B.C. Works'
Sulphur Dioxide Environmental Effects Monitoring Program

2024 Annual Report, Draft V.2

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Executive Summary

ATMOSPHERIC PATHWAYS

The atmospheric pathways activities implemented in 2024 were:

- continuous SO_2 monitoring and analysis
- passive SO_2 sampling and analysis, and
- sulphur deposition monitoring and analysis.

All **continuous SO_2 analyzers** passed B.C. ENV's audits and had greater than 90% data capture for SO_2 in 2024. However, the 2024 dataset has not yet been validated by B.C. ENV. Therefore all 2024 relevant datasets are considered preliminarily valid for comparisons to the 1-hour and annual average SO_2 Canadian Ambient Air Quality Standards (CAAQS).

Generally, Haul Road concentrations trend closely with SO_2 emissions from the smelter, while stations farther from the smelter change more noticeably due to seasonal weather patterns than due to changes in SO_2 emissions.

As in prior years, ambient concentrations of SO_2 remain low (below 4 ppb) most of the time, and higher concentrations occur infrequently.

Annual average and 99th percentile of 1-hour daily maximum monitored concentrations aligned closely with model results in 2024, with slight to moderate overprediction at all sites except Kitamaat Village for 1-hour 99th percentile regional-scale. Overall, these comparisons are consistent with the discussion in the 2019 Comprehensive Review (ESSA et al., 2020a) that predicted modelled concentrations in most areas are higher than measured concentrations, resulting in cautious risk assessments. In 2024, the relationship between modelled and monitored concentrations at Haul Road remained consistent with most years. Model underpredictions at Haul Road occurred in 2022, which differed from the patterns observed in 2024 and all other years (when model predictions were greater or equal to monitored values). The return to typical patterns (general overprediction) in 2023 and 2024 supports the previous report's hypothesis that the underprediction in 2022 was likely an artifact of the model's annual scaling method in a year with several months at very low SO_2 emission levels, rather than the possibility that the model's relationship to monitored data changed meaningfully.

The network of **passive samplers** was redeployed in the Kitimat Valley during 2024 following the same procedures as in 2016-2023. Deployment started in late April 2024 at 24 sites within the Kitimat Valley, primarily focused along the Wedeene and Bish roads to capture the plume path. Over 200 sample exposures were collected and analysed. The 2024 results are similar to the previous years' observations. Since 3 full years of passive data have been collected (2022-2024) using the new samplers, it is possible to develop a calibration relationship for the passive results by comparing the passive to the continuous SO_2 data. The calibrated dataset for 2024 is presented in this report. The spatial pattern is consistent with previous years.

Continued deployments are recommended during 2025 to further define the plume path.

Preliminary **sulphur wet deposition** monitoring data in 2024 show that average annual precipitation volume was consistently higher at Haul Road compared to levels at Lakelse Lake during 2014–2024. During 2024, precipitation volume at Haul Road (2285 mm) and at Lakelse Lake (1335 mm) were slightly lower than the eleven-year average, and the relationship between the two stations was consistent with past years. Higher weekly sulphate concentration (mg/L) and lower pH was observed at Haul Road compared with Lakelse Lake. The higher SO_4 and lower pH in rainfall at Haul Road are caused by the higher atmospheric concentration of SO_2 and corresponding higher S deposition at Haul Road. Higher rainfall volume and higher sulphate concentration observed at Haul Road combines to result in a more pronounced wet S deposition difference compared with Lakelse Lake on an annual and weekly basis.

Total mass of **SO_2 dry deposition** was calculated based on modelled dry deposition velocity and measured ambient SO_2 concentrations. The 'big-leaf' model was used to estimate hourly species-specific dry deposition velocity at four stations in the Kitimat Valley (Haul Road, Whitesail, Lakelse Lake, and Terrace Airport [YXT]) using 2024 meteorological data. Total mass of SO_2 dry deposition tended to be more heavily influenced by monitored SO_2 concentration at each site versus changes in SO_2 deposition velocity. This difference in SO_2 concentrations is clearly the reason for elevated dry deposition mass at Haul Road compared to other sites. Similar ratios of wet versus dry S deposition occur during each year from 2016 – 2024 at Haul Road.

There is no **KPI** for atmospheric pathways. The results from analyses of the atmospheric pathways line of evidence are inputs to the KPIs for the human health, terrestrial ecosystems, and aquatic ecosystems lines of evidence.

HUMAN HEALTH

Starting January 1, 2020, the SO_2 health KPI implemented the SO_2 Canadian Ambient Air Quality Standards (CAAQS). In 2024 the CAAQS value was 70 ppb, and in 2025 the CAAQS value changes to 65 ppb. The SO_2 health KPI is used to assess residential SO_2 ambient air quality. The SO_2 Health KPI for 2024 is a threshold for residential SO_2 ambient air concentration of 70 ppb and is evaluated as defined in the B.C. Air Quality Objectives.

For 2024 the **KPI** is calculated as the 3-year average of the annual 99th percentile of the D1HM (maximum daily 1-hour concentrations of SO_2) using validated data for years 2022 and 2023 and preliminary data from 2024. The 2024 KPI calculation results for Kitamaat Village, Riverlodge, Whitesail, and Industrial Ave were all well below the KPI (CAAQS value of 70 ppb) and, as such, demonstrate attainment of the KPI.

TERRESTRIAL ECOSYSTEMS (Soils content still in progress)

All terrestrial ecosystems work done in 2024 was under the **Vascular Plant and Cyanolichen Biodiversity Monitoring Program (PCMP; "the Program")**.

Activities for the vegetation component of the SO_2 EEM Program in 2024 included the second assessment of ten field sites, and the first assessment of one site added to the Program from the bank of alternates. Reconnaissance of additional alternate sites was also undertaken in 2024, adding two new sites to the bank of alternates for the Program. Analysis and presentation of results were provided in the December 2024 submission of the fourth annual report for the PCMP. As part of the regular PCMP activities, an assessment of vegetation and cyanolichen health was undertaken at all eleven assessed plots in the Kitimat-Terrace valley. As 2024 represented the first site re-assessments, we were given the long-awaited opportunity to examine trends and variability for the first time.

Vegetation health inspections were undertaken as part of regular PCMP assessments at the eleven 2024 sites in the Kitimat Valley. Cyanolichen health inspections are part of the cyanolichen assessment portion of the PCMP, and these inspections were also made at the eleven plots assessed in 2024. Overall, no patterns related to plant or cyanolichen health and deposition category were noted based on these inspections for 2024, or for the PCMP sites to-date.

The Program is designed to detect potential *differential trends* across deposition zones in the biodiversity of vascular plants in the low shrub and forb layers, and of arboreal cyanolichens occurring on conifers, in forest ecosystems of the Kitimat Valley.

The major components of biodiversity are species richness and abundance (or evenness), which were both assessed in 2024, as in the preceding three years, for plants in the low shrub and herb layers. No major systemic differences between deposition zones have been observed in plant (low shrub and herb) biodiversity measures in the initial assessments (2021-2024) and, as expected, no evidence of change over time, nor of a differential trend have been noted in the initial plant biodiversity re-measurement results for 2024. Sample sizes are small, because we are so early in the Program.

For cyanolichens, the data from the Project to-date generally show that cyanolichen diversity is inversely proportional to increasing deposition zone (largely as an historical artifact of fluoride emissions). The data also demonstrate the stochastic nature of this metric (e.g., if a host tree is lost from a plot, a dramatic shift in recorded cyanolichen diversity may occur; or, a "hotspot" of diversity may occur where there may be unique microhabitat conditions that contribute to higher richness). Remeasurement data for sites in 2024 show relative stability in cyanolichen richness within sites, but with some variability between individual assessments. By extension, no differential trends between deposition zones were detected. Again, sample sizes are small, because we are so early in the Program.

Plant and cyanolichen health and diversity are *informative indicators* for effects of SO_2 emissions from the smelter. With respect to the Evidentiary Framework, no Vegetation Health indicators have achieved the threshold for increased monitoring or mitigation.

In 2022, soil samples were collected and analysed for pH, exchangeable cations and exchangeable acidity at all established sites where collection was possible, and thus no soil sampling was undertaken in 2024: Each site that is actively in the program (i.e. has been fully assessed) has now also had a baseline soils assessment (with the exception of one site where the depth of the organic layer precluded mineral soil sampling). From the results of the analyses, sensitivity to acidification can be ranked.

The **KPI** of Critical Load Exceedance from modelled atmospheric S deposition will not be assessed for attainment during Phase III of the EEM Program (as noted in the Phase III Plan). The Phase III Comprehensive Review scheduled for 2026 will assess if a KPI can be established for the vegetation and lichen component of the Terrestrial Ecosystems line of evidence.

AQUATIC ECOSYSTEMS

The sampling in 2024 was conducted in the regional context of wetter-than-average hydrologic conditions that were significantly wetter than the very dry conditions of 2023 and a moderate increase in emissions to levels similar to those of 2017-2019 as operations stabilize after several years of significant changes.

Five of the seven sensitive lakes showed increases in CBANC between the pre-KMP baseline (2012) and the current period (2022–2024). LAK012 and LAK028 continue to be the only two lakes showing a long-term decline in CBANC (**Error! Reference source not found.**). LAK012 has had a long-term decline in CBANC (-15.3 μeq/L) with the lowest levels being observed since 2023 (~90 μeq/L), though it is within the lake-specific *change limit* threshold (-16.3 μeq/L). The current mean CBANC (99.1 μeq/L) remains well above the *level of protection* threshold (20 μeq/L). Similarly, the long-term decline in LAK028 (-11.7 μeq/L) results from an exceptionally low 2024 value (-21.1 μeq/L) marking the largest annual change recorded for this lake (declined by ~35 μeq/L from 2023). Mean CBANC (4.3 μeq/L) for the current period is now well below both the *level of protection* threshold and the 2012 baseline (16.0 μeq/L). Both lakes also indicate long-term declines in Base Cation Surplus (BCS; -16.9 μeq/L for LAK012 and -16.5 μeq/L in LAK028) which are of greater magnitude than those observed in the prior three years. No other sensitive lakes showed long-term declines in BCS, and none of the seven sensitive EEM lakes showed long-term declines in Gran ANC or pH.

The empirical analyses show no exceedances of the KPI but do show one exceedance of an informative indicator. LAK028 shows an exceedance of the BCS *change limit* threshold and is below the *level of protection* threshold (as it predominantly has been over the period of record) – therefore the empirical results show an exceedance of the BCS informative indicator.

Using the established statistical analysis methods, we evaluated the KPI and the informative indicators using the two-threshold structure. **None of the 11 EEM lakes have a high % belief in exceedance of either the KPI or any of the informative indicators.** LAK028 has a moderate % belief in exceedance of the KPI and all the other EEM lakes show a low % belief in exceedance of the CBANC KPI. One sensitive EEM lake (LAK28) shows a moderate % belief in exceedance of the BCS thresholds and one control lake show moderate % belief in the exceedance of the pH thresholds.

The overall conclusions across the four analytical approaches (empirical analyses, Bayesian statistical analyses, before-after-control-impact analyses, and the evidentiary framework) are that there is no support for any exceedances of the KPIs and there is support from one approach for an exceedance of one informative indicator.

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titration data available. NC194 does not have an estimated ANC threshold because it did not have appropriate titration data available........51

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2 Introduction

The purpose of the SO_2 Environmental Effects Monitoring (EEM) Program is to monitor effects of SO_2 on human health, terrestrial ecosystems, and aquatic ecosystems. Results from the SO_2 EEM Program will inform decisions regarding the need for changes to the scale or intensity of monitoring, as well as decisions regarding the need for mitigation. The SO_2 EEM Program includes impact threshold criteria either for emission reduction or other mitigations that, when exceeded, would trigger emission reduction and/or other mitigation.

The SO_2 EEM Program is structured around the conceptual model shown in Figure 2-1.

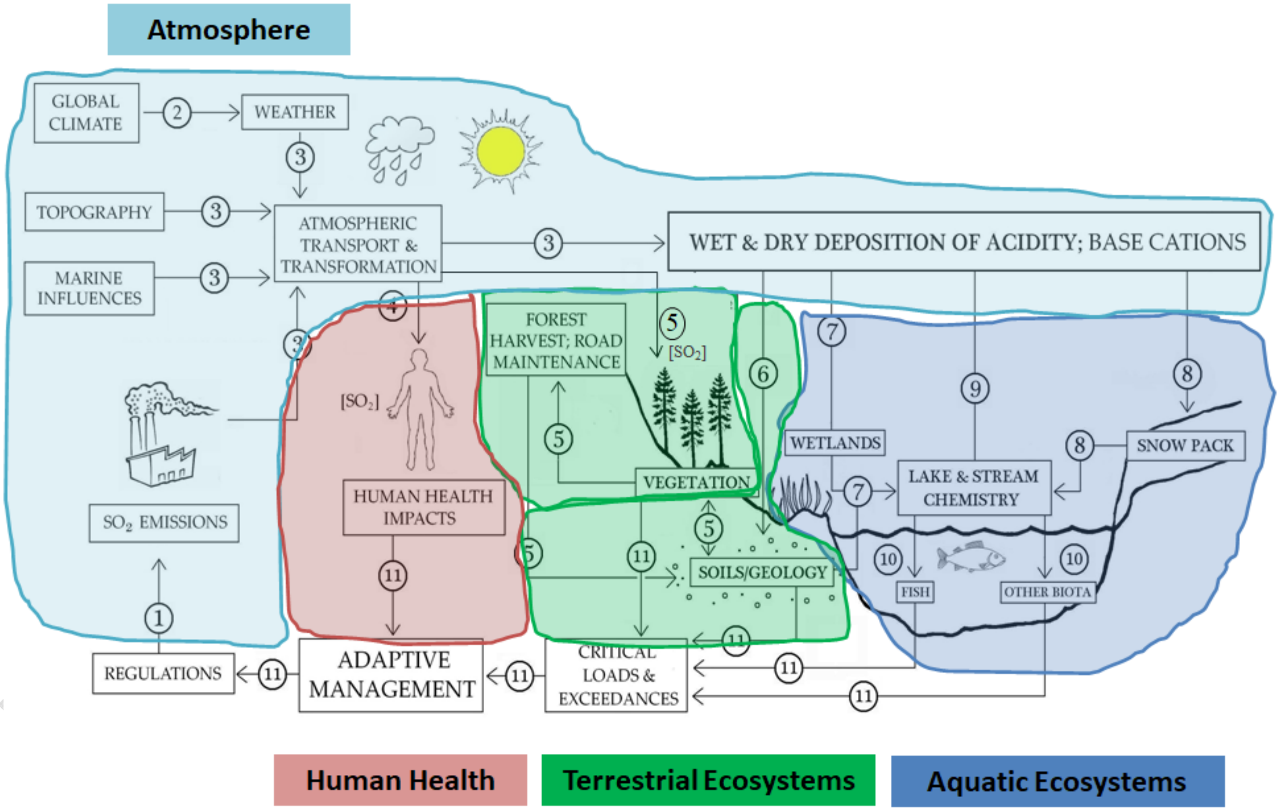


Figure 2-1. Conceptual (source-pathway-receptor) model of SO_2 emissions in the environment, showing linkages between sources and receptors. Source: Figure 1-1 from ESSA et al., 2020a.

This document comprises the SO_2 EEM Program 2024 Annual Report. It is organized into sections according to the pathway and receptor lines of evidence depicted Figure 2-2. The SO_2 EEM Program Annual Report for 2025 will be prepared in the spring of 2026.

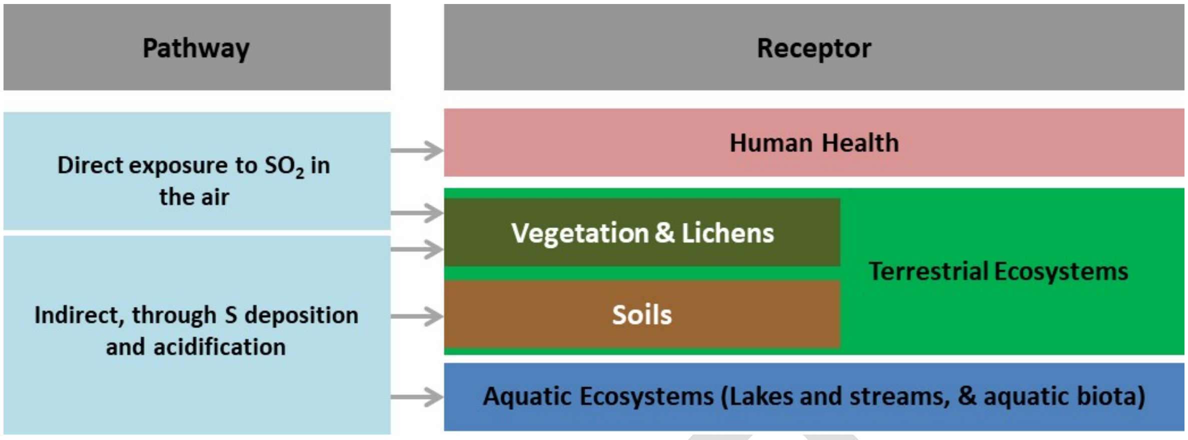
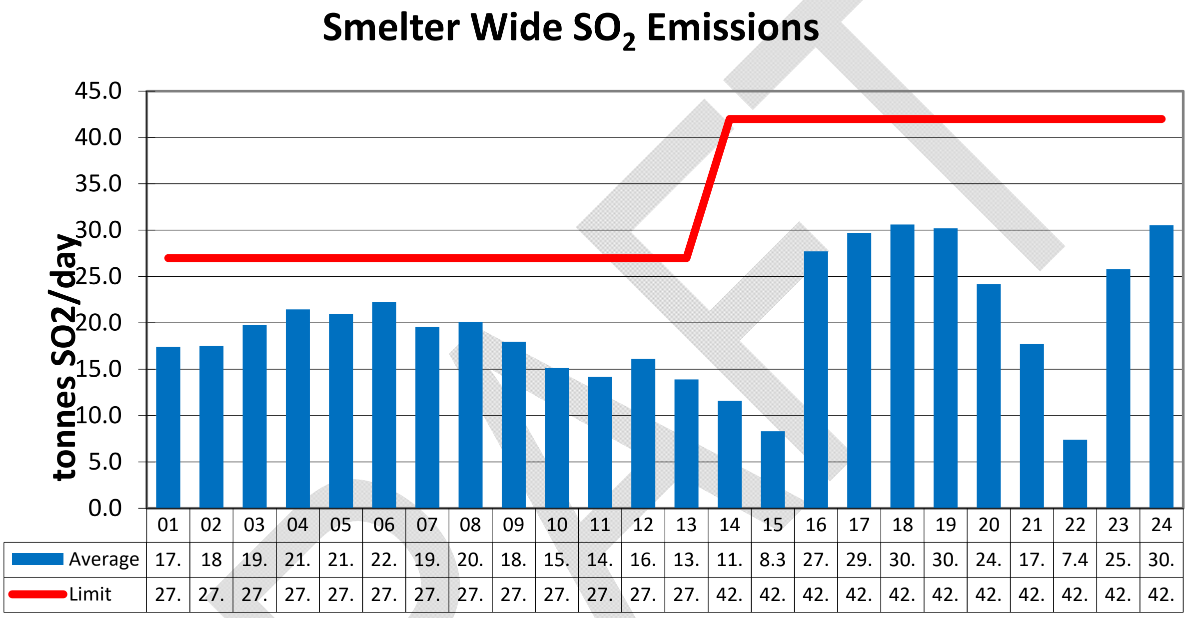


Figure 2-2. Organization of the five lines of evidence in the SO_2 EEM Program.

3 Facility Emissions

Average annual SO_2 emissions from the Kitimat smelter increased from an average 25.8 t/d rate in 2023 to 30.5 t/d in 2024, as the smelter returned to normal steady state operations (Figure 3-1). SO_2 emissions in 2024 remained below the 42 t/d permit limit. Average SO_2 monthly emissions ranged from 24.9 t/d to 32.9 t/d, with variation due to biannual maintenance shutdowns of the coke calciner, anode sulphur content and imported anode use (Figure 3-2).



	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Average	17.	18	19.	21.	21.	22.	19.	20.	18.	15.	14.	16.	13.	11.	8.3	27.	29.	30.	30.	24.	17.	7.4	25.	30.
Limit	27.	27.	27.	27.	27.	27.	27.	27.	27.	27.	27.	27.	27.	42.	42.	42.	42.	42.	42.	42.	42.	42.	42.	42.

Figure 3-1. Annual SO_2 emissions from the Kitimat smelter from 2013 to 2024. (Source: Rio Tinto)

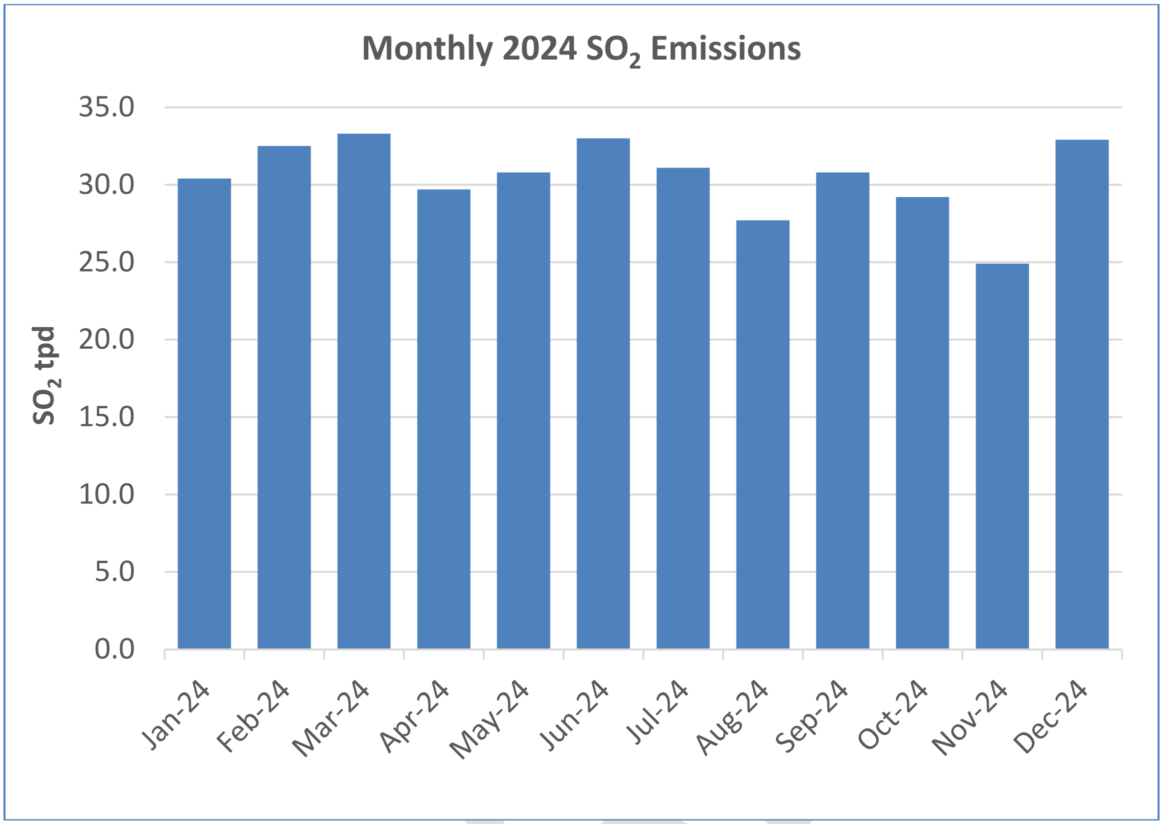


Figure 3-2. Average monthly SO_2 emissions from the Kitimat smelter throughout 2024. (Source: Rio Tinto)

4 EEM Activities

4.1 Atmospheric Pathways

4.1.1 SO_2 Concentrations – Continuous Monitoring

Continuous SO_2 monitoring data were collected from six existing continuous analysers: Haul Road (fenceline), Riverlodge (lower Kitimat), Whitesail (upper Kitimat), Kitamaat Village, Lakelse Lake[1], and Industrial Avenue (Figure 4-1). A seventh station (not pictured) was established in 2015 by the B.C. Ministry of Environment and Climate Change Strategy (B.C. ENV) in Terrace that can also be used to help assess SO_2 emissions from the smelter. The newest continuous SO_2 monitoring station was established in Service Centre (Industrial Avenue) in May 2020. The continuous air quality monitoring stations record hourly observations of SO_2. They provide information on air quality in the area on an ongoing basis and will provide important data for many EEM activities over the next several years.

All SO_2 analyzers passed B.C. ENV's[2] audits and had greater than 95% data capture for SO_2 in 2024. However, validated continuous SO_2 data are not available from the B.C. ENV until late in the following year or sometimes later. Validated datasets have not yet been completed and posted for 2024. Therefore, all 2024 relevant datasets are considered preliminarily valid for comparisons to the 1-hour and annual average SO_2 Canadian Ambient Air Quality Standards (CAAQS). The continuous SO_2 data summarized in this report include final, post-validated data for 2022 and 2023 and prior years and preliminary data for 2024.

Figure 4-2 shows the pattern of the monthly average SO_2 concentrations at the seven continuous monitoring stations from 2013 through 2024, along with monthly SO2 emissions over the same period.
presents the same data without the Haul Road and Industrial Avenue stations in order to show the detailed changes at the lower concentrations. Figure 4-2 shows that the Haul Road concentrations generally trend closely with SO2 emissions from the smelter.
(without Haul Road and Industrial Avenue stations) shows that stations farther from the smelter change more noticeably due to seasonal weather patterns than due to changes related to SO_2 emission levels. Even when smelter SO_2 emissions decreased drastically in August 2021, concentrations at Riverlodge, Whitesail, Kitamaat Village, Lakelse Lake, and Terrace were not substantially lower than concentrations during previous years' fall and winter months. While less noticeable, the spring-summer concentrations were lower in 2022 and returned to typical levels in 2023 and continued through 2024 at these stations.

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[1] The sole purpose of the Lakelse SO_2 analyzer is for estimating dry deposition and is not included in air quality monitoring network for British Columbia.

[2] B.C. Ministry of Environment and Climate Change Strategy (ENV) conducts audits on all monitoring stations within the network; however, since the Lakelse Lake monitor's purpose is for estimating dry deposition, it is not within the network and not audited by ENV.

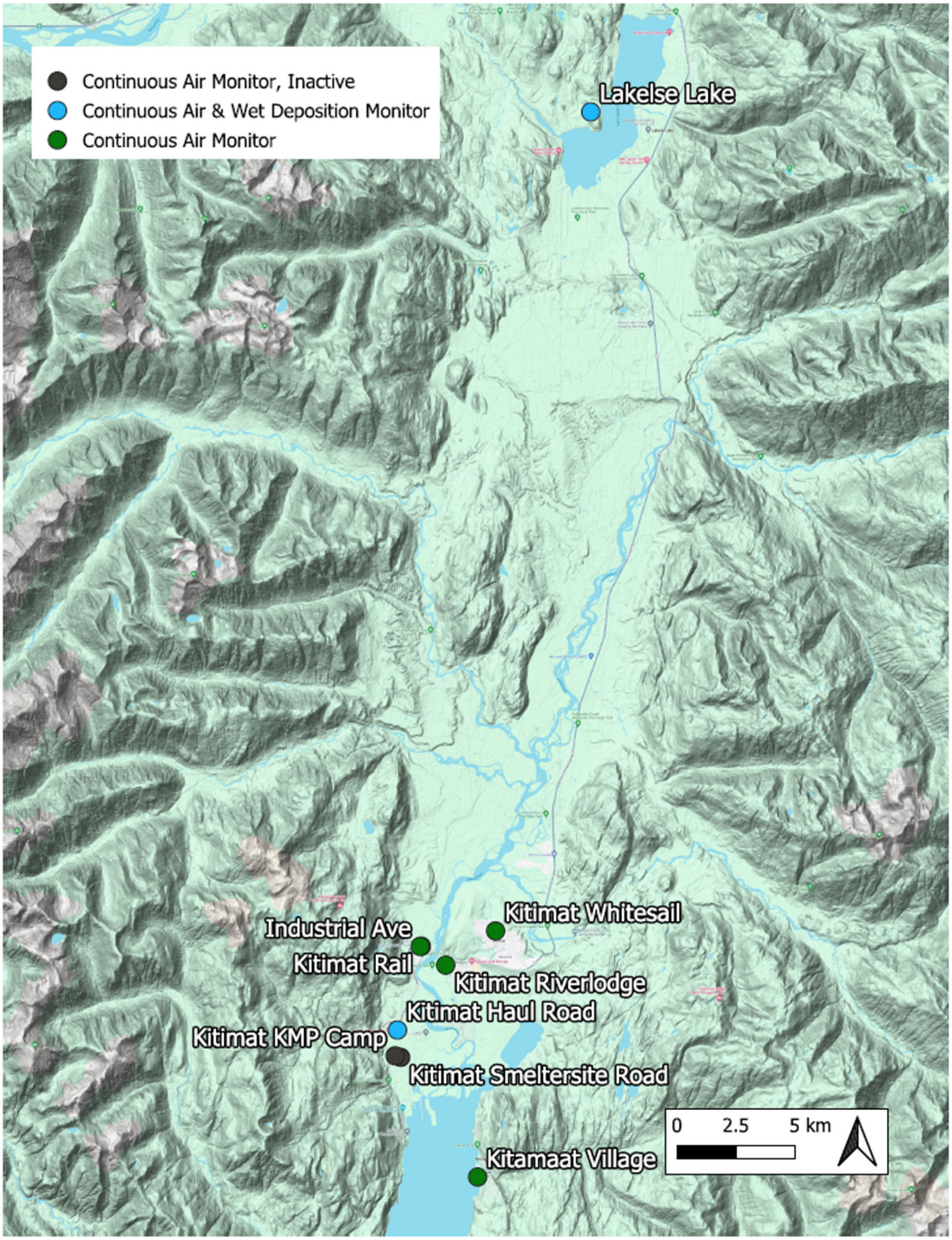
● Continuous Air Monitor, Inactive
● Continuous Air & Wet Deposition Monitor
● Continuous Air Monitor
Lakelse Lake
Kitimat Whitesail
Industrial Ave
Kitimat Rail
Kitimat Riverlodge
Kitimat Haul Road
Kitimat KMP Camp
Kitimat Smeltersite Road
Kitamaat Village
0
2.5
5 km

Figure 4-1. Locations of the six Rio Tinto continuous SO₂ analysers (Haul Road, Whitesail, Riverlodge, Kitamaat Village, Industrial Ave, Lakelse Lake).

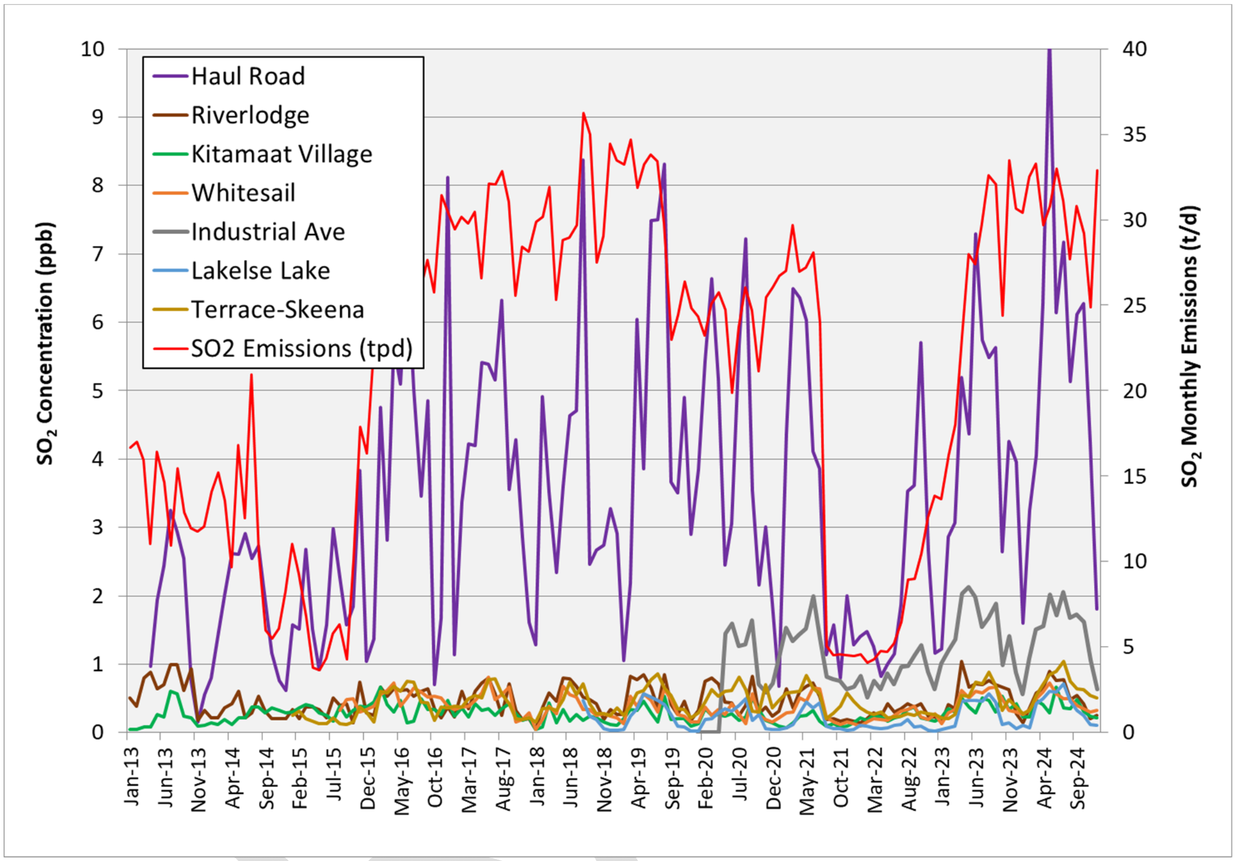

Figure 4-2. Monthly SO₂ emissions (red line) and monthly average ambient SO₂ concentrations at the seven continuous monitoring stations (purple, brown, green. orange, grey, blue and gold lines) for 2013 to 2024. (Source: Rio Tinto and Envista database)

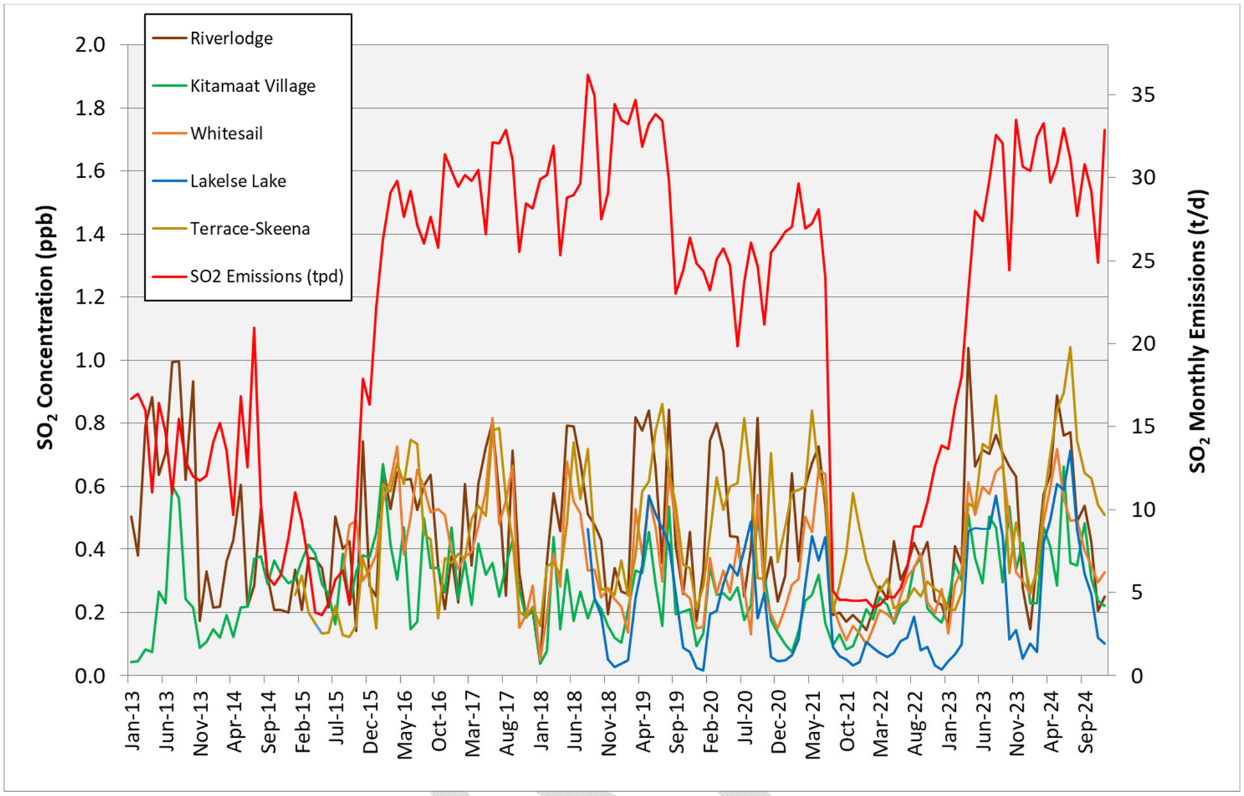

Figure 4-3. Monthly SO_2 emissions (red line) and monthly average ambient SO_2 concentrations at the seven continuous monitoring stations (purple, brown, green, orange, grey, blue and gold lines) for 2013 to 2024. (Source: Rio Tinto and Envista database)

Figure 4-4 shows a histogram depicting the relative frequency of hourly averaged concentrations of SO_2 at Haul Road (fenceline), Riverlodge (lower Kitimat), Whitesail (upper Kitimat), Kitamaat Village, and Industrial Avenue (Service Centre).[3] Low concentrations (below 4 ppb) occur most of the time (high frequency), and higher concentrations occur infrequently.

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[3] The sole purpose of the Lakelse SO_2 analyzer is for estimating dry deposition, and is not included in air quality monitoring network for British Columbia nor in Figure 4-4.

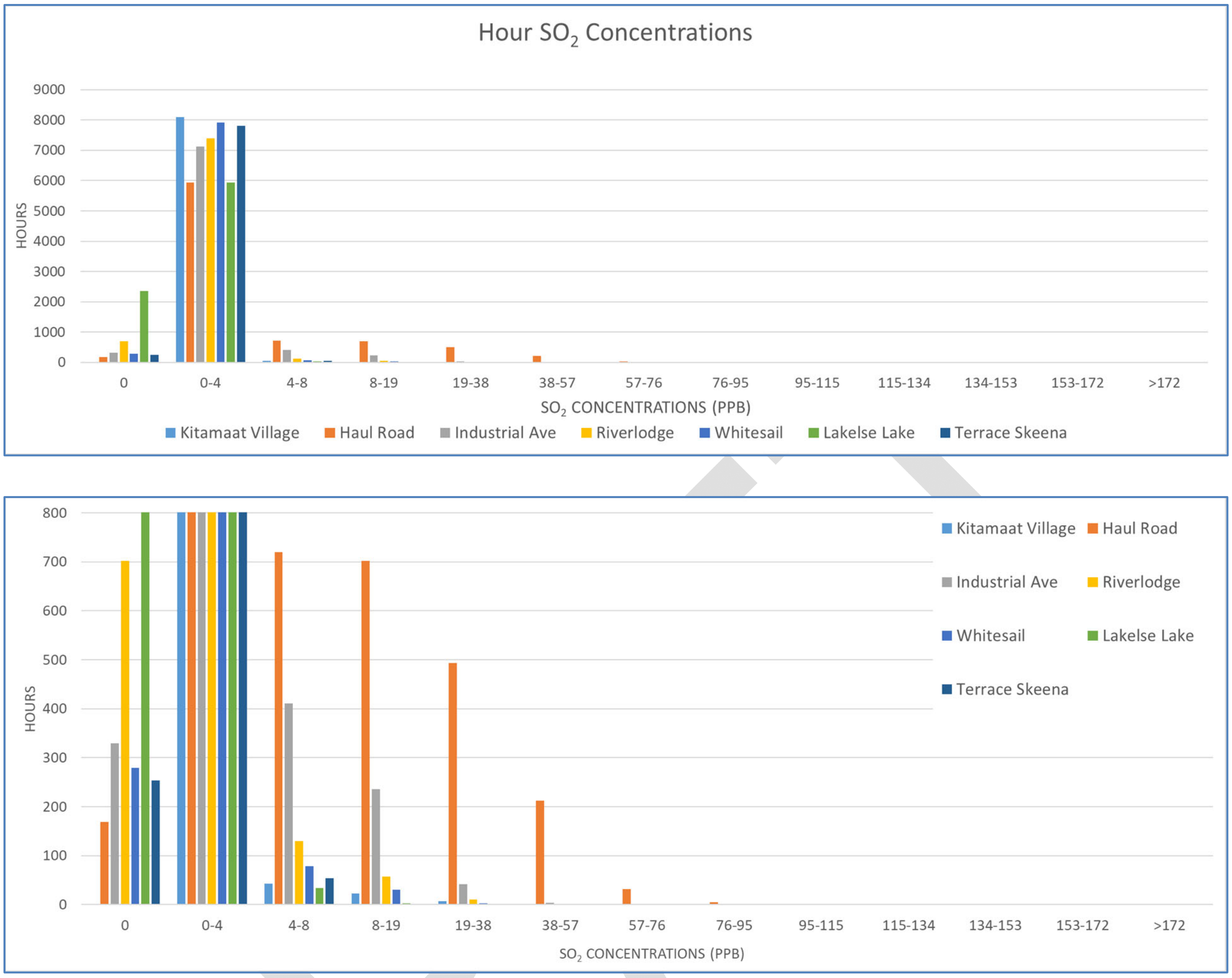

Figure 4-4. SO_2 hourly concentrations in 2024 at the Kitamaat Village, Haul Road, Industrial Avenue, Riverlodge, Whitesail, Lakelse Lake, and Terrace Skeena continuous monitoring stations (top graph). The bottom graph zooms in on the subset of the data showing lower frequencies (800 hours and less) of higher concentrations. (Source: Rio Tinto)

Comparison to the Model Output

Monitoring data collected at the four[4] monitor stations are compared to the air dispersion modelling results prepared for the EEM 2019 Comprehensive Review (ESSA et al., 2020a). The model comparisons in this section reflect the updated CALPUFF model results using corrected CALMET wind data.[5] Table 4-1, Figure 4-5, and Figure 4-6 show the comparison between monitored concentrations in 2024 and the predicted SO$_2$ concentrations from the air dispersion modelling analysis for 99th% 1-hour daily max and annual averaging periods. All results are in the form of the Canadian Ambient Air Quality Standards (CAAQS), which are used as the BC Air Quality Objectives for SO$_2$. These model results represent the actual emission scenario and apply the more realistic background concentrations that were applied in the 2019 Comprehensive Review for the model evaluation.

As shown in Table 4-1, annual average monitored concentrations align closely with model results in 2024, ranging from approximately one quarter of the modelled concentrations (23% and 24% at Riverlodge for local-scale and the regional-scale, respectively) to 77% (Haul Road for regional-scale). The 1-hour monitored concentrations also align with model results for all stations other than Kitamaat Village regional-scale (monitored is 131% of the regional scale modelled concentration). The remaining 1-hour monitor to model comparisons range from 35% (Whitesail local scale) to 79% (Haul Road regional scale). The Industrial Ave (Service Centre) station is not included in the comparison as the station was added after the modelling was completed.

