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B.C. Works SO_2 EEM Program – Technical Memo W11

Aquatic Ecosystems Actions and Analyses

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1 Introduction

This Technical Memo provides additional information on the data and analyses in support of the 2022 requirements for the Aquatic Ecosystems component of the B.C. Works' Sulphur Dioxide Environmental Effects Monitoring (EEM) Program (SO_2 EEM Phase III Plan, ESSA et al. 2023). These data and analyses thus provide the foundation for Section 3.4 in the SO_2 EEM Program 2022 Annual Report.

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 SO_2 Technical Assessment Report (STAR) (ESSA et al. 2013), the Kitimat Airshed Assessment (KAA) (ESSA et al. 2014a) and the 2019 EEM Comprehensive Review (ESSA et al. 2020a). 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, 2018; Limnotek 2019, 2020, 2021, 2022, 2023). Wherever possible, the description of methods in this Technical Memo refers to these reports instead of repeating information that is already well-documented elsewhere.

The following four documents (as described above) are listed here because they are referenced throughout this Technical Memo, often without their full citation:

- The STAR (ESSA et al. 2013)
- The KAA (ESSA et al. 2014a)
- 2019 SO_2 EEM Comprehensive Review (ESSA et al. 2020a)
- The SO_2 EEM Phase III Plan (ESSA et al. 2023)

2 Methods

2.1 Water Chemistry Sampling

EEM Lakes

The SO_2 Phase III EEM Program sampling plan includes eleven lakes: seven sensitive lakes, one less sensitive lake, and three control lakes (ESSA et al. 2023). The three control lakes (NC184, NC194 and DCAS14A) are all located outside of the zone of sulphur deposition from B.C. Works, and have pre-KMP baseline data for 2013 from sampling as part of the KAA (ESSA et al. 2014a). The five lakes that were unable to be sampled in 2020 (due to COVID-related constraints on helicopter flights) were sampled again in 2021 and 2022 as per previous years.

LAK027 was added for one-time sampling in 2021, as agreed to by ENV and Rio Tinto in May 2021. The intent was to resample one of the STAR lakes located relatively close to the smelter to check the validity of the conclusions made in the STAR, based on sampling completed in 2012, nine years prior to 2021. LAK027 was chosen because it was the only candidate that was moderately sensitive, whereas all the other lakes in the southern portion of the Kitimat Valley were determined to be insensitive based on the sampling during the STAR (except for LAK028, which was included in the SO_2 EEM Program because of its sensitivity). LAK027 was sampled again in 2022, as per the recommendation in the SO_2 EEM Program 2021 EEM Annual Report:

We recommend sampling LAK027 again in 2022. The widely-observed storm-driven dilution event negated the ability of this year's sampling to provide a meaningful comparison against the initial STAR data as intended.

In 2022, Limnotek sampled the eleven EEM lakes plus LAK027 according to the 2022 Aquatics Work Plan. The sampling methodology is described in detail in Limnotek (2023). Table 2-1~~Table 2-1~~ summarizes the sampling history of these 12 lakes. Figure 2-1~~Figure 2-1~~ shows a map of the lakes sampled in 2022.

Table 2-1. Summary of sampling sites within the SO_2 EEM Phase III Program. The rationale for lakes included in the SO_2 EEM Phase III Program is described in ESSA et al. 2023.

Sample Site	Year of Sampling											
	2012 STAR	2013 EEM	2014 EEM	2015 EEM	2016 EEM	2017 EEM	2018 EEM	2019 EEM	2020 EEM	2021 EEM	2022 EEM	
LAK006	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	EEM sensitive lake, included in Phase III
LAK012	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	EEM sensitive lake, included in Phase III
LAK022	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	EEM sensitive lake only accessible by helicopter, included in Phase III.
LAK023	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	EEM sensitive lake, included in Phase III
LAK028	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	EEM sensitive lake, included in Phase III
LAK042	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	EEM sensitive lake, included in Phase III
LAK044	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	EEM sensitive lake, included in Phase III
LAK016	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	EEM less sensitive lake, included in Phase III.
LAK027	✓									✓	✓	Resampling of STAR lake at southern end of valley.
NC184		✓†		✓	✓	✓	✓	✓		✓	✓	EEM control lakes added to EEM in 2015. Only accessible by helicopter, included in Phase III.
NC194		✓†		✓	✓	✓	✓	✓		✓	✓	
DCAS14A		✓†		✓	✓	✓	✓	✓		✓	✓	

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

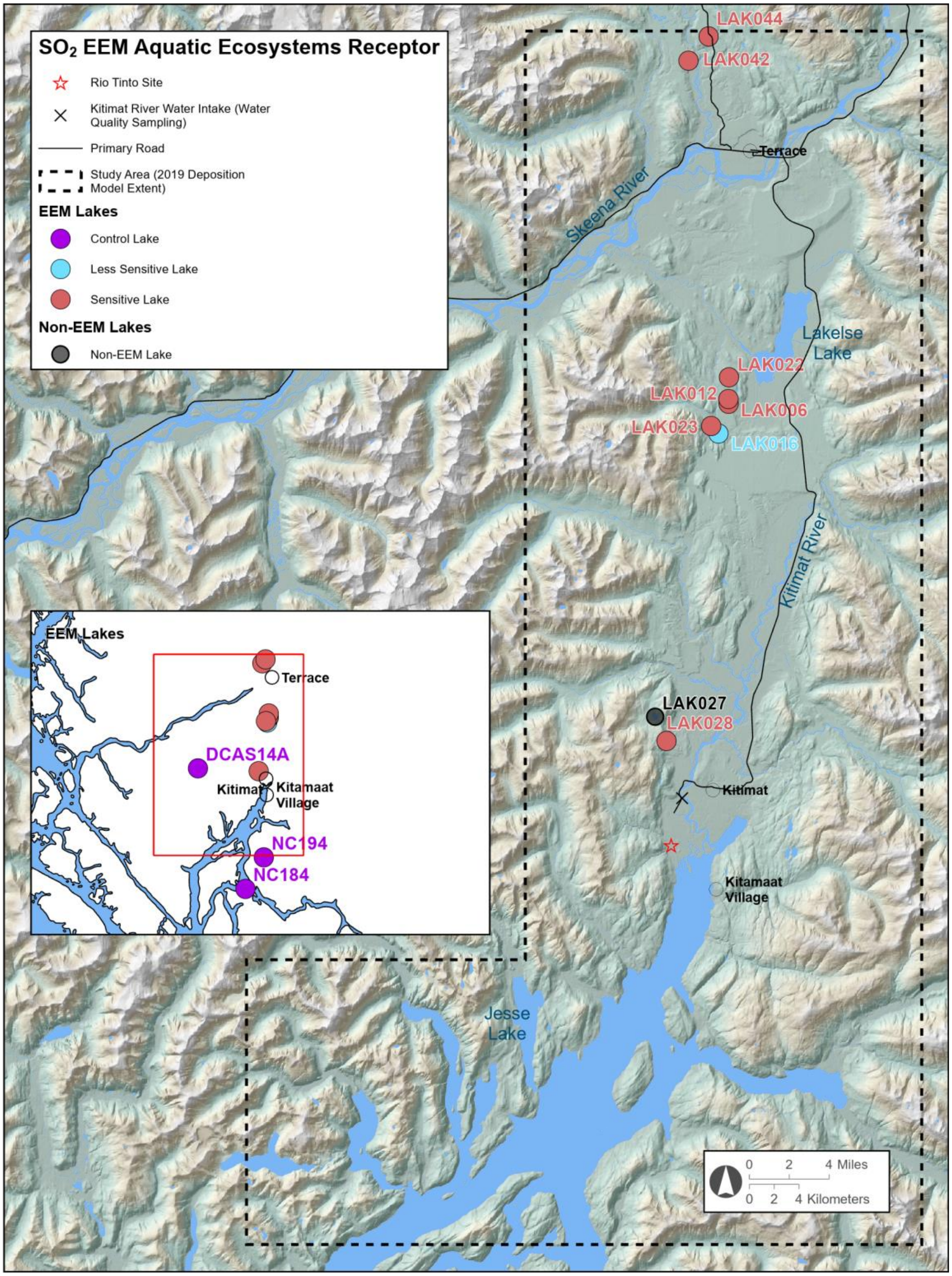


Figure 2-1. Location of the lakes in the EEM Program, including seven sensitive lakes (red), one less sensitive lake (blue) and three control lakes (purple). LAK027 was resampled in 2022 to compare with the STAR results.

Sampling frequency

Sampling frequency remained the same as last year:

- The sensitive lakes LAK006, LAK012, LAK023, LAK028, LAK042, and LAK044 on four occasions within the fall index period
- Sensitive lake LAK022, less sensitive lake LAK016, and the three control lakes were each sampled once during the Fall index period (as per previous years)
- LAK027 (not part of current SO_2 EEM Program) was sampled once
- LAK006 and LAK028 had five additional samples with full chemistry analysis taken over June through early September, to assess seasonal variability in lake chemistry

Continuous monitoring

Two lakes (LAK006, LAK028) had continuous monitoring of surface water pH, temperature and lake levels. LAK028 also had a similar instrument installed at depth. This work was planned, implemented and documented by Limnotek. The methods and results for 2022 are reported in Limnotek (2023).

Water chemistry data

There were no differences in the water chemistry analyses completed from the 2022 sampling compared to previous years. Continuing from 2020, analyses of Gran ANC are now *only* performed by the BASL facility (University of Alberta).

Al_{im} was not measured during this year's sampling season. In the SO_2 EEM Program 2020 Annual Report, we recommended discontinuing the measurement of Al_{im} going forward. These changes were not applied in the 2021 season because the field planning and purchasing was already in place for that year. This recommendation was therefore not implemented until 2022.

Integrating laboratory measurements of pH and Gran ANC from Trent and BASL laboratories

The planned transition of laboratory analysis of pH and Gran ANC from Trent University to the BASL laboratory at the University of Alberta was completed in 2020. In 2019, duplicate samples were sent to both laboratories to facilitate cross-laboratory comparisons (see Limnotek 2020).

To facilitate analyses over the entire period of record, we need an "integrated" data series for each of the two metrics. As in the SO_2 EEM Program 2020 Annual Report, we constructed an integrated time series by imputing Trent values for pH and Gran ANC for 2021 based on the regression of Trent values vs. BASL values from the 2019 data. This method was recommended and developed by Dr. Carl Schwarz (retired professor of statistics from Simon Fraser University) and is described in detail in the SO_2 EEM Program 2020 Annual Report.

2.2 Empirical Changes in Water Chemistry

The methods applied for examining empirical changes are the same as described in the last several years (except for the analysis of inorganic aluminum, which has been discontinued as it does not contribute novel information about lake chemistry).

2.3 Statistical Analyses of Changes in Water Chemistry

The 2019 Comprehensive Review performed an extensive series of statistical analyses of changes in water chemistry and concluded that the results from the Bayesian statistical analyses provided the greatest ability to assess the level of support for different hypotheses of chemical change. The 2019 Comprehensive Review further recommended that these analyses be re-run on an annual basis to assess status and detect any anomalous patterns. This annual report represents the fourth iteration of re-running those analyses with more recent monitoring data. These methods are described in detail in Appendix F of the 2019 Comprehensive Review (ESSA et al. 2020b) (see Bayesian Method 1 especially). The key metrics of interest are the differences in lake chemistry between the post-KMP average for the last three years (2020-2022) and the pre-KMP baseline (2012 for the sensitive and less sensitive lakes; 2013 for the control lakes). For the lakes that were not sampled in 2020, the post-KMP period used to compute average lake chemistry is still 2020-2022 and therefore only based on 2 years of data (2021 and 2022). Appendix 3 includes sensitivity analyses that examine the effect of using an alternative baseline representing the transition period as operations at the old smelter were wound down (2012-2014).

The results of the Bayesian statistical analyses are expressed in terms of: a) the % belief that the post-KMP values have exceeded the *level of protection* thresholds, and b) the % belief that the changes from the baseline period to the post-KMP period have exceeded the *change limit* thresholds. As applied in the 2019 Comprehensive Review, the % belief values are classified as low (< 20%), moderate (20% to <80%), or high (≥ 80%). This classification is done both for ease of interpretation, and to integrate the analyses for the two-threshold structure of the CBANC KPI and informative indicators into a single assessment for each indicator for each lake. As described in the Phase III Plan, the acidification indicators (CBANC, pH, Gran ANC and BCS) are only considered to be in exceedance if **both** thresholds are exceeded (i.e., the *level of protection* and the *change limit* thresholds). The single, integrated assessment of each of those indicators is determined according to the rules:

1. If the result for **either** threshold is **"low"**, then the overall assessment is **"low"**
2. The results for **both** thresholds must be **"high"** for an overall assessment of **"high"**
3. If result for **either** threshold is **"moderate"** and the results for the other threshold are "moderate" or "high", then the overall assessment is **"moderate"**.

As described in the SO_2 EEM Program Phase III Plan, the two-threshold structure avoids creating false positives by simultaneously considering the two dimensions of importance to aquatic organisms – the absolute level and the relative change in the water chemistry metrics used as acidification indicators.

Appendix 4 includes results of sensitivity analyses for the uncertainty associated with the imputation procedure associated with developing integrated data series for pH and Gran ANC following the transition of laboratories (details in Section 2.1).

We also evaluated differential trends between the sensitive lakes and the control lakes using the before-after control-impact (BACI) analysis methods described in the 2019 Comprehensive Review (i.e., Method 3: BACI using mean values). Using this method, we evaluated the sensitive lakes individually and as a group, for both CBANC (as an informative method, as the KPI is not based on this statistical approach) and the pH informative indicator.

2.4 Environmental Data

This section includes supplementary environmental observations or data utilized in the interpretation of the water chemistry results (see Section 4.3).

Providing the precipitation context for 2022 was more challenging this year than in previous years due to extensive missing data from climate stations. In past years, we have characterized precipitation patterns relevant to the interpretation of water chemistry sampling results by using the precipitation data for July to October from the Kitimat 2 and Terrace PCC climate stations. Those were the two stations in the valley with the most complete data as well as representing two different regions with the study area. But in 2022 (at the time of accessing the climate data[1]), the Terrace PCC station only has precipitation observations for 36% of the days within the July-October period, and the Kitimat 2 station only has precipitation observations for 22% of the period, including only two observations in September and zero observations in October. The extent of missing data rendered any comparisons with the precipitation data shown in previous years completely meaningless.

Instead, we are using the Terrace A station as an indicator of precipitation levels in the study area because it had 98% complete observation for July-October 2022. We have not used the Terrace A in previous years because it generally had a less complete record than the Terrace PCC station. For 2020, Terrace A has zero observations for July through the first few days of August, therefore we are using a comparison period of August 5 to October 31. We are excluding 2021 because the data coverage was still only 34% in this revised period, whereas it was 100%, 99%, and 98% for 2019, 2020, and 2022, respectively. In this approach, we have an apples-to-apples comparison of 2022 precipitation to at least 2019 and 2020, which were previously identified as being a significantly dry year and a significantly wet year. Having data only for Terrace and no appropriate data for Kitimat is a gap, albeit unavoidable.

Precipitation data from the Terrace A climate station shows that 2022 had similar total precipitation within the comparison period (August 5 to October 31) as 2019, which was a notably dry year (Table 2-2Table 2-2). However, the precipitation was significantly concentrated in October (~60%), making October notably wetter than either 2019 (dry year) or 2020 (wet year). By contrast, the total rainfall in September 2022 was 71 mm, which is 47% less than the 135 mm in 2020 and 28% less than the 99 mm in 2019.

During the two weeks prior to the annual sampling date on October 2, 2022 (i.e., the date in which all lakes are sampled), the Terrace A station measured only 21 mm of rainfall, compared to 118 mm and 67 mm in the 2-week periods before the 2020 and 2019 annual sampling dates, respectively. For reference, as reported in the SO_2 EEM Program 2021 Annual Report, the Kitimat 2 station measured 307 mm of rainfall and the Terrace PCC station measured 184 mm in the two weeks prior to the annual sampling date[2].

[1] Source: Data accessed via Environment Canada's *Historical Climate DataClimate data extraction tool* web portal (https://climate-change.canada.ca/climate-data/#/http://climate.weather.gc.ca), Accessed: March 2023.

[2] Note that these are different stations than reported this year. Consistent station-to-station comparisons are not possible for 2021 versus 2022 for reasons discussed in the text.

Figure 2-2Figure 2-2 shows that although the total summer-fall precipitation at the Terrace A station in 2022 was generally comparable to the dry year of 2019 (e.g., bottom row of Table 2-2Table 2-2), it was drier than 2019 when considering the period prior to lake sampling (first two rows of Table 2-2Table 2-2). The last of the lake chemistry samples were collected on October 20 and then 140 mm of rain (representing 74% of October rainfall and 44% of August-October rainfall) fell during October 23-31.

Table 2-2. Total Monthly Precipitation (mm) at Terrace A for 2019-2022.

	2019	2020	2021	2022
	Terrace A	Terrace A	Terrace A	Terrace A
August (5-31)	67.3	160.4	*Excluded due to excessive missing data*	60.6
September	99.4	142.8		71.0
October	138.6	134.8		189.9
Total	305.3	438.0	*n/a*	321.5

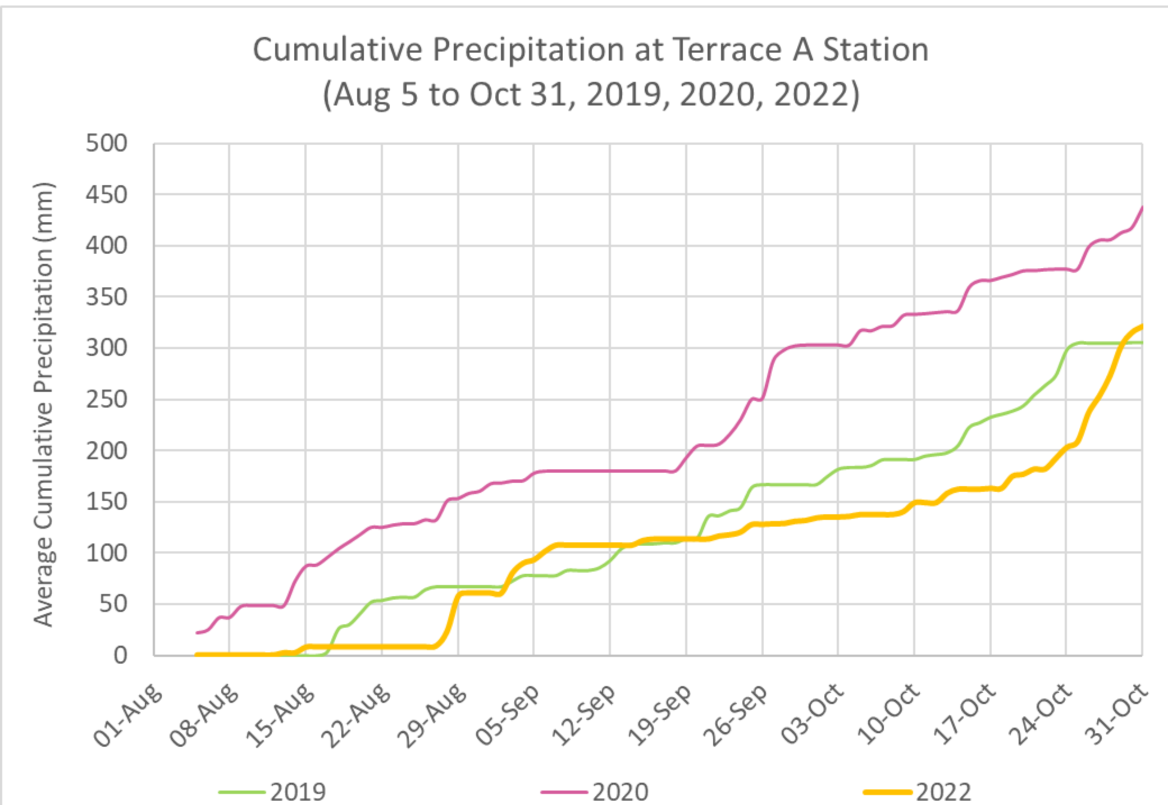


Figure 2-2. Cumulative precipitation at Terrace A station for August 5 to October 31 in 2019, 2020, and 2022.

2.5 Episodic Acidification

We reviewed the data record from the continuous pH monitors installed in LAK006 and LAK028 to identify any notable drops in pH. If any such changes were observed, we compared those results with the lake-level data to determine if they appeared to be correlated with high inflows to the lake.

2.6 Alignment of Evidentiary Framework with EEM Phase III Indicators

The "Simple Evidentiary Framework" developed in the 2019 Comprehensive Review and subsequently built into the SO_2 EEM Program Phase III Plan only considered post-KMP changes in pH and ANC[3] (relative to pre-KMP conditions), especially relative to the *change limit* thresholds, but did not consider the post-KMP state of either of those metrics with respect to the *level of protection* thresholds. The SO_2 EEM Program Phase III Plan made an important advance, moving to a two-threshold structure for the KPI and the pH and ANC informative indicators that consider both relative change and the absolute level of those indicators.

To be consistent with the SO_2 EEM Program Phase III Plan, we revised the Evidentiary Framework in the SO_2 EEM Program 2020 Annual Report by adding an assessment node associated with the *level of protection* threshold (Figure 2-3~~Figure 2-3~~). The new node was inserted earlier in the logic sequence than the two nodes assessing the level of change. In the two-threshold structure for the KPI and informative indicators, neither of the thresholds takes precedence – an exceedance of the indicator requires that both thresholds are exceeded with a high percent belief. Therefore, there is no inherent sequence between evaluating the *change* limit and *level of protection* thresholds. However, in the Evidentiary Framework, there is an additional node that considers whether there has been any change in the indicator prior to assessing against the *change limit* threshold, which makes the framework more precautionary, so we believe it made more sense to have the *level of protection* node earlier in the sequence than the two change-based nodes.

[3] Gran ANC in the 2019 Comprehensive Review; CBANC in the SO_2 EEM Program Phase III Plan (consistent with the revised KPI).

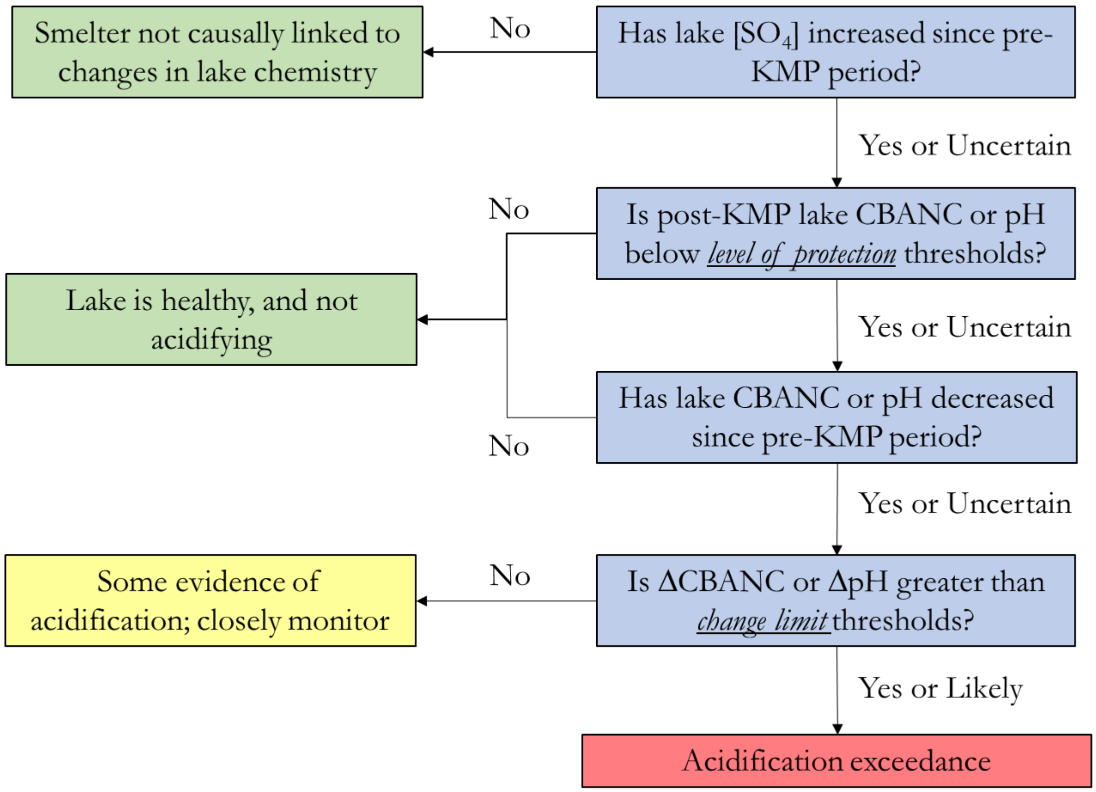


Figure 2-3. The Evidentiary Framework. The framework developed in the 2019 Comprehensive Review was revised in the SO_2 EEM Program 2020 Annual Report order to align with the two-threshold structure for the KPI and informative indicators in the SO_2 EEM Program Phase III Plan.

3 Results

3.1 Empirical Changes in Water Chemistry

Empirical changes in CBANC, Gran ANC, BCS, pH, [SO_4^{2-}], DOC, sum of base cations, chloride, and calcium are shown in Table 3-1~~Table 3-1~~. A map of the observed changes in [SO_4^{2-}], CBANC, and pH at the EEM lakes is shown in Figure 3-1~~Figure 3-1~~. Changes are reported in terms of the difference between the post-KMP average (2020-2022) and the pre-KMP baseline (2012 for the sensitive and less sensitive lakes; 2013 for the control lakes). 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 acquired from a given lake in a given year.

Unlike the annual reports prior to the 2019 Comprehensive Review, the annual changes between individual years are no longer reported and analyzed. As already stated in previous years (e.g., ESSA 2018, Technical Memo W07), year-to-year changes should be interpreted cautiously:

> *"… annual changes should be interpreted with substantial caution due to the combination of large natural variation (both within and between years) and*

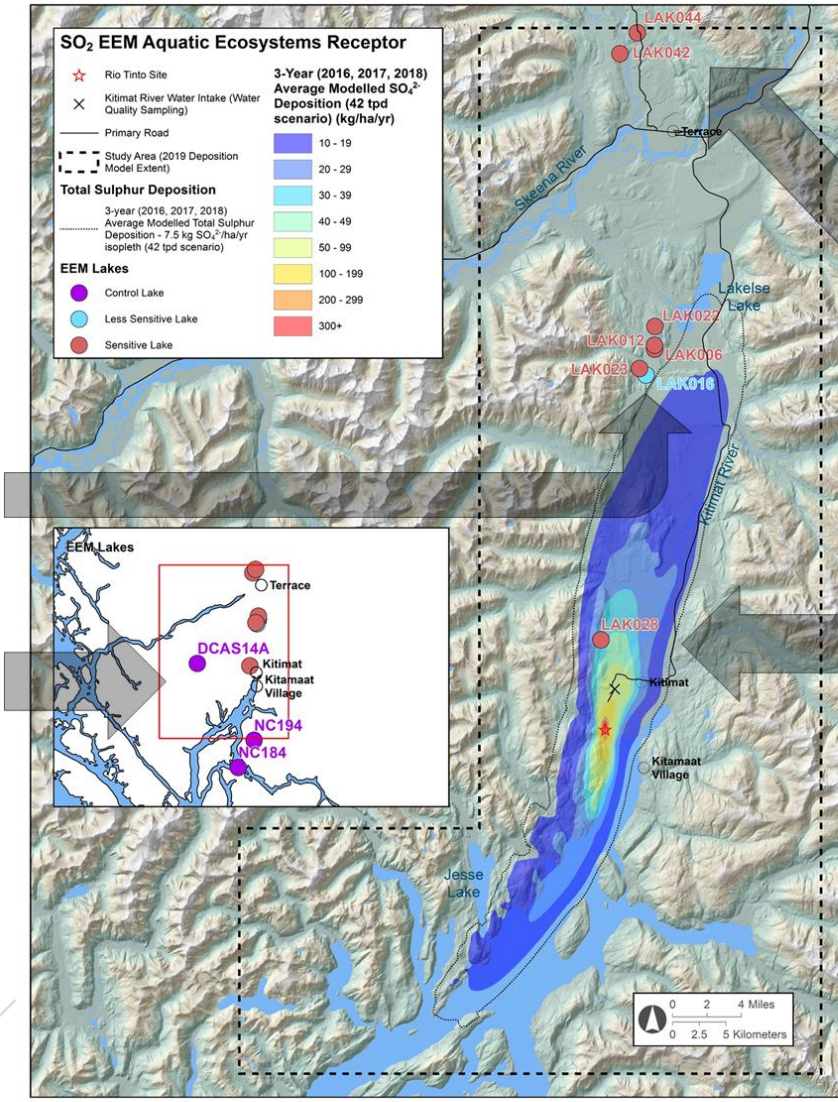
limitations on measurement precision… multiple years of observations are required to reliably detect changes in mean pH, Gran ANC and SO4; it is risky to draw conclusions based only on annual changes".

Furthermore, in the December 2018 workshop on the terms of reference for the SO_2 EEM Program Comprehensive Review, the ENV external acidification expert recommended that we stop reporting annual changes because inter-annual variability in lake chemistry is too variable to make any meaningful interpretation of the changes between two years.

