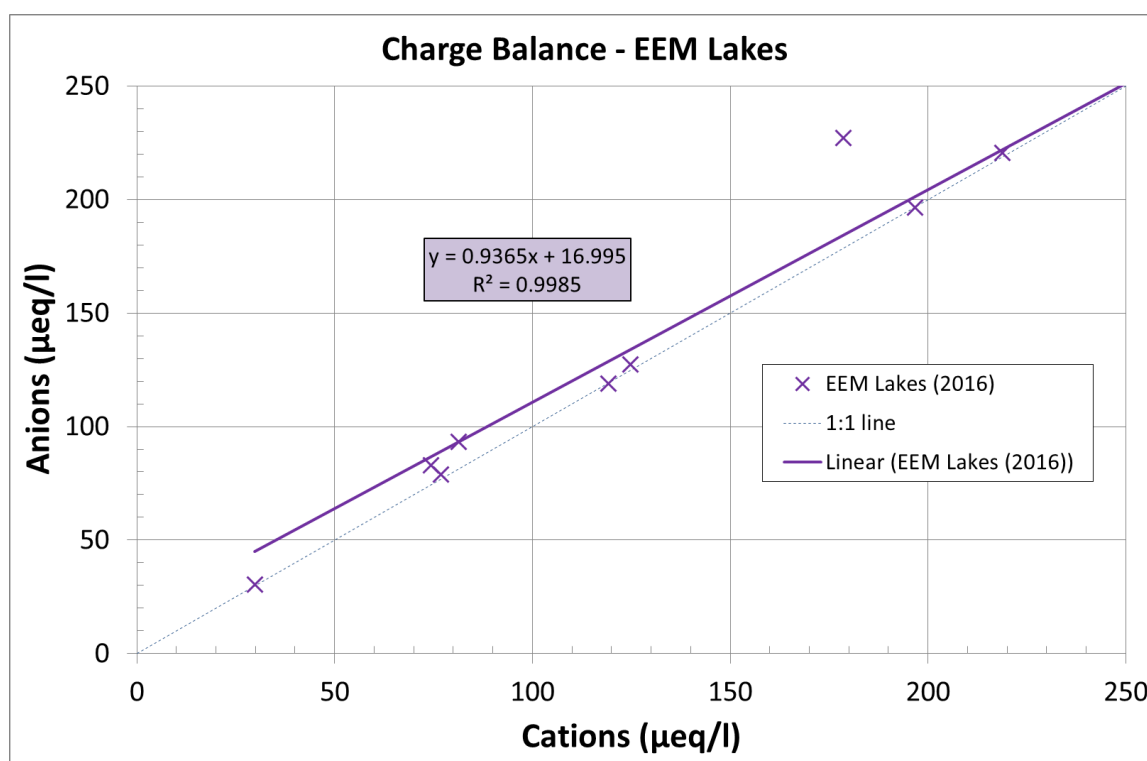


Figure 3-1. Analysis of charge balance for the EEM lakes in 2016. The Y-axis is the sum of all major anions (negatively charged ions); the X-axis the sum of all major cations (positively charged ions).

For each of the lakes with multiple within-season samples, Table 3-2 shows the measures of the charge balance check. In 2016, the average charge balance discrepancy was greater for this data set than for the single annual samples across all of the lakes, but still within acceptable limits for data quality.

³ 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.

Table 3-2. Measures of the charge balance check for lakes with multiple within-season samples. In 2014 and 2015, these included (LAK06, LAK12 and LAK023). In 2016, these included those same three lakes plus LAK028, LAK042 and LAK044. Negative (red) values for “Average %Diff” and “Average Difference” indicate less total charge from cations than from anions.

Year	# Lakes	Number of Samples	Average %Diff	Average Abs (%Diff)	Average Difference (µeq/L)	Average Abs(Diff) (µeq/L)
2014	3	15	-5.6	5.6	-11.1	11.1
2015	3	12	-3.5	3.5	-6.8	6.8
2016	6	24	-4.3	4.9	-10.4	11.6

Measured versus Estimated Conductivity

Measured and estimated conductivity were compared for each year of sampling, based on the data from annual sampling. Table 3-3 shows two diagnostic metrics of the conductivity check for the annual sample sets from 2012 to 2016. The data for 2016 demonstrate an acceptable relationship between measured and estimated conductivity. Estimated conductivity was lower than measured conductivity for all but one of the lakes sampled in 2016.

The conductivity check for the lakes in the EEM Program (sensitive and less sensitive), as sampled in 2016, is shown graphically in Figure 3-2. The linear trend line shown on the graph is heavily influenced by Lake 007 (not shown on the graph), which has conductivity values of an order of magnitude greater than most of the other lakes.

Table 3-3. Measures of the conductivity check for 2012 (STAR lakes), 2013 (EEM lakes, MOE3, Cecil Creek), 2014 (EEM lakes, MOE6), 2015 (EEM lakes, control lakes⁴), and 2016 (EEM lakes, control lakes). Positive values of “Average %Diff” indicate that the estimated conductivity was higher than the measured conductivity. Negative values (shown in red) indicate that the estimated conductivity was lower 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 ⁴	-3.0	6.1
2016	14	-7.5	9.1

⁴ As per Table 3-1, only NC184 and NC194 are included. DCAS14A is excluded due to data concerns that are being currently explored.

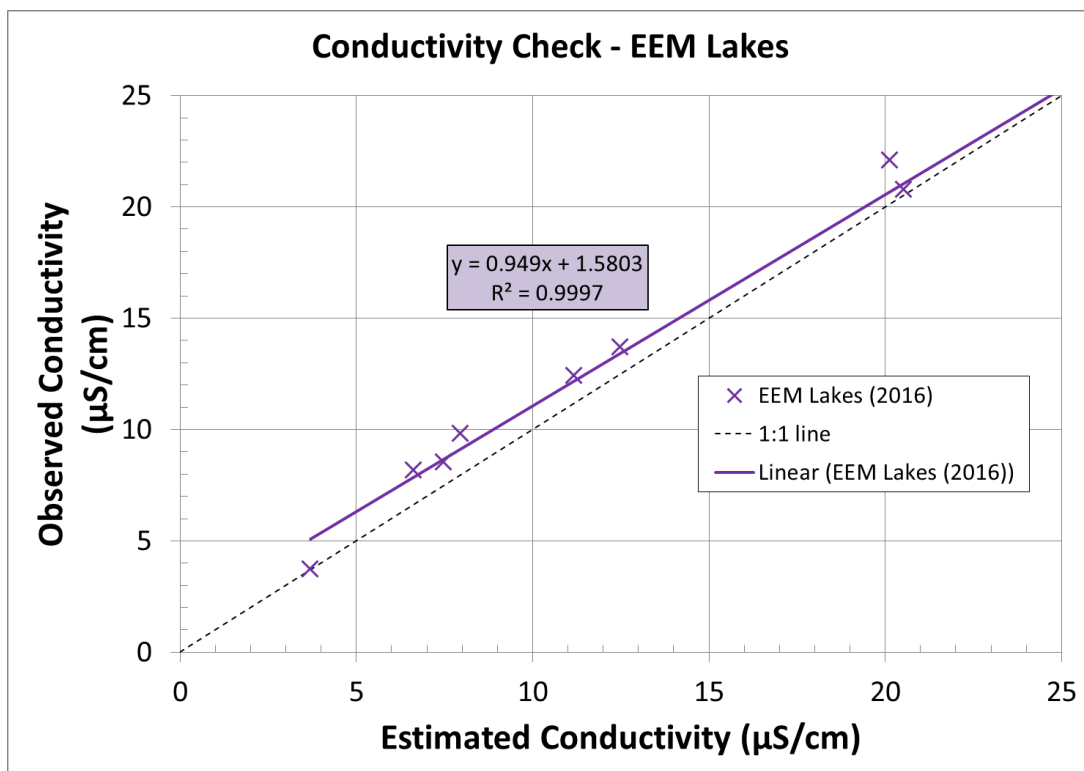


Figure 3-2. Conductivity check for the EEM lakes in 2016. Estimated conductivity is based on laboratory measurements of the concentrations of all ions and literature values for the conductivity of each ion, which is compared to the conductivity observed in field measurements.

For each of the lakes with multiple within-season samples, Table 3-4 shows the measures of the charge balance check. In 2016, the average conductivity difference was less for this data set than for the single annual samples across all of the lakes, but greater for the average of the absolute differences. However, the 2016 data still fall within acceptable limits for data quality. As explained in the footnote to Table 3-4, it appears that in 2015 the measured conductivity was erroneous for the three additional within-season samples taken at all three lakes, but that the ion measurements still showed acceptable charge balance (Table 3-2).

Table 3-4. Measures of the conductivity check for lakes with multiple within-season samples. In 2014 and 2015, these included (LAK06, LAK12 and LAK023). In 2016, these included those same three lakes plus LAK028, LAK042 and LAK044. Positive values of “Average %Diff” indicate that the estimated conductivity was higher than the measured conductivity.

Year	Lakes	Number of Samples	Average %Diff	Average Abs (%Diff)
2014	3	15	-3.2	6.2
2015	3	12	43.4 ⁵	46.3
2016	6	24	-6.5	11.9

pH measurements

Lab measurements of pH were made at two different labs in 2013 to 2016. Limnotek examined the differences in pH measurements for 2016 among the two labs and the field measurement and concluded that the differences were within the expected ranges (i.e., factory/lab specified measurement error associated with each instrument; Bennett and Perrin 2017). In 2016, the values measured by ALS were higher than those measured by Trent University for all lakes and the mean difference between the labs was greater than previous years. However, 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. 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 Annual Water Chemistry Sampling Results ①

Appendix 1 reports the results of the annual water chemistry sampling for the EEM lakes and control lakes from the sampling conducted in 2016 (with the data from 2012-2015 included for reference), for major water chemistry metrics (pH, DOC, Gran ANC, base cations, and major anions).

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 (Bennett and Perrin 2017). The Limnotek results for pH monitoring are summarized below in Table 3-5 and Table 3-6. Over the period of continuous monitoring (from April 10 to November 10, 2016), the pH varied by about 1.1 pH units in End Lake and by about 1.3 pH units in both Little End Lake and West Lake. The mean pH in all three lakes remained at or above 6.0, the level used as a biological threshold for analyses of critical loads (see STAR and KAA reports).

⁵ It appears that for all 3 lakes the measured conductivity values for samples taken October 13, 20, and 27 are in error. Based on the first sample taken at each lake (October 4), the average % difference in conductivity was only -5.8%, which is within the range of other years and within the range of acceptable limits. Measured conductivity dropped substantially after the first sample, while the estimated conductivity remained relatively similar. Further examination confirmed that estimated conductivity was calculated correctly and there were no suspect data in the ion concentrations. The ion measurements are the most important data for the EEM Program – the ion measurements for these samples appear to be consistent with the data from the first sample, and the charge balances for all of the samples are within the range of acceptable limits. These errors appear to be limited only to the conductivity measurements for these three dates.

The results from these lakes further confirm the results from the first two years of continuous monitoring – i.e., that these data show a high degree of variation in the half-hourly pH within each year, substantially higher than originally expected, but not in the mean annual pH. Understanding that natural intra-annual variation is very high was one of the primary reasons for conducting the power analyses as part of the 2015 EEM Annual Report (ESSA Technologies Ltd 2016) and the resultant recommendation that changes in primary lake chemistry metrics will need to be assessed within a probabilistic analytical framework rather than simple deterministic comparisons between years⁶. The power analyses showed that continuous monitoring will increase 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 (i.e., when the comprehensive review of the monitoring data is conducted in 2019).

A sharp drop in pH was observed in Little End Lake and West Lake at the very end of the monitoring period (Figure 6 in Bennett and Perrin 2017), coinciding with a large rainstorm (100mm of rainfall on November 8th and 9th) after a relatively dry October. During the first 10 days of November, Lake levels increased by about 0.25 m in End Lake and Little End Lake, and by about 0.45 m in West Lake (Figure 11 in Bennett and Perrin 2017). In End Lake, there was no sharp drop in pH following the storm, indicating hydrologic and biogeochemical differences between the End Lakes. There were no analyses of full lake chemistry in the three intensively monitored lakes on or following Nov 8 and 9, so it isn't possible to determine what chemical changes were associated with this pH decline. However, sampling of Lake 028 on Nov. 9th showed declines in pH, all base cations and sulphate since the previous sampling on October 31st, suggesting that base cation dilution is the most likely explanation for the pH decline in Lake 028 associated with the November 9th storm event.

⁶ As described in the power analysis, there is a high degree of variability in pH (the KPI) within most of the sensitive lakes and for Gran ANC and SO₄²⁻ (the informative indicators) within some of the sensitive lakes. In 2019, as part of the comprehensive evaluation of EEM monitoring data, we will therefore generate a probability distribution for the change in each primary metric (pH, ANC, SO₄²⁻), based on the 2012-2018 monitoring data, explicitly accounting for natural variability and measurement error. We will then compare those distributions to the evaluation thresholds for each indicator within each lake. The results will be expressed as the *probability that a particular lake has exceeded a particular threshold*.

