



KMP SO₂ EEM Program – Technical Memo W07

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 2017 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 2017 Annual Report (ESSA et al. 2018).

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	2017
Steady state water modelling	<i>No work planned for 2017 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] ²⁻ ; F-factor	<i>No work planned for 2017 on this task</i>
Fish presence / absence sampling	③ Resample if lake pH change reaches threshold.
Episodic acidification	④ <i>No work planned for 2017 on this task</i>
Amphibians	⑤ Conduct a literature review of potential effects of acidification on amphibians in the Kitimat Valley ¹ .

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; Bennett and Perrin 2018). 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 2017, 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

¹ Revised commitment developed based on recommendations from KPAC and discussions with Rio Tinto.

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 2018). Table 2-1 summarizes all of the EEM sites sampled during 2012-2017. Figure 2-1 shows a map of the lakes sampled in 2017.

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

Sample Site	Year of Sampling						Rationale for sampling
	2012 STAR	2013 EEM	2014 EEM	2015 EEM	2016 EEM	2017 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		✓ ²		✓	✓	✓	Control lakes added to EEM in 2015
NC194		✓ ¹		✓	✓	✓	
DCAS14A		✓ ¹		✓	✓	✓	

² Sampled as part of the Kitimat Airshed Assessment (ESSA et al. 2014a).

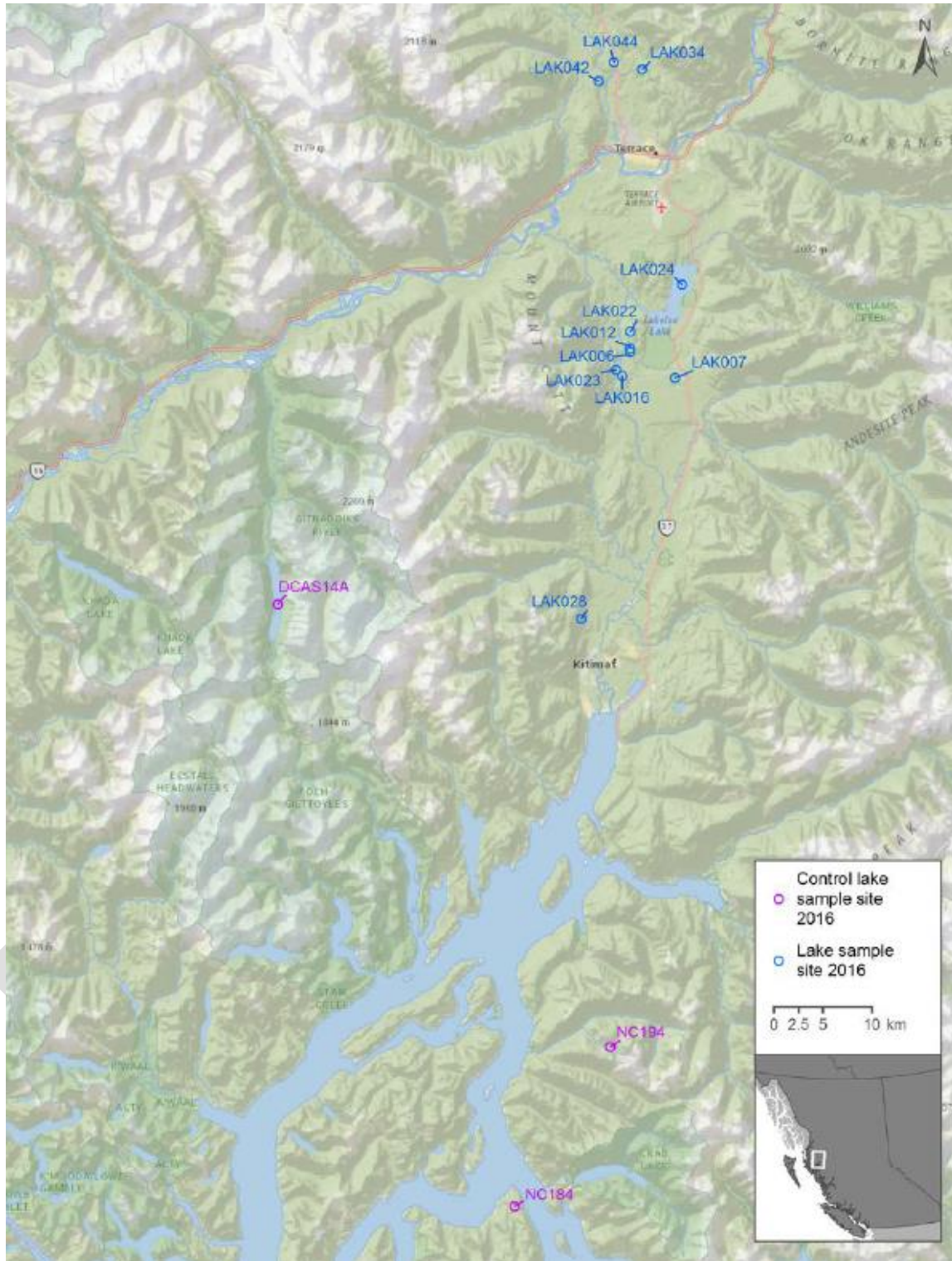


Figure 2-1. Location of the lakes that were sampled in 2017. The three control lakes are labelled with purple text (Source: Bennett and Perrin 2018).

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 access by helicopter or hiking. 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. This recommendation was based on the findings of the power analyses (reported in the 2015 EEM Annual Report), which 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⁻). Finally, lake level monitoring was added in 2016 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). The lake level monitoring was continued in 2017.

This work was planned, implemented and documented by Limnotek. The methods and results for 2017 are reported in Bennett and Perrin (2018).

For the lakes with more than multiple samples during the fall season, the data from the multiple within-season samples have been used to determine mean annual values. In the 2013/2014 and 2015 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 with last 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 (2018).

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 2017 have multiple measures of pH, including a field measurement and two lab measurements (Trent University and ALS). As described above in Section 2.2, three lakes also have additional measurements of pH from continuous meters. In addition, samples taken during the bi-weekly visits to calibrate the continuous pH meters were sent to the two labs to measure pH and ANC. 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 2018) 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, Bennett and Perrin 2017).

2.4 Inter-annual Changes

Observed Changes

The EEM Program now has six consecutive years of monitoring data with which to examine inter-annual changes in water chemistry parameters. The monitoring data from 2017 represent the second 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 up 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 2012-2017³. Year to year changes should be interpreted cautiously. The power analyses conducted and reported in the 2015 EEM Annual Report demonstrated that

³ 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.

the power to detect annual changes in pH, Gran ANC and SO₄ is very low due to high within-year and between-year variability, as well as measurement error. Of these three metrics, Gran ANC provided the most reliable indication of long term changes in acid-base chemistry (i.e., highest statistical power to detect changes of biological significance), but required ≥ 3 years of annual measurements to obtain acceptable statistical power in five of the sensitive lakes. Two of the seven sensitive lakes (LAK028 and LAK042) showed low statistical power to detect biologically significant changes in Gran ANC even after 10 years of annual measurements, due to high natural variability.

Expected Changes and Application of the Evidentiary Framework

The EEM Evidentiary Framework (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

Fish sampling was conducted in LAK028 in 2017 to determine if fish were present or absent. Details of the fish sampling methodology are described in Limnotek's technical report (Bennett and Perrin 2018).

Limnotek also 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.

2.7 Amphibian Monitoring ⑤

In 2017, Rio Tinto commissioned a literature review of acidification impacts on amphibians and potential pathways of effects in support of the EEM (ESSA Technologies Ltd. 2017). This work was predominantly completed in 2017 and is currently in the final stages of review.

2.8 Water Column Chemistry of LAK028

During the last two sampling visits to LAK028 (October 18 and 26) additional samples were taken at depths of 11 m and 16 m. On October 26, a profile of the water chemistry was conducted at a deep location near the centre of the lake to gain a more comprehensive understanding of the lake chemistry of LAK028. Samples were taken every 1 m for temperature, pH, conductivity, total dissolved solids concentration, turbidity, dissolved oxygen concentration.

2.9 Kitimat River Water Quality

Rio Tinto conducts water quality monitoring at their intake on the Kitimat River.

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 2018). 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 the annual sampling event. Table 3-1 shows four diagnostic metrics of the charge balance for the annual sample sets from 2012 to 2017. The charge balance for the 2017 data is better than almost all previous years.

The charge balance for the lakes in the EEM Program (sensitive and less sensitive), as sampled during the annual sampling event in 2017, 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 to 17 (EEM lakes, control lakes⁴). 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 ⁴	-2.9	3.1	-16.6	17.3
2016	14	-1.7	2.3	1.7	12.6
2017	14	0.5	3.3	-2.1	7.9

† These data represent the “annual samples” from each lake.

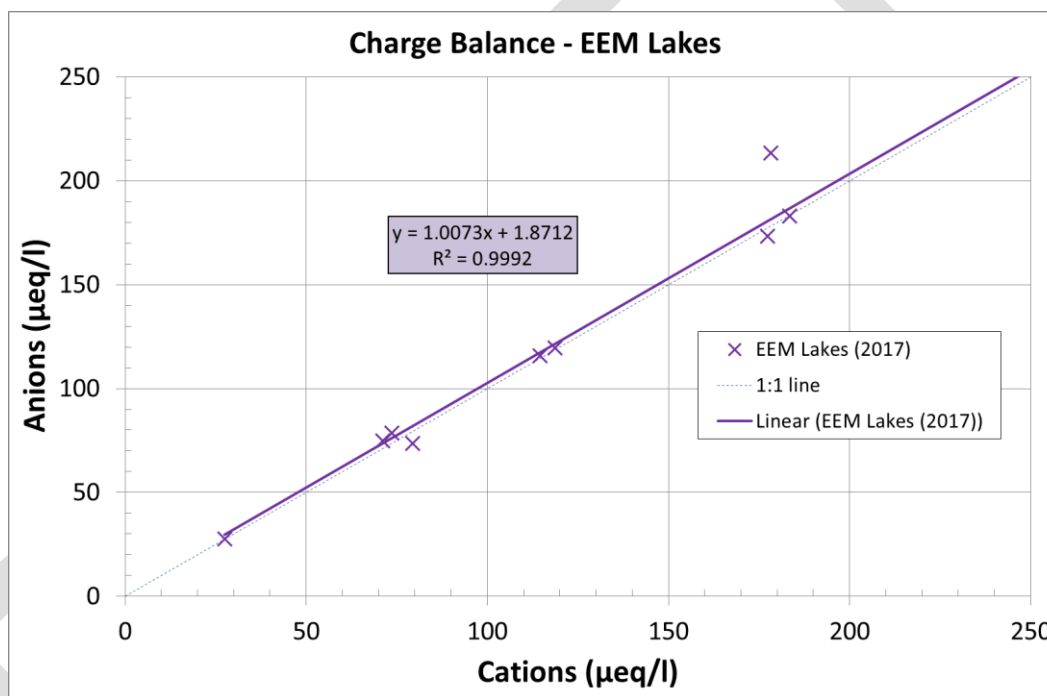


Figure 3-1. Analysis of charge balance for the EEM lakes in 2017. The Y-axis is the sum of all major anions (negatively charged ions); the X-axis the sum of all major cations (positively charged ions).

For each of the lakes with multiple within-season samples, Table 3-2 shows the measures of the charge balance check. In 2017, the average charge balance discrepancy was greater for this data set than for the single annual samples across all of the lakes, but still less than most previous years.

⁴ For 2015, only NC184 and NC194 are included. DCAS14A has been excluded from this summary because of issues with its measured value for total alkalinity.

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 and 2017, 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
2017	6	24	-1.3	3.5	-5.4	9.0

Measured versus Estimated Conductivity

Measured and estimated conductivity were compared for each year of sampling, based on the data from the annual sampling event. Table 3-3 shows two diagnostic metrics of the conductivity check for the annual sample sets from 2012 to 2017. The data for 2017 demonstrate an acceptable relationship between measured and estimated conductivity.

The conductivity check for the lakes in the EEM Program (sensitive and less sensitive), as sampled in 2017, 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 to 2017 (EEM lakes, control lakes⁵). 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 ⁵	-3.0	6.1
2016	14	-7.5	9.1
2017	14	-4.1	7.2

⁵ As per Table 3-1, only NC184 and NC194 are included. DCAS14A is excluded due to data concerns that are being currently explored.

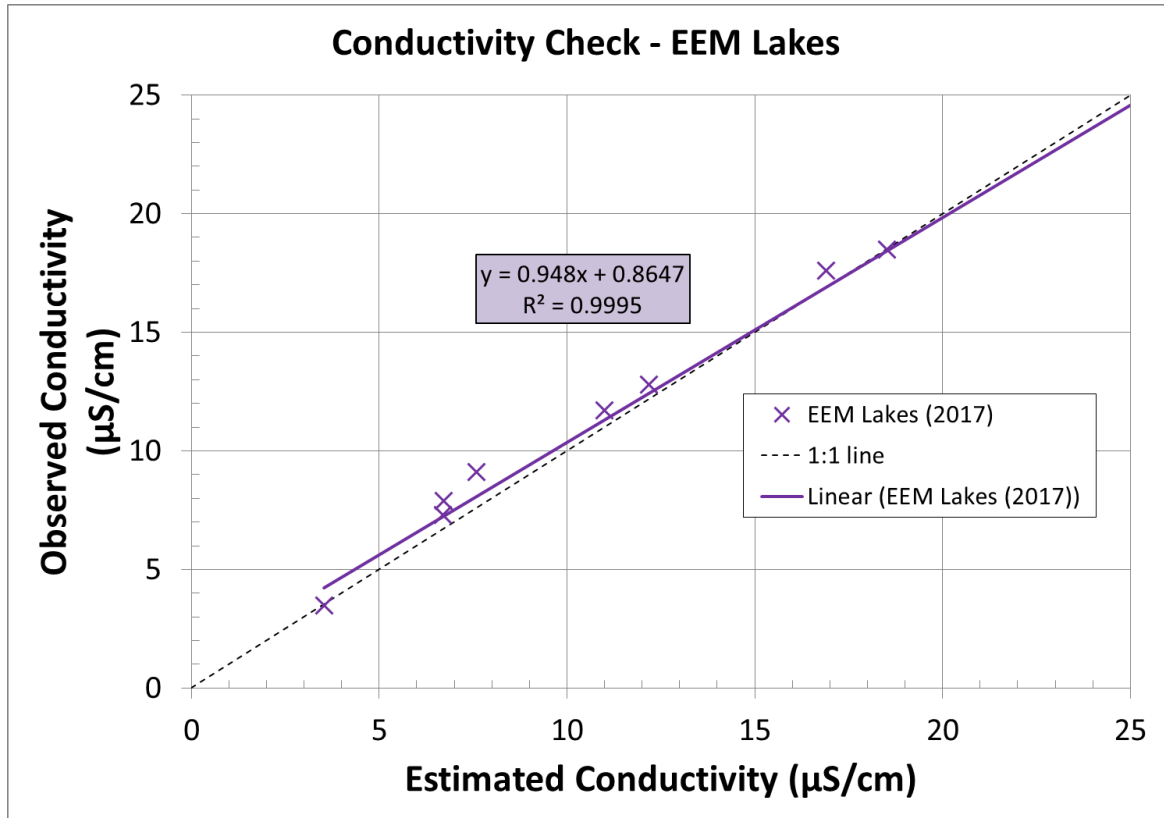


Figure 3-2. Conductivity check for the EEM lakes in 2017. Estimated conductivity is based on laboratory measurements of the concentrations of all ions and literature values for the conductivity of each ion, which is compared to the conductivity observed in field measurements.

For each of the lakes with multiple within-season samples, Table 3-4 shows the measures of the charge balance check. In 2017, the average conductivity difference 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. 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 and 2017, these lakes 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 ⁶	46.3
2016	6	24	-6.5	11.9
2017	6	24	-8.9	11.9

pH measurements

Lab measurements of pH were made at two different labs in 2013 to 2017. Limnotek examined the differences in pH measurements for 2017 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 2017, the values measured by ALS were higher than those measured by Trent University in all but one of the samples and the mean difference between the labs was similar to the previous 3 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 2017 (with the data from 2012-2016 included for reference), for major water chemistry metrics (pH, DOC, Gran ANC, base cations, and major anions).

3.3 Intensive Monitoring of Three Lakes ②

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 2018). The Limnotek results for pH monitoring are summarized below in Table 3-5 and

⁶ 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.

Table 3-7. Depending on the lake and pH sensor, pH varied by about 0.9 to 1.4 pH units over the period of continuous monitoring from April to November 2017. For sensor pH3 in End Lake, the range was 1.9 pH units but this reflects some extremely high readings that are suspected to be instrument errors. The mean pH values from all the sensors in End Lake and West Lake were the same in 2017 as they were in 2016, and therefore remained above pH 6.0, the level used as a biological threshold for analyses of critical loads (see STAR and KAA reports). The mean pH values for each of the sensors in Little End lake declined by 0.2 pH units, dropping below pH 6.0. Table 3-6 shows the results for mean pH for these three lakes for 2014 to 2017, which indicate that these lakes have decreased in pH but only by an average of 0.1 pH units across lakes and sensors.

The results from these lakes further confirm the results from previous 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 years. 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).

As described in the power analysis completed in 2015, 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 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*.

The Limnotek technical report (Bennet and Perrin 2018) describes notable patterns observed in the continuous pH data:

In Little End Lake, there was an upwards shift in pH of 0.5 pH units that occurred between Aug 12 and Aug 14 (Figure 9 [in Limnotek report]). The timing of this shift did not correspond with field maintenance visits which occurred on Aug 8 and Aug 21. The shift did correspond to a change in weather pattern from 12 hot, dry days (maximum air temperatures ranging from 27.9 to 33.7 degrees Celsius and no precipitation (Environment Canada “Terrace A” weather station, http://climate.weather.gc.ca/climate_data/daily_data_e.html?StationID=51037) to cooler air temperatures (<20°C) and several mm of rainfall (4mm on Aug 12 and 13). Daily average water temperature at 2 m below the surface peaked at 20.5°C on August 13 (Manta data). There were upward shifts in pH in End Lake and West Lake around the same time, but not of the same magnitude as in Little End Lake. An hypothesis is the change in pH in Little End Lake was due to an episodic increase in photosynthetic rate that would shift pH upwards but cause of a change in photosynthetic rate is unknown.