Table 3-1. Empirical changes in CBANC, Gran ANC, BCS, pH, SO_4^{2-}, DOC, base cations, chloride, calcium, and NO_3 for EEM lakes. These values represent the difference between the average of the post-KMP period (2020-2022) and the 2012 baseline. Numbers shown are the value in the later period minus the value in the earlier year. Increases are shaded in green; decreases are shaded in red. The Gran ANC and pH values are based on the "integrated" time series (i.e., values from the Trent University laboratory from 2012 to 2019 with the 2020, 2021, and 2022 values imputed from the values measured by the BASL laboratory ("integ"); see details in Section 2.1). Signs after each number show the direction of change in the reported values since the SO_2 EEM Program 2021 Annual Report (i.e., [+] = increase; [-] = decrease; [ ] = identical value).

SITE	CBANC (µeq/L)	Gran ANC (integ) (µeq/L)	BCS (µeq/L)	pH (integ)	SO4* (µeq/L)	DOC (mg/L)	∑ BC* (µeq/L)	Cl (µeq/L)	Ca* (µeq/L)
LAK006	20.2 [+]	11.6 [+]	14.2 [+]	0.2 [ ]	3.5 [-]	1.2 [+]	23.9 [+]	0.6 [-]	13.6 [+]
LAK012	4.1 [+]	11.3 [+]	-7.9 [+]	0.3 [ ]	9.0 [-]	2.4 [ ]	13.4 [+]	3.0 [-]	6.9 [+]
LAK022	4.1 [+]	-1.6 [-]	1.5 [ ]	-0.2 [-]	6.5 [-]	0.5 [ ]	10.8 [+]	0.3 [-]	5.7 [-]
LAK023	12.0 [-]	3.8 [+]	3.8 [+]	0.1 [ ]	-2.0 [-]	1.6 [-]	10.5 [+]	0.3 [-]	7.3 [-]
LAK028	-2.9 [+]	5.4 [+]	-17.9 [+]	0.0 [ ]	58.5 [-]	3.0 [+]	56.6 [+]	2.9 [-]	41.7 [-]
LAK042	17.7 [+]	18.5 [+]	10.6 [+]	0.2 [ ]	2.0 [-]	1.4 [-]	19.8 [+]	-0.5 [-]	11.2 [-]
LAK044	8.1 [+]	3.0 [ ]	7.0 [-]	0.2 [ ]	-2.1 [-]	0.2 [-]	6.2 [+]	0.5 [-]	1.9 [-]
Total ↑	**6**	**6**	**5**	**5**	**5**	**7**	**7**	**6**	**7**
Total ↓	**1**	**1**	**2**	**2**	**2**	**0**	**0**	**1**	**0**
LAK016	12.5 [+]	23.0 [+]	-1.5 [+]	0.0 [ ]	11.6 [ ]	2.8 [-]	25.0 [-]	1.4 [-]	16.3 [+]
Total ↑	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**
Total ↓	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**
DCAS14A	13.8 [-]	1.3 [-]	11.6 [-]	-0.3 [ ]	-3.8 [-]	0.5 [ ]	7.8 [-]	-2.6 [-]	3.5 [-]
NC184	-7.2 [-]	-1.2 [-]	-4.7 [-]	-0.3 [ ]	-1.7 [-]	-0.5 [+]	-9.0 [-]	-6.9 [-]	-4.7 [-]
NC194	0.3 [-]	-3.6 [-]	-1.2 [-]	-0.5 [-]	-1.6 [-]	0.3 [-]	-1.2 [-]	-2.1 [-]	-0.6 [-]
Total ↑	**2**	**1**	**1**	**0**	**0**	**2**	**1**	**0**	**1**
Total ↓	**1**	**2**	**2**	**3**	**3**	**1**	**2**	**3**	**2**

SO4*, BC* and Ca* mean that concentrations of sulfate, base cations and calcium were each reduced using the ratio of each to chloride in seawater, to account for marine sources.



LAKE	2012 to 2020-22 ΔSO_4^{2-}	Δ CBANC	ΔpH
Lak006	3.5	20.2	0.2
LAK012	9.0	4.1	0.3
LAK022	6.5	4.1	-0.2
LAK023	-2.0	12.0	0.1
LAK016	11.6	12.5	0.0

LAKE	2012 to 2020-22 ΔSO_4^{2-}	Δ CBANC	ΔpH
DCAS14A	-3.8	13.8	-0.3
NC184	-1.7	-7.2	-0.3
NC194	-1.6	0.3	-0.5

LAKE	2012 to 2020-22 ΔSO_4^{2-}	Δ CBANC	ΔpH
LAK042	2.0	17.7	0.2
LAK044	-2.1	8.1	0.2

LAKE	2012 to 2020-22 ΔSO_4^{2-}	Δ CBANC	ΔpH
LAK028	58.5	-2.9	0.0

Figure 3-1. Observed changes in SO_4^{2-}, CBANC and pH from the baseline period (2012) to the post-KMP period (2020-2022). Green cells indicate increases and red cells indicate decreases.

Exceptional Annual Context for 2022

The year 2022 was exceptional in the 11-year history of the SO_2 EEM Program. Notwithstanding the above-stated limitations on interpreting annual changes in lake chemistry, it is important to acknowledge the exceptional situation in 2022. Emissions from the smelter were dramatically less than in any previous year of the SO_2 EEM Program, due to a reduction in smelter operations associated with a labour dispute. In August 2021, emissions dropped by approximately 83%, from 27.1 tpd during January to June 2021, to 4.6 tpd during August to December 2021. This change was discussed in the SO_2 EEM Program 2021 Annual Report. We did not expect to see much influence of the reductions in emissions on lake chemistry in 2021 because: a) the drop in emissions happened only 1-2 months before the lakes were sampled in October 2021; and b) any small response to that change in emissions would have been swamped by the dominant influence of exceptionally wet hydrologic conditions in September and October 2021 (discussed last year).

Smelter emissions remained low into 2022 and started to increase very gradually only starting in the summer of 2022. As a result, the average emissions from September 2021 to August 2022 (i.e., the 12 months prior to the fall sampling period in 2022) were 5.1 tpd. Emissions during the 12 months prior to 2022 fall sampling were 21% of the levels in 2020 and 17% of the 2016-2018 period applied in the 2019 Comprehensive Review.

The prolonged reduction in emissions after August 2021 could alter lake chemistry, especially since the estimated water residence time is less than a year for most of the sensitive EEM lakes (less than nine months for 5 out of 7 sensitive EEM lakes, 1.4 years for LAK006, and 2.1 years for LAK044 (see 2019 Comprehensive Review, Technical Appendix 7, Table 7.19; ESSA et al. 2020b)). We expected that the decline in SO_2 emissions would cause a decline in lake [SO_4], and possibly an increase in CBANC, Gran ANC and pH, in at least the 5 sensitive EEM lakes with short water residence times. Increases in lake [SO_4] are generally associated with increases in lake base cations, due to cation exchange processes in the watershed. The converse also holds: decreases in lake [SO_4] would be expected to result in lower base cation concentrations.

The dominant responses in the 2022 data were generally consistent with our expectations:

- [SO_4] declined in all sensitive lakes except LAK028 (+3.5 μeq/L); some of the decreases were quite substantial
- Gran ANC went up in ALL lakes
- CBANC showed an increase in 4 of the sensitive EEM lakes, a limited decrease in 2 of them, and LAK042 (far north of the study area) decreased by 9.7 μeq/L
- pH increased by 0.2-0.8 pH units in all 11 lakes, with the same range across the sensitive EEM lakes alone)
- base cations dropped in all sensitive EEM lakes except LAK028 (+9.9 μeq/L)

The changes observed in 2022 *generally* countered the changes of the previous year:

- Across all lakes ~80% of the annual changes observed over 2021-2022 for CBANC, Gran ANC, BCS, pH, and SO_4 were in the opposite direction of the changes observed over 2020-2021
- For CBANC, this general pattern was less consistent - two lakes showed decreases for two years in a row (LAK023, LAK042) and two lakes showed increases for two years in a row (LAK016, LAK028)

- For pH, this general pattern was universally observed - all 11 lakes decreased in pH over 2020-2021 and increased in pH over 2021-2022
- The combined result from the two annual changes (i.e., the net change from 2020 to 2022) was more variable – that is, in some cases the changes in 2022 only partially offset the significant changes in 2021 and in other cases they more than offset the previous year's changes

An important net result is that these "reversals" of the previous year's anomalous changes tended on the whole to reduce the magnitude of changes based on the 3-year averaging period relative to the results reported last year.

Analyses of change based on the recent 3-year average

To protect aquatic ecosystems in the sensitive lakes, we want to avoid declines in recent measurements of CBANC, Gran ANC, BCS, and pH (i.e., the KPI and other acidification informative indicators) compared to the pre-KMP 2012 baseline. We use the average of the last 3 years to dampen the effects of an unusual year. Results of our analyses indicate a general recovery of lake chemistry in most of the sensitive lakes from the changes observed in 2021. The estimated changes since 2012 for CBANC, Gran ANC and BCS became more positive in 5 to 6 of the 7 sensitive lakes, as compared to the SO_2 EEM Program 2021 Annual Report (i.e., + signs next to these values in Table 3-1~~Table 3-1~~). Relative to the SO_2 EEM Program 2021 Annual Report, all seven sensitive lakes showed reductions in the estimated change in [SO_4] since 2012, consistent with the reductions in SO_2 emissions since August 2021. In addition, all seven lakes showed an increase in the estimated long-term change in base cations since 2012. The only exception to this general pattern of recovery is that the estimated change in pH since 2012 remained the same for 6 of the 7 sensitive lakes (i.e., no + or – sign next to these values in Table 3-1~~Table 3-1~~).

Of the two lakes showing a long-term decline in CBANC in last year's report, only LAK028 continues to show a long-term decline, albeit a smaller magnitude (-2.9 μeq/L now vs. -7.9 μeq/L last year). Two lakes still show long-term declines in BCS compared to 2012 (LAK012 and LAK028), though the magnitudes of these declines are smaller than in last year's report. LAK022 continues to be the only lake with a decline in Gran ANC relative to the 2012 baseline, though the magnitude is small and only slightly greater than previously reported (-1.6 μeq/L now vs. -0.9 μeq/L last year). LAK022 also continues to be the only lake with a decline in pH relative to pre-KMP conditions, which looks to have increased in magnitude but closer inspection reveals that the apparent increase is predominantly due to rounding (i.e., last year the calculated change was -0.149 and this year it increased to –0.16, a negligible difference). LAK022 is the only sensitive lake which is sampled just once per year; the other 6 lakes are sampled 4 times during the fall index period.

In LAK028 (the lake closest to the smelter with the highest deposition) mean [SO_4^{2-}] is estimated to have increased by 58.5 μeq/L since 2012, and total base cations (ΣBC^*) increased by 56.6 μeq/L (both lower magnitudes than shown in last year's Annual Report). The changes in ΣBC^* and SO_4^{2-} largely explain the observed change in CBANC, a decline of 2.9 μeq/L. CBANC equals the sum of base cations minus the sum of strong acid anions, and $\Delta\Sigma BC^* - \Delta[SO_4^{2-}] = 56.6 – 58.5 = –1.9$, close to the 2.9 μeq/L decline in CBANC. Gran ANC shows a long-term increase (5.4 μeq/L) in LAK028 and there continues to be no change in mean pH, similar to last year. LAK028 showed a decline in Base Cation Surplus (BCS) since the pre-KMP period, though BCS has shown considerable variation in LAK028, with its lowest value in 2013 (Table 3-2Table 3-2).

Table 3-2. Mean values of BCS in LAK028 by year. Units are µeq/L. Data from Appendix 1.

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BCS (µeq/L)	-5.1	-40.2	4.8	1.5	-24.9	-32.5	-8.4	-18.1	-26.7	-20.5	-10.6

Figure 3-2Figure 3-2 and Figure 3-3Figure 3-3 show the changes in the same water chemistry parameters graphically. These figures allow an alternate visualization of the distribution and variability in the observed changes between 2012 and 2020-2022.

For additional reference, Table 3-3Table 3-3 and Table 3-4Table 3-4 show the CBANC and pH values, respectively, over the period of record for EEM lakes, average values for the post-KMP period (2020-2022) and the differences between the post-KMP period and both the pre-KMP baseline (2012) and the transition period baseline (2012-2014). The changes in CBANC are generally similar using both the pre-KMP and the transition period as a baseline (Table 3-3Table 3-3), except for LAK012 which shows a much larger increase in CBANC from the transition period baseline. The changes in pH were consistently more negative using the 2012-2014 transition period as a baseline instead of the pre-KMP 2012 measurement (Table 3-4Table 3-4).

Appendix 2 provides a detailed set of figures showing the inter-annual changes in major water chemistry metrics (CBANC, Gran ANC, BCS, pH, SO_4^{2-}, base cations, calcium, chloride, and DOC) for each of the EEM lakes across the eleven years of annual monitoring (2012-2022). Similar figures are also included for the three control lakes based on their eight years of monitoring (2013, 2015-2019, and 2021-2022).

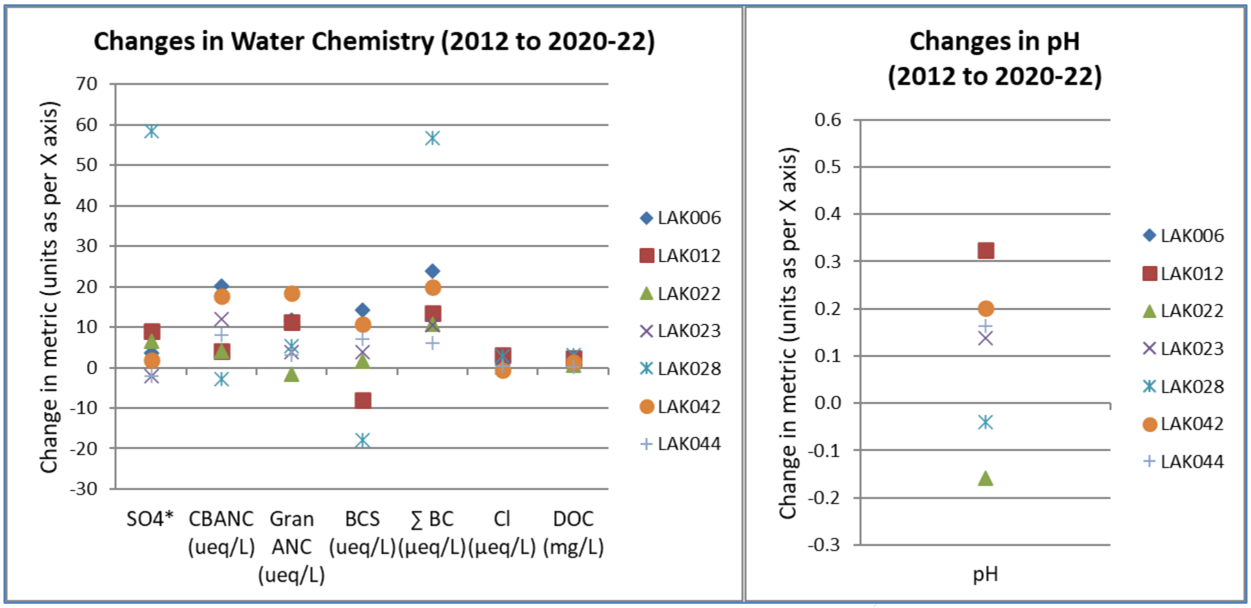


Figure 3-2. Changes in water chemistry metrics (left panel) and pH (right panel) across all of the sensitive EEM lakes, from 2012 to 2020-2022. Values shown are the mean 2020-2022 value minus the mean 2012 value. The large increase in lake SO_4^{2-} in LAK028 has been buffered by a large increase in base cations, due to cation exchange in watershed soils.

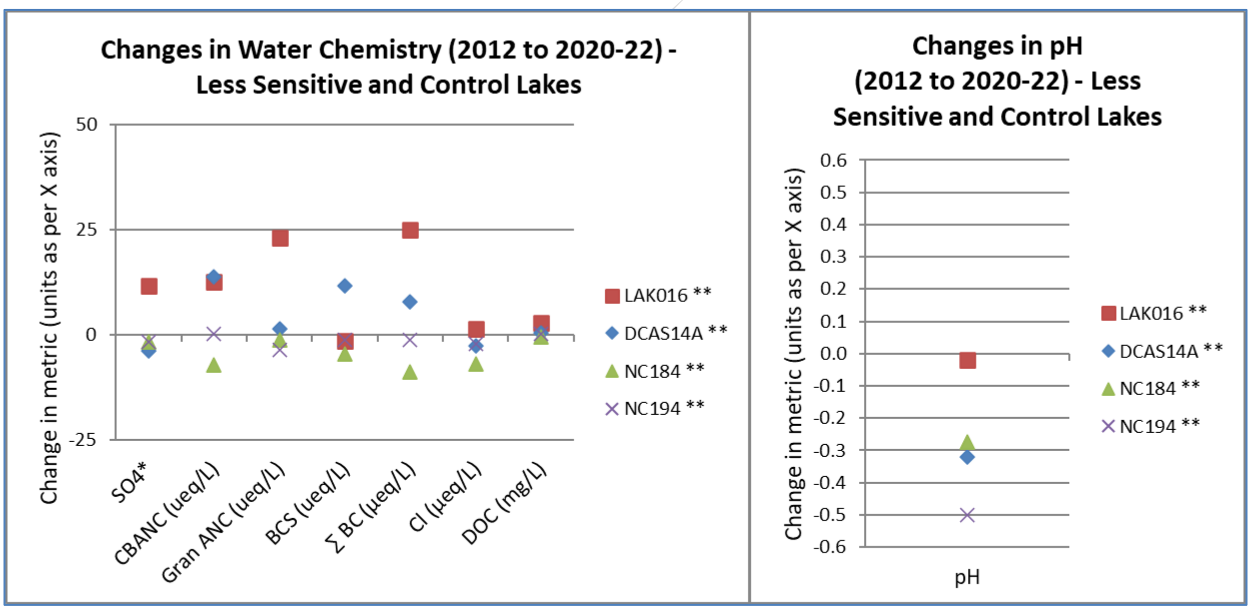


Figure 3-3. Changes in water chemistry metrics (left panel) and pH (right panel) across all of the less sensitive and control lakes, from 2012 to 2020-2022. Values shown are the mean 2020-2022 value minus the mean 2012 value. All three control lakes have shown no increase in SO_4* (left panel); the pH decrease (right panel) reflects very high precipitation in September 2021.

Table 3-3. CBANC values over period of record for EEM lakes, average CBANC values for the post-KMP period and the relative change from the pre-KMP baseline and the transition period baseline. The post-KMP averaging period applied in the 2019 comprehensive review (CR) is also shown for reference. Green represents an increase and red represents a decrease. Bolded purple values are below the 20 µeq/L *level of protection* threshold for CBANC.

	Mean CBANC values (µeq/L)											Post-KMP averaging period		Change from baseline to current post-KMP average (2020-22)	
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2016-18 (CR)	2020-22 (current)	From pre-KMP baseline (2012)†	From transition period baseline (2012-14)†
LAK006	49.2	43.1	52.9	55.1	56.9	58.0	59.3	63.8	70.3	67.8	70.1	58.0	69.4	20.2	21.0
LAK012	114.5	97.5	99.8	106.1	103.2	101.1	90.4	96.5	142.1	101.2	112.4	98.2	118.6	4.1	14.7
LAK022	67.9	62.0	76.1	75.2	80.3	70.4	76.6	74.8		68.8	75.4	75.8	72.1	4.1	3.4
LAK023	46.9	37.7	59.4	58.0	59.5	59.9	61.3	59.4	66.6	56.2	54.0	60.2	58.9	12.0	10.9
LAK028	**16.0**	**-8.1**	31.2	38.6	**12.3**	**0.7**	**8.4**	**4.5**	**8.0**	**11.7**	**19.3**	7.1	13.0	-2.9	0.0
LAK042	47.2	55.1	51.6	55.4	64.0	63.1	50.4	52.1	79.5	62.4	52.8	59.2	64.9	17.7	13.6
LAK044	**8.0**	**8.9**	**12.6**	**16.4**	**13.9**	**13.8**	**13.2**	**14.8**	**14.5**	**17.1**	**16.8**	13.6	16.1	8.1	6.3
LAK016	127.2	108.7	132.5	147.1	140.8	125.3	138.1	129.8		138.1	141.4	134.7	139.8	12.5	17.0
DCAS14A†		53.5		74.9	72.7	67.8	79.0	81.1		63.8	70.9	73.2	67.4	13.8	13.8
NC184†		80.4		73.0	94.6	76.3	95.0	86.1		61.2	85.3	88.6	73.2	-7.2	-7.2
NC194†		35.6		40.9	40.0	46.5	43.1	46.7		35.6	36.3	43.2	35.9	0.3	0.3

†The pre-KMP for the control lakes is 2013. The transition period baseline for the control lakes is also only 2013 because the lakes were not sampled in 2014. Therefore, the results for the two baselines are identical.

Table 3-4. pH values over period of record for EEM lakes, average pH values for the post-KMP period and the relative change from the pre-KMP baseline and the transition period baseline. The post-KMP averaging period applied in the 2019 comprehensive review (CR) is also shown for reference. Green represents an increase and red represents a decrease. Bolded purple values are below the *level of protection* threshold for pH (6.0). As explained in the STAR, the 2012 chemistry of most of the sensitive lakes was influenced by organic acids contributed by DOC. Mean DOC has not changed much in the sensitive lakes since 2012 (Figure 3-2~~Figure 3-2~~).

	Mean pH values											Post-KMP averaging period		Change from baseline to current post-KMP average (2020-22)	
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2016-18 (CR)	2020-22 (current)	From pre-KMP baseline (2012)†	From transition period baseline (2012-14)†
LAK006	**5.8**	6.2	6.1	6.0	6.0	6.0	6.1	6.1	6.0	**5.8**	6.2	6.0	6.0	0.2	0.0
LAK012	**5.6**	6.3	6.0	6.0	6.2	6.1	6.2	6.1	6.0	**5.7**	6.2	6.2	6.0	0.3	0.0
LAK022	**5.9**	6.2	6.3	6.1	6.1	6.1	6.1	6.1		**5.4**	6.1	6.1	**5.8**	-0.2	-0.3
LAK023	**5.7**	6.0	**5.9**	**5.9**	**5.9**	**5.9**	6.0	**5.8**	**5.9**	**5.7**	6.0	**5.9**	**5.8**	0.1	0.0
LAK028	**5.0**	**5.2**	**5.3**	**5.1**	**5.0**	**4.8**	**5.3**	**5.2**	**4.9**	**4.7**	**5.2**	**5.0**	**4.9**	0.0	-0.2
LAK042	**4.7**	**5.5**	**5.1**	**5.4**	**5.4**	**5.2**	**5.1**	**5.4**	**4.6**	**4.6**	**5.4**	**5.2**	**4.9**	0.2	-0.2
LAK044	**5.4**	**5.7**	**5.8**	**5.8**	**5.5**	**5.6**	**5.5**	**5.5**	**5.6**	**5.5**	**5.7**	**5.6**	**5.6**	0.2	0.0
LAK016	6.3	6.7	6.7	6.8	6.6	6.7	6.7	6.6		6.1	6.5	6.7	6.3	0.0	-0.3
DCAS14A†		6.5		6.6	6.6	6.6	6.8	6.6		**5.9**	6.4	6.6	6.2	-0.3	-0.3
NC184†		**5.7**		**5.5**	**5.8**	**5.4**	6.2	**5.7**		**5.1**	**5.8**	**5.8**	**5.5**	-0.3	-0.3
NC194†		6.6		6.5	6.4	6.4	6.5	6.4		**5.9**	6.3	6.4	6.1	-0.5	-0.5

†The pre-KMP for the control lakes is 2013. The transition period baseline for the control lakes is also only 2013 because the lakes were not sampled in 2014. Therefore, the results for the two baselines are identical.

Resampling of LAK027

Table 3-5~~Table 3-5~~ shows the results for LAK027 for ANC, pH, SO_4^{2-}, DOC, sum of base cations, chloride, and calcium, including the results from the 2012 STAR sampling and the difference between the two sampling years. As explained earlier (and in the recommendations of the SO_2 EEM Program 2021 Annual Report), LAK027 was resampled for a second year in 2022 due to the influence of anomalous hydrologic conditions in fall 2021 across all of the lakes. Therefore we are primarily focused on comparing 2022 to 2012 to achieve the original intent of resampling this lake. CBANC, Gran ANC, and BCS all increased substantially, whereas pH declined by 0.1 pH units. There were also substantial increases in both ΣBC* (123.9 µeq/L) and SO_4^{2-} (63.9 µeq/L) and the relative difference between those increases explains the increase in CBANC (i.e., 123.9 – 63.9 = 60.0 µeq/L).

Table 3-5. CBANC, Gran ANC, BCS, pH, SO42-, DOC, base cations, chloride, and calcium values for LAK027, from the 2012 STAR sampling and the resampling in 2021 and 2022. The change from 2012 to 2022 is shown. Increases are shaded in green; decreases are shaded in red. The Gran ANC and pH values are based on the "integrated" time series (i.e., values from the Trent University laboratory from 2012 with the 2022 values imputed from the values measured by the BASL laboratory ("integ"); see details in Section 2.1). Note that the imputation uses the regression based on the 2019 data for the EEM Lakes (i.e., LAK027 did not contribute to the regression).

	CBANC (µeq/L)	Gran ANC (integ) (µeq/L)	BCS (µeq/L)	pH (integ)	SO4* (µeq/L)	DOC (mg/L)	∑ BC* (µeq/L)	Cl (µeq/L)	Ca* (µeq/L)
2012	101.3	69.8	98.8	6.6	110.4	1.1	211.6	3.2	189.3
2021	94.8	56.9	65.9	5.9	90.3	6.4	185.2	8.2	157.9
2022	160.8	124.3	142.5	6.5	174.3	4.3	335.5	5.6	295.2
Change (2012 to 2022)	59.6	54.5	43.6	-0.1	63.9	3.2	123.9	2.5	105.9

3.2 Water Chemistry Sampling Results

Appendix 1 reports the results of the water chemistry sampling for the EEM lakes and control lakes from the sampling conducted in 2022 (with the data from 2012-2022 included for reference), for major water chemistry metrics (ANC, pH, DOC, base cations, and major anions).

Sulphate Levels Relative to B.C. Water Quality Guidelines

The B.C. water quality guideline for sulphate concentration in very soft waters is 128 mg/L. The sulphate concentration of the EEM lakes is shown in Figure 3-4~~Figure 3-4~~ for all water chemistry samples taken in 2022. All of the samples are less than 4% of the guideline. Other than LAK028, all other samples for all other lakes are less than 2% of the guideline.

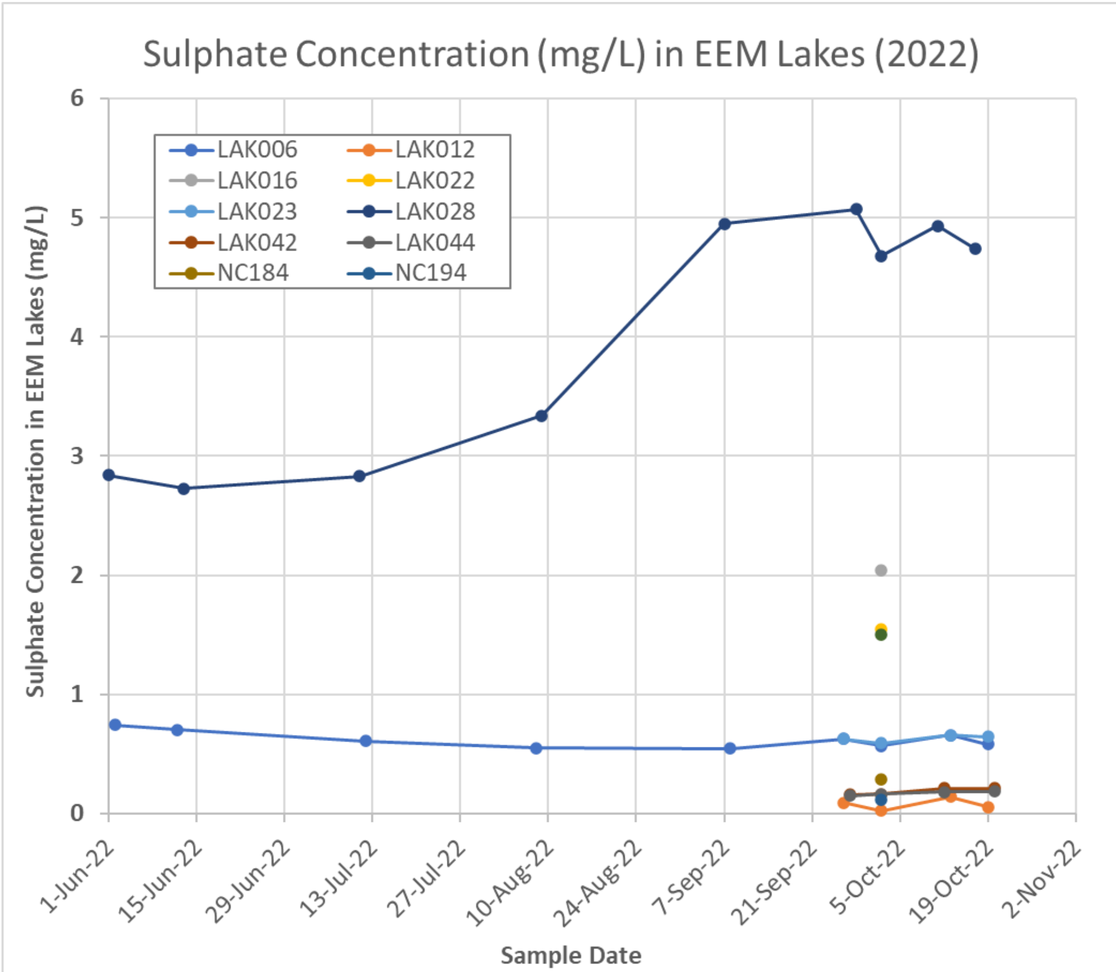


Figure 3-4. Sulphate concentration (mg/L) in EEM lakes during 2022. The applicable B.C. water quality guideline for sulphate concentration (i.e., for very soft waters) is 128 mg/L. All samples in 2022, across all EEM lakes, were <4% of the guideline.