Table 3-5. 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 2016. Source: Table 9 in Bennett and Perrin (2017)

Lake	Sensor	Number of observations	Minimum pH	Maximum pH	Range of pH	Mean pH ± SD
End	pH1	10254	5.9	6.8	1.0	6.3 ± 0.1
End	pH2	10254	5.9	7.1	1.2	6.2 ± 0.1
End	pH3	10253	5.8	8.7*	2.9	6.3 ± 0.1
Little End	pH1	9726	5.6	7.0	1.4	6.1 ± 0.2
Little End	pH2	9726	5.4	6.7	1.2	6.0 ± 0.2
Little End	pH3	9726	5.6	6.9	1.3	6.1 ± 0.2
West	pH1	10253	5.6	7.0	1.4	6.3 ± 0.2
West	pH2	10253	5.5	6.8	1.3	6.2 ± 0.2
West	pH3	10253	5.5	6.8	1.3	6.2 ± 0.2

* Extreme values on sensor pH3 in End Lake were possibly due to instrument error (Bennett and Perrin 2017).

Table 3-6. Variation in mean pH (± standard deviation) between instruments, by lake, during sampling in October 2016. Source: Table 10 in Bennett and Perrin (2017).

Instrument or lab	Mean pH ± sd in October, 2016 (n=4)		
	End Lake	Little End Lake	West Lake
WTW field pH meter	6.1 ± 0.1	6.1 ± 0.1	6.1 ± 0.1
Trent University	6.0 ± 0.1	6.2 ± 0.0	5.9 ± 0.0
ALS	6.3 ± 0.2	6.5 ± 0.2	6.2 ± 0.1
Manta sensors	6.3 ± 0.1	6.2 ± 0.1	6.0 ± 0.2
Instrument/lab effect (P)	0.005	0.001	0.015

Analyses of 2015 and 2016 data from the 3 intensively monitored lakes with continuous monitoring of pH show that the difference in mean August pH and mean October pH varies across years within lakes, and across lakes within years (Table 3-7). Across all lakes and years, the mean August pH was 0.05 pH units higher than the mean October pH, but there does not appear to be any consistent pattern. The results in Table 3-7 provide a preliminary indication that samples taken in August are not biased relative to samples taken in October in a particular year and therefore it appears reasonable to use data from August 2012 (without any bias correction) together with data from October 2013 and October 2014 as estimates of pre-KMP conditions. However, this analysis is only based on two years and should be repeated in subsequent years to confirm the finding.

Table 3-7. Mean pH in August vs. mean pH in October, for each of the three intensively monitored lakes with continuous pH monitoring. These values represent an averaging of all measurements from the three Manta probes within each lake during each monthly period. None of the differences are greater than the measurement error (+/- 0.2 pH units for Manta instrument). Note: the monthly averages and differences reported in this table appear not to match in some places due to rounding errors (pH values are reported to nearest 0.1 pH units, but the calculations were conducted with more significant digits).

Year	Month	Metric	Lake			
			West Lake (LAK023)	End Lake (LAK006)	Little End (LAK012)	
2015	Aug	COUNT	4455	4458	4101	
		MEAN pH	6.2	6.4	6.2	
		SD	0.1	0.1	0.2	
	Oct	COUNT	4455	4455	4458	
		MEAN pH	6.3	6.2	5.9	
		SD	0.1	0.1	0.1	
	DIFF (Aug-Oct pH)			-0.0	0.1	0.2
	2016	Aug	COUNT	4452	4449	4452
			MEAN pH	6.2	6.3	6.0
SD			0.1	0.1	0.2	
Oct		COUNT	4455	4455	4245	
		MEAN pH	6.1	6.3	6.2	
		SD	0.1	0.1	0.0	
DIFF (Aug-Oct pH)			0.1	-0.0	-0.2	
AVG. DIFF (Aug-Oct pH)			0.05			

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 3-8 and Table 3-9, and in terms of relative change in Table 3-10 and Table 3-11. Changes are shown for five time periods of comparison: 2012-2013, 2013-2014, 2014-2015, 2015-2016, and 2012-2016. The sensitive EEM lakes and less sensitive EEM lakes are presented separately within each of the tables. The inter-annual changes presented in this report use the mean annual values whenever multiple within-season samples were taken for a given lake in a given year⁷.

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 2015 and 2016. Although the tables show changes for other periods as well, these figures have only been included for the changes from 2015 to 2016. Changes from 2015 to 2016 in

⁷ This represents a change in practice from previous years, in which annual sampling values (and therefore intra-annual changes) were based only on the single samples taken on the day(s) in which sampling was conducted across all of the lakes. When the monitoring plan was expanded to include additional intra-annual sampling for some lakes in October (and sometimes November), these data were used to better understand intra-annual variability and help provide context for the inter-annual patterns observed.

particular are examined in more detail, in the context of expected changes based on the Evidentiary Framework, in the Discussion (Section 4).

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 five years of annual monitoring (2012-2016). Similar figures are also included for the three control lakes based on their three years of annual monitoring (2013, 2015, 2016).

However, as stated in Section 2.4, annual changes should be interpreted with substantial caution due to the combination of large natural variation (both within and between years) and limitations on measurement precision. The power analyses conducted and reported in the 2015 EEM Annual Report illustrated that *multiple* years of observations are required to reliably detect changes in mean pH, Gran ANC and SO₄; it is risky to draw conclusions based only on annual changes. We provide further discussion of these results in section 4.

Table 3-8. Inter-annual changes in pH, Gran ANC and SO₄²⁻ for EEM lakes, 2012-2016. 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 (µeq/L)					SO ₄ * (µeq/L)				
From	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
To	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016
LAK006	0.4	-0.1	-0.1	0.0	0.2	3.3	9.9	-6.5	-5.5	1.2	3.0	-2.3	-0.7	0.4	0.4
LAK012	0.6	-0.3	-0.1	0.3	0.6	6.5	5.2	-2.9	-0.1	8.8	5.2	4.5	1.7	-8.0	3.4
LAK022	0.2	0.1	-0.1	-0.1	0.1	8.5	10.5	-11.3	-1.1	6.6	16.9	-9.3	-5.3	1.7	4.0
LAK023	0.2	0.0	0.0	0.0	0.2	4.0	8.3	-2.1	-2.1	8.1	5.0	-5.1	-3.8	-2.4	-6.3
LAK028	0.2	0.1	-0.2	-0.2	0.0	8.8	17.8	-11.8	-15.7	-0.9	71.2	-33.7	-23.3	56.7	70.9
LAK042	0.8	-0.4	0.3	0.0	0.7	41.4	-8.5	1.3	0.2	34.4	-0.5	-1.8	-0.2	-0.5	-2.9
LAK044	0.3	0.1	0.0	-0.2	0.1	7.3	-2.7	0.3	-2.1	2.8	0.0	-1.6	-0.9	0.4	-2.1
Lakes with Increase	7	3	3	1	6	7	5	2	1	6	5	1	1	4	4
Lakes with Decrease	0	4	4	6	1	0	2	5	6	1	2	6	6	3	3

LAK007	0.0	0.1	-0.1	0.0	0.0	24.5	-16.4	119.9	-197.0	-69.0	15.1	-35.8	14.9	1.1	-4.7
LAK016	0.4	0.0	0.0	-0.2	0.3	28.3	8.8	7.4	-19.2	25.2	17.9	-8.7	-7.2	4.0	5.9
LAK024	¹	¹	-0.2	0.1	0.4	¹	¹	-29.1	20.1	163.6	¹	¹	-2.4	4.5	14.4
LAK034	0.1	-0.1	-0.1	-0.1	-0.3	111.0	-5.4	-27.1	-26.2	52.2	14.0	-21.1	-16.1	-0.9	-24.1
Lakes with Increase	2	2	1	1	2	3	1	2	1	3	3	0	1	3	2
Lakes with Decrease	1	1	3	3	2	0	2	2	3	1	0	3	3	1	2

¹ 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, chloride, and calcium for EEM lakes, 2012-2016. 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)					Ca* (µeq/L)				
From	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
To	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016
LAK006	-0.4	0.6	0.1	0.3	0.7	-3.0	8.0	1.2	2.1	8.2	2.9	-0.6	-1.5	-1.1	-0.2	-3.2	4.6	0.6	0.3	2.3
LAK012	-0.4	2.0	1.2	-2.4	0.4	-11.8	7.3	8.1	-11.2	-7.6	10.5	-4.4	0.8	-5.4	1.5	-9.7	4.5	5.5	-10.2	-9.9
LAK022	0.9	-0.6	0.6	0.4	1.3	11.0	4.9	-6.2	6.7	16.4	5.4	-3.3	-1.1	0.0	1.0	7.0	3.4	-4.4	4.0	10.0
LAK023	-0.1	1.6	-0.3	0.5	1.7	-2.1	15.2	-5.5	-1.2	6.4	3.0	-1.3	0.1	-1.3	0.5	-2.3	12.2	-3.2	-3.6	3.1
LAK028	2.2	-1.1	2.2	0.0	3.2	48.4	4.4	-15.9	31.8	68.7	11.7	-6.7	-2.0	1.0	3.9	37.6	0.8	-9.4	18.2	47.2
LAK042	-3.5	0.9	-2.3	1.5	-3.3	7.6	-5.3	3.7	8.1	14.0	1.6	4.1	-5.4	0.7	1.0	8.7	-5.5	0.2	5.9	9.3
LAK044	-0.2	0.3	-0.2	0.4	0.3	3.0	0.1	2.9	-2.1	4.0	3.3	-2.9	0.0	0.2	0.5	0.9	0.0	2.0	-1.6	1.4
Lakes with Increase	2	5	4	6	6	4	6	4	4	6	7	1	2	3	6	4	5	4	4	6
Lakes with Decrease	5	2	3	1	1	3	1	3	3	1	0	6	4	3	1	3	2	3	3	1
LAK007	-0.5	0.6	-0.5	0.5	0.2	-51.9	63.5	-7.8	35.1	38.9	11.7	-17.1	4.8	1.4	0.8	-46.2	50.8	-10.2	34.9	29.3
LAK016	0.5	-0.2	0.3	0.8	1.5	0.8	13.7	7.8	-2.1	20.2	6.0	-3.0	-0.6	-0.3	2.1	-3.2	8.0	8.5	-3.5	9.8
LAK024	1	1	0.5	0.5	1.3	1	1	-2.8	57.7	225.3	1	1	-6.8	11.0	42.7	1	1	-1.7	46.0	173.4
LAK034	0.1	2.4	0.5	0.0	3.0	56.0	8.6	-32.3	-21.8	10.6	2.5	-1.8	-0.3	-0.8	-0.4	33.4	8.7	-15.0	-16.4	10.7
Lakes with Increase	2	2	3	4	4	2	3	1	2	4	3	0	1	2	3	1	3	1	2	4
Lakes with Decrease	1	1	1	0	0	1	0	3	2	0	0	3	3	2	1	2	0	3	2	0

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

Table 3-10. Inter-annual changes (%) in pH, Gran ANC and SO₄²⁻ for EEM lakes, 2012-2016. 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 * (µeq/L)				
From	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
To	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016
LAK006	6%	-1%	-1%	0%	4%	13%	34%	-17%	-17%	5%	26%	-16%	-5%	3%	4%
LAK012	12%	-5%	-1%	5%	10%	11%	8%	-4%	0%	15%	84%	40%	11%	-46%	56%
LAK022	4%	2%	-2%	-1%	2%	31%	29%	-24%	-3%	24%	56%	-20%	-14%	5%	13%
LAK023	4%	-1%	0%	0%	4%	20%	35%	-7%	-7%	41%	26%	-21%	-20%	-16%	-33%
LAK028	5%	2%	-4%	-3%	0%	1	372%	-52%	-146%	1	125%	-26%	-25%	80%	125%
LAK042	17%	-6%	6%	0%	15%	1	-40%	10%	1%	1	-7%	-31%	-5%	-13%	-47%
LAK044	5%	2%	0%	-4%	2%	576%	-32%	6%	-34%	220%	0%	-26%	-19%	11%	-34%
Lakes with Increase	7	3	3	1	6	5	5	2	1	5	5	1	1	4	4
Lakes with Decrease	0	4	4	6	1	0	2	5	6	0	2	6	6	3	3
LAK007	-1%	2%	-1%	0%	0%	2%	-1%	8%	-13%	-5%	29%	-54%	49%	2%	-9%
LAK016	6%	1%	0%	-3%	4%	41%	9%	7%	-17%	37%	46%	-15%	-15%	10%	15%
LAK024	²	²	-3%	1%	5%	²	²	-6%	5%	55%	²	²	-7%	13%	58%
LAK034	2%	-2%	-2%	-2%	-4%	112%	-3%	-13%	-15%	53%	58%	-55%	-95%	-100% ³	-100%
Lakes with Increase	2	2	1	1	2	3	1	2	1	3	3	0	1	3	2
Lakes with Decrease	1	1	3	3	2	0	2	2	3	1	0	3	3	1	2

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.

³ The resulting SO₄²⁻ concentration for LAK034 for 2016 after correcting for marine influence was calculated as less than zero. Therefore the relative change from 2015 to 2016 was calculated as -104%. This value has been adjusted to -100%.