Overall, these comparisons are consistent with the discussion in the 2019 Comprehensive Review that predicted modelled concentrations in most areas are higher than measured concentrations, resulting in cautious risk assessments. While the comparison in 2021 and 2022 continued to support the 2019 Comprehensive Review conclusions related to model performance and general overprediction, comparisons for 2021 and 2022 show lower magnitude and fewer instances of overprediction and larger magnitude and more instances of underprediction than the same comparisons for historic years. The levels of overprediction seen when comparing 2023 and 2024 monitoring data are similar to historic years (2016-2020). Model underpredictions at Haul Road occurred in 2022, which differs from the patterns observed in 2024 and all other years (when model predictions were greater or equal to monitored values). The change in comparison in 2022 (and somewhat in 2021) was likely an artifact of the model scaling method using annual average during these two years with

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[4] The four stations with complete data used for model evaluation in the 2019 Comprehensive Review are used for model comparison in this section. Other stations either have incomplete data or are too distant for comparison.

[5] CALPUFF results revised for wind corrections for all years. ENV and Trinity reviewed wind direction data in 2021 and determined that the Whitesail station was aligned to magnetic north rather than true north prior to August 2018 and that the Yacht Club station wind direction was also misaligned historically and realigned to true north in early 2019. Therefore, the wind directions recorded at these two stations needed correcting for most or all of the Comprehensive Review CALPUFF model period. In addition, Yacht Club wind speed data was be invalidated by ENV for most of 2018. Trinity conducted a study for the full CALPUFF period (2016 through 2018) using the corrected wind data. An addendum to the Comprehensive Review report (ESSA et. al., 2022) evaluated the corrected CALPUFF results for each line of evidence in order to determine if the post-correction CALPUFF results are meaningfully different than the results from the original Comprehensive Review report and whether use of the post-corrected results would lead to different conclusions in the Comprehensive Review.

several individual months at very low SO_2 emission levels rather than the possibility that the model's relationship to monitored data changed meaningfully. This explanation is further supported by the 2023 and 2024 comparisons aligning with historic comparisons.

Table 4-1. 2024 Monitored Data Compared to Modelled Concentrations.

Site [a]	Averaging Period [b] / Model	Monitored Concentration (ppb)	Modelled Concentration [c] (ppb)	Monitored Concentration (ppb)	Modelled Concentration [c] (ppb)
		2024		3-Year Average	
Haul Road	Annual/Local	5.20	7.84	4.77	5.54
Kitamaat Village	Annual/Local	0.36	0.69	0.44	0.56
Riverlodge	Annual/Local	0.50	2.19	1.03	1.60
Whitesail	Annual/Local	0.44	1.12	0.58	0.86
Haul Road	Annual/Regional	5.20	6.74	3.89	4.78
Kitamaat Village	Annual/Regional	0.36	0.54	0.33	0.46
Riverlodge	Annual/Regional	0.50	2.13	0.47	1.57
Whitesail	Annual/Regional	0.44	1.27	0.36	0.96
Haul Road	99% 1HDM/Local	81.7	121	69.7	85
Kitamaat Village	99% 1HDM/Local	22.6	36	17.9	26
Riverlodge	99% 1HDM/Local	24.6	45	20.6	32
Whitesail	99% 1HDM/Local	16.7	48	14.3	34
Haul Road	99% 1HDM/Rgnl	81.7	102.9	70	72
Kitamaat Village	99% 1HDM/Rgnl	22.6	17.3	18	13
Riverlodge	99% 1HDM/Rgnl	24.6	41.5	21	29
Whitesail	99% 1HDM/Rgnl	16.7	32.5	14	23

[a] Industrial Ave station was not in operation in 2016-2018; therefore, the site is not included in this model comparison. The site is included in the comparison to the human health KPI in Section 3.2.

[b] Averaging periods and forms of results correspond to the CAAQS. 1HDM = 1-hour averaging period, daily maximum

[c] Modelled concentrations are based on results from the actual scenario using actual emissions for 2016, 2017, 2018, based on updated model from wind correction performed in 2021. For 2019 forward, the 3-year average actual model results are scaled from 2016-2018 average emissions to current year emission.

The following background value from Williams Lake is added to account for non-modelled sources of SO_2 (for 2019 forward, note the background is added after scaling model results).

Annual Average	0.26	ppb
99th% 1-hour Daily Max	1.80	ppb

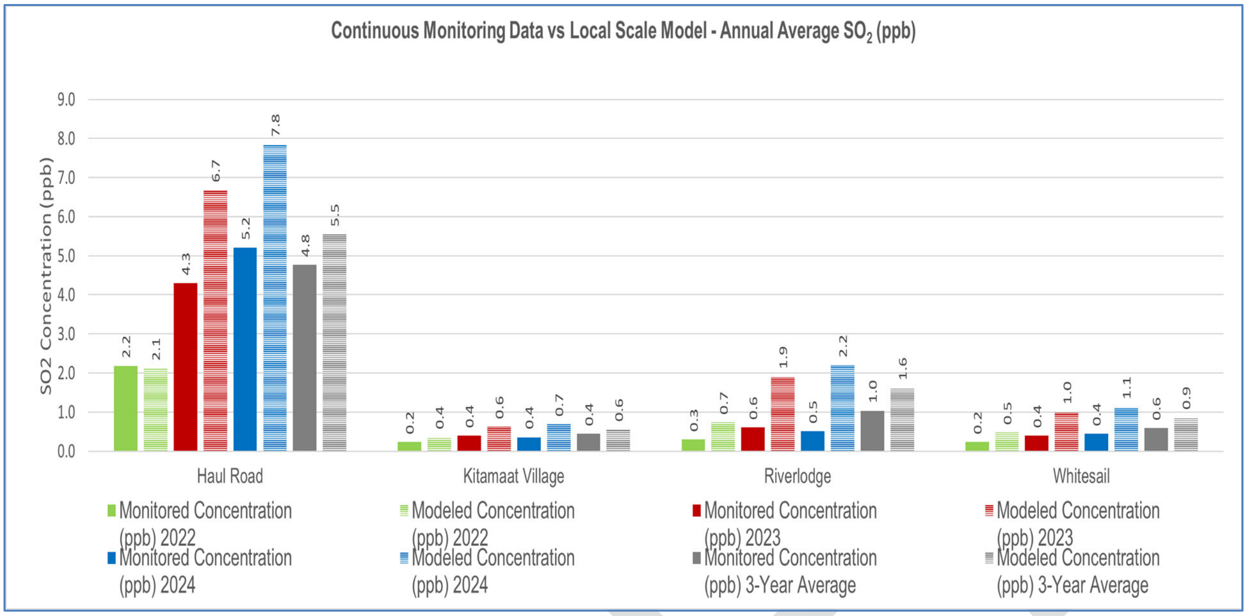

Figure 4-5. 2024 Monitored annual average data compared to modelled concentrations.

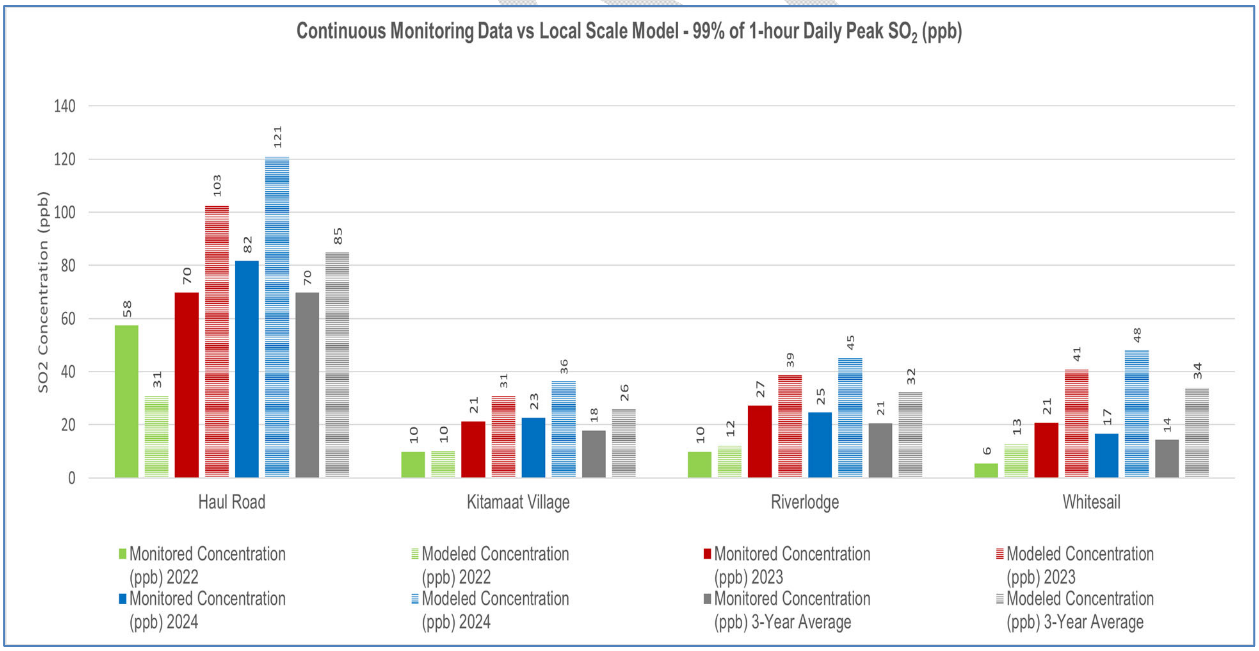

Figure 4-6. 2024 Monitored 1-hour data compared to modelled concentrations.

Network Optimization

Rio Tinto revised Phase 2 of the network optimization to incorporate the updated CALPUFF model results**Error! Bookmark not defined.** in 2022. B.C. ENV reviewed and provided comments in 2023, and the report addressing comments was updated in 2024 and submitted in January 2025. The Terms of Reference (TOR) for the SO_2 network optimization incorporating the latest monitoring data and the 2019 Comprehensive Review (ESSA et al., 2020a) model results was approved by B.C. ENV in December of 2020.

4.1.2 SO_2 Concentrations – Passive Sampling

The network of passive samplers was redeployed in the Kitimat Valley during 2024 following the same procedures as in 2016-2023 (ESSA et al., 2020a). The network was deployed starting April 25, 2024[6], at 24 sites within the Kitimat Valley (Figure 4-8), primarily focused along the Wedeene and Bish roads to capture the plume path. This network is referred to as the plume path network and historically referred to as the valley network.[7]

Based on the 2020 passive sampling plan (Trinity 2020), a detailed site evaluation was conducted and documented during the 2020 deployment. The original 15 sites deployed in 2020 were deployed in 2024. In addition, the sites added in 2021 and 2022 were also deployed in 2024. The six sites added in 2021 were based on reconnaissance performed in early 2021.[8] Location A05 (Kitamaat Village) was added in 2022 to understand the extent of the plume to the southeast and for another site to compare with continuous ambient SO_2 monitoring. Two more sites, V25 and V26, were added in 2024. V25 was added southwest of the Kitamaat Village site location to better understand the plume boundary to the south. V26 is located in Kemano at the BC Works Powerhouse and used as a background location.

As detailed in the Phase III EEM work plan's 2021-Specific Work Plan for Passive Sampling (ESSA et. al., 2021), the network changed from employing IVL SO_2 passive samplers to Bureau Veritas (BV) All-Season Passive Air Sampling System (PASS) and laboratory. All 2022 and later sample analysis was performed using the BV PASS system.

Six deployments, with an approximate exposure time of one-month (27–34 days), were carried out under the plume path network between late April and late October2024. Lake 28 sampling had five deployments from May to October 2024. The new background station in Kemano (V26) is a year-round sampling location; only its April through October data are included in this report. After a full year of data are available, the complete dataset for V26 will be included in the 2025 report issued in 2026.

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[6] The Lake 28 sampler was deployed later than the other sites, on May 22, 2024.

[7] A second network of passive samplers deployed in the urban and residential areas of Kitimat was in continuous operation from June 2018 through December 2019. The urban network study concluded in 2019 (before the time period of this report).

[8] Three of the six new 2021 sites (V17, V18/V18b, and V20) were added east and west of V01 to create an east-west transect to better understand the eastern and western boundaries of the plume path. The remaining three new 2021 sites (V21, V22, and V23) were added farther north near Terrace to better understand the northern boundary of the plume path (and to verify where the plume is not).

In 2024, there were 182 sample exposures across the plume path network collected and analysed during the six deployments. These included replicate samplers deployed approximately 22% of the time (39 duplicate exposures) and 33 blank samples (approximately five per sampling period).

The observed data show elevated atmospheric SO_2 along the plume path (Figure 4-8). The 2024 results within the plume path network are similar to historic observations with the exception of 2022 due to lower concentrations during the restart in 2022. The spatial pattern is consistent with previous years, other than spatial patterns being difficult to discern during the low-concentrations in 2022.

Table 3-2 and 3-3 present calibrated passive data; these data were adjusted using a linear relationship between monthly passive results from 2022 to 2024. Passive stations: A01, A02, A04, and A05, are co-located with the following continuous monitors: Haul Road, Riverlodge, Lakelse, and Kitamaat Village, respectively. Continuous averages collected over the same period were compared with monthly passive results from 2022 to 2024. With three years of data, a strong correlation is observed, yielding an R^2 value of 0.98, indicating a clear and reliable relationship between the passive and continuous sampling methods. Passive samples were adjusted using the equation $y=0.6892x +0.1057$. This equation was applied to all monthly passive samples, to calibrate 2024 monthly results by site and seasonal passive average values from 2022 to 2024.

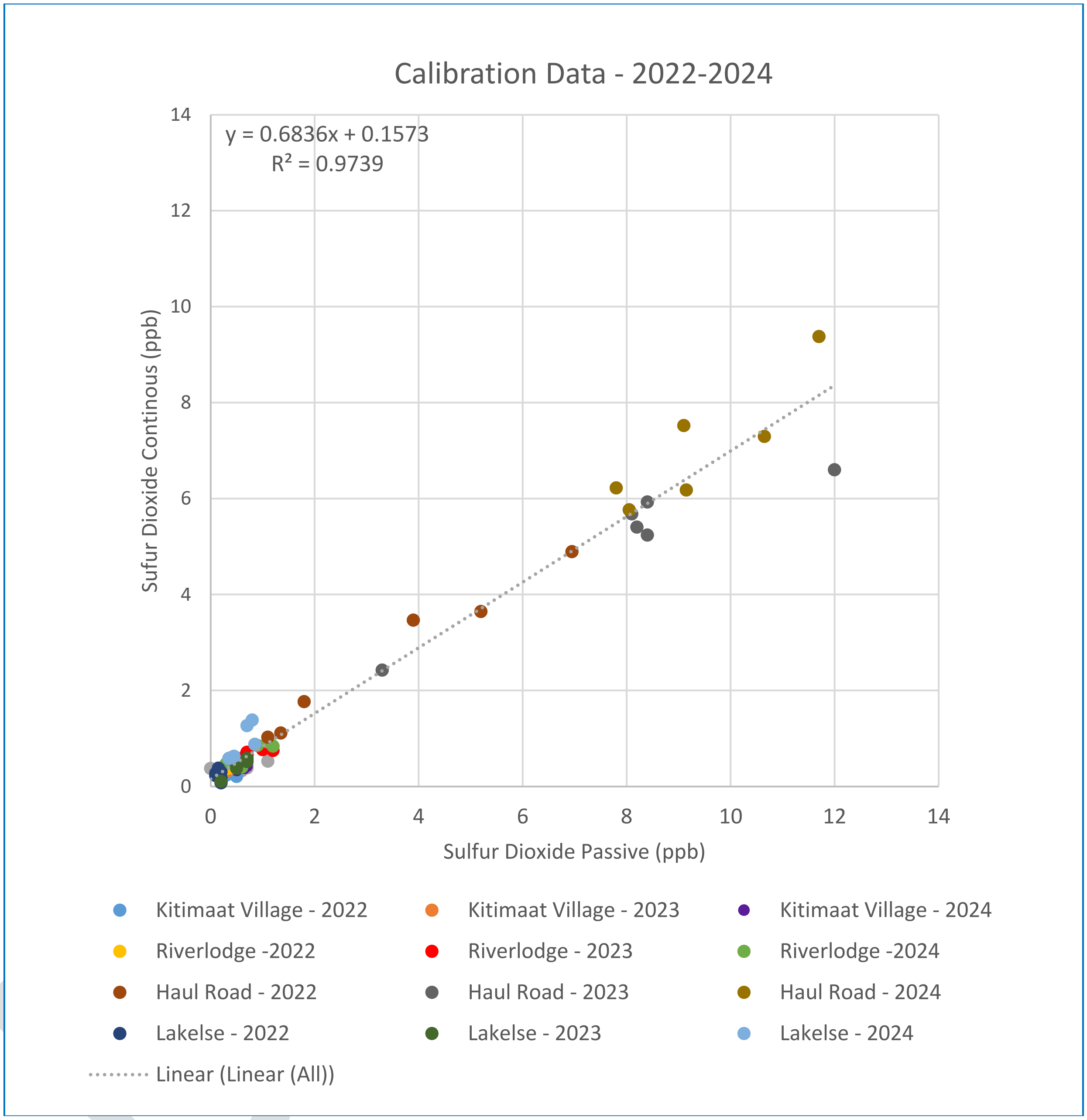

Figure 4-7. SO_2 Calibration data from 2022 to 2024. (Source: Rio Tinto)

Additional information can be found in Technical Memo P08, provided in Appendix A.

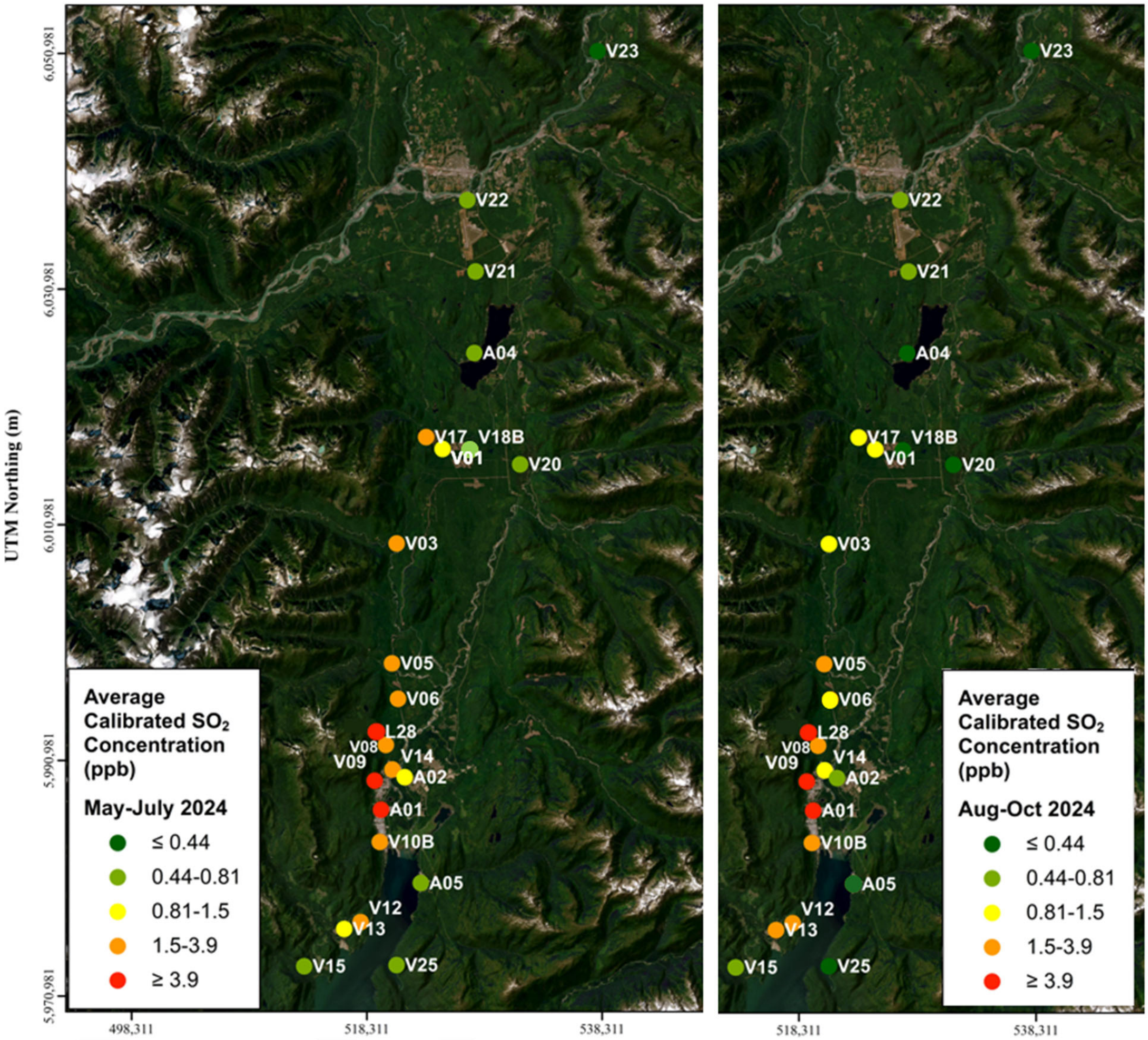

Figure 4-8. Average atmospheric sulphur dioxide (SO_2) concentration during May to July 2024 (left) and during August to October (right) in the Kitimat Valley passive diffusive monitoring networks (calibrated). Remote V26 not pictured (<0.44 for both seasons).

Table 4-2. Monthly calibrated concentration of SO_2 (ppb) from passive samplers in the SO_2 network during the 2024 sampling season.

ID	Site Name	UTM E	UTM N	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24
A01	Haul Road Station	519527	5986823	8.20	6.40	5.50	6.40	5.70[2]	7.40
A02	Riverlodge Station	521538	5989580	0.86	0.73	0.93	0.52	0.59	0.31
A04	Lakelse Lake NADP Station	527457	6025573	0.66	0.59	0.69	0.42	0.38	0.35
A05	Kitamaat Village Station	522907	5980600	0.55	0.45	0.55	0.59	0.45[2]	0.17
V01	Onion Lake Ski Trail North	524757	6017435	1.07	1.14	1.35	1.35	0.97	0.52
V03	Mound TKTP92	520853	6009407	N/A[1]	1.45[2]	1.90	1.48	1.07	0.66
V05	LNG Muster Station	520457	5999250	2.24	2.38	2.66	2.24	1.83	0.79
V06	Sand Pit	520970	5996240	1.97[2]	2.10	2.04	1.97	1.83	0.66
V08	Claque Mountain Trail at Powerline	519938	5992329	3.00[2]	2.52	3.28	2.38	3.83	1.28
V09	Sand Hill at Powerline	518985	5989292	4.86[2]	3.34	5.55	4.45	5.27	3.93
V10B	Pullout before Bish FSR	519425	5984090	4.45	2.59	N/A[1]	5.83	2.66	1.90
V12	Bish Road Pullout 4	517790	5977294	2.79	2.17	1.21	5.14	1.76	4.31
V13	Bish Road at Chevron LNG	516389	5976708	1.42	1.21[2]	0.93	2.52	0.79[2]	2.17
V14	Industrial Area Kitimat Hotel	520490	5990236	2.04	1.69	1.76	1.21	1.42	1.35
V15	Bish Mainline	512994	5973534	N/A[1]	0.45	0.79	1.21	0.52	0.24
V17	West Lake	523359	6018434	1.90	1.83	2.31	2.10	1.83	1.00
V18B	Wedeene mainline	527088	6017351	0.79	0.73	0.79	0.45	0.38	0.24
V20	Pipeline laydown	531354	6016121	0.45	0.45	0.66	0.38	0.31	<0.17
V21	South of airport	527566	6032493	0.79	0.59	0.86	0.52[2]	0.52	0.45
V22	Kitselas Development	526862	6038551	0.73	0.59	0.73	0.52[2]	0.52	0.66
V23	Gitaus water tower	537941	6051192	0.31	0.31	0.45	0.31	0.24	<0.17
V25	South of Kitamaat Village	520884	5973636	0.66	0.52	0.45	0.52	0.31	0.24
V26	Kemano	569684	5934713	<0.21	<0.17	<0.17	0.21	<0.17	<0.17
L28	Lake 28	519139	5993425	N/A	4.1	5.2	6.3	5.2[3]	4.5

[1] Site technician indicated an invalid sample due to visual anomalies or missing sample. These samples were not analyzed.

[2] Site technician indicated spider webs or spiders in close vicinity to the sample.

[3] Sampler project tracker indicated spider webs or spiders in close vicinity to the sample and heavy rain during sample collections

< Lab results yielded values below the detection limit, the detection limit was substituted as the conservative average.

Table 4-3. Yearly calibrated concentration of SO_2 (ppb) from passive samplers in the SO_2 network during the 2022-2024 sampling season.

ID	Site Name	UTM E	UTM N	2022	2023	2024	Average
A01	Haul Road Station	519527	5986823	2.44	5.11	6.59	4.70
A02	Riverlodge Station	521538	5989580	0.39	0.68	0.66	0.58
A04	Lakelse Lake NADP Station	527457	6025573	0.21	0.46	0.51	0.39
A05	Kitamaat Village Station	522907	5980600	0.36	0.54	0.46	0.45
V01	Onion Lake Ski Trail North	524757	6017435	0.30	0.88	1.06	0.75
V03	Mound TKTP92	520853	6009407	0.45	1.27	1.31	1.0
V05	LNG Muster Station	520457	5999250	0.66	1.74	2.02	1.47
V06	Sand Pit	520970	5996240	0.52	1.38	1.76	1.22
V08	Claque Mountain Trail at Powerline	519938	5992329	0.96	2.16	2.71	1.94
V09	Sand Hill at Powerline	518985	5989292	2.01	5.02	4.57	3.87
V10B	Pullout before Bish FSR	519425	5984090	1.66	3.94	3.48	3.03
V12	Bish Road Pullout 4	517790	5977294	1.93	4.49	2.90	3.11
V13	Bish Road at Chevron LNG	516389	5976708	0.74	2.31	1.51	1.52
V14	Industrial Area Kitimat Hotel	520490	5990236	0.57	1.37	1.58	1.17
V15	Bish Mainline	512994	5973534	0.30	0.79	0.64	0.58
V17	West Lake	523359	6018434	0.22	0.52	0.57	0.43
V18B	Wedeene mainline	527088	6017351	0.55	1.42	1.83	1.27
V20	Pipeline laydown	531354	6016121	0.21	0.39	0.40	0.33
V21	South of airport	527566	6032493	0.23	0.54	0.62	0.47
V22	Kitselas Development	526862	6038551	0.21	0.48	0.62	0.44
V23	Gitaus water tower	537941	6051192	0.27	0.32	0.30	0.30
V25	South of Kitamaat Village	520884	5973636	N/A	N/A	0.45	0.45
V26	Kemano	569684	5934713	N/A	N/A	0.19	0.19
L28	Lake 28	519139	5993425	1.48	4.28	5.07	3.61

4.1.3 Sulphur Wet and Dry Deposition

4.1.3.1 Wet Deposition (Precipitation Chemistry)

Validated annual wet deposition data values are not available from the National Atmospheric Deposition Program (NADP) until late in the following year. Therefore, annual deposition values are estimated for the reporting year using *preliminary* weekly datasets. The data summarized below include final, post-validated data for 2023 and prior years, and preliminary data for 2024 and 2023.[9,10]

Figure 4-8 compares the amount of annual precipitation (mm) Haul Road and Lakelse Lake precipitation chemistry monitoring stations during 2013 to 2024. Note that because the Lakelse Lake station was only in operation for part of 2013, data from that location are only shown for 2014 to 2024. Average annual precipitation volume was consistently higher at Haul Road compared to levels at Lakelse Lake during 2014–2024 (47% to 80% higher), averaging 2387 mm and 1479 mm, respectively. During 2024, precipitation volume at Haul Road (2285 mm) and at Lakelse Lake (1335 mm) were slightly lower than the eleven-year average, and the relationship between the two stations was consistent with past years (71% higher at Haul Road compared to Lakelse Lake).

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[9] January through September 20, 2022 data from NADP are weekly validated. September 20 through December 31, 2024 data are preliminary not yet validated.

[10] Similarly, the 2021 report showed final data for 2020 and prior and preliminary data for 2021. As a comparison point, the weekly 2021 data at Haul Road yielded an estimated annual SO_4 deposition rate of 40.6 kg SO_4^{2-}/ha/yr compared to the post-validated annual NADP value of 39.8 kg SO_4^{2-}/ha/yr (both marine-adjusted).

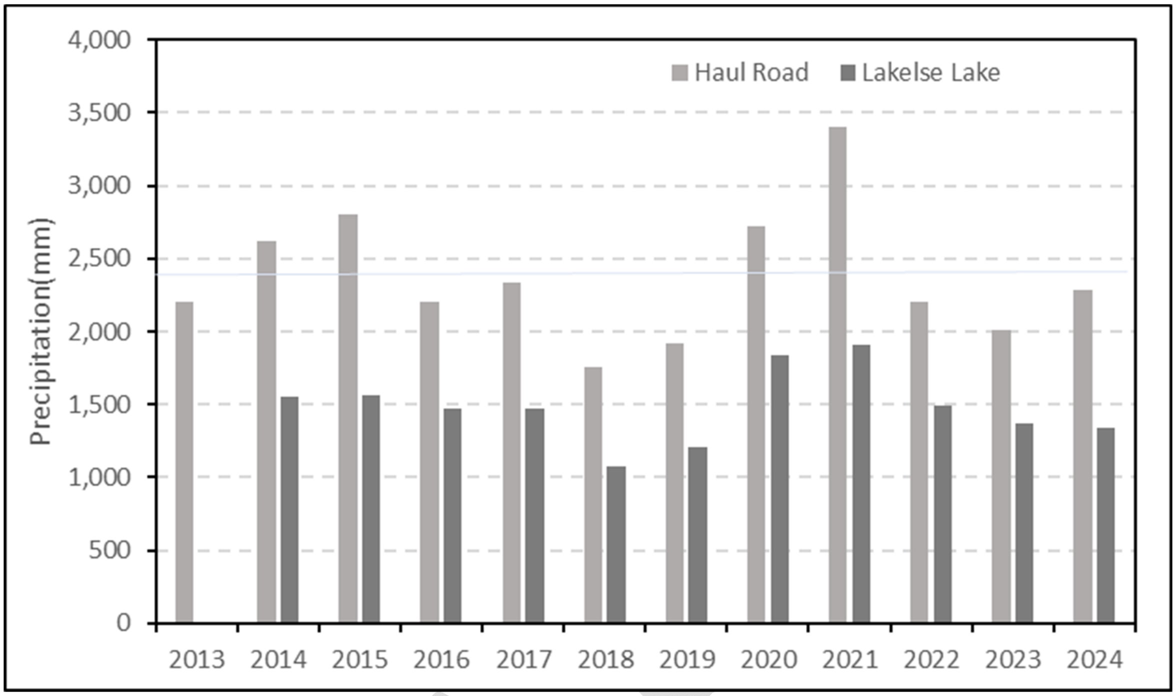

Figure 4-9. Annual precipitation volume (mm) from 2013 to 2024 at the Haul Road and Lakelse Lake precipitation chemistry monitoring stations. (Source: NADP [URL: https://nadp.slh.wisc.edu/precipitation/])

Weekly precipitation volume (mm) at the two stations (operated by the NADP) during the same eleven-year period showed a highly synchronous pattern but with generally higher volume at Haul Road (Figure 4-9). Higher volume was recorded at Lakelse Lake for only approximately 8% of the observations on average and 20% of observations in 2024. In addition, higher weekly sulphate concentration (mg/L) and lower pH was observed at Haul Road compared with Lakelse Lake (Figure 4-9). The higher SO_4 and lower pH in rainfall at Haul Road are caused by the higher atmospheric concentration of SO_2 and corresponding higher S deposition at Haul Road.

Figure 4-10. Weekly precipitation volume (mm) and chemistry (mg/L) at Haul Road (January 2013 to December 2024) and Lakelse Lake (April 2013–December 2024) showing inter-annual variation in precipitation volume (upper graph), sulphate concentration (middle graph) and precipitation pH (lower graph).[11]

Higher rainfall volume and higher sulphate concentration observed at Haul Road combines to result in a more pronounced wet S deposition difference compared with Lakelse Lake on an annual (Figure 4-11) and weekly basis (Figure 4-12).

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[11] Partial 2023 and complete 2024 data are preliminary and not yet validated by NADP.

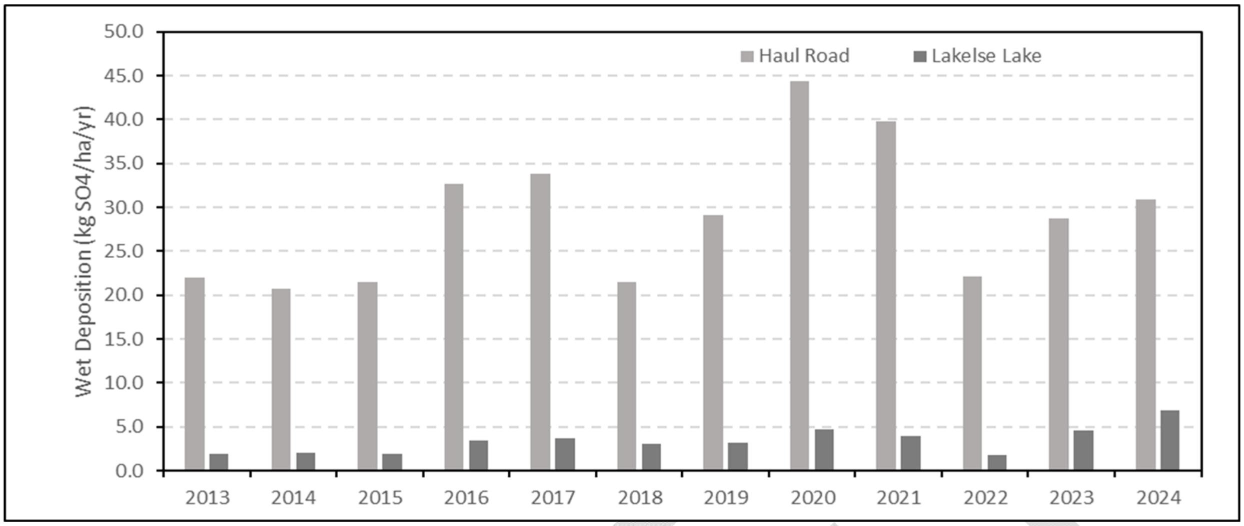

Figure 4-11. Annual wet deposition (kg SO_4/ha/yr) from 2013 to 2024 at the Haul Road and Lakelse Lake precipitation chemistry monitoring stations. (Source: NADP [URL: https://nadp.slh.wisc.edu/precipitation/])

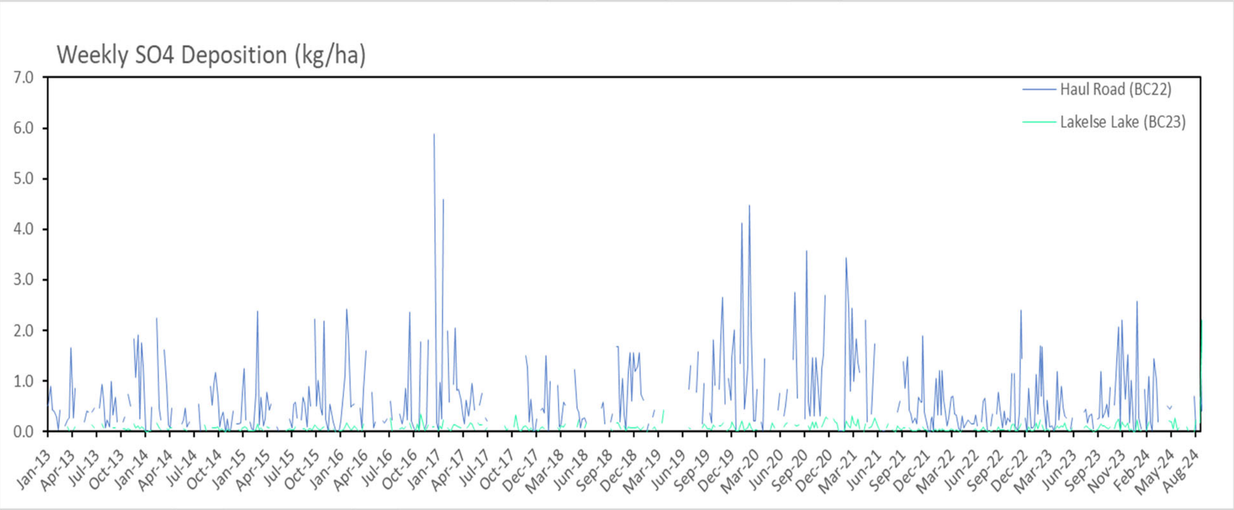

Figure 4-12. Weekly wet deposition (kg SO_4/ha/yr) from 2013 to 2024 at the Haul Road and Lakelse Lake precipitation chemistry monitoring stations. (Source: NADP [URL: https://nadp.slh.wisc.edu/precipitation/])

4.1.3.2 Dry deposition modelling methods

Dry deposition measurements are difficult and rarely conducted because of the requirements for highly sophisticated methods and instrumentation (Wesely and Hicks 2000). In general, dry deposition is modelled from air concentrations of gaseous and particulate species (e.g., SO_2 and p SO_4^{2-}) multiplied by a species-specific dry deposition velocity estimated using modelling techniques, i.e., ‘inferential’ models (Vet et al., 2014).

$$F = C \times V_d$$

Where:
F is the dry deposition flux,
C is the measured ambient air concentration, and
V_d is the deposition velocity, which is influenced by factors such as wind speed, height of observation, heat flux, moisture availability, vegetation, and surface roughness (Wesely and Hicks 2000).

The ‘big-leaf’ model developed by Environment and Climate Change Canada (Zhang et al., 2001, 2003a, 2003b; Zhang and He 2014) was used to estimate hourly species-specific V_d at four stations in the Kitimat Valley (Haul Road, Whitesail, Lakelse Lake, and Terrace Airport [YXT]). The V_d model required meteorological forcing variables on an hourly resolution for the period of interest (calendar year 2022). The data sources for the big-leaf dry deposition velocity model at four stations are shown in Table 4-2. The model also requires site-specific variables, such as latitude and land cover; deposition velocities were estimated for coniferous land cover only. For further details on the big-leaf model see Technical Memo D01 (2016) and Technical Memo D02 (2018).

Additional data sources became available beginning in May 2023 from the installation of solar irradiance instrumentation at Whitesail and temperature, relative humidity, solar irradiance, and surface pressure at Lakelse Lake. These data were incorporated into the report as available. Prior to May 2023 installation, the data used for dry deposition modelling was identical to the methods for prior years, as detailed in Table 4-2.

Table 4-2. Data sources for meteorological variables required to model deposition velocity at Haul Road, Whitesail, Lakelse Lake and Terrace Airport.

Variable	Kitimat: Haul Road	Kitimat: Whitesail	Lakelse Lake	Terrace Airport
Temperature	Haul Road hourly	Whitesail hourly	Lakelse Lake hourly Prior to May 13, 2023: Terrace Airport hourly	Terrace Airport hourly
Wind speed	Haul Road hourly	Whitesail hourly	Terrace Airport hourly	Terrace Airport hourly
Relative humidity	Whitesail hourly	Whitesail hourly	Lakelse Lake hourly	Terrace Airport hourly

Variable	Kitimat: Haul Road	Kitimat: Whitesail	Lakelse Lake	Terrace Airport
			Prior to May 13, 2023: Terrace Airport hourly	
Solar irradiance	Whitesail hourly Prior to May 13, 2023: Modelled from maximum and minimum daily temperature using Hargreaves method	Whitesail hourly Prior to May 13, 2023: Modelled from maximum and minimum daily temperature using Hargreaves method	Lakelse Lake hourly Prior to May 13, 2023: Modelled from maximum and minimum daily temperature using Hargreaves method	Modelled from maximum and minimum daily temperature using Hargreaves method
Precipitation rate	NADP Haul Road, obtained from University of Wisconsin	Haul Road	NADP Lakelse Lake, obtained from University of Wisconsin	Terrace Airport daily data, disaggregated by NADP Lakelse Lake hourly data
Surface pressure	Haul Road hourly[12]	Whitesail hourly[13]	Lakelse Lake hourly Prior to May 13, 2023: Terrace Airport hourly	Terrace Airport hourly
Snow depth	Environment Canada, Kitimat Hatchery, daily data applied to all hours	Environment Canada, Kitimat Hatchery, daily data applied to all hours	Terrace A / Terrace PCC daily snow depth, applied to all hours	Terrace A / Terrace PCC daily snow depth, applied to all hours
Cloud fraction	Environment Canada, Terrace Airport hourly	Environment Canada, Terrace Airport hourly	Environment Canada, Terrace Airport hourly	Environment Canada, Terrace Airport hourly

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[12] In 2023 at Haul Road and Whitesail the surface pressure was not available for much of the year. Available data was used and missing hours were substituted with data from nearby Riverlodge.

[13] The Vd for Lakelse Lake was first modelled for reporting year 2022 and was also modelled using data back to 2020. Dry sulphur deposition calculations based on SO_2 measured at Lakelse Lake for periods prior to 2020 (starting August 2018 when the Lakelse Lake SO_2 monitor was established) have applied modelled Vd from the Terrace Airport.

4.1.3.3 Dry deposition modelling results

Annual modelled dry deposition velocity (V_d) for SO$_2$ ranged between 0.05 – 4.68 cm/s for Haul Road, 0.06 – 4.47 cm/s for Whitesail, 0.03 – 4.80 cm/s for Lakelse Lake, and <0.01 – 4.36 cm/s for Terrace Airport. Figure 4-13 shows the annual distribution of modelled V_d for SO$_2$ at each location.