Bennet and Perrin (2018, p.29)

Similar to the pattern observed in 2016, a sharp drop in pH was observed among the Manta sensors in Little End Lake and West Lake in late October (Figure 9, Figure 10). This change started on the 20th of October, after five days of rain that began on the 15th of October (115mm of rainfall at the Terrace Airport). Another large storm event followed (154mm of rainfall) on the 21st to 24th of October and the pH in the lakes continued to decline. In End Lake, the decline in pH following the storm was not as abrupt, indicating hydrologic and biogeochemical differences between the End Lakes (Figure 8).

Bennet and Perrin (2018, p.29)

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 2017. Source: Table 10 in Bennett and Perrin (2018)

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

* Extreme values on sensor pH3 in End Lake were possibly due to instrument error (Bennett and Perrin 2018).

Table 3-6. Mean pH results from the continuous monitors in End, Little End and West lakes for 2014, 2015, 2016 and 2017. Measurements in 2014 were for a shorter period of time (late August to late November) than in other years (April to November), and had roughly half as many observations.

Lake	Sensor	2014 Mean pH ± SD	2015 Mean pH ± SD	2016 Mean pH ± SD	2017 Mean pH ± SD	Change in mean pH from 2014 to 2017
End	pH1	6.3 ± 0.2	6.3 ± 0.2	6.3 ± 0.1	6.3 ± 0.1	0.0
End	pH2	6.3 ± 0.2	6.3 ± 0.2	6.2 ± 0.1	6.2 ± 0.1	-0.1
End	pH3	6.4 ± 0.2	6.4 ± 0.2	6.3 ± 0.1	6.3 ± 0.2	-0.1
Little End	pH1	6.1 ± 0.2	6.0 ± 0.2	6.1 ± 0.2	5.9 ± 0.2	-0.2
Little End	pH2	6.0 ± 0.2	5.9 ± 0.2	6.0 ± 0.2	5.8 ± 0.2	-0.2
Little End	pH3	6.1 ± 0.2	6.0 ± 0.2	6.1 ± 0.2	5.9 ± 0.2	-0.2
West	pH1	6.4 ± 0.2	6.4 ± 0.2	6.3 ± 0.2	6.3 ± 0.2	-0.1
West	pH2	6.2 ± 0.2	6.3 ± 0.1	6.2 ± 0.2	6.2 ± 0.2	-0.0
West	pH3	6.4 ± 0.1	6.3 ± 0.1	6.2 ± 0.2	6.2 ± 0.2	-0.2

Table 3-7. Variation in mean pH (\pm standard deviation) between instruments, by lake, during sampling in May to October 2017. Source: Table 11 in Bennett and Perrin (2018).

Instrument or lab	Mean pH \pm sd in May to October, 2017 (n=15)		
	End Lake	Little End Lake	West Lake
WTW field pH meter	6.0 \pm 0.2	5.9 \pm 0.3	6.1 \pm 0.2
Trent University	6.0 \pm 0.1	6.0 \pm 0.2	5.8 \pm 0.1
ALS	6.3 \pm 0.2	6.4 \pm 0.2	6.2 \pm 0.1
Manta sensors	6.3 \pm 0.1	5.9 \pm 0.3	6.3 \pm 0.3
Instrument/lab effect (<i>P</i>)	<0.001	<0.001	<0.001

Analyses of data for 2015, 2016 and 2017 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 3-8). Across all lakes and years, the mean August pH was 0.02 pH units higher than the mean October pH, but there does not appear to be any consistent pattern. The results in Table 3-8 provide an 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) with sampling data collected in October of subsequent years. The results from 2017 confirm the preliminary finding in the 2016 EEM Annual Report (based only on 2015 and 2016 data). However, this analysis is still only based on three years and should be repeated in subsequent years for further confirmation of this finding.

Table 3-8. 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
2017	Aug	COUNT	4455	4314	4458
		MEAN pH	6.1	6.3	5.9
		SD	0.1	0.1	0.3
	Oct	COUNT	3945	3948	3942
		MEAN pH	6.1	6.3	6.0
		SD	0.2	0.1	0.1
DIFF (Aug-Oct pH)			0.0	-0.1	-0.1
AVG. DIFF (Aug-Oct pH)			0.02		

3.4 Inter-annual Changes

Inter-annual changes in pH, Gran ANC, SO₄²⁻, DOC, sum of base cations, chloride, and calcium are shown in terms of absolute change in Table 3-9, Table 3-10, and Table 3-11 and in terms of relative change in Table 3-12, Table 3-13, and Table 3-14. Changes are shown for six time periods of comparison: 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, and 2012-2017. 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.

⁷ This represents a change in practice from the 2013/2014 and 2015 Annual Reports, 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.

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 2016 and 2017. Although the tables show changes for other periods as well, these figures have only been included for the changes from 2016 to 2017. Changes from 2016 to 2017 in 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, calcium, SO₄²⁻, chloride, pH and DOC) for each of the EEM lakes across the six years of annual monitoring (2012-2017). Similar figures are also included for the three control lakes based on their four years of annual monitoring (2013 and 2015-2017).

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 3-9. Inter-annual changes in pH, Gran ANC and SO₄²⁻ for EEM lakes, 2012-2017. 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	2017	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017
To	2013	2014	2015	2016	2017	2017	2013	2014	2015	2016	2017	2017	2013	2014	2015	2016	2017	2017
LAK006	0.4	-0.1	-0.1	0.0	0.0	0.2	3.3	9.9	-6.5	-5.5	1.1	2.3	3.0	-2.3	-0.7	0.4	2.5	2.9
LAK012	0.6	-0.3	-0.1	0.3	-0.1	0.4	6.5	5.2	-2.9	-0.1	-7.6	1.2	5.2	4.5	1.7	-8.0	5.0	8.4
LAK022	0.2	0.1	-0.1	-0.1	0.0	0.1	8.5	10.5	-11.3	-1.1	-0.3	6.3	16.9	-9.3	-5.3	1.7	4.9	8.8
LAK023	0.2	0.0	0.0	0.0	-0.1	0.2	4.0	8.3	-2.1	-2.1	0.6	8.7	5.0	-5.1	-3.8	-2.4	-2.6	-8.9
LAK028	0.2	0.1	-0.2	-0.2	-0.2	-0.2	8.8	17.8	-11.8	-15.7	-5.0	-5.9	71.2	-33.7	-23.3	56.7	22.2	93.1
LAK042	0.8	-0.4	0.3	0.0	-0.2	0.5	41.4	-8.5	1.3	0.2	-11.7	22.7	-0.5	-1.8	-0.2	-0.5	3.5	0.6
LAK044	0.3	0.1	0.0	-0.2	0.1	0.2	7.3	-2.7	0.3	-2.1	3.0	5.8	0.0	-1.6	-0.9	0.4	0.4	-1.7
Total Lakes with Increase	7	3	3	1	1	6	7	5	2	1	3	6	5	1	1	4	6	5
Total Lakes with Decrease	0	4	4	6	6	1	0	2	5	6	4	1	2	6	6	3	1	2

LAK007	0.0	0.1	-0.1	0.0	0.0	0.0	24.5	-16.4	119.9	-197.0	13.0	-56.0	15.1	-35.8	14.9	1.1	0.4	-4.3
LAK016	0.4	0.0	0.0	-0.2	0.1	0.3	28.3	8.8	7.4	-19.2	-11.1	14.1	17.9	-8.7	-7.2	4.0	-1.8	4.1
LAK024	¹	¹	-0.2	0.1	-0.1	0.3	¹	¹	-29.1	20.1	-46.5	117.2	¹	¹	-2.4	4.5	-4.3	10.0
LAK034	0.1	-0.1	-0.1	-0.1	-0.1	-0.3	111.0	-5.4	-27.1	-26.2	-15.2	37.1	14.0	-21.1	-16.1	-0.9	0.1	-24.0
Total Lakes with Increase	2	2	1	1	2	3	3	1	2	1	1	3	3	0	1	3	2	2
Total Lakes with Decrease	1	1	3	3	2	1	0	2	2	3	3	1	0	3	3	1	2	2

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 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, Σ BC = 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* (μ eq/L)						Cl (μ eq/L)					
From	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017
To	2013	2014	2015	2016	2017	2017	2013	2014	2015	2016	2017	2017	2013	2014	2015	2016	2017	2017
LAK006	-0.4	0.6	0.1	0.3	-0.4	0.3	-3.0	8.0	1.2	2.1	3.7	11.9	2.9	-0.6	-1.5	-1.1	-0.1	-0.3
LAK012	-0.4	2.0	1.2	-2.4	0.1	0.6	-11.8	7.3	8.1	-11.2	3.2	-4.4	10.5	-4.4	0.8	-5.4	1.3	2.8
LAK022	0.9	-0.6	0.6	0.4	-0.8	0.6	11.0	4.9	-6.2	6.7	-5.0	11.4	5.4	-3.3	-1.1	0.0	-0.8	0.1
LAK023	-0.1	1.6	-0.3	0.5	-0.4	1.3	-2.1	15.2	-5.5	-1.2	-1.8	4.6	3.0	-1.3	0.1	-1.3	-0.7	-0.3
LAK028	2.2	-1.1	2.2	0.0	-0.8	2.4	48.4	4.4	-15.9	31.8	10.8	79.5	11.7	-6.7	-2.0	1.0	-1.3	2.7
LAK042	-3.5	0.9	-2.3	1.5	1.7	-1.6	7.6	-5.3	3.7	8.1	2.6	16.6	1.6	4.1	-5.4	0.7	-0.5	0.6
LAK044	-0.2	0.3	-0.2	0.4	-0.5	-0.2	1.0	2.1	2.9	-2.1	0.2	4.2	3.3	-2.9	0.0	0.2	-0.2	0.3
Total Lakes with Increase	2	5	4	6	2	5	4	6	4	4	5	6	7	1	2	3	1	5
Total Lakes with Decrease	5	2	3	1	5	2	3	1	3	3	2	1	0	6	4	3	6	2
LAK007	-0.5	0.6	-0.5	0.5	-0.5	-0.4	-51.9	63.5	-7.8	35.1	-93.5	-54.6	11.7	-17.1	4.8	1.4	0.6	1.4
LAK016	0.5	-0.2	0.3	0.8	-1.0	0.5	0.8	13.7	7.8	-2.1	-17.9	2.3	6.0	-3.0	-0.6	-0.3	-1.1	1.0
LAK024	¹	¹	0.5	0.5	-0.7	0.7	¹	¹	-2.8	57.7	-50.9	174.4	¹	¹	-6.8	11.0	-12.4	30.3
LAK034	0.1	2.4	0.5	0.0	-1.5	1.5	56.0	8.6	-32.3	-21.8	-34.5	-23.9	2.5	-1.8	-0.3	-0.8	-0.8	-1.3
Total Lakes with Increase	2	2	3	4	0	3	2	3	1	2	0	2	3	0	1	2	1	3
Total Lakes with Decrease	1	1	1	0	4	1	1	0	3	2	4	2	0	3	3	2	3	1

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

Table 3-11. Inter-annual changes in calcium for EEM lakes, 2012-2017. 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.

	Ca ⁺ (µeq/L)					
From	2012	2013	2014	2015	2016	2017
To	2013	2014	2015	2016	2017	2017
LAK006	-3.2	4.6	0.6	0.3	2.2	4.5
LAK012	-9.7	4.5	5.5	-10.2	0.7	-9.2
LAK022	7.0	3.4	-4.4	4.0	-4.0	6.0
LAK023	-2.3	12.2	-3.2	-3.6	0.6	3.8
LAK028	37.6	0.8	-9.4	18.2	7.8	54.9
LAK042	8.7	-5.5	0.2	5.9	0.5	9.8
LAK044	0.9	0.0	2.0	-1.6	-0.4	1.0
Total Lakes with Increase	4	5	4	4	5	6
Total Lakes with Decrease	3	2	3	3	2	1
LAK007	-46.2	50.8	-10.2	34.9	-99.8	-70.5
LAK016	-3.2	8.0	8.5	-3.5	-13.4	-3.6
LAK024			-1.7	46.0	-46.9	126.4
LAK034	33.4	8.7	-15.0	-16.4	-24.4	-13.7
Total Lakes with Increase	1	3	1	2	0	1
Total Lakes with Decrease	2	0	3	2	4	3

Table 3-12. 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	2017	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017
To	2013	2014	2015	2016	2017	2017	2013	2014	2015	2016	2017	2017	2013	2014	2015	2016	2017	2017
LAK006	6%	-1%	-1%	0%	0%	3%	13%	34%	-17%	-17%	4%	9%	26%	-16%	-5%	3%	22%	26%
LAK012	12%	-5%	-1%	5%	-2%	8%	11%	8%	-4%	0%	-12%	2%	84%	40%	11%	-46%	53%	137%
LAK022	4%	2%	-2%	-1%	0%	2%	31%	29%	-24%	-3%	-1%	23%	56%	-20%	-14%	5%	14%	29%
LAK023	4%	-1%	0%	0%	-1%	3%	20%	35%	-7%	-7%	2%	44%	26%	-21%	-20%	-16%	-21%	-47%
LAK028	5%	2%	-4%	-3%	-4%	-4%	372%	-52%	-146%	¹	¹	125%	-26%	-25%	80%	17%	164%	
LAK042	17%	-6%	6%	0%	-4%	11%	-40%	10%	1%	-84%	¹	-7%	-31%	-5%	-13%	106%	9%	
LAK044	5%	2%	0%	-4%	1%	4%	576%	-32%	6%	-34%	73%	454%	0%	-26%	-19%	11%	10%	-27%
Total Lakes with Increase	7	3	3	1	1	6	5	5	2	1	3	5	5	1	1	4	6	5
Total Lakes with Decrease	0	4	4	6	6	1	0	2	5	6	3	0	2	6	6	3	1	2

LAK007	-1%	2%	-1%	0%	0%	0%	2%	-1%	8%	-13%	1%	-4%	29%	-54%	49%	2%	1%	-8%
LAK016	6%	1%	0%	-3%	1%	6%	41%	9%	7%	-17%	-12%	21%	46%	-15%	-15%	10%	-4%	11%
LAK024	²	²	-3%	1%	-1%	4%	²	²	-6%	5%	-10%	39%	²	²	-7%	13%	-11%	40%
LAK034	2%	-2%	-2%	-2%	-1%	-5%	112%	-3%	-13%	-15%	-10%	37%	58%	-55%	-95%	-100% ³	³	-100%
Total Lakes with Increase	2	2	1	1	2	3	3	1	2	1	1	3	3	0	1	3	1	2
Total Lakes with Decrease	1	1	3	3	2	1	0	2	2	3	3	1	0	3	3	1	3	2

¹ LAK028 and LAK042 had negative ANC values in 2012 and therefore the percentage change could not be properly calculated. LAK028 also had negative ANC values in 2016 and 2017.

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%. The percent change from 2016 to 2017 could not be calculated due to the negative value in 2016.

Table 3-13. Inter-annual changes (%) in DOC, base cations and chloride for EEM lakes, 2012-2017. The differences between subsequent years and across the full record of sampling are shown. DOC = dissolved organic carbon, ΣBC = sum of base cations (e.g., Mg, Ca, K, Na), Cl = chloride. The * indicates that the ionic concentrations have been corrected for marine influence. Numbers shown are the value in the later year minus the value in the earlier year.

	DOC (mg/L)						Σ BC* (µeq/L)						Cl (µeq/L)					
From	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017
To	2013	2014	2015	2016	2017	2017	2013	2014	2015	2016	2017	2017	2013	2014	2015	2016	2017	2017
LAK006	-10%	19%	3%	8%	-9%	8%	-5%	14%	2%	3%	5%	20%	51%	-7%	-18%	-16%	-3%	-6%
LAK012	-9%	47%	20%	-32%	3%	12%	-10%	7%	7%	-9%	3%	-4%	254%	-30%	8%	-49%	24%	68%
LAK022	17%	-9%	11%	6%	-12%	10%	11%	5%	-5%	6%	-4%	12%	78%	-27%	-13%	0%	-11%	2%
LAK023	-3%	40%	-5%	9%	-7%	30%	-3%	24%	-7%	-2%	-3%	7%	67%	-18%	1%	-20%	-14%	-6%
LAK028	45%	-16%	36%	0%	-10%	50%	66%	4%	-13%	29%	8%	109%	193%	-38%	-18%	11%	-13%	44%
LAK042	-26%	9%	-21%	18%	18%	-12%	14%	-9%	7%	14%	4%	31%	26%	53%	-45%	11%	-7%	9%
LAK044	-12%	17%	-11%	27%	-23%	-9%	7%	14%	17%	-10%	1%	30%	59%	-33%	0%	4%	-3%	6%
Total Lakes with Increase	2	5	4	6	2	5	4	6	4	4	5	6	7	1	2	3	1	5
Total Lakes with Decrease	5	2	3	1	5	2	3	1	3	3	2	1	0	6	4	3	6	2

LAK007	-84%	610%	-65%	208%	-68%	-59%	-3%	4%	-1%	2%	-6%	-4%	48%	-47%	25%	6%	2%	6%
LAK016	14%	-4%	8%	19%	-20%	13%	0%	8%	4%	-1%	-10%	1%	95%	-24%	-6%	-3%	-13%	16%
LAK024	¹	¹	30%	23%	-25%	48%	¹	¹	-1%	11%	-9%	51%	¹	¹	-10%	19%	-18%	111%
LAK034	3%	51%	7%	0%	-20%	33%	28%	3%	-12%	-9%	-16%	-12%	42%	-21%	-4%	-14%	-16%	-22%
Total Lakes with Increase	2	2	3	4	0	3	2	3	1	2	0	2	3	0	1	2	1	3
Total Lakes with Decrease	1	1	1	0	4	1	1	0	3	2	4	2	0	3	3	2	3	1

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

Table 3-14. Inter-annual changes (%) calcium for EEM lakes, 2012-2017. 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.