Table 3-11. Inter-annual changes (%) in DOC, base cations and chloride for EEM lakes, 2012-2016. 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)					Ca* (µeq/L)				
From	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
To	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016	2013	2014	2015	2016	2016
LAK006	-10%	19%	3%	8%	19%	-5%	14%	2%	3%	14%	51%	-7%	-18%	-16%	-3%	-11%	17%	2%	1%	8%
LAK012	-9%	47%	20%	-32%	9%	-10%	7%	7%	-9%	-6%	254%	-30%	8%	-49%	36%	-13%	7%	8%	-14%	-13%
LAK022	17%	-9%	11%	6%	25%	11%	5%	-5%	6%	17%	78%	-27%	-13%	0%	14%	12%	5%	-6%	6%	17%
LAK023	-3%	40%	-5%	9%	40%	-3%	24%	-7%	-2%	10%	67%	-18%	1%	-20%	10%	-6%	33%	-6%	-8%	8%
LAK028	45%	-16%	36%	0%	66%	66%	4%	-13%	29%	94%	193%	-38%	-18%	11%	65%	79%	1%	-11%	24%	99%
LAK042	-26%	9%	-21%	18%	-25%	14%	-9%	7%	14%	26%	26%	53%	-45%	11%	17%	118%	-35%	2%	55%	126%
LAK044	-12%	17%	-11%	27%	17%	21%	1%	17%	-10%	28%	59%	-33%	0%	4%	10%	14%	0%	26%	-16%	21%
Lakes with Increase	2	5	4	6	6	4	6	4	4	6	7	1	2	3	6	4	5	4	4	6
Lakes with Decrease	5	2	3	1	1	3	1	3	3	1	0	6	4	3	1	3	2	3	3	1
LAK007	-84%	610%	-65%	208%	25%	-3%	4%	-1%	2%	3%	48%	-47%	25%	6%	3%	-4%	4%	-1%	3%	2%
LAK016	14%	-4%	8%	19%	40%	0%	8%	4%	-1%	12%	95%	-24%	-6%	-3%	34%	-3%	7%	7%	-3%	8%
LAK024	1	1	30%	23%	96%	1	1	-1%	11%	66%	1	1	-10%	19%	157%	1	1	0%	11%	63%
LAK034	3%	51%	7%	0%	67%	28%	3%	-12%	-9%	5%	42%	-21%	-4%	-14%	-8%	28%	6%	-9%	-11%	9%
Lakes with Increase	2	2	3	4	4	2	3	1	2	4	3	0	1	2	3	1	3	1	2	4
Lakes with Decrease	1	1	1	0	0	1	0	3	2	0	0	3	3	2	1	2	0	3	2	0

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

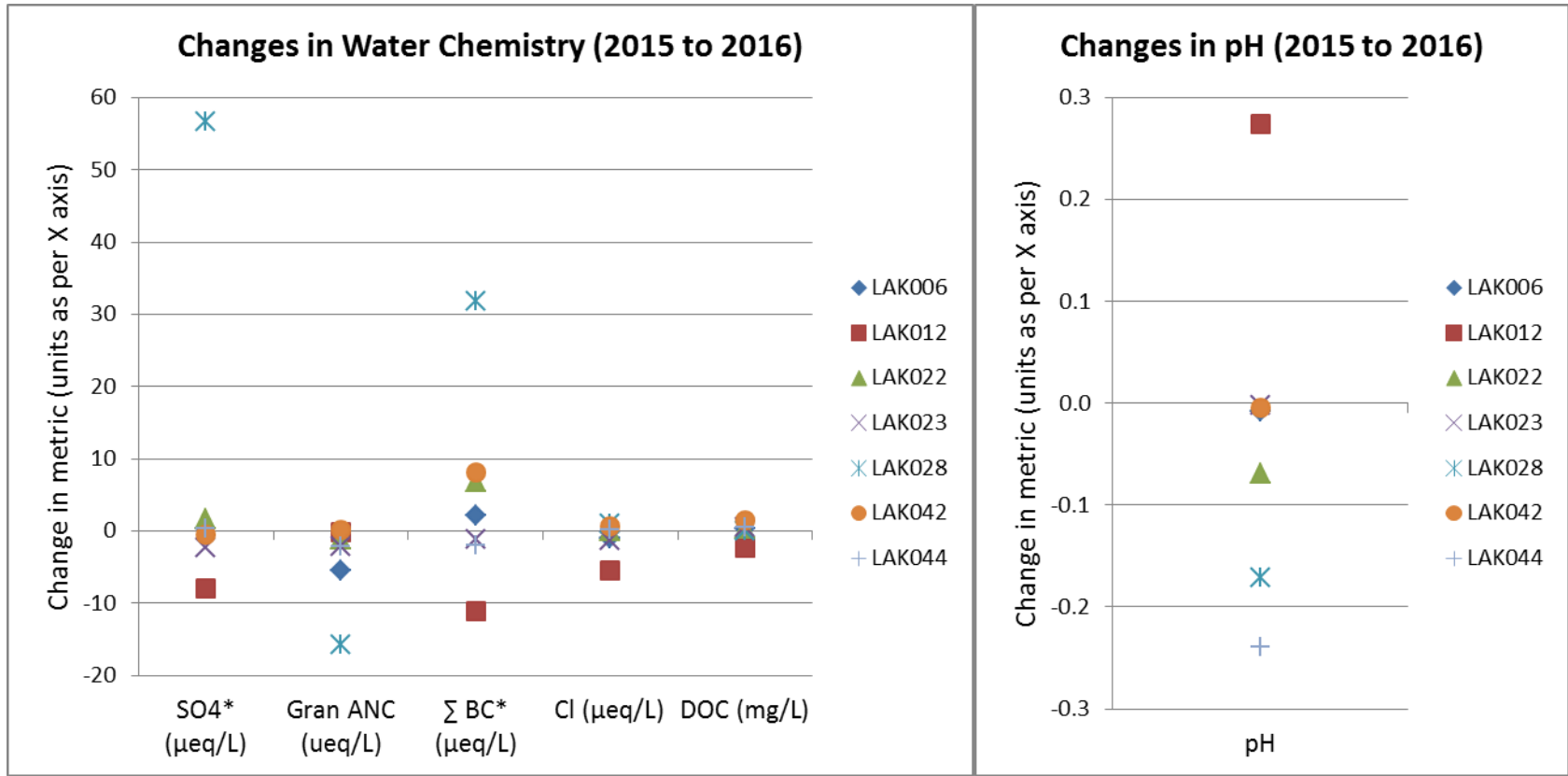


Figure 3-3: Changes in water chemistry metrics (left panel) and pH (right panel) across all of the sensitive EEM lakes, from 2015 to 2016. Values shown are 2016 value minus 2015 value.

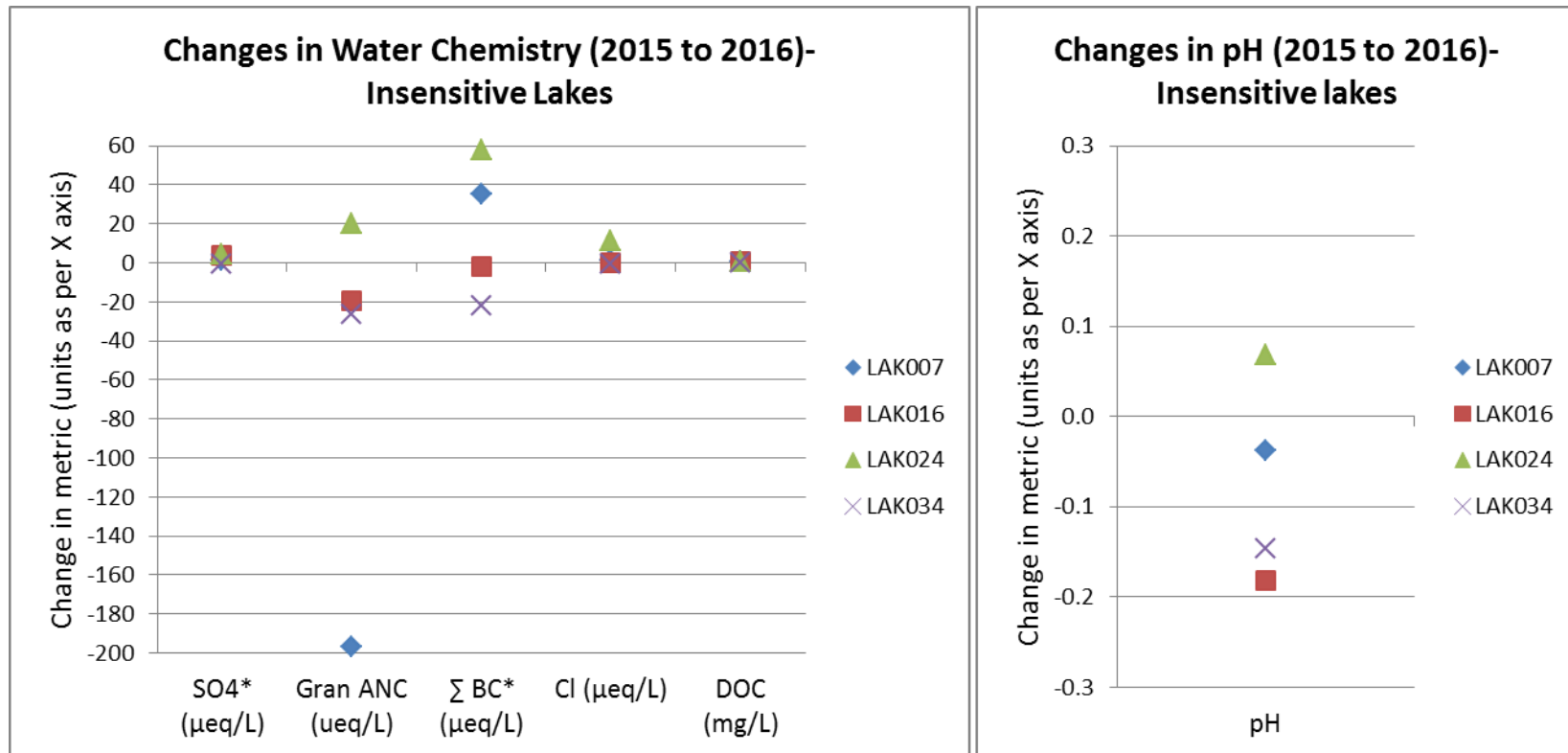


Figure 3-4: Changes in water chemistry metrics (left panel) and pH (right panel) across all of the less sensitive EEM lakes, from 2015 to 2016. Values shown are 2016 value minus 2015 value.

3.5 Episodic Acidification Studies ④

Research Project by Dr. Paul Weidman

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

4 Discussion

4.1 Application of the Evidentiary Framework

The principles of the evidentiary framework are applied in the interpretation of the results in the subsequent two sections. The evidentiary framework suggests that 2016 sulphate concentrations should increase relative to 2015 (due to increased emissions of SO₂), and that if changes in sulphate are driving acidification then ANC and pH levels should correspondingly decrease, if all other constituents and hydrologic conditions remained unchanged. As noted in the EEM Evidentiary Framework, changes in base cations, nitrate or DOC can also help to explain observed changes in ANC and pH.

4.2 Inter-annual Changes in Lake Chemistry, 2015-2016

Some of the main patterns observed in the changes in lake chemistry between 2015 and 2016 are reported in this section. These patterns are reported in two ways:

- By water chemistry metric across lakes (i.e., how do the general patterns for sulphate, ANC and pH align with changes that would be expected if acidification were occurring), and
- By lake across metrics (i.e., how do the patterns observed in each lake align with changes that would be expected if acidification driven by smelter emissions were occurring).

As emphasized in Sections 2.4 and 3.4, annual changes should be interpreted with great caution due to the high degree of natural variation (both within and between years) and measurement precision, which result in a low power to accurately detect annual changes in lake chemistry.

The following recommendation was put forth in the 2015 EEM Annual Report (based on the results of the power analyses):

- 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).

In accordance with this recommendation and previously emphasized cautions about interpreting the annual changes in measured values, the observed changes discussed in the following two sections should be considered as preliminary indicators of potential changes that may be occurring rather than definitive patterns of change. We are reporting on the annual changes that have been measured thus far but have not yet conducted analyses on the long-term trends. The comprehensive review in 2019 will rigorously analyses the multi-year, pre-/post-KMP trends and patterns in the data.