3.3 Statistical Analysis of Changes in Water Chemistry

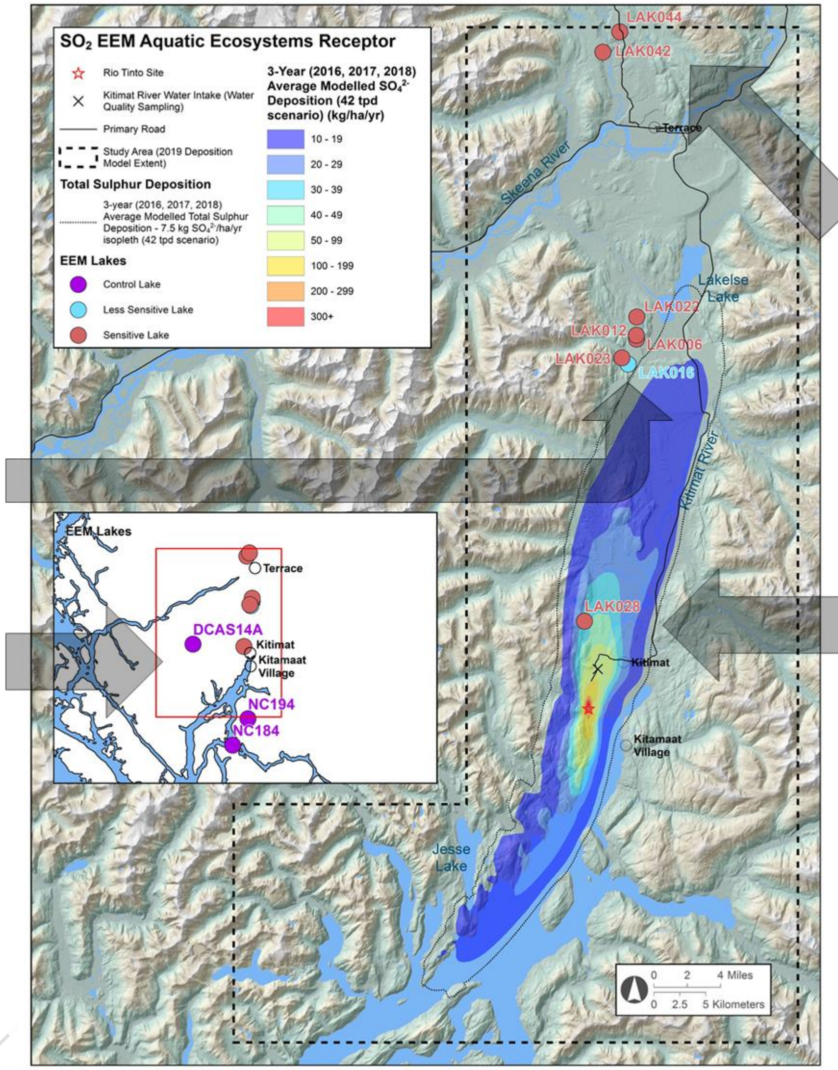
We have summarized the key results of the statistical analyses of changes in lake chemistry across all the lakes in the SO_2 EEM Program in Table 3-6~~Table 3-6~~ and Figure 3-5~~Figure 3-5~~. These results applied Bayesian Method 1, described in Appendix F of the 2019 Comprehensive Review (ESSA et al. 2020b).

Table 3-6. Summary of findings across all lakes monitored in the SO_2 EEM Program. The % belief values are derived from the Bayesian version of Method 1, as described in Aquatic Appendix F of the 2019 Comprehensive Review(ESSA et al. 2020b). Values of % belief < 20% are coloured green, 20-80% yellow, and >80% red. Both the Gran ANC and pH results are based on the integrated ("integ") time series (as per Section 2.1). Note: because NC194 does not have a lake-specific *change limit* threshold for CBANC / Gran ANC, it is not possible to evaluate these indicators).

	Changes in SO_4 (% belief that threshold exceeded; from Bayesian analysis method 1)	Exceedance of *CHANGE LIMIT* (% belief that metric value has decreased by more than the threshold; from Bayesian analysis method 1)				Exceedance of *LEVEL OF PROTECTION* (% belief that metric value is below threshold; from Bayesian analysis method 1)			
Metric	**SO_4**	**CBANC**	**Gran ANC (integ)**	**BCS**	**pH (integ)**	**CBANC**	**Gran ANC (integ)**	**BCS**	**pH (integ)**
Threshold	Increase > 0	Lake-spec.	Lake-spec.	Δ 13 ueq/L	Δ 0.3 pH units	20 ueq/L	30.7 ueq/L	0 ueq/L	6.0 pH units
LAK006	81%	0%	0%	1%	8%	0%	0%	0%	70%
LAK012	70%	23%	14%	42%	10%	0%	0%	0%	77%
LAK022	69%	13%	30%	9%	43%	0%	80%	0%	84%
LAK023	37%	6%	2%	3%	7%	0%	100%	0%	100%
LAK028	88%	13%	8%	62%	18%	100%	100%	100%	100%
LAK042	60%	6%	6%	20%	21%	0%	100%	80%	100%
LAK044	13%	0%	4%	1%	4%	100%	100%	0%	100%
LAK016	70%	2%	7%	33%	32%	0%	0%	0%	1%
DCAS14A	14%	5%	7%	13%	52%	0%	0%	0%	10%
NC184	15%	46%	30%	43%	48%	0%	100%	1%	97%
NC194	4%			4%	71%	0%	100%	0%	33%

LAKE	% belief in change ↑ SO_4^{2-}	↓ CBANC	↓ pH
LAK006	81%	0%	8%
LAK012	70%	23%	10%
LAK022	69%	13%	43%
LAK023	37%	6%	7%
LAK016	70%	2%	32%

LAKE	% belief in change ↑ SO_4^{2-}	↓ CBANC	↓ pH
DCAS14A	14%	5%	52%
NC184	15%	46%	48%
NC194	4%	n/a	71%



LAKE	% belief in change ↑ SO_4^{2-}	↓ CBANC	↓ pH
LAK042	60%	6%	21%
LAK044	13%	0%	4%

LAKE	% belief in change ↑ SO_4^{2-}	↓ CBANC	↓ pH
LAK028	88%	13%	18%

Figure 3-5. Spatial distribution of percent belief in chemical change. Numbers show % belief in: a) SO_4 increase (no threshold), b) CBANC decrease below lake-specific threshold, and c) pH decrease below 0.3 threshold. The % belief values are derived from the Bayesian version of Method 1, as described in Aquatic Appendix F of the 2019 Comprehensive Review(ESSA et al. 2020b). NC194 does not have an estimated ANC threshold because it did not have appropriate titration data available.

Before-After Control-Impact (BACI) Analyses

The results of the BACI analyses for CBANC, pH, Gran ANC, and BCS are shown in Table 3-7Table 3-7, Table 3-8Table 3-8, Table 3-9Table 3-9, and Table 3-10Table 3-10). None of the seven lakes showed statistically significant differences in Δ CBANC, Δ Gran ANC, or Δ BCS relative to the control lakes. One lake showed significantly more positive Δ pH over time than was observed in the control lakes, which is evidence against acidification.

Table 3-7. BACI analyses of mean CBANC for 7 sensitive and 3 control lakes. “BACI estimate” is a bit counter-intuitive: it is the Δ mean CBANC in the controls (i.e., CBANC $_{post\text{-}KMP}$ minus CBANC $_{pre\text{-}KMP}$), averaged over the 3 control lakes, minus the Δ mean CBANC in the sensitive lake. If BACI value is <0, then the Δ CBANC was lower in the controls than in the sensitive lake (and, equivalently, the Δ CBANC was greater (more positive) in the sensitive lake than in the controls), evidence against acidification (if statistically significant). If BACI value is >0, then Δ CBANC in the controls was greater than that in the sensitive lake (and, equivalently, the Δ CBANC was lower (less positive) in the sensitive lake than in the controls), evidence for acidification (if statistically significant). SE is the standard error of the BACI estimate. The p-value is the statistical significance of the test.

Site	BACI estimate	SE	p-value	Interpretation of BACI estimate	Change in interpretation from 2021
LAK006	-17.81	10.63	0.15	Change in CBANC was **more positive** in LAK006 than in the control lakes *(but not statistically significant)*	None
LAK012	8.31	11.13	0.49	Change in CBANC was **more negative** in LAK012 than in the control lakes *(but not statistically significant)*	None
LAK022	-1.82	11.03	0.88	Change in CBANC was **similar** in LAK022 to changes in the control lakes *(but not statistically significant)*	None
LAK023	-9.23	11.84	0.47	Change in CBANC was **more positive** in LAK023 than in the control lakes *(but not statistically significant)*	None
LAK028	4.50	10.68	0.69	Change in CBANC was **more negative** in LAK028 to changes in the control lakes *(but not statistically significant)*	None
LAK042	-15.38	14.98	0.35	Change in CBANC was **more positive** in LAK042 than in the control lakes *(but not statistically significant)*	None
LAK044	-5.90	10.85	0.61	Change in CBANC was **more positive** in LAK044 to changes in the control lakes *(but not statistically significant)*	From similar to more positive

Table 3-8. BACI analyses of mean pH (integrated) for 7 sensitive and 3 control lakes. "BACI estimate" is a bit counter-intuitive: it is the Δ mean pH in the controls (i.e., $pH_{post\text{-}KMP}$ minus $pH_{pre\text{-}KMP}$), averaged over the 3 control lakes, minus the Δ mean pH in the sensitive lake. If BACI value is <0, then the Δ pH was lower in the controls than in the sensitive lake (and, equivalently, the Δ pH was greater (more positive) in the sensitive lake than in the controls), evidence against acidification (if statistically significant). If BACI value is >0, then Δ pH in the controls was greater than that in the sensitive lake (and, equivalently, the Δ pH was lower (less positive) in the sensitive lake than in the controls), evidence for acidification (if statistically significant). SE is the standard error of the BACI estimate. The p-value is the statistical significance of the test.

Site	BACI estimate	SE	p-value	Interpretation of BACI estimate	Change in interpretation from 2021
LAK006	-0.55	0.17	0.02	Change in pH was **more positive** in LAK006 than in the control lakes *(but not statistically significant)*	None
LAK012	-0.67	0.16	0.01	Change in pH was **significantly more positive** in LAK012 than in the control lakes; *evidence against acidification*	None
LAK022	-0.20	0.16	0.26	Change in pH was **more positive** in LAK0022 than in the control lakes *(but not statistically significant)*	None
LAK023	-0.49	0.18	0.04	Change in pH was **more positive** in LAK023 than in the control lakes *(but not statistically significant)*	None
LAK028	-0.33	0.17	0.10	Change in pH was **more positive** in LAK028 than in the control lakes *(but not statistically significant)*	None
LAK042	-0.67	0.19	0.02	Change in pH was **more positive** in LAK042 than in the control lakes *(but not statistically significant)*	No longer significant
LAK044	-0.53	0.20	0.04	Change in pH was **more positive** in LAK044 than in the control lakes *(but not statistically significant)*	None

Table 3-9. BACI analyses of mean Gran ANC (integrated) for 7 sensitive and 3 control lakes. "BACI estimate" is a bit counter-intuitive: it is the Δ mean Gran ANC in the controls (i.e., Gran $ANC_{post\text{-}KMP}$ minus Gran $ANC_{pre\text{-}KMP}$), averaged over the 3 control lakes, minus the Δ mean Gran ANC in the sensitive lake. If BACI value is <0, then the Δ Gran ANC was lower in the controls than in the sensitive lake (and, equivalently, the Δ Gran ANC was greater (more positive) in the sensitive lake than in the controls), evidence against acidification (if statistically significant). If BACI value is >0, then Δ Gran ANC in the controls was greater than that in the sensitive lake (and, equivalently, the Δ Gran ANC was lower (less positive) in the sensitive lake than in the controls), evidence for acidification (if statistically significant). SE is the standard error of the BACI estimate. The p-value is the statistical significance of the test.

Site	BACI estimate	SE	p-value	Interpretation of BACI estimate	Change in interpretation from 2021
LAK006	-12.35	4.55	0.04	Change in Gran ANC was **more positive** in LAK006 than in the control lakes *(but not statistically significant)*	None
LAK012	-6.79	6.93	0.37	Change in Gran ANC was **more positive** in LAK012 than in the control lakes *(but not statistically significant)*	From more negative to more positive
LAK022	0.46	5.77	0.94	Change in Gran ANC was **similar** in LAK0022 than in the control lakes *(but not statistically significant)*	None
LAK023	-4.43	4.96	0.41	Change in Gran ANC was **more positive** in LAK023 than in the control lakes *(but not statistically significant)*	From similar to more positive
LAK028	-6.89	5.18	0.24	Change in Gran ANC was **more positive** in LAK028 than in the control lakes *(but not statistically significant)*	From similar to more positive
LAK042	-21.79	7.96	0.04	Change in Gran ANC was **more positive** in LAK042 than in the control lakes *(but not statistically significant)*	None
LAK044	-4.74	4.88	0.37	Change in Gran ANC was **more positive** in LAK044 than in the control lakes *(but not statistically significant)*	From similar to more positive

Table 3-10. BACI analyses of mean BCS (base cation surplus) for 7 sensitive and 3 control lakes. "BACI estimate" is a bit counter-intuitive: it is the Δ mean BCS in the controls (i.e., $BCS_{post\text{-}KMP}$ minus $BCS_{pre\text{-}KMP}$), averaged over the 3 control lakes, minus the Δ mean BCS in the sensitive lake. If BACI value is <0, then the Δ BCS was lower in the controls than in the sensitive lake (and, equivalently, the Δ BCS was greater (more positive) in the sensitive lake than in the controls), evidence against acidification (if statistically significant). If BACI value is >0, then Δ BCS in the controls was greater than that in the sensitive lake (and, equivalently, the Δ BCS was lower (less positive) in the sensitive lake than in the controls), evidence for acidification (if statistically significant). SE is the standard error of the BACI estimate. The p-value is the statistical significance of the test.

Site	BACI estimate	SE	p-value	Interpretation of BACI estimate	Change in interpretation from 2021
LAK006	-12.39	10.75	0.30	Change in BCS was **more positive** in LAK006 than in the control lakes *(but not statistically significant)*	None
LAK012	15.36	11.25	0.23	Change in BCS was **more negative** in LAK012 than in the control lakes *(but not statistically significant)*	None
LAK022	0.38	11.49	0.98	Change in BCS was **similar** in LAK0022 than in the control lakes *(but not statistically significant)*	From more negative to similar
LAK023	-1.42	12.09	0.91	Change in BCS was **similar** in LAK023 than in the control lakes *(but not statistically significant)*	None
LAK028	18.82	10.80	0.14	Change in BCS was **more negative** in LAK028 than in the control lakes *(but not statistically significant)*	None
LAK042	-11.33	12.62	0.41	Change in BCS was **more positive** in LAK042 than in the control lakes *(but not statistically significant)*	None
LAK044	-5.32	11.28	0.66	Change in BCS was **more positive** in LAK044 than in the control lakes *(but not statistically significant)*	From similar to more positive

Table 3-11. BACI analysis of Δ CBANC, Δ pH (integrated), Δ Gran ANC, and Δ BCS, respectively, with all lakes combined. BACI estimate is the Δ mean in the 3 control lakes (i.e., post-KMP minus pre-KMP, averaged over the 3 control lakes), minus the Δ mean in the 7 sensitive lakes (i.e., post-KMP minus pre-KMP, averaged over the 7 sensitive lakes). SE is the standard error of the BACI estimate. The p-value is the statistical significance of the test.

Metric	BACI estimate	SE	p-value	Interpretation of BACI estimate	Change in interpretation from 2021
CBANC	-7.66	9.74	0.44	Change in CBANC was **more positive** in the sensitive lakes than in the control lakes *(but not statistically significant)*	From more negative to more positive
pH (integ)	-0.42	0.12	0.00	Change in pH was **significantly more positive** in the sensitive lakes than in the control lakes; *evidence against acidification.*	None
Gran ANC (integ)	-11.45	8.14	0.17	Change in Gran ANC was **more positive** in the sensitive lakes than in the control lakes *(but not statistically significant)*	None
BCS	0.47	9.79	0.96	Change in BCS was **more negative** in the sensitive lakes than in the control lakes *(but not statistically significant)*	None

For the BACI analyses of changes in CBANC:

- None of the lakes showed a statistically significant effect – i.e., before-after differences that were significantly different than the before-after changes in the control lake group (all lakes have p-values >0.01)
- Four of the seven sensitive lakes (one more than last year) showed a ΔCBANC that was more positive than the ΔCBANC observed in the group of control lakes (negative effect in the BACI analysis), but none of these differences were statistically significant at $p<0.01$
- Two of the seven sensitive lakes showed a ΔCBANC that was more negative than the ΔCBANC observed in the group of control lakes (positive effect in the BACI analysis), but none of these differences were statistically significant at $p<0.01$
- When analyzed as a combined group, the sensitive lakes showed ΔCBANC that was more positive than the ΔCBANC observed in the group of control lakes, which was a reversal of the results from last year (though the results were not statistically significant in either year)
- No support for an effect across any of the lakes individually or an effect for all lakes combined.

For the BACI analyses of changes in pH:

- One of the lakes (decreased from two lakes last year) showed a statistically significant effect ($p < 0.01$) – i.e., before-after differences that were significantly different than the before-after changes in the control lake group (LAK012 and LAK042)
    - The change in pH for LAK012 was more positive than in the control lakes, a statistically significant difference which is evidence against acidification
    - LAK042 (which showed a significant effect last year) and LAK006 had p-values than only marginally exceeded the criterion for significance (i.e., 0.02 for both lakes), for changes in pH that were more positive than in the control lakes
    - None of the other lakes showed a statistically significant effect

- When analyzed as a combined group, the sensitive lakes showed a statistically significant effect (at $p < 0.01$) of a change that was more positive than in the control lakes, which is evidence against acidification.

For the BACI analyses of changes in Gran ANC:

- None of the lakes showed a statistically significant effect – i.e., before-after differences that were significantly different than the before-after changes in the control lake group (all lakes have p-values >0.01)
- Six of the seven sensitive lakes (up from two lakes last year) showed a Δ Gran ANC that was more positive than the Δ Gran ANC observed in the group of control lakes (negative effect in the BACI analysis), but none of these differences were statistically significant at p<0.01 (LAK006 and LAK042 have p-values of <0.05)
- No support for an effect across any of the lakes individually or an effect for all lakes combined.

For the BACI analyses of changes in BCS:

- None of the lakes showed a statistically significant effect – i.e., before-after differences that were significantly different than the before-after changes in the control lake group (all lakes have p-values >0.01)
- Three of the seven sensitive lakes (up from two lakes last year) showed a ΔBCS that was more positive than the ΔBCS observed in the group of control lakes (negative effect in the BACI analysis), but none of these differences were statistically significant at p<0.01
- Two of the seven sensitive lakes showed a ΔBCS that was more negative than the ΔBCS observed in the group of control lakes (positive effect in the BACI analysis), but none of these differences were statistically significant at p<0.01
- No support for an effect across any of the lakes individually or an effect for all lakes combined.

3.4 Episodic Acidification

We reviewed the data from the continuous pH monitors installed in LAK006 and LAK028 to identify any acidic episodes (Figure 3-6~~Figure 3-6~~, Figure 3-7~~Figure 3-7~~). The lake-level monitoring data are shown in Figure 3-8~~Figure 3-8~~.

LAK006 shows three periods with notable declines - late August, early September, and the very end of October – albeit the magnitude of these declines are quite small (i.e., declines of ~0.2 pH units over a period of less than one week). These periods align with notable increases in lake levels as the result of precipitation events. The decline at the end of October is also consistent with the pattern observed in previous years of pH decreasing during the end of the monitoring season as precipitation events increase in frequency and magnitude.

LAK028 showed only one pronounced drop (~0.4 pH units) in late October, corresponding with increased precipitation at the end of October. The late August and early September events observed in LAK006 are evident in the lake levels for LAK028 (i.e., significant local peaks in lake level) but do not show up as any notable declines in pH. Other than the decline at the end of October, which is consistent with the pattern observed in many previous years, the continuous pH data for LAK028 stayed within an range of ~0.2 pH units for the entire year.

Because this decline is at the very end of the field season, there are not any samples with full lake chemistry after this time with which to examine changes in lake chemistry during this period.

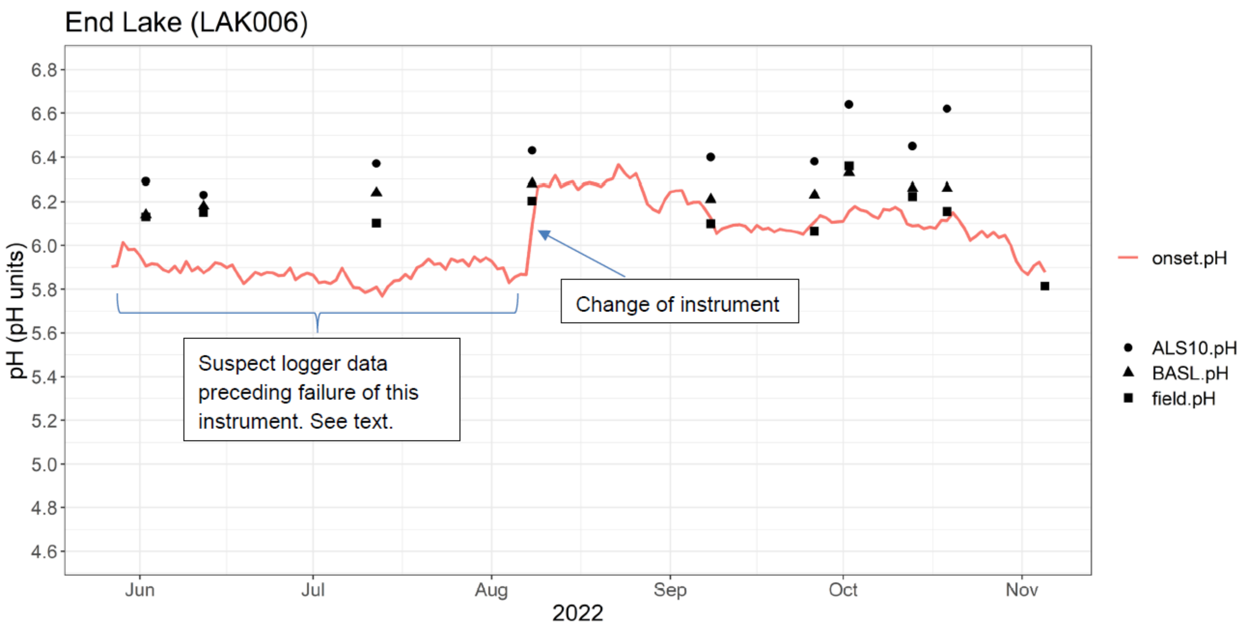


Figure 3-6. LAK006 pH measurements during the 2022 monitoring season, including continuous monitoring as well as field and laboratory measurements. See Limnotek 2023 for details on instrument failure referenced in the figure. Source: Limnotek 2023

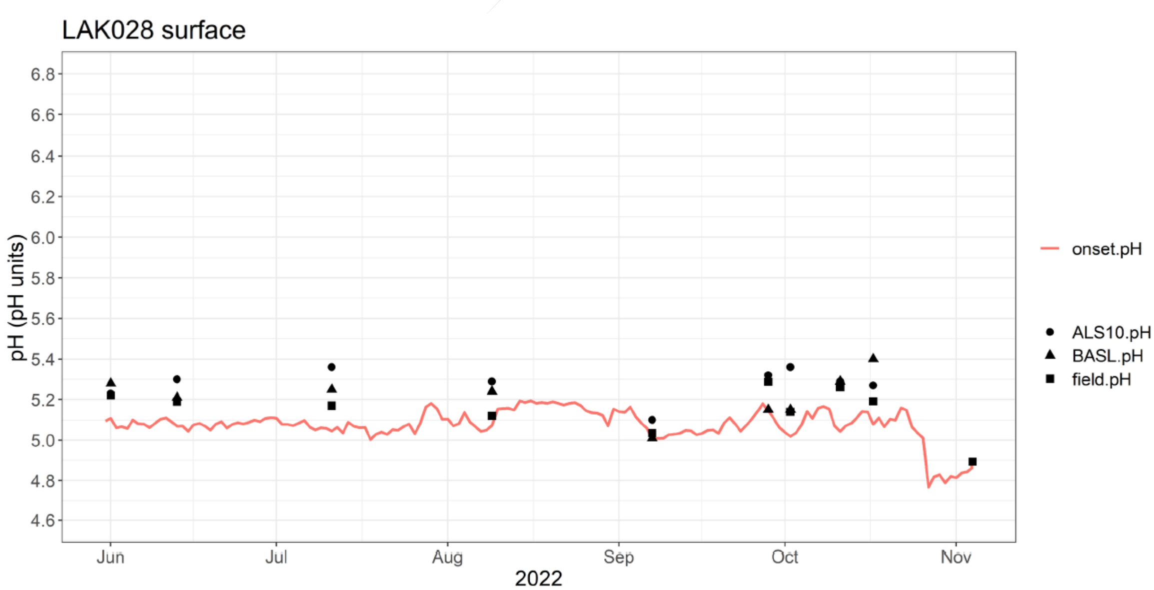


Figure 3-7. LAK028 pH measurements during the 2022 monitoring season, including continuous monitoring as well as field and laboratory measurements. Source: Limnotek 2023

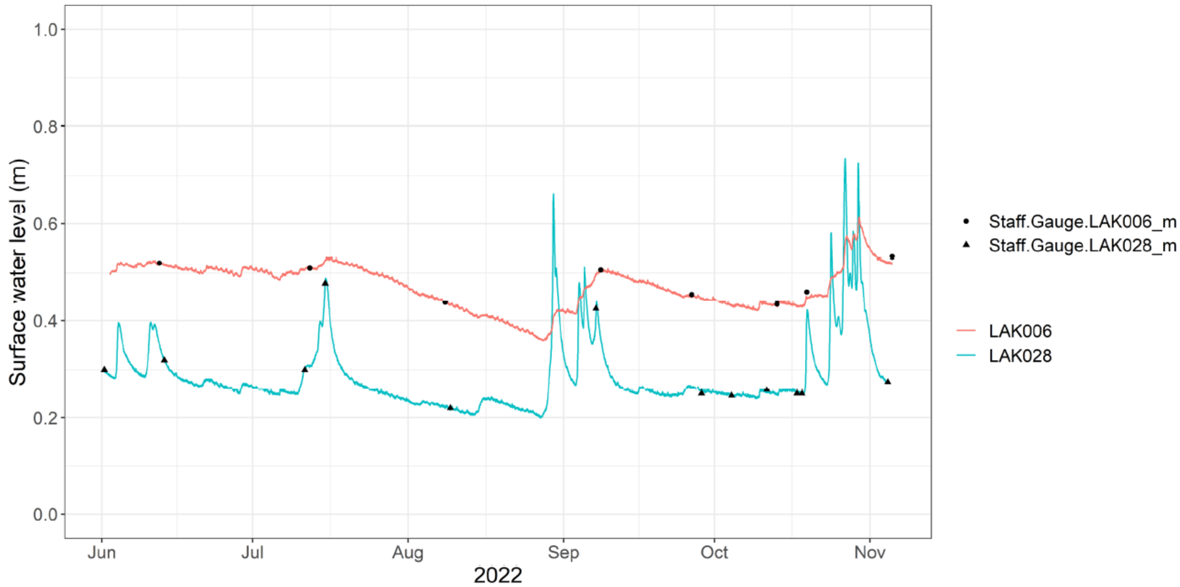


Figure 3-8. Water level during the 2022 monitoring season for LAK006 and LAK028. Source: Limnotek 2023

4 Discussion

4.1 Separating Natural and Anthropogenic Factors: the Environmental Context

The SO_2 EEM Program has moved away from reporting and analyzing the annual changes between individual years (due to challenges in interpretability associated with the high degree of variability). However, it is still useful to look at the year-to-year changes to assess whether there are any widespread patterns of significance that may influence our analyses and interpretation of long-term changes in water chemistry.

The graphs in Appendix 2 enable comparisons of the 2022 monitoring data to 2021. These graphs show (as also described in Section 3.1) that the patterns of annual change in the primary metrics had a high level of consistency across the entire region – i.e., pH and Gran ANC increased in all 11 lakes, BCS increased in 10 lakes, and CBANC increased in 8 lakes. These changes are consistent with significant reductions in emissions, and presumably also in deposition (deposition data still to be analyzed). The changes in the ANC metrics and pH are also consistent with the particularly dry hydrologic conditions in 2022. as well, since the three control lakes also showed increases in ANC metrics and pH, but showed either no change or slight increases in sulphate (see graphs in Appendix 2). The control lakes are serving their purpose of removing the effects of variation in emissions and deposition.