	Ca* (µeq/L)					
From	2012	2013	2014	2015	2016	2017
To	2013	2014	2015	2016	2017	2017
LAK006	-11%	17%	2%	1%	7%	15%
LAK012	-13%	7%	8%	-14%	1%	-12%
LAK022	12%	5%	-6%	6%	-6%	10%
LAK023	-6%	33%	-6%	-8%	1%	10%
LAK028	79%	1%	-11%	24%	8%	116%
LAK042	118%	-35%	2%	55%	3%	133%
LAK044	14%	0%	26%	-16%	-4%	15%
Total Lakes with Increase	4	5	4	4	5	6
Total Lakes with Decrease	3	2	3	3	2	1
LAK007	-4%	4%	-1%	3%	-8%	-6%
LAK016	-3%	7%	7%	-3%	-11%	-3%
LAK024			0%	11%	-11%	46%
LAK034	28%	6%	-9%	-11%	-19%	-11%
Total Lakes with Increase	1	3	1	2	0	1
Total Lakes with Decrease	2	0	3	2	4	3

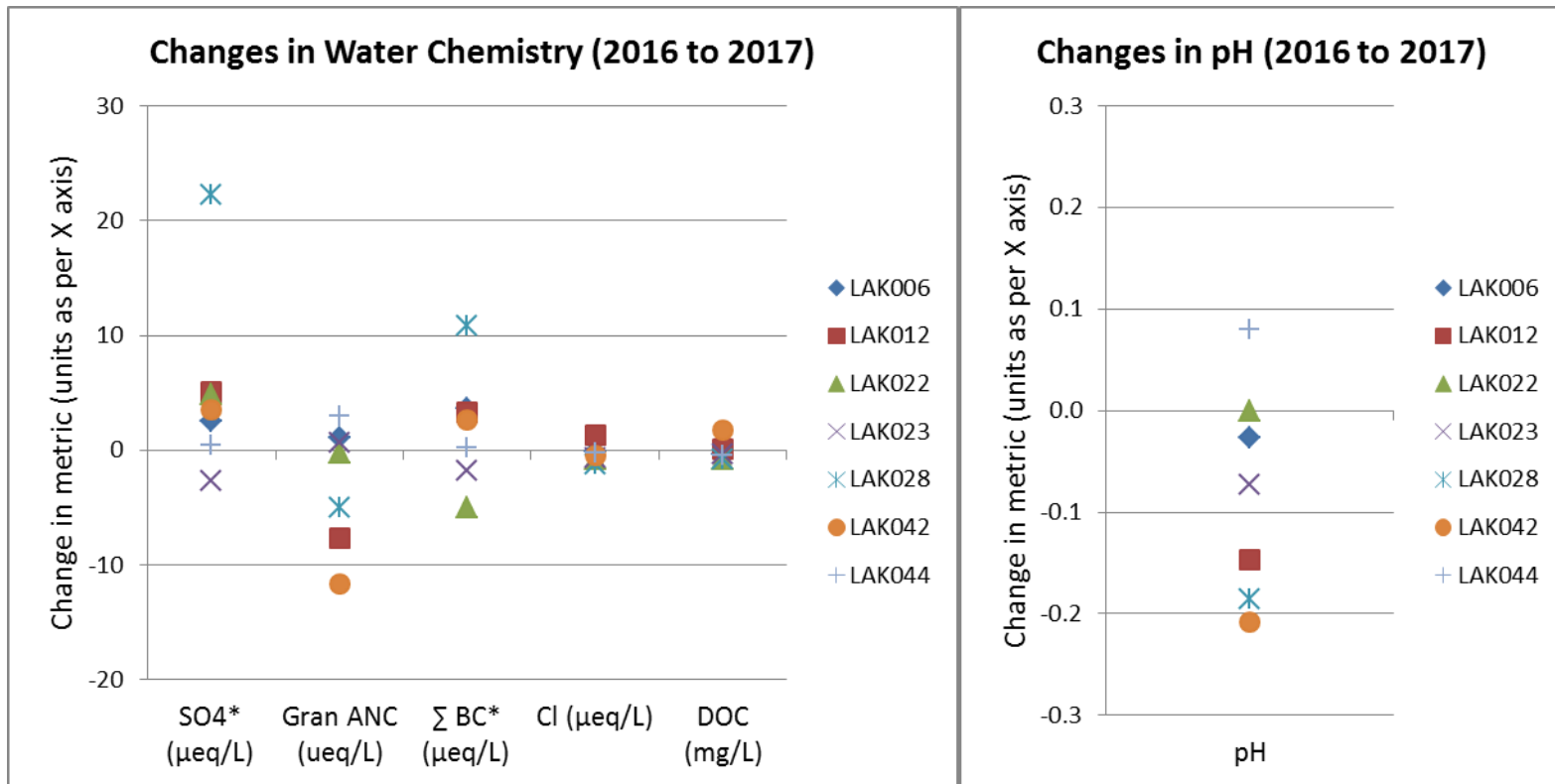


Figure 3-3. Changes in water chemistry metrics (left panel) and pH (right panel) across all of the sensitive EEM lakes, from 2016 to 2017. Values shown are the mean 2017 value minus the mean 2016 value.

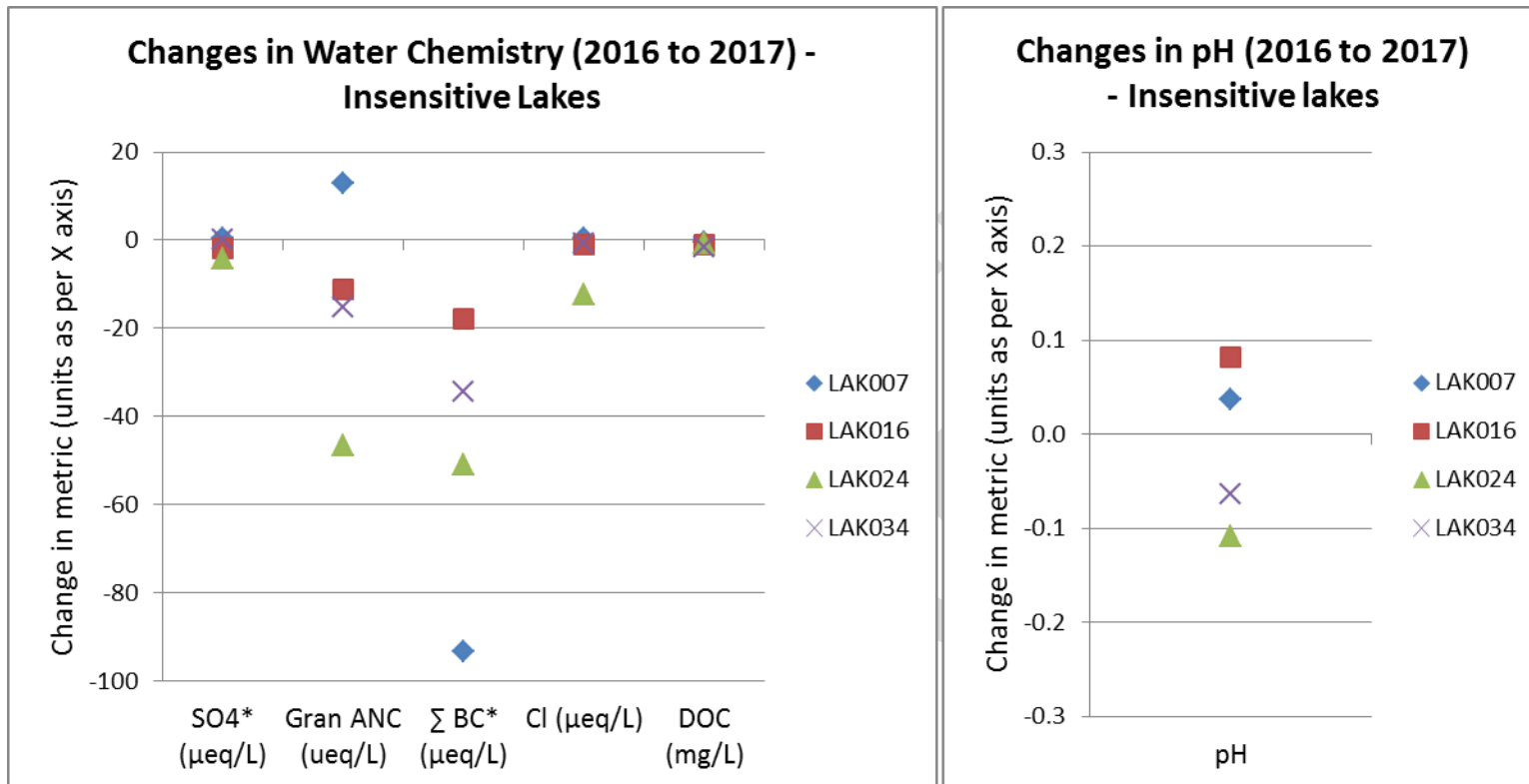


Figure 3-4. Changes in water chemistry metrics (left panel) and pH (right panel) across all of the less sensitive EEM lakes, from 2016 to 2017. Values shown are the mean 2017 value minus the mean 2016 value.

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.

Results from Intensive Monitoring of End Lake, Little End Lake and West Lake

The intensive monitoring of End Lake, Little End Lake and West Lake showed limited evidence of acidic episodes. As a simple screen, we reviewed the data from the continuous pH monitors for episodes in which the pH decreased by ≥ 0.3 pH units over a period ≤ 10 days. All three intensively monitored lakes showed a decline of 0.4 to 0.5 pH units over mid-October to the end of the sampling record in late October. This period closely aligns with the occurrence of fall storm events, as previously discussed in Section 3.3 and further described in the Limnotek report (Bennett and Perrin 2018, p.38-39):

The highest amount of precipitation fell in October, with a series of larger rain events starting Oct 15 and with the largest storm occurring on Oct 23 and 24 when 118mm of rain fell, accounting for 38% of the rainfall that month. Water surface elevation began to rise sharply on Oct 15 in all lakes (Figure 15 [in Limnotek report]) with levels peaking on October 24.

As expected, lake levels of these three lakes increased in response to these storm events. The total change in surface water elevation was 36 cm in End Lake, 37 cm in Little End Lake and 46 cm in West Lake (Bennett and Perrin 2018). This pattern of a marked decrease in pH at the end of the field monitoring season corresponding with the onset of fall storms with high precipitation and corresponding increases in lake level aligns with observations from previous years.

End Lake (LAK006). The pH decreased by up to 0.3 pH units (at lowest 30-min value) over June 24 to July 1 (7 days). The pH decreased by approximately 0.4 pH units over October 18 to 28 (10 days), although this level was still almost 0.4 pH units higher than the values measured at the beginning of the sampling period in late April. Weekly chemical sampling between October 16 and 13 showed a 0.2 unit decline in pH, but no significant changes in cations or anions (i.e., concentrations of sulphate, base cations and DOC were all more or less constant). However, there was a decline in Gran ANC of about 10 $\mu\text{eq/L}$ between October 16 and 23, suggesting that dilution of bicarbonate is the most likely explanation for the pH decline during this rainy week.

Little End Lake (LAK012). The pH decreased by 0.4-0.5 pH units over October 16 to 27 (11 days). However, LAK012 had also increased in pH by 0.5 pH units over 1 day in mid-August. Weekly chemical sampling between October 16 and 13 showed that sulphate, chloride and DOC all increased (by 9 $\mu\text{eq/L}$, 4 $\mu\text{eq/L}$ and 2 mg/L respectively), suggesting that the large rainstorm which began on October 15 flushed these ions and associated hydrogen ions from the watershed, lowering Gran ANC (by 12 $\mu\text{eq/L}$) and pH by 0.2 units. Base cations increased by 20 $\mu\text{eq/L}$ between October 16 and October 23, apparently also flushed from the watershed; base cation dilution was therefore not responsible for this acidic episode.

West Lake (LAK023). The pH decreased by approximately 0.3 pH units over September 9 to 11 (2 days); however, this occurred only shortly after the pH had increased by 0.4 pH units over September 2 to 5. The pH decreased by approximately 0.5 pH units October 14 to 27 (13 days). Surprisingly, the weekly chemical sampling between October 16 and 13 showed *no change* in pH (stayed at 5.9) and an *increase* in Gran ANC (by 6 µeq/L). During this week, sulphate concentrations increased by 6 µeq/L and base cations by 7 µeq/L, roughly balancing each other. The two sources of information (Manta sensors and weekly chemistry samples) are inconsistent, unlike in the other two intensively monitored lakes. Hence it isn't clear what pattern needs to be explained.

Anderson Creek. The pH of Anderson Creek was continuously monitored over the period from May to November by Rio Tinto using a Foxboro pH meter, and during a 6-week period in July and August by Limnotek using a Manta sensor, to provide comparative data, as described in Bennett and Perrin (2018). The Manta-measured pH varied between 7.2 and 7.8 during July and August, and showed no acidic episodes. Initially the Manta showed a higher pH value than the Foxboro, but pH measurements by the two instruments converged by early August. The Foxboro measurements in May are less reliable due to lack of proper calibration (S. Zettler, Rio Tinto, pers. comm.), and there were some unexplainable fluctuations in measured flow on November 8, a day with no measured precipitation (and only 7 mm on the previous two days). We therefore focus our attention on the period from August through October (Figure 3-6).

Over the period from August through October 2017, there were a number of storms that were associated with pH declines in Anderson Creek (Figure 3-6). A major storm on September 10 (108 mm at the rain gauge which is maintained at the main entrance to the smelter site) was associated with a pH decline from 7.4 to 6.3 (Figure 3-6). After the September 10 storm there was a generally dry period, and the pH of Anderson Creek recovered back to 7.2, before declining again to 6.7 (Figure 3-6) in association with a storm on September 23-25 (which deposited a total of 35 mm of rain, 21 mm on Sept. 24). By September 29 (the date on which all EEM lakes were sampled), the pH in Anderson Creek had increased to 6.9, but not back to its 'dry-weather' level of 7.2 to 7.3.

October 2017 was a very rainy month. Storms on October 5-9 brought 69 mm of rain and storms between October 14 and 24 brought 400 mm of rain. The October 5-9 storm was associated with a decline in pH in Anderson Creek, from a maximum of 7.2 on October 5 to a minimum of 6.6 on October 9. The October 14-24 storms led to a 20-35 cm increase in lake elevations in the intensively monitored lakes (Figure 15 in Bennett and Perrin 2018), and were associated with pH declines from 7.0 to 5.7 in Anderson Creek (Figure 3-6). The pH values in Anderson Creek dropped below 6 on two occasions - October 20 and October 23 (Figure 3-6). Without full chemistry measurements we can't assess which ionic changes were most closely associated with these acidic episodes.

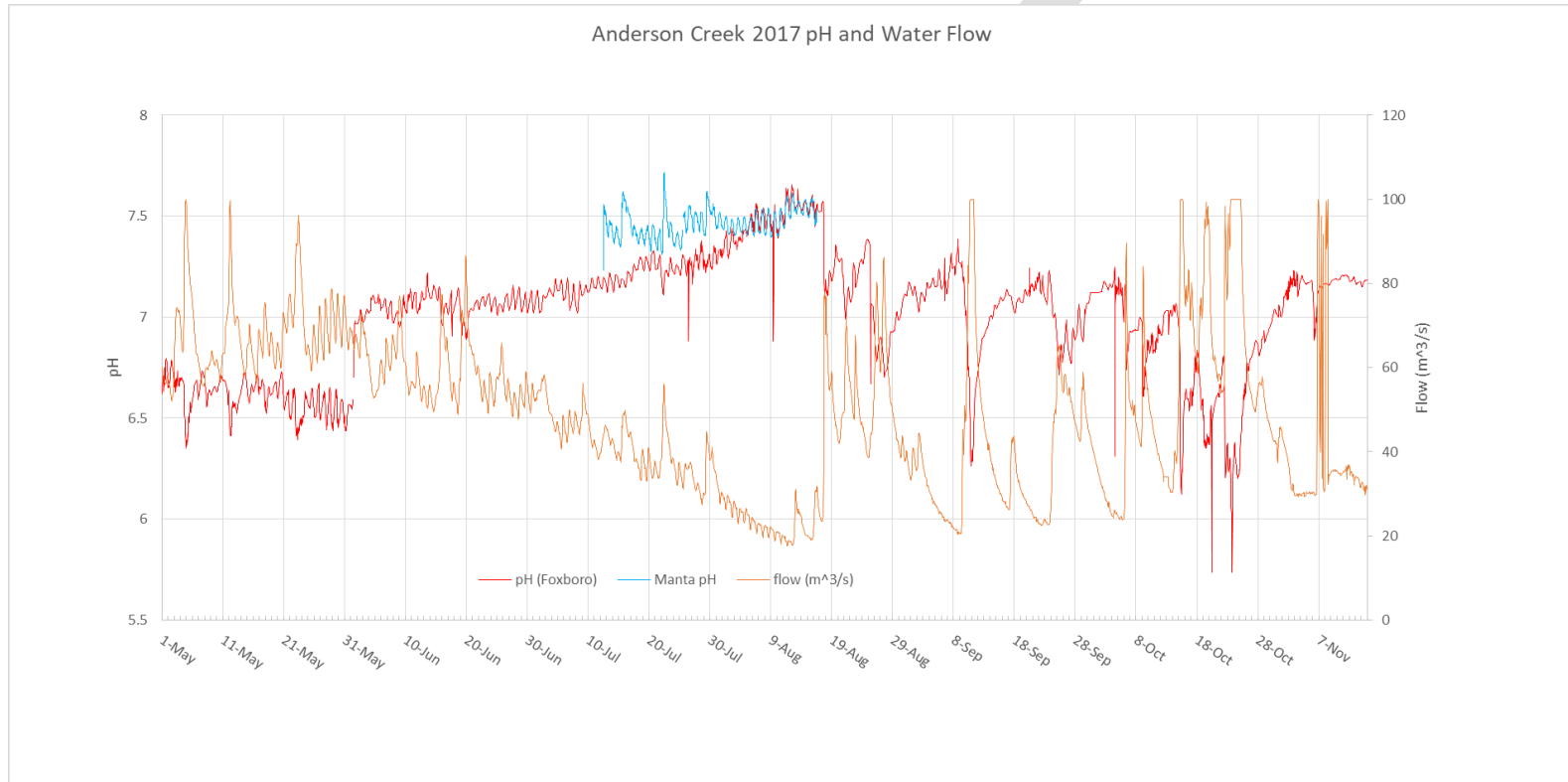


Figure 3-5. Measurements of pH (Foxboro – red line; Manta – blue line) and stream flow (orange line) in Anderson Creek from May to November. Some drift in pH measurements occurred during May due to a lack of calibration, as evidenced by the jump in pH on June 1. Appropriate calibration procedures occurred subsequent to August 1, but there was one missed calibration in June, and one missed calibration in July.