4.2.1 Observed Changes by Metric, 2015-2016

Sulphate

- Sulphate would be expected to increase in lakes (if they are responsive on an annual time scale) to increases in SO₂ emissions from KMP
- 4 of 7 sensitive lakes and 3 of 4 less sensitive lakes showed increases in SO₄²⁻ (corrected for influence of marine ions)
 - In LAK028, sulphate increased by approximately 80% (70.9 µeq/L)
 - The other 3 sensitive lakes with increases in SO₄²⁻ had small increases of 0.4 to 4 µeq/L (5-11%)
 - The less sensitive lakes with increases in SO₄²⁻ had increases of 2-13%
- Despite the increased emissions, 3 sensitive lakes and 1 less sensitive lake showed decreases in SO₄²⁻
 - In LAK012, LAK023 and LAK042, SO₄²⁻ decreased by 8.0, 2.4 and 0.5 µeq/L (respectively)
 - LAK034 decreased by 0.9 µeq/L to zero
 - For LAK023, LAK042 and LAK034, 2016 represented the third consecutive year of decreases, suggesting that if the lakes are in fact responsive to changes in smelter emissions, the response has a lag of greater than 1 year, or that the spatial pattern of sulphate deposition has changed under KMP, with less sulphate deposition occurring in these lakes
 - Two of these lakes (LAK034 and LAK042) are located at the northern extent of the study area and therefore receive lower levels of deposition. Further distance from the plume should mean greater dilution of emissions and could also mean that deposition levels vary more with changing wind patterns. However, the data from the other EEM lakes does not provide evidence for the distance from the smelter being a driving factor for lakes that had decreases in sulphate:
 - The other “far north” sensitive lake (LAK044), located near LAK034 and LAK044 showed little change in SO₄²⁻ (an increase of 0.4 µeq/L)
 - LAK012 had a considerably larger decrease in SO₄²⁻ (8 µeq/L) than both LAK034 and LAK042 despite being located much closer to the smelter
 - The two sensitive lakes near LAK012 and LAK023 (i.e., LAK006, LAK022) experienced small increases in SO₄²⁻ (+0.4 and +1.7 µeq/L, respectively)
 - We conclude that more years of data will be required to sort out the spatial pattern of changes in sulphate deposition.

ANC

- For the sensitive lakes, decreases in ANC would be expected (based on the evidentiary framework) to accompany increases in SO₂ emissions and resultant increases in SO₄²⁻ concentrations
 - This expected pattern of decreased ANC was observed in 6 of 7 sensitive lakes, and 4 of these 6 lakes also showed increased SO₄²⁻
 - The 1 sensitive lake that showed an increase in ANC (LAK042), demonstrated only a very small increase (0.2 µeq/L)
 - Base cations are expected to increase ANC, whereas sulphate is expected to decrease ANC. The 3 sensitive lakes with a negative value for {[Δ base cations] – [Δ sulphate]} also showed a decrease in ANC, which is what would be expected (LAK012, LAK028 and LAK044). LAK042 showed positive values for both {[Δ base cations] – [Δ sulphate]} and ΔANC, which would also be expected (although

the increase in ANC was very small). However, 3 sensitive lakes (LAK006, LAK022 and LAK023) had positive values for $\{[\Delta \text{ sum of base cations}] - [\Delta \text{ sulphate}]\}$ but showed declines in ANC, which would not be expected. However, the decreases in ANC were very small in LAK022 and LAK023 (-1.1 and -2.1 $\mu\text{eq/l}$, respectively), so one should not over-interpret these patterns.

- 5 of the 7 sensitive lakes demonstrated the pattern of inverse changes in ANC and SO₄²⁻ that would be expected if ANC is associated with changes in sulphate
 - The 2 lakes showing patterns contrary to expectations had only small decreases in ANC (-0.1 and -2.1 $\mu\text{eq/l}$) associated with their decreases in SO₄²⁻ – these small changes over only one year do not provide strong evidence of truly contrary pattern
- For the less sensitive lakes, changes in ANC would be expected to be independent of changes in SO₄²⁻ as well as being relatively small
 - ANC and SO₄²⁻ changed in the same direction for 2 of the less sensitive lakes and in opposite directions for the other 2 less sensitive lakes (although that alone does not mean that ANC is being influenced by SO₄²⁻)
 - 3 lakes showed decreases in ANC and 1 lake showed an increase (LAK024)
 - Of the 3 lakes that showed decreases in ANC, 2 of them also showed decreased in total base cations (Table 3-8, Table 3-9), though the magnitudes of change were only comparable in LAK034.
 - Decreases in ANC were within the range 13-17%; LAK024 increased in ANC by 5%

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)
 - 5 of 7 sensitive lakes demonstrate this expected pattern, with all 5 of those lakes showing decreases in the two metrics (although the magnitude of decrease in pH was negligible for 3 of the lakes)
 - All 4 less sensitive lakes demonstrate this expected pattern, including 3 lakes with decreases and 1 lake with increases in the two metrics
- pH decreased for 6 of 7 sensitive lakes and 3 of 4 less sensitive lakes; all of these decreases were within the accuracy of the pH meter used at Trent University (± 0.2 pH units)

Other metrics

- 10 of 11 EEM lakes increased in DOC
 - LAK042 increased by 1.5 mg/L; all other lakes changed by ≤ 1.0 mg/L
 - LAK028 and LAK034 had negligible increases in DOC
 - LAK012 decreased by 2.4 mg/L
- 6 of 11 EEM lakes increased in total base cations, so there was not a consistent pattern
- 6 of 11 EEM lakes decreased (5) or remained the same (1) in chloride.
 - 4 lakes increased in chloride by 0.2 to 1.4 $\mu\text{eq/l}$ (4-11%) and 1 lake (less sensitive) increased by 11.0 $\mu\text{eq/l}$ (19%)

4.2.2 Observed Changes by EEM Lake, 2015-2016

The observed changes for 2015 to 2016 for each lake in major lake chemistry metrics are summarized here. We then consider whether these changes are consistent with the expectations of a

potential KMP-driven acidification impact (as per the patterns of changed outlined in the evidentiary framework).

After a 9-year trend in generally declining SO₂ emissions, 2016 represented a substantial increase in emissions and therefore a strong reversal of this longer term trend. Emissions in 2016 provide a very strong contrast with previous years. This provides an opportunity to understand how responsive the EEM lakes are to changes in emissions, based on if and when this strong signal in emissions is reflected in changes in sulphate concentrations. With the 2016 sampling data, we can see which lakes are responsive on annual timescale to changes in emissions. Lakes that do not show an increase in sulphate concentrations in 2016 may simply be responsive on a longer timescale (which may be confirmed by sampling in future years) or are not particularly responsive to changes in emissions (due to the spatial distribution of sulphate deposition, or other factors). In previous years of the EEM program it was not possible to assess whether the generally observed decreases in sulphate were due to decreases in emission in the same year (i.e., highly responsive, little lag in effect) or a result of the many previous years of continuing decreases in emissions (i.e., less responsive, multi-year lag in effect).

However, as emphasized throughout this report, changes between individual years should be interpreted with a very high degree of caution given high natural variation and measurement error. Definitive conclusions should therefore not be drawn based on these simple inter-annual comparisons. The observed changes between 2015 and 2016 should be considered preliminary indications of the patterns that may be occurring, but it will not be possible to draw stronger conclusions about these patterns and potential mechanisms until more data are collected and analyzed in the comprehensive EEM review in 2019.

Control Lakes

Monitoring results for the three control lakes (DCAS14A, NC184, NC194; see Appendices 1 and 2) show that there were minimal changes (i.e., $\pm 4\%$) in sulphate concentrations between 2015 and 2016, which provides initial confirmation that these lakes are outside the area of deposition (a critical attribute for their suitability as control lakes). The control lakes have not been extensively analyzed at this point but will be an invaluable component of the comprehensive statistical analyses that will be conducted in 2019. Including reference samples from beyond the predicted SO₂ plume is an important component of the monitoring design for determining whether or not observed effects are related to smelter emissions. The control lakes will increase the power to accurately detect changes in the EEM lakes and will help advance our understanding of natural inter-annual variability in lake chemistry.

Sensitive EEM Lakes

LAK006. SO₄²⁻ increased, and ANC and pH decreased (by <0.05 pH units, well within the ± 0.2 pH units accuracy of laboratory pH measurements), as expected with increased sulphate emissions. The minor increase in DOC could also be contributing to decreased ANC.

➤ CONSISTENT with expectations from evidentiary framework

LAK012. Decrease in SO₄²⁻ (-8.0 µeq/l; -46%), which is highly unexpected if the lake is in fact receiving higher levels of sulphate deposition, and is responsive on annual scale to increased sulphate emissions. ANC decreased by a very small margin while pH increased (by 0.3 pH units, greater than the ± 0.2 pH units accuracy of laboratory pH measurements), which is contrary to

expected relationship between pH and ANC, but consistent with a decrease in sulphate concentrations.

- INCONSISTENT with expectations from evidentiary framework

LAK022. SO₄²⁻ increased, and ANC and pH decreased (by 0.1 pH units, within the ± 0.2 pH units accuracy of laboratory pH measurements), as expected with increased sulphate (albeit only a small increase). Decrease in ANC could be being mitigated by increase in base cations.

- CONSISTENT with expectations from evidentiary framework

LAK023. Decrease in SO₄²⁻ (2.4 µeq/L; -16%), which is not expected if lake is responsive on annual scale to increased sulphate emissions. ANC and pH decreased (by <0.05 pH units, well within the ± 0.2 pH units accuracy of laboratory pH measurements), which is consistent with the expected relationship between pH and ANC; however, the decrease in SO₄²⁻ suggests that the changes in pH and ANC are not being driven by SO₄²⁻. Decrease in ANC could be affected by a decrease in base cations. LAK023 also shows a very small increase in DOC, which should generally contribute to reduced ANC.

- INCONSISTENT with expectations from evidentiary framework

LAK028. Large increase in SO₄²⁻, as expected with increased sulphate emissions and indicating that the lake is responsive on an annual scale to such emissions. Among the acid-sensitive lakes, LAK028 demonstrated the most substantial changes between 2015 and 2016, including an 80% increase in sulphate concentrations (70.9 µeq/L), and a 29% increase in the concentration of base cations (31.8 µeq/L). ANC decreased (by 15.7 µeq/l) and pH decreased (by 0.2 pH units, within the ± 0.2 pH units accuracy of laboratory pH measurements), as expected for sensitive lakes with increased sulphate concentration. The large increase in base cations appears to be mitigating the magnitude of the decrease in ANC. DOC remained unchanged.

- CONSISTENT with expectations from evidentiary framework

LAK042. Decrease in SO₄²⁻ (-13%, but only -0.5 µeq/L), which is not expected if the lake is responsive on annual scale to increased sulphate emissions. However, LAK042 is one of the most distant from the smelter and therefore may have a limited and/or lagged response in sulphate concentrations to increases in emissions, or may in fact not have received increased deposition between 2015 and 2016 due to variations in wind patterns. ANC remained virtually unchanged (+ 0.2 µeq/l) and pH also remained unchanged (accuracy of laboratory pH measurements is ± 0.2 pH units).

Over the entire period from 2012 to 2016, LAK042 has shown an increase of 34.4 µeq/L in Gran ANC (Table 3-8), which was associated with an increase in base cations of 14 µeq/L, and a decrease in DOC of 3.3 mg/L (equivalent to a decrease in organic anions of 25 µeq/L if charge density were 7.5 µeq per mg of DOC); Table 3-9. Sulphate only decreased by 2.9 µeq/L over this period (Table 3-8), so it appears that the increase in GranANC was mostly related to an increase in base cations and a decrease in organic anions.

- INCONSISTENT with expectations from evidentiary framework⁸

LAK044. SO₄²⁻ increased by 0.4 µeq/l, , ANC decreased by 2.1 µeq/l and pH decreased (by 0.2 pH units, within the ± 0.2 pH units accuracy of laboratory pH measurements), as expected with increased sulphate emissions, albeit the increase in SO₄²⁻ was very small. LAK044 is also one of the most distant lakes from the smelter and therefore may have a limited and/or lagged response in

⁸ In absolute terms, the changes in pH, ANC and SO₄²⁻ are very small and therefore do not indicate any change, which is in itself unexpected given increased SO₂ emissions.

sulphate concentrations to increases in emissions. However, given the relatively small increase in sulphate, the 5-fold greater change in ANC is likely not being driven by increased sulphate. The change in ANC could potentially be influenced by the small decrease in base cations and moderate increase in DOC. The changes in SO₄²⁻, ANC and pH are consistent with the evidentiary framework, but the small magnitude of the increase in sulphate does not align with the expectations associated with KMP-driven acidification.

- NOT CONSISTENT with expectations from evidentiary framework

Less Sensitive EEM Lakes

The evidentiary framework is intended to identify patterns of change associated with the potential for an acidification effect driven by the increased sulphate emissions. The less sensitive lakes in the zone of increased sulphate deposition are expected to show an increase in sulphate concentrations, but are not expected to experience any acidification effect (i.e., declines in ANC and pH). Changes in ANC are expected to be relatively small and independent of changes in sulphate concentration and therefore our expectation is that the less sensitive lakes *should* be inconsistent with the evidentiary framework.

LAK007. ANC decreased by 13% (which resulted in the largest absolute decrease in ANC because the ANC of LAK007 is more than an order of magnitude larger than any of the sensitive lakes). The small increase in SO₄²⁻ is consistent in direction with the decrease in ANC, but far too small in magnitude to explain the observed decline (ANC decreased by 197.0 µeq/l and SO₄²⁻ increased by 1.1 µeq/l). Furthermore, the increase in base cations is inconsistent with the observed change in ANC. Although ANC decreased substantially, pH did not change at all (accuracy of laboratory pH measurements is ± 0.2 pH units), which is consistent with the lake being very high on the pH-ANC curve (i.e., changes in ANC are not expected to result in much change in pH). LAK007 has an ANC of about 1400 µeq/l so it is highly insensitive to acidification.