On the other hand, the changes in SO_4 and BC both appear to reflect the net balance between two opposing processes. The dry conditions alone could contribute to increasing concentrations of SO_4 but the consistent declines in SO_4 (as observed in 8 of 11 lakes, including

6 of 7 sensitive lakes) suggest that any such response to dryer conditions this year has been swamped by the effects of reduced emissions. Similarly, dry conditions could contribute to increasing concentrations of BC , through a concentration effect, but reduced deposition could reduce the inputs of BC into lakes both through changes in direct deposition of BC in the watershed (likely minor) and by reducing the amount of hydrogen-driven cation-exchange in the watershed (likely more significant). The consistent declines observed for BC (in 7 of 11 lakes, including 6 of 7 sensitive lakes) suggest that effects of the reduced emissions were much stronger than the influence of the hydrological conditions.

Although it is difficult to completely disentangle the relative contributions of these two major drivers in 2022 – dry hydrologic conditions and reduced emissions – it does appear that reduced emissions have been the more dominant influence on the lake chemistry observed in the sensitive lakes, and that dry conditions were the more dominant influence in the control lakes.

Environmentally mediated decrease in pH in LAK042 in 2020 – two years later

As described in detail in the SO_2 EEM Program 2020 Annual Report, LAK042 had a notable 1-year decrease in pH between 2019 and 2020 that was attributed to anomalous environmental conditions – i.e., high water levels flooding the shoreline and leading to a large increase in DOC and a concurrent drop in pH.

In the SO_2 EEM Program 2021 Annual Report, we reported:

> *"If it were not for the significant precipitation events in 2021, as described above, we may have expected to see some recovery of the pH in LAK042. However, the pH in LAK042 remained at a very similar level in the fall of 2020 and 2021. Since LAK042 was not sampled in 2021 prior to September, it is not possible to determine whether its pH remained at a similar level since the fall of 2020, or increased in the spring/summer of 2021 and then declined again during the fall of 2021. "*

In 2022, the pH in LAK042 increased by 0.8 pH units (the largest increase observed), effectively reversing the significant decrease from two years ago and returning to the 2019 levels (actually 0.1 pH units higher). However, given the context of emissions and precipitation conditions in 2022, it is not possible to disentangle how much of this increase is due to the contrast in environmental conditions in the months preceding sampling in the different years or the marked reduction in SO_2 emissions over the entire year. LAK042 and LAK044 both showed declines in [SO_4^{2}] consistent with reduced levels of S deposition.

4.2 Empirical Changes in Lake Chemistry with respect to the Aquatic Key Performance Indicator

This section only addresses the CBANC KPI and the pH informative indicator (of specific interest as the prior KPI) as the statistical analyses represent the primary assessment of the KPI and informative indicators.

The mean values of CBANC indicate that there have been no exceedances of the KPI.

For the CBANC KPI, only 2 of the 7 sensitive lakes (LAK028 and LAK044) have post-KMP values below the *level of protection* threshold. Both of those lakes were already below that threshold in 2012 (and the alternate, transition period baseline) and neither of those lakes have exceeded the *change limit* threshold (LAK028 shows a decrease of -2.9 µeq/L; LAK044 shows an increase of +8.1 µeq/L . None of the 7 sensitive lakes exceeded the *change limit* threshold and only one lake (LAK028) shows any long-term decrease in CBANC. In the sensitivity analyses with the alternate, transition period baseline (2012-2014), there are no lakes with an estimated long-term decrease in CBANC. The empirical data therefore indicate that none of the lakes exceeded the KPI.

For the pH informative indicator, 5 of the 7 sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028, LAK042, and LAK044) have post-KMP values below the *level of protection* threshold (a pH of 6.0). All 7 lakes were already below that threshold in 2012, and four of the lakes have been at or below that threshold throughout the entire period of record. None of the sensitive lakes have exceeded the *change limit* threshold. Only one lake (LAK022) shows any decrease in pH relative to 2012. The empirical data therefore indicate that none of the lakes have exceeded the pH informative indicator.

In the sensitivity analyses with the alternate, transition period baseline (2012-2014), 2 sensitive lakes show decreases of <0.1 pH units, 2 lakes (LAK028, LAK042) show decreases of ~0.2 pH units (LAK028 and LAK042), and 1 lake (LAK022) shows a decrease of ~0.3 pH units. The empirical data therefore indicate that one of the lakes exceeds the change limit for the pH informative indicator when evaluated against the alternate, transition period baseline.

The following section (Section 4.3) applies the statistical analyses to the same data to assess the percent belief that CBANC KPI and the pH, Gran ANC and BCS informative indicators could have been exceeded.

LAK027 – Comparison with STAR Results

As discussed earlier, LAK027 was resampled again in 2022 because of how the anomalous precipitation levels influenced lake chemistry across the region, thus confounding the original rationale for sampling LAK027 in 2021. As such, we currently focus on examining the changes between the values measured in the STAR in 2022.

The results for 2022 showed substantial increases in all of the main lake chemistry metrics (i.e., CBANC, Gran ANC, BCS, SO_4, DOC, BC, Cl, Ca) since 2012, with a small decrease in pH of 0.1 units. However, as discussed earlier 2022 was also subject to anomalous conditions (i.e., significantly reduced emissions), which tended to drive changes in the opposite direction than the previous year. Similar to the other EEM lakes, LAK027 shows very substantial changes between 2021 and 2022 that reflect the transition in influence between these sequential precipitation and emissions anomalies. It is therefore impossible to disentangle the potential long-term change in lake chemistry from the STAR from the short-term effects experienced by all the other EEM lakes. To obtain a more reliable assessment of the chemical status of LAK027, relative to the status observed in the STAR, it would be prudent to again resample this lake in 2023.

4.3 Statistical Analysis of Changes in Lake Chemistry

We evaluated the KPI and the informative indicators using the two-threshold structure (Table 4-1~~Table 4-1~~). None of the 11 EEM lakes have a high % belief in exceedance of either the KPI or any of the informative indicators. None of the 11 EEM lakes have even a moderate % belief in exceedance of the KPI - all lakes show a low % belief in exceedance of the CBANC KPI. However, three sensitive EEM lakes and two control lakes show moderate % belief of one or two of the informative indicators:

- LAK022 shows moderate % belief in exceedance of Gran ANC and pH
- LAK028 shows moderate % belief in exceedance of BCS
- LAK042 shows moderate % belief in exceedance of BCS and pH
- NC184 shows moderate % belief in exceedance of Gran ANC and pH
- NC194 shows moderate % belief in exceedance of pH

The only two changes in classification (across all lakes and metrics) from last year are the changes from low to moderate for LAK042 BCS and NC194 pH. All other results are the same as last year in terms of final classification.

Table 4-2~~Table 4-2~~ shows the results from 2022 compared to the results reported in the previous three annual reports and the 2019 comprehensive review, specifically for the evaluation of the *change limit*.

All 11 lakes have similar results to 2021 for CBANC, Gran ANC and pH – i.e., same classification and very similar percent belief values. All of the lakes were within 5% of their previous results for these metrics, which is very minor, except for LAK012 for CBANC (-12%) and NC194 for pH (+9%), which are still only small changes. For SO_4, there were a number of larger differences due to the significant reduction in emissions in 2022. The percent belief in an increase in SO_4 decreased in all 11 EEM lakes except LAK044, which still remained in the low category. LAK023 and LAK028 only decreased by ≤5% and LAK006, LAK012, LAK022, and LAK044 all decreased by 16-18%. The less sensitive lake (LAK016) and two of the control lakes had even larger decreases (-29% to -42%). Two sensitive lakes (LAK012 and LAK022) and the one less sensitive lake (LAK016) shifted from "high" to "moderate". These changes are not at all surprising given the dramatic reduction in emissions compared to all prior years.

Two of the control lakes (DCAS14A and NC184) shifted from a "moderate" to "low" percent belief in an increase in SO_4 (Table 4-2~~Table 4-2~~). This is because this year's report used a multi-year average for 2021 and 2022, which excluded higher concentrations of SO_4 in 2019 that were used in last year's report. The graphs of changes in SO_4 between 2021 and 2022 (Appendix 2) show that SO_4 actually increased slightly in two of the control lakes (DCAS14A and NC184) and remained the same in the third control lake (NC194). The fact that the control lakes showed different trends in SO_4 from the other lakes is encouraging. The control lakes were deliberately located outside of the plume, and were not affected by the large decrease in smelter emissions of SO_2 since August 2021.

This is only the third year that the Bayesian analyses were performed on CBANC. Despite the widespread changes in numerous water chemistry metrics observed in both 2021 and 2022, the CBANC results remain remarkably similar to the 2020 results for almost all of the lakes, possibly providing an indication of the robustness of the CBANC metric to anomalous conditions.

This is the fifth year that the Bayesian analyses were performed for Gran ANC and pH. That length of time provides an opportunity to see how the results have changed since these analyses were first implemented in the 2019 Comprehensive Review. For Gran ANC, there are only two lakes that have showed a change in category over the five years of repeating the analyses – LAK022 and NC194 increases from low to moderate, albeit still at the low end of the moderate range (~30% belief). For pH, 2 sensitive lakes, 1 less sensitive lake, and all 3 control lakes have showed a change in category – from low to moderate in all cases. In all cases, the shift occurred with the 2021 results (driven by high precipitation in September 2021) and the 2022 results remained quite similar[4]. LAK042 and LAK016 have been only in the low end of the moderate category. LAK022, DCAS14A and NC184 have been in the mid-range of the moderate category and only NC194 has been at the top end. However, decreases in pH in the control lakes must be driven by factors other than the smelter because they are well outside the deposition plume, and all three control lakes have a low percent belief in any sulphate increase (Table 4-2~~Table 4-2~~).

[4] Note: 4 out of these 5 lakes were not sampled in 2020, meaning the 2020 results were based only on 2018-2019, and therefore it is not actually possible to determine whether the shifts that show up in the 2021 results reflect changes in lake chemistry in 2020, 2021 or both

Table 4-1. Evaluation of the KPI and informative indicators based on the results for both the *change limit* and the *level of protection* thresholds. The first three sets of columns are the same as Table 3-6~~Table 3-6~~. The % belief values are derived from the Bayesian version of Method 1, as described in Aquatic Appendix F of the 2019 Comprehensive Review (ESSA et al. 2020b). Values of % belief < 20% are coloured green, 20-80% yellow, and >80% red. Both the Gran ANC and pH results are based on the integrated ("integ") time series (as per Section 2.1). Note: because NC194 does not have a lake-specific *change limit* threshold for CBANC / Gran ANC, it is not possible to evaluate these indicators).

	Changes in SO4	Exceedance of *CHANGE LIMIT*				Exceedance of *LEVEL OF PROTECTION*				KPI and Informative Indicator Evaluation			
	(% belief that threshold exceeded; from Bayesian analysis method 1)	(% belief that metric value has decreased by more than the threshold; from Bayesian analysis method 1)				(% belief that metric value is below threshold; from Bayesian analysis method 1)				(Classification of % belief that both the change limit and level of protections thresholds are exceeded)			
Metric	**SO_4**	**CBANC**	**Gran ANC (integ)**	**BCS**	**pH (integ)**	**CBANC**	**Gran ANC (integ)**	**BCS**	**pH (integ)**	**CBANC**	**Gran ANC (integ)**	**BCS**	**pH (integ)**
Threshold	Increase > 0	Lake-spec.	Lake-spec.	Δ 13 ueq/L	Δ 0.3 pH units	20 ueq/L	30.7 ueq/L	0 ueq/L	6.0 pH units	KPI	Inform. Indic.	Inform. Indic.	Inform. Indic.
LAK006	81%	0%	0%	1%	8%	0%	0%	0%	70%	LOW	LOW	LOW	LOW
LAK012	70%	23%	14%	42%	10%	0%	0%	0%	77%	LOW	LOW	LOW	LOW
LAK022	69%	13%	30%	9%	43%	0%	80%	0%	84%	LOW	MOD	LOW	MOD
LAK023	37%	6%	2%	3%	7%	0%	100%	0%	100%	LOW	LOW	LOW	LOW
LAK028	88%	13%	8%	62%	18%	100%	100%	100%	100%	LOW	LOW	MOD	LOW
LAK042	60%	6%	6%	20%	21%	0%	100%	80%	100%	LOW	LOW	MOD	MOD
LAK044	13%	0%	4%	1%	4%	100%	100%	0%	100%	LOW	LOW	LOW	LOW
LAK016	70%	2%	7%	33%	32%	0%	0%	0%	1%	LOW	LOW	LOW	LOW
DCAS14A	14%	5%	7%	13%	52%	0%	0%	0%	10%	LOW	LOW	LOW	LOW
NC184	15%	46%	30%	43%	48%	0%	100%	1%	97%	LOW	MOD	LOW	MOD
NC194	4%			4%	71%	0%	100%	0%	33%			LOW	MOD

Table 4-2. Comparison of the results of the updated statistical analyses of the changes relative to the *change limit* to the results in the previous two reporting periods (i.e., 2019 Annual Report and the 2019 comprehensive review (CR)). The 2021 results are the same as Table 3-6~~Table 3-6~~. The % belief values are derived from the Bayesian version of Method 1, as described in Aquatic Appendix F of the 2019 Comprehensive Review (ESSA et al. 2020b). Values of % belief < 20% are coloured green, 20-80% yellow, and >80% red.

LAKE	Changes in CBANC (% belief that CBANC *change limit* threshold exceeded)			Changes in SO_4 (% belief in SO_4 increase > 0 μeq/L)					Changes in Gran ANC (% belief that Gran ANC *change limit* threshold exceeded)					Changes in pH (% belief that pH *change limit* threshold exceeded)				
Results from:	**2020**	**2021**	**2022**	**CR**	**2019[1]**	**2020**	**2021**	**2022**	**CR**	**2019[1]**	**2020**	**2021**	**2022**	**CR**	**2019[1]**	**2020**	**2021**	**2022**
Sensitive Lakes																		
LAK006	2%	1%	0%	83%	85%	98%	97%	81%	0%	0%	5%	2%	0%	1%	0%	1%	5%	8%
LAK012	40%	35%	23%	91%	95%	99%	86%	70%	1%	0%	19%	18%	14%	1%	0%	1%	8%	10%
LAK022 [2]	2%	11%	13%	88%	89%	89%	87%	69%	0%	0%	10%	31%	30%	0%	0%	0%	39%	43%
LAK023	2%	3%	6%	5%	2%	0%	42%	37%	0%	0%	3%	2%	2%	1%	0%	3%	4%	7%
LAK028	13%	15%	13%	96%	97%	94%	92%	88%	2%	1%	0%	4%	8%	18%	6%	9%	18%	18%
LAK042	9%	6%	6%	36%	44%	81%	76%	60%	0%	0%	2%	4%	6%	2%	0%	13%	23%	21%
LAK044	0%	1%	0%	1%	0%	4%	6%	13%	0%	0%	3%	3%	4%	0%	0%	0%	1%	4%
Less Sensitive Lakes																		
LAK016 [2]	7%	7%	2%	97%	81%	81%	99%	70%	0%	0%	1%	4%	7%	1%	0%	6%	28%	32%
Control Lakes																		
DCAS14A [2]	1%	10%	5%	68%	75%	99%	56%	14%	0%	0%	1%	11%	7%	6%	0%	12%	50%	52%
NC184 [2]	10%	43%	46%	58% (in negligible increase)	69% (in negligible increase)	86%	50%	15%	5%	4%	17%	28%	30%	28%	14%	19%	48%	48%
NC194 [2]	n/a	n/a	n/a	1%	1%	2%	12%	4%	n/a	n/a	n/a	n/a	n/a	12%	4%	17%	62%	71%

[1] The 2019 Annual Report applied a 4-year post-KMP averaging period (i.e., 2016-2019; adding the new year of observations to the post-KMP period used in the CR), whereas the subsequent Annual Reports apply a 3-year post-KMP averaging period.

[2] For lakes not sampled in 2020, the post-KMP averaging periods applied in 2020 to 2022 are based on only two years of data.

4.4 Application of the Evidentiary Framework

We applied the evidentiary framework, as described in Section 2.6, using the updated results of the statistical analyses. The results are shown in Figure 4-1~~Figure 4-1~~ and the underlying values are compiled in Table 4-3~~Table 4-3~~. Results show that: a) 1 sensitive lake and 3 control lakes[5] land within the first box, "smelter not causally linked to changes in lake chemistry"; b) 1 less sensitive lake lands within the second box, "lake is healthy, and not acidifying"; and c) 6 sensitive lakes (LAK006, LAK012, LAK022, LAK023, LAK028 and LAK042) land within the third box, "some evidence of acidification; closely monitor".

For LAK028, this classification is based on: a) average post-KMP values below the *level of protection* for both CBANC and pH, and b) moderate support for a decline in CBANC (66% belief) and pH (57% belief), but with low support for exceedance of either *change limit* threshold (13% belief for CBANC and 18% belief for pH). The overall result is similar to last year, but the level of support for declines in CBANC has decreased from strong to moderate.

For LAK006, LAK012, LAK022, LAK023, and LAK042, this classification is based on pH only. All five lakes have 0% belief in CBANC being below the *level of protection.*

LAK022 and LAK042 show: a) average post-KMP values below the *level of protection* for pH only, and b) moderate support for declines in pH (60% and 36% belief, respectively), with moderate support for exceedance of the *change limit* threshold (43% and 21% belief, respectively).

LAK023 shows: a) average post-KMP values below the *level of protection* for pH only, and b) moderate support for declines in pH (28% belief), but with low support for exceedance of the *change limit* threshold for pH (7%).

LAK006 and LAK012 show: a) a moderate belief in exceeding the *level of protection* for pH (70% and 77% belief, respectively), and b) moderate to low support for declines in pH (25% and 20% belief, respectively), with low support for exceedance of the *change limit* threshold (8% and 10% belief, respectively).

There are no lakes that have acidification exceedances.

The only change in lake classification from last year's Annual Report is LAK012, due to the percent belief in a decrease in pH changing from 18% to 20% and thus being identified as a moderate level of support for such a change. This small change is within the range of variability from repeat runs of the Bayesian analyses. It is a negligible difference between years but happens to span the defined boundary between low and moderate classifications.

All of the other lakes have the same classification and generally very similar underlying results as last year.

[5] All of the control lakes are classified in the first box regardless of increases in sulphate because any such increases cannot be causally linked to the smelter due to their location well outside the smelter plume.

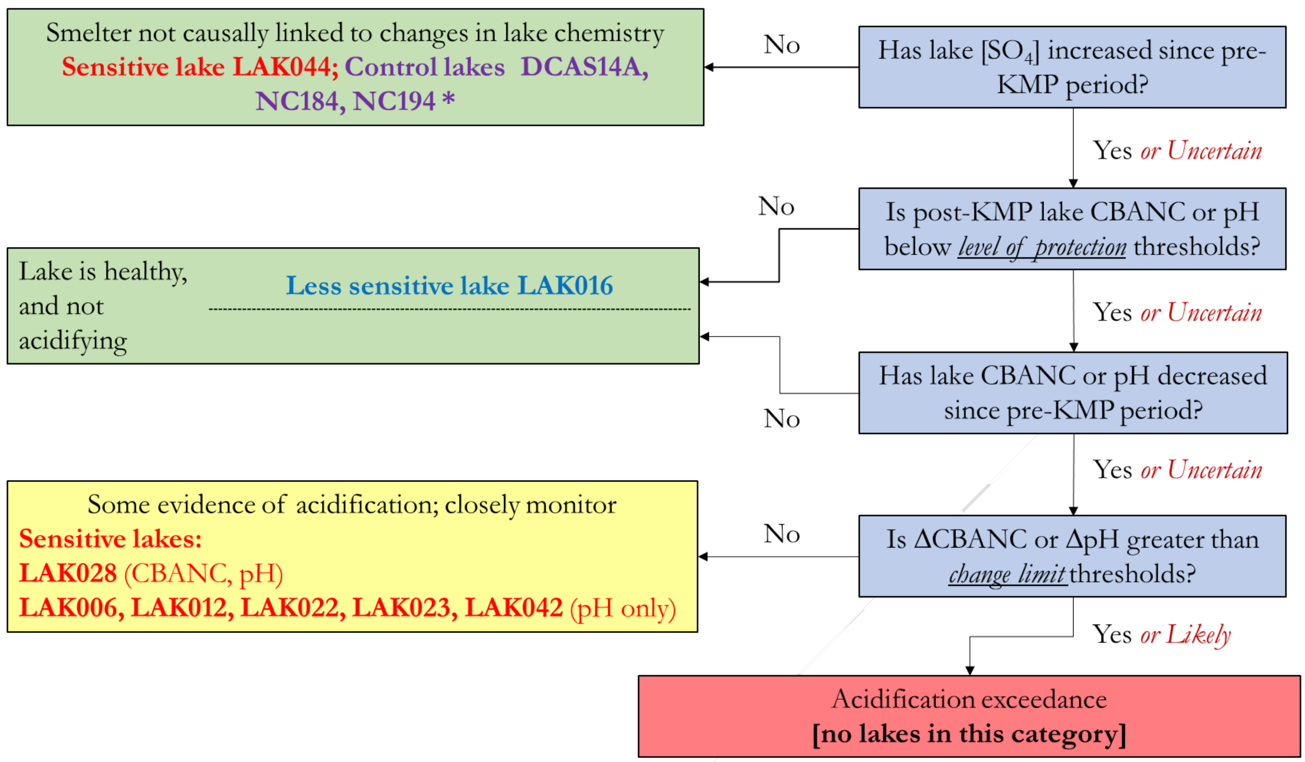


Figure 4-1. Classification of EEM lakes according to the simplified evidentiary framework. LAK028 has moderate support for declines in CBANC and pH but low support for exceeding either *change limit* threshold. LAK006, LAK012, LAK022, LAK023, and LAK042 have moderate support for declines pH with low to moderate support for exceeding the *change limit* thresholds; however, they are all still above the CBANC *level of protection*. The control lakes (*) all show low support for increases in SO_4; however, they are classified in the first box regardless of potential increase in sulphate (as observed in some past years) because any such increases cannot be causally linked to the smelter due to their location well outside the smelter plume.

Table 4-3. Results used in the application of the simple evidentiary framework. The first four columns are identical to Table 3-6~~Table 3-6~~ but the last two show the results for the % belief of *any* change in Gran ANC and pH. The % belief values are derived from the Bayesian version of Method 1, as described in Aquatic Appendix F of the 2019 Comprehensive Review (ESSA et al. 2020b). Values of % belief < 20% are coloured green, 20-80% yellow, and >80% red.

LAKE	**Changes in SO_4** (% belief in SO_4 increase / decrease)	**State of post-KMP CBANC** (% belief that CBANC *level of protection* threshold exceeded)	**State of post-KMP pH** (% belief that pH *level of protection* threshold exceeded)	**Changes in CBANC** (% belief that CBANC *change limit* threshold exceeded)	**Changes in pH** (% belief that pH *change limit* threshold exceeded)	**Change in CBANC (no threshold)** (% belief that CBANC decreased)	**Change in pH (no threshold)** (% belief that pH decreased)
Threshold type	**Any change (increase)**	**Level of Protection**	**Level of Protection**	**Change Limit**	**Change Limit**	**Any change (decrease)**	**Any change (decrease)**
Sensitive Lakes							
LAK006	81%	0%	70%	0%	8%	0%	25%
LAK012	70%	0%	77%	23%	10%	45%	20%
LAK022	69%	0%	84%	13%	43%	31%	60%
LAK023	37%	0%	100%	6%	7%	14%	28%
LAK028	88%	100%	100%	13%	18%	66%	57%
LAK042	60%	0%	100%	6%	21%	18%	36%
LAK044	13%	100%	100%	0%	4%	2%	16%
Less Sensitive Lakes							
LAK016	70%	0%	1%	2%	32%	8%	49%
Control Lakes							
DCAS14A	14%	0%	10%	5%	52%	15%	71%
NC184	15%	0%	97%	46%	48%	54%	63%
NC194	4%	0%	33%	n/a	71%	33%	82%

5 Recommendations

We recommend sampling LAK027 again in 2023. In 2021, the widely-observed storm-driven dilution event negated the ability of the sampling data to provide a meaningful comparison against the initial STAR data as intended. In 2022, the combination of exceptionally low deposition and particularly dry hydrologic conditions again negate the ability to provide the intended comparison.

We do not recommend any other changes or adjustments to next year's program.

6 References Cited

Bennett, S. and C.J. Perrin. 2017. Rio Tinto Alcan Kitimat Modernization Project: Environmental effects monitoring of lakes in 2016. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Alcan Ltd. 40pp. plus appendices.

Bennett, S. and C.J. Perrin. 2018. Rio Tinto Alcan Kitimat Modernization Project: Environmental effects monitoring of lakes in 2017. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Alcan Ltd. 49pp. plus appendices.

ESSA Technologies, J. Laurence, Limnotek, Risk Sciences International, Rio Tinto Alcan, Trent University, Trinity Consultants and University of Illinois. 2013. Sulphur Dioxide Technical Assessment Report in Support of the 2013 Application to Amend the P2-00001 Multimedia Permit for the Kitimat Modernization Project. Vol.2: Final Technical Report. Prepared for RTA, Kitimat, BC. 450 pp.

ESSA Technologies, J. Laurence, Risk Sciences International, Trent University, and Trinity Consultants. 2014a. Kitimat Airshed Emissions Effects Assessment. Report prepared for BC Ministry of Environment, Smithers, BC. 205 pp. + appendices.

ESSA Technologies, J. Laurence, Risk Sciences International, Trent University, and Trinity Consultants. 2020a. 2019 Comprehensive Review of Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project – Volume 2, V.2. Prepared June 30, 2020 for Rio Tinto, B.C. Works, Kitimat, B.C.

ESSA Technologies, J. Laurence, Risk Sciences International, Trent University, and Trinity Consultants. 2020b. 2019 Comprehensive Review of Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project – Volume 2: Technical Appendices (Appendix 7), V.3 Final. Prepared for Rio Tinto, B.C. Works, Kitimat, B.C.

ESSA Technologies Ltd. 2018. KMP SO_2 EEM Program - Technical Memo W07, Aquatic Ecosystems Actions and Analyses. Prepared for Rio Tinto Alcan, Kitimat, B.C., 62 pp.

ESSA Technologies, J. Laurence, Balanced Ecological Management, Risk Sciences International, Trent University, Trinity Consultants, and Rio Tinto. 2023. B.C. Works' Sulphur Dioxide Environmental Effects Monitoring Program – Phase III Plan for 2019 to 2025, Final. Prepared for Rio Tinto, B.C. Works, 65 pp plus appendices.

Limnotek. 2016. Rio Tinto Alcan Kitimat Modernization Project: Environmental effects monitoring of water and aquatic Biota in 2015. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Alcan Ltd. 66p.

Limnotek. 2019. Rio Tinto Kitimat Modernization Project: Environmental effects monitoring of lakes and streams in 2018. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Ltd. 84pp. plus appendices.

Limnotek. 2020. Rio Tinto SO_2 Environmental Effects Program: Monitoring of lakes and streams in 2019. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Ltd. 111pp.

Limnotek. 2021. Rio Tinto SO_2 Environmental Effects Program: Monitoring of lakes and streams in 2020. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Ltd. 76pp.

Limnotek. 2022. Rio Tinto BC Works SO_2 Environmental Effects Program: Monitoring of Lakes in 2021. Final Report. Prepared by Limnotek Research and Development Inc. for Rio Tinto Ltd. 72 pp. plus appendices.

Limnotek. 2023. Rio Tinto BC Works SO_2 Environmental Effects Program: Monitoring of Lakes in 2022. ~~Final~~ Report~~.~~ ~~Prepared~~ prepared by Limnotek Research and Development Inc. for Rio Tinto Ltd. ~~57~~ 73 pp. ~~plus appendices.~~

Perrin, C.J and S. Bennett 2015. Rio Tinto Alcan Kitimat Modernization Project: Environmental effects monitoring of lake water quality in 2014. Data report prepared by Limnotek Research and Development Inc. for Rio Tinto Alcan Ltd. 20pp.

Perrin, C.J., E. Parkinson and S. Bennett 2013. Rio Tinto Alcan Kitimat Modernization Project: Environmental effects monitoring of water and aquatic Biota in 2013. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Alcan Ltd. 41pp.

Appendix 1: Water Chemistry Data from Annual Sampling, 2012-2022

The two tables below show the sample results for each of the EEM lakes and control lakes from annual monitoring conducted from 2012 to 2022, including charge balance ANC (CBANC), Gran ANC, base cation surplus (BCS), pH, dissolved organic carbon (DOC), and the concentration of major anions and cations, as well as the sum of all base cations (BC). The pH of the water samples has been measured by three different laboratories with (Trent University, 2012-2019; ALS, 2013-2022; BASL, 2019-2022). Gran ANC also transitioned from Trent University to BASL, overlapping in 2019.