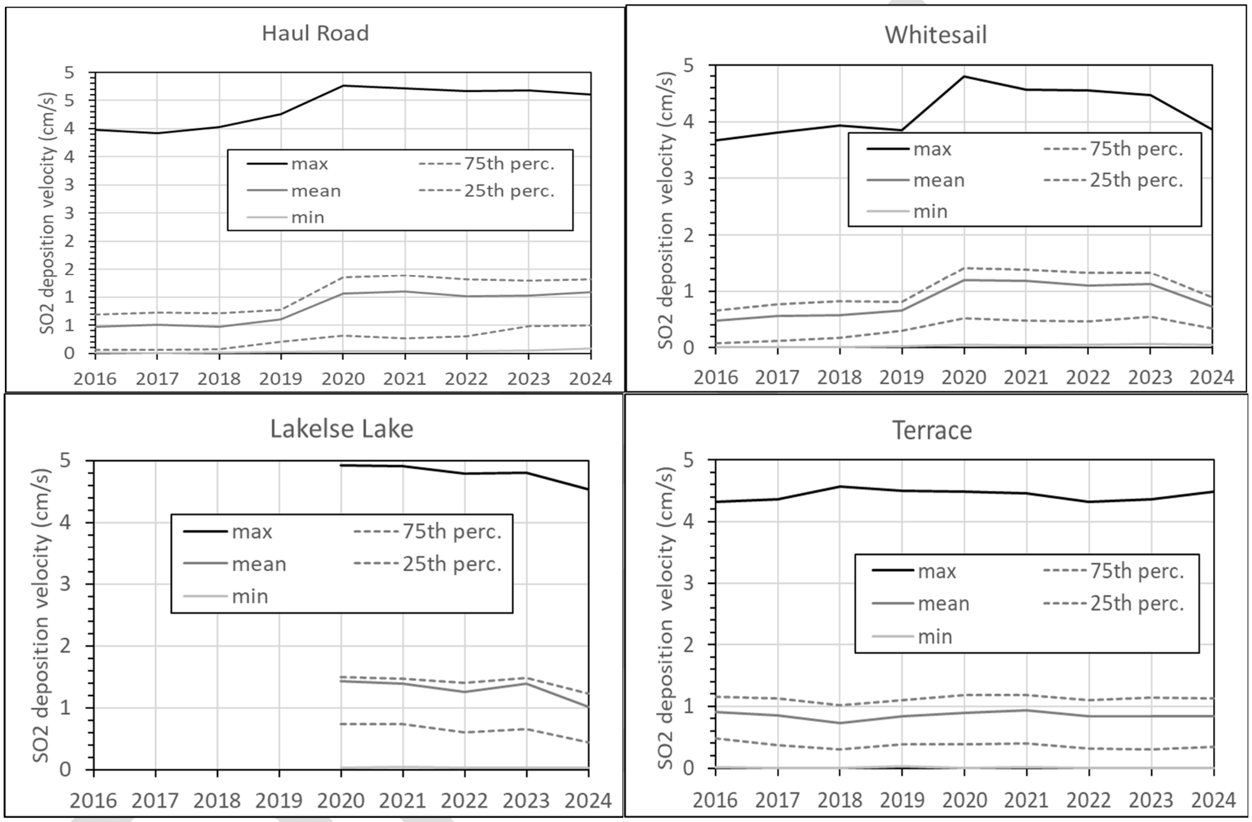
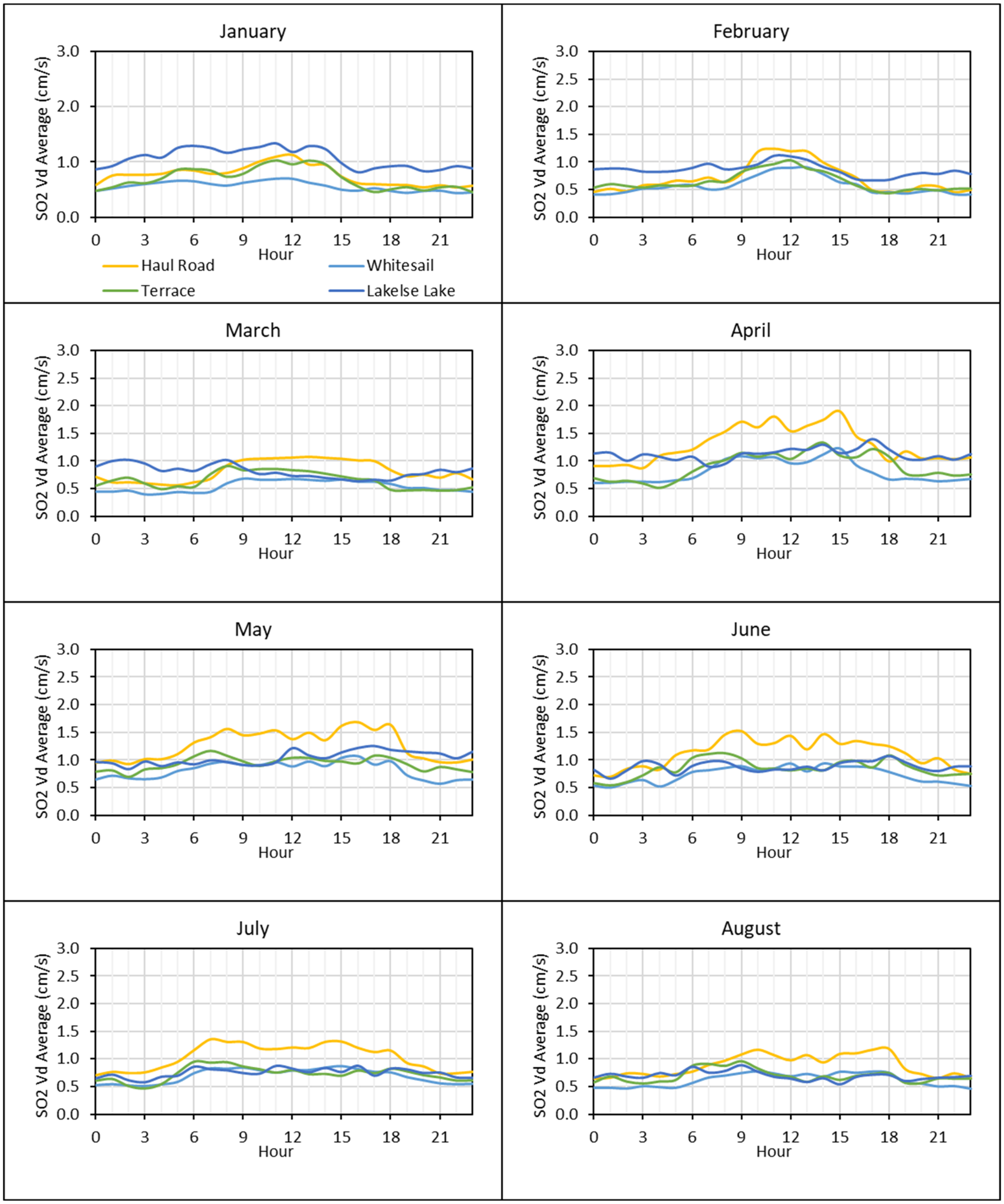


Figure 4-13. Annual distribution of SO$_2$ V_d for 2016 – 2023.

The annual distribution of SO$_2$ V_d was similar among all years 2016-2023, with a slight increase in overall magnitude during 2020 for Haul Road and Whitesail. This analysis also investigated trends in variable SO$_2$ V_d on a daily and seasonal basis. Figure 4-14 demonstrates the 2023 diurnal behavior of SO$_2$ V_d showing that SO$_2$ V_d is higher during daytime hours aligning similarly with trends in daily temperature and solar irradiance.


January
February
March
April
May
June
July
August
SO2 Vd Average (cm/s)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Hour
0
3
6
9
12
15
18
21
Haul Road
Whitesail
Terrace
Lakelse Lake

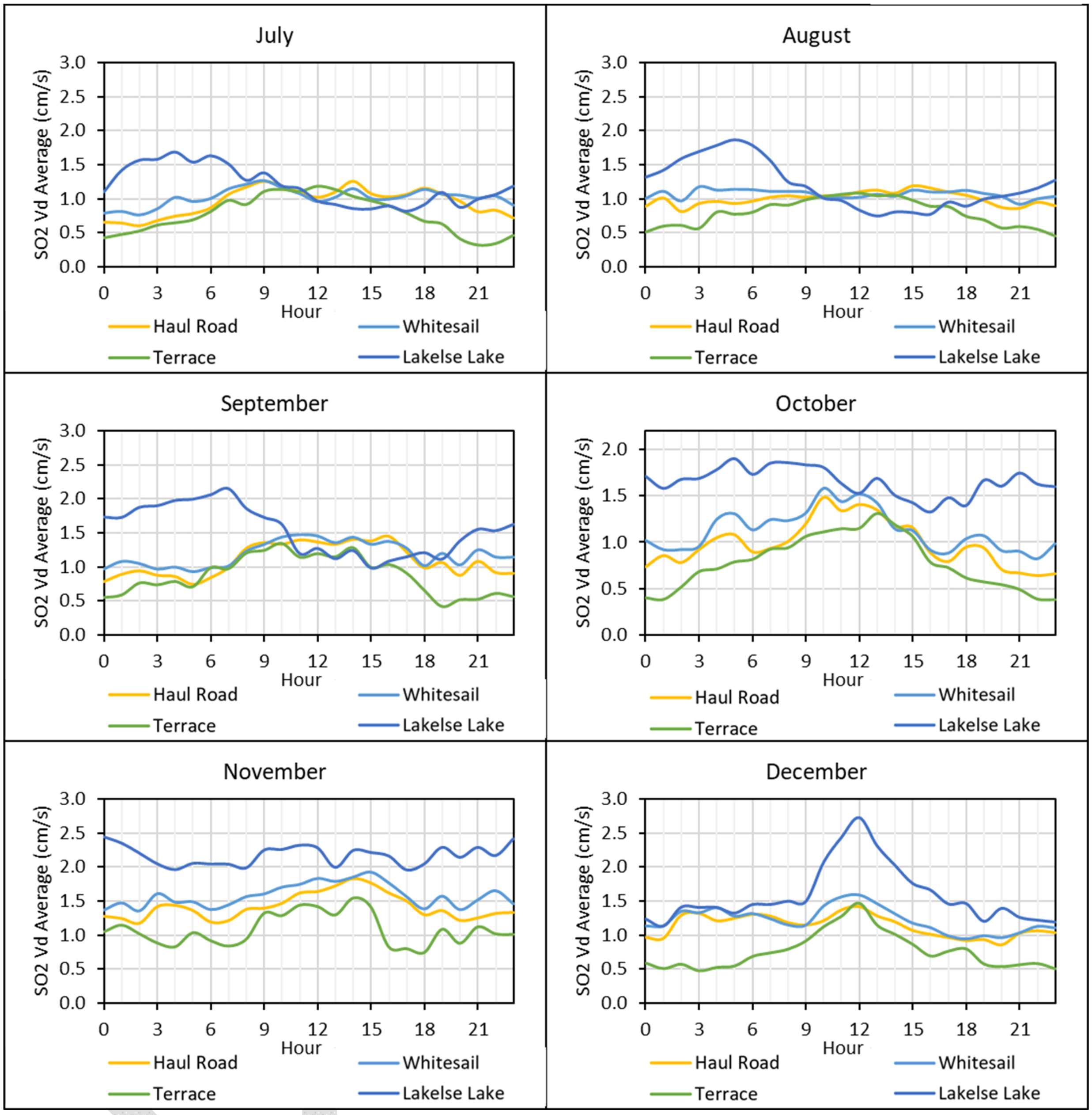


Figure 4-14. Diurnal behavior of SO_2 V_d in 2024.

Hourly SO_2 V_d was multiplied by the preliminary hourly monitored SO_2 concentrations to determine the total mass of SO_2 dry deposition in 2024. Dry deposition velocities were modelled at the Haul Road, Whitesail, and Lakelse Lake monitoring stations, using co-located SO_2 monitoring data and meteorological data (when available). The modelled dry deposition velocities for the Terrace airport were applied to the SO_2 monitoring data from the Terrace-Skeena Middle School. The total SO_2 dry deposition mass in 2023 was 50.5 kg/ha/yr for Haul Road, 4.9 kg/ha/yr for Whitesail, 2.7 kg/ha/yr for Lakelse Lake, and 3.6 kg/ha/yr for Terrace-Skeena Middle School. Figure 4-15 shows 2023 and prior years' SO_2 dry deposition mass.

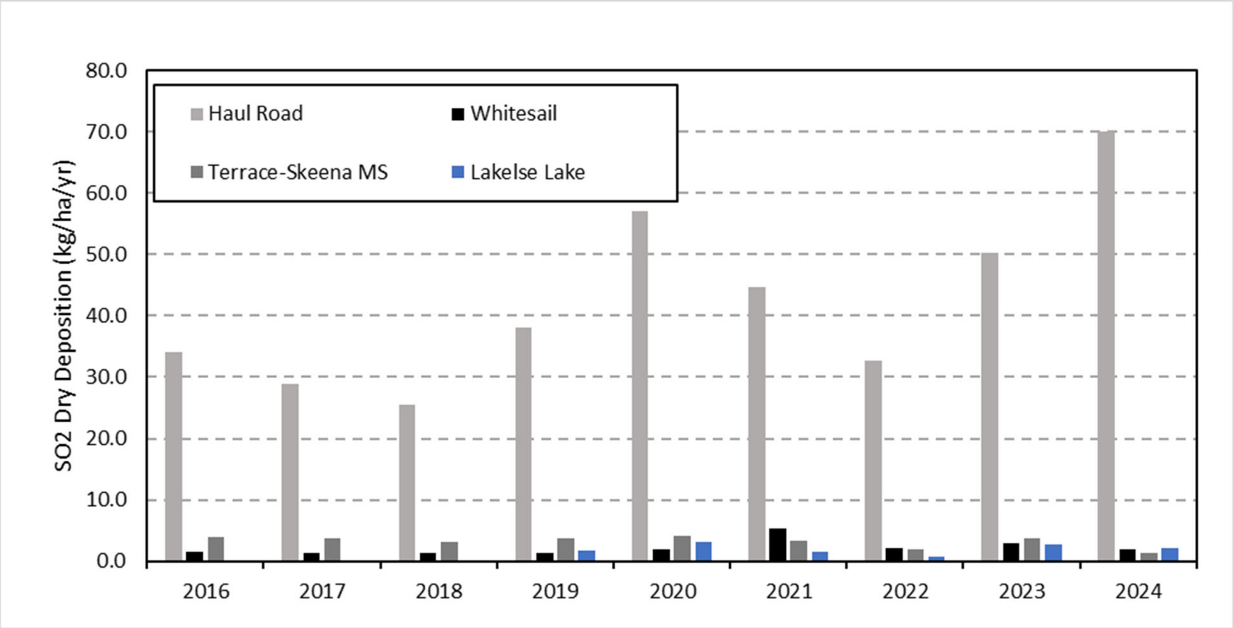


Figure 4-15. Annual SO_2 dry deposition mass 2016 – 2024.

Total mass of SO_2 dry deposition tended to be more heavily influenced by monitored SO_2 concentration at each site versus changes in SO_2 V_d. This difference in SO_2 concentrations is clearly the reason for elevated dry deposition mass at Haul Road compared to other sites. Similarly, dry deposition rates at all sites are higher in 2024 compared to 2022 due to the higher SO_2 concentrations and higher SO_2 emission rates from the smelter in 2024 compared to the low levels in2022. For this same reason, the 2024 dry deposition rates are mixed compared to 2023, following the relationship of SO_2 concentrations: Haul Road SO_2 concentration and dry S deposition rate are higher in 2024 compared to 2023, and other sites have slightly lower SO_2 concentrations and slightly lower dry S deposition in 2024 compared to 2024.

4.1.3.4 Total Sulphur Deposition

Figure 4-16 illustrates total mass of annual monitored wet deposition combined with modelled dry deposition at the Kitimat Haul Road location. Similar ratios of wet versus dry S deposition occur during each year from 2016 – 2023 at Haul Road.

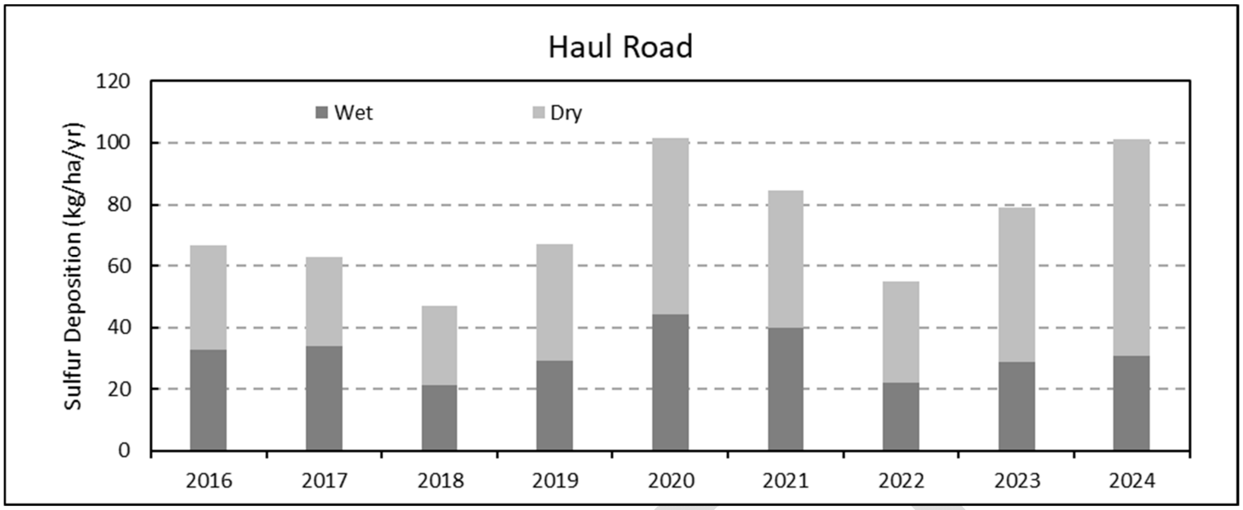


Figure 4-16. Haul Road wet and dry sulphur deposition annual total mass.

4.2 Human Health

B.C. ENV updated the province-wide interim SO_2 ambient air quality objective (IAAQO) in 2016, which became the SO_2 health KPI of the SO_2 EEM Program starting 2017. Starting January 1, 2020, the SO_2 health KPI implemented the SO_2 Canadian Ambient Air Quality Standards (CAAQS). In 2024, the CAAQS value was 70 ppb. In 2025 the CAAQS value changes to 65 ppb. The SO_2 health KPI is used to assess residential SO_2 ambient air quality. The SO_2 Health KPI for 2024 is a threshold for residential SO_2 ambient air concentration of 70 ppb and is evaluated through the following method as defined in the B.C. Air Quality Objectives:[14]

- *Achievement based on annual 99th percentile of daily 1-hour maximum (D1HM),*
- *averaged over three consecutive years,*
- *effective January 1, 2020;*
- *used to inform new air management decisions beginning January 1, 2017 and all air management decisions beginning January 1, 2020.*

Table 4-3 provides the KPI results for 2024, using the 3-year average of the 99th percentile of the D1HM for 2022 – 2024. The "Human Health KPI Calculations for 2024" memorandum is provided in Appendix B. The 2024 KPI calculation results for Kitamaat Village, Riverlodge, Whitesail, and Industrial Ave were all well below the KPI (CAAQS value of 70 ppb) and, as such, demonstrate attainment of the KPI.

Table 4-3. Calculation method and results for the SO_2 Health KPI in 2024.[a]

	99th percentile D1HM [b] SO_2 (ppb)			SO_2 Health KPI (ppb) (3-year average of 99th percentile D1HM[b])	KPI Attainment / Non-Attainment
Station	2022	2023	2024		
Kitamaat Village	9.8	21.2	22.6	17.9	Attainment
Riverlodge	9.9	27.3	24.6	20.6	Attainment
Whitesail	5.7	20.8	16.7	14.3	Attainment
Industrial Ave	18.6	40.0	38.5	32.4	Attainment

[a] Data for this table were extracted from the Envista database of B.C. ENV in March 2024. Verification of 2024 data by B.C. ENV was not confirmed as of the date of the download. Therefore, the 2024 datasets are *preliminary*.

[b] D1HM = Daily 1-hour average maximum.

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[14] BC air quality objectives (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/aqotable.pdf), footnote 18.

4.3 Terrestrial Ecosystems

This section contains a condensed summary of the major actions and knowledge gained in 2024 with respect to Terrestrial Ecosystems, including the Informative Indicators of soils, biodiversity and plant health.

For 2024, most Terrestrial Ecosystems subsections fall under the umbrella of the Vascular Plant and Cyanolichen Biodiversity Monitoring Program ("PCMP"). The PCMP plan was agreed to and finalized in November 2020 (Laurence et al., 2020), and the field manual to support its implementation finalized and agreed to in June 2021 (Coosemans and Laurence 2021), prior to commencing field activities. Terrestrial Ecosystems field activities scheduled for 2023 as part of the EEM Phase III included the following tasks:

- Complete first re-assessment of the ten sites in the Kitimat Valley that were originally assessed in 2021, and complete first assessment of one new site brought into the Program from the bank of alternate sites. Assessments include the following:
    - site characterization/assessment;
    - detailed vegetation assessments (low shrub and herb layers, as well as cyanolichens); and,
    - visual assessments of plant & cyanolichen health.
- Conduct additional reconnaissance to ensure, if required, a minimum of nine "alternate" sites (three in each deposition zone) are available in the Kitimat Valley.

PCMP monitoring for the Kitimat Valley sites is conducted using a 3-year rotating panel method: As of 2024, a total of 34 sites in the Kitimat Valley are monitored on this 3-year schedule (including the addition of site B36 to the Program this year, which brought the total number of active sites located in the Kitimat Valley up from 33 to 34. An additional two reference sites, assessed for the first time in 2022 in the Kemano Valley, are not part of the 3-year rotating panel and may be monitored on an *ad hoc* basis). The alternate sites are not assessed, but are available to the Program in case any of the active sites become unsuitable.

As of 2024, all 34 Kitimat Valley PCMP sites have now been assessed at least once, and ten of these sites have been assessed twice. Further detail on the 2024 assessments is provided in the following subsections, and in the *Vascular Plant and Cyanolichen Biodiversity Monitoring Program Fourth Annual Report: 2024 Field Season* (Coosemans and Schwarz 2024).

In accordance with the EEM schedule, no soil sampling was undertaken during 2024.

No notable deviations from the schedule of activities for 2024 were made.

4.3.1 Plant and Cyanolichen Biodiversity and Plant Health

Activities in 2023 centered around the continued implementation of the PCMP (begun in 2021), which replaces the vegetation component of the SO_2 EEM Program from previous years. In the 2019 Comprehensive Review (ESSA et al., 2020a), recommendations were made to transition vegetation sampling and analysis of western hemlock needles for S and assessment of visible injury to a more ecologically-based program designed to detect subtle changes in the occurrence and abundance of plants and cyanolichens. This recommendation was based on air dispersion modelling that showed air concentrations of SO_2 to be well below those that would cause visible injury to sensitive vegetation, and the lack of any such injury during the first phase of the SO_2 EEM Program. In addition, the concentrations of S (and fluoride) in western hemlock needles were at or near background concentrations reported in the scientific literature. For these reasons, emphasis was shifted to examining potential changes in biodiversity and health of plants and cyanolichens that might be mediated through long-term deposition of SO_4^{2-} and associated potential changes in soil chemistry.

Scheduled activities for the vegetation component of the SO_2 EEM Program in 2024 included the first re-assessment of ten PCMP field plots that were first assessed in 2021 (the first year of the PCMP), and the first assessment of a site brought into the active program from the bank of alternates, such that a total of eleven sites were assessed in 2024). Assessments were undertaken between June 28th and July 5th, 2024, and the analysis and presentation of results were completed for the end of December 2024 (Coosemans and Schwarz 2024).

In addition, following the site assessments, reconnaissance of two new alternate sites in the Kitimat Valley was undertaken. Two new alternate sites, A53 and A54, were located and added into the Program (note that they have not monumented with plot corners or center, and have not had detailed assessments nor soil sampling undertaken). As a result of the reconnaissance activities, the total number of alternate sites now integrated into the Program is currently eleven, and thus exceeds the minimum number of alternate sites required for the Program: Of these, five are classified in the Low Deposition Zone, three are in the Medium, and three are in the High Deposition Zone.

Field work undertaken at each of the eleven sites assessed in 2024 included documentation of site characteristics, abundance measures of all low shrub and herb species, abundance measures of cyanolichens (including new trial measures added to the Program in 2024), vegetation health inspections, and cyanolichen health inspections. All site assessments were undertaken between June 28 and July 5 in 2024.

4.3.1.1 Vascular plant and cyanolichen biodiversity monitoring

The PCMP was designed to detect potential changes in the biodiversity (patterns of species richness and abundance) trends of vascular plants in the low shrub and forb layers, and of cyanolichens, in natural coniferous forest ecosystems of the Kitimat Valley (including the Lakelse Watershed). The Program focuses on detecting mid- to long- term effects on plants and cyanolichens associated with acidification due to emissions of SO_2 from Rio Tinto BC Works. As such, initial differences between vegetation and cyanolichen biodiversity between sites are expected—the data collected from plots are not "baseline," but simply "initial." Data from each site that has been remeasured is compared with itself (year-to-year comparisons) to determine if differential changes correlating with deposition zone (i.e., non-parallel trends) are occurring over the mid- to long- term, potentially shifting biodiversity or altering community structure.

The Program was implemented very much as planned in the field session of 2024, with no notable deviations. Details of cumulative adjustments to the PCMP can be found in Coosemans and Schwarz (2024).

4.3.1.1.1 Vascular plant biodiversity

Initial trend data were analysed for all remeasured sites, with a close focus on those species identified as acid-sensitive and/or culturally important. While there were, as expected, changes and variations in species diversity at sites between years, there was no evidence of any common trend or differential trend for any species or species group, meaning that there was no statistical indication that any species or species group assessed is *generally* increasing or decreasing in the Kitimat Valley over the 3-year monitoring period, nor that any species or species group is *differentially* increasing or decreasing in relation to deposition class.

Diversity profiles provide another means of examining biodiversity across a continuum of diversity measures (i.e., richness and abundance) and indices, and were introduced into Program reporting in 2023. These profiles are presented as a set of graphs for each site re-assessed in 2024 (see Figure 4-17 and Figure 4-18). In interpreting diversity profiles, note that the far left of the profile (scale 0) shows relative species richness, and that with increasing values of q (the x-axis), the effective number of species becomes increasingly dominated by common species. Parallel profiles have equivalent evenness; a diversity profile that remains above another across the whole profile is more diverse. Diversity profiles that cross one another cannot be ranked in terms of diversity, but one can draw conclusions as to whether richness or evenness are higher for one compared with another.

For 2024, diversity profiles are presented in Figure 4-17 and Figure 4-18 for the ten remeasured sites, both for transect-based data and for whole-plot abundance data, respectively (i.e., data are presented for both methods we use to measure diversity at the sites). While we note that transect and/or whole plot abundance data in B04 and in B26 do show notable differences between the years, in both these cases, the differences appear to be attributable to artefacts related to low abundance and/or inherent sample variability between years. From the figures, we see that, for both transect-based and whole plot diversity measures, the sites generally do not show notable change between the diversity profiles for the two years of measurement (2021 and 2024). Again, this supports conclusions above that there is, as of yet, no evidence of common trends nor differential trends in biodiversity measures over the three-year period at sites that have been remeasured.

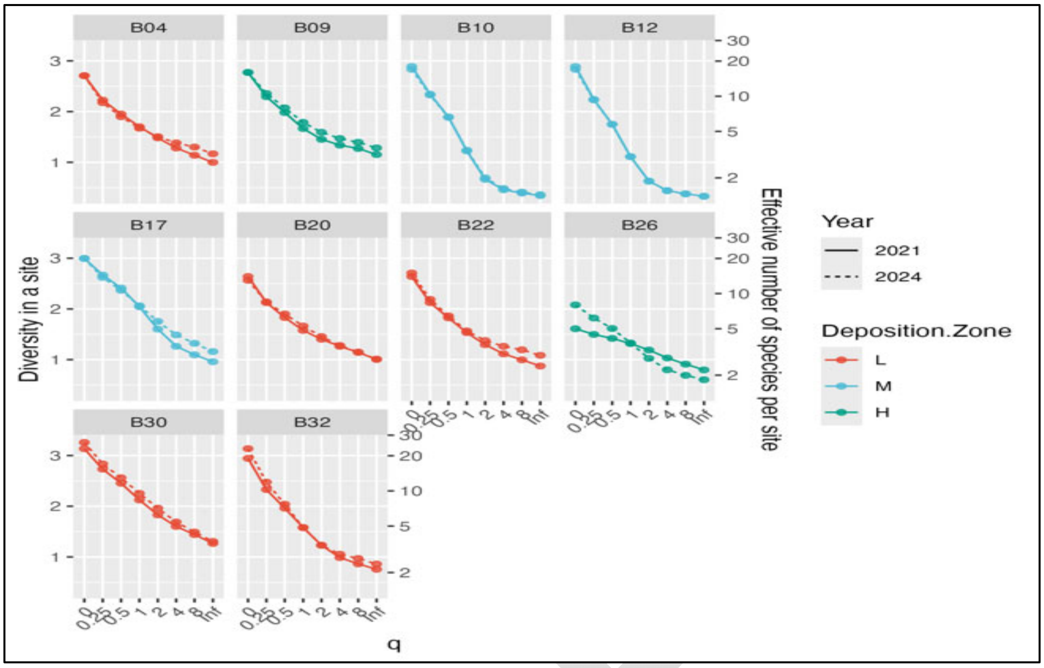


Figure 4-17: Diversity profiles from whole-plot abundance data for 2021 and 2024.

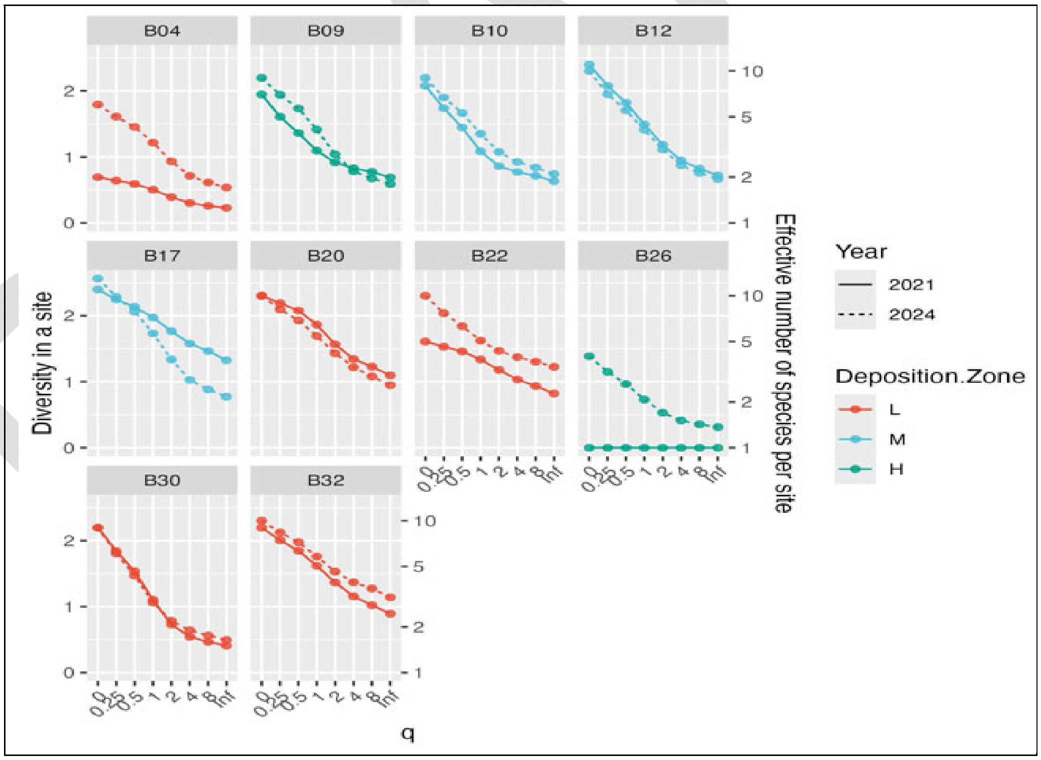


Figure 4-18: Diversity profiles from whole-plot abundance data for 2021 and 2024.

4.3.1.1.2 *Cyanolichen biodiversity*

While 2024 represented the fourth year of the Program—and the first PCMP remeasurement year—similar assessments were undertaken by Patrick Williston in 2016/2017, and repeated in 2020 (Williston 2020) at or near many of the cyanolichen plots undertaken during the 2024 PCMP assessments. Although not strictly comparable as methods were less limiting and locations were not precisely the same, the data are, nonetheless, informative. Table 4-4 summarizes cyanolichen species richness at all plots assessed in 2024 as part of the PCMP, including Willison's 2016/17 and 2020 counts, and our own data from 2021. As expected, these data generally show that cyanolichen diversity is inversely proportional to increasing deposition zone (largely as an historical artifact of fluoride emissions); however, the data also demonstrate the stochastic nature of this metric. Interestingly, we found high cyanolichen richness at Site B36 (see Table 4-4), currently classified as a High deposition location found at the approximate boundary between High and Medium zones: This location seems to represent a microsite "hotspot" that could be related to a variety of current and/or historical factors, but is certainly both informative and interesting that this diversity of cyanolichens was observed at this location.

Table 4-4. Cyanolichen richness recorded at assessed sites 2016-2023. Text is colour-coded for Deposition Zone: Green = Low; Orange = Medium; and Red = High.

Site	Cyanolichen richness 2016/17[1]	Cyanolichen richness 2020[1]	Cyanolichen richness 2021 PCMP	Cyanolichen richness 2024 PCMP
B04	6	7	6	4[3]
B09	0	0	0	0
B10	4	4	5	5
B12[2]	2	2	4	1[3]
B17	0	0	0	1[3]
B20	10	6	10	7[3]
B22	5	2	2	7[3]
B26	0	0	0	0
B30	6	10	4	6
B32	2	2	0	1
B36	N/a	N/a	N/a	11[4]

[1] From Williston (2020); [2] B12 was moved from the original ENV plot to another area in the same stand; [3] additional cyanolichen species on non-countable substrates were also observed (but not counted here) at sites B04, B12 & B20 in 2024; [4] this number represents the sum of cyanolichens visible with the naked eye and use of a hand lens during field study, though we note that an additional cyanolichen (found on a collected voucher twig), was only visible using a microscope in an office setting: specimens that were not visible in the field are noted but not included in the count.

Available metrics for comparing relative abundance for cyanolichens in the PCMP has been limited to a coarse measure of species tallies and their associated relative abundance rating categories (based on the number of individuals or colonies detected per plot) for species that occurred *inside plot boundaries* (note that lichen search areas may extend outside plot boundaries to contribute to species richness information through the 1-hour timed search, but abundances are noted only *within* the site boundaries). Note that no slopes can be calculated for these data. In 2024, we began trialing two additional abundance measures, which we anticipate will enable more effective analysis of biodiversity in future years, when it has been used at least on two occasions at any given site.

In the meantime, the species tallies/abundance rating metric has been used to compare across remeasurement sites in 2024, and included ten species over a total of seven sites (Table 4-4 and

Table 4-5. Comparison of cyanolichen tallies and abundance ratings inside plots between 2021 and 2024, by species.; three sites had zero cyanolichen occurrences *inside plot boundaries* in both 2021 and 2024): Although cyanolichen relative abundances decreased *within* plot boundaries between 2021 and 2024 at Medium deposition sites, the very small sample size (a total of five species in two sites could be compared across years), and the high variability noted in Low deposition sites (where an additional six (for a total of ten) species in five sites could be compared across years; note that there were no High deposition sites with cyanolichens observed inside plot boundaries), there is no evidence of differential trends among deposition classes at this time.

Table 4-5. Comparison of cyanolichen tallies and abundance ratings inside plots between 2021 and 2024, by species.

Site	Species Code	Tally Inside Plot (individuals or colonies)			Abundance Rating Inside Plot		
		2021	2024	Change?	2021	2024	Change?
B04	LOBALIN	>15	10	Decrease	3	3	No
B12	LOBALIN	2	0	Decrease	1	0	Decrease
B22	LOBALIN	3	0	Decrease	2	0	Decrease
B30	LOBALIN	>15	30	No	3	3	No
B04	LOBAORE	1	20	Increase	1	3	Increase
B10	LOBAORE	4	0	Decrease	2	0	Decrease
B12	LOBAORE	1	0	Decrease	1	0	Decrease
B20	LOBAORE	4	5	Increase	2	2	No
B30	LOBAORE	>15	10	Decrease	3	3	No
B22	LOBAPUL	0	2	Increase	0	1	Increase
B04	NEPHBEL	10	5	Decrease	2	2	No
B10	NEPHBEL	8	0	Decrease	1	0	Decrease
B30	NEPHBEL	>15	1	Decrease	3	1	Decrease
B04	NEPHHEL2	>15	5	Decrease	3	2	Decrease
B10	NEPHHEL2	4	0	Decrease	1	0	Decrease
B30	NEPHHEL2	>15	1	Decrease	3	1	Decrease
B30	NEPHPAR	0	2	Increase	0	1	Increase
B20	NEPHRES	1	0	Decrease	1	0	Decrease
B32	PELTBRI	1	1	No	1	1	No
B04	PSEUANO	1	0	Decrease	1	0	Decrease
B04	STICFUL	1	0	Decrease	1	0	Decrease
B30	STICFUL	0	2	Increase	0	1	Increase

4.3.1.2 Vascular plant and cyanolichen biodiversity monitoring

2020 was the final year of the previous VMP, wherein the health of vegetation at 23 sites in the vicinity of the smelter was assessed. Visual assessment of plant health continues to be an important activity in the Terrestrial Ecosystem Line of Evidence. New protocols were developed as part of the program design to assure that the assessment of plant health continues—and now also includes cyanolichens. The methods are described in Coosemans and Laurence (2021). Since 2021, vegetation health is now primarily monitored through visual inspection of vegetation and cyanolichens at PCMP sites whenever each is assessed (typically on a three-year, rotating basis). In 2024, the eleven assessed sites were visually inspected between June 28th and July 5th, as part of the PCMP field activities.

All vegetation—and particularly plants of cultural importance, low shrubs and herbaceous species—is examined within sites and in their immediate vicinity during each assessment. Plants at the PCMP sites are assessed for symptoms of insect infestation, plant disease, and abiotic factors such as drought, frost, mechanical injury, and air pollutants. With respect to cyanolichen health, assessors examine specimens noting whether they appear Normal, Stressed or Injured in terms of visibly reduced growth (relative to typical for the region); changes in morphology; colour (e.g., signs of bleaching); or presence of necrotic tissue.

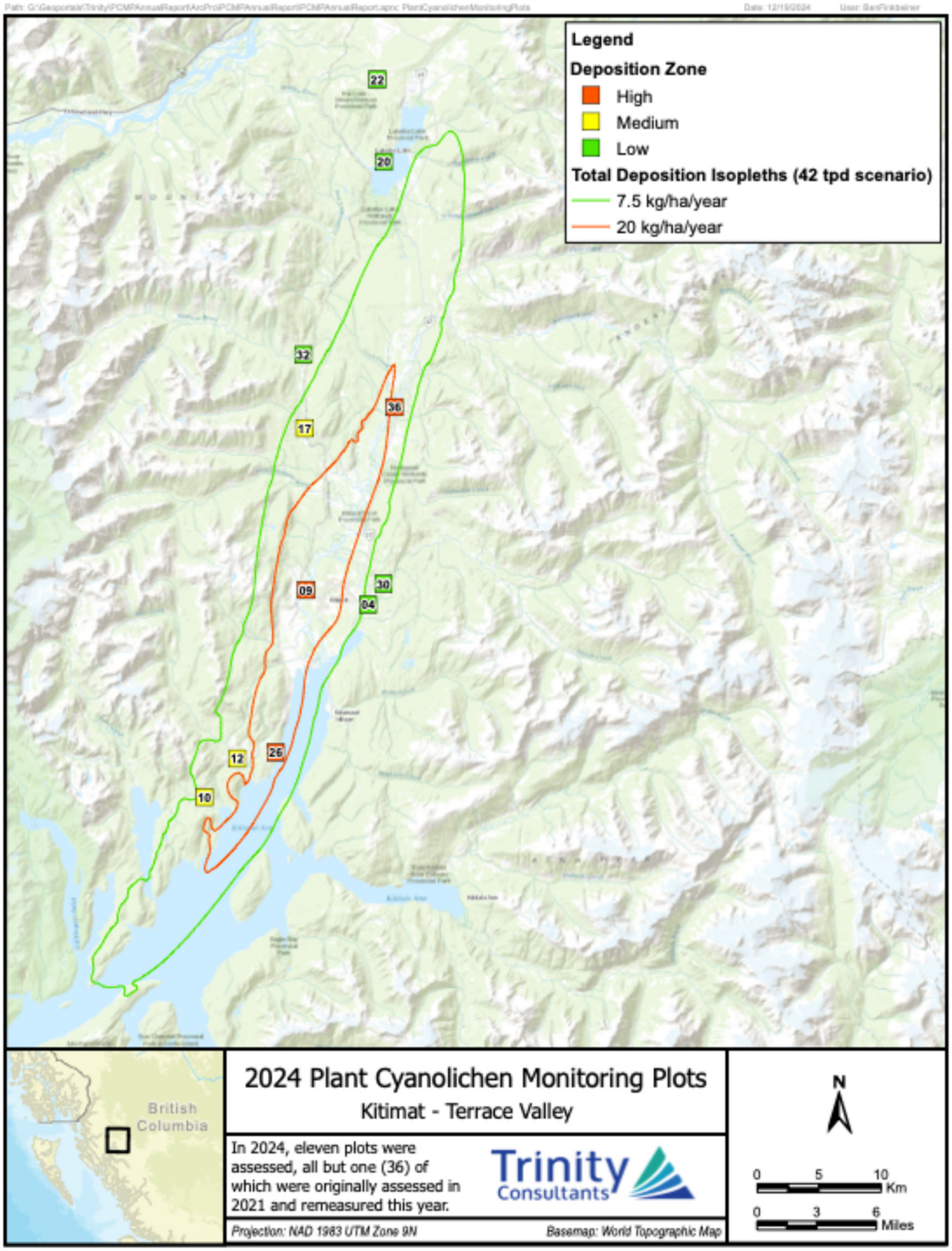
As part of the context for health assessments, weather patterns leading up to—and through—the growing season of each given year is considered: The study area experienced relatively normal temperatures, but drier than normal weather during the growing period months up to and including the plant health assessment period; additionally, precipitation levels were in a significant deficit prior to the growing period (2023 ended with a deficit of 157mm (~12%) compared with its normal total precipitation, and the deficit in the first six months of 2024 leading into the PCMP assessment period was an additional 264mm). For the growing season as a whole, dry conditions prevailed, and temperatures were elevated from 1.0 – 1.9 °C for the remainder of the growing season (July-September) following the assessments. (Government of Canada 2024a & 2024b: Kitimat and Terrace area weather station data and their historical averages, respectively). While the timing of the field program is aimed to minimize weather (and climate) impacts, some effects may still negatively impact vegetation and lichens, as described in the following paragraphs.

In 2024, vegetation generally appeared to be generally healthy/thriving, with relatively limited insect feeding activity and a low incidence of fungal pathogens across the region at the time of assessment. Notable at most sites were impacts from a late-season frost, which damaged or killed shrubs, and also potentially impacted herbaceous species. The impacts of extended dry conditions were also noted at some sites, including impacts on cyanolichens.

In 2024, only one lichen species at one site was identified as stressed: *Peltigera brittanica* at B32 (a Low deposition site) appeared in poor health, dry and of low vigour. The impacts of extended dry conditions were noted for cyanolichens at two additional sites (B10 & B22; Medium & Low deposition sites, respectively), but the specimens were otherwise considered healthy at these locations and at all other PCMP sites where cyanolichens were encountered in 2024.

No symptoms of visible chemical injury (e.g., due to either gaseous fluoride or sulphur dioxide) were noted in plants or cyanolichens at any of the plots in 2024, nor were any noted at plots in the previous three years of the PCMP.