- CONSISTENT with expectations for an insensitive lake

LAK016. SO₄²⁻ increased, and ANC and pH decreased (by 0.2 pH units, within the ± 0.2 pH units accuracy of laboratory pH measurements), as would be expected for a *sensitive* lake under increased sulphate emissions, but would not be expected for a less sensitive lake. Decreased base cations and increased DOC could also be contributing to the decrease in ANC, albeit the change in base cations is relatively insignificant and change in DOC is very small in absolute terms. For a less sensitive lake, pH is not expected to change much in association with changes in ANC. However, LAK016 has an ANC of about 100 µeq/l so it is moderately sensitive to acidification.

- CONSISTENT with expectations for a moderately sensitive lake

LAK024. SO₄²⁻ increased, as expected with increased sulphate emissions. ANC and pH both increased (pH increased by 0.1 pH units, laboratory accuracy is ± 0.2 pH units), which is the opposite of what would occur if the lake were sensitive to acidification. The increase in ANC is proportionally small and could potentially be associated with the corresponding increase in base cations. LAK024 has an ANC of about 500 µeq/l so it is insensitive to acidification.

- CONSISTENT with expectations for an insensitive lake

LAK034. SO₄²⁻ decreased (from very low in 2015 to zero), which is not expected with increased sulphate emissions. However, LAK034 is one of the most distant lakes from the smelter and therefore may have limited/lagged response in sulphate concentrations to increases in emissions. ANC and pH both decreased (by 0.1 pH units, within the ± 0.2 pH units accuracy of laboratory pH measurements), but given lack of sulphate and minimal change from the previous year, the decrease

in ANC could not be driven by sulphate. The decrease in ANC (-15%) could potentially be associated with the corresponding decrease in base cations. LAK024 has an ANC of about 150 µeq/l so it can be considered relatively insensitive to acidification (compared to the seven acid-sensitive lakes).

- CONSISTENT with expectations for a relatively insensitive lake distant from the smelter

4.2.3 Observed Changes in LAK028

The data and analyses from the STAR and EEM program have thus far suggested that LAK028 has the highest potential risk of acidification due to KMP. The data do not show that acidification is presently occurring, but the patterns observed remain consistent with the possibility of acidification occurring in the future. With only one year of post-KMP observations, high natural variability and measurement error, it is not possible to make any conclusions about trends at this point. However, if the observations from this year accurately represent underlying changes in lake chemistry, as opposed to simply reflecting the high degree of variability and uncertainty, then these changes would be consistent with the patterns associated with acidification – that is, a large increase in SO₄²⁻ concurrent with decreases in ANC and pH (although within the limits of the laboratory accuracy), and offsetting increases in base cations. For this reason, we have provided some further exploration of LAK028 in the current annual report.

As part of the STAR, the results of the Steady State Water Chemistry model showed that LAK028 had the highest predicted exceedance of critical loads of acidity for all the STAR lakes, and was one of only 5 lakes with a predicted steady state pH that represents a decrease in pH of greater than 0.3 pH units. Geographically, it is located much closer to the smelter than any of the other sensitive lakes. In fact, the data collected in 2012 suggested that the chemistry of LAK028 had already been influenced by exposure to emissions of the pre-KMP smelter (see section 9.4.1.2.3 of STAR report, ESSA et al. 2013). The anion composition analyses showed that among lakes with pH < 6, LAK028 was the only lake with an anion composition signature that was strongly consistent with a hypothesis of smelter influence. LAK028 had the highest levels of sulphate (51% of total anions) and by far the highest level of fluoride (18% of total anions), providing strong evidence of smelter effects.

We have compared LAK028 to acid-sensitive lakes from the northeast U.S. that had been acidified by sulphate deposition, as analyzed by Sullivan et al. (1988). Figure 4-1 shows that the sulphate and ANC levels for LAK028 are comparable to those acid-sensitive lakes, except that LAK028 has slightly lower ANC than many of those lakes due to organic acids. One indicator of acidification is the ratio of SO₄²⁻ * to total base cations (a ratio > 1 is indicative of acidification), as described in Sullivan et al. (1988). In LAK028, this ratio was < 1 in all years except for 2013 (Table 4-1). The monitoring data collected thus far shows that base cations are increasing as sulphate increases, neutralizing much of the H⁺ associated with the SO₄²⁻ *.

There are two ways of estimating the proportion of deposited acidity that was neutralized between 2015 and 2016. First, one can compute the F-factor ($\Delta \text{Base Cations}_{2015-2016} / \Delta \text{Sulphate}_{2015-2016}$). From Table 4-1, F is estimated at 0.56⁹. From this method, one can infer that 56% of the deposited acidity was neutralized through increases in base cations. This is higher than the F-factor that was assumed for the STAR (0.44), indicating a higher level of acid neutralization by cation exchange, but the two values are still roughly comparable. However, this estimate is only based on the changes between two individual years and is therefore highly sensitive to variability in the sample

⁹ F-factor₂₀₁₅₋₂₀₁₆ = $[\Delta \text{Base Cations}_{2015-2016}] / [\Delta \text{Sulphate}_{2015-2016}] = [31.76 \text{ µeq/l}] / [56.68 \text{ µeq/l}] = 0.56$

measurements used. The second way of estimating the proportion of deposited acidity that was neutralized between 2015 and 2016 is to compare the decrease in Gran ANC (15.72 µeq/l) to the increase in SO₄²⁻ (56.68 µeq/l). If there were no mechanisms of acid neutralization, the decrease in Gran ANC would equal the increase in SO₄²⁻. This comparison implies that 72%¹⁰ of the deposited acidity was neutralized through one neutralizing process or another. One possible explanation for the difference between the two methods described above is that some of the deposited sulphate was neutralized by sulphate reduction, which has been described by Baker et al. (1986) and Kelly et al. (1987), and used in acidification modelling by Marmorek et al. (1990). Further investigations are required as to the potential significance of this mechanism in LAK028.

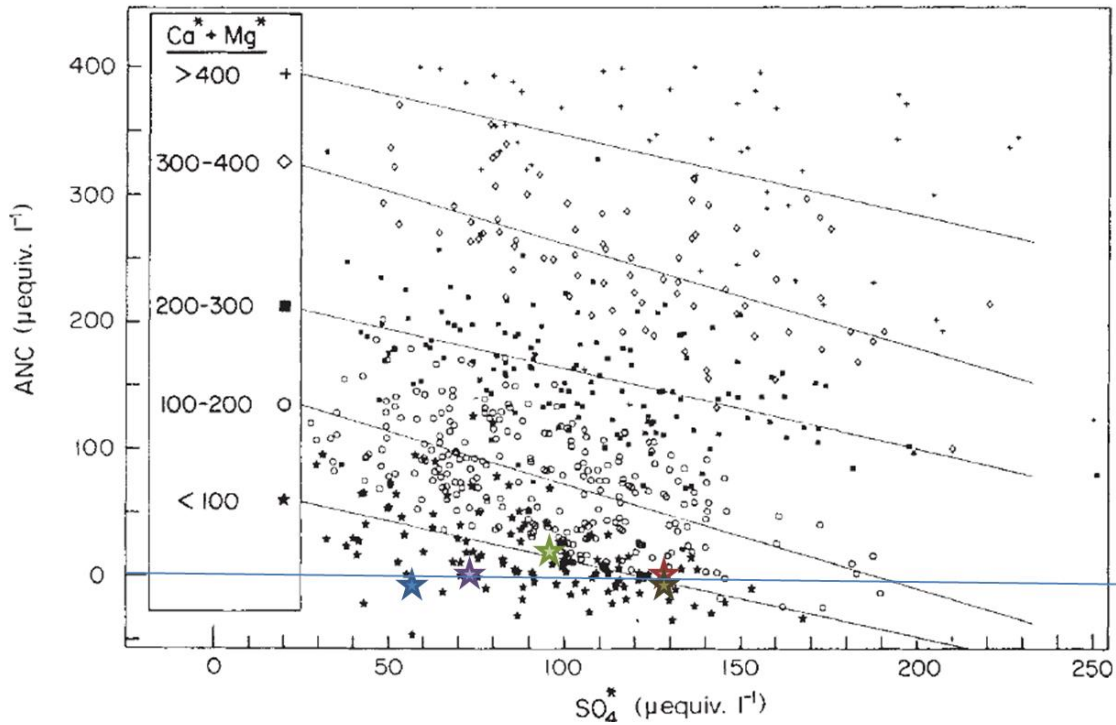


Figure 4-1. ANC and SO₄²⁻ * for LAK028 compared to acid sensitive lakes in the northeast U.S. The underlying figure is from Sullivan et al. (1988), showing the relationship between ANC and SO₄²⁻ * as stratified by the sum of marine-adjusted Ca and Mg cations. The stars represent the data for LAK028 from each of the annual sampling events (blue = 2012, red = 2013, green = 2014, purple = 2015, brown = 2016). The * (e.g., Ca*, Mg*) signifies that concentrations have been adjusted to account for marine influence.

¹⁰ $(\Delta\text{SO}_4^{2-*} - \Delta\text{Gran ANC}) / \Delta\text{SO}_4^{2-*} = (56.68 \mu\text{eq/l} - 15.72 \mu\text{eq/l}) / 56.68 \mu\text{eq/l} = 0.72$

Table 4-1. Sulphate and base cation concentrations for LAK028. Values in 2016 are mean annual values; previous years only had annual samples.

Year	SO ₄ [*] (µeq/L)	Ca [*] (µeq/L)	Mg [*] (µeq/L)	Ca ⁺ +Mg ⁺	∑ BC [*] (µeq/L)	Gran ANC	SO ₄ [*] / ∑ 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

Changes over 2012-2016. LAK028 showed a 70.9 µeq/l increase in the SO₄²⁻ anion over 2012-2016 (Table 3-8), which was almost completely balanced by a 68.7 µeq/l increase in total base cations (Table 3-9). The increase in base cations over 2012-2016 likely reflects more than just cation exchange (possibly greater weathering rates or less dilution of base cations with reduced runoff), since much of the increase occurred between 2012 and 2013 (Table 4-1). Though DOC increased by 3.2 mg/L between 2012 and 2016 (Table 3-9), contributing possibly up to 24 µeq/l in organic anions¹¹, there has been a negligible change over 2012-2016 in both Gran ANC (-0.9 µeq/l, Table 3-8) and pH (0.0 pH units, Table 3-8). Our preliminary conclusion is that the acidity contributed by increases in SO₄²⁻ over 2012-2016 appears to have been balanced by increases in base cations (as well as possibly other mechanisms discussed above, such as sulphate reduction), and increases in DOC do not appear to have resulted in any further acidification. Due to the many sources of variability in lake chemistry data (i.e., between-year variation, within-year natural variation, measurement errors), it is fortunate to observe an approximate match of the changes in sulphate and base cations over 2012-2016 in LAK028. It will be important to reassess this conclusion with more years of data.

5 Recommendations

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

Some of the reviews of this year's report have suggested some additional analyses that should be considered in future years. The primary analysis of interest will be comparisons (in the 2019 report) of observed changes in pH and ANC to the thresholds of interest. The EEM report (ESSA et al. 2014b, pg. 32) recommended that laboratory Gran ANC titrations be used to estimate lake-specific ANC thresholds that correspond to a pH decline of 0.3, thereby taking into account the unique mix of organic anions found in each lake. Recent work by ESSA has demonstrated how past lab reports of Gran ANC titrations can be used to derive ANC thresholds. We recommend that the lab reports from all past lake samples be retrieved from Trent University in 2018, and used to estimate the mean ANC threshold (and its variation) for each EEM lake. Other secondary analyses suggested by the KPAC will also be explored in future years (e.g., analyses of changes in calcium, as per recent literature; further analyses of charge balance to investigate potential explanations for changes in ANC or total base cations; exploration of snowmelt data to help identify the timing potential acidic

¹¹ assuming a charge density of 7.5 µeq/l of organic anion per mg of DOC, consistent with the STAR and Oliver et al (1983)

episodes). In addition, we recommend an exploration of the potential role of sulphate reduction in LAK028, applying simple models from the literature based on estimated runoff, depth, watershed area and lake area.

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Appendix 1: Water Chemistry Data from Annual Sampling, 2012-2016

The three tables below shows the sample results for each of the EEM lakes and control lakes from annual monitoring conducted from 2012 to 2016, 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 2013-2016, the pH of the water samples was measured by two different laboratories (Trent University and ALS).

The first table follows the convention of previous EEM Annual Reports, designating only the first sample (for lakes with multiple within-season samples), taken on the day(s) in which annual sampling was conducted across all EEM lakes, as the “annual sampling” value. The second table provides the mean annual value and standard deviation for each metric for lakes with multiple within-season samples, as calculated from all the within-season samples. Lakes with only a single annual sample will show the same value in both tables and no measure of variability. The third lake presents the sampling data in its “raw” units, as measured, without converting concentration values to charge equivalents. Although acidification studies require converting measured concentrations to charge equivalents, these unconverted values may be more familiar and therefore easier to interpret for some audiences.