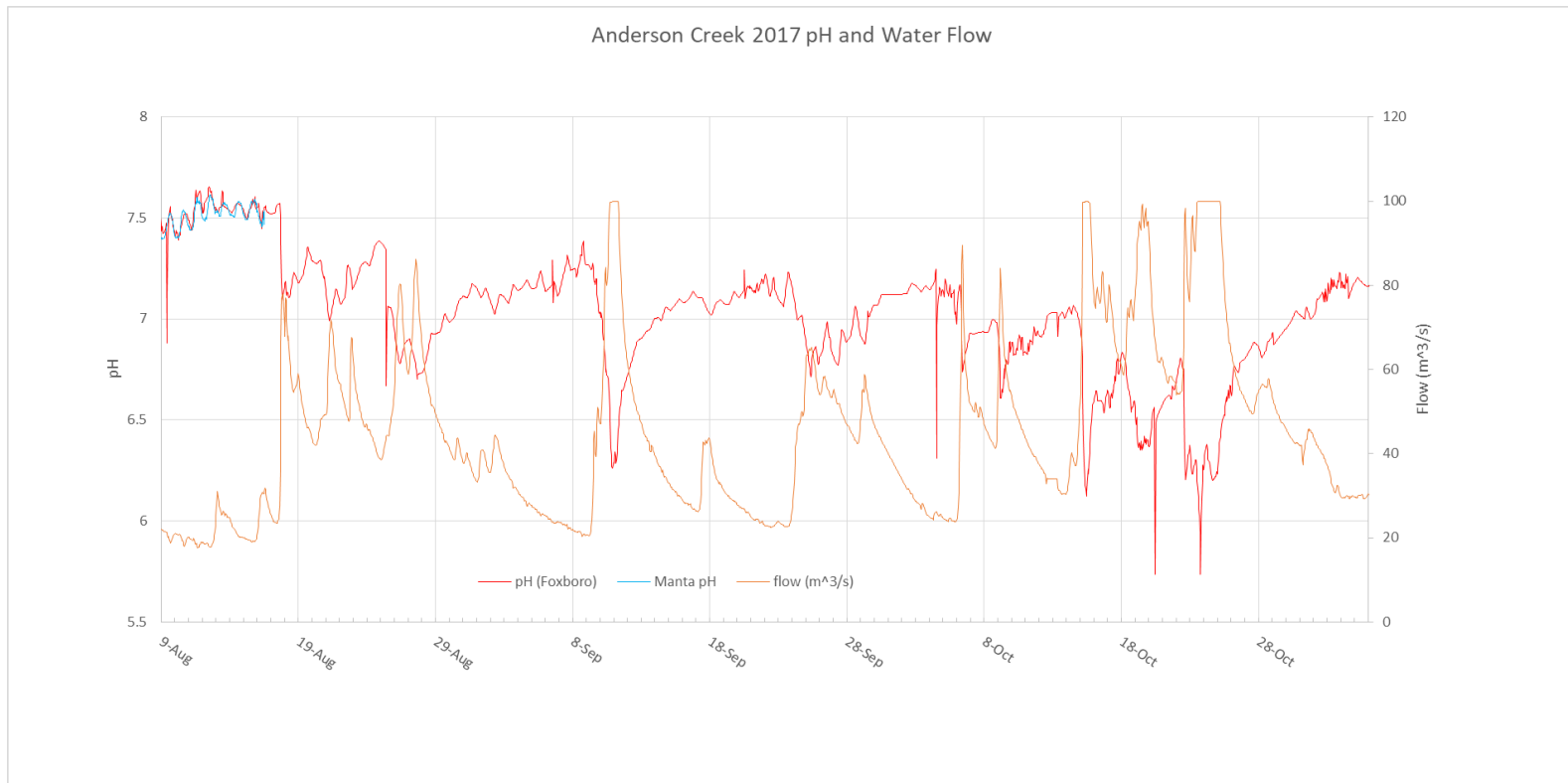


Figure 3-6. Measurements of pH (Foxboro – red line; Manta – blue line) and stream flow (orange line) in Anderson Creek during September and October.

3.6 Fish Sampling ③

No fish were captured in LAK028. One salamander was caught in one of the minnow traps. Additionally, no fish have been observed by the field crew during field visits to LAK028 in either 2016 or 2017.

From Bennet and Perrin (2018, p.46): “No fish were found in LAK028. The debris jam that formed a drop in the outlet stream likely produced a barrier for upstream fish movement. Further downstream, the channel was mostly a steep cascade that also would be expected to inhibit upstream fish migration. These two physical features alone may explain the lack of fish in LAK028.”

3.7 Water Column Chemistry of LAK028

Water column sampling from LAK028 strongly suggests the presence of meromixis (surface and bottom waters do not mix), which was also implied by the small surface area relative to lake depth. The results of the water column sampling (see Bennett and Perrin 2018) show that thermal and chemical conditions change significantly at depths >9 m. The surface mixed layer (<9 m) had water temperature typical of north coast lakes in the fall, high dissolved oxygen that could support fish, conductivity and inorganic nitrogen concentrations typical of nutrient deficient lakes, and a surface pH (~ 5) at the low end of tolerances for aquatic organisms. The bottom water layer was anoxic and would not support fish, with higher pH, higher conductivity, a warming thermocline, an odour of H₂S, and other evidence of sulphur-reducing green and/or purple bacteria. See Bennett and Perrin (2018) for the sampling results, depth profiles of different chemistry metrics, and further interpretation of the observed patterns.

3.8 Kitimat River Water Quality

The results of the water quality sampling at the Rio Tinto intake on the Kitimat River are shown in Appendix 3. None of the results showed exceedances of the BC water quality objectives. The maximum measured sulphate concentration was less than 1% of the BC Drinking Water Guideline. Rio Tinto plans to improve the consistency in this sampling in 2018 (e.g., parameters sampled and timing of samples).

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 sulphate concentrations should increase if there are either increased emissions of SO₂⁸ or changing meteorological

⁸ Mean daily SO₂ emissions increased moderately from 27.8 tons per day in 2016 to 29.7 tons per day in 2017 (a 6.8% increase).

patterns which result in increased sulphate deposition from the same SO₂ emissions. 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, 2016-2017

Some of the main patterns observed in the changes in lake chemistry between 2016 and 2017 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, particularly in lake pH due its high variability.

Lake chemistry in 2017 could potentially have been affected by some of the large storm events in September and October (reflected in the flow of Anderson Creek in Figure 3-6, and in the lake levels of the intensively monitored lakes - Figure 15 in Bennett and Perrin 2018). The pH fluctuations in Anderson Creek, and in the three intensively monitored lakes, provide a general indication of the potential impacts of storm events on pH levels, though pH changes are not translatable across lakes (due to differences in neutralizing capacity and current pH levels). The sensitive lakes have lower pH levels than Anderson Creek, and therefore would be expected to have smaller pH declines due to the logarithmic nature of the pH scale.

All EEM lakes were sampled on September 29, so we examined the prior weather patterns to see if there might have been an influence on observed water chemistry. The pH fluctuations in Anderson Creek (discussed in section 3.5) indicate that the stream pH dropped from 7.2 to 6.7 in association with a storm on September 23 to 25 (which deposited 35 mm of rain). Therefore the EEM lake pH measurements on September 29th might have been a bit lower than they would have been if the preceding week had been dry weather. However, as noted above, pH declines are not translatable across lakes at different levels of acidity. The pH drop from 7.2 to 6.7 in Anderson Creek (equivalent to an increase in [H⁺] of 0.136 µeq/L), would only have lowered the pH of a lake at pH 5.00 (e.g., LAK028) to 4.99. It therefore seems unlikely that the rains preceding the September 29 sampling date had a significant effect on the pH measured in LAK028 on that day (5.0).

Some of the lake sampling in October overlapped with the major storms discussed above in section 3.5. An important question is whether these rainstorms created a “wet weather bias” in the apparent annual trends from 2016 to 2017, and from 2012 to 2017. As discussed above in section 3.5, there were inconsistent chemical responses to the late October storms in the three

intensively monitored lakes (End Lake – LAK006, Little End Lake – LAK012 and West Lake – LAK023). Sampling occurred on September 29, October 11, 17 and 24 in LAK042 and LAK044; on September 29, October 10, 18 and 26 in LAK028; and on September 29, October 9, 16 and 23 in LAK006, LAK012, and LAK023 (intensively studied lakes, discussed in section 3.5). However, as illustrated in Appendix 4, there was also no consistent pattern amongst these lakes in their chemical responses to the late October storms. In LAK028, pH declined by 0.3 pH units (from 5.0 to 4.7) between September 29 and October 10 (coinciding with the 69 mm rains of October 5-9), but didn't change much between the October 18 and 26 sampling dates, despite the much larger 400 mm rains during this period. Between October 18 and 26 there were significant declines in sulphate, Gran ANC, Ca and total base cations, but little change in pH (less than a 0.05 pH unit decrease; see Appendix 4). The lack of consistent patterns may reflect the fact these lakes were sampled weekly, which is too infrequent a sampling interval to confidently infer the effects of rainstorms on water chemistry. Detailed studies of storm events (e.g., Wiggington et al. 1996) have sampled water chemistry on much finer time scales (e.g., hourly during rapid changes in flow).

An alternate way to explore the issue of “wet weather bias” in 2017 is to examine the Manta pH data from the intensively monitored lakes. Table 3-8 shows that there has been little change across years and lakes in the differences between August and October mean pH values in the three intensively monitored lakes. If the rainstorms in October of 2017 had exerted an unusual effect on pH readings relative to other years, we would have expected 2017 to show a larger difference between August and October pH values than has been seen in other years, but this is not the case. It is however still possible that the particular sampling dates in October, or October as a whole, had a wet weather bias. Table 4-1 shows the effects of different averaging intervals on the lake pH measured by the Manta instruments in End Lake, Little End Lake and West Lake. For these three lakes, there is no evidence that the October sampling dates for full water chemistry had significantly lower mean pH values than either the mean pH values for October 2017, or the mean pH values for the May-October period in 2017. So, at least in the intensively monitored lakes, there doesn't appear to be a wet weather bias.

Table 4-1 Changes in lake pH over different averaging intervals in the intensively monitored lakes.

Lake	Mean pH ± SD on lake chemistry on 4 sampling dates in October 2017 [n]	Mean pH ± SD in October 2017 [n]	Mean pH ± SD over May-October 2017 [n]
End	6.3 ± 0.1 [n=570]	6.3 ± 0.1 [n=3,948]	6.3 ± 0.2 [n=26,445]
Little End	6.0 ± 0.1 [n=567]	6.0 ± 0.1 [n=3,942]	5.9 ± 0.2 [n=26,583]
West	6.1 ± 0.1 [n=561]	6.1 ± 0.2 [n=2,945]	6.2 ± 0.2 [n=24,030]

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, 2016-2017

Sulphate

- Sulphate would be expected to increase in lakes (if they are responsive on an annual time scale) due to increases in SO₂ emissions from KMP, or changes in wind patterns which caused changes in the amount of sulphate deposited to a given watershed (relative to past years) from the same emissions
- 6 of 7 sensitive lakes and 2 of 4 less sensitive lakes showed increases in SO₄²⁻ (corrected for influence of marine ions)
 - LAK028 had the largest increase (+22.2 µeq/L, representing an increase of 17%); this is less than a third of the magnitude of the increase from the previous year
 - The other 5 sensitive lakes with increases in SO₄²⁻ had smaller increases of 0.4 to 5.0 µeq/L (10-53%), which is a similar range to the previous year.
 - LAK042 showed an increase in SO₄²⁻ of 3.5 µeq/L, after four consecutive years of decreases, suggesting that if the lake is in fact responsive to changes in smelter emissions, the response has a lag of over 1 year, or that changes in wind patterns in 2017 brought more sulphate deposition to LAK042 compared to past years
 - The 2 less sensitive lakes with increases in SO₄²⁻ had increases of just 0.1 and 0.4 µeq/L
 - For LAK034, although SO₄²⁻ increased, the concentration is still near zero (0.06 µeq/L) after decreases in the previous three years
- Despite the moderately increase in emissions, 1 sensitive lake and 2 less sensitive lakes showed decreases in SO₄²⁻
 - LAK023 (West Lake) decreased by 2.6 µeq/L, which is surprising given that the nearby LAK006 and LAK012 (End Lake and Little End Lake) showed increases of 2.5 and 5.0 µeq/L (respectively)
 - LAK016 and LAK024 decreased by 1.8 (-4%) and 4.3 (-11%) µeq/L, respectively
 - For LAK023, 2017 marked the 4th consecutive year of decreases, suggesting that if this lake is in fact responsive to changes in smelter emissions, the response has a lag of greater than 2 year, or that the path of SO₂ movement from the smelter, including the influence of topography and wind patterns, results in less sulphate deposition LAK023 than to LAK006 and LAK012

ANC

For the sensitive lakes, decreases in ANC would be expected (based on the evidentiary framework) to accompany increases in SO₄²⁻ concentrations

- 4 of the 7 sensitive lakes showed decreased ANC and increased SO₄²⁻, consistent with the evidentiary framework
 - LAK012, LAK022, and LAK028 showed decreases of 0.3 to 7.6 µeq/L

- LAK042 showed a more prominent decrease 11.7 µeq/L (-84%), which cannot be explained by the increase in sulphate (3.5 µeq/L) alone; there remains a further decrease of 8.2 µeq/L in ANC (i.e., 11.7 µeq/L – 3.5 µeq/L) which is due to some other factor. The most likely explanation for the additional decrease in ANC is the increase in DOC of 1.7 mg/l, which would contribute about 10.5 µeq/l of acidity, mediated by the addition of base cations (2.6 µeq/L). The cause of the increase in DOC is unknown, but could reflect changes in wetlands or vegetation along the shoreline and watershed of LAK042.
- 3 of the 7 sensitive lakes showed an increase in ANC
 - LAK006 and LAK023 demonstrated only very small increases in ANC (1.1 and 0.6 µeq/L or +4% and +2%, respectively)
 - In LAK044, ANC increased by 73% (3.0 µeq/L),
 - For all 3 lakes, the increase in ANC could possibly be related to decreases in DOC
 - For 2 of the lakes, the increase in ANC could also be associated with the increase in base cations
- LAK042 and LAK044 showed the largest decrease and largest increase, respectively, despite their proximate locations to each other
- Base cations are expected to increase ANC, whereas sulphate is expected to decrease ANC.
 - 4 of the 5 sensitive lakes with a negative value for $\{[\Delta \text{ base cations}] - [\Delta \text{ sulphate}]\}$ also showed a decrease in ANC, which is what would be expected (LAK012, LAK022, LAK028 and LAK042). LAK012 and LAK028 also showed this pattern last year.
 - LAK006 and LAK023 showed positive values for both $\{[\Delta \text{ base cations}] - [\Delta \text{ sulphate}]\}$ and ΔANC , which would also be expected (although the increases in ANC were very small). Neither of these lakes showed this pattern last year.
 - However, LAK044 had a negative value for $\{[\Delta \text{ sum of base cations}] - [\Delta \text{ sulphate}]\}$ but showed an increase in ANC, which would not be expected. The increase in ANC is most likely associated with the decrease in DOC of 0.5 mg/L from 2016 to 2017 (equivalent to a decrease in organic acidity of 3.0 µeq/L). Last year this lake showed a pattern consistent with expectations (positive increases in both metrics). However, although the pattern in 2017 is inconsistent with expectations, the changes in base cations (+0.2 µeq/L) and sulphate (+0.4 µeq/L) were both very small, so one should not over-interpret this result.

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 3 of the less sensitive lakes (contrary to the evidentiary framework) and in opposite directions for the other less sensitive lake (consistent with the evidentiary framework, although that alone does not mean that ANC is being influenced by SO₄²⁻, as discussed below
- 3 lakes showed decreases in ANC and 1 lake showed an increase (LAK007)
- Of the 3 lakes that showed decreases in ANC, all of them also showed decreased in total base cations (Table 3-9, Table 3-10), and the magnitudes of change were comparable for 2 of the lakes (LAK016 and LAK024). If sulphate were responsible for decreased ANC, one would expect to see increases in base cations due to cation exchange in the soils. The most likely explanation for the decreased ANC is a reduction in base cation supply from the watershed, due to changes in either weathering rates or transport of base cations

from the watershed to the lake (reflecting year to year variation in soil temperature and/or hydrology).

- Decreases in ANC were within the range of 10-12% (approximately 3-5% smaller than the previous year); LAK007 increased in ANC by 1%

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)
 - 2 of 7 sensitive lakes have decreases of <0.05 pH units, which therefore round to zero; one of those lakes has an increase in ANC and one has a decrease
 - Of the 5 sensitive lakes with changes of >0.05 pH units, 4 of them demonstrate this expected pattern; 3 lakes show decreases in the two metrics and 1 shows increases
 - Only 2 of 4 less sensitive lakes demonstrate this expected pattern, with decreases in the two metrics
- pH decreased for 4 of 7 sensitive lakes and 2 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

- 9 of 11 EEM lakes decreased in DOC, which is a reversal of the dominant pattern in the previous year
 - LAK034 decreased by 1.5 mg/L
 - LAK042 increased by 1.7 mg/L (similar to last year's increase of 1.5 mg/L)
 - All other lakes changed by $\leq \pm 1.0$ mg/L
- Base cations
 - 5 of 7 sensitive lakes increased in total base cations (all changes $\leq \pm 8\%$)
 - LAK028 increased by 10.8 $\mu\text{eq/L}$ and all other lakes changed by ≤ 5.0 $\mu\text{eq/L}$
 - All 4 less sensitive lakes decreased in total base cations (-17.9 to -93.5 $\mu\text{eq/L}$ or -6 to -16%)
- 9 of 11 EEM lakes decreased in chloride
 - One possible explanation for this pattern could be the very dry summer in 2017, which would have decreased the supply of chloride from the ocean
 - The magnitude of change for 10 of 11 lakes varied from -1.3 to +1.3 $\mu\text{eq/L}$
 - For LAK024, chloride decreased by 12.4 $\mu\text{eq/L}$ (-18%), effectively reversing the substantial increase observed the previous year
- Calcium
 - 5 of 7 sensitive lakes increased in calcium
 - LAK028 increased by 7.8 $\mu\text{eq/L}$ (+8%), but the changes in all other lakes (increases and decreases) were ≤ 4.0 $\mu\text{eq/L}$ (see discussion of LAK028 below)
 - All 4 less sensitive lakes decreased in calcium (-8% to -19%)

4.2.2 Observed Changes by EEM Lake, 2016-2017

The observed changes for 2016 to 2017 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 provided a very strong contrast with previous years. Mean daily SO₂ emissions in 2017 (29.7 tons per day) showed a 6.8% increase over 2016 (27.8 tons per day).