There did not appear to be patterns or substantial differences in the degree of insect feeding or the incidence and severity of plant diseases related to the location of the sites in relation to deposition zones, and the level of insect activity and plant diseases appeared typical for the region. Similarly, effects of drought, frost or other weather-related conditions did not appear related to the location of sites in relation to deposition, and appeared typical in comparison with other locations in the region. Vegetation and cyanolichens have shown no health or injury patterns across the sites of the PCMP in 2024 or in previous years of the Program.



In 2024, eleven plots were assessed, all but one (36) of which were originally assessed in 2021 and remeasured this year.

Figure 4-19. Map showing sites assessed during 2024 in relation to modeled sulphate Deposition Zones (note that isopleths are based on the 2016-2018 meteorological year average).

4.3.2 Soils - Content under development

4.4 Aquatic Ecosystems (Lakes, Streams and Aquatic Biota)

This section contains a condensed summary of the major actions and knowledge gained in 2024 with respect to the Aquatic Ecosystems receptor. Further detail can be found in the Aquatic Ecosystems Actions and Analyses Technical Memo W13 (provided in Appendix C) and the Technical Report of Lake Monitoring in 2024 (provided in Appendix D).

4.4.1 Major Actions Taken in 2023

The Phase III EEM 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 Kitimat Airshed Emissions Effects Assessment (ESSA et al., 2014). Sampling of these eleven EEM lakes was conducted in accordance with the EEM Phase III Plan.

LAK027 was added for one-time sampling in 2021, as agreed to by B.C. ENV and Rio Tinto in May 2021. The intent was to resample one of the Sulphur Dioxide Technical Assessment Report (STAR) (ESSA et al., 2013) 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 already included in the SO$_2$ EEM Program because of its sensitivity). LAK027 was sampled again in 2022, 2023, and 2024, as per rationale summed up in the following recommendation from the SO$_2$ EEM Program 2023 EEM Annual Report: "*We recommend sampling LAK027 again in 2024. 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 negated the ability to provide the intended comparison. In 2023, the region was again subject to anomalous conditions (i.e., exceptionally dry conditions and substantial increase in emissions from a greatly reduced level during 2022). LAK027 does not show any evidence of acidification. With another year, we will have sampling across four different types of years and should be able to make a more robust confirmation of that conclusion*".

We examined the empirical changes in water chemistry between the pre-KMP baseline (2012) and the last three years (2022-2024, representing the current averaging period), especially with respect to the KPI thresholds (Table 4-7). We also conducted statistical analyses on the changes between these two periods, repeating two sets of analyses applied in (and since) the 2019 Comprehensive Review (ESSA et al., 2020a) with the more recent years of data: 1) the Bayesian "Method 1" to assess the % belief that any of the lakes had exceeded their KPI or informative indicator thresholds; and 2) the "Method 3" before-after control-impact (BACI) analyses of the differential trends between the sensitive EEM lakes (individually and as a group) and the control lakes for the same four metrics.

Finally, we applied the simplified evidentiary framework with the results from the Bayesian statistical analyses, as per previous years. The current version of the evidentiary framework was developed in 2020 to more fully align with the two-threshold structure of the KPI and acidification informative indicators in the EEM Phase III Plan. The revision and rationale with respect to the version from the 2019 Comprehensive Review are described in Section 2.6 of Technical Memo W09.

4.4.2 Knowledge Gained from Actions taken in 2024

4.4.2.1 Annual Context – Hydrology and Emissions

Precipitation / Hydrologic Context

This year we continued to use data from the two NADP stations (Haul Road, BC22; Lakelse Lake, BC23) to provide the precipitation context (and by proxy, the hydrologic context of the lakes) for 2024. With respect to the timing of sampling, 2024 was significantly wetter than 2023 but not exceptionally wet with respect to the five-year average. The cumulative precipitation for August–September[15] was approximately triple that of 2023 (287% for Haul Road and 313% for Lakelse Lake). However, relative to the 2019–2023 average, total August–September precipitation in 2024 was only slightly higher at Haul Road (110%) and moderately higher at Lakelse Lake (136%). Although the cumulative precipitation through to the end of October was similar to the exceptionally wet conditions recorded in 2021, the August-September levels were notably lower than 2021 conditions (69% for Haul Road and 76% for Lakelse Lake).

Emissions Context

As reported in previous years' Annual Reports, average daily smelter emissions declined moderately from 2019 to 2020 (30.2 to 24.2 tpd), then significantly in the latter half of 2021 (down to 5 tpd for Aug-Dec 2021), remained low through 2022 (7.4 tpd), and then increased through 2023 (average of 25.8 tpd). In 2024, average emissions (30.5 tpd) were 18% higher than in 2023, and similar to emissions during 2017-2019 (29.7-30.6 tpd). The 12- and 6-month average emissions at the time of fall sampling in 2024 (30.7 and 30.5 tpd, respectively) also were within the range observed in 2017-2019. The moderate one-year increase in emissions might influence lake chemistry but we do not expect the emissions in 2024 to contribute to any major changes in lake chemistry data (unlike the major fluctuations in emissions observed over 2020-2023).

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[15] Cumulative precipitation in August and September is used as an indicator of the hydrologic conditions relevant to the lake chemistry at the time of sampling because September 28th was the date that all of the lakes were sampled and those with repeat samples during the fall index period were sampled between September 24th and October 17th. The August-September total thus approximates the precipitation conditions in the two months prior to sampling.

4.4.2.2 Empirical Changes in Water Chemistry

Empirical changes in CBANC, pH, Gran ANC, SO_4^{2-}, DOC, sum of base cations, chloride, and calcium are shown in Table 4-7. Changes are reported in terms of the difference between the current post-KMP averaging period (2021-2023) 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.

The mean values of CBANC for the post-KMP averaging period indicate that there have been no exceedances of the KPI thresholds (Table 4-8). However, the formal analysis of the KPI is done with the results of the Bayesian statistical analyses.

To protect aquatic ecosystems in the sensitive lakes, we want to avoid declines in current measurements of CBANC, Gran ANC, BCS, and pH (i.e., the KPI and other acidification informative indicators) that are greater than the established thresholds (Table 4-8), using 2012 as a pre-KMP baseline. We use the average of the most recent 3 years to dampen the effects of an unusual year.

Five of the seven sensitive lakes show increases in CBANC since the 2012 baseline (Table 4-7). LAK012 and LAK028 continue to be the only two lakes that show a long-term decline in CBANC (-15.3 μeq/L in LAK012, and -11.7 μeq/L in LAK028). For context, the lake-specific *change limit* threshold for ANC in LAK012 is -16.3 μeq/L, though the mean CBANC over the last 3 years (99.1 μeq/L) is well above the *level of protection* threshold (20 μeq/L). For LAK028, the magnitude of CBANC decline has increased significantly (from -0.7 μeq/L to -11.7 for the current year); these changes are less than the *change limit* threshold ANC for LAK028 of -13.4 μeq/L and the current mean CBANC (4.3 μeq/L) is considerably lower than the *level of protection* threshold (20 μeq/L) and the 2012 baseline (16.0 μeq/L). LAK012 and LAK028 also continue to be the only two sensitive lakes with a long-term decline in BCS. The declines in BCS for LAK012 (-16.9 μeq/L) and LAK028 (-16.5 μeq/L) are greater in magnitude than the previous three years.

LAK012 shows a mix of responses. There have been declines in CBANC and BCS, but a small long-term increase in Gran ANC (1.3 μeq/L, relative to an ANC *change limit* threshold of -16.3 μeq/L) and the second largest increase in pH across all EEM lakes (+0.4 pH units, relative to a pH *change limit* threshold of -0.3 pH units).

For LAK028—the lake closest to the smelter and subject to the highest deposition—the long-term decline in CBANC (-11.7 μeq/L) is driven by an exceptionally low 2024 value of -21.1 μeq/L. This marks the largest annual change recorded for the lake, with a decline of ~35 μeq/L since 2023. The ANC *change limit* threshold for LAK028 is -13.4 μeq/L. This decline stems from a large annual increase in SO_4^{2-} that exceeded the increase in total base cations (ΣBC*). The observed changes in ΣBC* and SO42- essentially explain the change in CBANC, a decline of -11.7 μeq/L. CBANC equals the sum of base cations minus the sum of strong acid anions, and ΔΣBC* - Δ[SO42-] = 54.0 – 64.9 = -10.9, very close to the -11.7 μeq/L change in CBANC. Additionally, Chloride increased by 68% (6.6 to 11.1 μeq/L), Gran ANC has had a long-term increase (+5.1 μeq/L), and mean pH remains stable (+0.1 pH units), consistent with recent years. BCS has declined by -16.5 μeq/L since the baseline, with the 2024 value (-52.0 μeq/L) representing the lowest on record, surpassing the previous low from 2013 (-40.2 μeq/L). This exceeds the BCS *change limit* threshold of -13 μeq/L. The empirical analyses thus show that LAK028 has exceeded the change limit threshold for BCS in addition to having been predominantly below the level of protection threshold – therefore empirical results show that LAK028 exceeds the thresholds for the BCS informative indicator.

None of the sensitive or less sensitive lakes are showing any decline in pH. LAK022, which in the prior two EEM reports had been the only lake with a decline in pH, now shows no long-term change. All other sensitive and less sensitive lakes show a long-term increase in pH within the range of 0.1 to 0.4 pH units. By contrast, two of the control lakes (DCAS14A and NC194) show a long-term decline (-0.2 pH units) with the third control showing no change (NC184). The causes for the 0.2 pH unit declines in DCAS14A and NC194 are not clear, but they are not related to SO_2 emissions, since [SO_4] has declined slightly in all three control lakes (Table 4-7) and there is no statistical evidence of a long-term increase in [SO_4] (Table 4-7).

For the CBANC KPI, only 2 of the 7 sensitive lakes (LAK028 and LAK044) have values for the current averaging period 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 their *change limit* threshold (LAK028 shows a decrease of -11.7 μeq/L; LAK044 shows an increase of +8.5 μeq/L). None of the 7 sensitive lakes exceeded the *change limit* threshold and only two lakes (LAK012 and LAK028) show long-term decreases in CBANC. In the sensitivity analyses with the alternate, transition period baseline (2012-2014), LAK012 and LAK028 are also the only lakes with an estimated long-term decrease in CBANC (-4.8 μeq/L and -8.7 μeq/L, respectively). The empirical data therefore suggest that none of the lakes exceeded the KPI, though the statistical analyses are the key determinant of our conclusions.

For the pH informative indicator, 4 of the 7 sensitive lakes (LAK023, LAK028, LAK042, and LAK044) have values for the current averaging period below the *level of protection* threshold (pH 6.0). As described in the STAR (section 9.4.1.2.4), all 7 sensitive lakes were already below pH 6.0 in 2012, reflecting primarily the influence of organic acids and in some cases the effects of historical smelter emissions (particularly in LAK028). Four of the lakes have been at or below pH 6.0 throughout the entire period of record. None of the sensitive lakes show any decrease in pH relative to 2012 and therefore none have exceeded the *change limit* threshold. In the sensitivity analyses with the alternate, transition period baseline (2012-2014), both LAK022 and LAK028 show decreases of ~0.1 pH units, LAK044 shows no change, and the other 4 sensitive lakes show increases. The empirical data therefore indicate that none of the lakes have exceeded the pH informative indicator.

Resampling of LAK027

The results for LAK027 are shown in Table 3-6 in Technical Memo W13. We examined the changes between the values measured in the STAR in 2012 and those observed in 2024 as well as the average of the past three years, as consistent with the approach used for the EEM lakes.

When using the 3-year averaging period, the results show that all of the lake chemistry metrics except pH increased. CBANC, Gran ANC and BCS show levels that are 161%, 178%, and 148% of their 2012 levels, respectively, and are at levels that we would likely no longer classify as “moderately sensitive”. The data show that pH decreased by 0.1 pH units. Focusing just on the

CBANC (as the KPI), the results show that CBANC is higher than 2012 for every potential combination of the recent four years of sampling (except for 2021 that showed a moderate decline during an exceptionally wet year that many lakes had moderate to large decreases in CBANC). The current averaging period has a CBANC of 163 µeq/L, which represents an increase of 62 µeq/L.

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Table 4-6. Empirical changes in CBANC, Gran ANC, BCS, pH, SO_4^{2-}, DOC, base cations, chloride, and calcium for EEM lakes. These values represent the difference between the current averaging period (2022-2024) 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 values in 2020 onwards imputed from the values measured by the BASL laboratory (“integ”); see details in Section 2.1 of Technical Memo W12). Signs after each number show the direction of change in the reported values since the SO_2 EEM Program 2023 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	17.1 [-]	9.7 [-]	15.7 [ ]	0.3 [+]	3.7 [+]	0.3 [-]	20.9 [-]	0.2 [-]	10.5 [-]
LAK012	-15.3 [-]	1.3 [-]	-16.9 [-]	0.4 [ ]	4.7 [-]	0.3 [-]	-10.4 [-]	2.1 [+]	-11.1 [-]
LAK022	7.7 [+]	2.3 [+]	4.9 [-]	0.1 [+]	9.3 [+]	0.6 [-]	17.1 [+]	1.0 [+]	9.5 [+]
LAK023	6.0 [-]	1.9 [-]	2.1 [-]	0.2 [ ]	1.1 [+]	0.8 [-]	7.4 [-]	0.8 [+]	4.8 [-]
LAK028	-11.7 [-]	5.1 [-]	-16.5 [-]	0.1 [ ]	64.9 [+]	1.0 [-]	54.0 [+]	2.2 [+]	37.2 [+]
LAK042	9.9 [-]	30.5 [+]	25.6 [+]	0.6 [+]	1.5 [+]	-3.1 [-]	11.5 [-]	0.0 [+]	5.8 [-]
LAK044	8.5 [-]	4.5 [ ]	8.0 [ ]	0.2 [ ]	-2.9 [-]	0.1 [-]	5.7 [-]	0.6 [+]	1.4 [-]
Total ↑	**5**	**7**	**5**	**7**	**6**	**6**	**6**	**7**	**6**
Total ↓	**2**	**0**	**2**	**0**	**1**	**1**	**1**	**0**	**1**
LAK016	6.7 [-]	17.7 [-]	3.7 [+]	0.1 [ ]	12.8 [+]	0.6 [-]	20.4 [+]	1.8 [+]	11.5 [+]
Total ↑	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Total ↓	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
DCAS14A	23.3 [-]	8.3 [+]	23.9 [+]	-0.1 [+]	0.8 [+]	-0.1 [-]	20.5 [+]	-2.2 [+]	14.2 [+]
NC184	12.6 [+]	17.9 [+]	23.2 [+]	0.2 [+]	-0.9 [+]	-2.1 [-]	11.6 [+]	-4.5 [+]	11.3 [+]
NC194	4.0 [+]	-2.2 [-]	3.1 [+]	-0.2 [ ]	-1.6 [+]	0.2 [ ]	2.5 [+]	-1.4 [+]	2 [+]
Total ↑	**3**	**2**	**3**	**1**	**1**	**1**	**3**	**0**	**3**
Total ↓	**0**	**1**	**0**	**2**	**2**	**2**	**0**	**3**	**0**

4.4.2.3 Statistical Analyses of Changes in Water Chemistry

We have summarized the key results of the statistical analyses of changes in lake chemistry in Table 4-7 and Figure 4-20. These results applied Bayesian Method 1, described in Appendix F of the 2019 Comprehensive Review (ESSA et al., 2020b).

We evaluated the KPI and the informative indicators using the two-threshold structure (Table 4-2 in Technical Memo W12). **None of the 11 EEM lakes have a high % belief in exceedance of either the KPI or any of the informative indicators.** LAK028 has a moderate % belief in exceedance of the KPI and all the other EEM lakes show a low % belief in exceedance of the CBANC KPI. One sensitive EEM lake and one control lake show moderate % belief of one or two of the informative indicators:

- LAK028 shows moderate % belief in exceedance of BCS
- NC184 shows moderate % belief in exceedance of pH

The results of the Bayesian statistical analyses are generally similar to our previous report, but have fewer moderate classifications than recent years (3 in 2024, 4 in 2023, and 8 in 2022). The only changes in classification (across all lakes and metrics) from last year are the changes from low to moderate for CBANC in LAK028 and from moderate to low for pH in LAK022 and Gran ANC in NC184. All other results are the same as last year in terms of final classification.

This is now the fifth year that the Bayesian analyses were performed on CBANC. Despite the widespread changes in numerous water chemistry metrics observed in 2021-2023 due to anomalous hydrologic and emissions conditions, the CBANC results remain remarkably similar to the 2020 results for almost all of the lakes, suggesting that the CBANC metric may be robust to anomalous conditions. The exception is LAK028, where the results have changed notably in response to the drop in CBANC in 2024 discussed earlier as part of empirical changes.

This is the sixth 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. The results have remained very stable over these six years. For Gran ANC, there are only two of eleven lakes that have showed any change in category over the six years of repeating the analyses: LAK022 and NC194 changed from low to moderate, albeit still at the low end of the moderate range (~30% belief), and LAK022 has returned to low again in 2023. For pH, 2 sensitive lakes, 1 less sensitive lake, and all 3 control lakes changed categories – from low to moderate in all cases. In all cases, the shift occurred with the 2021 results (likely driven by high precipitation in September 2021[16]) and the 2022 results remained quite similar. LAK042 and LAK016, which were only in the low end of the moderate category for pH change, have returned to low in 2023. LAK022, DCAS14A, NC184, and NC194 are in the lower-mid-range of the moderate category. Decreases in pH in the control lakes must be driven by factors other than the smelter

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[16] 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

because they are well outside the deposition plume, and all three control lakes have a low percent belief in any sulphate increase.

This is the seventh 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. The results have generally remained very stable over these six years with one notable pattern observed in multiple lakes. All of the lakes that changed from low to moderate experienced that change in 2021, an exceptionally wet year with pronounced declines in ANC and pH across all lakes. In many cases, those lakes returned to low or at least showed a step decrease with moderate in 2024, which was when the 2021 values were dropped from the current averaging period. In a few cases that shift back to low occurred after only two years.

The key outcomes from the BACI (before-after control-impact) analyses include:

- For Gran ANC, BCS, and pH (i.e., all four primary metrics analyzed) 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)
- With respect to the direction of the BACI effects (i.e., changes in the sensitive lakes versus changes in the control lakes):
    - For CBANC, changes were more negative for all sensitive lakes except LAK006
    - For pH, changes were more positive for all sensitive lakes except LAK028 (similar)
    - For Gran ANC and BCS, changes were predominantly more negative for the sensitive EEM lakes[17]
    - However, none of these differences were statistically significant
- When analysed as a group with all seven sensitive EEM lakes combined:
    - Changes in CBANC, Gran ANC, BCS, and pH were not statistically significant

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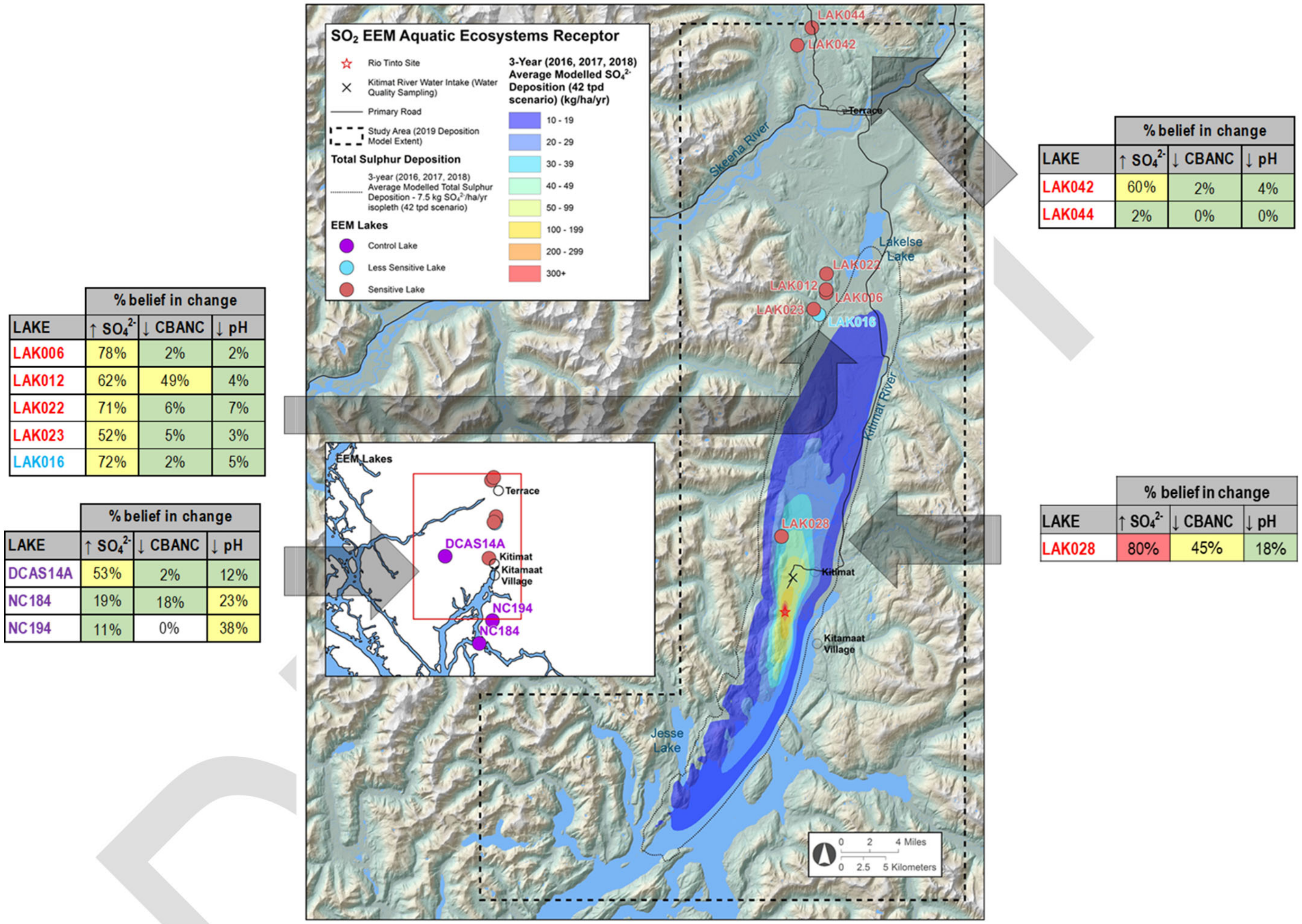
[17] When analyzed as individual lakes, 5 of 7 sensitive EEM lakes showed changes that were more negative than the controls, but when analyzed as a group the direction was more positive than the controls, due to the influence of one lake with a positive direction having an BACI estimate of much greater magnitude than the rest. However, none of the results were statistically significant.

Table 4-7. 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.

	Changes in SO_4	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 protection* 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)**
Thresholds	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	78%	2%	2%	1%	2%	0%	0%	0%	11%	LOW	LOW	LOW	LOW
LAK012	62%	49%	18%	64%	4%	0%	0%	0%	18%	LOW	LOW	LOW	LOW
LAK022	71%	6%	14%	9%	7%	0%	51%	0%	27%	LOW	LOW	LOW	LOW
LAK023	52%	5%	4%	6%	3%	0%	100%	0%	98%	LOW	LOW	LOW	LOW
LAK028	80%	45%	12%	50%	18%	100%	100%	100%	100%	MOD	LOW	MOD	LOW
LAK042	60%	2%	1%	2%	4%	0%	100%	1%	100%	LOW	LOW	LOW	LOW
LAK044	2%	0%	1%	0%	0%	100%	100%	0%	100%	LOW	LOW	LOW	LOW
LAK016	72%	2%	4%	8%	5%	0%	0%	0%	0%	LOW	LOW	LOW	LOW
DCAS14A	53%	2%	1%	2%	12%	0%	0%	0%	0%	LOW	LOW	LOW	LOW
NC184	19%	18%	19%	18%	23%	0%	49%	0%	66%	LOW	LOW	LOW	MOD
NC194	11%	▨	▨	2%	38%	0%	100%	0%	0%	noRel	noRel	LOW	LOW



	% belief in change		
LAKE	↑ SO_4^{2-}	↓ CBANC	↓ pH
LAK006	78%	2%	2%
LAK012	62%	49%	4%
LAK022	71%	6%	7%
LAK023	52%	5%	3%
LAK016	72%	2%	5%

	% belief in change		
LAKE	↑ SO_4^{2-}	↓ CBANC	↓ pH
DCAS14A	53%	2%	12%
NC184	19%	18%	23%
NC194	11%	0%	38%

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

	% belief in change		
LAKE	↑ SO_4^{2-}	↓ CBANC	↓ pH
LAK028	80%	45%	18%

Figure 4-20. Spatial distribution of percent belief in chemical change from 2012 to 2022-2024. 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. **NC194 does not have an estimated ANC threshold because it did not have appropriate titration data available.**

4.4.2.4 Application of the Evidentiary Framework

We applied the evidentiary framework using the updated results of the statistical analyses (Figure 4-21; detailed results in Table 4-3 of Technical Memo W13). A lake may appear in different parts of the evidentiary framework depending on whether we use CBANC or pH as criteria (CBANC is the KPI and pH is an informative indicator). To be precautionary, we consider the lake's appropriate assignment to be the furthest position into the evidentiary framework. Results show that: a) 1 sensitive lake (LAK044) and all 3 control lakes[18] land within the first box, *"smelter not causally linked to changes in lake chemistry"*; b) 4 sensitive lake (LAK006, LAK012, LAK023, and LAK042) and 1 less sensitive lake (LAK016) land within the second box, *"lake is healthy, and not acidifying"*; and c) 2 sensitive lakes (LAK022 and LAK028) land within the third box, *"some evidence of acidification; closely monitor"*. The situation for the lakes landing in the third box is expanded upon below.

For LAK028, this classification is based on: a) values for the current averaging period below the *level of protection* for both CBANC and pH, and b) moderate support for a decline in CBANC (67% belief) and pH (43% belief), with moderate support for exceedance of the *change limit* threshold for CBANC (45% belief) and low support for exceedance of the *change limit* threshold for pH (18%). For CBANC, the overall result is the same as last year but the support for exceedance of the *change limit* threshold increased from low (6% belief) to moderate (45% belief), as driven by the low CBANC values observed in 2024. For pH, the overall result is the same as last year and the percent belief values for both any change in pH as well as exceedance of the *change limit* threshold are very similar.

For LAK022, this classification is based on pH only. LAK022 shows: a) a moderate belief in exceeding the *level of protection* for pH (27% belief), and b) moderate support for declines in pH (26% belief), with low support for exceedance of the *change limit* threshold (7% belief). Although this is the same overall result as last year, the level of support has declined notably – from 75% to 27% for exceedance of the *level of protection* threshold for pH (from the high end to the low end of the moderate range), from 50% to 26% for declines in pH, and from 32% to 7% for exceedance of the *change limit* threshold for pH. For CBANC, there continues to be a 0% belief in LAK022 being below the *level of protection*.

There are no lakes that have acidification exceedances.

The changes in lake classification from last year's Annual Report include four lakes that have "moved up" a step in the evidentiary framework. Three lakes (LAK006, LAK023, and LAK042) all moved from the yellow box to the second green box because of the support for a decline in pH decreasing from 21-24% belief to 9-11%. Those changes are not large in absolute terms but moved all three lakes from the very low end of the moderate range squarely into the middle of the low range. LAK012 remained in the same classification but changed to the earlier entry point for pH (which was already the case for CBANC) – i.e., from having moderate support (44% belief) for being below the *level of protection* threshold for pH but low support

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[18] 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. In both 2022 and 2023, all three control lakes showed a low percent belief in SO_4 changes since 2013.

for any decline in pH, to having low support (18% belief) in being below the *level of protection* threshold.

The only changes of >25% belief in the underlying results for the sensitive lakes were: a) for LAK028, the percent belief in exceeding the *change limit* for CBANC increased by 39%; b) for LAK022, the percent belief for exceeding the *level of protection* and *change limit* thresholds for pH decreased by 48% and 25%, respectively; and c) for LAK012, the percent belief for exceeding the *level of protection* for pH decreased by 26%. For control lake DCAS14A, the percent belief in an increase in sulphate increased by 37% and the percent belief in an exceedance of the *change limit* threshold decreased by 31%; however, all three control lakes are classified in the first box regardless of potential increase in sulphate because any such increases cannot be causally linked to the smelter due to their location well outside of the smelter plume.

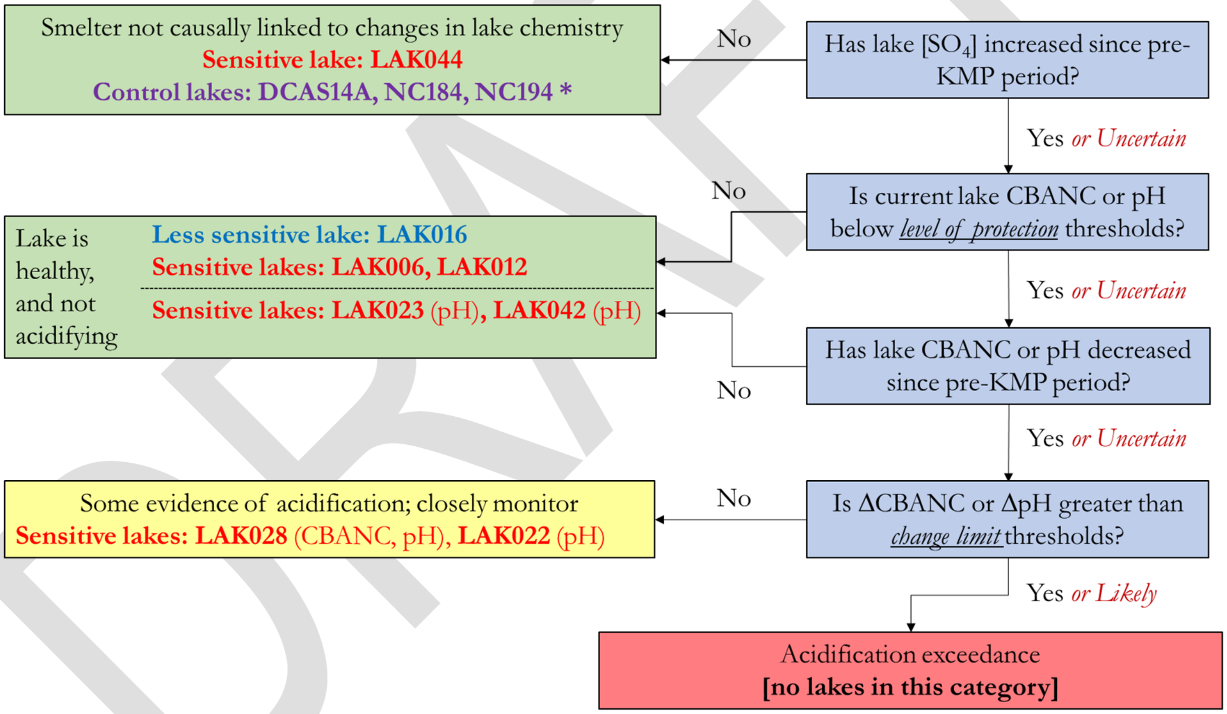


Figure 4-21. Classification of EEM lakes according to the simplified evidentiary framework. LAK028 has moderate support for declines in CBANC and pH but low support for exceeding either *change limit* threshold. LAK006, LAK022, LAK023, and LAK042 have moderate support for declines pH with low to low-moderate support for exceeding the *change limit* thresholds; however, they are all still above the CBANC *level of protection*. The control lakes (*) are all classified in the first box regardless of increases 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 4-8. Thresholds for *level of protection* and *change limits* for aquatic acidification KPI and informative indicators. Source: ESSA et al., 2023

Indicators	Type	Level of Protection (i.e., absolute threshold)	Change Limit (i.e., relative threshold)
CBANC	KPI	Decrease below 20 μeq/L	Decrease greater than lake-specific thresholds†
pH	Informative	Decrease below 6.0 pH units	Decrease ≥0.3 pH units
Gran ANC	Informative	Decrease below 30.7 μeq/L	Decrease greater than lake-specific thresholds†
BCS	Informative	Decrease below 0 μeq/L	Decrease greater than 13 μeq/L

† The lake-specific thresholds for CBANC and Gran ANC are shown in Table 14 of the SO_2 EEM Phase III Plan (ESSA et al., 2023) and Appendix 5 of Technical Memo W12.

4.4.2.5 Conclusions

Drawing upon the results from the four approaches above (empirical analyses, Bayesian statistical analyses, BACI statistical analyses, and the evidentiary framework), we found:

1. No support for any exceedances of the KPIs
2. Support from one approach for exceedance of one informative indicator for one lake (i.e., empirical analyses of BCS for LAK028)

None of the lakes exceed their Key Performance Indicator (CBANC).

Informative indicators are secondary indicators to support the overall evaluation of acidification risk. The empirical analyses show an exceedance for one informative indicator for LAK028 but the statistical analyses do not show an exceedance of that indicator. **An exceedance of an informative indicator flags that there is some evidence of acidification and that the lake should be closely monitored – this is already the long-standing interpretation for LAK028.** This result confirms the existing interpretation and support for close monitoring of LAK028. It does not represent a major shift in underlying chemistry and does not suggest a need for changes to the monitoring program. The program is performing as intended – i.e., multiple supporting indicators and multiple approaches to evaluate acidification risk.

4.4.3 Recommendations for 2025

We do not recommend sampling LAK027 again. The data collected over the past four years indicate that LAK027 has a low acidification risk, which confirms the conclusions of the STAR for this lake. Despite anomalous conditions in different years, the multiple years of resampling across a diversity of conditions have achieved the original intent of the resampling.

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

5 Climate Change

The SO_2 EEM Program collects data that are of value for understanding and tracking the effects of climate change in the Kitimat Valley. Rio Tinto has volunteered to add the tracking of climate change indicators using some of the data currently collected by the SO_2 EEM Program and some additional new monitoring data.

The purpose of this chapter is to synthesize the SO_2 EEM collected monitoring data through the lens of climate change into indicators for tracking the changes in climate and the physical effects of the climatic change over time. The intent of adding climate change to the SO_2 EEM Program is to be able to provide an understanding of how the climate and environment are changing in the Kitimat Valley using the SO_2 EEM Program's monitoring data.

This chapter presents the climate indicators without analysis or interpretation of the indicators, as the analysis will be undertaken in Comprehensive Review.

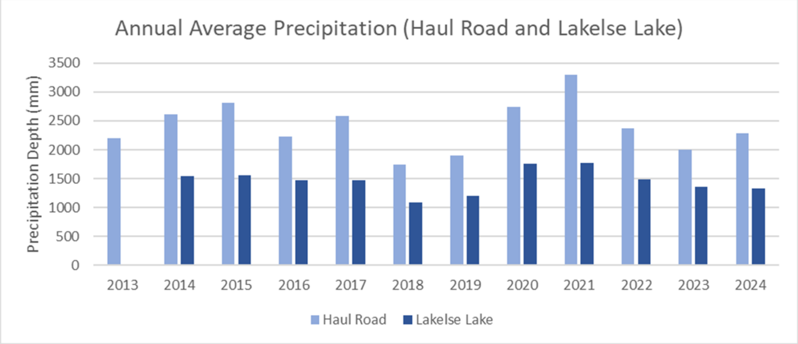
5.1 Activities Undertaken

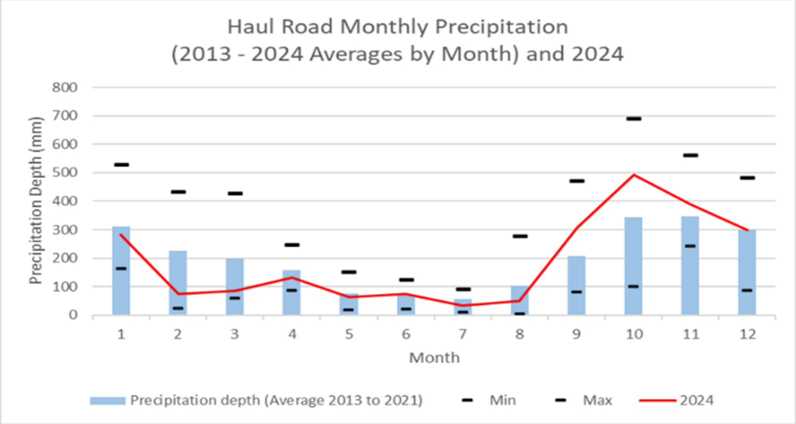
We have started to assemble data sets for the climate change indicators and review both the data quality and suitability of the data for supporting the indicators. We have also started to explore the specific statistics of the indicators. We voluntarily installed solar irradiance monitors (Hukseflux ISO 9060 SR05) in May, 2023 at both the Lakelse Lake Deposition and Whitesail monitoring stations and have begun to track the solar radiation. We have noted that the solar radiation measurements at the Lakelse Lake station may be affected by shading of the adjacent forests; this will be reviewed in 2025. We also voluntarily added soil moisture probes (HOBO MX Soil Moisture Data Loggers) that were installed in May 2023 at the primary Lakelse Lake Soil Plot. We have also added growing degree days (GDD) at the Haul Road using 28 years of temperature data (1997–2024). These data will be analyzed in the 2026 Comprehensive Review.

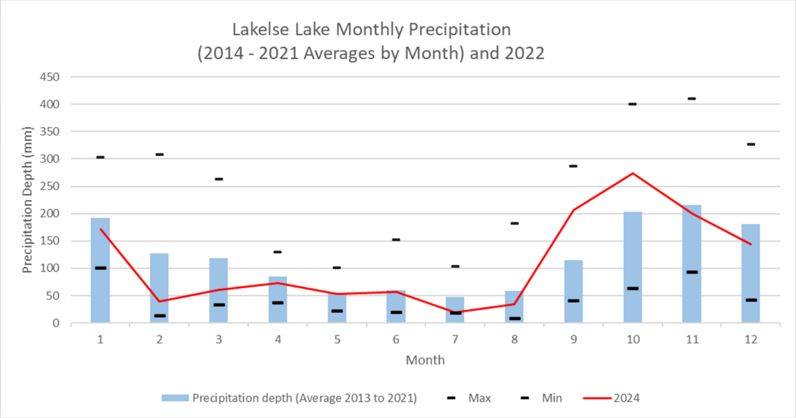
5.2 Climate Change Indicators

5.2.1 Meteorological Indicators

NADP Precipitation Annual Average Against Historical Normal







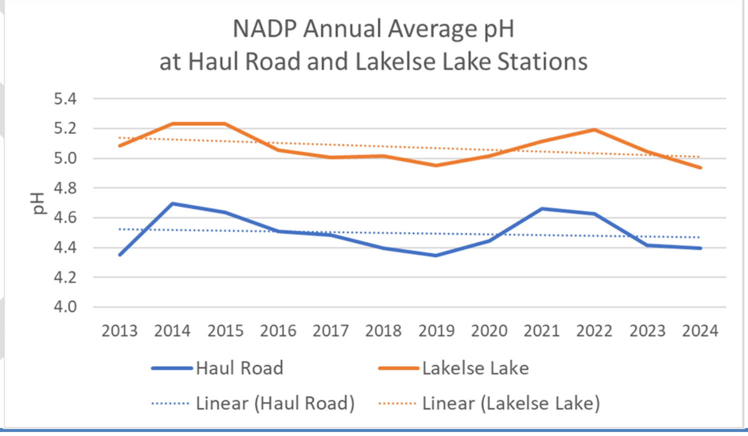
NADP Precipitation Patterns (cumulative and storm depths)


Haul Road NADP Cumulative Precipitation

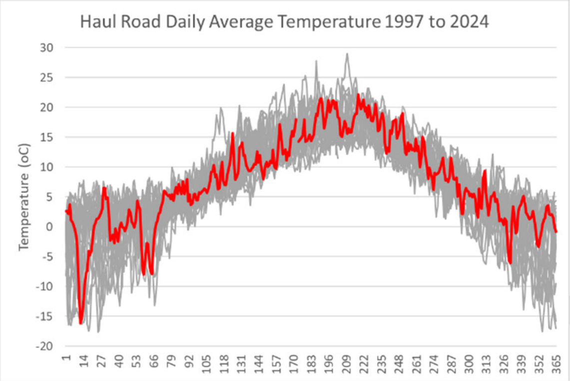
Lakelse Lake NADP Cumulative Precipitation

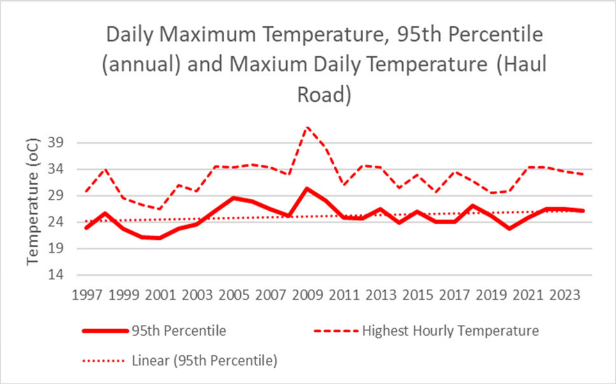
2024 (solid red line) significantly drier than 11-year average for the Haul Road (2410 mm) and the 10-year average for the Lakelse Lake station (1472 mm). However, September and October had higher precipitation than average and the cumulative precipitation depths for both stations were within the typical range. Storm patterns will be examined in the 2026 Comprehensive Review.

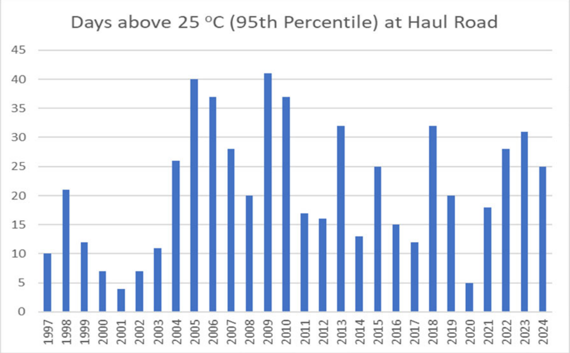
NADP Precipitation pH (weekly and annual average)

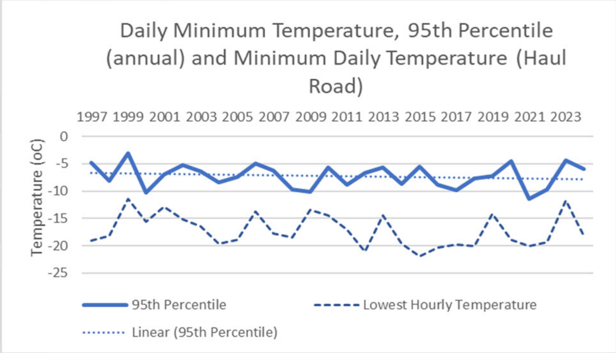

NADP Annual Average pH
at Haul Road and Lakelse Lake Stations

Air Temperature Against Historical Normal (seasonal, extremes and annual averages)



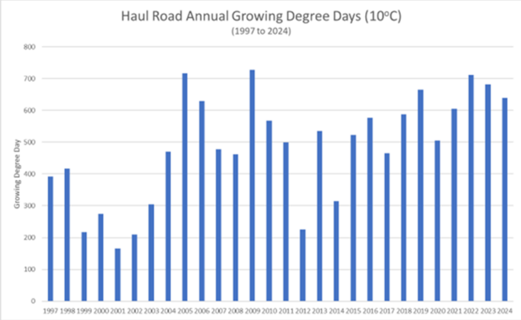


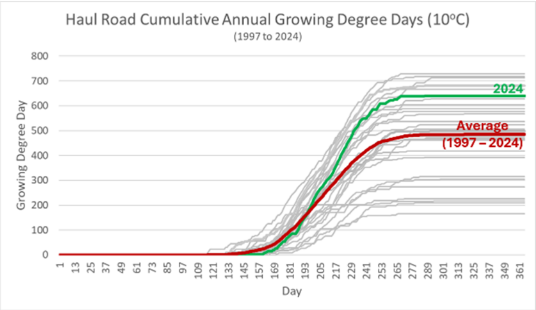




Air temperature data at the smeltersite (Haul Road, Yacht Club and the Kitimat 2 cooperative climate network station) was evaluated and the Haul road station was selected for the indicator based on the longer term history of avilable continuous data. Data from the Kitimat 2 (Smelter main security gate) station (1966 – 2020) will added to the Haul Road station data to create a long term data set for the air temperature indicator.