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

Lake	Year	CBANC (µeq/L)	SE	Gran ANC (µeq/L) (Trent)	SE	Gran ANC (µeq/L) (BASL)	SE	BCS (µeq/L)	SE	pH (Trent)	SE	pH (ALS)	SE	pH (BASL)	SE	DOC (mg/L)	SE	SO4 * (µeq/L)	SE	Cl (µeq/L)	SE	F (µeq/L)	SE	Ca * (µeq/L)	SE	Mg * (µeq/L)	SE	K * (µeq/L)	SE	Na * (µeq/L)	SE	∑ BC * (µeq/L)	∑ Anions (µeq/L)
Lak006	2012	49.2		25.7				34.6		5.8						3.6		11.4		5.8		4.5		30.3		12.5		2.9		14.9		60.6	66.2
LAK007	2012	1452.4		1437.6				1452.5		8.0						0.6		51.4		24.6		2.8		1272.2		157.0		19.3		55.4		1503.9	1552.5
LAK012	2012	114.5		57.0				94.5		5.6						4.6		6.1		4.2		5.0		74.5		20.8		5.2		20.0		120.6	115.9
LAK016	2012	127.2		68.7				112.0		6.3						3.7		39.0		6.3		7.8		117.7		20.5		7.3		20.8		166.3	166.4
LAK022	2012	67.9		27.8				44.5		5.9						5.3		30.2		6.9		6.1		58.1		16.0		3.2		20.8		98.1	99.4
LAK023	2012	46.9		19.8				29.3		5.7						4.2		19.0		4.5		5.6		39.4		12.0		3.7		10.8		65.9	72.2
LAK024	2012	315.4		299.5				311.7		7.1						1.4		24.8		27.3		1.6		273.2		33.0		4.2		29.6		340.0	376.5
LAK028	2012	16.0		-4.0				-5.1		5.0						4.9		56.9		6.1		20.7		47.5		9.5		3.1		12.8		72.9	95.7
LAK034	2012	177.6		99.4				158.1		6.7						4.5		24.1		5.8		5.8		119.3		31.6		5.8		44.9		201.7	221.4
LAK042	2012	47.2		-20.4				-15.4		4.7						13.2		6.2		6.1		3.2		7.4		22.7		3.1		20.3		53.4	73.4
LAK044	2012	8.0		1.3				2.5		5.4						1.7		6.2		5.6		2.9		6.8		3.2		4.1		0.0		14.2	27.7
Lak006	2013	43.1		29.0				30.3		6.2		6.1				3.2		14.4		8.7		5.6		27.1		13.0		5.3		12.2		57.6	80.1
LAK007	2013	1385.6		1462.1				1388.3		7.9		8.1				0.1		66.5		36.3		3.7		1226.0		156.5		21.9		47.6		1452.0	1598.9
LAK012	2013	97.5		63.5				79.5		6.3		6.1				4.2		11.3		14.7		8.2		64.8		20.3		9.2		14.6		108.9	168.1
LAK016	2013	108.7		96.9				90.9		6.7		7.2				4.2		56.9		12.3		11.5		114.4		23.9		11.2		17.6		167.1	206.6
LAK022	2013	62.0		36.4				33.9		6.2		6.1				6.2		47.1		12.4		8.7		65.1		19.2		6.0		18.8		109.1	145.9
LAK023	2013	37.7		23.8				20.7		6.0		6.0				4.0		24.1		7.5		7.4		37.1		13.3		5.1		8.3		63.9	89.7
LAK024	2013																																
LAK028	2013	-8.1		4.8				-40.2		5.2		5.5				7.1		128.1		17.7		32.0		85.1		18.3		5.0		13.0		121.3	184.0
LAK034	2013	219.5		210.4				199.4		6.9		7.4				4.7		38.1		8.2		10.0		152.7		41.7		9.2		54.1		257.7	287.0
LAK042	2013	55.1		21.0				10.0		5.5		5.4				9.7		5.7		7.7		3.2		16.0		22.3		3.4		19.3		61.0	87.4
LAK044	2013	8.9		8.6				4.5		5.7		6.0				1.5		6.2		8.9		3.8		7.8		3.6		5.9		-2.0		15.3	35.0
Lak006	2014	52.9	2.0	38.8	0.6			37.2	2.6	6.1	0.1	6.6	0.2			3.8	0.3	12.1	0.6	8.1	1.2	4.8	0.1	31.7	0.5	14.6	0.4	4.7	0.3	14.5	1.2	65.5	84.2
LAK007	2014	1484.8		1445.7				1484.5		8.1		8.0				0.7		30.7		19.2		1.9		1276.8		156.7		20.2		61.8		1515.5	1527.8
LAK012	2014	99.8	3.1	68.8	6.8			71.8	7.9	6.0	0.1	6.7	0.2			6.3	1.0	15.8	5.2	10.3	2.2	5.2	0.2	69.3	1.6	21.3	0.6	7.3	0.5	18.3	1.6	116.1	135.7
LAK016	2014	132.5		105.7				115.6		6.7		6.7				4.0		48.2		9.3		9.5		122.4		25.0		10.1		23.3		180.8	194.2
LAK022	2014	76.1		46.9				51.0		6.3		6.4				5.7		37.8		9.0		6.9		68.5		18.9		5.2		21.4		114.0	133.0
LAK023	2014	59.4	3.3	32.1	1.1			34.3	2.1	5.9	0.1	6.7	0.3			5.7	0.4	18.9	1.0	6.1	0.3	6.2	0.2	49.3	3.9	14.9	0.4	4.0	0.1	10.8	0.3	79.0	93.0
LAK024	2014	473.4		472.1				468.1		7.6		7.5				1.7		37.2		65.7		2.3		402.3		50.1		7.8		50.2		510.4	617.9

Lake	Year	CBANC (µeq/L)	SE	Gran ANC (µeq/L) (Trent)	SE	Gran ANC (µeq/L) (BASL)	SE	BCS (µeq/L)	SE	pH (Trent)	SE	pH (ALS)	SE	pH (BASL)	SE	DOC (mg/L)	SE	SO4 * (µeq/L)	SE	Cl (µeq/L)	SE	F (µeq/L)	SE	Ca * (µeq/L)	SE	Mg * (µeq/L)	SE	K * (µeq/L)	SE	Na * (µeq/L)	SE	∑ BC * (µeq/L)	∑ Anions (µeq/L)
LAK028	2014	31.2		22.6				4.8		5.3		5.7				5.9		94.4		11.0		23.3		85.9		17.7		4.4		17.6		125.7	156.6
LAK034	2014	249.1		205.0				217.2		6.7		7.0				7.0		17.0		6.5		7.7		161.4		43.6		9.4		51.9		266.3	270.9
LAK042	2014	51.6		12.5				1.8		5.1		5.4				10.6		4.0		11.8		2.6		10.5		23.6		3.7		17.9		55.7	89.4
LAK044	2014	12.6		5.9				6.8		5.8		5.6				1.8		4.6		5.9		2.8		7.8		3.9		5.3		0.4		17.3	28.5
Lak006	2015	55.1	0.8	32.4	0.4			38.7	1.5	6.0	0.1	6.4	0.3			3.9	0.2	11.5	0.3	6.6	0.3	4.4	0.1	32.3	0.3	14.8	0.2	3.9	0.1	15.7	0.3	66.7	77.0
LAK007	2015	1461.9		1565.6				1463.9		8.0		7.9				0.3		45.6		24.0		2.6		1266.6		161.5		21.0		58.6		1507.7	1666.8
LAK012	2015	106.1	2.0	65.9	2.1			71.8	3.9	6.0	0.1	6.3	0.2			7.5	1.0	17.6	3.1	11.1	1.7	4.7	0.1	74.8	3.9	23.2	0.9	8.1	0.8	18.0	0.8	124.2	140.3
LAK016	2015	147.1		113.1				128.8		6.8		6.9				4.3		40.9		8.7		8.6		130.9		25.0		9.8		22.9		188.6	192.1
LAK022	2015	75.2		35.6				47.0		6.1		6.2				6.3		32.5		7.9		5.9		64.1		18.1		4.4		21.2		107.8	117.3
LAK023	2015	58.0	1.0	30.0	1.0			34.4	0.9	5.9	0.1	6.2	0.1			5.4	0.4	15.1	0.7	6.2	0.3	5.2	0.2	46.1	1.5	13.9	0.3	3.8	0.1	9.7	0.1	73.5	83.0
LAK024	2015	472.8		443.0				465.0		7.4		7.5				2.2		34.7		59.0		2.1		400.5		49.3		8.7		49.0		507.6	580.6
LAK028	2015	38.6		10.8				1.5		5.1		5.3				8.1		71.1		9.0		20.5		76.5		15.7		3.2		14.4		109.8	122.1
LAK034	2015	233.0		177.8				198.5		6.6		6.7				7.6		0.9		6.2		4.7		146.5		37.1		5.3		45.1		234.0	231.8
LAK042	2015	55.4		13.8				16.9		5.4		5.5				8.3		3.8		6.5		2.3		10.7		23.1		2.5		23.0		59.3	70.7
LAK044	2015	16.4		6.2				11.6		5.8		5.8				1.6		3.7		5.9		2.7		9.8		4.4		5.5		0.5		20.3	28.0
Lak006	2016	56.9	2.4	26.9	1.0			38.9	2.4	6.0	0.0	6.3	0.1			4.2	0.1	11.8	0.2	5.6	0.2	4.2	0.1	32.6	0.5	14.8	0.7	4.2	0.6	17.2	0.9	68.8	74.0
LAK007	2016	1495.8		1368.6				1495.2		8.0		8.1				0.8		46.7		25.4		2.6		1301.5		162.8		20.2		58.3		1542.8	1474.0
LAK012	2016	103.2	1.6	65.8	1.2			81.0	2.1	6.2	0.0	6.5	0.1			5.1	0.3	9.5	0.5	5.6	0.2	4.6	0.1	64.7	0.8	20.8	0.6	6.0	0.6	21.6	0.8	113.0	115.7
LAK016	2016	140.8		93.9				118.3		6.6		6.9				5.2		44.9		8.5		8.2		127.4		26.4		8.9		23.7		186.5	189.4
LAK022	2016	80.3		34.4				50.1		6.1		6.4				6.7		34.2		7.9		5.8		68.1		19.2		4.2		23.1		114.6	119.0
LAK023	2016	59.5	1.4	27.9	1.9			33.6	1.0	5.9	0.0	6.2	0.1			5.8	0.1	12.7	0.2	4.9	0.2	5.1	0.1	42.5	0.9	14.1	0.4	4.7	0.5	11.0	0.8	72.3	80.8
LAK024	2016	525.1		463.1				514.8		7.5		7.6				2.7		39.2		70.0		2.3		446.5		55.3		9.5		53.9		565.3	619.2
LAK028	2016	12.3	3.8	-4.9	6.2			-24.9	5.2	5.0	0.1	5.1	0.1			8.1	0.3	127.8	8.1	10.0	0.5	26.8	0.8	94.7	8.3	23.8	1.7	3.7	0.2	19.5	1.6	141.6	179.1
LAK034	2016	212.2		151.6				177.6		6.5		7.1				7.6		0.0		5.4		4.4		130.0		34.3		3.8		44.1		212.3	215.4
LAK042	2016	64.0	1.7	14.0	1.5			18.0	1.1	5.4	0.0	5.7	0.0			9.8	0.2	3.3	0.2	7.2	0.2	2.2	0.1	16.7	1.7	24.7	0.4	2.7	0.2	23.3	0.2	67.4	78.8
LAK044	2016	13.9	0.6	4.1	1.3			7.0	0.6	5.5	0.0	6.0	0.1			2.0	0.1	4.1	0.1	6.1	0.1	2.3	0.1	8.2	0.4	4.1	0.0	5.5	0.1	0.3	0.2	18.2	27.7
Lak006	2017	58.0	0.6	27.9	2.7			42.1	1.0	6.0	0.1	6.4	0.1			3.8	0.1	14.4	0.3	5.4	0.2	4.2	0.0	34.8	0.5	15.6	0.2	4.1	0.1	18.0	0.4	72.5	71.4
LAK007	2017	1402.3		1381.6				1404.3		8.0		8.0				0.3		47.1		25.9		2.4		1201.7		165.2		19.9		62.6		1449.4	1492.4
LAK012	2017	101.1	3.7	58.2	3.2			78.2	1.9	6.1	0.1	6.5	0.1			5.2	0.5	14.6	2.6	7.0	1.2	4.4	0.1	65.4	4.5	21.7	1.2	7.7	1.0	21.5	0.9	116.3	117.5
LAK016	2017	125.3		82.7				107.8		6.7		6.8				4.1		43.2		7.3		7.7		114.0		24.7		6.9		22.9		168.6	167.5
LAK022	2017	70.4		34.2				44.2		6.1		6.3				5.9		39.0		7.1		5.4		64.1		19.5		3.8		22.2		109.6	112.4
LAK023	2017	59.9	1.5	28.5	2.4			36.0	1.3	5.9	0.0	6.2	0.0			5.4	0.1	10.1	1.7	4.2	0.3	4.6	0.0	43.2	2.1	13.8	0.3	2.3	0.2	11.2	0.3	70.5	71.3
LAK024	2017	479.2		416.6				472.3		7.4		7.6				2.0		34.9		57.5		2.0		399.6		52.2		8.5		54.2		514.4	557.5
LAK028	2017	0.7	5.3	-9.9	4.5			-32.5	7.8	4.8	0.1	5.1	0.1			7.3	0.6	150.0	13.0	8.7	1.0	27.2	1.7	102.5	11.0	26.5	2.5	3.5	0.4	19.9	1.6	152.4	199.2
LAK034	2017	177.6		136.5				150.7		6.4		6.8				6.0		0.1		4.5		3.4		105.6		30.3		2.7		39.1		177.8	179.1
LAK042	2017	63.1	3.0	2.3	2.1			8.4	2.7	5.2	0.1	5.4	0.1			11.6	1.1	6.8	0.9	6.7	0.5	2.4	0.0	17.1	2.7	26.9	1.1	2.8	0.3	23.2	0.5	70.0	80.8
LAK044	2017	13.8	0.3	7.0	2.2			9.1	0.3	5.6	0.1	6.0	0.1			1.6	0.0	4.5	0.2	5.9	0.1	2.2	0.0	7.9	0.1	4.2	0.1	5.6	0.1	0.7	0.2	18.4	26.2
Lak006	2018	59.3	1.2	28.3	1.2			43.6	1.5	6.1	0.0	6.4	0.0			3.8	0.1	15.7	0.2	6.1	0.1	4.2	0.1	36.2	0.3	16.1	0.5	4.3	0.3	18.5	0.6	75.1	82.1
LAK007	2018	1443.8		1407.6				1445.7		8.1		8.1				0.3		47.1		27.9		2.6		1251.5		157.4		20.6		61.3		1490.8	1518.7
LAK012	2018	90.4	1.2	50.9	4.3			70.5	0.9	6.2	0.1	6.6	0.1			4.6	0.1	14.6	0.7	6.2	0.3	4.6	0.1	58.3	0.4	19.7	0.6	6.2	0.3	21.1	0.8	105.2	112.3
LAK016	2018	138.1		92.8				118.4		6.7		6.9				4.6		45.3		7.3		8.1		128.5		23.3		7.3		24.3		183.5	195.3

Lake	Year	CBANC (µeq/L)	SE	Gran ANC (µeq/L) (Trent)	SE	Gran ANC (µeq/L) (BASL)	SE	BCS (µeq/L)	SE	pH (Trent)	SE	pH (ALS)	SE	pH (BASL)	SE	DOC (mg/L)	SE	SO4 * (µeq/L)	SE	Cl (µeq/L)	SE	F (µeq/L)	SE	Ca * (µeq/L)	SE	Mg * (µeq/L)	SE	K * (µeq/L)	SE	Na * (µeq/L)	SE	∑ BC * (µeq/L)	∑ Anions (µeq/L)
LAK022	2018	76.6		30.3				51.8		6.1		6.3				5.6		43.2		7.3		5.8		72.1		19.3		4.2		24.4		119.9	120.1
LAK023	2018	61.3	0.7	23.0	0.7			36.3	1.6	6.0	0.1	6.4	0.1			5.6	0.2	14.1	0.9	4.9	0.2	4.9	0.1	45.9	0.3	15.0	0.3	3.3	0.2	11.4	0.4	75.5	78.6
LAK024	2018	553.5		509.9				548.8		7.6		7.6				1.6		42.6		77.3		2.4		472.7		56.4		9.4		57.2		595.7	680.2
LAK028	2018	8.4	1.8	4.2	1.6			-10.2	1.9	5.3	0.0	5.5	0.0			4.4	0.1	107.5	2.0	6.6	0.2	20.9	0.3	76.4	0.9	19.0	0.5	2.8	0.1	17.9	0.7	116.0	147.4
LAK034	2018	183.4		130.6				161.0		6.5		6.6				5.1		0.1		3.7		3.7		113.1		27.7		2.1		40.8		183.7	176.3
LAK042	2018	50.4	1.0	0.6	1.9			0.7	1.3	5.1	0.0	5.3	0.0			10.6	0.4	6.3	0.1	6.1	0.2	2.3	0.1	8.8	0.6	23.9	0.5	2.3	0.1	21.8	0.1	56.8	74.4
LAK044	2018	13.2	0.3	3.9	0.9			7.0	0.2	5.5	0.0	5.9	0.0			1.9	0.1	4.5	0.1	6.4	0.1	2.2	0.0	8.3	0.1	4.1	0.2	5.5	0.1	-0.2	0.3	17.7	27.5
Lak006	2019	63.8	2.2	31.6	2.7	40.0	1.1	49.7	1.8	6.1	0.0	6.5	0.1	6.2	0.0	3.5	0.2	16.8	0.6	6.7	0.6	4.0	0.2	38.0	0.6	17.8	0.4	5.1	0.2	19.9	0.9	80.8	74.1
LAK007	2019	1443.5		1374.5		1496.3		1445.4		8.1		8.1		8.0		0.3		43.0		27.1		2.4		1246.6		158.4		20.4		61.2		1486.5	1469.6
LAK012	2019	96.5	0.4	55.3	0.9	64.1	2.6	74.8	1.6	6.1	0.0	6.6	0.1	6.2	0.0	5.0	0.3	13.5	0.9	7.1	0.2	4.4	0.2	59.7	0.5	21.3	0.2	6.5	0.2	22.6	0.6	110.1	121.4
LAK016	2019	129.8		90.8		100.9		111.2		6.6		7.1		6.6		4.4		58.6		9.0		7.9		127.9		26.5		9.7		24.4		188.6	219.5
LAK022	2019	74.8		35.9		44.4		47.8		6.1		6.4		6.2		6.0		49.3		8.7		5.6		71.5		22.4		5.0		25.3		124.2	123.4
LAK023	2019	59.4	1.6	20.7	2.4	26.8	1.5	33.4	1.3	5.8	0.0	6.3	0.1	6.0	0.0	5.9	0.2	13.5	0.8	5.4	0.2	4.8	0.2	42.2	0.4	15.4	0.6	3.3	0.2	12.1	1.1	73.1	79.4
LAK024	2019	570.7		496.9		548.7		566.0		7.7		7.7		7.3		1.6		40.8		75.3		2.1		478.3		58.1		8.7		66.3		611.4	652.5
LAK028	2019	4.5	4.4	3.3	0.7	4.0	3.1	-18.1	6.0	5.2	0.0	5.4	0.0	5.1	0.0	5.2	0.3	148.5	4.0	11.3	0.6	25.8	1.1	103.5	1.2	26.6	0.5	3.7	0.2	20.0	0.9	153.7	200.1
LAK034	2019	196.8		148.9		166.9		173.8		6.4		7.0		6.6		5.3		0.9		4.5		4.1		122.1		30.4		1.8		43.5		197.8	195.9
LAK042	2019	52.1	2.1	10.1	0.6	16.5	1.0	9.1	1.4	5.4	0.0	5.6	0.1	5.4	0.0	9.2	0.5	7.6	0.6	6.2	0.3	2.3	0.1	12.6	1.8	23.1	0.6	2.2	0.3	22.0	0.3	59.9	77.1
LAK044	2019	14.8	0.6	6.1	0.4	6.6	0.3	5.7	1.2	5.5	0.0	5.9	0.1	5.7	0.0	2.5	0.3	4.7	0.3	6.5	0.3	2.3	0.1	8.9	0.2	4.5	0.2	6.0	0.2	0.3	0.2	19.6	32.0
Lak006	2020	70.3	1.5			44.7	1.3	48.1	3.8			6.3	0.0	6.1	0.0	5.1	0.5	15.3	0.5	6.5	0.6	4.0	0.1	44.9	1.3	17.6	0.7	4.7	0.4	18.6	0.4	85.7	91.4
LAK012	2020	142.1	6.4			93.1	9.0	101.4	4.9			6.4		6.1	0.0	8.8		15.6		9.3		5.0		97.5		28.1		7.8		24.5		157.9	165.7
LAK016	2020																																
LAK022	2020																																
LAK023	2020	66.6	0.5			29.6	1.6	37.6	2.8			6.1		6.0	0.0	6.4		13.9		5.1		4.8		49.0		15.7		3.7		12.2		80.6	80.5
LAK028	2020	8.0	1.4			0.5	0.6	-26.7	1.5			5.0	0.0	5.0	0.0	7.6	0.2	149.1	4.2	9.8	0.2	24.3	0.9	110.6	3.2	24.5	0.6	3.4	0.2	20.3	0.9	158.8	193.3
LAK042	2020	79.5	0.4			-10.0	3.6	-13.2	0.9			4.8		4.7	0.1	19.2		7.6		6.5		2.5		23.6		33.2		2.9		27.5		87.2	102.9
LAK044	2020	14.5	0.9			2.4	1.6	8.1	1.1			5.7	0.1	5.6	0.0	1.9	0.0	5.2	0.2	6.9	0.1	2.1	0.1	8.4	0.2	4.6	0.1	6.6	0.0	0.3	0.5	19.9	21.8
Lak006	2021	67.8	3.6			39.1	0.8	46.0	3.8			6.3	0.1	5.9	0.0	5.0	0.5	17.5	0.5	6.8	0.5	4.0	0.2	45.0	1.8	17.2	0.7	4.9	0.2	18.3	0.8	85.4	91.3
LAK012	2021	101.2	2.6			58.7	6.9	68.1	4.1			6.3	0.0	5.8	0.0	7.3	0.7	28.7	2.6	6.5	0.9	4.2	0.2	79.4	2.7	23.9	0.6	6.0	0.2	21.6	0.8	130.8	133.3
LAK016	2021	138.1				95.9		97.9				6.7		6.2		8.7		59.5		8.2		8.7		139.4		28.0		8.2		23.3		198.8	213.4
LAK022	2021	68.8				20.6		44.2				5.4		5.5		5.6		41.9		7.6		5.6		65.1		20.1		3.9		21.8		110.8	104.5
LAK023	2021	56.2	3.9			24.9	1.0	32.4	3.9			6.1	0.1	5.7	0.0	5.4	0.3	24.5	1.1	4.7	0.3	4.6	0.3	51.9	2.8	15.1	0.6	3.5	0.2	11.5	0.5	81.9	82.0
LAK028	2021	11.7	1.9			-5.7	0.9	-31.9	2.5			4.9	0.1	4.8	0.0	9.4	0.3	96.9	6.8	10.2	0.5	19.4	0.3	76.5	3.7	17.9	1.4	2.7	0.1	12.9	1.2	110.0	141.1
LAK042	2021	62.4	4.3			-11.8	3.8	-16.5	4.3			4.7	0.1	4.7	0.1	16.5	0.6	13.5	1.1	5.6	0.3	2.3	0.2	20.9	1.8	28.2	0.6	2.7	0.1	24.3	0.8	76.1	100.5
LAK044	2021	17.1	1.4			5.4	1.9	9.5	1.6			5.5	0.1	5.5	0.0	2.2	0.2	4.2	0.3	5.6	0.1	1.8	0.1	9.4	1.4	4.4	0.3	6.5	0.2	1.1	0.3	21.5	25.6
Lak006	2022	70.1	1.3			44.1	1.7	52.2	1.7			6.5	0.0	6.3	0.0	4.2	0.3	12.1	0.4	5.9	0.3	3.7	0.0	42.0	0.7	17.2	0.2	4.2	0.1	18.9	0.5	82.3	84.7
LAK012	2022	112.4	1.1			81.9	1.6	90.2	2.2			6.7	0.0	6.3	0.0	5.1	0.2	1.0	0.5	5.8	0.1	4.1	0.0	67.7	1.1	22.0	0.2	3.2	0.1	20.7	0.5	113.6	115.9
LAK016	2022	141.4				113.1		123.2				7.0		6.6		4.3		41.7		7.3		7.3		128.5		24.8		8.6		21.8		183.6	188.4
LAK022	2022	75.4				39.4		47.8				6.3		6.2		6.2		31.6		6.8		5.1		62.6		18.7		4.0		21.7		107.1	107.0
LAK023	2022	54.0	0.5			26.3	5.8	29.6	1.3			6.2	0.0	6.1	0.0	5.5	0.2	12.7	0.3	4.6	0.1	4.2	0.0	39.4	0.4	13.3	0.1	3.9	0.1	10.2	0.3	66.8	72.0
LAK028	2022	19.3	4.0			10.4	1.9	-10.6	3.6			5.3	0.1	5.2	0.1	6.6	0.4	100.4	1.8	7.1	0.1	16.4	0.8	80.7	2.2	18.7	0.3	3.2	0.1	17.3	0.5	119.9	139.4
LAK042	2022	52.8	1.3			15.4	1.7	15.6	2.2			5.6	0.0	5.5	0.0	8.1	0.3	3.4	0.3	4.8	0.4	1.7	0.1	11.0	0.3	20.6	0.3	2.2	0.2	22.5	0.7	56.3	65.7

Lake	Year	CBANC (µeq/L)	SE	Gran ANC (µeq/L) (Trent)	SE	Gran ANC (µeq/L) (BASL)	SE	BCS (µeq/L)	SE	pH (Trent)	SE	pH (ALS)	SE	pH (BASL)	SE	DOC (mg/L)	SE	SO4 * (µeq/L)	SE	Cl (µeq/L)	SE	F (µeq/L)	SE	Ca * (µeq/L)	SE	Mg * (µeq/L)	SE	K * (µeq/L)	SE	Na * (µeq/L)	SE	∑ BC * (µeq/L)	∑ Anions (µeq/L)
LAK044	2022	16.8	0.4			7.3	0.5	10.9	1.6			5.8	0.1	5.8	0.0	1.8	0.3	3.0	0.1	5.7	0.2	1.7	0.1	8.2	0.2	4.2	0.1	6.7	0.3	0.8	0.2	19.9	22.1
NC184	2012																																
NC194	2012																																
DCAS14A	2012																																
NC184	2013	80.4		16.2				25.6		5.7						11.6		5.7		24.0		0.3		50.5		17.5		4.4		13.8		86.2	132.0
NC194	2013	35.6		28.0				35.3		6.6						0.7		3.6		7.6		0.3		23.2		3.4		5.2		7.4		39.2	59.3
DCAS14A	2013	53.5		50.6				49.9		6.5						1.4		33.4		9.2		0.6		63.9		10.3		10.3		6.1		90.6	115.6
NC184	2014																																
NC194	2014																																
DCAS14A	2014																																
NC184	2015	73.0		18.4				27.2		5.5		5.6				9.8		5.7		21.7		0.5		48.8		16.1		2.9		10.8		78.7	104.6
NC194	2015	40.9		33.0				40.2		6.5		6.5				0.8		2.3		7.3		0.5		26.9		4.4		4.3		7.9		43.4	56.3
DCAS14A	2015	74.9						73.6		6.6		6.7				0.9		35.7		7.3		0.5		77.6		12.4		11.2		9.9		111.0	49.0
NC184	2016	94.6		27.3				44.9		5.8		6.2				10.6		5.5		21.2		0.5		62.6		19.3		2.7		15.5		100.1	120.5
NC194	2016	40.0		28.7				35.1		6.4		6.6				1.6		2.3		7.9		0.5		26.4		4.3		3.8		7.9		42.4	55.4
DCAS14A	2016	72.7		57.5				68.3		6.6		6.8				1.5		36.8		8.5		0.5		77.5		11.8		10.5		9.7		109.6	116.1
NC184	2017	76.3		9.8				13.0		5.4		6.0				13.3		4.7		14.7		0.5		45.2		17.4		2.5		15.9		81.0	104.6
NC194	2017	46.5		12.4				44.8		6.4		6.4				1.0		2.5		4.8		0.5		29.9		5.7		3.6		9.9		49.1	39.4
DCAS14A	2017	67.8		51.0				63.3		6.6		6.7				1.5		31.1		5.6		0.5		68.2		11.8		9.1		9.9		99.0	99.0
NC184	2018	95.0		44.0				63.1		6.2		6.4				7.0		8.3		16.6		0.5		67.8		17.3		3.1		15.3		103.4	113.3
NC194	2018	43.1		26.1				45.0		6.5		6.7				0.3		2.6		5.1		0.5		28.3		4.3		4.1		9.1		45.8	45.6
DCAS14A	2018	79.0		59.3				77.3		6.8		6.8				1.0		41.3		7.3		0.5		85.6		12.6		11.5		10.7		120.4	124.2
NC184	2019	86.1	1.7	24.9	1.5	47.3	14.2	42.9	2.2	5.7	0.0	6.1	0.1	5.9	0.0	9.3	0.3	7.1	0.2	23.2	1.0	0.5	0.0	58.3	0.3	19.0	0.6	2.6	0.1	13.5	1.1	93.3	114.5
NC194	2019	46.7	0.6	30.4	5.3	41.4	0.2	44.7	0.4	6.4	0.0	6.6	0.1	6.5	0.0	1.0	0.2	2.7	0.3	9.2	0.4	0.5	0.0	31.4	0.6	4.8	0.1	4.7	0.2	8.5	0.3	49.4	50.0
DCAS14A	2019	81.1	1.5	58.6	5.9	73.0	0.3	78.3	1.4	6.6	0.1	6.8	0.0	6.6	0.0	1.2	0.0	41.0	0.9	8.8	1.0	0.5	0.0	85.3	1.2	13.7	0.2	11.9	0.3	11.9	0.3	122.8	138.6
NC184	2020																																
NC194	2020																																
DCAS14A	2020																																
NC184	2021	61.2				9.2		6.4				5.1		5.2		11.6		3.5		18.9		0.3		37.3		13.5		2.0		11.8		64.7	100.8
NC194	2021	35.6				27.4		33.1				6.2		6.0		1.1		2.1		5.9		0.3		22.4		3.9		3.8		7.7		37.8	54.9
DCAS14A	2021	63.8				55.6		55.0				6.6		6.0		2.4		28.5		7.9		0.6		63.6		11.9		10.2		9.4		95.1	101.0
NC184	2022	85.3				25.2		35.5				6.1		5.9		10.6		4.5		15.2		0.3		54.3		18.0		2.8		14.7		89.8	110.1
NC194	2022	36.3				28.6		35.1				6.5		6.4		0.9		1.9		5.1		0.3		22.7		4.0		3.8		7.7		38.3	40.8
DCAS14A	2022	70.9				62.7		68.1				6.8		6.5		1.2		30.7		5.4		0.3		71.2		11.4		10.1		9.1		101.7	98.5