The 2016 sampling data provided the opportunity to see where lakes are responsive on annual timescale to changes in emissions. As discussed in the 2016 Annual Report, some of the lake chemistry metrics in some of the lakes appeared to be responsive to the 2016 increase in SO₂ emissions but others did not respond in 2016. Lakes that did not show an increase in sulphate concentrations in 2016 may simply be responsive on a longer timescale 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 2016 and 2017, as with annual changes in previous years, 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 changes in sulphate concentrations between 2016 and 2017 of -5.7 µeq/L (-16%), -0.8 µeq/L (-14%), and +0.2 µeq/L (+10%), respectively, which provides additional evidence that they are not being influenced by the smelter emissions. 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 statistical power to accurately detect changes in the EEM lakes and will help advance our understanding of natural inter-annual variability in lake chemistry.

It should be noted that although NC184 shows a decrease in pH of 0.4 units from 2016 to 2017, that this does not mean that the KPI has been exceeded (which only apply to the EEM sensitive lakes) or that it is less suitable as a control. In fact the observations from 2017 reinforce its suitability as a control lake because the results demonstrate that NC184 is a sensitive lake outside

of the deposition zone of the smelter. The pH of NC184 has previously shown both an increase of 0.3 pH units and another decrease of 0.3 pH units. The change in pH from 2016 to 2017 corresponds with a large decrease in ANC that appears to be associated with a decrease in base cations of comparable magnitude, possibly related to the dry conditions in the summer of 2017 (although only one of the other two control lakes displays a comparable pattern). One of the objectives of the control lakes is to gain a better understanding of other regional patterns in lake chemistry beyond increased sulfur emissions in the plume that may be influencing lake chemistry. As discussed above, the control lakes are not being further analyzed at this point.

Sensitive EEM Lakes

LAK006. SO₄²⁻ increased by 2.5 µeq/L, but ANC increased by 1.1 µeq/L and pH remained unchanged (i.e., by < ± 0.05 pH units, well within the ± 0.2 pH units accuracy of laboratory pH measurements). The increase in ANC could be driven by the increase in base cations. The increase in ANC is approximately equal to the difference between Δ BC and Δ SO₄.

- INCONSISTENT with expectations from evidentiary framework

LAK012. SO₄²⁻ increased by 5.0 µeq/L, with a decrease in ANC (-7.6 µeq/L) and a decrease in pH (by 0.1 pH units, within the ± 0.2 pH units accuracy of laboratory pH measurements), as expected with increased sulphate. Base cations also increased, but by a smaller magnitude than the increase in sulphate.

- CONSISTENT with expectations from evidentiary framework

LAK022. SO₄²⁻ increased by 4.9 µeq/L, ANC decreased by a very small margin (-0.3 µeq/L) and pH remained unchanged (i.e., by < ± 0.05 pH units, well within the ± 0.2 pH units accuracy of laboratory pH measurements). The limited change in ANC may partly reflect decreases of 0.8 mg/l in DOC (which would contribute about 5.4 µeq/L⁹ of ANC and decreases of 0.8 µeq/L in chloride), which likely counterbalanced the decrease in base cations and the increase in SO₄²⁻.

- INCONSISTENT with expectations from evidentiary framework

LAK023. Decrease in SO₄²⁻ (-2.6 µeq/L; -21%) for the fourth consecutive year, which is not expected if the lake is responsive on a 1-2 year time scale to increased sulphate emissions. ANC increased by a small amount (0.6 µeq/L; +2%) and pH decreased (by 0.1 pH units, within the ± 0.2 pH units accuracy of laboratory pH measurements). DOC decreased by 0.8 mg/L, which could remove about 4.4 µeq/L of acidity; this decrease in organic acids was supplemented by both the decrease in mineral acidity from sulphate, and the decrease in acidity associated with chloride (decreased by 1.3 µeq/L).

- INCONSISTENT with expectations from evidentiary framework

LAK028. Large increase in SO₄²⁻ (22.2 µeq/L, 17% increase) as expected with increased sulphur emissions (though larger than the 6.8% increase in emissions from 2016 to 2017) 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 2016 and 2017 in absolute terms, including a 22.2 µeq/L increase in sulphate concentrations and a 10.8 µeq/L increase in base cations. ANC decreased (-5.0 µeq/L) and pH decreased (by 0.2 pH units, within the ± 0.2 pH units

⁹ Organic anions calculated based DOC using the methodology of Oliver et al. (1983), as applied throughout the STAR, EEM and the rest of this report.

accuracy of laboratory pH measurements), as expected for sensitive lakes with increased sulphate concentration. The increase in base cations appears to be mitigating the magnitude of the decrease in ANC. These changes appear to be a continuation of similar patterns observed in the previous year, albeit with reduced magnitudes of change.

- CONSISTENT with expectations from evidentiary framework

LAK042. SO₄²⁻ increased by 3.5 µeq/L, ANC decreased (-11.7 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. In 2016, LAK042 had decreased in sulphate and it was hypothesized that as one of the most distant lakes from the smelter LAK042 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. However, the observations from 2017 are consistent with the expectations based on increase emissions.

Despite having the largest absolute decrease in ANC of any of the sensitive lakes from 2016 to 2017, LAK042 still has the largest increase in ANC over the period of record from 2012 to 2017 (22.7 µeq/L; Table 3-9), which was associated with the second largest increase in base cations (16.6 µeq/L, and a decrease in DOC of 1.7 mg/L (equivalent to a decrease in organic anions of 10.5 µeq/L); Table 3-10. Given that sulphate increased by 0.6 µeq/L over this period (Table 3-9), it appears that the increase in ANC was mostly related to an increase in base cations and a decrease in organic anions.

- CONSISTENT with expectations from evidentiary framework with respect to annual changes in 2017, but INCONSISTENT with respect to changes over the period of record

LAK044. SO₄²⁻ increased by 0.4 µeq/L, ANC increased by 3.0 µeq/L and pH increased by 0.1 pH units (within the ± 0.2 pH units accuracy of laboratory pH measurements). The changes in ANC and pH are consistent with each other but not with the increase in SO₄²⁻, albeit that SO₄²⁻ increased by only a very small margin. LAK044 is also one of the most distant lakes from the smelter and therefore may have a limited and/or lagged response in SO₄²⁻ concentrations to increases in emissions. ANC does not appear to be responding to changes in SO₄²⁻, but could be responding to the decrease in DOC (small change but equivalent to a decrease in organic ions of a greater magnitude than the increase in ANC).

- INCONSISTENT 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. SO₄²⁻ increased by a very small margin (0.4 µeq/L) but ANC also increased (by 13.0 µeq/L). The direction and magnitude of the change in base cations is inconsistent with the observed change in ANC. Although ANC increased, the pH remained unchanged (i.e., by < ± 0.05 pH units, well within the ± 0.2 pH units accuracy of laboratory pH measurements), 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⁻ decreased (-1.8 µeq/L), which is not expected with increased sulphate emissions. ANC decreased (-11.1 µeq/L), which is not consistent with a decrease in SO₄²⁻. The decrease in ANC could be associated with the larger decrease in base cations (-17.9 µeq/L). The increase in pH (by 0.1 pH units, within the ± 0.2 pH units accuracy of laboratory pH measurements) is inconsistent with a decrease in ANC. 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 80 µeq/L so it is moderately sensitive to acidification.

- CONSISTENT with expectations for a moderately sensitive lake

LAK024. SO₄²⁻ decreased (-4.3 µeq/L), which is not expected with increased sulphate emissions. ANC decreased (-46.5 µeq/L), which is not consistent with a decrease in SO₄²⁻. The decrease in ANC is very likely associated with the decrease in base cations (-50.9 µeq/L), which is of very similar magnitude. The decrease in pH (by 0.1 pH units, within ± 0.2 pH units accuracy of laboratory pH measurements) is consistent with the change in ANC but the change in ANC is clearly not being driven by sulphate. LAK024 has an ANC of about 500 µeq/L so it is insensitive to acidification.

- CONSISTENT with expectations for an insensitive lake

LAK034. SO₄²⁻ increased but only from 0.0 to 0.1 µeq/L. The ultra-low levels of SO₄²⁻ in 2016 and 2017 suggest that LAK034 is not being influenced by the sulphate emissions. However, LAK034 is one of the most distant lakes from the smelter and therefore it is possible that it may simply have a limited/lagged response in sulphate concentrations to increases in emissions. ANC decreased (-15.2 µeq/L) and pH decreased (by 0.1 pH units, within the ± 0.2 pH units accuracy of laboratory pH measurements), but given lack of sulphate, the decrease in ANC could not be driven by sulphate. The decrease in ANC is likely associated with the corresponding decrease in base cations (-34.5 µeq/L). LAK034 has an ANC of about 135 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 indicate that both Gran ANC and pH increased over the period from 2012 to 2014 (as the old smelter was decommissioned, and SO₂ emissions declined), but that sulphate concentrations increased (contrary to expectations). Since 2015, sulphate has increased, and both pH and GranANC have declined. These changes are consistent with a hypothesis of sulphate-driven acidification, though pH (the primary KPI) has not declined significantly below levels observed in 2012, given the measurement error of pH (± 0.2 pH units). With only two years of post-KMP observations, high natural variability and measurement error, it is not possible to make any conclusions about trends at this point. We have provided some further exploration of LAK028 in the current annual report. Table 4-2 and Figure 4-1 show the monitoring data for LAK028 for pH, ANC, and SO₄²⁻ over the period of record.

Table 4-2. pH, Gran ANC and SO₄²⁻* for LAK028 compared to pre-KMP baseline (2012-14) and EEM thresholds.

	2012	2013	2014	2015	2016	2017	2012 to 2017	EEM thresholds	
	Value	Value	Value	Value	Value	Value		Value	Δ
pH	5.0	5.2	5.3	5.1	5.0	4.8	-0.2	4.7 ¹	-0.3 ¹
Gran ANC (µeq/L)	-4.0	4.8	22.6	10.8	-4.9	-9.9	-5.9	n/a ²	n/a ²
SO ₄ ²⁻ * (µeq/L)	57.5	129.9	95.6	72.0	128.8	150.9	93.4	n/a ³	n/a ³

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

² Thresholds for the EEM informative indicator of Gran ANC are under development. We are using the titration data from the laboratory methods for determining Gran ANC to determine lake-specific pH-ANC relationships, from which we can calculate the change in ANC associated with a pH decrease of 0.3 units. This work is in progress and will be ready for the comprehensive review in 2019.

³ The appropriate thresholds for the EEM informative indicator of SO₄²⁻ will be calculated based on the Gran ANC thresholds (using the ESSA-DFO model) once we have developed the Gran ANC thresholds (as described in the previous footnote).

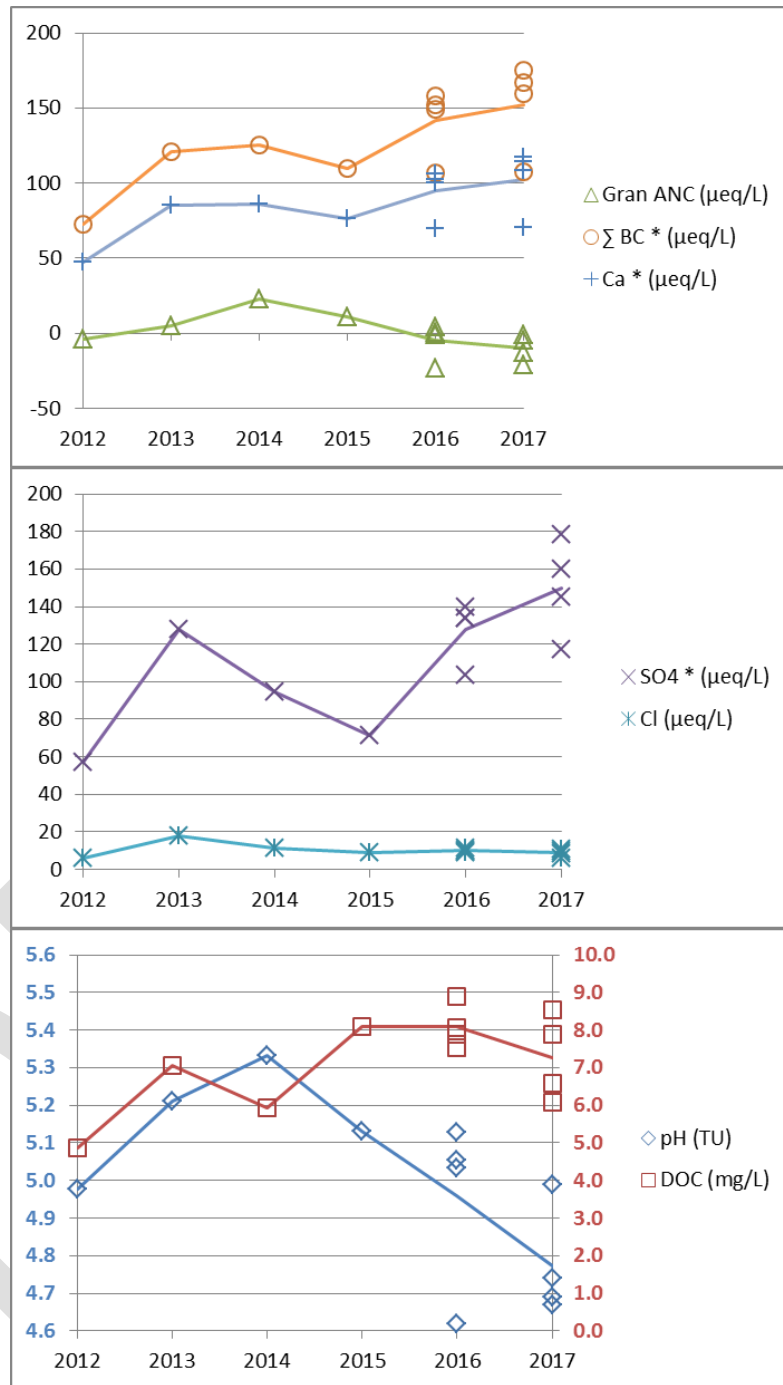


Figure 4-1. Changes in lake chemistry for LAK028 from 2012 to 2017. The solid lines represent the annual trend – i.e., based on the single annual sample in 2012-2015 and based on the mean of all within-season samples in 2016 and 2017. The points represent the values from individual sampling events in each year.

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. The data collected in 2012 suggested that the chemistry of LAK028 had already been influenced by exposure to emissions of the pre-KMP smelter, with high sulphate and fluoride concentrations (see section 9.4.1.2.3 of STAR report, ESSA et al. 2013).

We compared LAK028 to acid-sensitive lakes from the northeast U.S., as analyzed by Sullivan et al. (1988). Figure 4-2 shows that the sulphate and ANC levels for LAK028 are comparable to those acid-sensitive lakes, except that LAK028 has slightly lower ANC 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 4-3), but it has been increasing in recent years, up to 0.98 in 2017, meaning it is at the threshold for indicating acidification. The monitoring data shows that base cations are increasing as sulphate increases, neutralizing some of the H⁺ associated with the SO₄²⁻.

There are two ways of estimating the proportion of deposited acidity that was neutralized between 2016 and 2017. First, one can compute the F-factor ($\Delta \text{Base Cations}_{2016-2017} / \Delta \text{Sulphate}_{2016-2017}$). From the data in Table 4-3, F₂₀₁₆₋₂₀₁₇ is estimated at 0.49¹⁰. From this method, one can infer that 49% of the acidity deposited between 2016 and 2017 was neutralized through increases in base cations. This is marginally higher than the F-factor that was assumed for the STAR (0.44), indicating a slightly higher level of acid neutralization by cation exchange, but lower than the F-factor calculated last year for 2015-2016 (0.56); however these values are still very similar. Looking over the time period from 2015 to 2017 generates an estimated F-factor of 0.54, very similar to that computed for 2015-2016 (0.56).¹¹

The second way of estimating the proportion of deposited acidity that was neutralized between 2016 and 2017 is to compare the decrease in Gran ANC (4.97 µeq/L) to the increase in SO₄²⁻ (22.20 µeq/L). If there were no mechanisms of acid neutralization, and no other changes in water chemistry, the decrease in Gran ANC would equal the increase in SO₄²⁻. This comparison implies that 78%¹² (74% when using the change from 2015 to 2017) 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). The water column sampling conducted in LAK028 in 2017 (Section 3.7) provides indirect evidence that sulphur reduction is occurring in the lake (i.e., sampling from depths below 9 m indicate presence sulphur reducing bacteria, odour of H₂S, and very low measurements of sulphate). Sulphate reduction could also be occurring in wetlands within the watershed of LAK028, but we have no way of confirming that this has or has not occurred. Another mechanism of acid neutralization is through conversion of hydrogen to aluminum in either watershed soils or in the lake. Between 2015 and 2016, the

¹⁰ F-factor₂₀₁₆₋₂₀₁₇ = $[\Delta \text{Base Cations}_{2016-2017}] / [\Delta \text{Sulphate}_{2016-2017}] = [10.82 \text{ µeq/L}] / [22.20 \text{ µeq/L}] = 0.49$

¹¹ F-factor₂₀₁₅₋₂₀₁₇ = $[\Delta \text{Base Cations}_{2015-2017}] / [\Delta \text{Sulphate}_{2015-2017}] = [42.58 \text{ µeq/L}] / [78.88 \text{ µeq/L}] = 0.54$

¹² $(\Delta \text{SO}_4^{2-} - \Delta \text{Gran ANC}) / \Delta \text{SO}_4^{2-} = (22.20 \text{ µeq/L} - 4.97 \text{ µeq/L}) / 22.20 \text{ µeq/L} = 0.78$

concentration of total aluminum increased by 9 µeq/l (from 67 to 76 µeq/L) and by 2 µeq/L between 2016 and 2017.