Values from the “annual sampling” site visits

Lake	Year	Lab pH (Trent)	Lab pH (ALS)	DOC (mg/L)	Gran ANC (µeq/L)	SO4 (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

Lake	Year	Lab pH (Trent)	Lab pH (ALS)	DOC (mg/L)	Gran ANC (µeq/L)	SO4 (µeq/L)	Cl (µeq/L)	F (µeq/L)	Ca (µeq/L)	Mg (µeq/L)	K (µeq/L)	Na (µeq/L)	Σ BC (µeq/L)
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
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
Lak006	2016	6.0	6.5	4.2	25.8	12.4	5.6	4.3	16.3	3.4	22.4	75.7	78.9
Lak007	2016	8.0	8.1	0.8	1368.6	49.3	25.4	2.6	167.9	20.7	80.0	1571.0	1480.3
LAK012	2016	6.2	6.7	5.1	64.8	9.0	5.4	4.5	22.2	5.1	26.4	118.0	119.1
LAK016	2016	6.6	6.9	5.2	93.9	45.8	8.5	8.2	28.1	9.1	31.0	195.9	196.6
LAK022	2016	6.1	6.4	6.7	34.4	35.0	7.9	5.8	20.7	4.3	29.9	123.3	127.4
LAK023	2016	6.0	6.3	6.1	31.0	12.8	5.1	4.9	15.5	3.9	15.4	79.8	93.4
LAK024	2016	7.5	7.6	2.7	463.1	46.4	70.0	2.3	69.1	10.8	114.0	643.0	634.9
LAK028	2016	5.1	5.2	7.9	0.2	140.7	9.0	29.2	29.5	3.9	28.4	168.0	227.1
LAK034	2016	6.5	7.1	7.6	151.6	0.5	5.4	4.4	35.4	3.9	48.7	218.2	220.5
LAK042	2016	5.4	5.6	9.3	11.7	3.4	6.8	2.2	25.8	2.5	29.4	69.5	83.1
LAK044	2016	5.5	5.9	2.3	2.3	4.6	5.9	2.3	5.2	5.8	5.9	26.4	30.3

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)
NC184	2013	5.7		11.6	16.2	8.1	24.0	0.3	51.4	22.2	4.9	34.4	112.8
NC194	2013	6.6		0.7	28.0	4.4	7.6	0.3	23.5	4.9	5.4	13.9	47.7
DCAS14A	2013	6.5		1.4	50.6	34.4	9.2	0.6	64.2	12.1	10.5	14.0	100.8
NC184	2015	5.5	5.6	9.8	18.4	8.0	21.7	0.5	49.7	20.4	3.3	29.4	102.8
NC194	2015	6.5	6.5	0.8	33.0	3.1	7.3	0.5	27.1	5.8	4.4	14.2	51.5
DCAS14A	2015	6.6	6.7	0.9		36.4	7.3	0.5	77.8	13.8	11.3	16.2	119.2
NC184	2016	5.8	6.2	10.6	27.3	7.7	21.2	0.5	63.4	23.5	3.1	33.7	123.6
NC194	2016	6.4	6.6	1.6	28.7	3.1	7.9	0.5	26.7	5.9	4.0	14.7	51.2
DCAS14A	2016	6.6	6.8	1.5	57.5	37.7	8.5	0.5	77.8	13.5	10.7	17.0	119.0

Mean Annual Values

The mean annual values and standard deviation have been calculated for all lakes with multiple within-season samples. Sample values with no standard deviation indicate that only a single annual sample was taken for that particular lake in that particular year.

Lake	Year	pH		pH		DOC		Gran ANC		SO4		Cl		F		Ca		Mg		K		Na		Σ BC
		TU	SD'	ALS	SD	mg/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	
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
LAK024	2013																							
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	6.1	0.1	6.6	0.6	3.8	1.0	38.8	2.5	12.9	2.2	8.1	0.6	4.8	0.5	32.0	8.7	16.2	0.8	4.9	0.2	21.5	0.7	74.6
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	6.0	0.2	6.7	0.4	6.3	2.2	68.8	15.2	16.9	11.7	10.3	4.9	5.2	0.5	69.7	3.7	23.3	1.7	7.5	1.2	27.1	1.5	127.5
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	5.9	0.1	6.7	0.6	5.7	1.0	32.1	2.5	19.6	2.2	6.1	0.6	6.2	0.5	49.5	8.7	16.1	0.8	4.1	0.2	16.1	0.7	85.9
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
LAK006	2015	6.0	0.1	6.4	0.6	3.9	0.3	32.4	0.7	12.1	0.7	6.6	0.6	4.4	0.2	32.6	0.6	16.1	0.3	4.0	0.1	21.4	0.2	74.1
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	6.0	0.2	6.3	0.3	7.5	2.1	65.9	4.2	18.7	6.4	11.1	3.3	4.7	0.3	75.2	7.9	25.4	2.4	8.3	1.7	27.5	1.5	136.5
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

Lake	Year	pH		pH		DOC		Gran ANC		SO ₄		Cl		F		Ca		Mg		K		Na		Σ BC µeq/L
		TU	SD ¹	ALS	SD	mg/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	µeq/L	SD	
LAK023	2015	5.9	0.1	6.2	0.1	5.4	0.7	30.0	2.0	15.8	1.5	6.2	0.6	5.2	0.3	46.4	3.0	15.1	0.7	3.9	0.2	15.0	0.6	80.4
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
LAK006	2016	6.0	0.1	6.3	0.2	4.2	0.2	26.9	2.0	12.4	0.4	5.6	0.4	4.2	0.2	32.8	1.0	15.9	1.2	4.3	1.2	22.0	1.6	75.0
LAK007	2016	8.0		8.1		0.8		1368.6		49.3		25.4		2.6		1302.5		167.9		20.7		80.0		1571.0
LAK012	2016	6.2	0.0	6.5	0.2	5.1	0.5	65.8	2.3	10.1	1.1	5.6	0.3	4.6	0.2	64.9	1.7	21.9	1.2	6.1	1.2	26.4	1.4	119.3
LAK016	2016	6.6		6.9		5.2		93.9		45.8		8.5		8.2		127.8		28.1		9.1		31.0		195.9
LAK022	2016	6.1	0.0	6.4	0.1	6.7	0.2	34.4	3.8	35.0	0.4	7.9	0.4	5.8	0.2	68.4	1.8	20.7	0.8	4.3	1.1	29.9	1.3	123.3
LAK023	2016	5.9		6.2		5.8		27.9		13.2		4.9		5.1		42.7		15.1		4.8		15.2		77.8
LAK024	2016	7.5		7.6		2.7		463.1		46.4		70.0		2.3		449.1		69.1		10.8		114.0		643.0
LAK028	2016	5.0	0.2	5.1	0.2	8.1	0.6	-4.9	12.5	128.8	16.2	10.0	1.1	26.8	1.7	95.1	16.6	25.7	3.3	3.8	0.4	28.1	2.4	152.7
LAK034	2016	6.5		7.1		7.6		151.6		0.5		5.4		4.4		130.2		35.4		3.9		48.7		218.2
LAK042	2016	5.4	0.0	5.7	0.1	9.8	0.4	14.0	3.1	4.0	0.5	7.2	0.5	2.2	0.2	16.9	3.4	26.1	0.8	2.9	0.4	29.5	0.6	75.4
LAK044	2016	5.5	0.0	6.0	0.3	2.0	0.2	4.1	2.6	4.8	0.2	6.1	0.3	2.3	0.1	8.4	0.7	5.3	0.1	5.6	0.2	5.6	0.2	25.0
NC184	2013	5.7				11.6		16.2		8.1		24.0		0.3		51.4		22.2		4.9		34.4		112.8
NC194	2013	6.6				0.7		28.0		4.4		7.6		0.3		23.5		4.9		5.4		13.9		47.7
DCAS14A	2013	6.5				1.4		50.6		34.4		9.2		0.6		64.2		12.1		10.5		14.0		100.8
NC184	2015	5.5		5.6		9.8		18.4		8.0		21.7		0.5		49.7		20.4		3.3		29.4		102.8
NC194	2015	6.5		6.5		0.8		33.0		3.1		7.3		0.5		27.1		5.8		4.4		14.2		51.5
DCAS14A	2015	6.6		6.7		0.9				36.4		7.3		0.5		77.8		13.8		11.3		16.2		119.2
NC184	2016	5.8		6.2		10.6		27.3		7.7		21.2		0.5		63.4		23.5		3.1		33.7		123.6
NC194	2016	6.4		6.6		1.6		28.7		3.1		7.9		0.5		26.7		5.9		4.0		14.7		51.2
DCAS14A	2016	6.6		6.8		1.5		57.5		37.7		8.5		0.5		77.8		13.5		10.7		17.0		119.0

¹SD = standard deviation

Sampling Data in “Raw” Units

The annual or mean annual values (depending on whether the lake had multiple within-season samples) are presented in their “raw” units, as measured, without converting concentration values to charge equivalents.