[1] SE = standard error

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	Gran Alkalinity (mg/L) (Trent)	Gran Alkalinity (mg/L) (BASL)	pH (Trent)	pH (ALS)	pH (BASL)	DOC (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	1.3		5.8			3.6	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	71.9		8.0			0.6	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	2.9		5.6			4.6	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	3.4		6.3			3.7	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	1.4		5.9			5.3	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	1.0		5.7			4.2	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	15.0		7.1			1.4	40.0	1.3	1.0	0.0	0.4	2.4	5.5	0.5	0.2	1.2	0.0	0.0	0.0
LAK028	2012	-0.2		5.0			4.9	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	5.0		6.7			4.5	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	-1.0		4.7			13.2	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	0.1		5.4			1.7	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	1.5		6.2	6.1		3.2	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	73.2		7.9	8.1		0.1	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	3.2		6.3	6.1		4.2	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	4.9		6.7	7.2		4.2	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	1.8		6.2	6.1		6.2	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	1.2		6.0	6.0		4.0	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	0.2		5.2	5.5		7.1	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	10.5		6.9	7.4		4.7	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	1.1		5.5	5.4		9.7	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	0.4		5.7	6.0		1.5	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	1.9		6.1	6.6		3.8	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	72.4		8.1	8.0		0.7	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	3.4		6.0	6.7		6.3	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	5.3		6.7	6.7		4.0	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	2.3		6.3	6.4		5.7	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	1.6		5.9	6.7		5.7	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	23.6		7.6	7.5		1.7	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	1.1		5.3	5.7		5.9	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	10.3		6.7	7.0		7.0	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	0.6		5.1	5.4		10.6	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	0.3		5.8	5.6		1.8	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	1.6		6.0	6.4		3.9	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	78.4		8.0	7.9		0.3	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	3.3		6.0	6.3		7.5	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	5.7		6.8	6.9		4.3	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	1.8		6.1	6.2		6.3	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
LAK023	2015	1.5		5.9	6.2		5.4	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

Lake	Year	Gran Alkalinity (mg/L) (Trent)	Gran Alkalinity (mg/L) (BASL)	pH (Trent)	pH (ALS)	pH (BASL)	DOC (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)
LAK024	2015	22.2		7.4	7.5		2.2	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	0.5		5.1	5.3		8.1	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	8.9		6.6	6.7		7.6	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	0.7		5.4	5.5		8.3	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	0.3		5.8	5.8		1.6	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	1.3		6.0	6.3		4.2	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	68.5		8.0	8.1		0.8	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	3.3		6.2	6.5		5.1	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	4.7		6.6	6.9		5.2	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	1.7		6.1	6.4		6.7	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	1.4		5.9	6.2		5.8	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	23.2		7.5	7.6		2.7	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	-0.2		5.0	5.1		8.1	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	7.6		6.5	7.1		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	0.7		5.4	5.7		9.8	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	0.2		5.5	6.0		2.0	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	1.4		6.0	6.4		3.8	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	69.1		8.0	8.0		0.3	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	2.9		6.1	6.5		5.2	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	4.1		6.7	6.8		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	1.7		6.1	6.3		5.9	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	1.4		5.9	6.2		5.4	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	20.9		7.4	7.6		2.0	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	-0.5		4.8	5.1		7.3	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	6.8		6.4	6.8		6.0	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	0.1		5.2	5.4		11.6	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	0.4		5.6	6.0		1.6	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
Lak006	2018	1.4		6.1	6.4		3.8	8.8	0.8	0.2	0.1	2.5	2.5	0.7	0.2	0.2	0.5	0.0	0.1	0.0
Lak007	2018	70.4		8.1	8.1		0.3	147.4	2.4	1.0	0.0	2.5	2.5	25.1	2.0	0.8	2.0	0.0	0.0	0.0
LAK012	2018	2.5		6.2	6.6		4.6	11.5	0.7	0.2	0.1	2.5	2.5	1.2	0.3	0.2	0.6	0.3	0.1	0.0
LAK016	2018	4.6		6.7	6.9		4.6	20.0	2.2	0.3	0.2	2.5	2.5	2.6	0.3	0.3	0.7	0.0	0.1	0.0
LAK022	2018	1.5		6.1	6.3		5.6	13.4	2.1	0.3	0.1	2.5	2.5	1.5	0.3	0.2	0.7	0.0	0.1	0.0
LAK023	2018	1.1		6.0	6.4		5.6	9.4	0.7	0.2	0.1	2.5	2.5	0.9	0.2	0.1	0.4	0.0	0.1	0.0
LAK024	2018	25.5		7.6	7.6		1.6	70.2	2.4	2.7	0.0	2.5	2.5	9.5	0.9	0.4	2.8	0.0	0.0	0.0
LAK028	2018	0.2		5.3	5.5		4.4	17.7	5.2	0.2	0.4	2.5	3.3	1.5	0.2	0.1	0.5	0.1	0.5	0.0
LAK034	2018	6.5		6.5	6.6		5.1	17.8	0.0	0.1	0.1	2.5	2.5	2.3	0.3	0.1	1.0	0.0	0.0	0.0
LAK042	2018	0.0		5.1	5.3		10.6	8.6	0.3	0.2	0.0	2.5	2.5	0.2	0.3	0.1	0.6	0.3	0.4	0.0
LAK044	2018	0.2		5.5	5.9		1.9	3.6	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	2019	1.6	2.0	6.1	6.5	6.2	1.1	8.3	0.8	0.2	0.1	2.5	2.5	0.8	0.2	0.2	0.6	0.0	0.0	0.0
Lak007	2019	68.8	74.9	8.1	8.1	8.0	0.3	147.2	2.2	1.0	0.0	2.5	2.5	25.0	2.0	0.8	1.9	0.0	0.0	0.0
LAK012	2019	2.8	3.2	6.1	6.6	6.2	1.8	11.0	0.7	0.3	0.1	3.2	2.5	1.2	0.3	0.3	0.7	0.2	0.0	0.0

Lake	Year	Gran Alkalinity (mg/L) (Trent)	Gran Alkalinity (mg/L) (BASL)	pH (Trent)	pH (ALS)	pH (BASL)	DOC (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)
LAK016	2019	4.5	5.1	6.6	7.1	6.6	2.5	19.8	2.9	0.3	0.2	2.5	6.2	2.6	0.3	0.4	0.7	0.0	0.1	0.0
LAK022	2019	1.8	2.2	6.1	6.4	6.2	1.3	13.6	2.4	0.3	0.1	2.5	2.5	1.4	0.3	0.2	0.8	0.1	0.1	0.0
LAK023	2019	1.0	1.3	5.8	6.3	6.0	1.0	7.1	0.7	0.2	0.1	2.5	3.6	0.9	0.2	0.1	0.4	0.0	0.1	0.0
LAK024	2019	24.9	27.5	7.7	7.7	7.3	6.9	66.8	2.3	2.7	0.0	8.0	2.5	9.6	0.9	0.4	3.0	0.0	0.0	0.0
LAK028	2019	0.2	0.2	5.2	5.4	5.1	5.4	24.0	7.2	0.4	0.5	11.9	5.2	2.1	0.4	0.2	0.7	0.1	0.6	0.0
LAK034	2019	7.5	8.4	6.4	7.0	6.6	3.0	17.8	0.1	0.2	0.1	2.5	2.5	2.5	0.4	0.1	1.1	0.0	0.0	0.0
LAK042	2019	0.5	0.8	5.4	5.6	5.4	1.5	6.6	0.4	0.2	0.0	4.3	2.5	0.3	0.3	0.1	0.6	0.2	0.3	0.0
LAK044	2019	0.3	0.3	5.5	5.9	5.7	1.5	2.4	0.3	0.2	0.0	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2020		2.2		6.3	6.1	5.1	8.5	0.8	0.2	0.1	2.5	2.5	0.9	0.2	0.2	0.6	0.1	0.1	0.0
LAK012	2020		4.7		6.4	6.1	8.8	15.1	0.8	0.3	0.1	2.5	2.5	2.0	0.4	0.3	0.7	0.5	0.1	0.1
LAK016	2020																			
LAK022	2020																			
LAK023	2020		1.5		6.1	6.0	6.4	7.3	0.7	0.2	0.1	2.5	2.5	1.0	0.2	0.1	0.4	0.0	0.1	0.0
LAK028	2020		0.0		5.0	5.0	7.6	25.0	7.2	0.3	0.5	25.4	3.8	2.2	0.3	0.1	0.7	0.1	0.7	0.0
LAK042	2020		-0.5		4.8	4.7	19.2	14.2	0.4	0.2	0.0	2.5	2.5	0.5	0.4	0.1	0.8	0.6	0.6	0.0
LAK044	2020		0.2		5.6	5.6	1.9	2.5	0.1	0.1	0.0	2.5	2.5	0.2	0.1	0.2	0.1	0.0	0.0	0.0
Lak006	2021		2.0		6.3	5.9	5.0	8.3	0.9	0.2	0.1	2.5	5.3	0.9	0.2	0.2	0.6	0.1	0.1	0.0
LAK012	2021		2.9		6.3	5.8	7.3	13.1	1.4	0.2	0.1	12.9	4.8	1.6	0.3	0.2	0.6	0.4	0.1	0.0
LAK016	2021		4.8		6.7	6.2	8.7	20.5	2.9	0.3	0.2	18.1	2.5	2.8	0.4	0.3	0.7	0.1	0.2	0.0
LAK022	2021		1.0		5.4	5.5	5.6	12.6	2.1	0.3	0.1	2.5	2.5	1.3	0.3	0.2	0.7	0.1	0.2	0.0
LAK023	2021		1.2		6.1	5.7	5.4	8.3	1.2	0.2	0.1	18.7	3.3	1.0	0.2	0.1	0.4	0.0	0.1	0.0
LAK028	2021		-0.3		4.9	4.8	9.4	20.4	4.7	0.4	0.4	20.5	3.2	1.5	0.2	0.1	0.5	0.2	0.7	0.0
LAK042	2021		-0.6		4.7	4.7	16.5	14.5	0.7	0.2	0.0	2.5	4.1	0.4	0.4	0.1	0.7	0.5	0.5	0.0
LAK044	2021		0.3		5.5	5.5	2.2	2.7	0.2	0.2	0.0	2.5	2.5	0.2	0.1	0.3	0.1	0.0	0.0	0.0
Lak006	2022		1.8		5.2	5.0	3.4	9.4	0.5	0.2	0.1	2.0	2.5	0.7	0.2	0.1	0.4	0.1	0.0	0.0
LAK012	2022		4.1		6.7	6.3	5.1	11.9	0.1	0.2	0.1	2.5	2.5	1.4	0.3	0.1	0.6	0.2	0.0	0.0
LAK016	2022		5.7		7.0	6.6	4.3	20.7	2.0	0.3	0.1	7.2	6.0	2.6	0.3	0.3	0.6	0.0	0.1	0.0
LAK022	2022		2.0		6.3	6.2	6.2	12.1	1.6	0.2	0.1	2.5	2.5	1.3	0.2	0.2	0.6	0.1	0.1	0.0
LAK023	2022		1.3		6.2	6.1	5.5	7.6	0.6	0.2	0.1	2.5	2.5	0.8	0.2	0.2	0.3	0.0	0.1	0.0
LAK028	2022		0.4		4.3	4.2	5.3	18.6	3.9	0.2	0.2	2.6	2.0	1.3	0.2	0.1	0.4	0.1	0.4	0.0
LAK042	2022		0.8		5.6	5.5	8.1	7.0	0.2	0.2	0.0	2.5	3.1	0.2	0.3	0.1	0.6	0.2	0.2	0.0
LAK044	2022		0.4		5.8	5.8	1.8	3.4	0.2	0.2	0.0	2.5	2.5	0.2	0.1	0.3	0.1	0.0	0.0	0.0
NC184	2012																			
NC194	2012																			
DCAS14A	2012																			
NC184	2013	0.8		5.7			11.6	10.0	0.4	0.9	0.0	5.0	1.0	1.0	0.3	0.2	0.8			
NC194	2013	1.4		6.6			0.7	3.9	0.2	0.3	0.0	1.0	1.0	0.5	0.1	0.2	0.3			
DCAS14A	2013	2.5		6.5			1.4	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	2014																			
NC194	2014																			
DCAS14A	2014																			

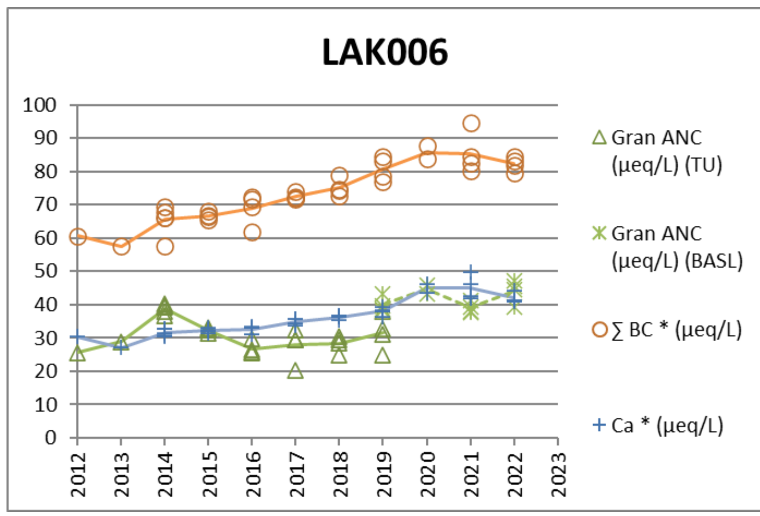
Lake	Year	Gran Alkalinity (mg/L) (Trent)	Gran Alkalinity (mg/L) (BASL)	pH (Trent)	pH (ALS)	pH (BASL)	DOC (mg/L)	Conductivity (µS/s)	SO4 (mg/L)	Cl (mg/L)	F (mg/L)	NO3 (µg/L)	NH4 (µg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)
NC184	2015	0.9		5.5	5.6		9.8	11.6	0.4	0.8	0.0	2.5	2.5	1.0	0.2	0.1	0.7	0.2	0.3	0.0
NC194	2015	1.7		6.5	6.5		0.8	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	1.4		5.8	6.2		10.6	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	1.4		6.4	6.6		1.6	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	2.9		6.6	6.8		1.5	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	0.5		5.4	6.0		13.3	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	0.6		6.4	6.4		1.0	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	2.6		6.6	6.7		1.5	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
NC184	2018	2.2		6.2	6.4		7.0	12.3	0.5	0.6	0.0	2.5	2.5	1.4	0.3	0.1	0.7	0.1	0.2	0.0
NC194	2018	1.3		6.5	6.7		0.3	5.4	0.2	0.2	0.0	2.5	2.5	0.6	0.1	0.2	0.3	0.0	0.0	0.0
DCAS14A	2018	3.0		6.8	6.8		1.0	14.7	2.0	0.3	0.0	2.5	2.5	1.7	0.2	0.5	0.4	0.0	0.0	0.0
NC184	2019	1.2	2.4	5.7	6.1	5.9	1.1	11.1	0.5	0.8	0.0	3.7	2.5	1.2	0.3	0.1	0.8	0.1	0.3	0.0
NC194	2019	1.5	2.1	6.4	6.6	6.5	0.9	5.3	0.2	0.3	0.0	2.5	2.5	0.6	0.1	0.2	0.4	0.0	0.0	0.0
DCAS14A	2019	2.9	3.7	6.6	6.8	6.6	1.4	13.7	2.0	0.3	0.0	10.3	2.5	1.7	0.2	0.5	0.4	0.0	0.0	0.0
NC184	2020																			
NC194	2020																			
DCAS14A	2020																			
NC184	2021		0.5		5.1	5.2	11.6	9.5	0.3	0.7	0.0	2.5	2.5	0.8	0.2	0.1	0.6	0.2	0.3	0.0
NC194	2021		1.4		6.2	6.0	1.1	3.3	0.1	0.2	0.0	2.5	2.5	0.5	0.1	0.2	0.3	0.0	0.0	0.0
DCAS14A	2021		2.8		6.6	6.0	2.4	10.8	1.4	0.3	0.0	39.8	2.5	1.3	0.2	0.4	0.4	0.0	0.0	0.0
NC184	2022		1.3		6.1	5.9	10.6	10.9	0.3	0.5	0.0	2.5	2.5	1.1	0.3	0.1	0.6	0.1	0.3	0.0
NC194	2022		1.4		6.5	6.4	0.9	4.6	0.1	0.2	0.0	2.5	2.5	0.5	0.1	0.2	0.3		0.0	0.0
DCAS14A	2022		3.1		6.8	6.5	1.2	12.1	1.5	0.2	0.0	2.5	2.5	1.4	0.2	0.4	0.3	0.0	0.0	0.0

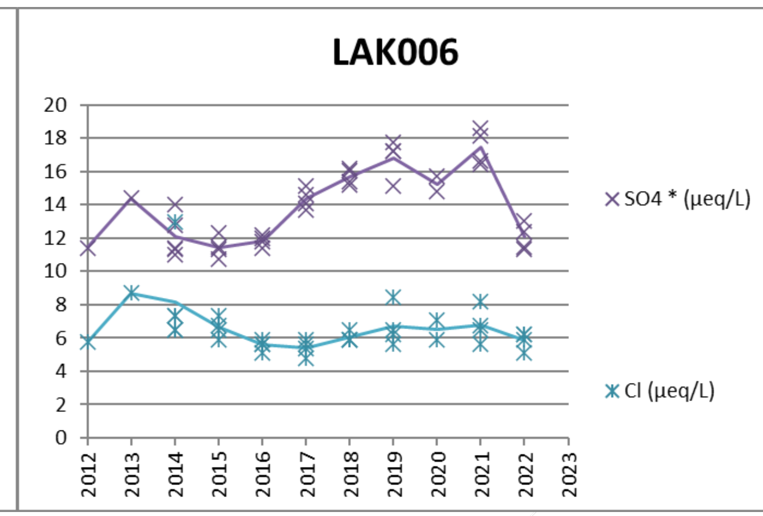
Appendix 2: Changes in Ion Concentrations from 2012 to 2022

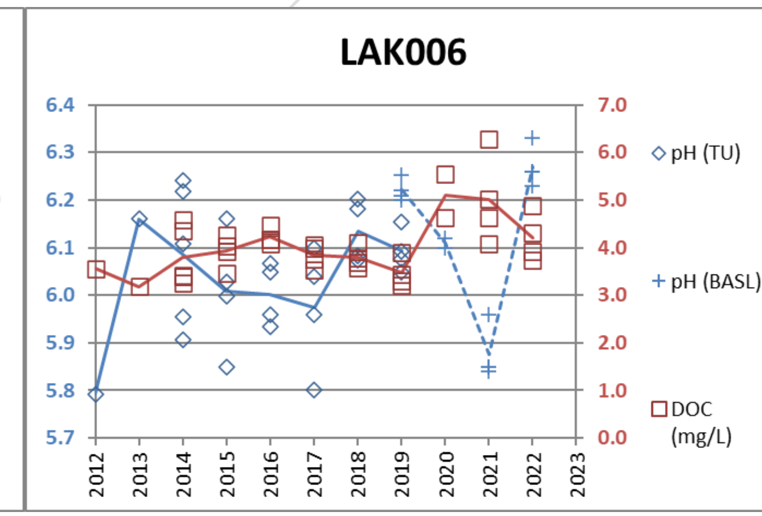
For each of the EEM lakes, the figures in this appendix show the inter-annual changes in six major water chemistry metrics from 2012 to 2022: Gran ANC, base cations and calcium (left panel), sulfate and chloride (centre-left panel), pH and dissolved organic carbon (centre-right panel), and CBANC, Gran ANC, and BCS (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 center-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.

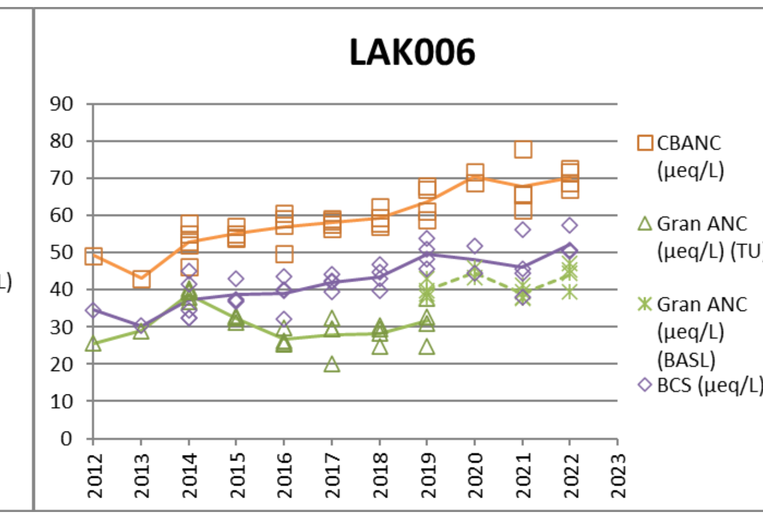
These figures show the results for all of the sampling events for each lake in each year, whether that included multiple within-season samples or only a single annual sample. The points represent the values for individual sampling events. The solid lines represent the annual trend, based on either the 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.