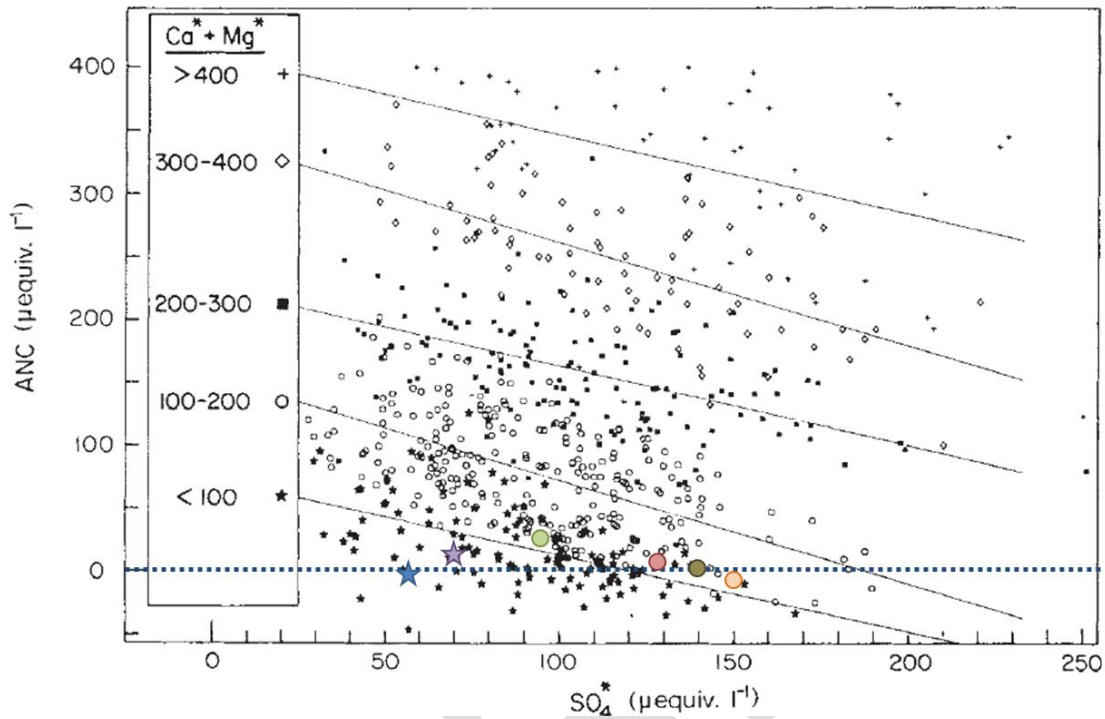


Figure 4-2. ANC and SO₄²⁻* for LAK028 compared to acid sensitive lakes in the northeast U.S. The underlying figure is from Sullivan et al. (1988), showing the relationship between ANC and SO₄²⁻* as stratified by the sum of marine-adjusted Ca and Mg cations. The stars represent the data for LAK028 from each of the annual sampling events (blue = 2012, red = 2013, green = 2014, purple = 2015, brown = 2016, orange = 2017). The * (e.g., Ca*, Mg*) signifies that concentrations have been adjusted to account for marine influence.

Table 4-3. Sulphate and base cation concentrations for LAK028. Values in 2016 and 2017 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
2017	149.99	102.48	26.49	128.97	152.41	-9.89	0.98	4.77

Changes over 2012-2017. LAK028 showed a 93.1 µeq/L increase in the SO₄²⁻* anion over 2012-2017 (Table 3-9), which was mostly balanced by a 79.5 µeq/L increase in total base cations (Table 3-10). The increase in base cations over 2012-2017 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 4-3). Though DOC increased by 2.4

mg/L between 2012 and 2017 (Table 3-10), with an increase of 11.4 µeq/L in organic anions¹³, there has been only a smaller decrease over 2012-2017 in Gran ANC (-5.9 µeq/L, Table 3-9). Our preliminary conclusion in 2016 was that the acidity contributed by increases in SO₄²⁻ over 2012-2016 appeared 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 did not appear to have resulted in any further acidification.

Potential Neutralization of Acidity by Sulphate Reduction

Equation 6 in Marmorek et al. (2000) estimates F_L , the fraction of acidity neutralized by sulphate reduction, as follows:

$$F_L = \frac{S_S}{R \times (r+1) + S_S} \quad [1],$$

where:

- S_S = the sulphate mass transfer coefficient (the height of the water column from which sulphate is removed each year, e.g. 0.5 m);
- R = runoff in m/yr;
- r = the ratio of the area of the watershed to the area of the lake

As discussed in Marmorek et al. (2000), F_L will be largest in watersheds with low runoff and a small watershed to lake area ratio, which together generate a long water residence time, giving the bacteria more time for sulphate reduction.

Table 25 of the EEM Program plan (ESSA et al. 2014) has the necessary information to apply equation [1]. Calculations indicate that the fraction of acidity neutralized by this mechanism (last column of Table 4-4) is likely quite small for all of the lakes, and only 2.4% for LAK028. Therefore despite the interesting confirmation of sulphate reduction in LAK028 by Bennett and Perrin (2018), in-lake neutralization by sulphate reduction is likely only responsible for a small fraction of the acid neutralization occurring in the watershed of LAK028. Much of the deposited acidity will flow through LAK028 without being neutralized, due to the large watershed-to-lake area ratio (10.8), and high runoff (1.58 m), which together make a large denominator in equation [1]. LAK044, which has the longest residence time of all of the lakes, is the only lake where the fraction of acidity neutralized exceeds 0.1.

¹³ Based on the annual calculation of organic anions based on the methodology of Oliver et al (1983), as applied throughout the STAR and EEM.

Table 4-4. Fraction of acidity neutralized by sulphate reduction within each of the sensitive EEM lakes, based on equation 6 in Marmorek et al. (1990). Data on lake area, watershed area and runoff are from Table 25 in the EEM Program Plan (ESSA et al. 2014). Calculations for LAK028 are highlighted.

SITE_ID	Lake Area (ha)	Depth at sampling point (m)	Watershed Area (ha)	Runoff (m)	F _L (acid neutralization by SO ₄ reduction)
LAK006	10.25	5.7	91.2	0.88	0.054
LAK012	2.30	3.5	90.1	0.86	0.014
LAK022	5.74	10.1	39.9	0.83	0.070
LAK023	6.77	2.7	40.3	0.90	0.074
LAK028	1.02	15.5	11.9	1.58	0.024
LAK042	1.46	12.0	37.2	0.60	0.031
LAK044	2.01	15.0	9.9	0.64	0.116
LAK047	1.61	0.5	42.9	2.41	0.007
LAK054	1.52	5.1	125.3	1.61	0.004
LAK056	1.77	6.6	27.3	1.60	0.019

5 Recommendations

The 2018 sampling plan for water chemistry should follow the 2017 sampling plan. No additional changes are recommended at this time. Additional information on within-season variability in lake chemistry for LAK028, LAK042 and LAK044 (included in 2016 and 2017) will be valuable for analyzing trends over time, as will continued sampling of the control lakes, and the intensively monitored lakes.

The trends in LAK028 are of particular interest. The 2018 sampling of LAK028 will provide important additional information for assessing long term trends. LAK028 has very high year-to-year variability in both Gran ANC and pH. So far we only have two years with 4 samples during the fall index period (prior years had only one sample per year). We will have greater confidence in the apparent changes in water chemistry after collecting additional data in 2018 (i.e., another year with four samples in the fall index period), and thoroughly assessing all the data in the comprehensive 2019 report.

We recommend completing an analysis of the bathymetry of LAK028, as was done previously for End Lake, Little End Lake and West Lake. This will provide a more precise estimate of the volume of LAK028, from which we can derive more accurate estimates of the water residence time in LAK028, which will be helpful for modelling changes in its water chemistry over time.

We also recommend resampling the eight tributaries collectively called Goose Creek, six of which were sampled in 2014, and two of which were sampled in 2015. These tributaries of the Kitimat River are below the steep hill on which LAK028 is found, and are reportedly used for spawning by cutthroat trout. Resampling these tributaries will provide an indication if there have been any significant changes in the water chemistry of these streams since 2014-2015. One of these streams is acid sensitive (Goose Ck 4, Gran ANC < 50 µeq/L), two are moderately acid-sensitive

(Goose Creek 1 and 2, Gran ANC < 100 µeq/L), and five are insensitive to acidification (Gran ANC > 200 µeq/L), as described in ESSA (2015, 2016).

An option worthy of consideration in 2018 is to sample the benthic organisms in the Goose Creek tributaries, and compare their community composition to that expected from other streams in the region with similar attributes, using the Reference Condition Approach (RCA). RCA has been used across many parts of the province by the Ministry of Environment. The streams would be sampled at the end of summer during the period with the lowest flow.

Another option that we have considered is to sample the littoral benthos in LAK028, but we (ESSA and Limnotek) believe that sampling the Goose Creek tributaries would provide information of much greater value due to the potential use of these streams by cutthroat trout. LAK028 is inaccessible to fish due to high stream gradients, and the 2017 sampling found no fish there.

The primary future analyses of interest will be the 6-year comprehensive assessment in 2019. 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 have acquired the lab reports from all past lake samples from Trent University, and are in the process of estimating a lake-specific mean ANC threshold (and its variation) for each EEM lake. We will complete these analyses in 2018, and use these thresholds in the comprehensive 2019 report.

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

The two tables below shows the sample results for each of the EEM lakes and control lakes from annual monitoring conducted from 2012 to 2017, 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 2013-2017, the pH of the water samples was measured by two different laboratories (Trent University and ALS).

The first 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 second table 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.

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		DOC		Gran ANC		SO ₄ ⁻		Cl		F		Ca ⁺		Mg ⁺		K ⁺		Na ⁺		∑ 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		
LAK006	2012	5.8				3.6		25.7		11.4		5.8		4.5		30.3		12.5		2.9		14.9		60.6
LAK007	2012	8.0				0.6		1437.6		51.4		24.6		2.8		1272.2		157.0		19.3		55.4		1503.9
LAK012	2012	5.6				4.6		57.0		6.1		4.2		5.0		74.5		20.8		5.2		20.0		120.6
LAK016	2012	6.3				3.7		68.7		39.0		6.3		7.8		117.7		20.5		7.3		20.8		166.3
LAK022	2012	5.9				5.3		27.8		30.2		6.9		6.1		58.1		16.0		3.2		20.8		98.1
LAK023	2012	5.7				4.2		19.8		19.0		4.5		5.6		39.4		12.0		3.7		10.8		65.9
LAK024	2012	7.1				1.4		299.5		24.8		27.3		1.6		273.2		33.0		4.2		29.6		340.0
LAK028	2012	5.0				4.9		-4.0		56.9		6.1		20.7		47.5		9.5		3.1		12.8		72.9
LAK034	2012	6.7				4.5		99.4		24.1		5.8		5.8		119.3		31.6		5.8		44.9		201.7
LAK042	2012	4.7				13.2		-20.4		6.2		6.1		3.2		7.4		22.7		3.1		20.3		53.4
LAK044	2012	5.4				1.7		1.3		6.2		5.6		2.9		6.8		3.2		4.1		0.0		14.2
LAK006	2013	6.2		6.1		3.2		29.0		14.4		8.7		5.6		27.1		13.0		5.3		12.2		57.6
LAK007	2013	7.9		8.1		0.1		1462.1		66.5		36.3		3.7		1226.0		156.5		21.9		47.6		1452.0
LAK012	2013	6.3		6.1		4.2		63.5		11.3		14.7		8.2		64.8		20.3		9.2		14.6		108.9
LAK016	2013	6.7		7.2		4.2		96.9		56.9		12.3		11.5		114.4		23.9		11.2		17.6		167.1
LAK022	2013	6.2		6.1		6.2		36.4		47.1		12.4		8.7		65.1		19.2		6.0		18.8		109.1
LAK023	2013	6.0		6.0		4.0		23.8		24.1		7.5		7.4		37.1		13.3		5.1		8.3		63.9
LAK024	2013																							
LAK028	2013	5.2		5.5		7.1		4.8		128.1		17.7		32.0		85.1		18.3		5.0		13.0		121.3
LAK034	2013	6.9		7.4		4.7		210.4		38.1		8.2		10.0		152.7		41.7		9.2		54.1		257.7
LAK042	2013	5.5		5.4		9.7		21.0		5.7		7.7		3.2		16.0		22.3		3.4		19.3		61.0

Lake	Year	pH		DOC		Gran ANC		SO ₄ [*]		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		
LAK044	2013	5.7		6.0		1.5		8.6		6.2		8.9		3.8		7.8		3.6		5.9		-2.0	15.3	
Lak006	2014	6.1	0.1	6.6	0.6	3.8	1.0	38.8	2.5	12.1	2.2	8.1	0.6	4.8	0.5	31.7	8.7	14.6	0.8	4.7	0.2	14.5	0.6	65.5
LAK007	2014	8.1		8.0		0.7		1445.7		30.7		19.2		1.9		1276.8		156.7		20.2		61.8		1515.5
LAK012	2014	6.0	0.2	6.7	0.4	6.3	2.2	68.8	15.2	15.8	11.6	10.3	4.9	5.2	0.5	69.3	3.5	21.3	1.3	7.3	1.1	18.3	3.6	116.1
LAK016	2014	6.7		6.7		4.0		105.7		48.2		9.3		9.5		122.4		25.0		10.1		23.3		180.8
LAK022	2014	6.3		6.4		5.7		46.9		37.8		9.0		6.9		68.5		18.9		5.2		21.4		114.0
LAK023	2014	5.9	0.1	6.7	0.6	5.7	1.0	32.1	2.5	18.9	2.2	6.1	0.6	6.2	0.5	49.3	8.7	14.9	0.8	4.0	0.2	10.8	0.6	79.0
LAK024	2014	7.6		7.5		1.7		472.1		37.2		65.7		2.3		402.3		50.1		7.8		50.2		510.4
LAK028	2014	5.3		5.7		5.9		22.6		94.4		11.0		23.3		85.9		17.7		4.4		17.6		125.7
LAK034	2014	6.7		7.0		7.0		205.0		17.0		6.5		7.7		161.4		43.6		9.4		51.9		266.3
LAK042	2014	5.1		5.4		10.6		12.5		4.0		11.8		2.6		10.5		23.6		3.7		17.9		55.7
LAK044	2014	5.8		5.6		1.8		5.9		4.6		5.9		2.8		7.8		3.9		5.3		0.4		17.3
Lak006	2015	6.0	0.1	6.4	0.6	3.9	0.3	32.4	0.7	11.5	0.7	6.6	0.6	4.4	0.2	32.3	0.6	14.8	0.3	3.9	0.1	15.7	0.6	66.7
Lak007	2015	8.0		7.9		0.3		1565.6		45.6		24.0		2.6		1266.6		161.5		21.0		58.6		1507.7
LAK012	2015	6.0	0.2	6.3	0.3	7.5	2.1	65.9	4.2	17.6	6.1	11.1	3.3	4.7	0.3	74.8	7.8	23.2	1.8	8.1	1.6	18.0	1.6	124.2
LAK016	2015	6.8		6.9		4.3		113.1		40.9		8.7		8.6		130.9		25.0		9.8		22.9		188.6
LAK022	2015	6.1		6.2		6.3		35.6		32.5		7.9		5.9		64.1		18.1		4.4		21.2		107.8
LAK023	2015	5.9	0.1	6.2	0.1	5.4	0.7	30.0	2.0	15.1	1.5	6.2	0.6	5.2	0.3	46.1	3.0	13.9	0.6	3.8	0.1	9.7	0.2	73.5
Lak024	2015	7.4		7.5		2.2		443.0		34.7		59.0		2.1		400.5		49.3		8.7		49.0		507.6
LAK028	2015	5.1		5.3		8.1		10.8		71.1		9.0		20.5		76.5		15.7		3.2		14.4		109.8
LAK034	2015	6.6		6.7		7.6		177.8		0.9		6.2		4.7		146.5		37.1		5.3		45.1		234.0
LAK042	2015	5.4		5.5		8.3		13.8		3.8		6.5		2.3		10.7		23.1		2.5		23.0		59.3
LAK044	2015	5.8		5.8		1.6		6.2		3.7		5.9		2.7		9.8		4.4		5.5		0.5		20.3
Lak006	2016	6.0	0.1	6.3	0.2	4.2	0.2	26.9	2.0	11.8	0.3	5.6	0.4	4.2	0.2	32.6	1.0	14.8	1.3	4.2	1.2	17.2	1.8	68.8
Lak007	2016	8.0		8.1		0.8		1368.6		46.7		25.4		2.6		1301.5		162.8		20.2		58.3		1542.8
LAK012	2016	6.2	0.0	6.5	0.2	5.1	0.5	65.8	2.3	9.5	1.1	5.6	0.3	4.6	0.2	64.7	1.7	20.8	1.2	6.0	1.2	21.6	1.6	113.0
LAK016	2016	6.6		6.9		5.2		93.9		44.9		8.5		8.2		127.4		26.4		8.9		23.7		186.5
LAK022	2016	6.1		6.4		6.7		34.4		34.2		7.9		5.8		68.1		19.2		4.2		23.1		114.6
LAK023	2016	5.9	0.0	6.2	0.1	5.8	0.2	27.9	3.8	12.7	0.4	4.9	0.4	5.1	0.2	42.5	1.8	14.1	0.9	4.7	1.1	11.0	1.5	72.3
LAK024	2016	7.5		7.6		2.7		463.1		39.2		70.0		2.3		446.5		55.3		9.5		53.9		565.3
LAK028	2016	5.0	0.2	5.1	0.2	8.1	0.6	-4.9	12.5	127.8	16.3	10.0	1.1	26.8	1.7	94.7	16.7	23.8	3.5	3.7	0.4	19.5	3.2	141.6
LAK034	2016	6.5		7.1		7.6		151.6		0.0		5.4		4.4		130.0		34.3		3.8		44.1		212.3
LAK042	2016	5.4	0.0	5.7	0.1	9.8	0.4	14.0	3.1	3.3	0.5	7.2	0.5	2.2	0.2	16.7	3.4	24.7	0.7	2.7	0.4	23.3	0.4	67.4
LAK044	2016	5.5	0.0	6.0	0.3	2.0	0.2	4.1	2.6	4.1	0.2	6.1	0.3	2.3	0.1	8.2	0.8	4.1	0.1	5.5	0.2	0.3	0.4	18.2
Lak006	2017	6.0	0.1	6.4	0.2	3.8	0.2	27.9	5.3	14.4	0.6	5.4	0.5	4.2	0.1	34.8	0.9	15.6	0.5	4.1	0.2	18.0	0.8	72.5
LAK007	2017	8.0		8.0		0.3		1381.6		47.1		25.9		2.4		1201.7		165.2		19.9		62.6		1449.4
LAK012	2017	6.1	0.2	6.5	0.1	5.2	1.0	58.2	6.5	14.6	5.2	7.0	2.4	4.4	0.1	65.4	9.0	21.7	2.3	7.7	1.9	21.5	1.9	116.3
LAK016	2017	6.7		6.8		4.1		82.7		43.2		7.3		7.7		114.0		24.7		6.9		22.9		168.6
LAK022	2017	6.1		6.3		5.9		34.2		39.0		7.1		5.4		64.1		19.5		3.8		22.2		109.6
LAK023	2017	5.9	0.0	6.2	0.1	5.4	0.1	28.5	4.7	10.1	3.4	4.2	0.5	4.6	0.1	43.2	4.2	13.8	0.7	2.3	0.5	11.2	0.6	70.5
LAK024	2017	7.4		7.6		2.0		416.6		34.9		57.5		2.0		399.6		52.2		8.5		54.2		514.4
LAK028	2017	4.8	0.1	5.1	0.1	7.3	1.1	-9.9	9.0	150.0	25.9	8.7	1.9	27.2	3.4	102.5	21.9	26.5	5.0	3.5	0.7	19.9	3.1	152.4
LAK034	2017	6.4		6.8		6.0		136.5		0.1		4.5		3.4		105.6		30.3		2.7		39.1		177.8