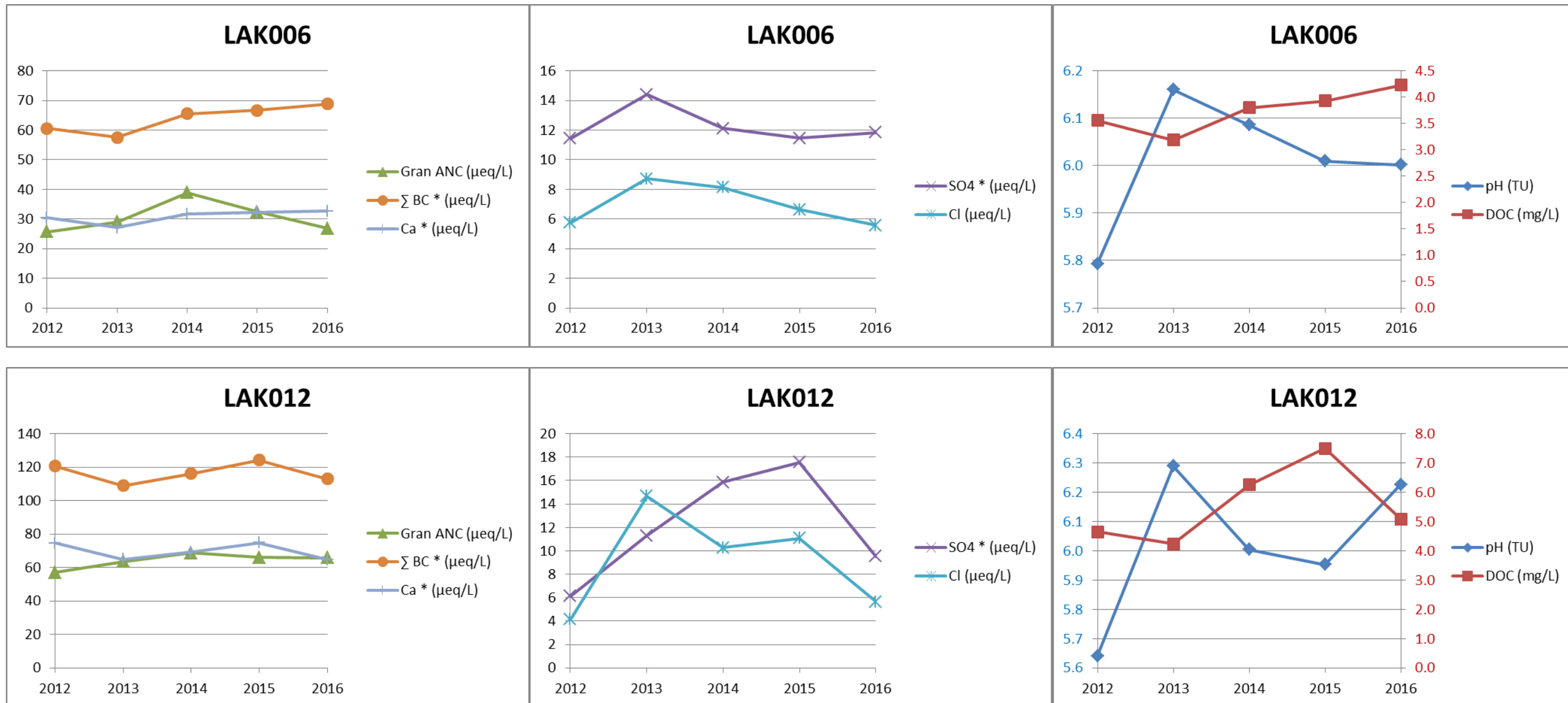
Lake	Year	pH (TU)	pH (ALS)	DOC (mg/L)	Gran Alkalinity (mg/L)	Conductivity (µS/s)	SO4 (mg/L)	Cl (mg/L)	F (mg/L)	NO3 (µg/L)	NH4 (µg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)
Lak006	2012	5.8		3.6	1.3	6.7	0.6	0.2	0.1	0.1	3.0	0.6	0.2	0.1	0.5	0.0	0.1	0.0
Lak007	2012	8.0		0.6	71.9	148.9	2.6	0.9	0.1	4.7	1.8	25.5	2.0	0.8	1.8	0.0	0.0	0.0
LAK012	2012	5.6		4.6	2.9	12.7	0.3	0.1	0.1	0.7	3.4	1.5	0.3	0.2	0.5	0.7	0.1	0.2
LAK016	2012	6.3		3.7	3.4	17.9	1.9	0.2	0.1	0.8	3.9	2.4	0.3	0.3	0.6	0.0	0.1	0.0
LAK022	2012	5.9		5.3	1.4	10.7	1.5	0.2	0.1	0.7	3.7	1.2	0.2	0.1	0.6	0.0	0.1	0.0
LAK023	2012	5.7		4.2	1.0	7.5	0.9	0.2	0.1	0.3	3.3	0.8	0.2	0.1	0.3	0.0	0.1	0.0
LAK024	2012	7.1		1.4	15.0	40.0	1.3	1.0	0.0	0.4	2.4	5.5	0.5	0.2	1.2	0.0	0.0	
LAK028	2012	5.0		4.9	-0.2	12.2	2.8	0.2	0.4	1.5	3.4	1.0	0.1	0.1	0.4	0.1	0.4	0.0
LAK034	2012	6.7		4.5	5.0	22.4	1.2	0.2	0.1	1.6	4.9	2.4	0.4	0.2	1.1	0.0	0.0	0.0
LAK042	2012	4.7		13.2	-1.0	11.9	0.3	0.2	0.1	0.7	8.5	0.2	0.3	0.1	0.6	0.6	0.4	0.0
LAK044	2012	5.4		1.7	0.1	3.1	0.3	0.2	0.1	0.4	3.0	0.1	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2013	6.2	6.1	3.2	1.5	7.0	0.7	0.3	0.1	2.5	2.5	0.5	0.2	0.2	0.5	0.0	0.0	0.0
Lak007	2013	7.9	8.1	0.1	73.2	147.0	3.4	1.3	0.1	2.5	2.5	24.6	2.0	0.9	1.8	0.0	0.0	0.0
LAK012	2013	6.3	6.1	4.2	3.2	12.8	0.6	0.5	0.2	2.5	2.5	1.3	0.3	0.4	0.6	0.4	0.1	0.0
LAK016	2013	6.7	7.2	4.2	4.9	20.3	2.8	0.4	0.2	22.7	7.1	2.3	0.3	0.4	0.6	0.0	0.0	0.0
LAK022	2013	6.2	6.1	6.2	1.8	13.8	2.3	0.4	0.2	2.5	2.5	1.3	0.3	0.2	0.7	0.1	0.1	0.0
LAK023	2013	6.0	6.0	4.0	1.2	9.6	1.2	0.3	0.1	30.1	2.5	0.7	0.2	0.2	0.3	0.0	0.1	0.0
LAK024	2013																	
LAK028	2013	5.2	5.5	7.1	0.2	20.3	6.2	0.6	0.6	20.4	2.5	1.7	0.3	0.2	0.6	0.2	0.6	0.0
LAK034	2013	6.9	7.4	4.7	10.5	28.3	1.9	0.3	0.2	2.5	2.5	3.1	0.5	0.4	1.4	0.0	0.0	0.0
LAK042	2013	5.5	5.4	9.7	1.1	8.0	0.3	0.3	0.1	2.5	2.5	0.3	0.3	0.1	0.6	0.3	0.3	0.0
LAK044	2013	5.7	6.0	1.5	0.4	3.3	0.3	0.3	0.1	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2014	6.1	6.6	3.8	1.9	8.5	0.6	0.3	0.1	7.7	40.5	0.6	0.2	0.2	0.5	0.0	0.1	0.0
Lak007	2014	8.1	8.0	0.7	72.4	154.2	1.6	0.7	0.0	2.5	2.5	25.6	2.0	0.8	1.8	0.0	0.0	0.0
LAK012	2014	6.0	6.7	6.3	3.4	13.9	0.8	0.4	0.1	7.6	5.3	1.4	0.3	0.3	0.6	0.3	0.1	0.0
LAK016	2014	6.7	6.7	4.0	5.3	21.5	2.4	0.3	0.2	2.5	6.7	2.5	0.3	0.4	0.7	0.0	0.1	0.0
LAK022	2014	6.3	6.4	5.7	2.3	14.4	1.9	0.3	0.1	2.5	2.5	1.4	0.3	0.2	0.7	0.1	0.1	0.0
LAK023	2014	5.9	6.7	5.7	1.6	9.3	0.9	0.2	0.1	10.9	5.3	1.0	0.2	0.2	0.4	0.0	0.1	0.0
LAK024	2014	7.6	7.5	1.7	23.6	63.1	2.1	2.3	0.0	5.1	2.5	8.1	0.8	0.4	2.5	0.0	0.0	0.0
LAK028	2014	5.3	5.7	5.9	1.1	20.2	4.6	0.4	0.4	2.5	2.5	1.7	0.2	0.2	0.6	0.1	0.5	0.0
LAK034	2014	6.7	7.0	7.0	10.3	27.5	0.9	0.2	0.1	2.5	2.5	3.2	0.5	0.4	1.3	0.1	0.0	0.0
LAK042	2014	5.1	5.4	10.6	0.6	10.8	0.3	0.4	0.1	2.5	2.5	0.2	0.3	0.2	0.6	0.4	0.3	0.0
LAK044	2014	5.8	5.6	1.8	0.3	3.6	0.3	0.2	0.1	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2015	6.0	6.4	3.9	1.6	5.6	0.6	0.2	0.1	3.4	5.4	0.7	0.2	0.2	0.5	0.1	0.1	0.0
Lak007	2015	8.0	7.9	0.3	78.4	151.2	2.3	0.9	0.0	5.6	2.5	25.4	2.0	0.8	1.8	0.0	0.0	0.0
LAK012	2015	6.0	6.3	7.5	3.3	10.1	0.9	0.4	0.1	8.3	8.0	1.5	0.3	0.3	0.6	0.3	0.1	0.0
LAK016	2015	6.8	6.9	4.3	5.7	20.7	2.0	0.3	0.2	7.9	2.5	2.6	0.3	0.4	0.7	0.0	0.1	0.0
LAK022	2015	6.1	6.2	6.3	1.8	12.8	1.6	0.3	0.1	2.5	2.5	1.3	0.2	0.2	0.6	0.1	0.1	0.0

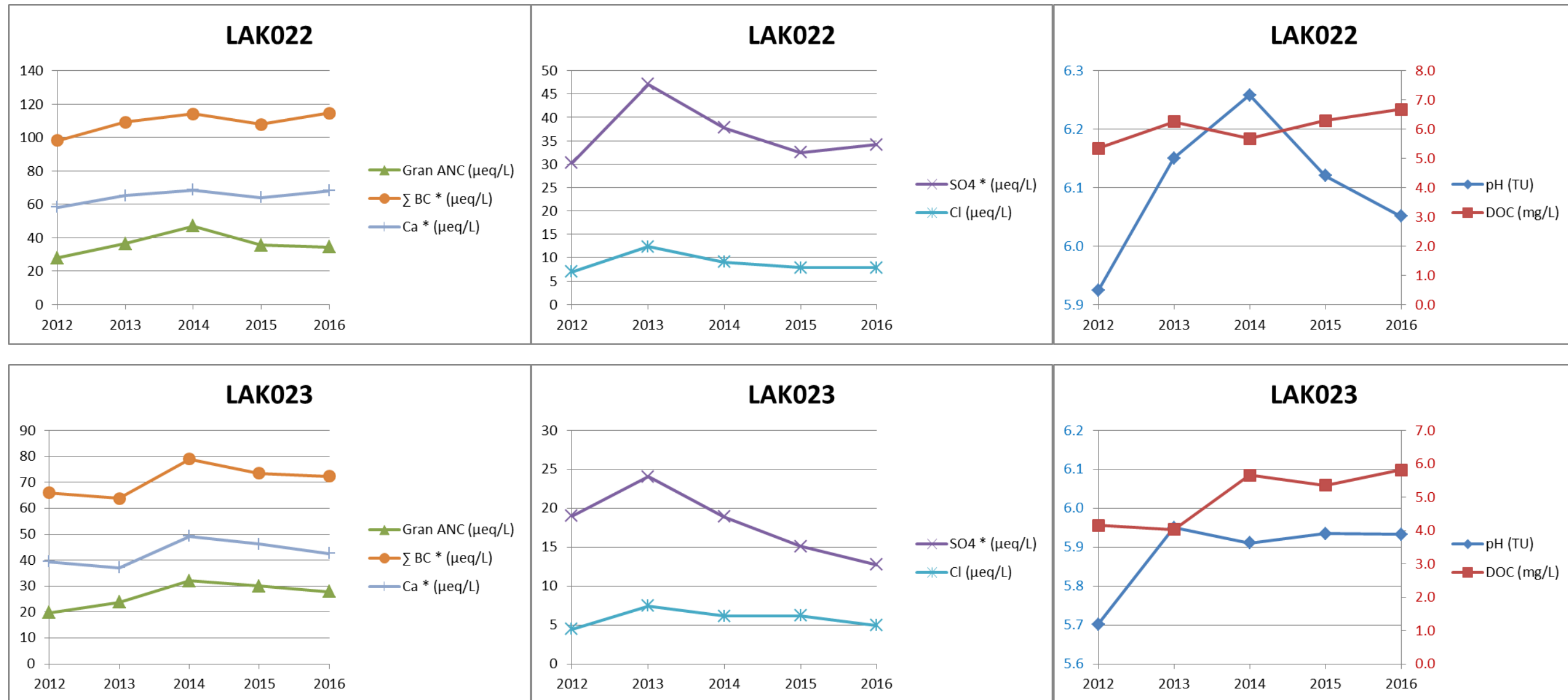
Lake	Year	pH (TU)	pH (ALS)	DOC (mg/L)	Gran Alkalinity (mg/L)	Conductivity (µS/s)	SO4 (mg/L)	Cl (mg/L)	F (mg/L)	NO3 (µg/L)	NH4 (µg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)
LAK023	2015	5.9	6.2	5.4	1.5	5.9	0.8	0.2	0.1	6.3	2.5	0.9	0.2	0.2	0.3	0.0	0.1	0.0
LAK024	2015	7.4	7.5	2.2	22.2	58.7	2.0	2.1	0.0	8.1	2.5	8.1	0.7	0.4	2.3	0.1	0.0	0.0
LAK028	2015	5.1	5.3	8.1	0.5	17.8	3.5	0.3	0.4	2.5	2.5	1.5	0.2	0.1	0.5	0.2	0.6	0.0
LAK034	2015	6.6	6.7	7.6	8.9	22.3	0.1	0.2	0.1	2.5	2.5	2.9	0.5	0.2	1.2	0.1	0.0	0.0
LAK042	2015	5.4	5.5	8.3	0.7	8.1	0.2	0.2	0.0	2.5	2.5	0.2	0.3	0.1	0.7	0.2	0.3	0.0
LAK044	2015	5.8	5.8	1.6	0.3	3.5	0.2	0.2	0.1	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2016	6.0	6.3	4.2	1.3	7.8	0.6	0.2	0.1	2.5	2.5	0.7	0.2	0.2	0.5	0.0	0.1	0.0
Lak007	2016	8.0	8.1	0.8	68.5	153.7	2.4	0.9	0.1	6.5	2.5	26.1	2.0	0.8	1.8	0.0	0.0	0.0
LAK012	2016	6.2	6.5	5.1	3.3	12.4	0.5	0.2	0.1	5.0	4.7	1.3	0.3	0.2	0.6	0.3	0.1	0.0
LAK016	2016	6.6	6.9	5.2	4.7	20.8	2.2	0.3	0.2	10.9	2.5	2.6	0.3	0.4	0.7	0.0	0.1	0.0
LAK022	2016	6.1	6.4	6.7	1.7	13.7	1.7	0.3	0.1	2.5	2.5	1.4	0.3	0.2	0.7	0.1	0.1	0.0
LAK023	2016	5.9	6.2	5.8	1.4	9.1	0.6	0.2	0.1	2.5	5.1	0.9	0.2	0.2	0.4	0.0	0.1	0.0
LAK024	2016	7.5	7.6	2.7	23.2	66.3	2.2	2.5	0.0	20.7	2.5	9.0	0.8	0.4	2.6	0.1	0.0	0.0
LAK028	2016	5.0	5.1	8.1	-0.2	23.7	6.2	0.4	0.5	21.5	2.5	1.9	0.3	0.2	0.6	0.1	0.7	0.0
LAK034	2016	6.5	7.1	7.6	7.6	22.1	0.0	0.2	0.1	2.5	2.5	2.6	0.4	0.2	1.1	0.1	0.0	0.0
LAK042	2016	5.4	5.7	9.8	0.7	8.8	0.2	0.3	0.0	2.5	3.7	0.3	0.3	0.1	0.7	0.2	0.3	0.0
LAK044	2016	5.5	6.0	2.0	0.2	3.9	0.2	0.2	0.0	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
NC184	2013	5.7		11.6	0.8	10.0	0.4	0.9	0.0	0.0	0.0	1.0	0.3	0.2	0.8			
NC194	2013	6.6		0.7	1.4	3.9	0.2	0.3	0.0	0.0	0.0	0.5	0.1	0.2	0.3			
DCAS14A	2013	6.5		1.4	2.5	10.6	1.7	0.3	0.0	52.6	2.5	1.3	0.1	0.4	0.3	0.0	0.0	0.0
NC184	2015	5.5	5.6	9.8	0.9	11.6	0.4	0.8	0.0	2.5	2.5	1.0	0.2	0.1	0.7	0.2	0.3	0.0
NC194	2015	6.5	6.5	0.8	1.7	5.4	0.1	0.3	0.0	2.5	2.5	0.5	0.1	0.2	0.3	0.0	0.0	0.0
DCAS14A	2015	6.6	6.7	0.9	48.6	14.0	1.8	0.3	0.0	6.8	2.5	1.6	0.2	0.4	0.4	0.0	0.0	0.0
NC184	2016	5.8	6.2	10.6	1.4	12.8	0.4	0.8	0.0	2.5	2.5	1.3	0.3	0.1	0.8	0.1	0.3	0.0
NC194	2016	6.4	6.6	1.6	1.4	5.9	0.1	0.3	0.0	2.5	2.5	0.5	0.1	0.2	0.3	0.0	0.0	0.0
DCAS14A	2016	6.6	6.8	1.5	2.9	14.8	1.8	0.3	0.0	2.5	2.5	1.6	0.2	0.4	0.4	0.0	0.0	0.0