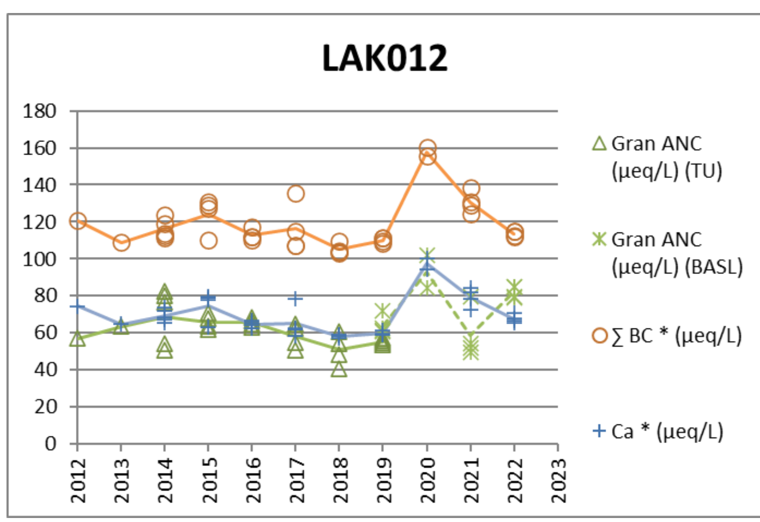
Sensitive Lakes

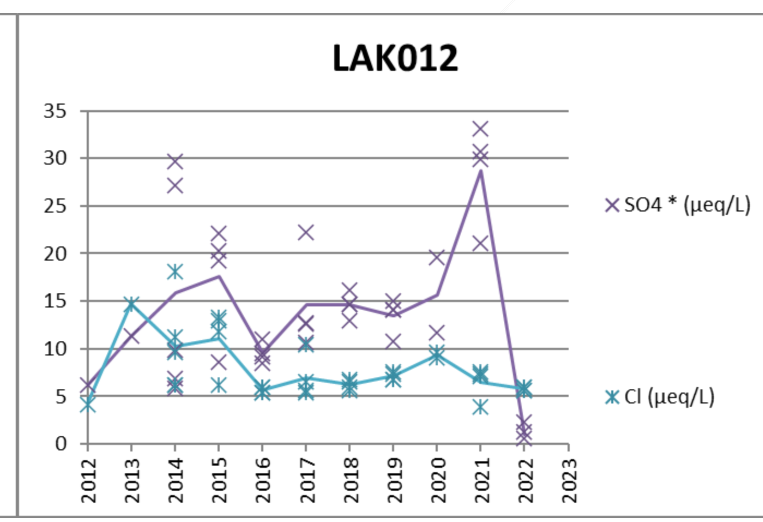


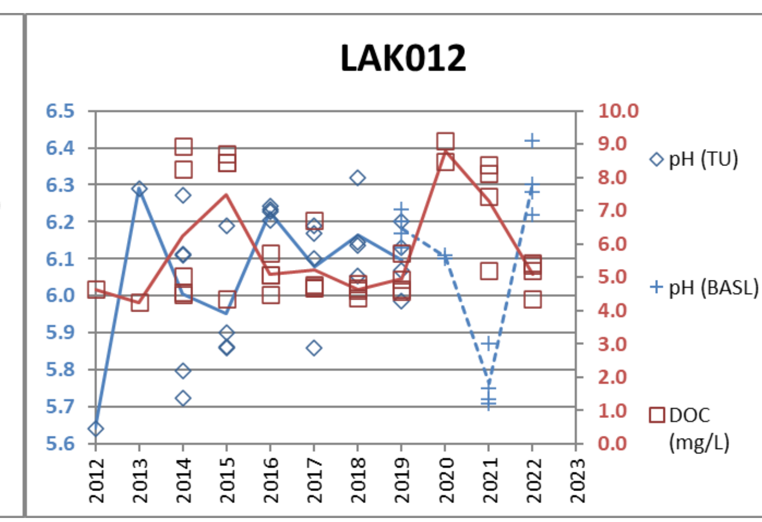


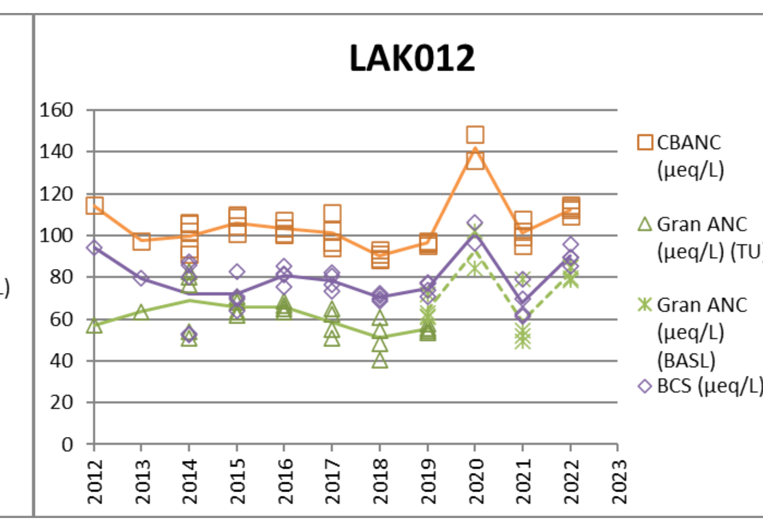


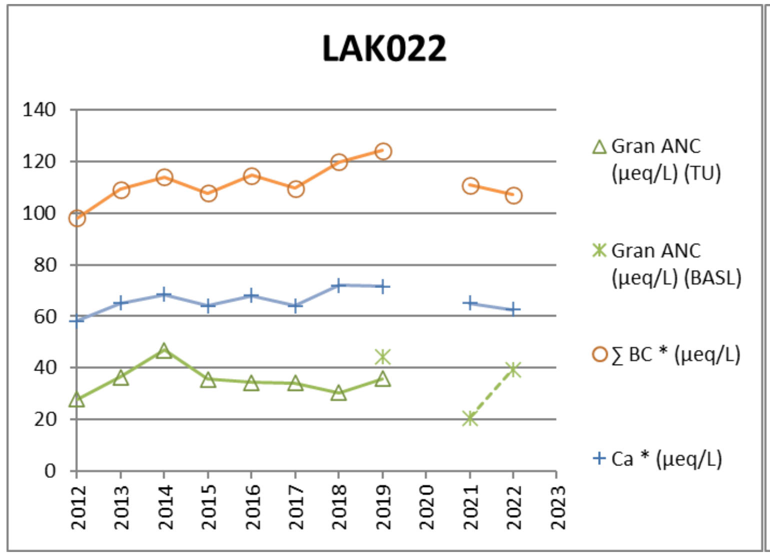


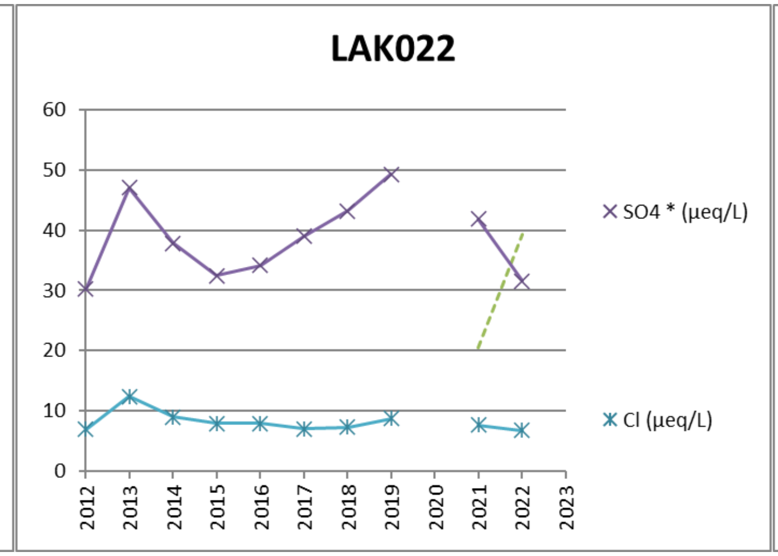


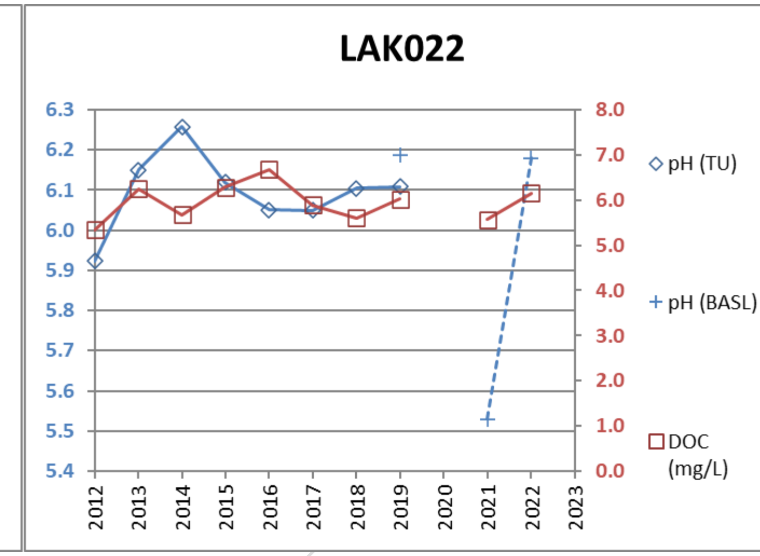


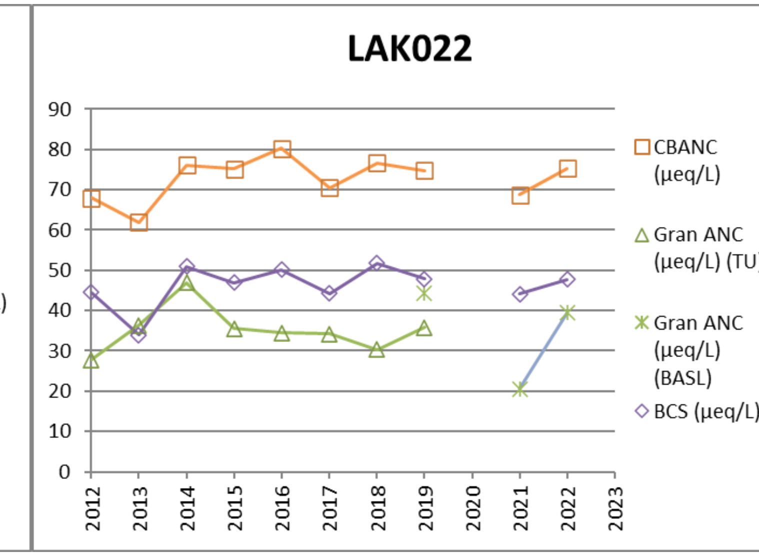


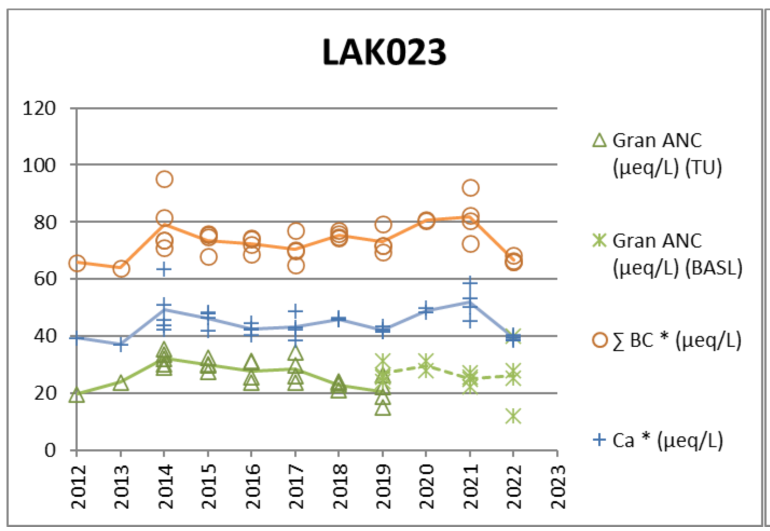


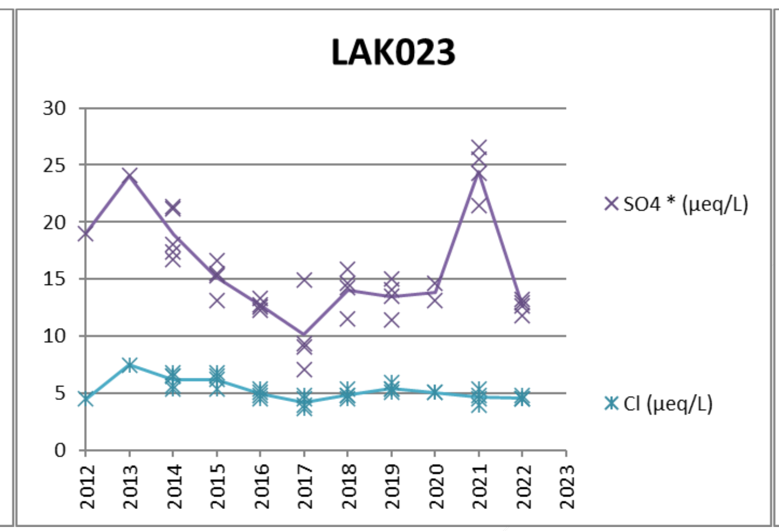

LAK022
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
∑ BC * (μeq/L)
Ca * (μeq/L)

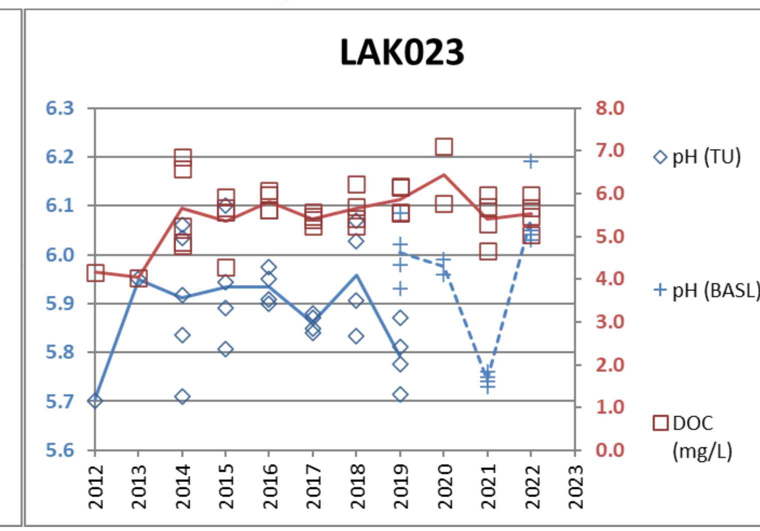

LAK022
SO4 * (μeq/L)
Cl (μeq/L)

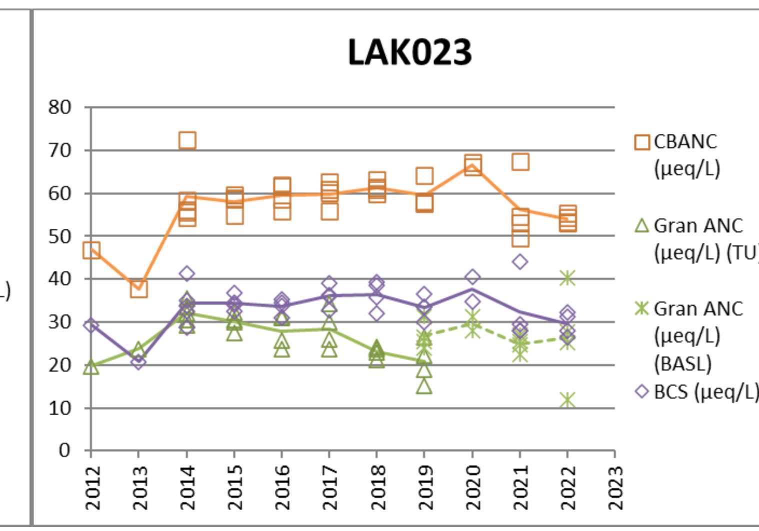

LAK022
pH (TU)
pH (BASL)
DOC (mg/L)


LAK022
CBANC (μeq/L)
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
BCS (μeq/L)


LAK023
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
∑ BC * (μeq/L)
Ca * (μeq/L)


LAK023
SO4 * (μeq/L)
Cl (μeq/L)


LAK023
pH (TU)
pH (BASL)
DOC (mg/L)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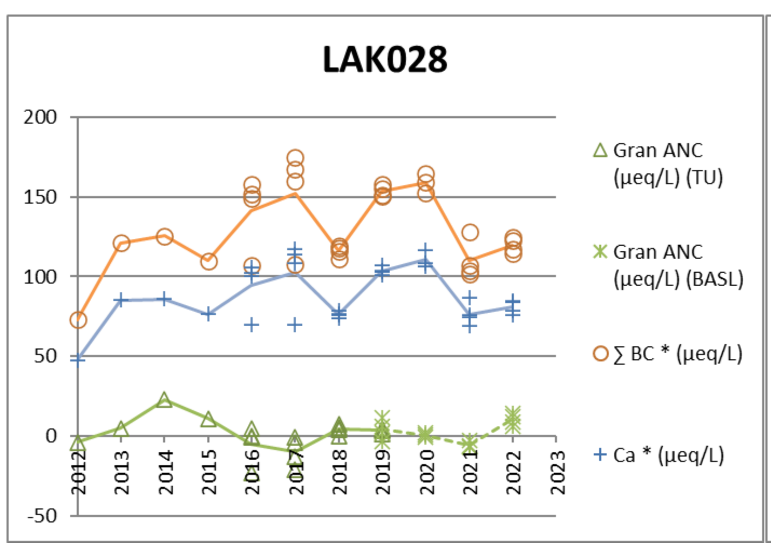
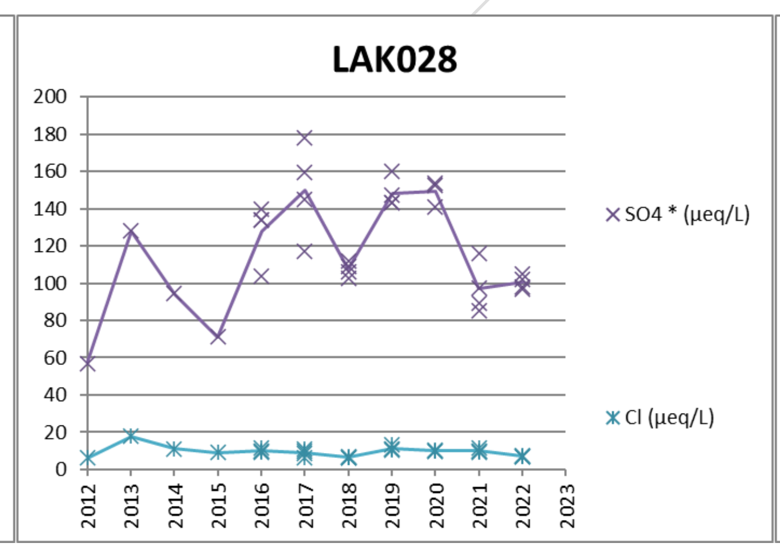
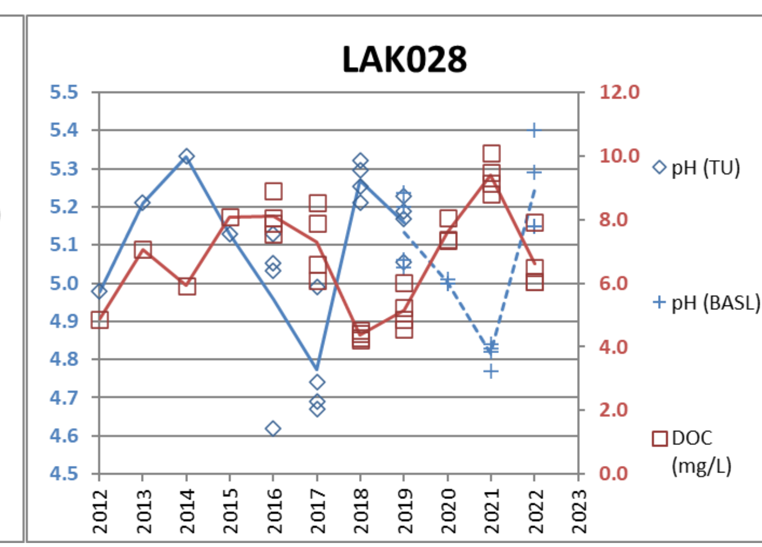
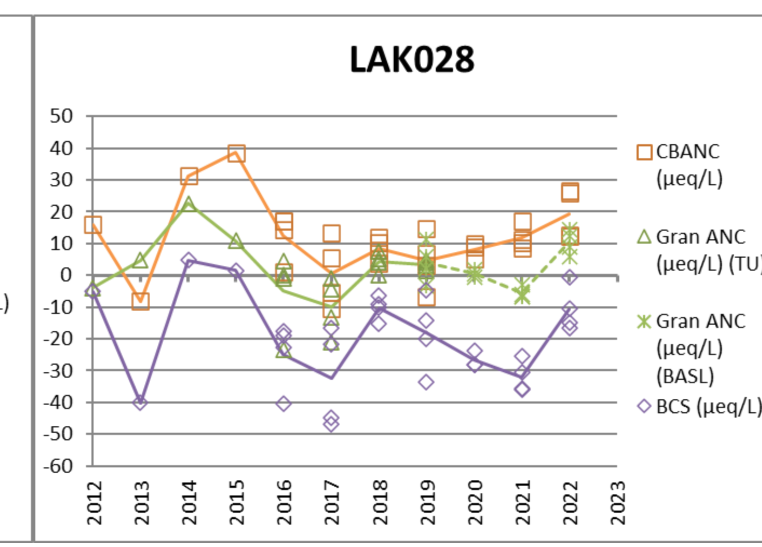
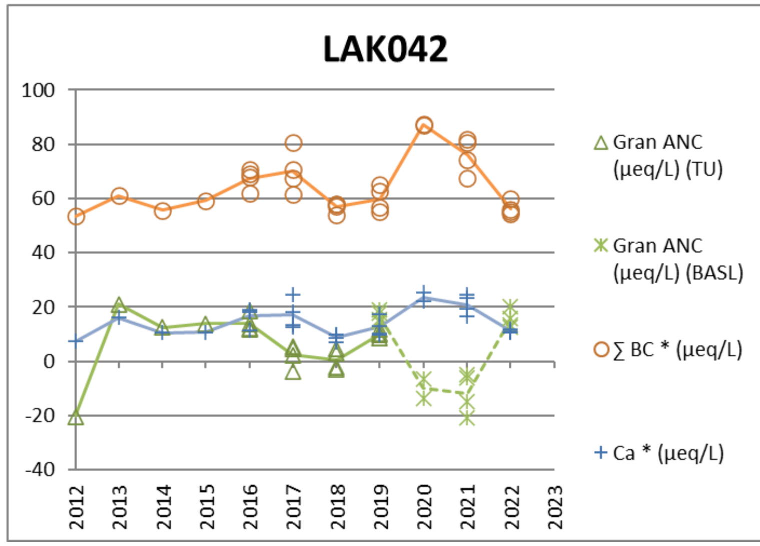
CBANC (μeq/L)
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
BCS (μeq/L)

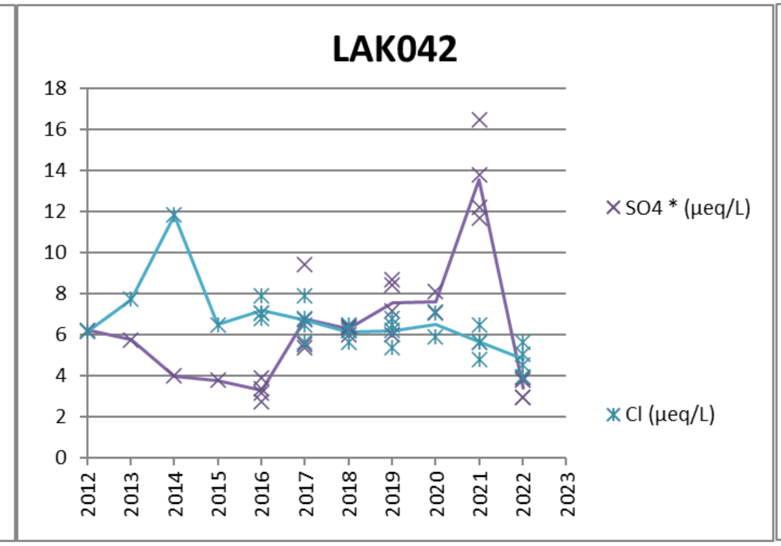

LAK028
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
∑ BC * (μeq/L)
Ca * (μeq/L)

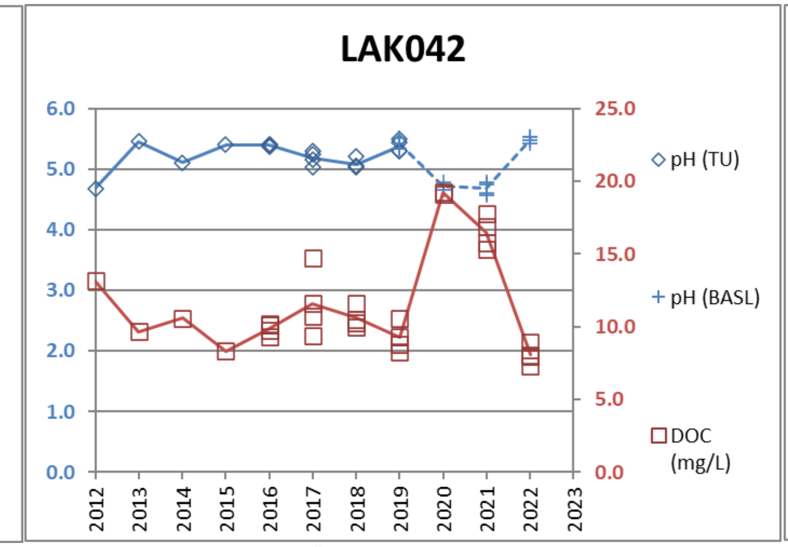

LAK028
SO4 * (μeq/L)
Cl (μeq/L)

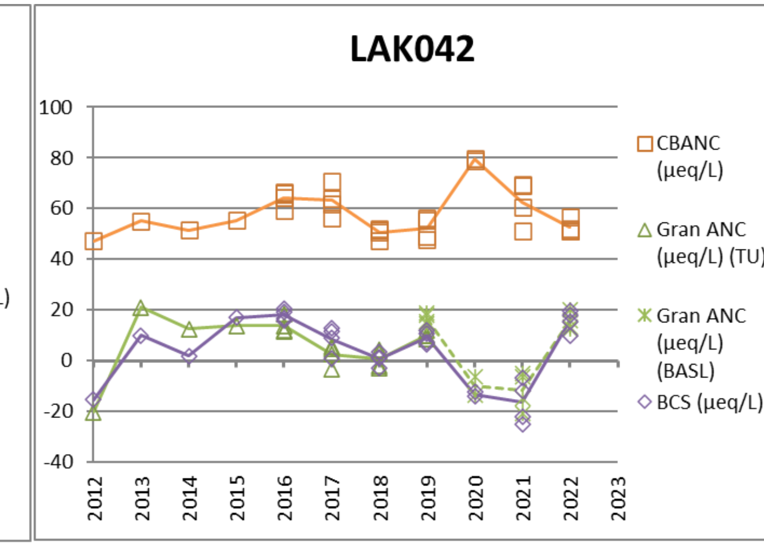

LAK028
pH (TU)
pH (BASL)
DOC (mg/L)

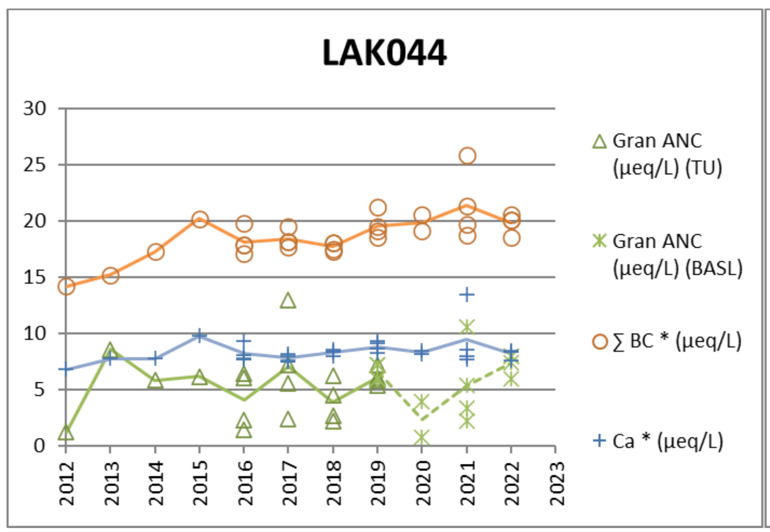

LAK028
CBANC (μeq/L)
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
BCS (μeq/L)


LAK042
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
∑ BC * (μeq/L)
Ca * (μeq/L)


LAK042
SO4 * (μeq/L)
Cl (μeq/L)


LAK042
pH (TU)
pH (BASL)
DOC (mg/L)


LAK042
CBANC (μeq/L)
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
BCS (μeq/L)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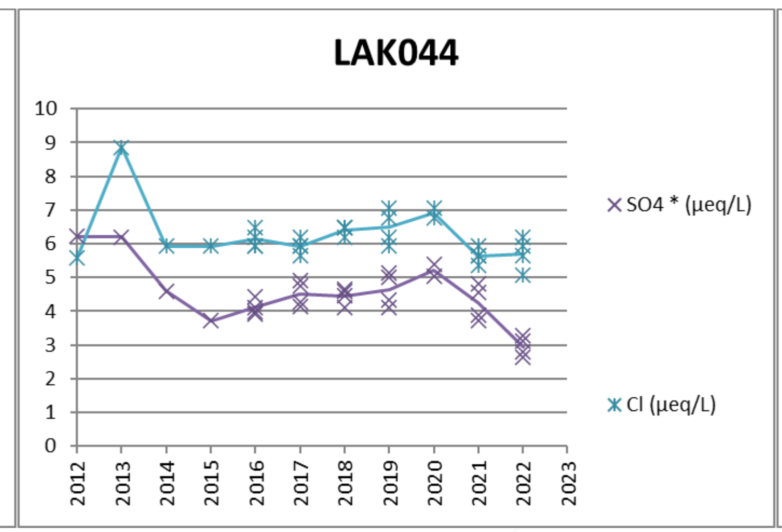
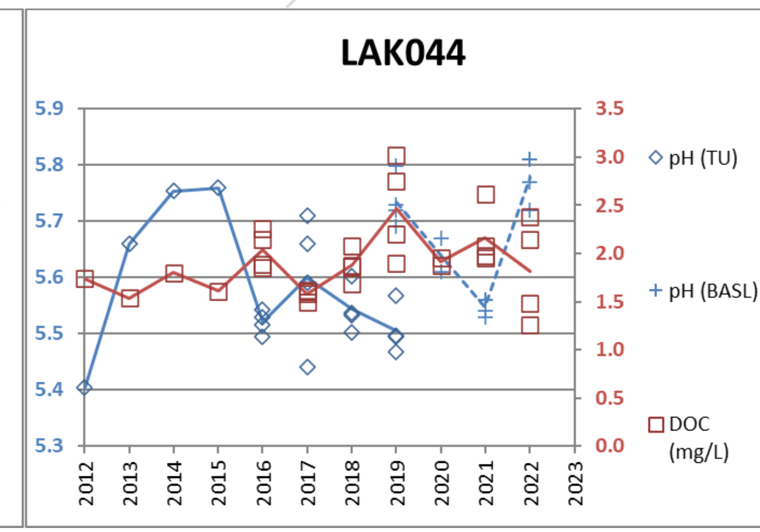
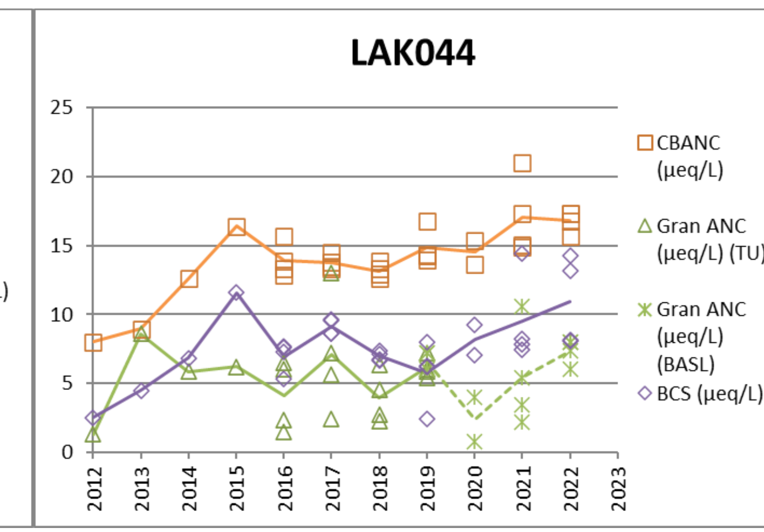
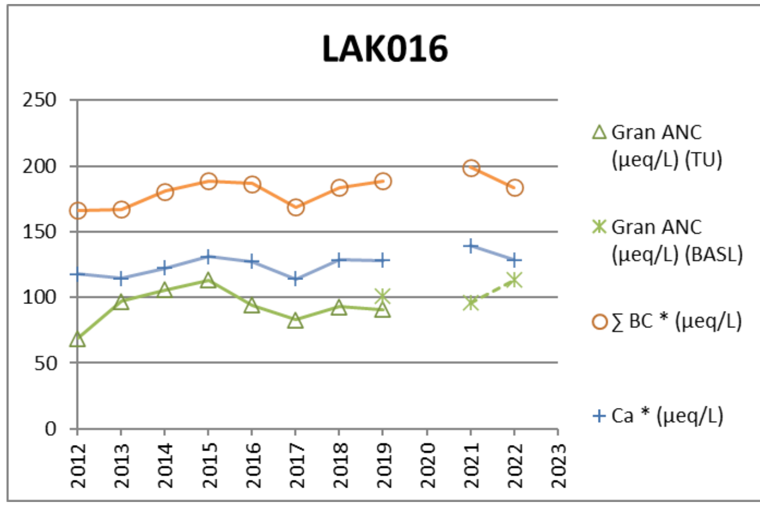
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
∑ BC * (μeq/L)
Ca * (μeq/L)

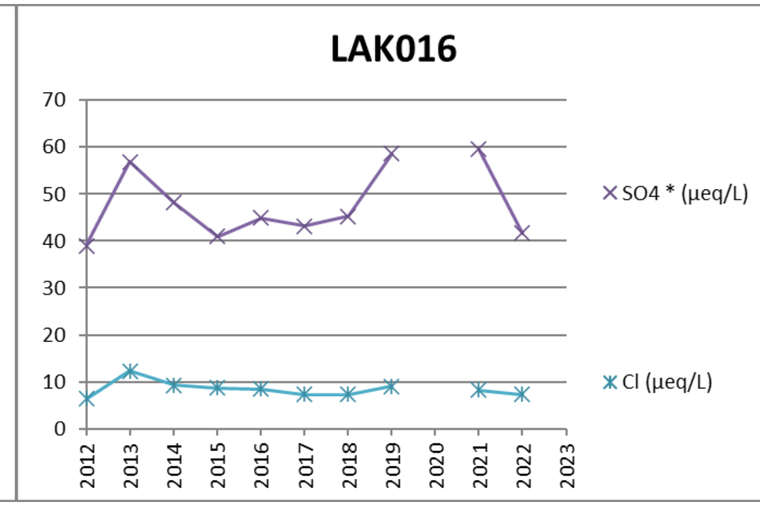

LAK044
SO4 * (μeq/L)
Cl (μeq/L)

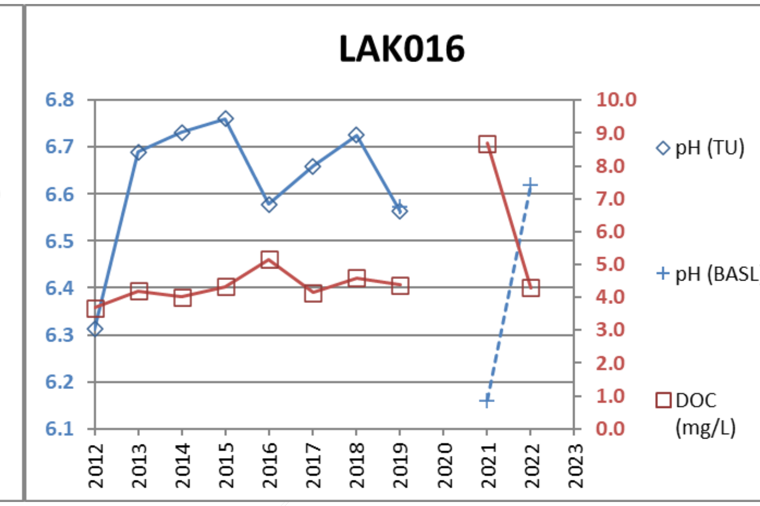

LAK044
pH (TU)
pH (BASL)
DOC (mg/L)