Lake	Year	pH		pH		DOC		Gran ANC		SO ₄ [*]		Cl		F		Ca [*]		Mg [*]		K [*]		Na [*]		Σ BC [*]
		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	µeq/L
LAK042	2017	5.2	0.1	5.4	0.3	11.6	2.3	2.3	4.2	6.8	1.9	6.7	0.9	2.4	0.1	17.1	5.5	26.9	2.3	2.8	0.5	23.2	0.9	70.0
LAK044	2017	5.6	0.1	6.0	0.2	1.6	0.1	7.0	4.4	4.5	0.4	5.9	0.2	2.2	0.0	7.9	0.3	4.2	0.2	5.6	0.2	0.7	0.4	18.4
NC184	2013	5.7				11.6		16.2		5.7		24.0		0.3		50.5		17.5		4.4		13.8		86.2
NC194	2013	6.6				0.7		28.0		3.6		7.6		0.3		23.2		3.4		5.2		7.4		39.2
DCAS14A	2013	6.5				1.4		50.6		33.4		9.2		0.6		63.9		10.3		10.3		6.1		90.6
NC184	2015	5.5		5.6		9.8		18.4		5.7		21.7		0.5		48.8		16.1		2.9		10.8		78.7
NC194	2015	6.5		6.5		0.8		33.0		2.3		7.3		0.5		26.9		4.4		4.3		7.9		43.4
DCAS14A	2015	6.6		6.7		0.9				35.7		7.3		0.5		77.6		12.4		11.2		9.9		111.0
NC184	2016	5.8		6.2		10.6		27.3		5.5		21.2		0.5		62.6		19.3		2.7		15.5		100.1
NC194	2016	6.4		6.6		1.6		28.7		2.3		7.9		0.5		26.4		4.3		3.8		7.9		42.4
DCAS14A	2016	6.6		6.8		1.5		57.5		36.8		8.5		0.5		77.5		11.8		10.5		9.7		109.6
NC184	2017	5.4		6.0		13.3		9.8		4.7		14.7		0.5		45.2		17.4		2.5		15.9		81.0
NC194	2017	6.4		6.4		1.0		12.4		2.5		4.8		0.5		29.9		5.7		3.6		9.9		49.1
DCAS14A	2017	6.6		6.7		1.5		51.0		31.1		5.6		0.5		68.2		11.8		9.1		9.9		99.0

¹ SD = standard deviation

DRAFT

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
Lak006	2017	6.0	6.4	3.8	1.4	8.8	0.7	0.2	0.1	2.5	2.5	0.7	0.2	0.2	0.5	0.0	0.1	0.0
Lak007	2017	8.0	8.0	0.3	69.1	149.0	2.4	0.9	0.0	2.5	2.5	24.1	2.1	0.8	2.0	0.0	0.0	0.0
LAK012	2017	6.1	6.5	5.2	2.9	12.9	0.7	0.2	0.1	9.7	5.6	1.3	0.3	0.3	0.6	0.3	0.1	0.0
LAK016	2017	6.7	6.8	4.1	4.1	18.5	2.1	0.3	0.1	2.5	2.5	2.3	0.3	0.3	0.7	0.0	0.1	0.0
LAK022	2017	6.1	6.3	5.9	1.7	12.8	1.9	0.3	0.1	2.5	2.5	1.3	0.3	0.2	0.6	0.0	0.1	0.0
LAK023	2017	5.9	6.2	5.4	1.4	7.9	0.5	0.2	0.1	7.7	2.5	0.9	0.2	0.1	0.3	0.0	0.1	0.0
LAK024	2017	7.4	7.6	2.0	20.9	57.4	2.0	2.0	0.0	11.2	2.5	8.1	0.8	0.4	2.4	0.1	0.0	0.0
LAK028	2017	4.8	5.1	7.3	-0.5	26.9	7.2	0.3	0.5	25.3	3.3	2.1	0.3	0.1	0.6	0.1	0.7	0.0
LAK034	2017	6.4	6.8	6.0	6.8	17.6	0.0	0.2	0.1	2.5	2.5	2.1	0.4	0.1	1.0	0.1	0.0	0.0
LAK042	2017	5.2	5.4	11.6	0.1	9.8	0.4	0.2	0.0	2.5	5.4	0.3	0.3	0.1	0.7	0.3	0.4	0.0
LAK044	2017	5.6	6.0	1.6	0.4	4.4	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		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
NC184	2017	5.4	6.0	13.3	0.5	11.4	0.3	0.5	0.0	2.5	2.5	0.9	0.2	0.1	0.7	0.2	0.3	0.0
NC194	2017	6.4	6.4	1.0	0.6	4.9	0.1	0.2	0.0	2.5	2.5	0.6	0.1	0.1	0.3	0.0	0.0	0.0
DCAS14A	2017	6.6	6.7	1.5	2.6	11.7	1.5	0.2	0.0	2.5	2.5	1.4	0.2	0.4	0.3	0.0	0.0	0.0

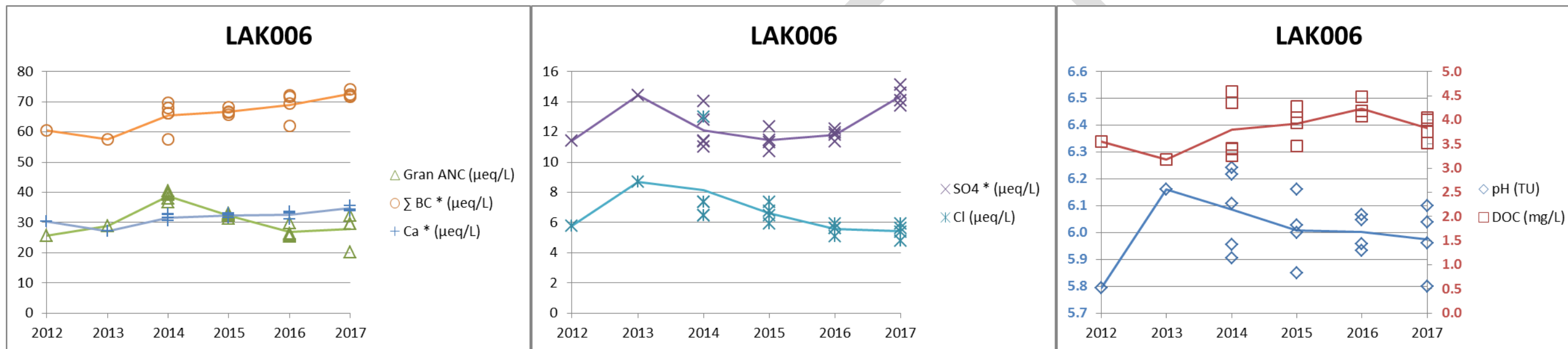
DRAFT

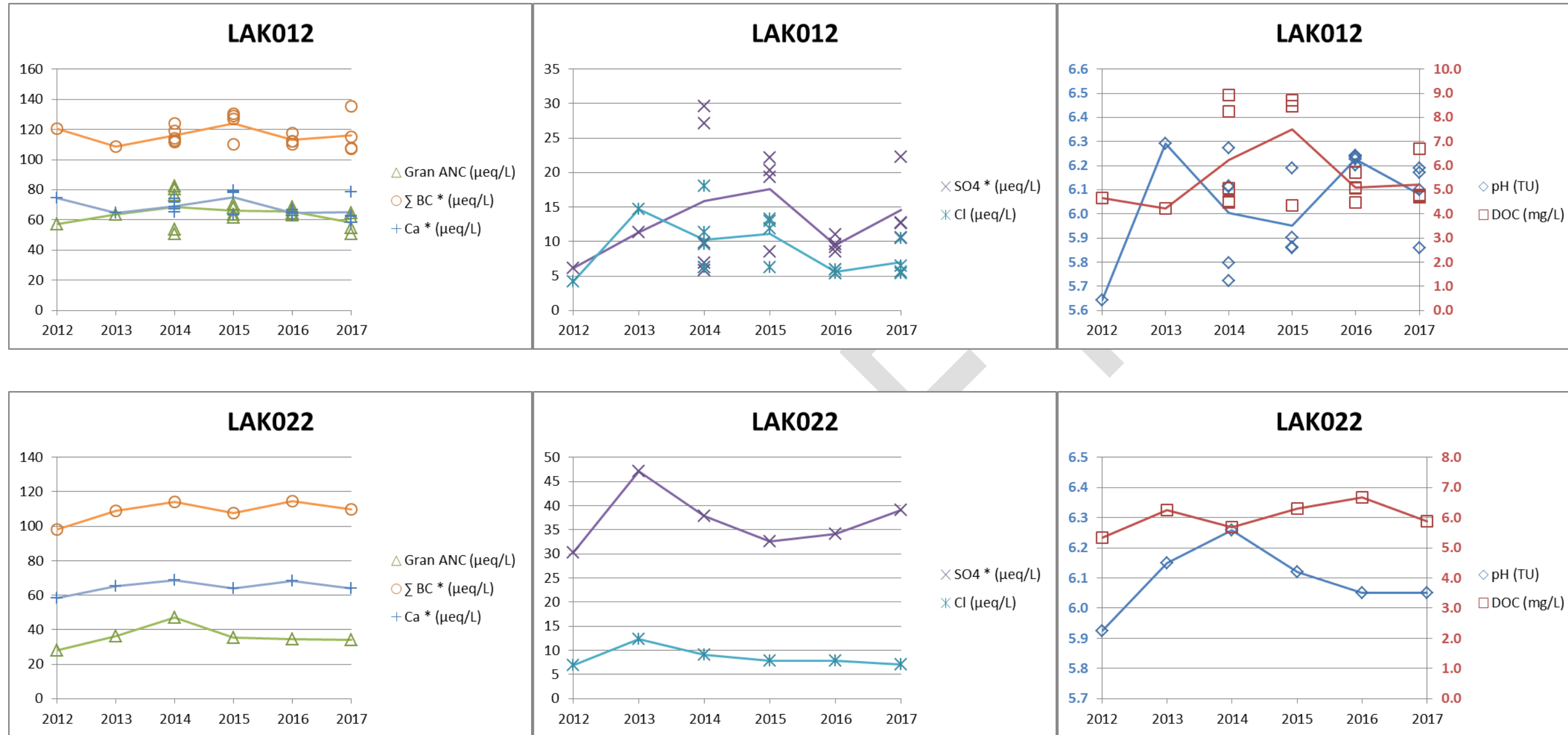
Appendix 2: Changes in Ion Concentrations from 2012 to 2017

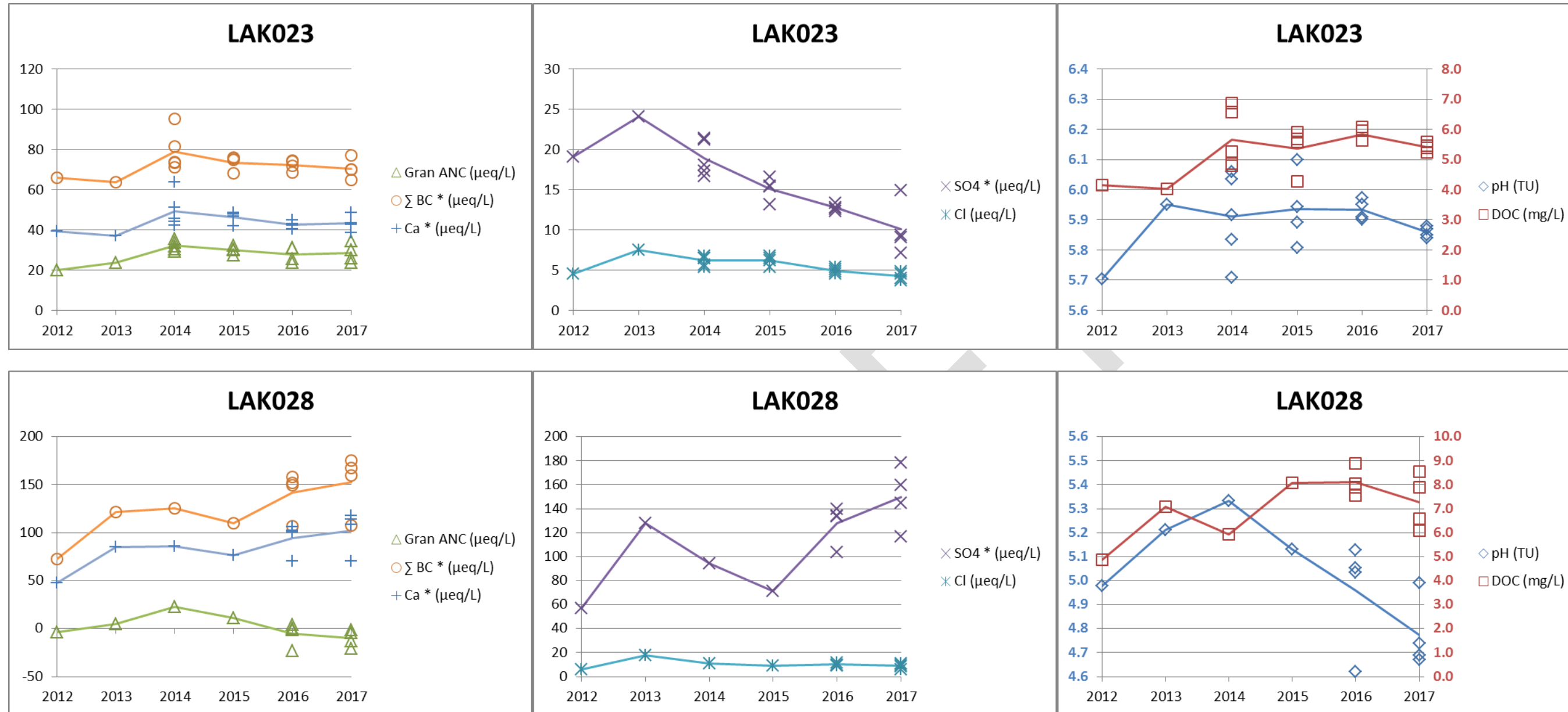
For each of the EEM lakes, the figures in this appendix show the inter-annual changes in six major water chemistry metrics from 2012 to 2017: Gran ANC, base cations and calcium (left panel), sulfate and chloride (centre panel), and pH and dissolved organic carbon (right panel). The selection of each 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. The axis for pH does not 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 for individual lakes across the sampling record and determining whether similar patterns are observed across lakes and/or metrics.

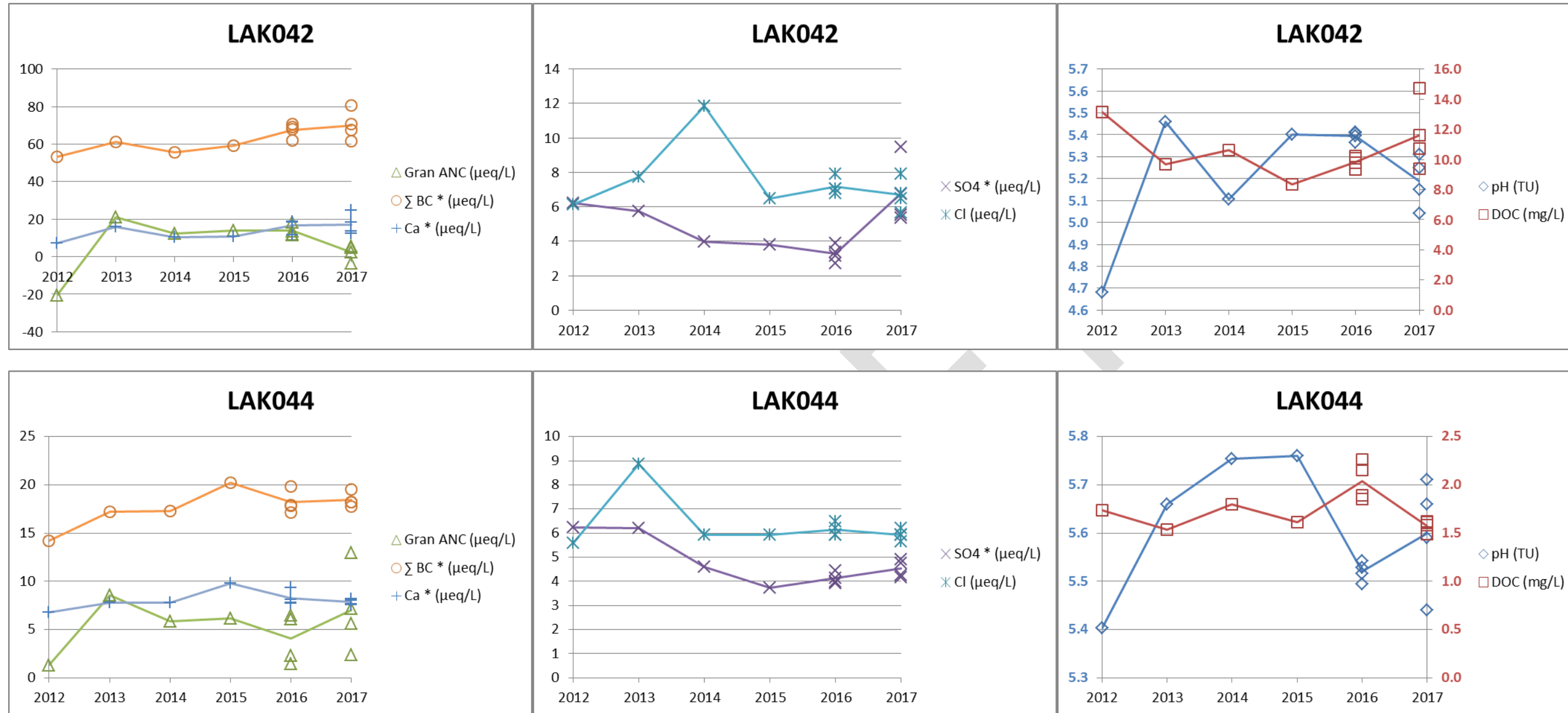
These figures show the results for all of the sampling events for each lake in each year, whether that included multiple within-season samples or only a single annual sample. The points represent the values for individual sampling events. The solid lines represent the annual trend, based on either the single annual sample or the average of all the within-season samples, as appropriate for the lake and year. For the sensitive lakes (the only lakes where intensive, within-season sampling was conducted), the point markers have been made hollow so that it is possible to see if there were multiple within-season samples with similar values.