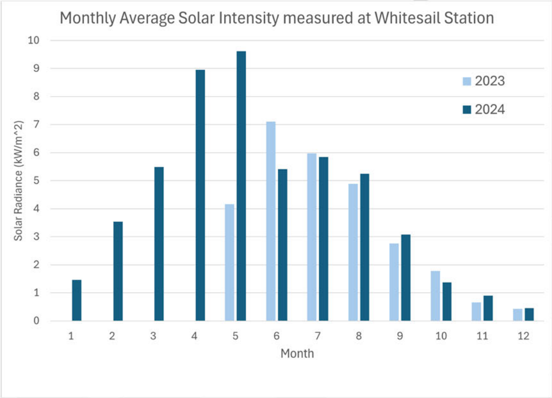
Growing Degree Days (10^{o}C)

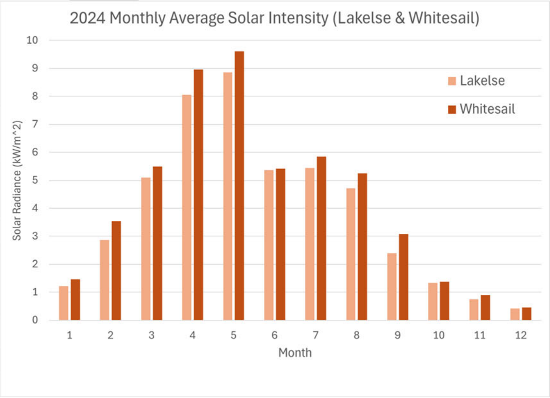




Growing degree days (GDD) has been added as an indicator based on a QP recommendation. The GDD is calculated by (T_{max}+T_{min})/2-Base Temperature (10^{o}C), with a GDD of zero where T_{min} < Base Temperature. 28 Years of temperature measurements from the Haul Road station has been compiled into GDD data. GDD is a useful indicator to help understand the weather influences on the Terrestrial Ecosystems Line of Evidence.

Solar Irradiance

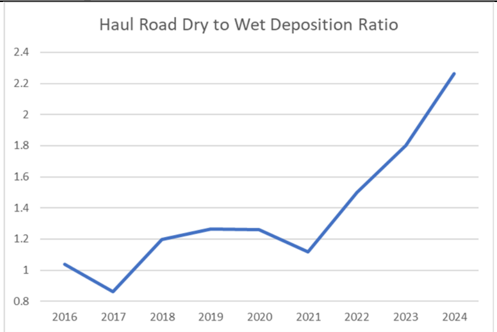


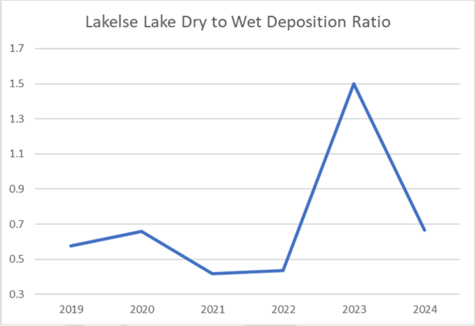


Solar irradiance monitors were voluntarily installed at Lakselse Lake and Whitesail air monitoring stations in May 2023. Data between Lakelse Lake and the Whitesail stations are similar, but the Lakelse monitor has a slightly lower average solar radiance measurement (potentially affected by shading from terrain and adjacent forest). The siting of the monitors will be reviewed in 2025. The monitors were voluntarily installed to first see if the sulphate dry deposition estimates with the BIG LEAF model could be improved and secondarily if the data could be used as climate change indicator (such as cloud cover and wildfire smoke haze)

4.2.2 Effects Monitoring Indicators

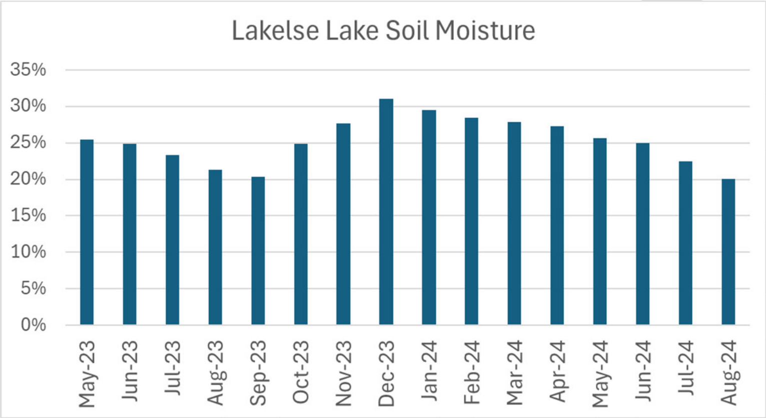
SO4 Deposition Rates and Ratios of Wet vs. Dry Deposition (seasonal and annual averages)





Deposition data are being analyzed to develop a seasonal deposition indicator

Soil Moisture at Lakelse Lake

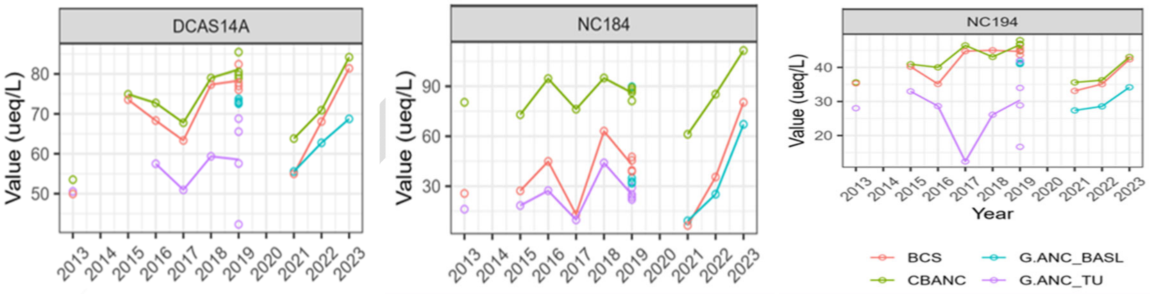


Soil moisture loggers were voluntarily installed at three locations in the primary Lakelse Lake soil monitoring plot in May 2023. The soil moisture chart is the average of the three moisture loggers (hourly measurements). Data from September 2024 to April 2025 was not downloaded from the monitoring plots at the time of this report.

Vascular Plant Biodiversity

Monitoring plots were established in the Kemano Valley.

Lake Chemistry (Control Lakes DCAS14A, NC194 and NC184)



Water Temperature and Water Levels (Lak006 and Lak028)

Data evaluation and analysis are in progress for developing the indicator.

5.3 Additional Studies

A project will be sponsored under SO_2 EEM Phase III that will review and summarize the available predictions and literature for climate change in the Kitimat Valley and develop predictions for environmental responses. The intent of this project is to develop an understanding of the predicted climate changes that may occur in the Kitimat Valley and to develop an understanding of the potential effects of the changes.

This study will be completed as part of the 2026 Comprehensive Review.

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7 List of Cited EEM Technical Memos

The numbering of Technical Memos continues from the numbers in the previous Annual Reports. The Human Health KPI Calculations Memo for 2024 is provided in Appendix A, and Aquatic Ecosystems Technical Memo W13 for 2024 is provided in Appendix B.

Human Health KPI Calculations Technical Memo for 2024 (March 30 2025, Trinity Consultants.)

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Technical Memo D02. Atmospheric Sulphur Dioxide – Method for Estimating Dry Deposition: 2017 Update (June 2018, Trent University)

Technical Memo P08. Atmospheric Sulphur Dioxide – Passive Diffusive Sampler Network: 2024 Results (April 2025, Trinity Consultants)

Technical Memo W09. Aquatic Ecosystems Actions and Analyses (July 2019, ESSA Technologies Ltd.)

Technical Memo W12. Aquatic Ecosystems Actions and Analyses (April 2024, ESSA Technologies Ltd.)

Technical Memo W13. Aquatic Ecosystems Actions and Analyses (April 2025, ESSA Technologies Ltd.)

Vascular Plant and Cyanolichen Biodiversity Monitoring Program, Forth Annual Report: 2024 Field Season (December 23, 2024, Balanced Ecological Management Co.)

Appendix A: Technical Memo P08 – Atmospheric Sulphur Dioxide – Passive Diffusive Sampler Network: 2024 Results

The following pages contain **B.C. Works SO_2 EEM Program Technical Memo P08**, in PDF format.

B.C. Works SO_2 EEM Program – Technical Memo P08

Atmospheric Sulphur Dioxide

Passive Diffusive Sampler Network: 2024 Results

April 2025

Prepared for:

Rio Tinto, BC Works
1 Smeltersite Road, P.O. Box 1800,
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Prepared by:

Trinity Consultants
4525 Wasatch Blvd. Suite 200
Salt Lake City, UT 84124

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1 Introduction

The network of passive samplers was redeployed in the Kitimat Valley during 2024 following the same procedures that were utilized in previous years. The network was deployed at 24 sites within the Kitimat Valley (Figure 1), starting April 22, 2024.[1] The network was primarily focused along the Wedeene and Bish roads to capture the plume path. This network is referred to as the plume path network and historically referred to as the valley network.[2] Two sites were added in 2024, V25 and V26. The V25 site is located southwest of Kitamaat Village Site with the purpose of evaluating transport further south of Kitamaat Village. Site V26 is located in Kemano, BC at the Rio Tinto BC Works Powerhouse. This site is intended as a background sampler and samples are collected year-round.

2 Overview

During 2024, the sulphur dioxide (SO_2) passive diffusive sampler network in the Kitimat Valley began monitoring on April 22nd and finished on October 29th, following (approximately) six one-month exposures.

Based on Trinity Consultant's 2020 passive sampling plan, a detailed site evaluation was conducted and documented during the 2020 deployment. The original 15 sites deployed in 2020 were deployed in 2024. In addition, the six sites added in 2021 based on reconnaissance performed in early 2021 were also deployed in 2024.[3] Location A05 (Kitamaat Village) was added in 2022 to understand the extent of the plume to the southeast and for another site to compare with continuous ambient SO_2 monitoring. Two new sites were added in 2024, V25 and V26. The V25 site is located southwest of Kitamaat Village Site to better understand the plume boundary to the south. Site V26 is located in Kemano, BC at the Rio Tinto BC Works Powerhouse. This site is intended as a background sampler and samples are collected year-round.

As detailed in the Phase III EEM work plan's 2021-Specific Work Plan for Passive Sampling (ESSA et. al., 2021), the network changed from employing IVL SO_2 passive samplers to Bureau Veritas (BV) All-Season Passive Air Sampling System (PASS) and laboratory. All 2024 sample analysis was performed using the BV PASS system.

3 Study Design

Six deployments, with an approximate exposure time of one-month (27-34 days), were carried out under the plume path network between late April and late October 2024. Lake 28 samples had five deployments from May- October 2024, on a schedule consistent with other Lake 28 sampling activities.

In 2024, there were 182 sample exposures across the plume path network collected and analyzed during the six deployments. These included duplicate samplers deployed approximately 22% of the

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[1] The L28 Lake site first deployment was on May 22, 2024.

[2] A second network of passive samplers deployed in the urban and residential areas of Kitimat was in continuous operation from June 2018 through December 2019. The urban network study concluded in 2019 (before the time period of this report)

[3] Three of the six new 2021 sites (V17, V18/V18b, and V20) were added east and west of V01 create an east-west transect to better understand the eastern and western boundaries of the plume path. The remaining three new 2021 sites (V21, V22, and V23) were added farther north near Terrace to better understand the northern boundary of the plume path (and to verify where the plume is not).

time (39 duplicate exposures). Blanks were deployed approximately 18% of the time (33 blank exposures).

4 Results

The observed data show elevated atmospheric SO_2 along the plume path results shown in Figure 1 and Figure 2 data are calibrated by using a 2022 through 2024 BV PASS calibration analysis using sample results co-located at continuous monitoring stations.

The 2024 results within the plume path network are similar to historic observations, although higher concentrations were monitored in 2023 and 2024 compared to 2022 due to lower concentrations during the restart in 2022. The spatial pattern is consistent with previous years. It is recommended that deployments are continued during 2025 to further define the plume into the transition to normal operation.

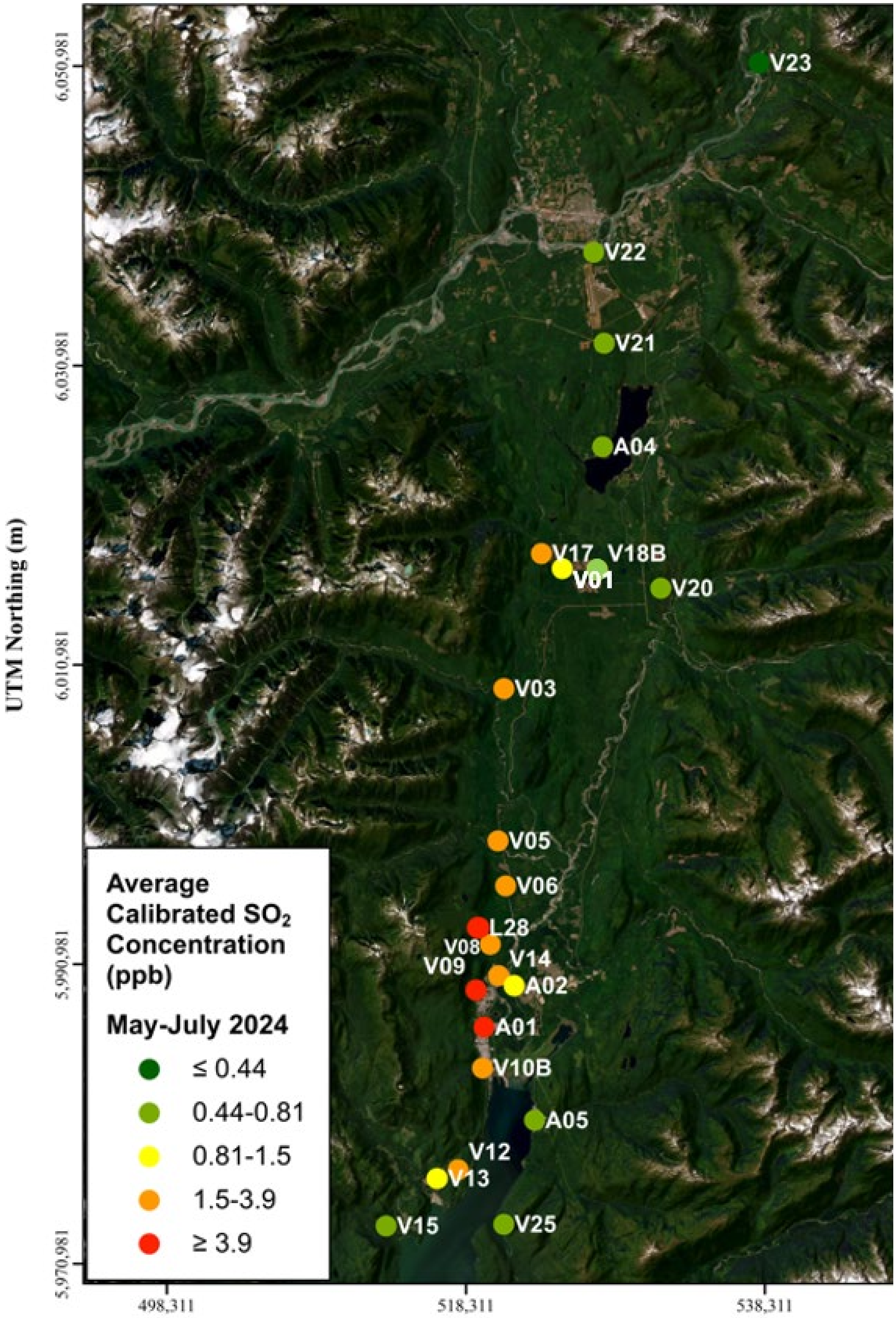

Figure 1 **Average Atmospheric Sulphur Dioxide (SO_2) Concentration during May to July 2024 in the**

Kitimat Valley Passive Diffusive Monitoring Network (calibrated). V26 is not pictured.

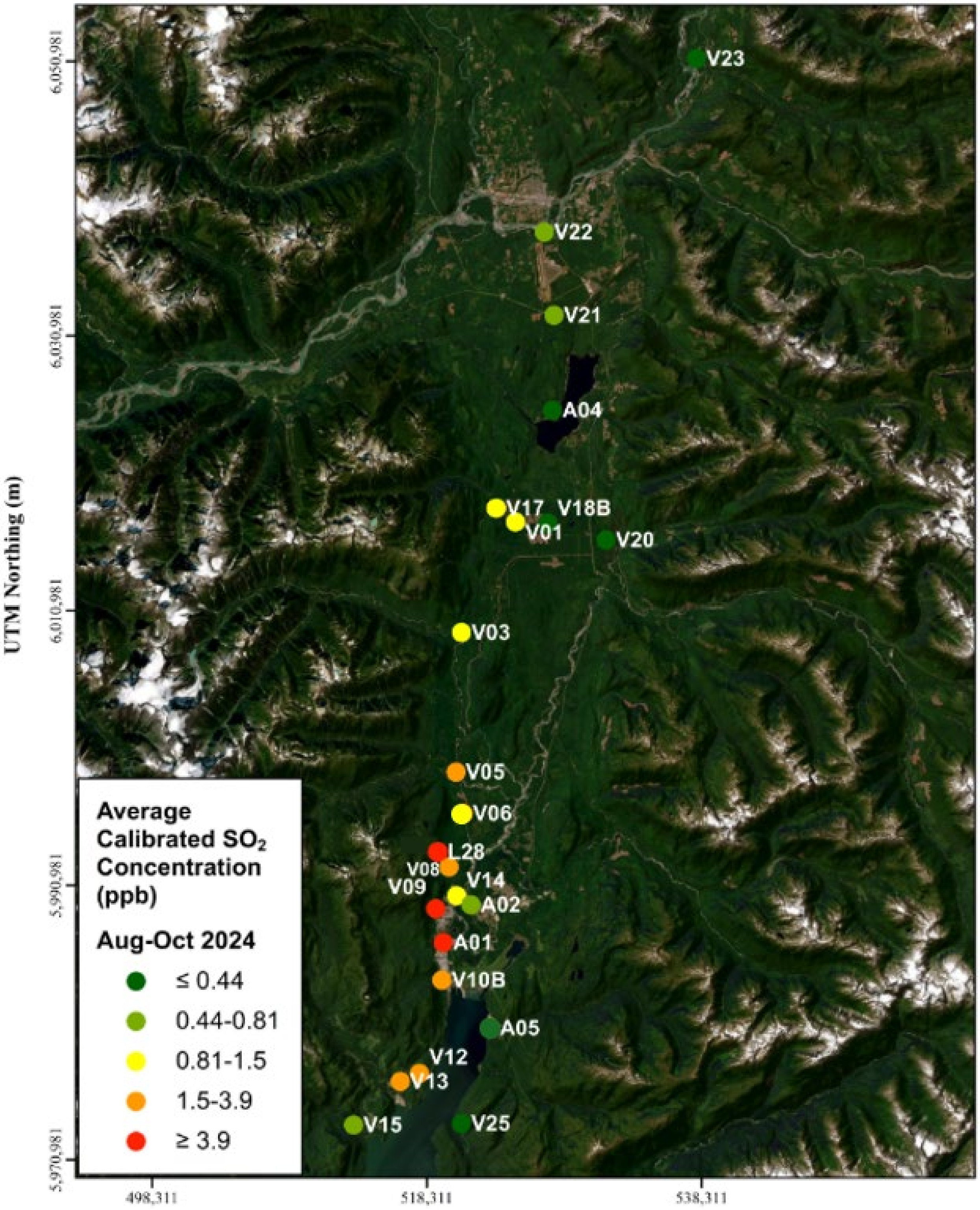

Figure 2 **Average Atmospheric Sulphur Dioxide (SO2) Concentration August to October 2024 in the Kitimat Valley Passive Diffusive Monitoring Network (calibrated). V26 is not pictured.**

Ambient SO_2 data were collected from the continuous SO_2 analyzers at Haul Road, Riverlodge, Lakelse, and Kitamaat Village were compared to the passive SO_2 sampling data to understand accuracy and precision of the passive method. In general, there was good correlation between passive and active at three of the sites; however, correlation decreases at sites that have average concentrations consistently below 1 ppb.

Tables 1 and 2 present a comparison of the ambient sampler results with the collocated passive SO_2 samples analyzed by Bureau Veritas laboratory collected for the Haul Road (AO1), Riverlodge (AO2), Lakelse (AO4), and Kitamaat Village (AO5) monitoring stations. SO_2 comparisons were made on a 30-day sampling basis.

Table 1 **Comparison of SO_2 Passive Sampling Data to Ambient SO_2 Data at Station A01 and A02**

	Haul Road (AO1)			Riverlodge (AO2)		
End Date (2023)	Bureau Veritas Passive (ppb)	Active (ppb)	Diff. (ppb)	Bureau Veritas Passive (ppb)	Active (ppb)	Diff. (ppb)
May	11.7	9.4	2.3	1.1	0.9	0.2
June	9.1	7.5	1.6	0.9	0.9	0.0
July	7.8	6.2	1.6	1.2	0.8	0.4
August	9.2	6.2	3.0	0.6	0.4	0.2
Sept	8.1	5.8	2.3	0.7	0.5	0.2
Oct	10.7	7.3	3.4	0.3	0.5	-0.2
		Average	2.35		Average	0.13
		St. Dev.	0.66		St. Dev.	0.16

Table 2 **Comparison of SO_2 Passive Sampling Data to Ambient SO_2 Data at Station A04 and A05**

	Lakelse (AO4)			Kitamaat Village (AO5)		
End Date (2023)	Bureau Veritas Passive (ppb)	Active (ppb)	Diff. (ppb)	Bureau Veritas Passive (ppb)	Active (ppb)	Diff. (ppb)
May	0.8	0.5	0.3	0.7	0.6	0.0
June	0.7	0.5	0.2	0.5	0.4	0.1
July	0.9	0.7	0.2	0.7	0.4	0.3
August	0.5	0.4	0.0	0.7	0.4	0.3
Sept	0.4	0.2	0.2	0.5	0.3	0.2
Oct	0.4	0.1	0.2	0.1	0.3	-0.2
		Average	0.18		Average	0.11
		St. Dev.	0.08		St. Dev.	0.16

The statistical differences between the active and passive monitors are shown below in Table 3. The averages column shows the average concentration difference between the active and passive monitors. The standard deviations and correlation coefficients (r^2) for the difference between active and passive monitors are also listed.

Table 3 Statistical Analysis of Active to Passive Concentrations

Statistic	Haul Road	Riverlodge	Lakelse	Kitamaat Village
Average (ppb)	2.35	0.13	0.18	0.11
Standard Deviation	0.66	0.16	0.08	0.16
r^2	0.77	0.76	0.86	0.78

The correlation coefficients are similar at all locations in 2024. The passive samples appear to be biased high compared to the active sampling across all sites that have colocation. Given that there are now 3 years of passive data available (2022 to 2024), it is appropriate to evaluate the passive samples using a regression analysis.

RioTinto evaluated the relationship using a regression analysis of all passive and continuous data collected during the 2022 to 2024 programs. Passive stations A01, A02, A04, and A05, are co-located with continuous SO_2 monitors at the Haul Road, Riverlodge, Lakelse, and Kitamaat Village stations, respectively. Continuous averages collected over the same period were compared with monthly passive results from 2022 to 2024. With three years of data, a strong correlation was observed, yielding an R^2 value of 0.98, indicating a clear and reliable relationship between the passive and continuous sampling methods. Therefore, passive samples were calibrated using the equation y=0. 6892x +0. 1057. This equation was applied to all monthly passive samples, to calibrate 2024 monthly results by site, in addition to yearly seasonal passive average values from 2022 to 2024.

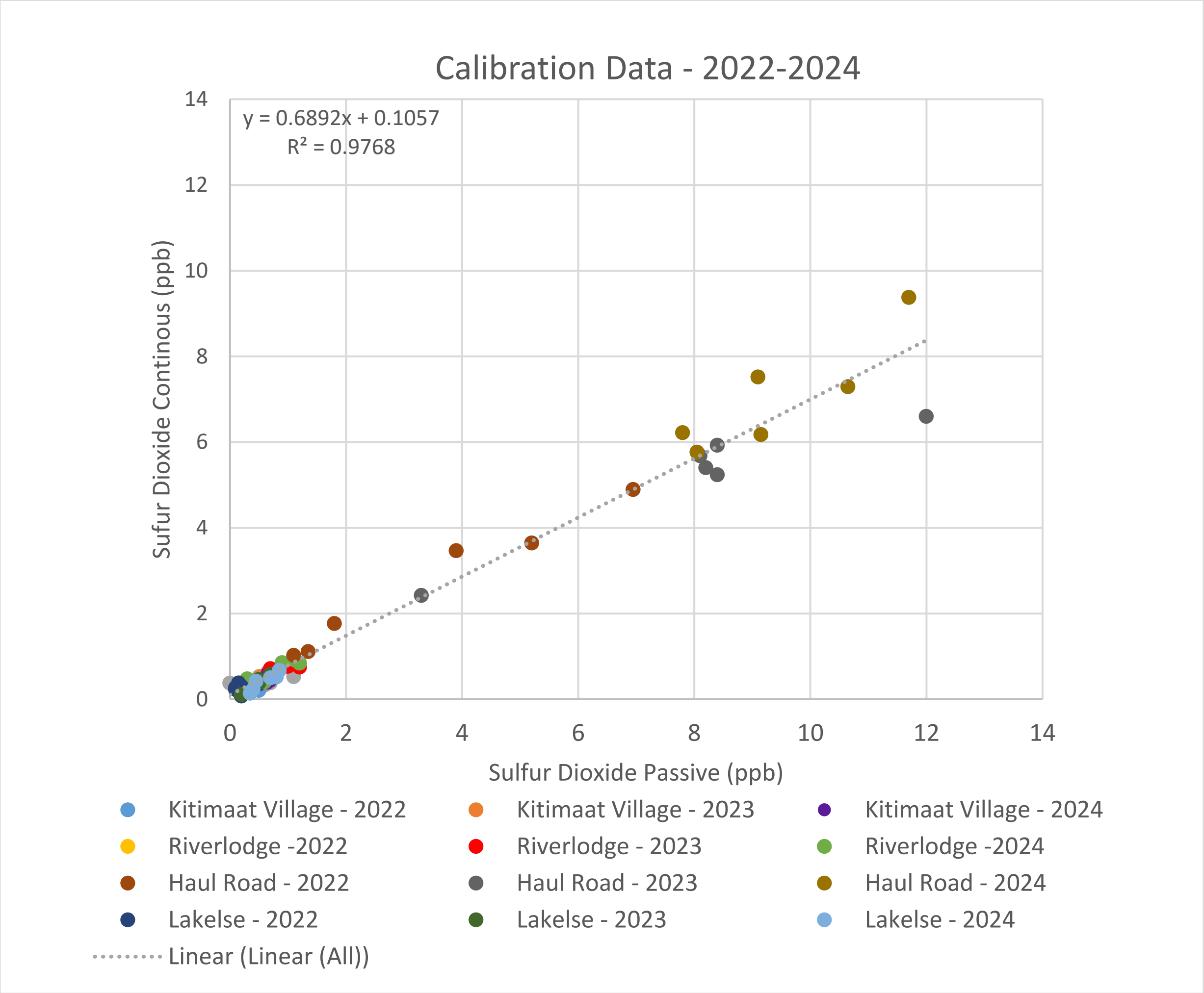

Figure 3. Calibration Plot of all data 2022-2024

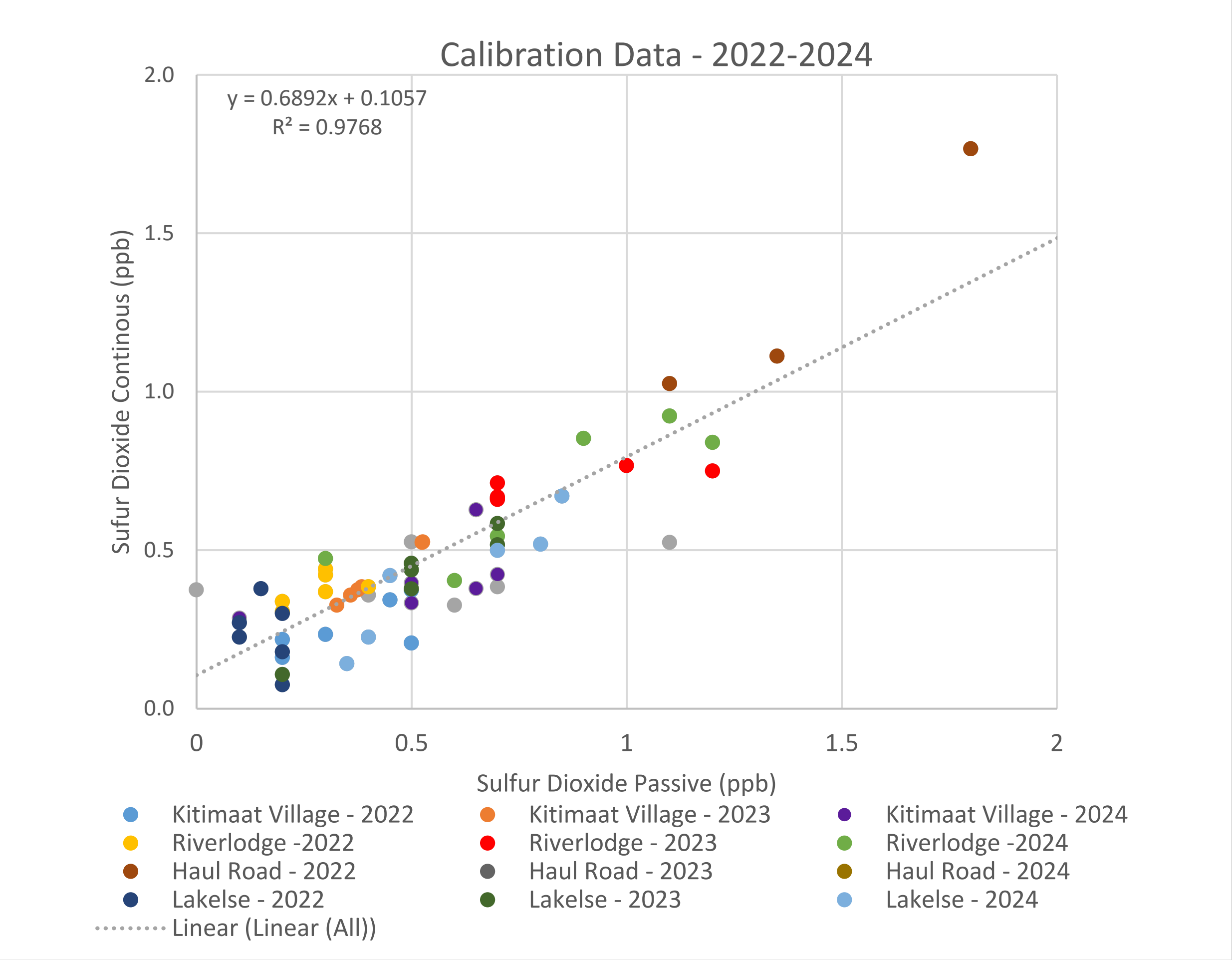

Figure 4: Calibration Plot of Data at Low Concentrations

Table 3-3. Yearly calibrated concentration of SO_2 (ppb) from passive samplers in the SO_2 network during the 2022-2024 sampling season.

ID	Site Name	UTM E	UTM N	2022	2023	2024	Average
A01	Haul Road Station	519527	5986823	2.44	5.11	6.59	4.70
A02	Riverlodge Station	521538	5989580	0.39	0.68	0.66	0.58
A04	Lakelse Lake NADP Station	527457	6025573	0.21	0.46	0.51	0.39
A05	Kitamaat Village Station	522907	5980600	0.36	0.54	0.46	0.45
V01	Onion Lake Ski Trail North	524757	6017435	0.30	0.88	1.06	0.75
V03	Mound TKTP92	520853	6009407	0.45	1.27	1.31	1.0
V05	LNG Muster Station	520457	5999250	0.66	1.74	2.02	1.47
V06	Sand Pit	520970	5996240	0.52	1.38	1.76	1.22
V08	Claque Mountain Trail at Powerline	519938	5992329	0.96	2.16	2.71	1.94
V09	Sand Hill at Powerline	518985	5989292	2.01	5.02	4.57	3.87
V10B	Pullout before Bish FSR	519425	5984090	1.66	3.94	3.48	3.03
V12	Bish Road Pullout 4	517790	5977294	1.93	4.49	2.90	3.11
V13	Bish Road at Chevron LNG	516389	5976708	0.74	2.31	1.51	1.52
V14	Industrial Area Kitimat Hotel	520490	5990236	0.57	1.37	1.58	1.17
V15	Bish Mainline	512994	5973534	0.30	0.79	0.64	0.58
V17	West Lake	523359	6018434	0.22	0.52	0.57	0.43
V18B	Wedeene mainline	527088	6017351	0.55	1.42	1.83	1.27
V20	Pipeline laydown	531354	6016121	0.21	0.39	0.40	0.33
V21	South of airport	527566	6032493	0.23	0.54	0.62	0.47
V22	Kitselas Development	526862	6038551	0.21	0.48	0.62	0.44
V23	Gitaus water tower	537941	6051192	0.27	0.32	0.30	0.30
V25	South of Kitamaat Village	520884	5973636	N/A	N/A	0.45	0.45
V26	Kemano	569684	5934713	N/A	N/A	0.19	0.19
L28	Lake 28	519139	5993425	1.48	4.28	5.07	3.61

5 Conclusion

The 2024 results demonstrate a similar spatial pattern in SO_2 compared with 2022 and 2023. Comparison between passive and continuous monitoring data show a strong correlation, indicating a clear and reliable relationship between the passive and continuous sampling methods. In summary, the results from the 2024 network continue to support the use of passive samplers to provide empirical observations of atmospheric SO_2 concentrations to (a) assess spatial and temporal changes, (b) evaluate modelled concentration fields, and (c) estimate dry deposition of SO_2. It is recommended that deployments are continued during 2025 to evaluate the ongoing spatial distribution after the restart was completed.

Appendix A.

Table 4: Passive SO_2 Sampling Network Station Identifier, Name, and UTM Location

ID	Site Name	UTM E	UTM N
A01	Haul Road Station	519527	5986823
A02	Riverlodge Station	521538	5989580
A04	Lakelse Lake NADP Station	527457	6025573
A05	Kitamaat Village Station	522907	5980600
V01	Onion Lake Ski Trail North	524757	6017435
V03	Mound TKTP92	520853	6009407
V05	LNG Muster Station	520457	5999250
V06	Sand Pit	520970	5996240
V08	Claque Mountain Trail at Powerline	519938	5992329
V09	Sand Hill at Powerline	518985	5989292
V10B	Pullout before Bish FSR	519425	5984090
V12	Bish Road Pullout 4	517790	5977294
V13	Bish Road at Chevron LNG	516389	5976708
V14	Industrial Area Kitimat Hotel	520490	5990236
V15	Bish Mainline	512994	5973534
V17	West Lake	523359	6018434
V18B	Wedeene mainline	527088	6017351
V20	Pipeline laydown	531354	6016121
V21	South of airport	527566	6032493
V22	Kitselas Development	526862	6038551
V23	Gitaus water tower	537941	6051192
L28	Lake 28 Sampling	519138	5993424

Table 5 Passive Sampling Results in ppb

Station	May (ppb)	June (ppb)	July (ppb)	August (ppb)	September (ppb)	October (ppb)
A01	7.8	10.9	7.7	5.3	8.8	3.3
A02	1.2	0.8	0.7	0.9	0.8	0.7
A04	0.7	0.6	0.5	0.7	0.5	0.2
A05	0.4	0.4	1.0	0.7	0.6	0.7
V01	1.8	1.2	1.4	1.0	0.9	0.4
V03	1.8	1.9	2.0	2.5	1.3	0.6
V05	1.9	2.7	3.1	3.2	2.6	0.7
V06	2.8	2.1	2.5	1.5	1.7	0.5
V08	3.9	3.9	3.9	2.2	2.9	1.1
V09	7.8	9.2	10.7	6.5	5.9	2.8
V10B	7.1	7.4	4.8	2.2	3.2	8.7
V12	5.1	3.2	3.1	4.6	5.3	16.9
V13	3.4	1.6	2.0	1.3	2.9	8.0
V14	2.9	2.0	1.4	1.6	2.2	1.0
V15	1.2	0.9	1.1	0.9	0.8	1.1
V17	Not Collected	2.0	3.0	1.6	2.8	0.2
V18B	0.7	0.8	0.7	0.7	0.4	0.2
V20	0.6	0.5	0.4	0.5	0.3	0.2
V21	0.8	0.6	0.7	0.9	0.6	0.3
V22	0.5	0.5	0.8	0.7	0.6	0.2
V23	0.4	0.4	0.4	0.4	0.2	0.1
L28	5.1	9.2	6.1	8.1	5.7	1.2

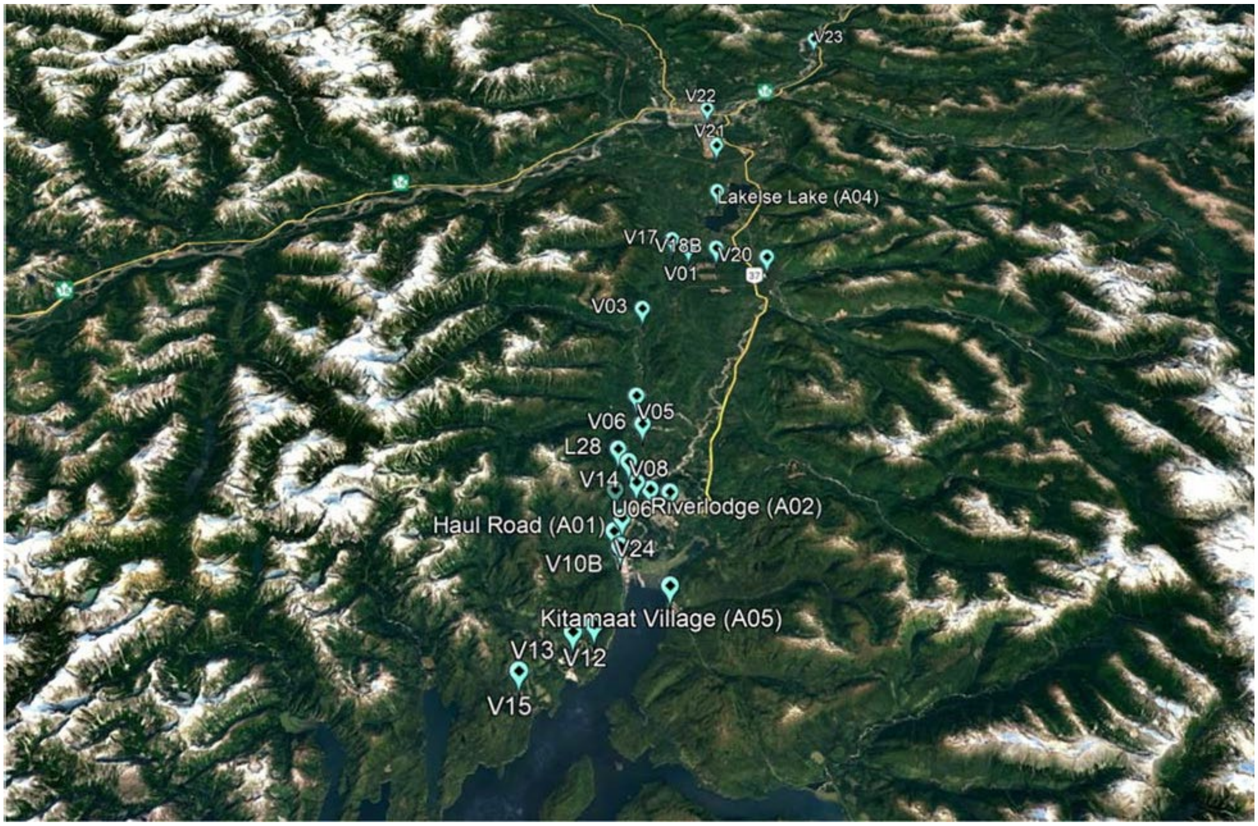

Figure 3 : Site Locations and IDs for the Kitimat Valley (V) and Ambient (A) Passive Diffusive Sampler Network; see Figure A1 and Table A1 for Further Details on Site Locations.

Appendix B: Human Health KPI Calculations Memorandum for 2024

The following pages contain the **Memorandum for the Human Health KPI Calculations for 2024**, in PDF format.

Trinity Consultants

MEMORANDUM

To: Mr. Shawn Zettler - Rio Tinto

From: Anna Henolson, Cara Keslar - Trinity Consultants

Date: June 19, 2025

RE: Human Health KPI Calculations for 2024

The SO_2 Environmental Effects Monitoring (EEM) Program establishes Key Performance Indicators (KPIs) of various pathways in order to monitor effects of SO_2 from Rio Tinto's Kitimat aluminum smelter. This memorandum describes the SO_2 monitoring data collected in 2022 through 2024 in the Kitimat area and the methodology used in order to compare to the human health KPI for reporting year 2024.

The June 2025 revision of this letter corrects the 3-year average value for Whitesail. All other values and descriptions are unchanged.

Health KPI

British Columbia Ministry of Environment and Climate Change Strategy (BC ENV) updated the province-wide interim SO_2 ambient air quality objective (IAAQO) in 2016, which became the SO_2 health KPI of EEM Program starting 2017. Starting January 1, 2020, the SO_2 health KPI implemented the SO_2 Canadian Ambient Air Quality Standards (CAAQS). In 2020, the CAAQS value was 70 ppb. The SO_2 health KPI is used to assess residential SO_2 ambient air quality.

Exceptional Events

Exceptional events may occur from:

- Fire within the community that may emit SO_2;
- Emergency conditions at the facilities within the Kitimat airshed;
- Vandalism or corruption of data from other point sources such as vehicle emissions in close proximity to the ambient air monitoring station; and
- Temporary global events that impact SO_2 levels such as a volcano eruption.

These types of exceptional events could affect the determination of the health KPI.