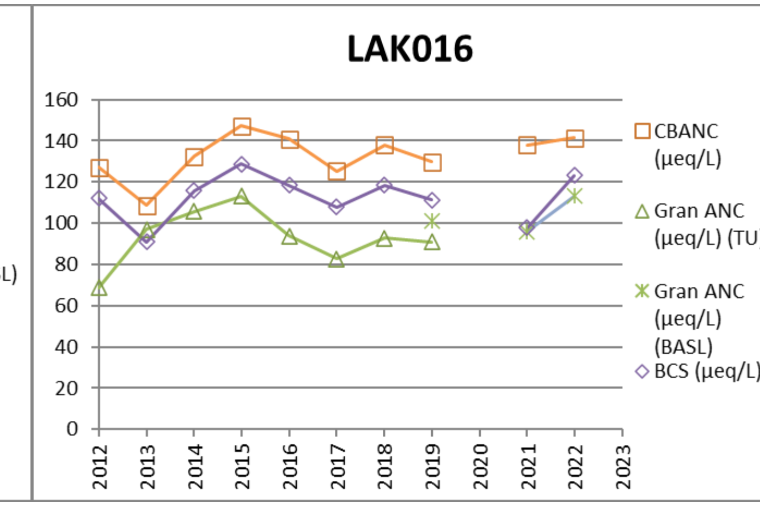

LAK044
CBANC (μeq/L)
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
BCS (μeq/L)

Less Sensitive Lakes

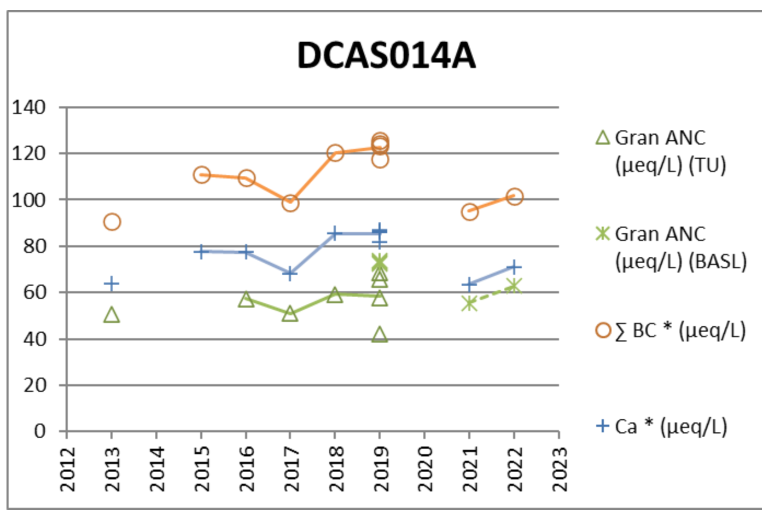


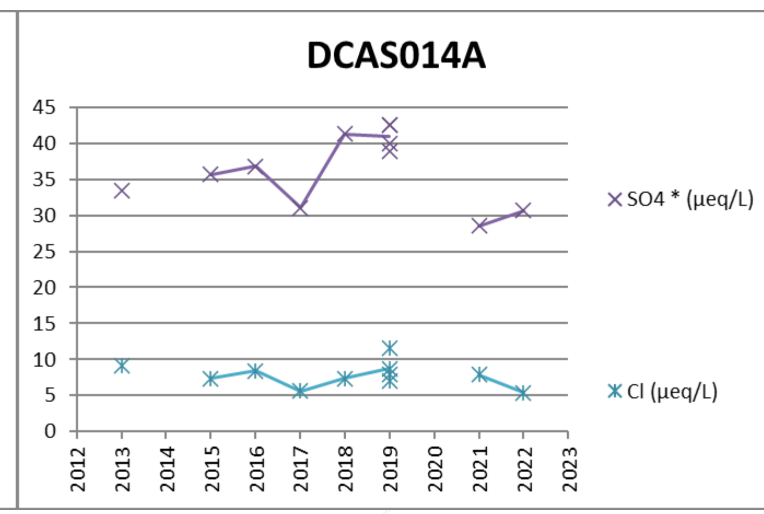


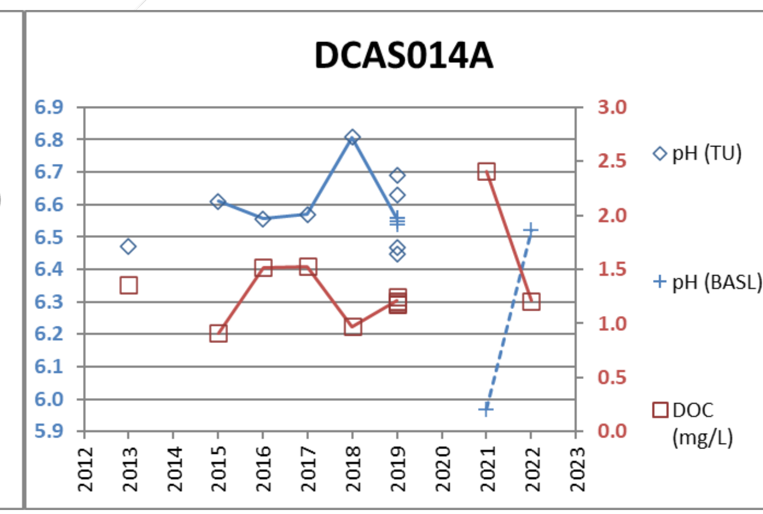


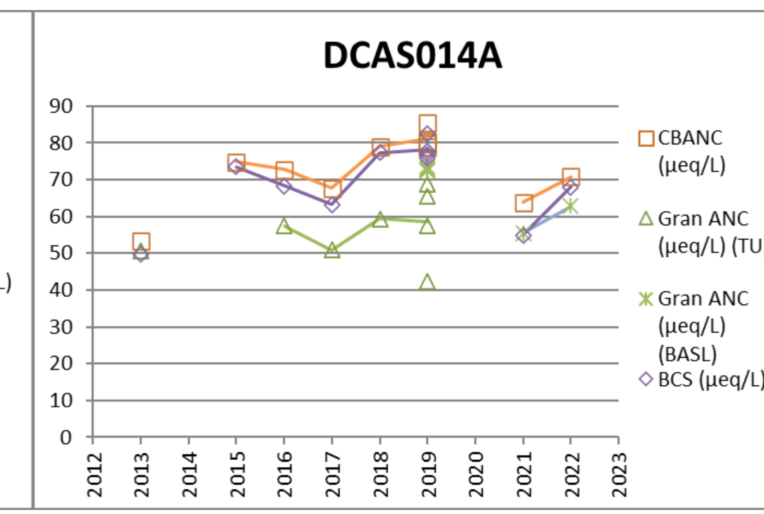


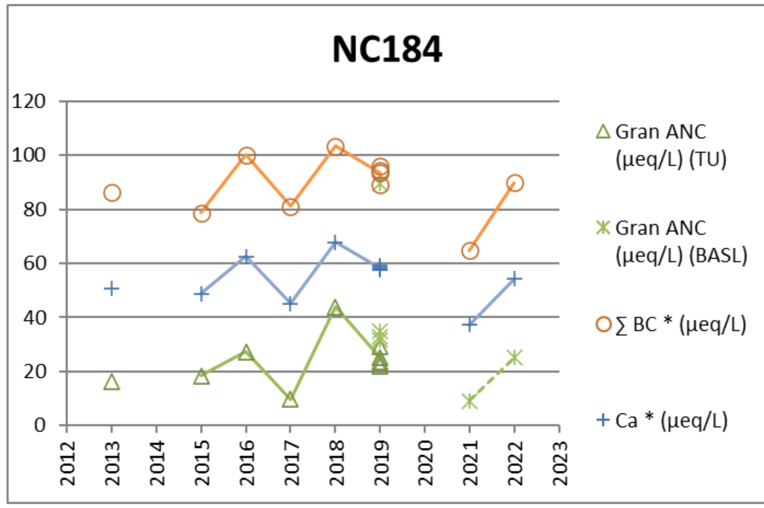
Control Lakes

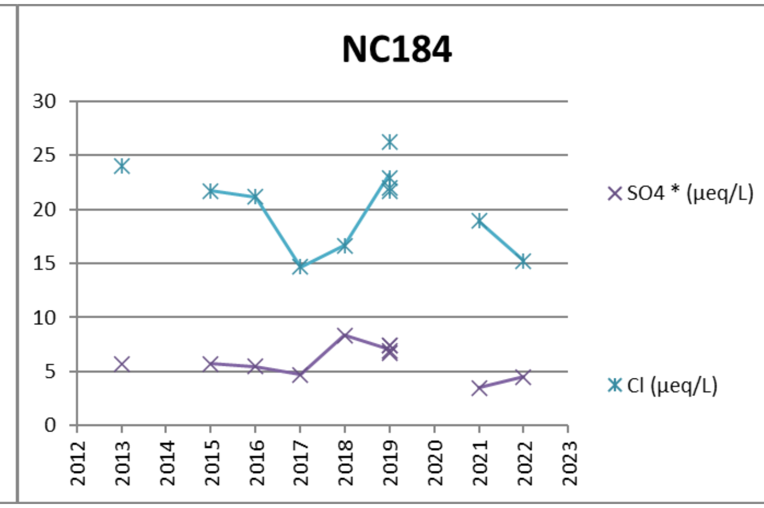


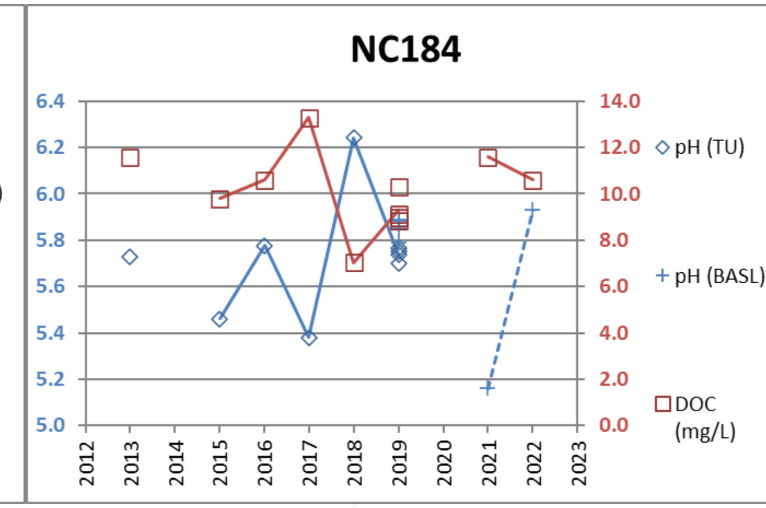


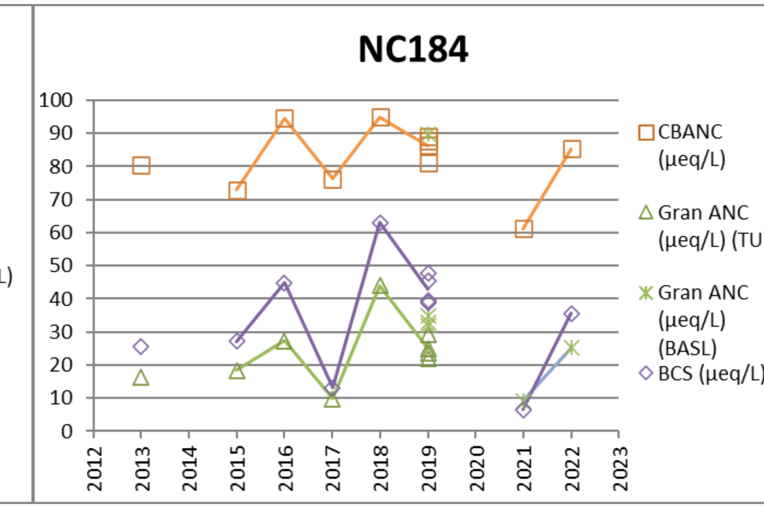


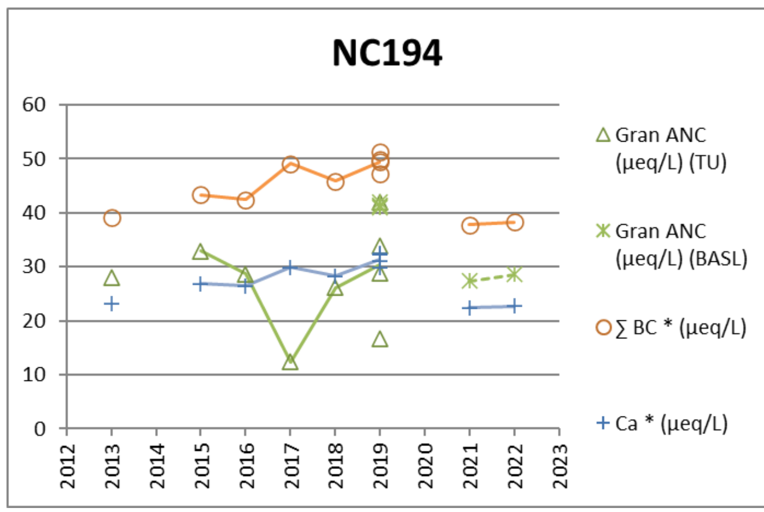


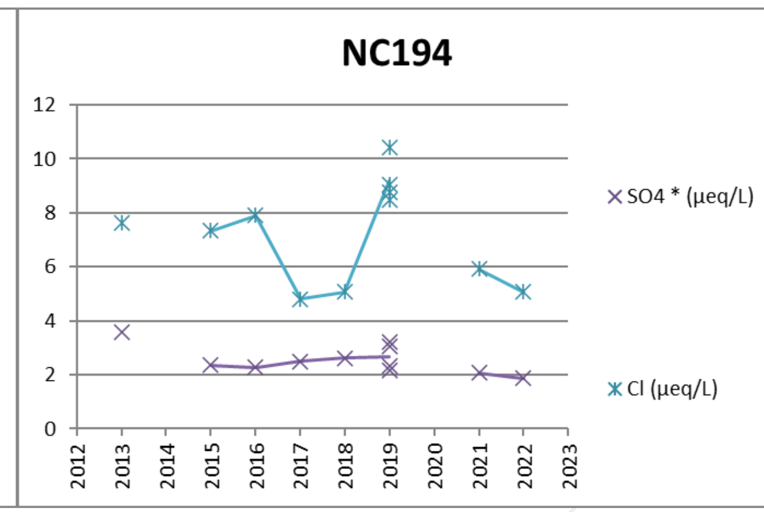

NC184
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
∑ BC * (μeq/L)
Ca * (μeq/L)

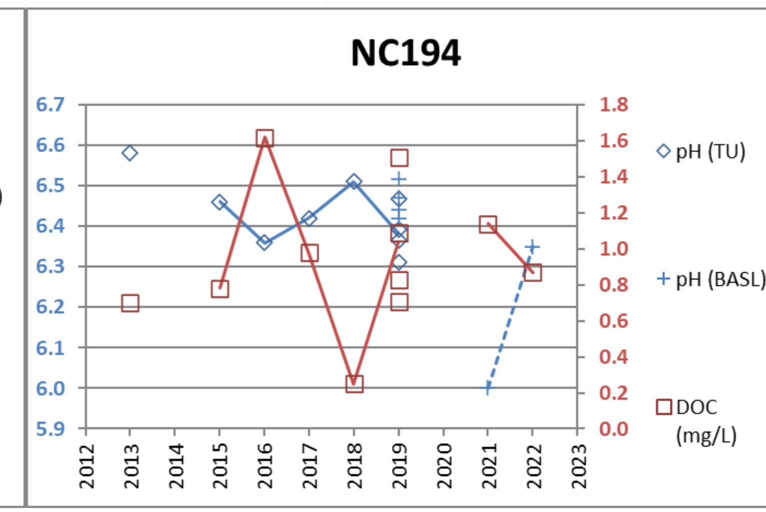

NC184
SO4 * (μeq/L)
Cl (μeq/L)

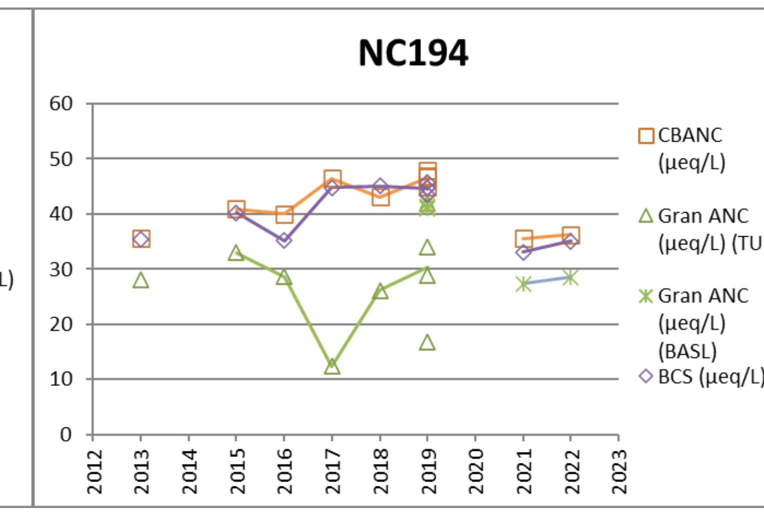

NC184
pH (TU)
pH (BASL)
DOC (mg/L)


NC184
CBANC (μeq/L)
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
BCS (μeq/L)


NC194
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
∑ BC * (μeq/L)
Ca * (μeq/L)


NC194
SO4 * (μeq/L)
Cl (μeq/L)


NC194
pH (TU)
pH (BASL)
DOC (mg/L)


NC194
CBANC (μeq/L)
Gran ANC (μeq/L) (TU)
Gran ANC (μeq/L) (BASL)
BCS (μeq/L)

Appendix 3: Sensitivity Analyses for Statistical Analyses of Post-KMP Changes in Lake Chemistry

This appendix includes the results of the primary statistical analyses presented in Section 3.3 alongside the results of the sensitivity analyses performed using the alternate transition period baseline (2012-2014, as compared to the 2012 pre-KMP baseline applied in the base case). The upper panel shows the % belief in an exceedance of the *change limit*, the middle panel shows the % belief in an exceedance of the *level of protection*, and the bottom panel indicates the level of support for an overall exceedance of each indicator (based on the approach described in the main text).

SUMMARY OF EXCEEDANCES - *of CHANGE LIMIT* (from statistical analyses)

Scenario	BASE CASE				SENSITIVITY - alternative baseline			
Post-KMP	2020-2022				2020-2022			
Baseline	2012				2012-2014			
Metric	CBANC	Gran ANC (integ)	BCS	pH (integ)	CBANC	Gran ANC (integ)	BCS	pH (integ)
Thresholds	Lake-spec	Lake-spec	Δ 13 ueq/L	Δ 0.3 pH units	Lake-spec	Lake-spec	Δ 13 ueq/L	Δ 0.3 pH units
LAK006	0%	0%	1%	8%	0%	0%	0%	9%
LAK012	23%	14%	42%	10%	4%	4%	11%	16%
LAK022	13%	30%	9%	43%	5%	47%	4%	55%
LAK023	6%	2%	3%	7%	2%	4%	1%	5%
LAK028	13%	8%	62%	18%	16%	23%	43%	35%
LAK042	6%	6%	20%	21%	0%	16%	26%	39%
LAK044	0%	4%	1%	4%	0%	5%	0%	5%
LAK016	2%	7%	33%	32%	1%	9%	14%	46%
DCAS14A	5%	7%	13%	52%	4%	7%	15%	52%
NC184	46%	30%	43%	48%	45%	30%	39%	48%
NC194			4%	71%			5%	70%

SUMMARY OF EXCEEDANCES - *of LEVEL OF PROTECTION* (from statistical analyses

Scenario	BASE CASE			
Post-KMP	2020-2022			
Metric	CBANC	Gran ANC (integ)	BCS	pH (integ)
Thresholds	20 ueq/L	30.7 ueq/L	0 ueq/L	6.0 pH units
LAK006	0%	0%	0%	70%
LAK012	0%	0%	0%	77%
LAK022	0%	80%	0%	84%
LAK023	0%	100%	0%	100%
LAK028	100%	100%	100%	100%
LAK042	0%	100%	80%	100%
LAK044	100%	100%	0%	100%
LAK016	0%	0%	0%	1%
DCAS14A	0%	0%	0%	10%
NC184	0%	100%	1%	97%
NC194	0%	100%	0%	33%

__Note__: This row of tables (i.e., *level of protection*) is not missing a table – there is no "alternative baseline" scenario because the *level of protection* is solely based on the post-KMP status. Therefore, the overall assessment under the alternative baseline scenario (i.e., middle table in last row of tables) is based on the alternative baseline scenario the *change limit* assessment and the base case scenario for the *level of protection* assessment.

KPI & INFORM. INDICATOR EVALUATION - Exceedance of Level of Protection AND Change Limit

Scenario	BASE CASE				SENSITIVITY - alternative baseline			
Post-KMP	2020-2022				2020-2022			
Baseline	2012				2012-2014			
Metric	CBANC	Gran ANC (integ)	BCS	pH (integ)	CBANC	Gran ANC (integ)	BCS	pH (integ)
Thresholds	Lake-spec	Lake-spec	∆ 13 ueq/L	∆ 0.3 pH units	Lake-spec	Lake-spec	∆ 13 ueq/L	∆ 0.3 pH units
LAK006	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
LAK012	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
LAK022	LOW	MOD	LOW	MOD	LOW	MOD	LOW	MOD
LAK023	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
LAK028	LOW	LOW	MOD	LOW	LOW	MOD	MOD	MOD
LAK042	LOW	LOW	MOD	MOD	LOW	LOW	MOD	MOD
LAK044	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
LAK016	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
DCAS14A	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
NC184	LOW	MOD	LOW	MOD	LOW	MOD	LOW	MOD
NC194	noRel	noRel	LOW	MOD	noRel	noRel	LOW	MOD

Appendix 4: Sensitivity Analyses on Imputation of Gran ANC and pH Values for Integrated Time Series

This appendix includes the results of the Bayesian statistical analyses for Gran ANC and pH using alternate values for the imputed 2020, 2021, and 2022 values in order to explore the sensitivity of the results to the uncertainty in the imputation process (see description in Section 2.1 of the SO_2 EEM Program 2020 Aquatic Technical Memo W09 for full details). Results are shown for the range of data series for Gran ANC and pH across the base case scenario, the alternative baseline scenario, and the alternative post-KMP period scenario. For each scenario, the tables below show the results across all lakes for each data series and the range of results across all of the permutations of a particular metric for each lake. *Note: "Gran ANC (imputed)" is the same metric that is referenced as "Gran ANC (integ)" in the main text; same for pH as well.*

SUMMARY OF EXCEEDANCES - *of CHANGE LIMIT* (from statistical analyses)

Scenario	BASE CASE											
Post-KMP	2020-2022										2020-2022	
Baseline	2012										2012	
Metric	Gran ANC (imputed)	Gran ANC (imp+1SD)	Gran ANC (imp+2SD)	Gran ANC (imp-1SD)	Gran ANC (imp-2SD)	pH (imputed)	pH (imp+1SD)	pH (imp+2SD)	pH (imp-1SD)	pH (imp-2SD)	Gran ANC	pH
Thresholds	Lake-spec	Lake-spec	Lake-spec	Lake-spec	Lake-spec	Δ 0.3 pH units	Δ 0.3 pH units	Δ 0.3 pH units	Δ 0.3 pH units	Δ 0.3 pH units	Range (max-min)	
LAK006	0%	1%	1%	1%	1%	8%	6%	4%	11%	16%	1%	12%
LAK012	14%	11%	12%	14%	11%	10%	9%	7%	11%	16%	3%	9%
LAK022	30%	32%	31%	30%	31%	43%	37%	33%	47%	54%	2%	21%
LAK023	2%	1%	1%	1%	1%	7%	5%	3%	11%	14%	1%	11%
LAK028	8%	8%	7%	8%	6%	18%	13%	12%	28%	40%	2%	28%
LAK042	6%	5%	5%	6%	4%	21%	20%	16%	26%	32%	2%	16%
LAK044	4%	2%	4%	4%	4%	4%	3%	2%	6%	8%	2%	6%
LAK016	7%	7%	7%	10%	8%	32%	26%	21%	40%	42%	3%	21%
DCAS14A	7%	8%	7%	8%	7%	52%	48%	40%	57%	65%	1%	25%
NC184	30%	25%	27%	31%	29%	48%	42%	38%	52%	58%	6%	20%
NC194						71%	60%	52%	73%	79%	0%	27%

Scenario	SENSITIVITY - alternative baseline											
Post-KMP	2020-2022										2020-2022	
Baseline	2012-2014										2012-2014	
Metric	Gran ANC (imputed)	Gran ANC (imp+1SD)	Gran ANC (imp+2SD)	Gran ANC (imp-1SD)	Gran ANC (imp-2SD)	pH (imputed)	pH (imp+1SD)	pH (imp+2SD)	pH (imp-1SD)	pH (imp-2SD)	Gran ANC	pH
Thresholds	Lake-spec	Lake-spec	Lake-spec	Lake-spec	Lake-spec	Δ 0.3 pH units	Δ 0.3 pH units	Δ 0.3 pH units	Δ 0.3 pH units	Δ 0.3 pH units	Range (max-min)	
LAK006	0%	1%	1%	1%	2%	9%	3%	2%	13%	29%	2%	27%
LAK012	4%	3%	3%	5%	5%	16%	10%	6%	23%	36%	2%	30%
LAK022	47%	46%	46%	49%	50%	55%	44%	32%	68%	78%	4%	46%
LAK023	4%	4%	3%	5%	5%	5%	2%	1%	10%	21%	2%	20%
LAK028	23%	24%	23%	23%	25%	35%	20%	10%	55%	74%	2%	64%
LAK042	16%	15%	15%	16%	17%	39%	31%	20%	52%	60%	2%	40%
LAK044	5%	5%	4%	6%	6%	5%	2%	1%	12%	30%	2%	29%
LAK016	9%	9%	8%	10%	11%	46%	35%	24%	61%	76%	3%	52%
DCAS14A	7%	7%	8%	8%	8%	52%	46%	41%	57%	63%	1%	22%
NC184	30%	30%	27%	29%	32%	48%	40%	40%	54%	62%	5%	22%
NC194						70%	61%	50%	74%	78%	0%	28%

SUMMARY OF EXCEEDANCES - *of LEVEL OF PROTECTION* (from statistical analyses)

Scenario	BASE CASE											
Post-KMP	2020-2022										2020-2022	
Metric	Gran ANC (imputed)	Gran ANC (imp+1SD)	Gran ANC (imp+2SD)	Gran ANC (imp-1SD)	Gran ANC (imp-2SD)	pH (imputed)	pH (imp+1SD)	pH (imp+2SD)	pH (imp-1SD)	pH (imp-2SD)	Gran ANC	pH
Thresholds	30.7 ueq/L	30.7 ueq/L	30.7 ueq/L	30.7 ueq/L	30.7 ueq/L	6.0 pH units	6.0 pH units	6.0 pH units	6.0 pH units	6.0 pH units	Range (max-min)	
LAK006	0%	2%	2%	3%	6%	70%	23%	14%	88%	100%	6%	86%
LAK012	0%	0%	0%	0%	0%	77%	35%	21%	86%	95%	0%	74%
LAK022	80%	82%	79%	82%	84%	84%	67%	61%	93%	97%	5%	36%
LAK023	100%	100%	100%	100%	100%	100%	78%	48%	100%	100%	0%	52%
LAK028	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%
LAK042	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%
LAK044	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%
LAK016	0%	0%	0%	0%	0%	1%	0%	0%	8%	20%	0%	20%
DCAS14A	0%	0%	0%	0%	0%	10%	4%	1%	28%	45%	0%	44%
NC184	100%	100%	100%	100%	100%	97%	98%	97%	100%	99%	0%	3%
NC194	100%	100%	100%	100%	100%	33%	12%	3%	30%	53%	0%	50%

Appendix 5: Lake-specific thresholds for change limits for CBANC

The lake-specific CBANC thresholds for the *change limit* are shown in the table below. The table and caption below are directly copied from Table 14 of the SO_2 EEM Program Phase III Plan.

Lake-specific thresholds for change limits in CBANC. Values calculated from analyses of the titration data, showing the change in CBANC associated with a pH decline of 0.3 pH units from the 2012 (or 2013 for control lakes) pH value for each lake. A lake-specific threshold cannot be estimated for control lake NC194 given limited data.

	EEM Group	Lake-specific CBANC threshold (μeq/L)
LAK006	Sensitive Lake	-10.8
LAK012	Sensitive Lake	-16.3
LAK022	Sensitive Lake	-11.5
LAK023	Sensitive Lake	-10.5
LAK028	Sensitive Lake	-13.4
LAK042	Sensitive Lake	-24.4
LAK044	Sensitive Lake	-6.2
LAK016	Less Sensitive Lake	-25.6
DCAS14A	Control Lake	-21.7
NC184	Control Lake	-10.8
NC194	Control Lake	n.a.