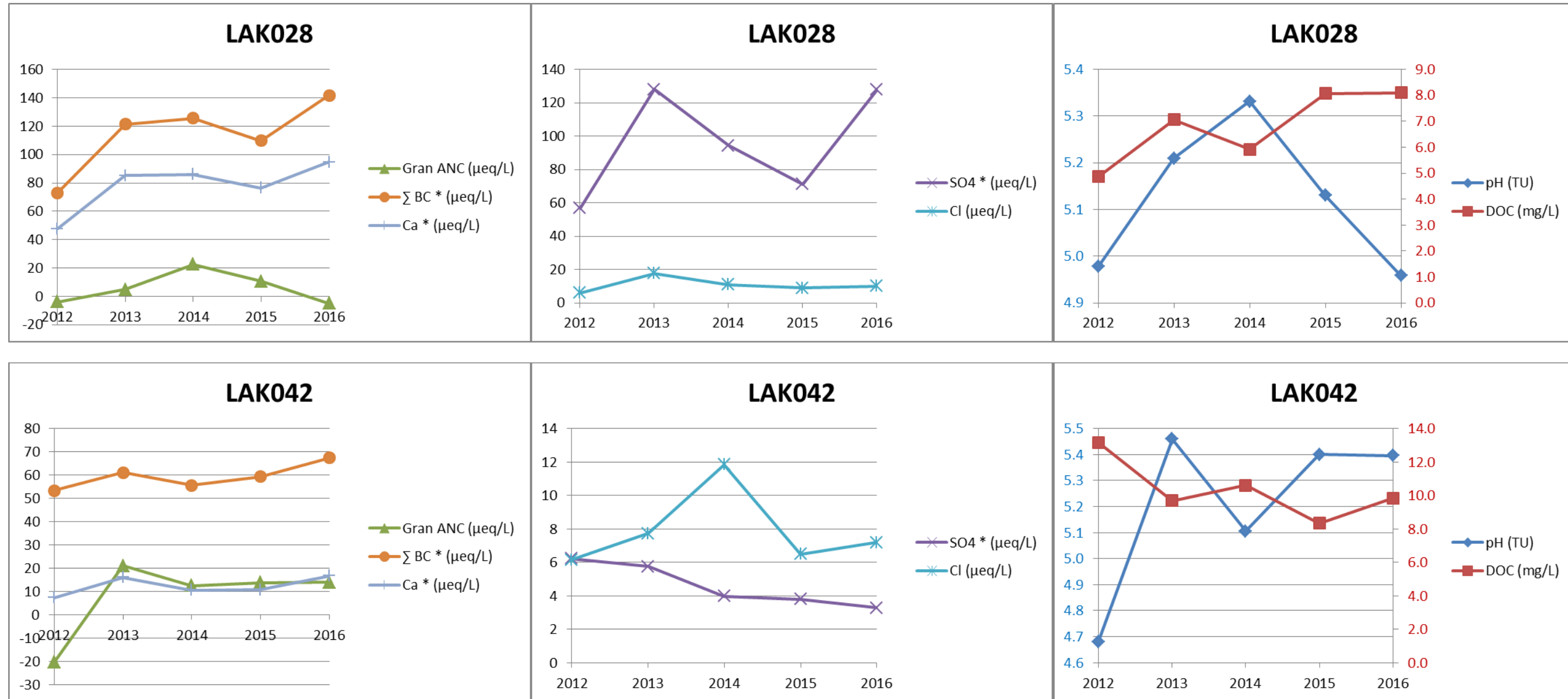
Appendix 2: Changes in Ion Concentrations from 2012 to 2016

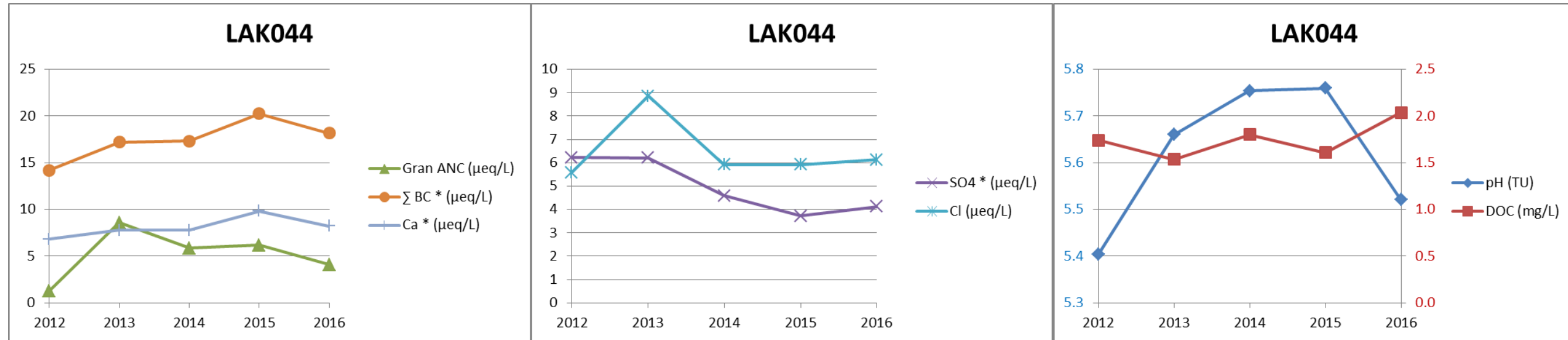
For each of the EEM lakes, the figures in this appendix show the inter-annual changes in six major water chemistry metrics from 2012 to 2016: Gran ANC, base cations and calcium (left panel), sulfate and chloride (centre panel), and pH and dissolved organic carbon (right panel). The selection of each 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

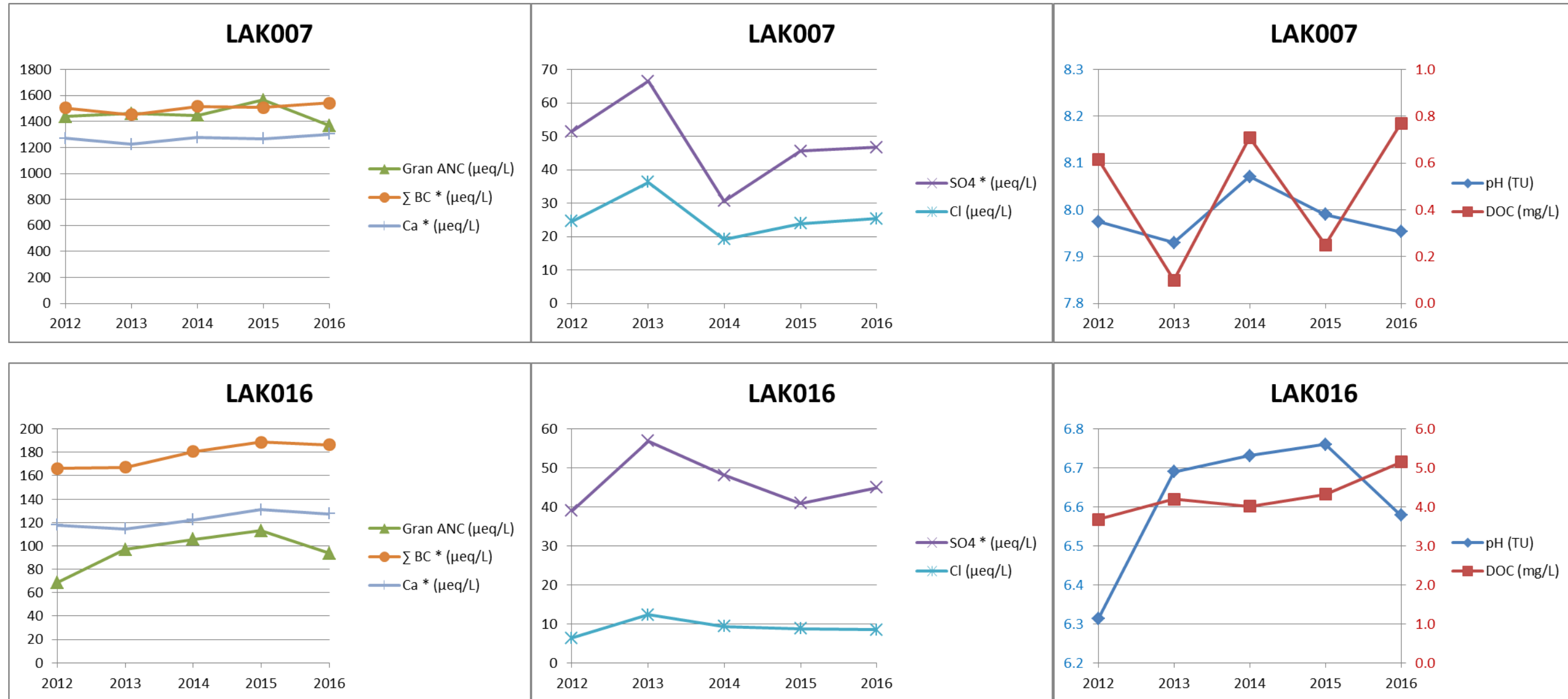


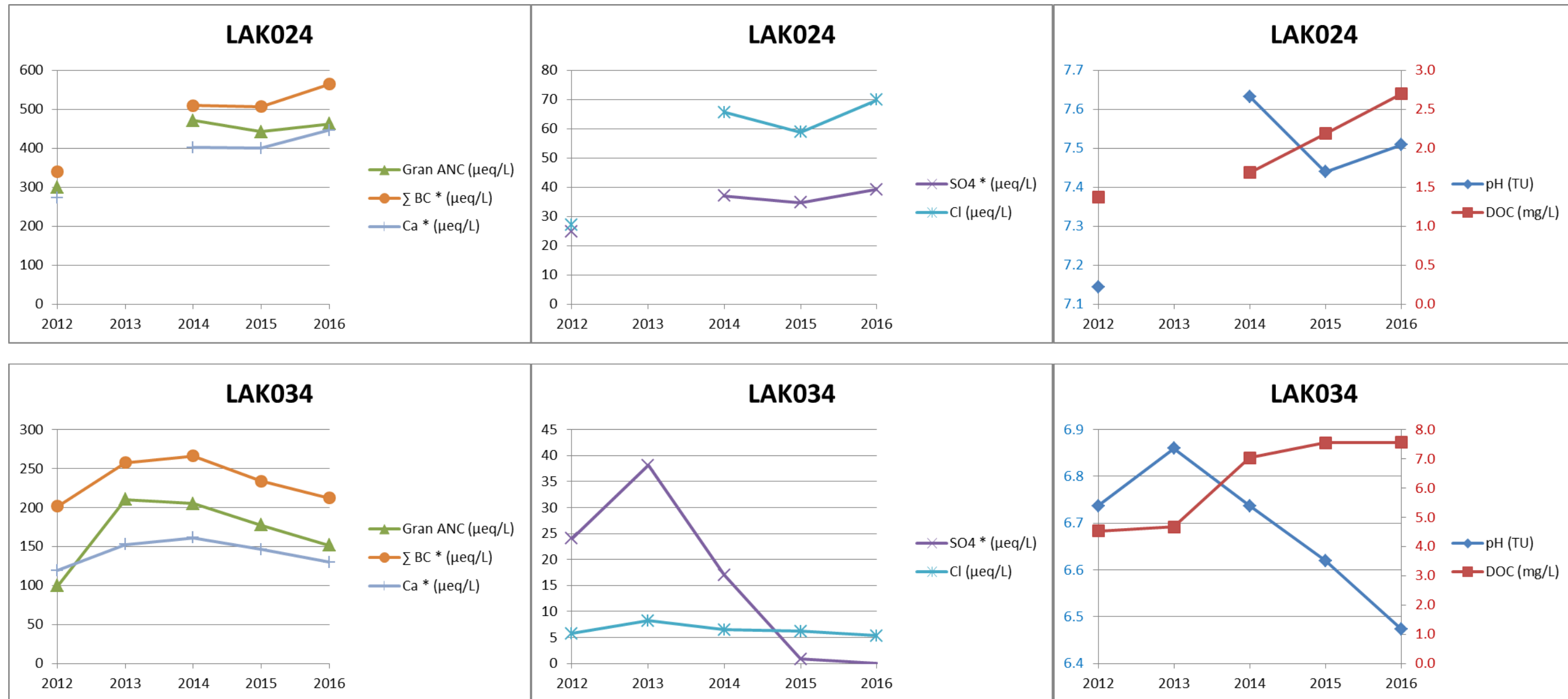






Less Sensitive Lakes





Control Lakes