On May 9, the Kitamaat Village station recorded an hourly value over 70 ppb. During this time, winds were light (less than 3 m/s) and from the southeast, and $PM_{2.5}$ was elevated. The elevated $PM_{2.5}$ data suggests that a fire or other combustion in the community could have emitted SO_2 and $PM_{2.5}$. Even though the wind data suggests that the SO_2 concentrations may not have originated from the smelter, it is also possible that stable conditions could have inhibited mixing, and there is no other direct evidence of a fire or other unusual event. Because the available information is not definitive, May 9 is not considered an exceptional event and still included in the KPI determination.

Calculation Methodology

The monitoring data at residential areas in Kitimat is collected at three residential monitoring stations: Riverlodge, Whitesail, and Kitamaat Village[1]. The Industrial Avenue monitoring station (located in Service Centre) is also designated as a KPI attainment site per the decision issued by B.C. ENV on October 25, 2022.[2] The effective date listed in the decision is January 1, 2023. The station began collecting data in May 2020. Following the January 1, 2023 effective date in the ENV decision, the station is collecting data for KPI attainment purposes beginning January 1, 2023.[3]

Ambient SO_2 monitors collect the SO_2 measurements continuously and hourly measurements are reported to BC ENV's Envista database[4]. The measurements at these monitor stations are reviewed and validated by BC ENV on an annual basis:

- Monitoring data for 2022 was validated as of March 2025.
- Monitoring data for 2023 was validated as of March 2025
- Monitoring data for 2024 was not validated as of the date of this memorandum (March 26, 2025)

The hourly measurements for calendar years 2022, 2023, and 2024 were downloaded from the Envista database after the validation was complete, when applicable, and processed following the procedures described in *Guidance Document on Achievement Determinations for Canadian Ambient Air Quality Standards for Sulphur Dioxide*[5] (the Guidance). Following the Guidance, the monitoring data were processed in the following steps:

1. Check daily data completeness and determine the daily 1-hour maximum concentration.
    - Daily measurements are the hourly readings from 1 AM to 12 AM marked for the same day.
    - A valid daily value is calculated as the maximum hourly reading from the day:
        - Where at least 18 hourly measurements are available in a day, the daily value is the maximum value from those readings in the same day; or

Where less than 18 hourly measurements are available in a day but at least one hourly measurement exceeds 70 ppb, the daily value is the maximum value from available readings in the same day.

- All values are reported to the nearest 0.1 ppb.
- A summary of daily completeness is provided in Attachment 1.

2. Check quarterly and annual data completeness. A summary of quarterly and annual data completeness is provided in Table 1.
    - The dataset is considered complete when there are at least 60% of all daily maximum 1-hour measurements in each quarter and at least 75% of all daily maximum 1-hour measurements in each year.
    - Periods which do not satisfy the data completeness criteria are flagged. All periods were complete for all four stations for 2022 – 2024.
    - Completeness percentages in Table 1 are based on valid hours.

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[1] Note that the BC ENV Envista database lists the Kitamaat Village monitoring station as the Haisla Village monitoring station.

[2] Letter from Douglas Hill (B.C. ENV) to Shawn Zettler (Rio Tinto). October 25, 2023. https://j200.gov.bc.ca/pub/ams/download.aspx?PosseObjectId=150676770

[3] The Janauary 1, 2023 effective date was based on the expectation that the smelter was expected to reach normal operations. The smelter reached normal operation in October 2023.

[4] BC Air Data Archive Website (Envista database), available at https://envistaweb.env.gov.bc.ca/.

[5] *Guidance Document on Achievement Determination for Canadian Ambient Air Quality Standards for Sulphur Dioxide,* CCME, 2020, available at https://ccme.ca/en/res/gdadforcaaqsforsulphurdioxide_en1.0.pdf.

Table 1. Quarterly and Annual Data Completeness

Period [a]	Site	2022	2023	2024
Q1	Kitamaat Village	100.0%	100.0%	90.1%
	Riverlodge	100.0%	98.9%	100.0%
	Whitesail	98.9%	98.9%	100.0%
	Industrial Ave	76.7%	88.89%	95.6%
Q2	Kitamaat Village	100.0%	100.0%	95.6%
	Riverlodge	100.0%	100.0%	97.8%
	Whitesail	96.7%	63.7%	96.7%
	Industrial Ave	100.0%	97.80%	96.7%
Q3	Kitamaat Village	98.9%	100.0%	98.9%
	Riverlodge	100.0%	95.7%	98.9%
	Whitesail	95.7%	98.9%	97.8%
	Industrial Ave	100.0%	100.00%	94.6%
Q4	Kitamaat Village	100.0%	100.0%	97.8%
	Riverlodge	98.9%	100.0%	100.0%
	Whitesail	97.8%	100.0%	98.9%
	Industrial Ave	100.0%	98.9%	98.9%
Annual	Kitamaat Village	99.7%	100.0%	95.6%
	Riverlodge	99.7%	98.6%	99.2%
	Whitesail	97.3%	90.4%	98.4%
	Industrial Ave	94.2%	96.4%	96.4%
	[a] Q1 refers to January to March, Q2 refers to April to June, Q3 refers to July to September, and Q4 refers to October to December.			

3. Calculate the 99th percentile value of daily 1-hour maximum values for each year at each station.
   - Firstly, all daily 1-hour maximum values for the year are sorted from highest to lowest. For example, there were 363 valid daily 1-hour maximum values at Riverlodge for 2024, and these 363 values were ordered from highest to lowest.
   - Secondly, count the number of valid daily values, and determine the corresponding rank for the annual 99th percentile value following Table 5-2 of the Guidance. For example, the corresponding rank equivalent to annual 99th percentile is 4 for Riverlodge for 2024, as there were more than 300 daily values.
   - Lastly, report the value in the corresponding rank equivalent to annual 99th percentile of the daily 1-hour maximum values. The value is reported to the nearest 0.1 ppb as specified in the Guidance. For example, the 4th highest daily value reported for Riverlodge for 2024 is 24.6 ppb.
4. Calculate the three-year average of annual 99th percentile of the daily 1-hour maximum values at each station.

The annual 99th percentile value of daily 1-hour maximum values for each year at each station and the three-year average values at each station are summarized in Table 2. The three-year average of annual 99th percentile of daily 1-hour maximum during 2022, 2023 and 2024 at all three monitor stations are also compared to the SO_2 CAAQS of 70 ppb, as shown in Table 2. Since all 99th percentile values are below 70 ppb, all three monitor stations are considered in the attained status regarding this human health KPI. All hourly measurements in 2022 and 2023 were below 70 ppb; there was one hourly value in 2024 above 70 ppb (95.1 ppb at Kitamaat Village station).

The high value at Kitamaat Village occurred on May 9 in the early morning. $PM_{2.5}$ was also elevated at the Kitamaat Village station, indicating a source other than the smelter may have contributed to the higher concentrations. Elevated SO_2 was monitored at all stations. During this period, light winds and stable conditions appear to have inhibited mixing until the diurnal wind pattern in the area shifted to dissipate the airmass.

Table 2. Annual 99th Percentile and Three-Year Average

Monitor Station	Annual 99th Percentile of Daily 1-hour Maximum [a] (ppb)			Three-Year Average [a] (ppb)	Health KPI Attainment Status
	2022	2023	2024		
Kitamaat Village	9.8	21.2	22.6	17.9	Attained
Riverlodge	9.9	27.3	24.6	20.6	Attained
Whitesail	5.7	20.8	16.7	14.3	Attained
Industrial Ave	18.6	40.0	38.5	32.4	Attained

a. All values are reported with one decimal per Table 5-4 of the CCME Guidance

2024 Monitoring Data Review

The BC ENV began a pilot project in Kitimat to issue alerts when SO_2 levels equal or exceed 36 ppb. According to the ENV information page, "It is expected that 1-hour SO_2 levels of 35 ppb and lower will pose little or no additional health risk to even sensitive individuals."[6] The periods of time in 2024 with elevated SO_2 concentrations at these three residential monitor stations were infrequent. The periods of time that the Industrial Avenue site had elevated SO_2 concentrations were also infrequent, there were four (4) hours higher than 36 ppb in 2024. The date and hour with hourly SO_2 measurements equal to or higher than 36 ppb include:

- At Industrial Ave between 2 PM and 3 PM on February 22, 2024 (43.2 ppb)
- At Industrial Ave between 3 PM and 4 PM on March 6, 2024 (44.7 ppb)
- At Industrial Ave between 8 AM and 9 AM on May 9, 2024 (38.5 ppb)
- At Kitamaat Village between 9 AM and 10 AM on May 9, 2024 (41.2 ppb)
- At Riverlodge between 9 AM and 10 AM on May 9, 2024 (47.8 ppb)
- At Kitamaat Village between 10 AM and 11 AM on May 9, 2024 (95.1 ppb)
- At Kitamaat Village between 11 AM and 12 PM on May 9, 2024 (45.2 ppb)
- At Riverlodge between 8 AM and 9 AM on July 9, 2024 (37.7 ppb)
- At Riverlodge between 10 AM and 11 AM on July 9, 2024 (60.4 ppb)
- At Industrial Ave between 12 PM and 1 PM on August 31, 2024 (51.5 ppb)

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[6] https://www2.gov.bc.ca/gov/content/environment/air-land-water/air/air-quality/measuring/kitimat-so2-alert-pilot-project

Attachment 1

Daily 1-hour Maximum Concentrations and Completeness

Note: The daily completeness is calculated by the number of valid hourly measurements in the day divided by 24. Where the daily completeness is below 75% (less than 18 measurements), the daily 1-hr maximum value for the given day is not calculated unless the daily 1-hr maximum exceeds 70 ppb.

	Daily Max 1-hr (ppb)				Daily Completeness			
Date	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail
1/1/2024	2.3	3.5	2.8	1.2	95.8%	95.8%	95.8%	95.8%
1/2/2024	0.3	0.3	0.1	0.3	95.8%	95.8%	95.8%	91.7%
1/3/2024	0.3	0.7	0.1	0.7	95.8%	95.8%	95.8%	95.8%
1/4/2024	0.3	12.8	0.4	0.3	95.8%	95.8%	95.8%	95.8%
1/5/2024	0.2	2.8	0.3	0.4	95.8%	95.8%	91.7%	95.8%
1/6/2024	0.8	1.9	0.3	0.6	91.7%	95.8%	95.8%	91.7%
1/7/2024		1.2	0.1	0.3	0.0%	95.8%	95.8%	95.8%
1/8/2024		0.7	0.1	0.3	0.0%	95.8%	95.8%	91.7%
1/9/2024		1.7	0.3	0.3	29.2%	87.5%	95.8%	95.8%
1/10/2024	0.2	2.1	0.3	0.2	95.8%	95.8%	91.7%	83.3%
1/11/2024		0.5	0.2	0.4	58.3%	95.8%	95.8%	95.8%
1/12/2024		0.5	0.1	0.2	37.5%	95.8%	95.8%	95.8%
1/13/2024	0.3	0.2	0.1	0.2	95.8%	95.8%	95.8%	95.8%
1/14/2024	0.2	0.2	0.1	0.4	95.8%	95.8%	95.8%	95.8%
1/15/2024	0.2	0.2	0.2	0.5	95.8%	95.8%	95.8%	95.8%
1/16/2024	0.7	0.6	0.2	0.3	95.8%	95.8%	95.8%	95.8%
1/17/2024	4.9	0.3	0.2	0.4	95.8%	95.8%	95.8%	95.8%
1/18/2024	0.4	0.4	0.2	0.4	91.7%	87.5%	91.7%	95.8%
1/19/2024	0.4	0.3	0.2	0.4	95.8%	95.8%	95.8%	79.2%
1/20/2024	0.2		0.2	0.3	95.8%	66.7%	95.8%	95.8%
1/21/2024	0.7		0.1	0.2	95.8%	0.0%	95.8%	95.8%
1/22/2024	0.4		0.1	0.2	95.8%	54.2%	95.8%	95.8%
1/23/2024	0.5	0.8	0.2	0.5	95.8%	95.8%	95.8%	95.8%
1/24/2024	0.5	1.4	0.2	0.3	95.8%	95.8%	95.8%	87.5%
1/25/2024	0.5	2.5	0.5	1.7	95.8%	95.8%	95.8%	95.8%
1/26/2024	1	5.1	2.3	5.4	95.8%	91.7%	95.8%	95.8%
1/27/2024	0.5	1.4	0.9	1.1	95.8%	95.8%	95.8%	95.8%
1/28/2024	1.4	1.4	0.5	1.2	95.8%	95.8%	91.7%	95.8%
1/29/2024	0.5	8.6	0.5	1.8	91.7%	95.8%	95.8%	91.7%
1/30/2024	0.4	11.6	0.5	0.5	95.8%	87.5%	87.5%	83.3%
1/31/2024	0.4	1	0.2	0.2	87.5%	95.8%	95.8%	95.8%
2/1/2024	0.5	1.3	0.2	0.2	95.8%	95.8%	95.8%	95.8%
2/2/2024	0.5	3.3	1.9	1.4	95.8%	95.8%	95.8%	95.8%
2/3/2024	0.3	1.2	0.2	0.3	95.8%	95.8%	95.8%	95.8%
2/4/2024		2.5	0.2	0.3	58.3%	95.8%	95.8%	95.8%
2/5/2024		1.6	0.1	0.4	45.8%	95.8%	95.8%	91.7%
2/6/2024	0.3	1.8	0.3	0.4	95.8%	91.7%	95.8%	95.8%
2/7/2024	0.3	0.7	0.3	0.3	95.8%	95.8%	95.8%	95.8%
2/8/2024	0.3	1.3	0.3	0.4	95.8%	95.8%	95.8%	95.8%
2/9/2024	0.3	1.5	0.3	0.4	95.8%	91.7%	95.8%	95.8%
2/10/2024	1.1	1.9	0.9	1.3	95.8%	95.8%	95.8%	95.8%
2/11/2024	0.3	1.8	0.3	0.4	95.8%	95.8%	95.8%	95.8%
2/12/2024	27.7	4.9	1	0.6	95.8%	91.7%	95.8%	95.8%
2/13/2024	0.3	1.2	0.2	0.6	95.8%	95.8%	95.8%	95.8%
2/14/2024	7	1.2	0.3	0.4	95.8%	79.2%	95.8%	95.8%
2/15/2024	0.6	0.8	0.2	0.6	95.8%	95.8%	95.8%	95.8%
2/16/2024	0.7	0.2	0.3	0.5	95.8%	91.7%	95.8%	95.8%
2/17/2024	0.7	0.6	0.3	0.4	95.8%	95.8%	95.8%	95.8%
2/18/2024	0.7	2.3	0.4	0.4	83.3%	95.8%	95.8%	95.8%
2/19/2024	0.5	1.4	0.4	0.4	95.8%	95.8%	95.8%	95.8%
2/20/2024	4.2	1.9	0.3	3.8	95.8%	95.8%	91.7%	95.8%

Date	Daily Max 1-hr (ppb)				Daily Completeness			
	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail
2/21/2024	7.6	2.2	0.2	0.5	91.7%	95.8%	95.8%	91.7%
2/22/2024	3.5	43.2	7.8	5.9	95.8%	95.8%	95.8%	95.8%
2/23/2024	0.5	30.7	2.8	0.6	95.8%	95.8%	95.8%	95.8%
2/24/2024	0.5	14.1	0.4	0.2	95.8%	95.8%	95.8%	95.8%
2/25/2024	0.5	18.1	17.3	2.4	95.8%	95.8%	95.8%	95.8%
2/26/2024	0.4	1.3	6.6	6.6	95.8%	95.8%	95.8%	95.8%
2/27/2024	0.3	0.3	0.3	0.3	95.8%	95.8%	95.8%	95.8%
2/28/2024	0.5	0.6	0.2	0.3	95.8%	91.7%	95.8%	95.8%
2/29/2024	0.6	0.7	0.2	0.4	95.8%	95.8%	95.8%	95.8%
3/1/2024	0.3	0.5	0.2	0.2	95.8%	95.8%	95.8%	95.8%
3/2/2024	0.4	0.1	0.3	0.3	95.8%	95.8%	95.8%	95.8%
3/3/2024		0.3	0.4	0.4	45.8%	95.8%	95.8%	95.8%
3/4/2024		0.7	0.3	0.4	54.2%	95.8%	95.8%	95.8%
3/5/2024	3.3	1.4	0.2	0.6	95.8%	95.8%	95.8%	83.3%
3/6/2024	2.7	44.7	15.3	5.7	95.8%	95.8%	95.8%	95.8%
3/7/2024	1.4	2.1	1.1	1.3	95.8%	95.8%	87.5%	95.8%
3/8/2024	0.3	1.9	1	2.2	95.8%	91.7%	95.8%	95.8%
3/9/2024	0.6	1.1	0.5	0.4	95.8%	95.8%	95.8%	95.8%
3/10/2024	2.9	10.2	1.3	3.7	95.8%	95.8%	95.8%	95.8%
3/11/2024	0.7	3.7	2	1.6	95.8%	100.0%	95.8%	95.8%
3/12/2024	8.2	21.6	9.8	7.4	91.7%	95.8%	95.8%	95.8%
3/13/2024	0.2	18.2	0.7	0.2	95.8%	95.8%	95.8%	95.8%
3/14/2024	0.3	2.8	0.4	0.4	95.8%	95.8%	91.7%	95.8%
3/15/2024	0.4	31.4	15.9	6.6	83.3%	95.8%	95.8%	91.7%
3/16/2024	2.1	2.6	3.9	3.6	95.8%	95.8%	95.8%	95.8%
3/17/2024	1.6	15.5	2.2	2.2	95.8%	95.8%	95.8%	95.8%
3/18/2024	22.6	13.5	6.4	5.2	95.8%	95.8%	95.8%	91.7%
3/19/2024	3.5	15.8	4.6	5.4	95.8%	95.8%	95.8%	95.8%
3/20/2024	3.4	1.5	1.8	2.2	95.8%	95.8%	95.8%	95.8%
3/21/2024	6.7	30.8	11.5	6.3	95.8%	95.8%	95.8%	95.8%
3/22/2024	0.4	0.9	0.5	0.5	95.8%	95.8%	95.8%	95.8%
3/23/2024	0.9	1.8	0.4	0.4	95.8%	95.8%	95.8%	95.8%
3/24/2024	1.6	9.7	3.9	3.7	95.8%	95.8%	95.8%	95.8%
3/25/2024	0.1	12.5	0.9	0.4	95.8%	91.7%	95.8%	95.8%
3/26/2024	0.2	6.6	1.5	0.4	95.8%	95.8%	95.8%	95.8%
3/27/2024	1.6		1.1	1	95.8%	50.0%	95.8%	95.8%
3/28/2024	0.2	2	0.2	0.3	95.8%	100.0%	91.7%	95.8%
3/29/2024	2	3.3	2.9	3.2	95.8%	95.8%	95.8%	95.8%
3/30/2024	0.3	8.7	1.3	0.8	95.8%	100.0%	95.8%	95.8%
3/31/2024	0.2	11.1	7.3	0.7	95.8%	100.0%	95.8%	95.8%
4/1/2024	0.2	11.9	3.7	1.2	95.8%	100.0%	95.8%	95.8%
4/2/2024	0.2	9	10.1	6.5	95.8%	91.7%	91.7%	95.8%
4/3/2024	0.2	12.5	5.7	1.6	91.7%	95.8%	95.8%	91.7%
4/4/2024	3.2	0.7	0.2	0.4	95.8%	95.8%	95.8%	95.8%
4/5/2024	2	25.6	12.6	10.5	95.8%	95.8%	95.8%	95.8%
4/6/2024	0.2	9.8	10.1	1	95.8%	95.8%	91.7%	95.8%
4/7/2024	0.2	10.6	1	0.5	91.7%	95.8%	95.8%	91.7%
4/8/2024	0.1	6.9	0.4	0.5	95.8%	95.8%	95.8%	95.8%
4/9/2024	0.2	6.1	0.7	0.3	95.8%	95.8%	83.3%	95.8%
4/10/2024	7.7	10.2	6.4	6.5	95.8%	95.8%	95.8%	95.8%
4/11/2024	0.2	0.9	0.3	0.7	95.8%	95.8%	95.8%	95.8%

	Daily Max 1-hr (ppb)				Daily Completeness			
Date	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail
4/12/2024	0.2	2.4	7.8	0.5	95.8%	95.8%	95.8%	95.8%
4/13/2024	0.2	2.3	7.1	0.5	95.8%	95.8%	95.8%	95.8%
4/14/2024	0.2	4.2	0.8	0.6	95.8%	95.8%	95.8%	95.8%
4/15/2024	0.3	4.4	0.6	1.3	95.8%	95.8%	95.8%	95.8%
4/16/2024	1.5	0.8	0.9	0.6	95.8%	83.3%	95.8%	95.8%
4/17/2024	4	0.8	0.2	0.6	95.8%	91.7%	95.8%	95.8%
4/18/2024	0.7	1.3	0.3	0.5	95.8%	95.8%	95.8%	95.8%
4/19/2024	0.9	1.2	0.2	0.9	95.8%	95.8%	95.8%	95.8%
4/20/2024	0.4	6.4	3	1.9	95.8%	95.8%	95.8%	95.8%
4/21/2024	0.5	15.8	7.8	0.6	95.8%	95.8%	95.8%	95.8%
4/22/2024	0.5	17.6	18.2	14.1	95.8%	95.8%	95.8%	95.8%
4/23/2024	0.6	23.7	7.7	1.3	95.8%	91.7%	95.8%	95.8%
4/24/2024	0.5	8.4	1	1	95.8%	95.8%	95.8%	95.8%
4/25/2024	1.3	1.1	0.7	0.9	95.8%	95.8%	95.8%	95.8%
4/26/2024	4.3	8.7	3	11.2	95.8%	95.8%	95.8%	95.8%
4/27/2024	0.5	9	9.3	14.8	95.8%	95.8%	95.8%	95.8%
4/28/2024	0.4	18.1	9.6	1.9	95.8%	95.8%	95.8%	95.8%
4/29/2024	0.4	6.9	0.7	1	95.8%	95.8%	91.7%	95.8%
4/30/2024	0.4	9	2.7	3.7	91.7%	91.7%	95.8%	91.7%
5/1/2024	0.6	18.3	12.2	6.8	95.8%	95.8%	95.8%	95.8%
5/2/2024	3	11	9.3	3.8	95.8%	95.8%	95.8%	95.8%
5/3/2024	0.6	2.2	1.1	0.7	95.8%	95.8%	95.8%	95.8%
5/4/2024	1.5	4.9	3.2	4.4	95.8%	95.8%	95.8%	95.8%
5/5/2024	1	2.6	0.4	0.9	95.8%	95.8%	95.8%	95.8%
5/6/2024	0.5	19.5	8.8	0.8	95.8%	95.8%	95.8%	95.8%
5/7/2024	0.3	6.3	12	1	95.8%	95.8%	95.8%	95.8%
5/8/2024	0.5	7.1	7.3	0.6	95.8%	95.8%	95.8%	91.7%
5/9/2024	95.1	38.5	47.8	25.2	95.8%	95.8%	95.8%	95.8%
5/10/2024	0.5	7.2	0.9	1	95.8%	95.8%	95.8%	95.8%
5/11/2024	2	10.2	9	6.3	95.8%	95.8%	95.8%	95.8%
5/12/2024	0.3	18.2	1.1	0.4	95.8%	95.8%	95.8%	95.8%
5/13/2024	0.2	12.5	6.9	0.4	95.8%	91.7%	95.8%	95.8%
5/14/2024	0.2	3.5	0.4	0.4	95.8%	95.8%	95.8%	95.8%
5/15/2024	0.3	2.4	0.3	0.4	91.7%	95.8%	91.7%	95.8%
5/16/2024	0.5	4.6		3	95.8%	91.7%	33.3%	95.8%
5/17/2024	0.3	8.6	1	0.8	95.8%	95.8%	75.0%	95.8%
5/18/2024		7	1.8	1.7	70.8%	95.8%	95.8%	91.7%
5/19/2024	0.4	19	3.5	5.1	95.8%	95.8%	91.7%	95.8%
5/20/2024		10.3	13.7	0.2	66.7%	95.8%	83.3%	95.8%
5/21/2024	3.1	7	4.3	5.7	91.7%	95.8%	75.0%	95.8%
5/22/2024		4		2.4	70.8%	95.8%	62.5%	95.8%
5/23/2024	0.2	3.2	0.9	0.4	87.5%	91.7%	95.8%	91.7%
5/24/2024	0.4	6.1	0.1	0.5	100.0%	95.8%	95.8%	95.8%
5/25/2024	0.3	3.4	0.1	0.4	95.8%	95.8%	95.8%	95.8%
5/26/2024	0.3	8.8	6.9	7.7	95.8%	95.8%	95.8%	95.8%
5/27/2024	4.7	15.2	10.7	8.5	95.8%	95.8%	95.8%	95.8%
5/28/2024	1.1	10.5	2.6	1.4	95.8%	95.8%	95.8%	95.8%
5/29/2024		11.2	5.5	0.5	58.3%	95.8%	87.5%	95.8%
5/30/2024	0.2	7	6.3	7.5	95.8%	87.5%	95.8%	95.8%
5/31/2024	18.5	16.5	8.9	9.7	100.0%	95.8%	95.8%	95.8%
6/1/2024	0.2	2.4	2.1	0.4	95.8%	95.8%	95.8%	95.8%

	Daily Max 1-hr (ppb)				Daily Completeness			
Date	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail
6/2/2024	2.5	1.9	0.6	1.1	95.8%	95.8%	95.8%	95.8%
6/3/2024	0.3	3.3	3.2	0.6	95.8%	95.8%	95.8%	95.8%
6/4/2024	0.5	4.4	3.2	3	91.7%	91.7%	95.8%	95.8%
6/5/2024	0.2	13.3	3.4	1	95.8%	95.8%	95.8%	95.8%
6/6/2024	0.9	12.1	1	2.5	95.8%	91.7%	87.5%	91.7%
6/7/2024	5	1.6	2.8	4.3	100.0%	95.8%	95.8%	95.8%
6/8/2024	3	9.9	8.3	6.3	95.8%	91.7%	95.8%	95.8%
6/9/2024	0.3	20.3	9.4	0.6	95.8%	95.8%	95.8%	95.8%
6/10/2024	0.3	2.4	1.2	1.7	83.3%	83.3%	79.2%	83.3%
6/11/2024	0.6	11.1	1	0.9	95.8%	95.8%	95.8%	95.8%
6/12/2024	0.2	12.2	0.4		95.8%	95.8%	95.8%	58.3%
6/13/2024	14.5	20.6	17.1		95.8%	95.8%	95.8%	54.2%
6/14/2024	0.3	2.8	1.8		100.0%	95.8%	91.7%	41.7%
6/15/2024	0.5	2.5	0.9	0.5	95.8%	95.8%	95.8%	91.7%
6/16/2024	8	7.5	6.2	3.7	95.8%	95.8%	95.8%	95.8%
6/17/2024	0.3	26.7	20.6	19.1	95.8%	95.8%	95.8%	95.8%
6/18/2024	0.2		0.2	0.3	95.8%	41.7%	95.8%	95.8%
6/19/2024	0.4		28.2	13.1	95.8%	0.0%	95.8%	83.3%
6/20/2024	0.3		4	1.1	95.8%	50.0%	95.8%	95.8%
6/21/2024	7.2	13.8	23	16.5	100.0%	87.5%	95.8%	95.8%
6/22/2024	0.6	12.5	14.3	3.7	95.8%	95.8%	95.8%	95.8%
6/23/2024	0.2	4	0.5	0.4	95.8%	95.8%	95.8%	95.8%
6/24/2024	0.2	2.2	0.3	0.4	95.8%	83.3%	95.8%	95.8%
6/25/2024	8.1	6.5	7.2	4.8	95.8%	95.8%	95.8%	95.8%
6/26/2024	1.9	1.2	1.2	2.5	95.8%	95.8%	95.8%	95.8%
6/27/2024	0.3	2.4	1.3	0.4	95.8%	95.8%	95.8%	95.8%
6/28/2024	0.5	2.7	0.1	0.3	100.0%	91.7%	95.8%	95.8%
6/29/2024	1.6	14	3	1.8	95.8%	95.8%	95.8%	95.8%
6/30/2024	0.5	1.8	0.2	0.3	95.8%	95.8%	95.8%	95.8%
7/1/2024	0.4	7.6	1	0.3	95.8%	91.7%	95.8%	83.3%
7/2/2024	0.4	8.1	0.4	0.2	95.8%	91.7%	91.7%	95.8%
7/3/2024	0.4	4.8	0.3	0.8	91.7%	95.8%	95.8%	91.7%
7/4/2024	0.3	20.6	8.7	0.5	95.8%	95.8%	95.8%	95.8%
7/5/2024	0.4	13.6	2.6	0.5	100.0%	95.8%	95.8%	95.8%
7/6/2024	11.4	15.2	11.8	8	95.8%	95.8%	95.8%	95.8%
7/7/2024	4	18.5	16.4	4.9	95.8%	95.8%	91.7%	95.8%
7/8/2024	8.9		5.6	4.7	95.8%	54.2%	91.7%	91.7%
7/9/2024	0.3		60.4	14.2	91.7%	54.2%	95.8%	95.8%
7/10/2024	0.4	18	5.6	0.2	95.8%	95.8%	95.8%	95.8%
7/11/2024	0.3	13.6	0.6	0.1	95.8%	95.8%	95.8%	95.8%
7/12/2024	3.6	2.9	5.3	3.7	100.0%	95.8%	95.8%	95.8%
7/13/2024	0.6	35.2	20.7	14.4	95.8%	95.8%	95.8%	95.8%
7/14/2024	2.7	9.9	4.5	5.7	95.8%	95.8%	95.8%	95.8%
7/15/2024	0.3	3.9	0.3	0.1	95.8%	95.8%	95.8%	95.8%
7/16/2024	0.3	35.6	13.2	9.3	95.8%	95.8%	95.8%	95.8%
7/17/2024	0.3	4.1	0.4	0.3	87.5%	95.8%	95.8%	95.8%
7/18/2024	0.3	29	1.1	0.3	91.7%	95.8%	87.5%	95.8%
7/19/2024	0.2	6.3	1.1	0.3	95.8%	91.7%	95.8%	95.8%
7/20/2024	0.7	17.3	11.5	7.7	95.8%	95.8%	95.8%	95.8%
7/21/2024	0.3	4.7	0.2	0.3	95.8%	95.8%	95.8%	95.8%
7/22/2024	0.4	7.6	0.7	0.3	95.8%	95.8%	95.8%	95.8%

	Daily Max 1-hr (ppb)				Daily Completeness			
Date	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail
7/23/2024	0.4	14.3	2.4	0.3	95.8%	95.8%	95.8%	95.8%
7/24/2024	4.9	20.3	8.5	7.7	75.0%	79.2%	79.2%	95.8%
7/25/2024	0.3	4.3	0.4	0.5	95.8%	95.8%	95.8%	95.8%
7/26/2024	0.4	8.9	0.5	0.3	95.8%	95.8%	95.8%	95.8%
7/27/2024	0.3	1.2	0.4	0.2	95.8%	95.8%	95.8%	95.8%
7/28/2024	0.4	2.7	0.2	0.3	95.8%	95.8%	95.8%	95.8%
7/29/2024	0.4	1.5	0.1	0.3	95.8%	91.7%	95.8%	95.8%
7/30/2024	0.3	1.2	0.1	0.2	95.8%	95.8%	91.7%	95.8%
7/31/2024	0.4	9.3	0.2	0.2	91.7%	95.8%	95.8%	91.7%
8/1/2024	0.7	11.7	1.8	7.6	95.8%	95.8%	95.8%	91.7%
8/2/2024	3.1	10.8	5	5.3	95.8%	95.8%	95.8%	95.8%
8/3/2024	5.5	7.9	5.2	4.4	95.8%	95.8%	95.8%	95.8%
8/4/2024	3.3		4.3	5.3	95.8%	54.2%	95.8%	95.8%
8/5/2024	1.9		0.6	0.8	95.8%	0.0%	95.8%	95.8%
8/6/2024	1.6		0.9	0.7	95.8%	37.5%	95.8%	95.8%
8/7/2024	10.4	10.7	6.7	6.3	95.8%	79.2%	95.8%	95.8%
8/8/2024	9	12.2	4.4	3	95.8%	95.8%	95.8%	87.5%
8/9/2024		9.6	3.6	12	45.8%	91.7%	95.8%	83.3%
8/10/2024	0.1	5	0.1	0.2	95.8%	95.8%	95.8%	95.8%
8/11/2024	0.1	13.2	4.2	16.7	95.8%	95.8%	95.8%	95.8%
8/12/2024	0.1	3.7	0.4	0.2	95.8%	95.8%	95.8%	95.8%
8/13/2024	0.1	8.8	0.2		95.8%	95.8%	95.8%	66.7%
8/14/2024	0.1	1.9	0.1	0.6	87.5%	87.5%	87.5%	95.8%
8/15/2024	18.5	24.4	12.8	10.6	95.8%	95.8%	95.8%	95.8%
8/16/2024	0.5	13.1	8	2.5	95.8%	87.5%	95.8%	95.8%
8/17/2024	6.3	2.5	5.4	7.8	95.8%	95.8%	95.8%	95.8%
8/18/2024	0.8	1	1	1.2	95.8%	95.8%	95.8%	95.8%
8/19/2024	0.1	8.6	1.1	0.2	95.8%	95.8%	95.8%	95.8%
8/20/2024	0.2	4.2	0.9	0.2	95.8%	95.8%	95.8%	95.8%
8/21/2024	0.9	2.3	0.6	0.7	95.8%	95.8%	95.8%	95.8%
8/22/2024	2.9	15	4.6	4	95.8%	95.8%	91.7%	95.8%
8/23/2024	0.2	1	0.2	0.3	91.7%	95.8%	95.8%	91.7%
8/24/2024	0.4	18.6	0.6	0.6	95.8%	95.8%	95.8%	95.8%
8/25/2024	0.2	6	7.2	0.3	95.8%	95.8%	95.8%	95.8%
8/26/2024	0.7	3.9	1.4	0.8	95.8%	95.8%	95.8%	95.8%
8/27/2024	0.1	7.7	0.8	0.3	95.8%	95.8%	95.8%	95.8%
8/28/2024	0.1	3.7	0.5	0.6	95.8%	91.7%	95.8%	95.8%
8/29/2024	0.2	6.9	1.1	0.2	95.8%	95.8%	95.8%	91.7%
8/30/2024	0.1	5.7	0.2	0.3	95.8%	87.5%	95.8%	95.8%
8/31/2024	28.8	51.5	16.8	11.5	95.8%	95.8%	95.8%	95.8%
9/1/2024	2.9	28.1	24.6	14.7	95.8%	95.8%	95.8%	95.8%
9/2/2024	0.2	3.6	0.2	0.3	95.8%	95.8%	95.8%	95.8%
9/3/2024	0.1	9	0.7	0.3	95.8%	95.8%	95.8%	95.8%
9/4/2024	4	22.9	17.1	8.1	95.8%	91.7%	95.8%	91.7%
9/5/2024	2	27.2	10.1	3.3	95.8%	95.8%	95.8%	95.8%
9/6/2024	0.3	22.6	1.8	0.4	95.8%	83.3%	95.8%	87.5%
9/7/2024	0.2	1.4	0.3	0.4	95.8%	95.8%	95.8%	95.8%
9/8/2024	0.2	9.6	4.5	0.4	95.8%	91.7%	95.8%	95.8%
9/9/2024	0.3	23.3	12.3	6.3	95.8%	95.8%	95.8%	95.8%
9/10/2024	2.2	7	4.6	4.8	95.8%	95.8%	95.8%	95.8%
9/11/2024	0.5	1.6	0.4	0.6	95.8%	95.8%	95.8%	95.8%

	Daily Max 1-hr (ppb)				Daily Completeness			
Date	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail
9/12/2024	3.3	23.8	5	2.9	95.8%	95.8%	95.8%	95.8%
9/13/2024	0.2	3.6	0.4	0.4	95.8%	95.8%	95.8%	95.8%
9/14/2024	6.7	1.6	0.9	1	95.8%	100.0%	91.7%	95.8%
9/15/2024	0.3	6.4		0.3	91.7%	100.0%	66.7%	91.7%
9/16/2024	0.4	1.3	0.4	0.3	79.2%	91.7%	75.0%	95.8%
9/17/2024	0.2	4.2	0.4	0.3	95.8%	91.7%	95.8%	95.8%
9/18/2024	0.2	6.7	0.9	0.3	95.8%	95.8%	91.7%	95.8%
9/19/2024	0.3	7.8	11.8		87.5%	95.8%	91.7%	70.8%
9/20/2024	0.2	8.7	1.3	0.3	95.8%	95.8%	95.8%	95.8%
9/21/2024	0.3	3.2	1.1	0.6	95.8%	95.8%	95.8%	95.8%
9/22/2024	0.2	7.8	0.2	0.3	95.8%	95.8%	95.8%	95.8%
9/23/2024	0.2	2	0.2	0.3	95.8%	95.8%	95.8%	95.8%
9/24/2024	10.1	4.6	2.3	1.1	95.8%	95.8%	95.8%	95.8%
9/25/2024	0.5	5.9	5.6	0.6	95.8%	100.0%	95.8%	95.8%
9/26/2024	1	3.4	0.6	0.7	95.8%	100.0%	95.8%	95.8%
9/27/2024	0.8	8.8	1.7	0.4	95.8%	100.0%	91.7%	95.8%
9/28/2024	2.2	0.7	0.4	0.4	95.8%	100.0%	95.8%	95.8%
9/29/2024	0.7	10.5	7.9	0.7	95.8%	100.0%	95.8%	95.8%
9/30/2024	5.5	4.9	1.4	1.9	95.8%	100.0%	95.8%	95.8%
10/1/2024	0.3	11.7	4.5	0.6	95.8%	95.8%	95.8%	95.8%
10/2/2024	0.4	3.5	0.7	0.3	95.8%	91.7%	91.7%	91.7%
10/3/2024	5.1	7.5	5.3	2.6	95.8%	83.3%	91.7%	95.8%
10/4/2024	0.4	9.1	1.8	1.4	95.8%	75.0%	95.8%	95.8%
10/5/2024	0.2	4.3	0.6	0.3	95.8%	95.8%	95.8%	95.8%
10/6/2024	0.7	4.2	1.6	1.3	100.0%	95.8%	95.8%	95.8%
10/7/2024	0.2	3.5	0.3	0.4	95.8%	91.7%	91.7%	95.8%
10/8/2024	0.2	3.7	0.7	0.3	91.7%	95.8%	95.8%	91.7%
10/9/2024	0.2	2.8	0.7	0.4	95.8%	95.8%	95.8%	95.8%
10/10/2024	0.3	3.2	0.4	2	95.8%	95.8%	95.8%	95.8%
10/11/2024	0.2	1.3	0.3	0.3	95.8%	95.8%	95.8%	95.8%
10/12/2024	5.6	3.7	4.7	5.4	95.8%	95.8%	95.8%	95.8%
10/13/2024	0.3	3.5	0.6	0.5	95.8%	95.8%	95.8%	95.8%
10/14/2024	0.2	4.1	1.7	0.8	95.8%	95.8%	95.8%	95.8%
10/15/2024	2.9	3.6	1	0.9	95.8%	95.8%	95.8%	95.8%
10/16/2024	0.4	9.8	3.5	0.7	95.8%	95.8%	95.8%	95.8%
10/17/2024	0.1	9.8	3.6	0.3	83.3%	95.8%	95.8%	95.8%
10/18/2024	0.3	6.7	0.2	0.4	95.8%	95.8%	95.8%	95.8%
10/19/2024	3.3	4.2	1.4	0.9	95.8%	95.8%	95.8%	95.8%
10/20/2024	0.2	11.3	1.8	0.3	95.8%	95.8%	95.8%	95.8%
10/21/2024	0.3	0.8	0.1	0.2	95.8%	95.8%	79.2%	95.8%
10/22/2024		14.3	4.8	17.1	62.5%	95.8%	95.8%	95.8%
10/23/2024	0.6	16	7.6	0.5	95.8%	95.8%	95.8%	95.8%
10/24/2024	0.2	12.7	7.5	0.2	95.8%	91.7%	95.8%	95.8%
10/25/2024	0.3	1	0.3	0.3	95.8%	95.8%	95.8%	95.8%
10/26/2024	0.9	3.3	1.8	1.6	95.8%	95.8%	95.8%	95.8%
10/27/2024	0.2	3	0.2	0.4	95.8%	95.8%	95.8%	95.8%
10/28/2024	0.3	1.9	0.7	0.7	95.8%	95.8%	95.8%	95.8%
10/29/2024	0.4	2.2	0.2	0.4	95.8%	95.8%	95.8%	95.8%
10/30/2024	0.5	3.1	0.2	0.4	87.5%	95.8%	83.3%	87.5%
10/31/2024	0.7	1.8	0.2	0.3	91.7%	87.5%	95.8%	91.7%
11/1/2024	0.2	1.1	0.2	0.4	95.8%	95.8%	95.8%	95.8%

	Daily Max 1-hr (ppb)				Daily Completeness			
Date	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail
11/2/2024	1.9	2.5	0.5	1.7	95.8%	95.8%	95.8%	95.8%
11/3/2024	1.4	15.8	0.6	0.6	95.8%	95.8%	95.8%	95.8%
11/4/2024	1	7.4	3.2	4	95.8%	95.8%	95.8%	91.7%
11/5/2024	0.7	16.5	10.6	0.6	95.8%	95.8%	95.8%	95.8%
11/6/2024	0.2	3.1	0.6	0.6	95.8%	83.3%	87.5%	95.8%
11/7/2024	0.3	4.4	1.1	0.7	95.8%	95.8%	91.7%	95.8%
11/8/2024	0.2	3.9	2.6	0.4	95.8%	91.7%	87.5%	95.8%
11/9/2024	20	4.7	3.8	5.3	95.8%	95.8%	95.8%	95.8%
11/10/2024	0.2	1.5	0.1	0.4	95.8%	95.8%	95.8%	95.8%
11/11/2024	0.2	2.5	0.1	0.5	95.8%	95.8%	95.8%	95.8%
11/12/2024	0.4	4.4	1	1	95.8%	91.7%	95.8%	95.8%
11/13/2024	0.2	1.5	0.1	0.4	95.8%	95.8%	95.8%	95.8%
11/14/2024	0.2	16.2	2.3	0.4	95.8%	91.7%	79.2%	95.8%
11/15/2024	0.2	2.7	0.3	0.3	79.2%	75.0%	95.8%	95.8%
11/16/2024	0.2	10.2	0.6	0.4	95.8%	91.7%	95.8%	95.8%
11/17/2024	0.1	6.2	0.1	0.4	95.8%	95.8%	95.8%	95.8%
11/18/2024	0.9	4.9	0.4	0.7	95.8%	95.8%	95.8%	95.8%
11/19/2024	0.5	1.1	0.2	0.3	95.8%	91.7%	95.8%	95.8%
11/20/2024	0.2	0.3	0.1	0.3	100.0%	95.8%	95.8%	95.8%
11/21/2024	0.2	0.4	0.2	0.2	95.8%	95.8%	95.8%	95.8%
11/22/2024	0.2	0.3	0.2	0.3	91.7%	95.8%	91.7%	95.8%
11/23/2024	0.2	0.3	0.2	0.3	91.7%	95.8%	95.8%	91.7%
11/24/2024	0.2	0.4	0.1	0.2	95.8%	95.8%	95.8%	95.8%
11/25/2024	0.1	0.8	0.2	0.2	95.8%	95.8%	95.8%	95.8%
11/26/2024	0.2	1.2	0.2	0.2	95.8%	95.8%	95.8%	95.8%
11/27/2024	0.7	4.3	1	1.6	95.8%	95.8%	95.8%	95.8%
11/28/2024	0.2	1.5	0.3	0.3	95.8%	95.8%	91.7%	95.8%
11/29/2024	0.2	7.7	2.5	1.5	95.8%	91.7%	95.8%	95.8%
11/30/2024	0.2	0.3	0.2	0.4	91.7%	95.8%	91.7%	95.8%
12/1/2024		9.3	1.7	0.9	70.8%	95.8%	95.8%	95.8%
12/2/2024	0.2	1.5	0.2	0.3	95.8%	95.8%	95.8%	95.8%
12/3/2024	0.2	7.7	0.7	0.3	91.7%	91.7%	95.8%	79.2%
12/4/2024	0.3	1.1	0.9	1.3	95.8%	95.8%	91.7%	95.8%
12/5/2024	0.3	8.9	0.5	0.7	95.8%	95.8%	95.8%	95.8%
12/6/2024	0.2	10.1	0.6	0.7	95.8%	75.0%	95.8%	95.8%
12/7/2024	0.3	5.6	2.6	0.4	95.8%	91.7%	95.8%	95.8%
12/8/2024	0.6		0.3	0.6	95.8%	66.7%	95.8%	95.8%
12/9/2024	2.3	0.6	1.1	3.7	95.8%	79.2%	95.8%	95.8%
12/10/2024	1.9	0.9	0.4	0.8	95.8%	91.7%	95.8%	95.8%
12/11/2024	0.2	0.5	0.3	0.6	95.8%	95.8%	95.8%	95.8%
12/12/2024	0.5	1.9	0.6	0.7	95.8%	95.8%	95.8%	95.8%
12/13/2024	1.5	0.4	0.5		83.3%	95.8%	95.8%	70.8%
12/14/2024	0.2	0.8	0.3	0.4	95.8%	95.8%	95.8%	95.8%
12/15/2024	0.8	2.2	0.6	1.4	95.8%	95.8%	91.7%	95.8%
12/16/2024	0.2	0.3	0.3	0.3	83.3%	95.8%	91.7%	91.7%
12/17/2024	0.3	0.3	0.3	0.3	87.5%	95.8%	95.8%	95.8%
12/18/2024	0.3	0.2	0.2	0.4	87.5%	95.8%	95.8%	95.8%
12/19/2024	0.3	0.2	0.2	0.3	95.8%	95.8%	91.7%	95.8%
12/20/2024	0.3	1.8	0.2	0.3	95.8%	87.5%	95.8%	95.8%
12/21/2024	0.4	1.2	0.3	0.5	95.8%	95.8%	95.8%	95.8%
12/22/2024	0.4	1	0.4	0.4	95.8%	95.8%	95.8%	95.8%

Date	Daily Max 1-hr (ppb)				Daily Completeness			
	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail	Kitamaat Village	Industrial Ave.	Riverlodge	Whitesail
12/23/2024	1.1	3.3	0.5	0.5	95.8%	95.8%	95.8%	95.8%
12/24/2024	0.5	9.2	0.6	0.8	95.8%	95.8%	95.8%	95.8%
12/25/2024	0.4	0.9	0.5	0.5	95.8%	95.8%	95.8%	95.8%
12/26/2024	1.3	2.5	0.8	1.2	95.8%	95.8%	95.8%	95.8%
12/27/2024	0.4	0.9	0.4	0.5	95.8%	95.8%	95.8%	95.8%
12/28/2024	0.3	0.8	0.3	0.4	95.8%	95.8%	95.8%	95.8%
12/29/2024	0.3	1.6	0.4	0.4	95.8%	95.8%	95.8%	95.8%
12/30/2024	0.3	0.9	0.4	0.3	95.8%	95.8%	87.5%	95.8%
12/31/2024	0.3	0.5	0.4	0.2	95.8%	95.8%	95.8%	95.8%

Appendix C: Technical Memo W13 – Aquatic Ecosystems Actions and Analyses

The following pages contain **B.C. Works SO$_2$ EEM Program Technical Memo W13**, in PDF format.