Sensitive Lakes

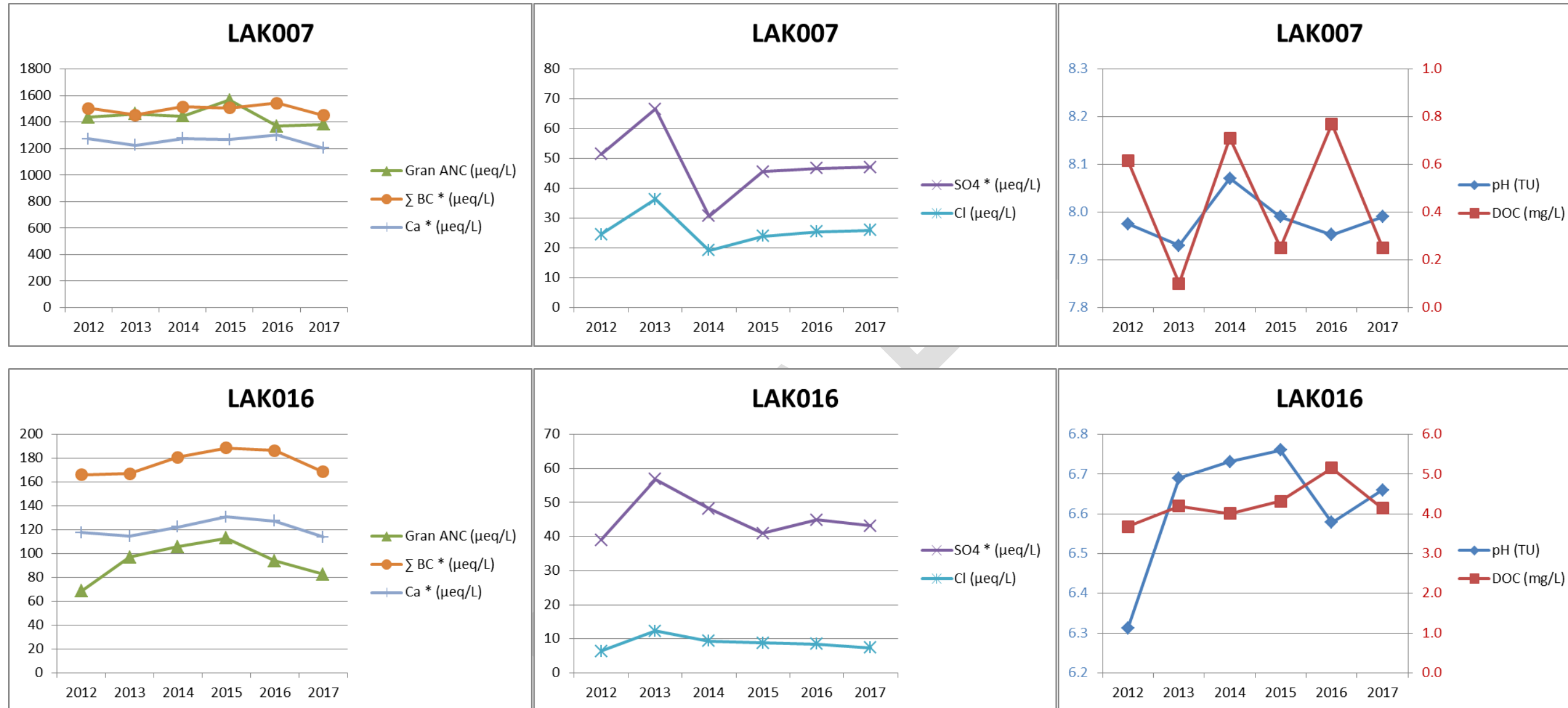


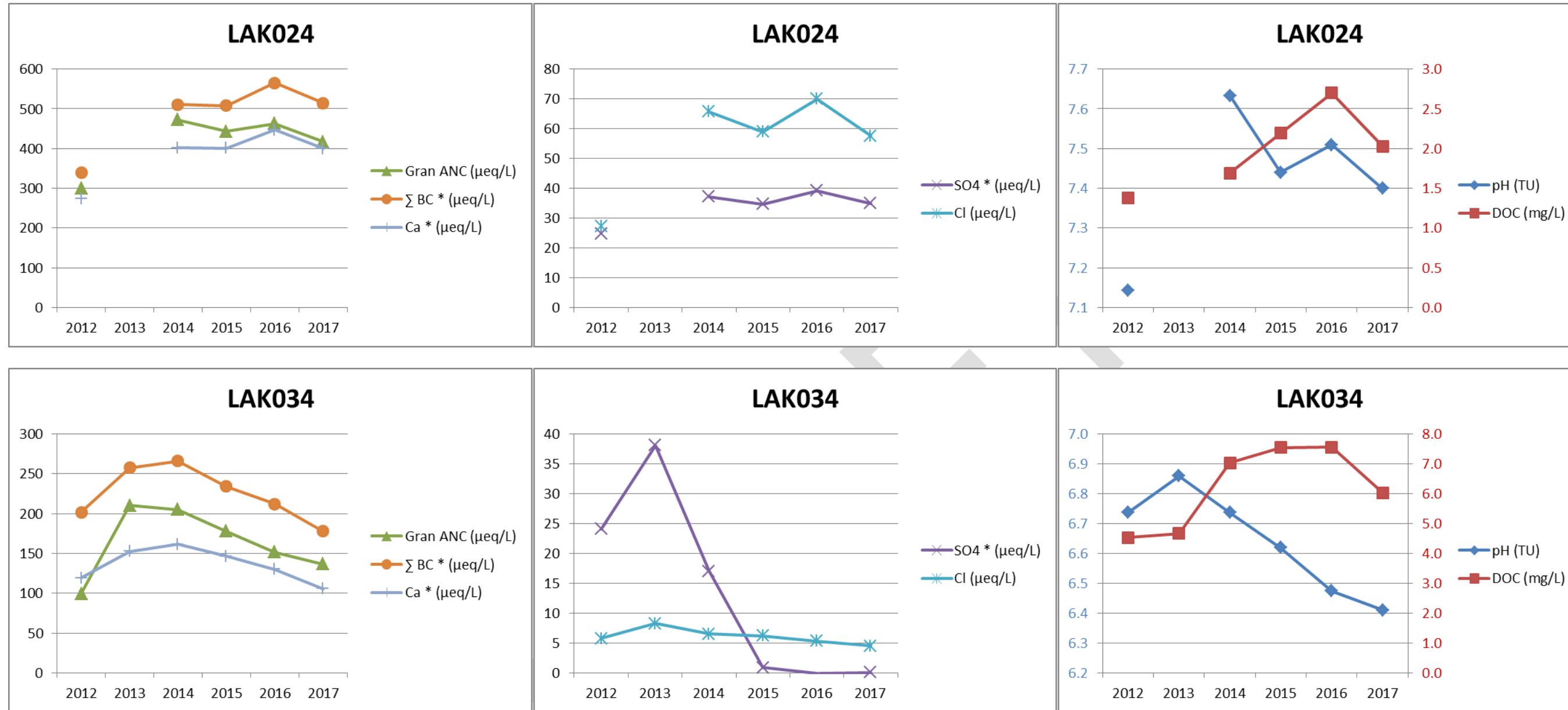




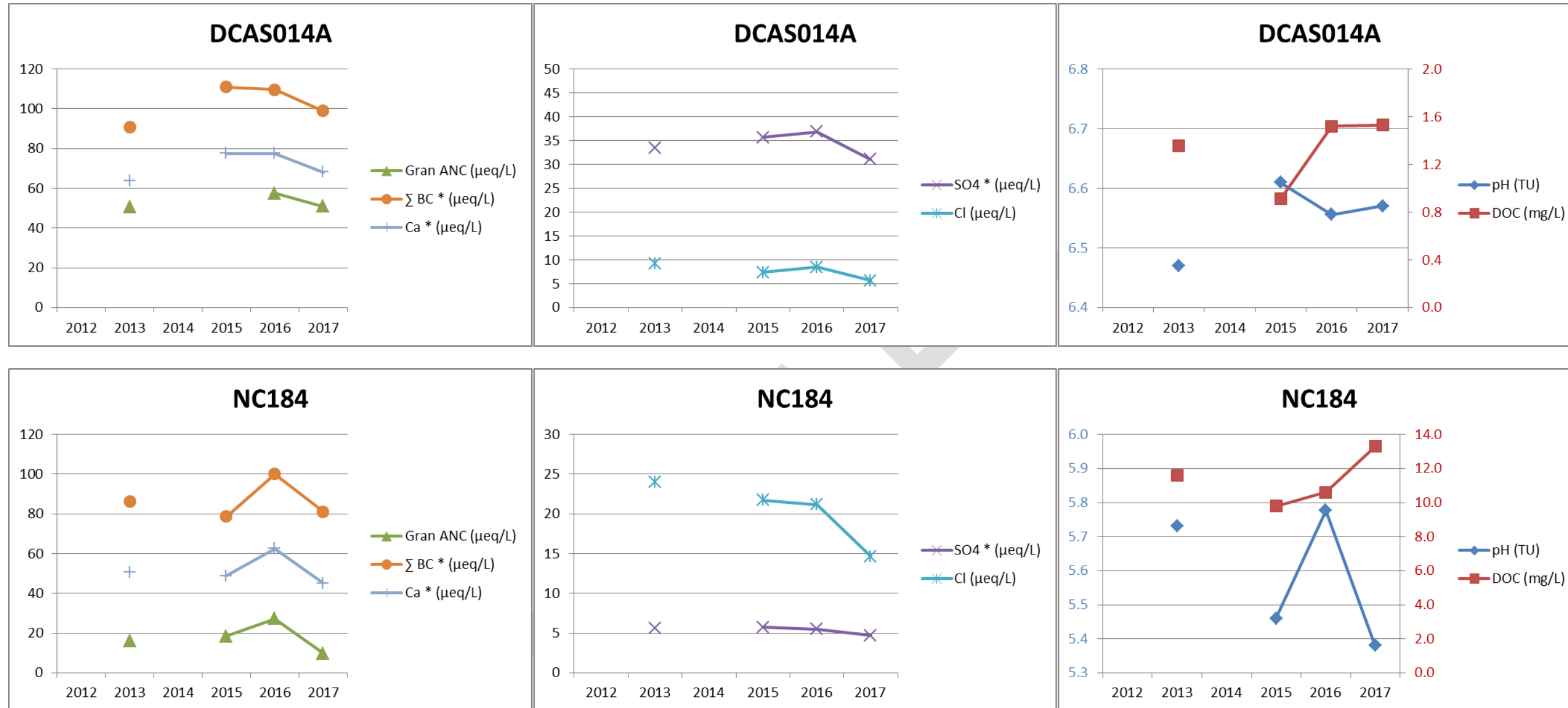


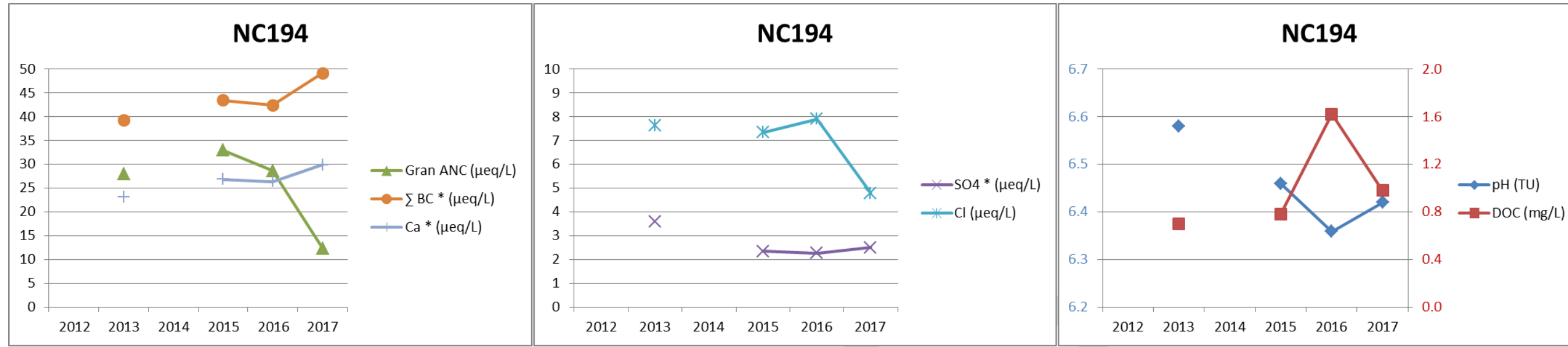
Less Sensitive Lakes





Control Lakes





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Appendix 3: Kitimat River Water Quality Sampling

The following water quality sampling was conducted at the Rio Tinto intake from the Kitimat River (see Sections 2.9 and 3.8).

Parameter	Units	BC Drinking Water Quality Guidelines	Sampling Date					
			26-Jun-17	31-Aug-17	30-Sep-17	9-Oct-17	30-Nov-17	31-Dec-17
Dissolved Sulphate (SO ₄)	mg/l	500		2.04	1.85	1.95		3.94
Fluoride (F)	mg/l	1.5	0.032	0.028	0.036	0.037	0.041	0.017
Nitrate plus Nitrite (N)	mg/l			0.04	0.049	0.049	0.085	0.11
Total Suspended Solids	mg/l		<4.0	<4.0	8.5	53.8	0	0
Dissolved Calcium (Ca)	mg/l		4.02	3.75	5.27	5.03	4.88	7.34
Dissolved Magnesium (Mg)	mg/l		0.384	0.398	0.588	0.598	0.579	0.883
Dissolved Hardness (CaCO ₃)	mg/l			11	15.6	15	14.6	22
pH			7.33	7.45	7.56	7.32	7.28	7.41
Dissolved Aluminum (Al)	mg/l	9.5	0.0217	0.0225	0.0452	0.054	0.0931	0.0234
Dissolved Antimony (Sb)	mg/l		<0.00050		<0.00050	<0.00050	<0.00050	<0.00050
Dissolved Arsenic (As)	mg/l	0.01	<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Barium (Ba)	mg/l		0.0081		0.0113	0.0108	0.0108	0.0153
Dissolved Beryllium (Be)	mg/l		<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Bismuth (Bi)	mg/l		<0.0010		<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Boron (B)	mg/l		<0.050		<0.050	<0.050	<0.050	<0.050
Dissolved Cadmium (Cd)	mg/l	0.005	<0.000010		<0.000010	<0.000010	<0.000010	<0.000010
Dissolved Chromium (Cr)	mg/l		<0.0010		<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Cobalt (Co)	mg/l		<0.00020		<0.00020	<0.00020	<0.00020	<0.00020
Dissolved Copper (Cu)	mg/l	1	0.00312		0.0143	0.00727	0.0114	0.0042
Dissolved Iron (Fe)	mg/l	0.3	0.0427		0.0837	0.088	0.128	0.115
Dissolved Lead (Pb)	mg/l	0.01	<0.00020		<0.00020	<0.00020	<0.00020	<0.00020
Dissolved Lithium (Li)	mg/l		<0.0020		<0.0020	<0.0020	<0.0020	<0.0020
Dissolved Manganese (Mn)	mg/l	0.05	0.004		0.0068	0.0047	0.0148	0.0219
Dissolved Mercury (Hg)	mg/l	0.001	<0.000050					
Dissolved Molybdenum (Mo)	mg/l	0.25	<0.0010		<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Nickel (Ni)	mg/l		<0.0010		<0.0010	<0.0010	<0.0010	<0.0010
Dissolved Selenium (Se)	mg/l	0.01	<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Silicon (Si)	mg/l		1.58		2.39	2.01	2.55	3.2
Dissolved Silver (Ag)	mg/l		<0.000020		<0.000020	<0.000020	<0.000020	<0.000020
Dissolved Strontium (Sr)	mg/l		0.0235		0.0322	0.0312	0.0281	0.0425
Dissolved Thallium (Tl)	mg/l		<0.000010		<0.000010	<0.000010	<0.000010	<0.000010
Dissolved Tin (Sn)	mg/l		<0.0050		<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Titanium (Ti)	mg/l		<0.0050		<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Uranium (U)	mg/l		<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Vanadium (V)	mg/l		<0.0050		<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Zinc (Zn)	mg/l	5	<0.0050		<0.0050	<0.0050	<0.0050	<0.0050
Dissolved Zirconium (Zr)	mg/l		<0.00010		<0.00010	<0.00010	<0.00010	<0.00010
Dissolved Potassium (K)	mg/l		0.354		0.605	0.548	0.429	0.658
Dissolved Sodium (Na)	mg/l		0.807		1.27	1.13	1.29	2.7
Dissolved Sulphur (S)	mg/l		<3.0		<3.0	<3.0	<3.0	<3.0

Appendix 4: Patterns of Water Chemistry Change During October 2017