B.C. Works SO_2 EEM Program – Technical Memo W13

Aquatic Ecosystems Actions and Analyses

April 2025

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1 Introduction

This Technical Memo provides additional information on the data and analyses in support of the 2024 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 2024 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, 2024). 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 completed as part of the KAA (ESSA et al. 2014a).

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, 2023, and 2024 as per rationale summed up in the following recommendation from the SO_2 EEM Program 2023 EEM Annual Report:

> *We recommend sampling LAK027 again in 2024. 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 negated the ability to provide the intended comparison. In 2023, the region was again subject to anomalous conditions (i.e., exceptionally dry conditions and substantial increase in emissions from a greatly reduced level during 2022). LAK027 does not show any evidence of acidification. With another year, we will have sampling across four different types of years and should be able to make a more robust confirmation of that conclusion.*

In 2024, Limnotek sampled the eleven EEM lakes plus LAK027 according to the 2024 Aquatics Work Plan. The sampling methodology is described in detail in Limnotek (2025). Table 2-1 summarizes the sampling history of these 12 lakes. Figure 2-1 shows a map of the lakes sampled in 2024.

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													Rationale
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	
	STAR	EEM	EEM	EEM	EEM	EEM	EEM	EEM	EEM	EEM	EEM	EEM	EEM	
LAK006	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	EEM sensitive lake, included in Phase III
LAK012	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
LAK022	✓	✓	✓	✓	✓	✓	✓	✓	‡	✓	✓	✓	✓	
LAK023	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
LAK028	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
LAK042	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
LAK044	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
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.
NC194		✓†		✓	✓	✓	✓	✓	‡	✓	✓	✓	✓	
DCAS14A		✓†		✓	✓	✓	✓	✓	‡	✓	✓	✓	✓	

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

‡ LAK022 and the three control lakes are only accessible by helicopter and therefore were unable to be sampled in 2020 due to COVID protocols.

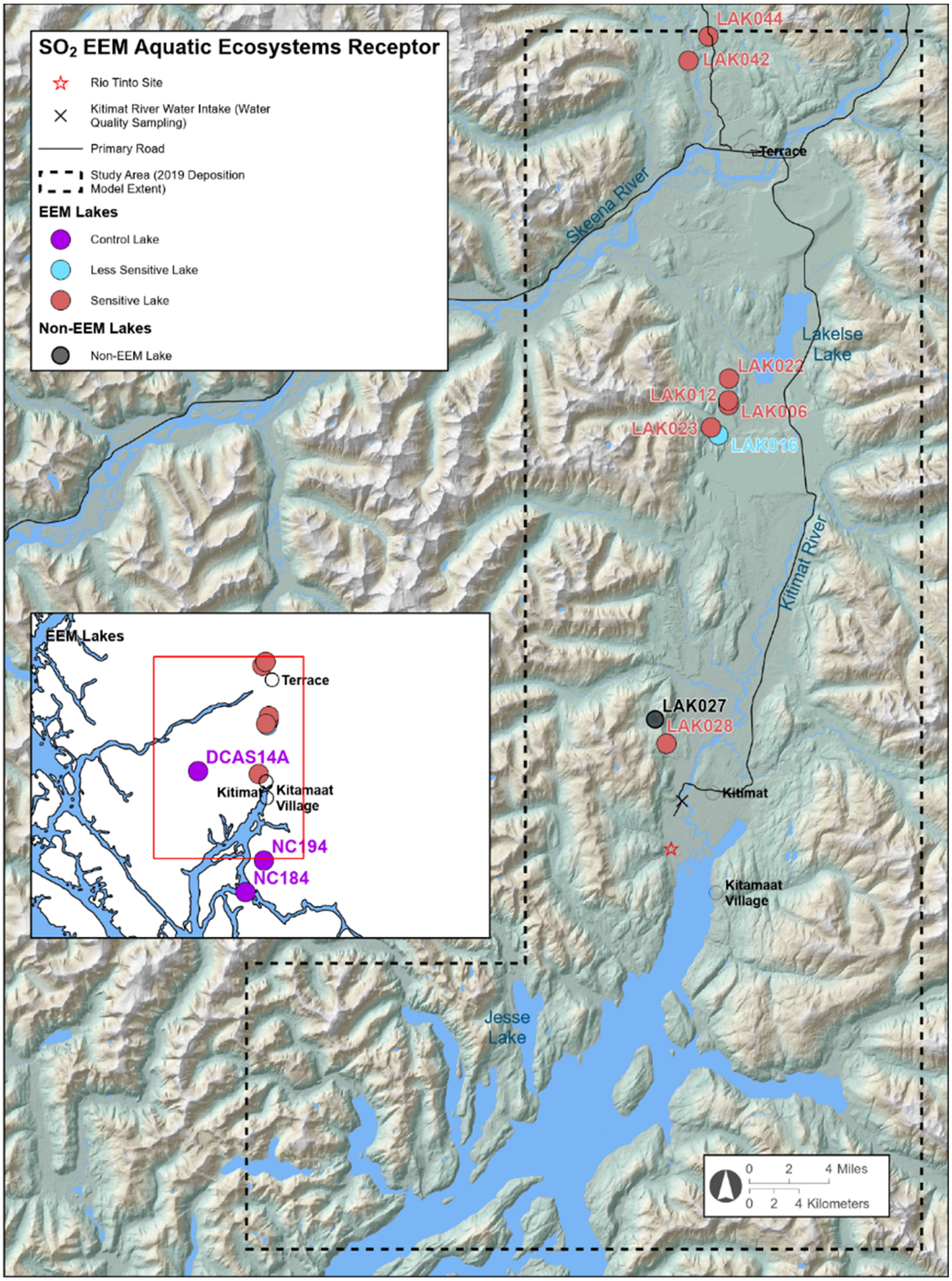

Figure 2-1. Location of the lakes in the EEM Program, including seven sensitive lakes (red), one less sensitive lake (blue) and three control lakes (purple). LAK027 was resampled in 2024 to compare with the STAR results.

Sampling frequency

Sampling frequency remained the same as last year:

- The sensitive lakes LAK006, LAK012, LAK023, LAK028, LAK042, and LAK044 were each sampled 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 May 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 and continuous temperature monitoring across the depth profile. This work was planned, implemented and documented by Limnotek. The methods and results for 2024 are reported in Limnotek (2025).

Water chemistry data

There were no differences in the water chemistry analyses completed from the 2024 sampling compared to previous years. Continuing from 2020, analyses of Gran ANC are now *only* performed by the BASL facility (University of Alberta).

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

The 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 2021-2024 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.

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 fifth 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 current averaging period (i.e., the average of the 3 most recent years; 2022-2024) and the pre-KMP baseline (2012 for the sensitive and less sensitive lakes; 2013 for the control lakes). 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 values of the current averaging period have exceeded the *level of protection* thresholds, and b) the % belief that the changes from the baseline period to the current averaging 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 (Base Cation Surplus)) 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 the result for **either** threshold is **"moderate"** and the result for the other threshold is **"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. For example, naturally acidified lakes with higher concentrations of organic acids likely have always been below the *level of protection* threshold, but if they have not exceeded the *change limit* threshold then aquatic biota are unlikely to be negatively impacted.

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 CBANC (as an informative method, as the KPI is not based on this statistical approach) as well as for the pH, Gran ANC, and BCS informative indicators.

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).

We are using data from the two NADP stations (Haul Road, BC22; Lakelse Lake, BC23) to provide the precipitation context (and by proxy, the hydrologic context of the lakes) for 2024.

In prior EEM reports, we have observed that precipitation during the period from August to October is correlated with the chemistry of water sampled in October; drier years show increases in CBANC and pH, while wetter years show decreases. Precipitation data from the Haul Road and Lakelse Lake NADP stations for August through October indicate that 2024 was one of the wettest years in recent history (Table 2-2 andTable 2-3). For Haul Road and Lakelse Lake NADP stations, total precipitation levels for August through October in 2024 were approximately 1.5 times greater than the average of the previous five years (2019-2023), and about 2.9 and 2.6 times greater (respectively) than the very dry conditions in 2023. Cumulative precipitation in 2024 far exceeded that of 2022 and 2023 (Figure 2-2), with particularly high rainfall recorded in October. Although 2024 recorded the highest total precipitation for the August–October period, 2021 had a higher cumulative total prior to mid-October, when sampling is usually completed.

Further investigation suggests that a more appropriate indicator of precipitation influences on water chemistry is the cumulative total precipitation over August and September. For example, in 2024, all lakes were sampled on September 28th and the six sensitive lakes with multiple samples within the fall index period were sampled from September 24th to October 17th. When considering only August-September, cumulative precipitation was still much higher in 2024 than 2023 (287% for Haul Road and 313% for Lakelse Lake) but notably lower than the exceptionally wet year of 2021 (31% lower for Haul Road and 24% lower for Lakelse Lake). The 2024 cumulative precipitation levels for August-September were only similar to the 2019-2023 average for Haul Road (110%) and slightly higher for Lakelse Lake (136%).

Table 2-2. Total Monthly Precipitation (mm) at Haul Road NADP station (BC22) for 2019-2024.

	2019	2020	2021	2022	2023	2024
	BC22	BC22	BC22	BC22	BC22	BC22
August	104	262	55	146	33	51
September	143	207	468	120	92	308
October	242	215	304	398	173	494
Total	489	684	826	664	298	852

Table 2-3. Total Monthly Precipitation (mm) at Lakelse Lake NADP station (BC23) 2019-2024.

	2019	2020	2021	2022	2023	2024
	BC23	BC23	BC23	BC23	BC23	BC23
August	52	162	35	64	15	34
September	80	64	284	68	62	207
October	142	142	156	224	119	274
Total	273	368	476	356	197	515

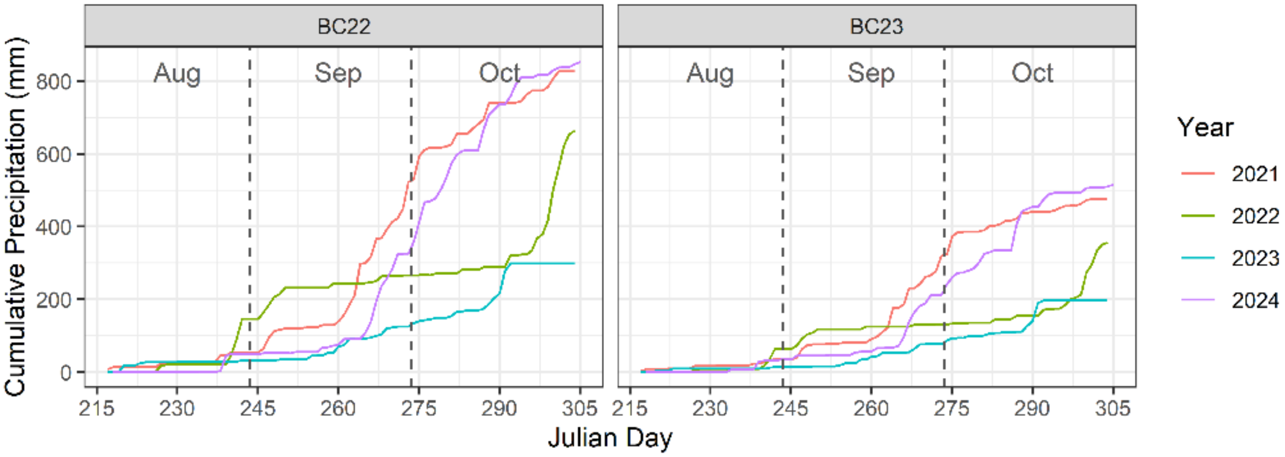

Figure 2-2. Cumulative precipitation at Haul Road (BC22) and Lakelse Lake (BC23) NADP stations for August to October in 2021, 2022, 2023, and 2024.

2.5 Episodic Acidification

We reviewed the data record from the continuous pH monitors installed in LAK006 and LAK028 to identify any notable pH declines. 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[1] (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.

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

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). 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 it makes more sense to have the *level of protection* node earlier in the sequence than the two change-based nodes.

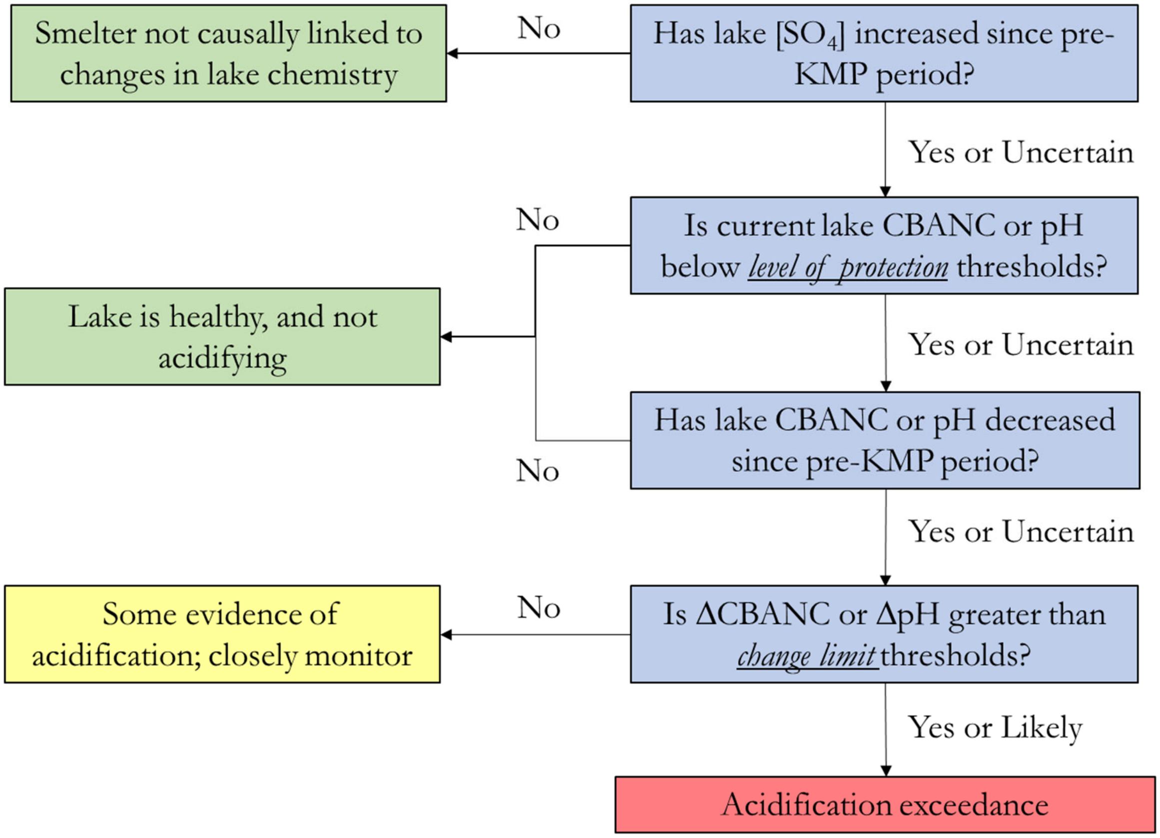


Figure 2-3. The Evidentiary Framework. The framework developed in the 2019 Comprehensive Review was revised in the SO_2 EEM Program 2020 Annual Report order to align with the two-threshold structure for the KPI and informative indicators in the SO_2 EEM Program Phase III Plan.

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. A map of the observed changes in [SO_4^{2-}], CBANC, and pH at the EEM lakes is shown in Figure 3-1. Changes are reported in terms of the difference between the current averaging period (2022-2024) 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 in detail. As already stated in previous years (e.g., ESSA 2018, Technical Memo W07), year-to-year changes should be interpreted cautiously:

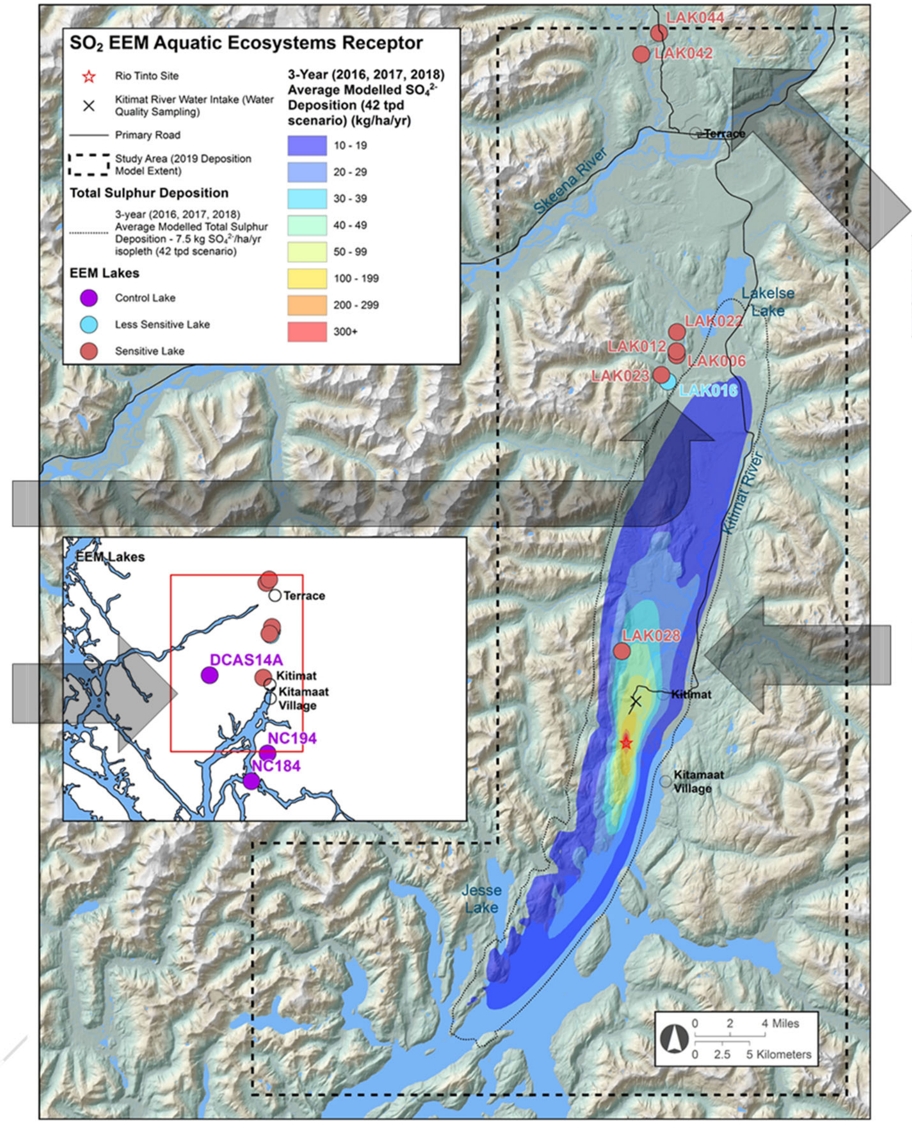
> *"… annual changes should be interpreted with substantial caution due to the combination of large natural variation (both within and between years) and limitations on measurement precision… multiple years of observations are required to reliably detect changes in mean pH, Gran ANC and SO_4; it is risky 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. We still examine the annual changes in the context of understanding the extent to which any dominant factors in a particular year (e.g., anomalous hydrologic or emissions conditions) result in a pronounced regional pattern, but we do not analyze or interpret all of the annual changes observed in all of the metrics.

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 current averaging period (2022-2024) 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 to 2024 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 2023 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	17.1 [-]	9.7 [-]	15.7 [ ]	0.3 [+]	3.7 [+]	0.3 [-]	20.9 [-]	0.2 [-]	10.5 [-]
LAK012	-15.3 [-]	1.3 [-]	-16.9 [-]	0.4 [ ]	4.7 [-]	0.3 [-]	-10.4 [-]	2.1 [+]	-11.1 [-]
LAK022	7.7 [+]	2.3 [+]	4.9 [-]	0.1 [+]	9.3 [+]	0.6 [-]	17.1 [+]	1.0 [+]	9.5 [+]
LAK023	6.0 [-]	1.9 [-]	2.1 [-]	0.2 [ ]	1.1 [+]	0.8 [-]	7.4 [-]	0.8 [+]	4.8 [-]
LAK028	-11.7 [-]	5.1 [-]	-16.5 [-]	0.1 [ ]	64.9 [+]	1.0 [-]	54.0 [+]	2.2 [+]	37.2 [+]
LAK042	9.9 [-]	30.5 [+]	25.6 [+]	0.6 [+]	1.5 [+]	-3.1 [-]	11.5 [-]	0.0 [+]	5.8 [-]
LAK044	8.5 [-]	4.5 [ ]	8.0 [ ]	0.2 [ ]	-2.9 [-]	0.1 [-]	5.7 [-]	0.6 [+]	1.4 [-]
Total ↑	**5**	**7**	**5**	**7**	**6**	**6**	**6**	**7**	**6**
Total ↓	**2**	**0**	**2**	**0**	**1**	**1**	**1**	**0**	**1**
LAK016	6.7 [-]	17.7 [-]	3.7 [+]	0.1 [ ]	12.8 [+]	0.6 [-]	20.4 [+]	1.8 [+]	11.5 [+]
Total ↑	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Total ↓	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
DCAS14A	23.3 [-]	8.3 [+]	23.9 [+]	-0.1 [+]	0.8 [+]	-0.1 [-]	20.5 [+]	-2.2 [+]	14.2 [+]
NC184	12.6 [+]	17.9 [+]	23.2 [+]	0.2 [+]	-0.9 [+]	-2.1 [-]	11.6 [+]	-4.5 [+]	11.3 [+]
NC194	4.0 [+]	-2.2 [-]	3.1 [+]	-0.2 [ ]	-1.6 [+]	0.2 [ ]	2.5 [+]	-1.4 [+]	2 [+]
Total ↑	**3**	**2**	**3**	**1**	**1**	**1**	**3**	**0**	**3**
Total ↓	**0**	**1**	**0**	**2**	**2**	**2**	**0**	**3**	**0**

SO_4*, 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.



	2012 to 2022-24		
LAKE	ΔSO_4^{2-}	Δ CBANC	ΔpH
LAK006	3.7	17.1	0.3
LAK012	4.7	-15.3	0.4
LAK022	9.3	7.7	0.1
LAK023	1.1	6.0	0.2
LAK016	12.8	6.7	0.1

	2012 to 2022-24		
LAKE	ΔSO_4^{2-}	Δ CBANC	ΔpH
DCAS14A	0.8	23.3	-0.1
NC184	-0.9	12.6	0.2
NC194	-1.6	4.0	-0.2

	2012 to 2022-24		
LAKE	ΔSO_4^{2-}	Δ CBANC	ΔpH
LAK042	1.5	9.9	0.6
LAK044	-2.9	8.5	0.2

	2012 to 2022-24		
LAKE	ΔSO_4^{2-}	Δ CBANC	ΔpH
LAK028	64.9	-11.7	0.1

Figure 3-1. Observed changes in SO_4^{2-}, CBANC and pH from the baseline period (2012) to the current averaging period (2022-2024). Green cells indicate increases and red cells indicate decreases.

Emissions Context for 2024

As reported in previous years' Annual Reports, average daily smelter emissions declined moderately from 2019 to 2020 (30.2 to 24.2 tpd), then significantly in the latter half of 2021 (down to 5 tpd for Aug-Dec 2021), remained low through 2022 (7.4 tpd), and then increased through 2023 (average of 25.8 tpd). In 2024, average emissions (30.5 tpd) were 18% higher than in 2023, and similar to emissions during 2017-2019 (29.7-30.6 tpd). The 12- and 6-month average emissions at the time of fall sampling in 2024 (30.7 and 30.5 tpd, respectively) also were within the range observed in 2017-2019. The moderate one-year increase in emissions might influence lake chemistry but we do not expect the emissions in 2024 to contribute to any major changes in lake chemistry data (unlike the major fluctuations in emissions observed over 2020-2023).

Analyses of change based on the recent 3-year average

To protect aquatic ecosystems in the sensitive lakes, we want to avoid declines in CBANC, Gran ANC, BCS, and pH (i.e., the KPI and other acidification informative indicators) that are greater than the established thresholds, using 2012 as a pre-KMP baseline. We use the average of the most recent 3 years to dampen the effects of an unusual year.

For LAK012, the long-term decline in CBANC (-15.3 μeq/L) results from CBANC dropping in 2023 to levels on par with the lowest CBANC levels observed for the lake (~90 μeq/L; Table 3-3) then remaining at that level in 2024. The ANC *change limit* threshold for LAK012 is -16.3 μeq/L. For BCS, the annual mean value has decreased for the second year in a row and the 2024 value represents the lowest mean value across the period of record. However, LAK012 still shows a small long-term increase in Gran ANC (1.3 μeq/L) and the second largest increase in pH across all EEM lakes (+0.4 pH units, relative to a pH *change limit* threshold of -0.3 pH units). LAK012 is the only lake with a decline in base cations (no associated *change limit* threshold).

In LAK028 (the lake closest to the smelter with the highest deposition) the long-term decline in CBANC (-11.7 μeq/L) results from an exceptionally low CBANC value in 2024 (-21.1 ueq/L; the previous lowest mean CBANC was -8.1 μeq/L in 2013). The 2024 CBANC represents the largest annual change on record (a decline of ~35 μeq/L from 2023); however, one-year declines of ~25 μeq/L have previously been observed in LAK028 in 2013 and 2016. The ANC *change limit* threshold for LAK028 is -13.4 μeq/L. The significant drop in CBANC in 2024 is the result of a large annual increase in SO_4 of a greater magnitude than the annual increase in total base cations. Comparing the current averaging period to 2012, mean $[SO_4^{2-}]$ is estimated to have increased by 64.9 μeq/L, which is roughly balanced by an increase in total base cations (ΣBC*) of 54.0 μeq/L over the same period. The observed changes in ΣBC* and SO_4^{2-} essentially explain the change in CBANC, a decline of -11.7 μeq/L. CBANC equals the sum of base cations minus the sum of strong acid anions, and $\Delta\Sigma BC^* - \Delta[SO_4^{2-}] = 54.0 - 64.9 = -10.9$, very close to the -11.7 μeq/L change in CBANC. However, chloride (a secondary strong acid anion) also increased by 68% in 2024, from 6.6 to 11.1 μeq/L, which represents a higher concentration than 2020-2023 but similar to the rest of the period of record. Gran ANC shows a long-term increase (5.1 μeq/L) in LAK028 and there continues to be no decline in mean pH (+0.1 pH units), similar to the results reported in the last couple of years. LAK028 showed a decline in BCS of -16.5 μeq/L since the pre-KMP baseline. Though BCS has shown considerable variation in LAK028 (Table 3-2), the value in 2024 (-52.0 μeq/L) is the lowest value on record, with the second lowest value in 2013 (-40.2). The BCS *change limit* threshold is -13 μeq/L. The empirical analyses thus show that LAK028 has exceeded the *change limit* threshold for BCS in addition to having been predominantly below the *level of protection* threshold – therefore empirical results show that LAK028 exceeds the thresholds for the BCS informative indicator.

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	2023	2024
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	-2.5	-52.0

None of the sensitive or less sensitive lakes are showing any decline in pH. LAK022, which in prior EEM reports had been the only lake with a decline in pH (i.e., 2021 and 2022 Annual Reports), now shows a small long-term increase in pH. All of the sensitive and less sensitive lakes show a long-term increase in pH within the range of 0.1 to 0.6 pH units. By contrast, two of the control lakes (DCAS14A and NC194) show a long-term decline of 0.1 and 0.2 pH units, respectively, with the third control lake (NC184) showing an increase of 0.2 pH units. The causes for the declines in DCAS14A and NC194 are not clear, but they're not related to SO_2, since [SO_4] has shown very limited change in all three control lakes (i.e., within +/- 2.0 μeq/L; Table 3-1).

Figure 3-2 and Figure 3-3 show the changes in the same water chemistry parameters graphically. These figures provide a regional picture of the distribution and variability in the observed changes in sensitive lakes between 2012 and 2022-2024.

For additional reference, Table 3-3 and Table 3-4 show the CBANC and pH values, respectively, over the period of record for EEM lakes, together with four summary metrics: 1) values for the current averaging period (2022-2024); 2) differences between the current averaging period and the pre-KMP baseline (2012); 3) differences between the current averaging period and the transition period baseline (2012-2014); plus 4) the values for the averaging period used in the 2019 Comprehensive Review (2016-2018) for reference. The changes in CBANC are generally similar using both the pre-KMP and transition period baselines (Table 3-3). The two lakes with declines in CBANC (LAK012 and LAK028) both show smaller decreases in CBANC using the transition period baseline than with the pre-KMP baseline. The changes in pH were consistently less positive (or more negative) for the sensitive and less sensitive lakes when using the transition period baseline instead of the pre-KMP baseline (Table 3-4), but no lakes showed a pH decline greater than the 0.3 unit change limit threshold. For the control lakes, the two baselines are identical because they were only sampled once during the period of 2012 to 2014 (i.e., 2013).

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 thirteen years of annual monitoring (2012-2024). Similar figures are also included for the three control lakes based on their ten years of monitoring (2013, 2015-2019, and 2021-2024).

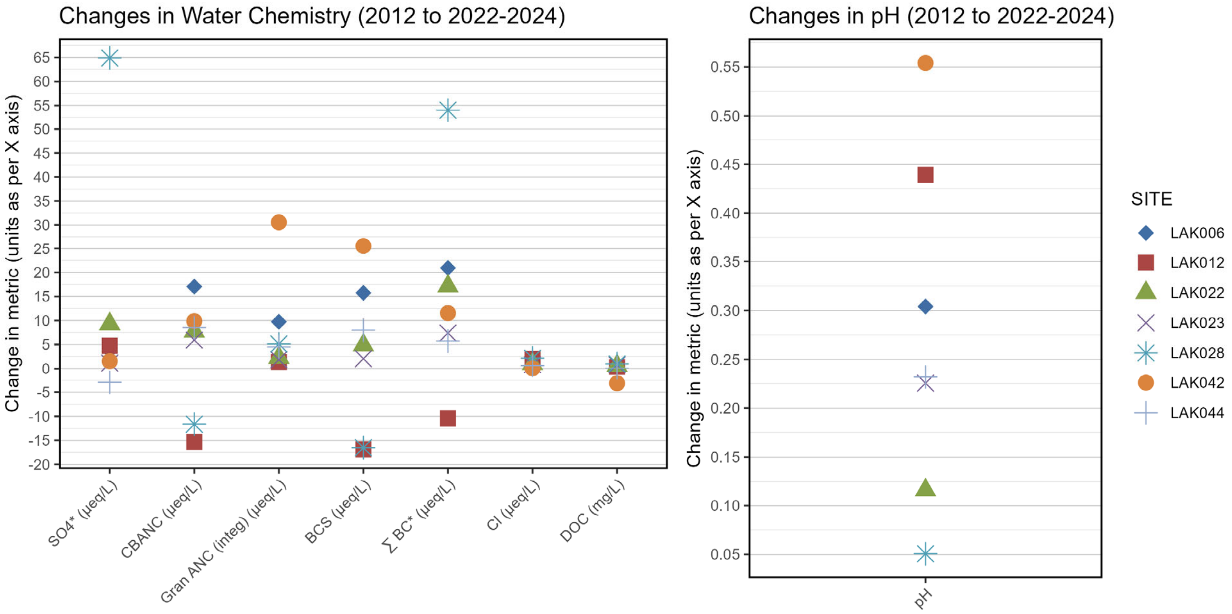


Figure 3-2. Changes in water chemistry metrics (left panel) and pH (right panel) across the seven sensitive EEM lakes, from 2012 to 2022-2024. Values shown are the mean 2022-2024 value minus the mean 2012 value. The large increase in lake SO_4^{2-} in LAK028 has been buffered by a large increase in base cations, due to cation exchange in watershed soils.

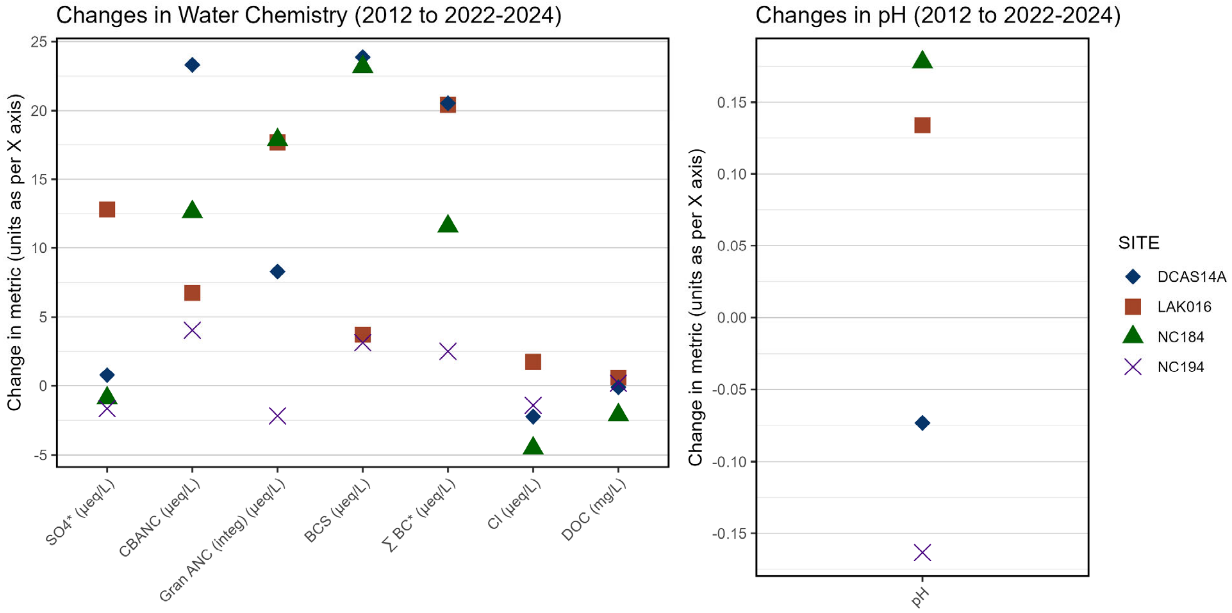


Figure 3-3. Changes in water chemistry metrics (left panel) and pH (right panel) across the less sensitive lake (LAK016) and the three control lakes, from 2012 to 2022-2024. Values shown are the mean 2022-2024 value minus the mean 2012 value. All three control lakes have shown minimal change in SO_4* (left panel); the pH decreases (right panel) largely reflects increased precipitation in 2024.

Table 3-3. CBANC values over period of record for EEM lakes, average CBANC values for the current averaging 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)													Averaging period		Change from baseline to current average (2022-24)	
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2016-18 (CR)	2022-24 (Current)	Pre-KMP baseline (2012) †	Transition Period (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	66.6	62.2	58.0	66.3	17.1	17.9
LAK012	114.5	97.5	99.8	106.1	103.2	101.1	90.4	96.5	142.1	101.2	112.4	92.2	92.8	98.2	99.1	-15.4	-4.8
LAK022	67.9	62.0	76.1	75.2	80.3	70.4	76.6	74.8		68.8	75.4	81.4	70.2	75.8	75.7	7.8	7.0
LAK023	46.9	37.7	59.4	58.0	59.5	59.9	61.3	59.4	66.6	56.2	54.0	57.0	47.5	60.2	52.9	6.0	4.9
LAK028	**16.0**	**-8.1**	31.2	38.6	**12.3**	**0.7**	**8.4**	**4.5**	**8.0**	**11.7**	**19.3**	**14.7**	**-21.1**	**7.1**	**4.3**	-11.7	-8.7
LAK042	47.2	55.1	51.6	55.4	64.0	63.1	50.4	52.1	79.5	62.4	52.8	57.2	61.2	59.2	57.1	9.9	5.8
LAK044	**8.0**	**8.9**	**12.6**	**16.4**	**13.9**	**13.8**	**13.2**	**14.8**	**14.5**	**17.1**	**16.8**	**16.7**	**16.1**	**13.6**	**16.5**	8.5	6.7
LAK016	127.2	108.7	132.5	147.1	140.8	125.3	138.1	129.8		138.1	141.4	128.1	132.3	134.7	133.9	6.7	11.1
DCAS14A		53.5		74.9	72.7	67.8	79.0	81.1		63.8	70.9	84.2	75.4	73.2	76.8	23.3	23.3
NC184		80.4		73.0	94.6	76.3	95.0	86.1		61.2	85.3	111.5	82.3	88.6	93.0	12.6	12.6
NC194		35.6		40.9	40.0	46.5	43.1	46.7		35.6	36.3	43.1	39.7	43.2	39.7	4.1	4.1

†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 current averaging 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).

	Mean pH values													Post-KMP and current averaging period		Change from baseline to current average (2022-24)	
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2016-18 (CR)	2022-24 (Current)	Pre-KMP baseline (2012) †	Transition Period (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	6.2	**5.9**	6.0	6.1	0.3	0.1
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	**5.9**	6.2	6.1	0.4	0.1
LAK022	**5.9**	6.2	6.3	6.1	6.1	6.1	6.1	6.1		**5.4**	6.1	6.1	**5.9**	6.1	6.0	0.1	-0.1
LAK023	**5.7**	**6.0**	**5.9**	**5.9**	**5.9**	**5.9**	**6.0**	**5.8**	**5.9**	**5.7**	**6.0**	6.0	**5.8**	**5.9**	**5.9**	0.2	0.1
LAK028	**5.0**	**5.2**	**5.3**	**5.1**	**5.0**	**4.8**	**5.3**	**5.2**	**4.9**	**4.7**	**5.2**	**5.2**	**4.7**	**5.0**	**5.0**	0.1	-0.1
LAK042	**4.7**	**5.5**	**5.1**	**5.4**	**5.4**	**5.2**	**5.1**	**5.4**	**4.6**	**4.6**	**5.4**	**5.4**	**4.9**	**5.2**	**5.2**	0.6	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**	**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	6.5	6.3	6.7	6.4	0.1	-0.1
DCAS14A		6.5		6.6	6.6	6.6	6.8	6.6		**5.9**	6.4	6.5	6.3	6.6	6.4	-0.1	-0.1
NC184		**5.7**		**5.5**	**5.8**	**5.4**	6.2	**5.7**		**5.1**	**5.8**	6.4	**5.5**	5.8	**5.9**	0.2	0.2
NC194		6.6		6.5	6.4	6.4	6.5	6.4		**5.9**	6.3	6.8	6.1	6.4	6.4	-0.2	-0.2

†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 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, the difference between the 2024 and 2012, and the difference between the current averaging period and 2012. As explained earlier, LAK027 was resampled in multiple years due to the influence of anomalous hydrologic conditions and/or emissions in each of those years. Therefore, we compare 2024 to 2012 to achieve the original intent of resampling this lake and assess the changes in terms of the current averaging period for consistency with the rest of the EEM Program.

All of the lake chemistry metrics in Table 3-5 except pH show increases, often substantial, from 2012 – both in terms of 2024 alone and the 3-year average. CBANC, Gran ANC, SO_4, base cations, and Cl all increased by 30-60% from 2012 to 2024, DOC increased by 400%, BCS increased moderately, and pH decreased by 0.4 pH units. When compared to the average of 2022-2024, the increases were generally much larger and pH decreased by only 0.1 pH units. The 3-year average pH (6.5) is well above the level of protection threshold of 6.0.

The relative difference between the 2012 to 2024 increases in ΣBC* (96.7 μeq/L) and SO_4^{2-} (64.8 μeq/L) almost perfectly explains the 31.5 μeq/L increase in CBANC between 2012 and 2024 (i.e., 96.7 μeq/L – 64.8 μeq/L = 31.9 μeq/L). The data suggest that LAK027 demonstrates a high level of watershed neutralization of deposited SO_4^{2-}, as well as hydrologic change. The implied F-factor ($\Delta BC^*/\Delta SO_4^*$ = 96.7 μeq/L / 64.8 μeq/L = 1.49) is greater than 1.0 (indicative of complete neutralization of all deposited acidity), indicating that other factors besides cation exchange likely contributed to the increase in base cations (possibly from higher rates of weathering due to warmer temperatures and/or changes in precipitation patterns). This general result is consistent with the result reported last year (1.76; based on the change from 2012 to 2023), which was a strongly contrasting year in terms of hydrologic conditions. For comparison, the implied F-factor based on the recent 3-year average is 1.74. Figure 3-3 shows that the control lakes have experienced an increase in base cations from 2012 to 2022-2024 despite little or no change in sulphate, supporting the hypothesis that climatic factors are responsible for regional increases in base cations.

Table 3-5. CBANC, Gran ANC, BCS, pH, SO_4, DOC, base cations, chloride, and calcium values for LAK027, from the 2012 STAR sampling and the resampling in 2021, 2022, 2023, and 2024. The change from 2012 to 2024 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 2021-2024 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
2023	195.8	155.7	187.4	6.7	234.6	2.3	431.1	6.5	383.0
2024	132.8	91.6	108.1	6.3	175.2	5.6	308.4	7.3	265.2
Current Period (2022-2024)	**163.1**	**123.9**	**146.0**	**6.5**	**194.7**	**4.1**	**358.3**	**6.5**	**314.5**
Change (2012 to 2024)	31.5	21.9	9.3	-0.4	64.8	4.4	96.7	4.2	75.9
Change (2012 to 2022-24)	61.9	54.1	47.2	-0.1	84.3	2.9	146.7	3.3	125.2

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 2024 (with the data from 2012-2024 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 for all water chemistry samples taken in 2024. All of the samples are less than 8% of the guideline. Other than LAK028, all samples for all other lakes are less than 3% of the guideline.

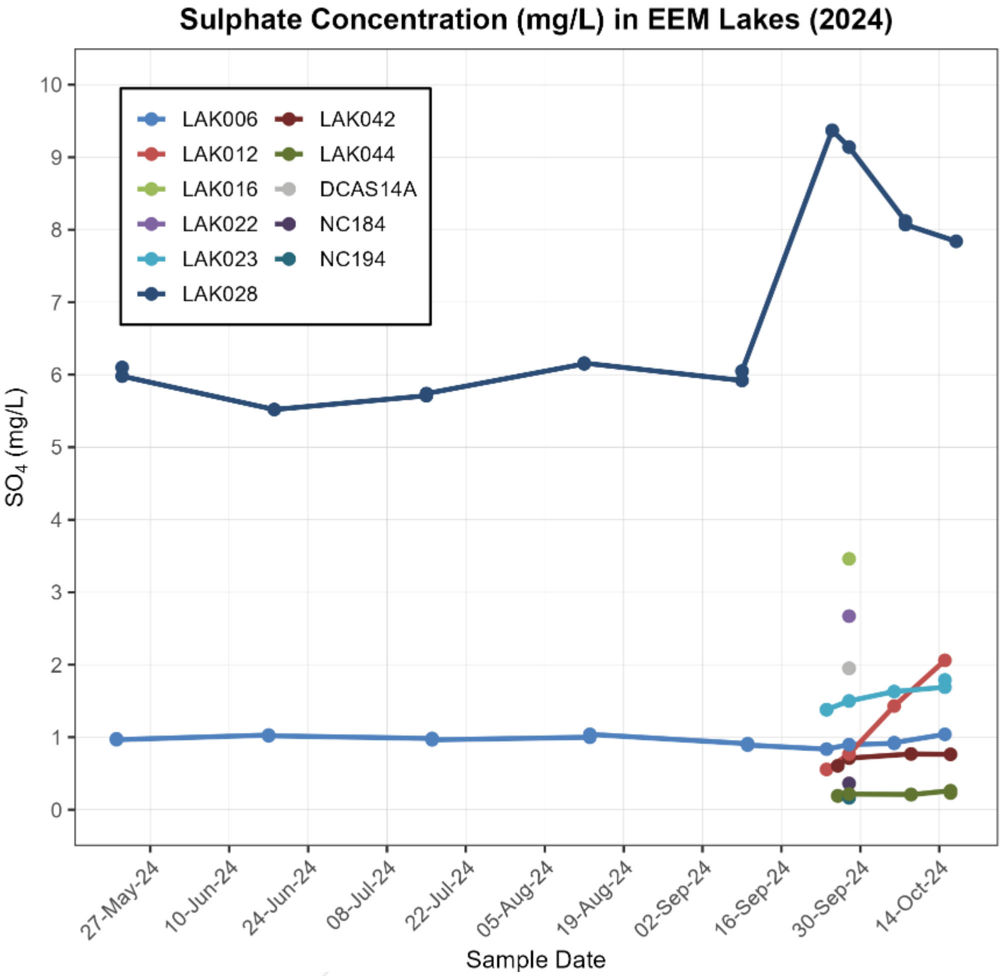


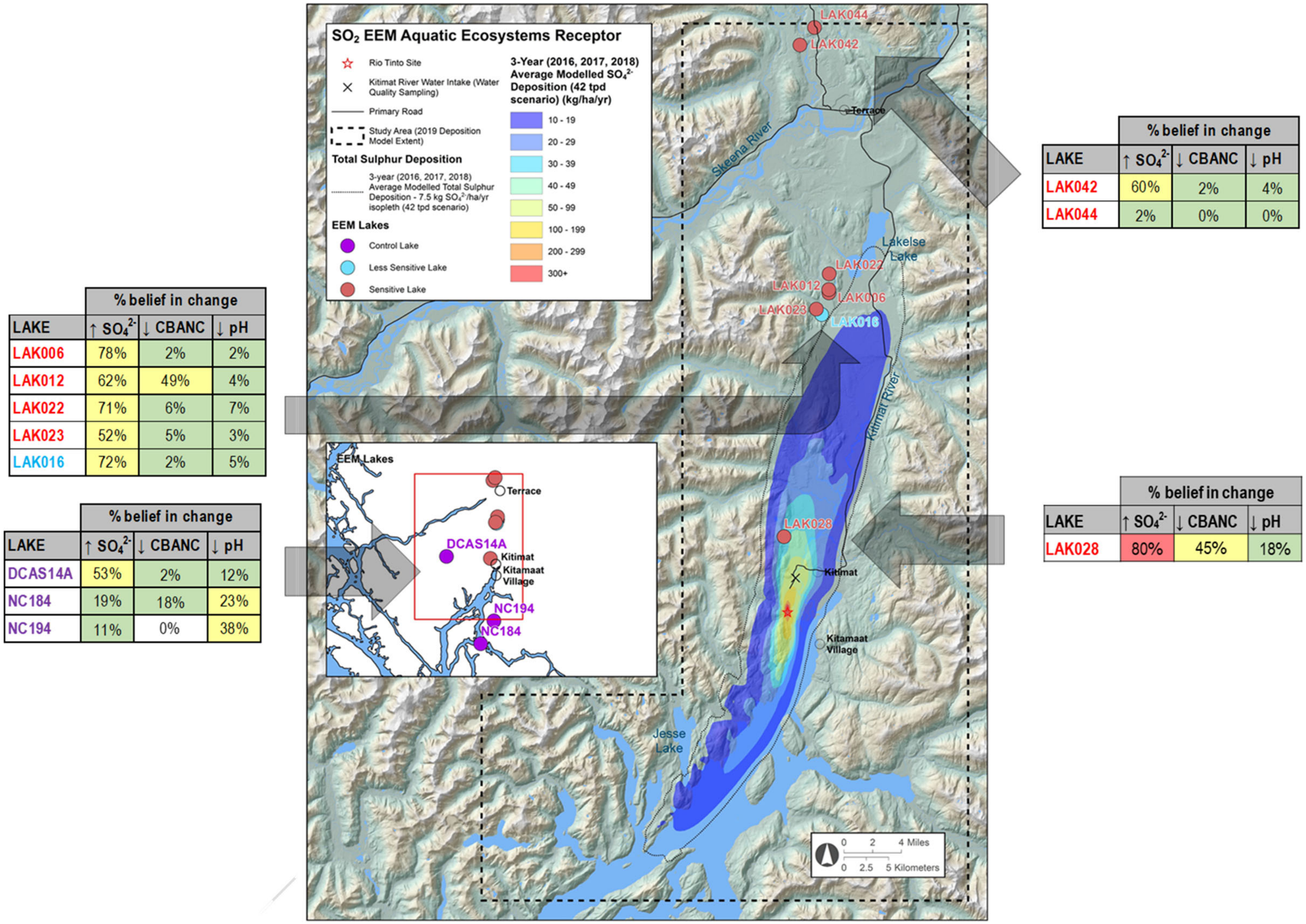
Figure 3-4. Sulphate concentration (mg/L) in EEM lakes during 2024. The applicable B.C. water quality guideline for sulphate concentration (i.e., for very soft waters) is 128 mg/L. All samples in 2024, across all EEM lakes, were <8% of the guideline.

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 and Figure 3-5. These results applied Bayesian Method 1, described in Appendix F of the 2019 Comprehensive Review (ESSA et al. 2020b). While six of the sensitive lakes show evidence of increases in SO_4 (the exception being LAK044, located in the north of the study area), two of the three control lakes do not. None of the lakes show a high percent belief in exceedance of the *change limit* thresholds for CBANC, Gran ANC, BCS or pH. Exceedance of the *level of protection* is to be expected for lakes with a higher percentage of organic anions, which reduces Gran ANC, BCS and pH. In the STAR, all 7 sensitive lakes had pH <6 and >25% organic anions (Table 9.4-8 of the STAR).

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	**Exceedance of *CHANGE LIMIT***				**Exceedance of *LEVEL OF PROTECTION***			
	(% 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)			
Metric	**SO_4**	**CBANC**	**Gran ANC (integ)**	**BCS**	**pH (integ)**	**CBANC**	**Gran ANC (integ)**	**BCS**	**pH (integ)**
Thresholds	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	78%	2%	2%	1%	2%	0%	0%	0%	11%
LAK012	62%	49%	18%	64%	4%	0%	0%	0%	18%
LAK022	71%	6%	14%	9%	7%	0%	51%	0%	27%
LAK023	52%	5%	4%	6%	3%	0%	100%	0%	98%
LAK028	80%	45%	12%	50%	18%	100%	100%	100%	100%
LAK042	60%	2%	1%	2%	4%	0%	100%	1%	100%
LAK044	2%	0%	1%	0%	0%	100%	100%	0%	100%
LAK016	72%	2%	4%	8%	5%	0%	0%	0%	0%
DCAS14A	53%	2%	1%	2%	12%	0%	0%	0%	0%
NC184	19%	30%	19%	18%	23%	0%	49%	0%	66%
NC194	11%	▨	▨	2%	38%	0%	100%	0%	0%



LAKE	% belief in change ↑ SO_4^{2-}	↓ CBANC	↓ pH
LAK006	78%	2%	2%
LAK012	62%	49%	4%
LAK022	71%	6%	7%
LAK023	52%	5%	3%
LAK016	72%	2%	5%

LAKE	% belief in change ↑ SO_4^{2-}	↓ CBANC	↓ pH
DCAS14A	53%	2%	12%
NC184	19%	18%	23%
NC194	11%	0%	38%

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

LAKE	% belief in change ↑ SO_4^{2-}	↓ CBANC	↓ pH
LAK028	80%	45%	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 3-7, Table 3-8, Table 3-9, and Table 3-10). None of the seven lakes showed statistically significant differences in Δ CBANC, Δ pH, Δ Gran ANC, or Δ BCS relative to the control lakes.

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 $_{\text{current-period}}$ minus CBANC $_{\text{pre-KMP}}$), 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 2023
LAK006	-3.73	10.26	0.73	Change in CBANC was **more positive** in LAK006 than in the control lakes *(but not statistically significant)*	None
LAK012	28.67	13.51	0.07	Change in CBANC was **more negative** in LAK012 than in the control lakes *(but not statistically significant)*	None
LAK022	5.61	9.12	0.56	Change in CBANC was **more negative** in LAK022 to changes in the control lakes *(but not statistically significant)*	From similar to more negative
LAK023	7.38	9.42	0.46	Change in CBANC was **more negative** in LAK023 than in the control lakes *(but not statistically significant)*	From similar to more negative
LAK028	24.99	14.94	0.13	Change in CBANC was **more negative** in LAK028 to changes in the control lakes *(but not statistically significant)*	None
LAK042	3.46	10.12	0.74	Change in CBANC was **more negative** in LAK042 than in the control lakes *(but not statistically significant)*	From similar to more negative
LAK044	4.82	9.94	0.64	Change in CBANC was **more negative** in LAK044 to changes in the control lakes *(but not statistically significant)*	From similar to more negative

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., $pH_{current-period}$ minus $pH_{pre-KMP}$), 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 2023
LAK006	-0.32	0.24	0.22	Change in pH was **more positive** in LAK006 than in the control lakes *(but not statistically significant)*	None
LAK012	-0.46	0.24	0.10	Change in pH was **more positive** in LAK012 than in the control lakes *(but not statistically significant)*	None
LAK022	-0.14	0.23	0.58	Change in pH was **more positive** in LAK022 than in the control lakes *(but not statistically significant)*	None
LAK023	-0.25	0.24	0.34	Change in pH was **more positive** in LAK023 than in the control lakes *(but not statistically significant)*	None
LAK028	-0.07	0.23	0.77	Change in pH was **similar** in LAK028 than in the control lakes *(but not statistically significant)*	More positive to similar
LAK042	-0.57	0.24	0.05	Change in pH was **more positive** in LAK042 than in the control lakes *(but not statistically significant)*	None
LAK044	-0.25	0.28	0.39	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 $_{\text{current-period}}$ minus Gran ANC $_{\text{pre-KMP}}$), 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 2023
LAK006	-1.75	13.18	0.90	Change in Gran ANC was **similar** in LAK006 than in the control lakes *(but not statistically significant)*	From more positive to similar
LAK012	6.64	15.63	0.68	Change in Gran ANC was **more negative** in LAK012 than in the control lakes *(but not statistically significant)*	None
LAK022	5.71	13.12	0.68	Change in Gran ANC was **more negative** in LAK022 than in the control lakes *(but not statistically significant)*	None
LAK023	6.13	12.88	0.65	Change in Gran ANC was **more negative** in LAK023 than in the control lakes *(but not statistically significant)*	From similar to more negative
LAK028	2.86	13.89	0.84	Change in Gran ANC was **more negative** in LAK028 than in the control lakes *(but not statistically significant)*	From similar to more negative
LAK042	-22.56	12.98	0.12	Change in Gran ANC was **more positive** in LAK042 than in the control lakes *(but not statistically significant)*	None
LAK044	3.49	13.06	0.80	Change in Gran ANC was **more negative** in LAK044 than in the control lakes *(but not statistically significant)*	From similar to more negative

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., $BCS_{current\text{-}period}$ 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 2023
LAK006	0.99	15.54	0.95	Change in BCS was **similar** in LAK006 than in the control lakes *(but not statistically significant)*	From more positive to similar
LAK012	33.62	17.81	0.10	Change in BCS was **more negative** in LAK012 than in the control lakes *(but not statistically significant)*	None
LAK022	11.84	14.62	0.44	Change in BCS was **more negative** in LAK022 than in the control lakes *(but not statistically significant)*	None
LAK023	14.67	14.97	0.36	Change in BCS was **more negative** in LAK023 than in the control lakes *(but not statistically significant)*	None
LAK028	33.27	18.84	0.12	Change in BCS was **more negative** in LAK028 than in the control lakes *(but not statistically significant)*	None
LAK042	-8.82	15.84	0.59	Change in BCS was more **positive** in LAK042 than in the control lakes *(but not statistically significant)*	None
LAK044	8.74	15.78	0.60	Change in BCS was **more negative** in LAK044 than in the control lakes *(but not statistically significant)*	None

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., current averaging period minus pre-KMP baseline, averaged over the 3 control lakes), minus the Δ mean in the 7 sensitive lakes (i.e., current 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 2023
CBANC	3.25	10.66	0.76	Change in CBANC was **more negative** in the sensitive lakes than in the control lakes *(but not statistically significant)*	From more positive to more negative
pH (integ)	-0.23	0.12	0.06	Change in pH was **more positive** in the sensitive lakes than in the control lakes *(but not statistically significant)*	None
Gran ANC (integ)	-6.14	9.36	0.52	Change in Gran ANC was **more positive** in the sensitive lakes than in the control lakes *(but not statistically significant)*	None
BCS	8.54	11.35	0.46	Change in BCS was **more negative** in the sensitive lakes than in the control lakes *(but not statistically significant)*	None

<u>For the BACI analyses of changes in CBANC:</u>

- 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).
- All sensitive lakes, except LAK006, showed a Δ CBANC that was more negative than the Δ CBANC observed in the group of control lakes (positive effect in the BACI analysis), but none of these differences were statistically significant at $p<0.01$.
- Four lakes changed from “similar” in 2023 to “more negative” in 2024.
- When analyzed as a combined group, the sensitive lakes showed ΔCBANC that was more negative than the Δ CBANC observed in the group of control lakes, which is a reversal of direction from last year; however, the results were not statistically significant in either year.
- CONCLUSION: **No support for an effect** across any of the lakes individually or an effect for all lakes combined.

<u>For the BACI analyses of changes in pH:</u>

- All sensitive lakes except LAK028 showed Δ pH that was more positive than the Δ pH observed in the group of control lakes (negative effect in the BACI analysis) but none of these differences were statistically significant a $p<0.01$.
- LAK028 showed a Δ pH that was similar to the control lakes
- LAK012 was the only lake that had a statistically significant effect in 2022 (more positive) but the results in 2023 and 2024 were not statistically significant (p-values of 0.08 and 0.10, respectively).
- LAK042, which showed a significant positive effect in 2021, then marginally exceeded the criterion for significance in 2022 (p-value = 0.02), had p-values of 0.05 in both 2023 and 2024.

- When analyzed as a combined group, the sensitive lakes showed a change that was more positive than in the control lakes; however, the effect is not statistically significant (as it was in 2022 but not 2023).
- CONCLUSION: **No support for an effect** across any of the lakes individually or an effect for all lakes combined.

<u>For the BACI analyses of changes in Gran ANC:</u>

- 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).
- Five of the seven sensitive lakes showed a Δ Gran ANC that was more negative than the Δ Gran ANC 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.
- One lake showed Δ Gran ANC that was relatively similar (LAK006) and one lake showed Δ Gran ANC that was more positive (LAK042), though neither of these effects were statistically significant at p<0.01.
- Four lakes changed towards the negative direction since last year – three lakes changed from “similar” to “more negative” (LAK023, LAK028, and LAK044) and one lake changed from “more positive” to “similar” (LAK006).
- When analyzed as a combined group, the sensitive lakes showed a change that was more positive than in the control lakes; however, the results were not statistically significant.
- CONCLUSION: **No support for an effect** across any of the lakes individually or an effect for all lakes combined.

<u>For the BACI analyses of changes in BCS:</u>

- 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)
- Five 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.
- One lake showed ΔBCS that was relatively similar (LAK006) and one lake showed ΔBCS that was more positive (LAK042), though neither of these effects were statistically significant at p<0.01.
- When analyzed as a combined group, the sensitive lakes showed a change that was more negative than in the control lakes; however, the results were not statistically significant.
- CONCLUSION: **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 3-7). The lake-level monitoring data are shown in Figure 3-8.

LAK006 shows only one period with a notable decline – late October – albeit the magnitude is quite small (i.e., declines of ~0.2 pH units over a period of one week). This period follows after a rapid but temporary increase in the lake level likely resulting from precipitation events in mid-October. However, this drop is part of a longer decline in pH from earlier in September through to the end of the record that is 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. However, this long pH decline starts in early to mid-September but the lake levels do not increase until late September.

LAK028 showed only one pronounced drop (~0.5 pH units) in late September, directly corresponding with the rapid increase in the level of LAK006 (data for LAK028 is not available during that period). There was an anomalous rapid increase then decrease in early August that does not correspond with any change in lake levels.

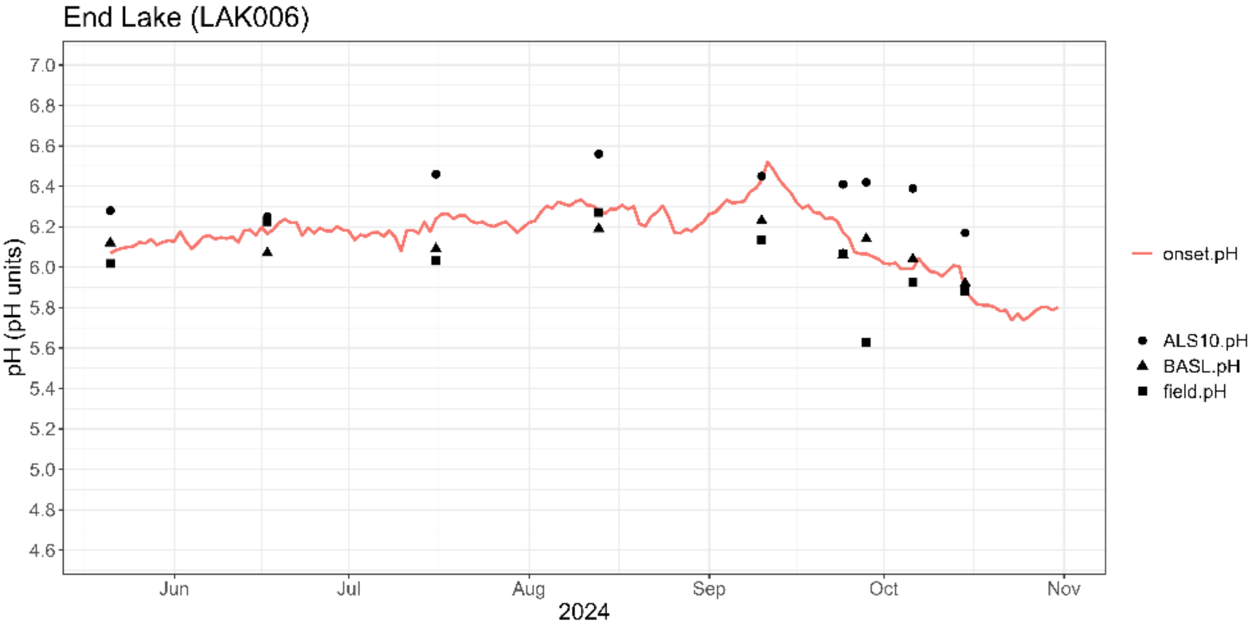


Figure 3-6. LAK006 pH measurements during the 2024 monitoring season, including continuous monitoring as well as field and laboratory measurements. See Limnotek (2025) for details on instrument failure referenced in the figure. Source: Limnotek (2025).

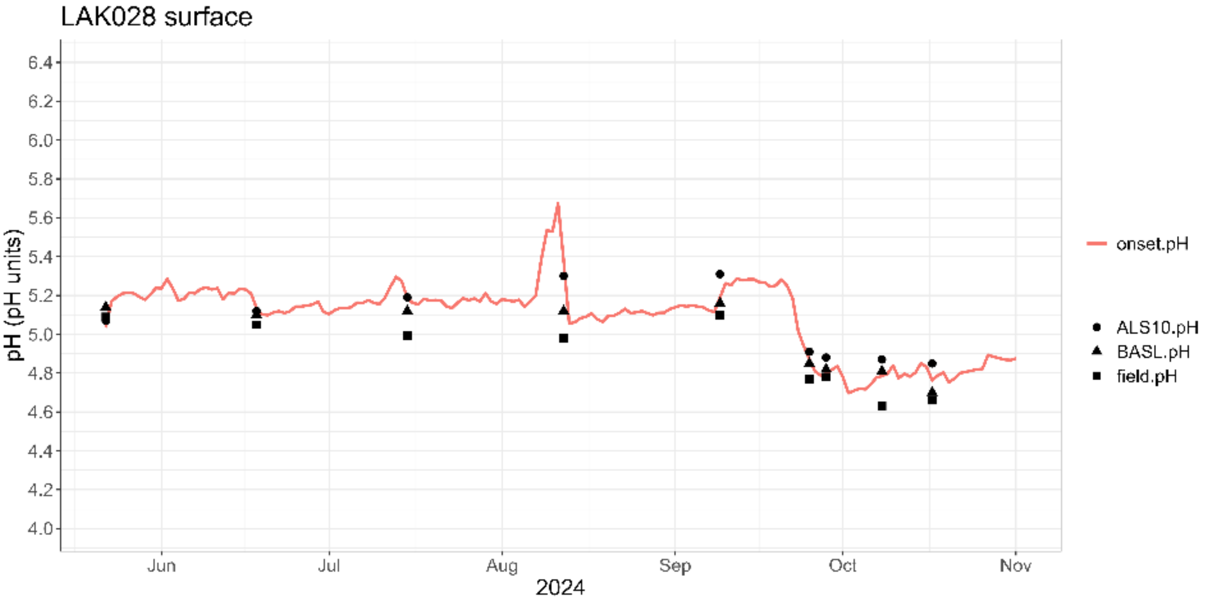


Figure 3-7. LAK028 pH measurements during the 2024 monitoring season, including continuous monitoring as well as field and laboratory measurements. Source: Limnotek (2025).

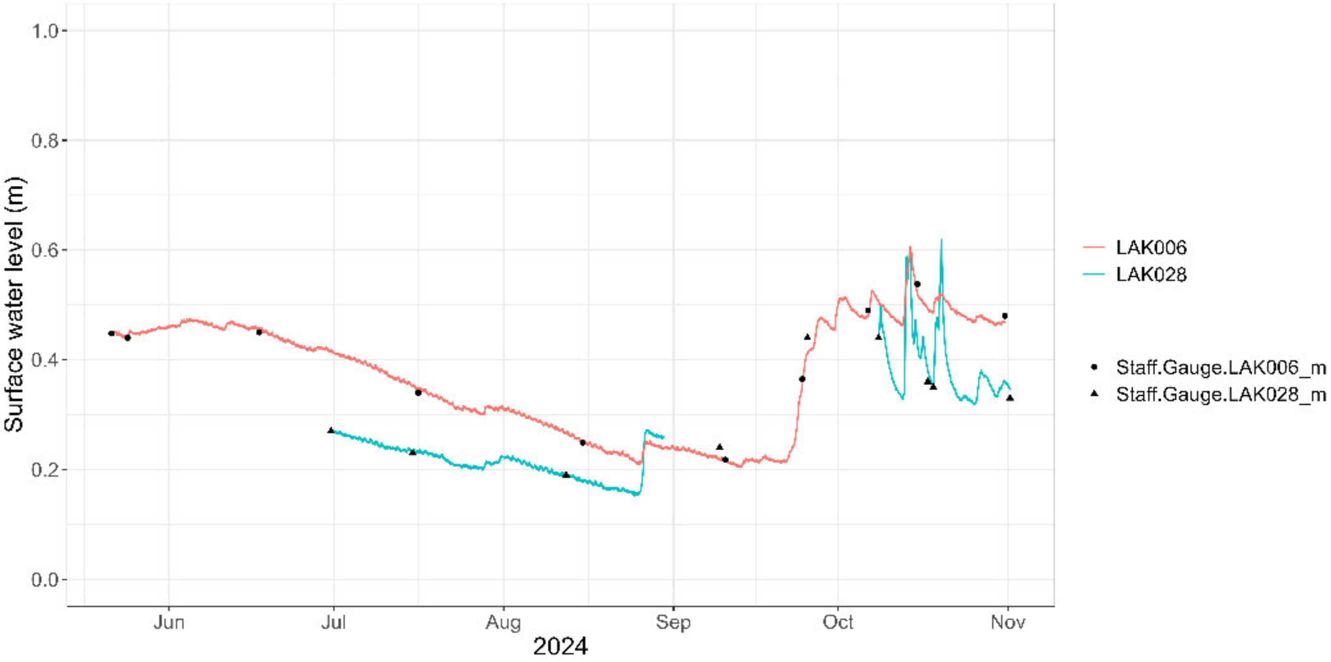


Figure 3-8. Water level during the 2024 monitoring season for LAK006 and LAK028. As per Limnotek (2025): *Note that water level is relative to a benchmark at each lake, not to a common benchmark.* Source: Limnotek (2025).

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.

As described in Section 2.4, the environmental conditions in August through mid-October were very wet, which would tend to result in decreases in CBANC, pH, Gran ANC, BCS, SO_4, and base cations through a dilution effect. As discussed briefly in Section 3.1, emissions in 2024 did not change as dramatically from the previous year as had been the case in several recent reporting cycles. Emissions returned to the levels that existed in 2017-2019 after four years with significant decreases and subsequent increases. The average annual emissions in 2024 were about 18% higher than in 2023, which might influence lake chemistry but is much smaller than the annual changes reported in the last several years. Table 4-1 compares the expected effects of wetter conditions and increased emissions on major water chemistry parameters to the observed changes in the sensitive and less sensitive lakes.

Table 4-1. Observed changes in sensitive and less sensitive lakes compared to expected effects of wetter conditions and increased emissions.

Parameter	Effect of wetter conditions	Effect of increased emissions	Observed changes in sensitive & less sensitive lakes	Observed changes in control lakes	Conclusions
SO4	Decrease	Increase	7 increased 1 similar	1 increased 2 similar	Non-control lakes align with emissions effect, little change in control lakes
CBANC	Decrease	Decrease	4 decreased 2 increased 2 similar	3 decreased	Control lakes align with wetter conditions[2]; half of non-control lakes align with both
pH	Decrease	Decrease	7 decreased 1 similar	3 decreased	Lakes align with both
Gran ANC	Decrease	Decrease	8 decreased	2 decreased 1 similar	Lakes align with both. Large decrease in control lake NC184 (from 67.1 to 24.4 µeq/L) not related to SO4, which hardly changed (4.1 to 5.6 µeq/L) but is related in increase in DOC. Decrease in LAK042 (15.9 to 3.6 µeq/L) partly related to increase in DOC.
BCS	Decrease	Decrease	7 decreased 1 similar	3 decreased	Non-control lakes align with both; control lakes align with wetter conditions.
Base Cations	Decrease	Increase	6 increased 2 similar	1 decreased 2 similar	Non-control lakes align with emissions effect; control lakes align with wetter conditions
DOC	Increase	Neutral, though acidification decreases DOC (see section 3.5.3 of STAR)	5 increase 3 similar	1 increase 2 similar	Lakes align with hydrologic effect. Increases in DOC in control lake NC184 (4.1 mg/L) and LAK042 (3.2 mg/L) likely contributed to decreases in Gran ANC in these two lakes.

The graphs in Appendix 2 enable comparisons of the 2024 monitoring data to 2023 in more detail than the qualitative summary in Table 4-1. These graphs further show that the patterns of annual change in 2024 had a high level of consistency across the entire region for most of the metrics.

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[2] The decrease in CBANC in the control lakes far exceeds the small increases in SO_4 so the control lakes only support the hypothesis of changes due to wetter conditions.

All 11 EEM lakes decreased or remained relatively similar in pH, Gran ANC, and BCS. All 11 EEM lakes increased or stayed similar in DOC. Sensitive LAK042 and control lake NC184 showed increases in DOC that correlate with their declines in Gran ANC. LAK042 has shown substantial precipitation-driven fluctuations in DOC, pH and Gran ANC in past years. All 11 EEM lakes increased or stayed relatively similar for SO_4. All 8 sensitive and less sensitive EEM lakes increased or remained relatively similar for base cations but the 3 control lakes all decreased. CBANC is the only metric that showed decreases and increases for sensitive and less sensitive lakes; but all 3 control lakes decreased.

Overall, the observed patterns of annual change in 2024 do not clearly indicate greater influence of emissions or hydrology; both appear to have been important. It is difficult to disentangle the relative contributions of emissions and hydrology because the two drivers produce the same effect on multiple water chemistry parameters. However, since there was little change in SO_4 in the control lakes between 2023 and 2024, observed changes in other parameters within these lakes can be confidently related to hydrology. It's clear wetter conditions in 2024 affected all EEM lakes. The increase in $SO4_4$ and base cations in the sensitive and less sensitive lakes demonstrates that increased emissions also affected the EEM lakes within the plume.

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), with respect to empirical changes. 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 values for the current averaging period 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 their *change limit* threshold (LAK028 shows a decrease of -11.7 μeq/L; LAK044 shows an increase of +8.5 μeq/L). None of the 7 sensitive lakes exceeded the *change limit* threshold and only two lakes (LAK012 and LAK028) show long-term decreases in CBANC. In the sensitivity analyses with the alternate, transition period baseline (2012-2014), LAK012 and LAK028 are also the only lakes with an estimated long-term decrease in CBANC (-4.8 μeq/L and -8.7 μeq/L, respectively). The empirical data therefore suggest that none of the lakes exceeded the KPI, though the statistical analyses are the key determinant of our conclusions.

LAK028, which has always been below the *level of protection* threshold, is closer to its *change limit* threshold of -13.4 μeq/L than previous years. The change from the baseline to the current averaging period is -11.7 μeq/L, as compared with the previously reported changes of -0.7 μeq/L, -3.0 μeq/L, and -7.9 μeq/L in 2023, 2022, and 2021, respectively. This larger decline is significantly influenced by the exceptionally low CBANC value in 2024 (as discussed in Section 3.1).

For the pH informative indicator, 4 of the 7 sensitive lakes (LAK023, LAK028, LAK042, and LAK044) have values for the current averaging period below the *level of protection* threshold (pH 6.0). As described in the STAR (section 9.4.1.2.4), all 7 sensitive lakes were already below pH 6.0 in 2012, reflecting primarily the influence of organic acids and in some cases the effects of historical smelter emissions (particularly in LAK028). Four of the lakes have been at or below pH 6.0 throughout the entire period of record. None of the sensitive lakes show any decrease in pH relative to 2012 and therefore none have exceeded the *change limit* threshold. In the sensitivity analyses with the alternate, transition period baseline (2012-2014), both LAK022 and LAK028 show decreases of 0.1 pH units, LAK044 shows no change, and the other 4 sensitive lakes show increases. The empirical data therefore indicate that none of the lakes have exceeded the pH informative indicator.

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 have been exceeded.

LAK027 – Comparison with STAR Results

As discussed earlier, LAK027 was resampled again in 2024 because of anomalous effects in 2021 (very wet year), 2022 (very dry year and very low emissions), and 2023 (even drier year and significant increase in emissions), thus confounding the original rationale for resampling LAK027 in 2021. We therefore focus on examining the changes between the values measured in the STAR in 2012 and to those observed in 2024 as well as the average of the past three years, analogous to the evaluation of the EEM lakes.

Although this year was still somewhat of an anomalous year (i.e., much wetter than average, as discussed in Section 2.4), we now have sampling across four different types of years that provides enough information to address the original motivating question – i.e., does LAK027 continue to show no or minimal risk of acidification as was assessed in the STAR.

When focussing on the changes from 2012 to 2024, Table 3-5 shows that all of the lake chemistry metrics except pH increased by notable margins. For pH, the 2024 pH value was 0.4 pH units below the 2012 value. However, this result must be interpreted within the context of 2024 being a very wet year. In 2024, every lake but LAK044 declined in pH from the previous year, the average change across all 11 EEM lakes (sensitive, less sensitive, and control) was a decline of 0.4 pH units, and the average change in the control lakes (providing an indication of regional patterns not influenced by the smelter) was a decline of 0.6 pH units. Taking the hydrologic conditions into account suggests that this measured change in pH does not necessarily indicate such a pronounced long-term change as the empirical values alone suggest. Furthermore, despite the large drop in 2024, the pH level in LAK027 was still 0.3 pH units above the *level of protection* threshold. By contrast, even with a large one-year drop in CBANC from ~196 µeq/L to ~133 µeq/L in 2024, the CBANC for LAK027 still remained well above 2012 levels.

Given that we now have multiple recent years of sampling data for LAK027, it is useful to also assess the changes in lake chemistry using the same approach as applied to the EEM lakes (i.e., using the 3-year average). These results also show that all of the lake chemistry metrics except pH increased (Table 3-5). However, these results show that pH only decreased by 0.1 pH units and the increases shown for the KPI and other two informative indicators are substantially larger than the results for 2024 alone. CBANC, Gran ANC and BCS show levels that are 161%, 178%, and 148% of their 2012 levels, respectively, and are at levels that we would likely no longer classify as "moderately sensitive".

Focusing just on the CBANC (as the KPI), the results show that CBANC is higher than 2012 for every potential combination of the recent four years of sampling, except for 2021 that showed a moderate decline during an exceptionally wet year that many lakes had moderate to large decreases in CBANC. The current averaging period has a CBANC of 163 µeq/L, which represents an increase of 62 µeq/L.

The data collected over the past four years indicate that LAK027 has a low acidification risk, which confirms the conclusions of the STAR for this lake. This reaffirmed conclusion is based on:

a) High CBANC, Gran ANC and BCS – much higher than thresholds for classifying sensitive lakes and many times higher than the *level of protection* thresholds for the EEM
b) Large *increases* in CBANC, Gran ANC, and BCS – i.e., no evidence of long-term decline
c) pH well above the *level of protection* threshold
d) the small decline in pH does not exceed the criterion applied in the STAR

Based on the conclusions above, there is no benefit to continuing to sample LAK027.

4.3 Statistical Analysis of Changes in Lake Chemistry

We evaluated the KPI and the informative indicators using the two-threshold structure (Table 4-2). **None of the 11 EEM lakes have a high % belief in exceedance of either the KPI or any of the informative indicators.** LAK028 has a moderate % belief in exceedance of the KPI and all the other EEM lakes show a low % belief in exceedance of the CBANC KPI. One sensitive EEM lake and one control lake show moderate % belief of one or two of the informative indicators:

- LAK028 shows moderate % belief in exceedance of BCS
- NC184 shows moderate % belief in exceedance of pH

The conclusions of the Bayesian statistical analyses are generally similar to our previous report, but have fewer moderate classifications than recent years (3 in 2024, 4 in 2023, and 8 in 2022). The only changes in classification (across all lakes and metrics) from last year are the changes from low to moderate for CBANC in LAK028 and from moderate to low for pH in LAK022 and Gran ANC in NC184. All other results are the same as last year in terms of final classification. Overall, the list of lakes with moderate % belief in exceedance of one or more indicators decreased from 2 sensitive lakes to 1 and remained the same with 1 control lake.

Table 4-3 shows the results from 2024 compared to the results reported in the previous five annual reports and the 2019 comprehensive review, specifically for the evaluation of the *change limit*. The results show only two instances where the percent belief increased from low to moderate in 2024. LAK028 increased from 6% to 45% for CBANC. DCAS14A increased from 16% to 53% for SO_4, which represents a return to previous levels after two years of in the low classification. For indicator results remaining in moderate, there are no instances of increases >9%. None of the results classified as high.

This is now the fifth year that the Bayesian analyses were performed on CBANC. Despite the widespread changes in numerous water chemistry metrics observed in 2021-2023 due to anomalous hydrologic and emissions conditions, the CBANC results remain remarkably similar to the 2020 results for almost all of the lakes, suggesting that the CBANC metric may be robust to anomalous conditions. The exception is LAK028, where the results have changed notably in response to the drop in CBANC in 2024 discussed earlier as part of empirical changes.

This is the seventh 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. The results have generally remained very stable over these six years with one notable pattern observed in multiple lakes. All of the lakes that changed from low to moderate experienced that change in 2021, an exceptionally wet year with pronounced declines in ANC and pH across all lakes. In many cases, those lakes returned to low or at least showed a step decrease with moderate in 2024, which was when the 2021 values were dropped from the current averaging period. In a few cases that shift back to low occurred after only two years.

Table 4-2. 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. 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	**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 protection* 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)**
Thresholds	Increase > 0	Lake-spec.	Lake-spec.	∆ 13 ueq/L	∆ 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	78%	2%	2%	1%	2%	0%	0%	0%	11%	LOW	LOW	LOW	LOW
LAK012	62%	49%	18%	64%	4%	0%	0%	0%	18%	LOW	LOW	LOW	LOW
LAK022	71%	6%	14%	9%	7%	0%	51%	0%	27%	LOW	LOW	LOW	LOW
LAK023	52%	5%	4%	6%	3%	0%	100%	0%	98%	LOW	LOW	LOW	LOW
LAK028	80%	45%	12%	50%	18%	100%	100%	100%	100%	MOD	LOW	MOD	LOW
LAK042	60%	2%	1%	2%	4%	0%	100%	1%	100%	LOW	LOW	LOW	LOW
LAK044	2%	0%	1%	0%	0%	100%	100%	0%	100%	LOW	LOW	LOW	LOW
LAK016	72%	2%	4%	8%	5%	0%	0%	0%	0%	LOW	LOW	LOW	LOW
DCAS14A	53%	2%	1%	2%	12%	0%	0%	0%	0%	LOW	LOW	LOW	LOW
NC184	19%	18%	19%	18%	23%	0%	49%	0%	66%	LOW	LOW	LOW	MOD
NC194	11%	▨	▨	2%	38%	0%	100%	0%	0%	noRel	noRel	LOW	LOW

Table 4-3. Comparison of the results of the updated statistical analyses of the changes relative to the *change limit* to the results from previous Annual Reports plus the 2019 Comprehensive Review (CR)). The 2024 results are the same as 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**	**2023**	**2024**	**CR**	**2019[1]**	**2020**	**2021**	**2022**	**2023**	**2024**	**CR**	**2019[1]**	**2020**	**2021**	**2022**	**2023**	**2024**	**CR**	**2019[1]**	**2020**	**2021**	**2022**	**2023**	**2024**
Sensitive Lakes																										
LAK006	2%	1%	0%	0%	2%	83%	85%	98%	97%	81%	79%	78%	0%	0%	5%	2%	0%	1%	2%	1%	0%	1%	5%	8%	8%	2%
LAK012	40%	35%	23%	40%	49%	91%	95%	99%	86%	70%	62%	62%	1%	0%	19%	18%	14%	14%	18%	1%	0%	1%	8%	10%	9%	4%
LAK022 [2]	2%	11%	13%	7%	6%	88%	89%	89%	87%	69%	74%	71%	0%	0%	10%	31%	30%	18%	14%	0%	0%	0%	39%	43%	32%	7%
LAK023	2%	3%	6%	0%	5%	5%	2%	0%	42%	37%	44%	52%	0%	0%	3%	2%	2%	1%	4%	1%	0%	3%	4%	7%	9%	3%
LAK028	13%	15%	13%	6%	45%	96%	97%	94%	92%	88%	98%	80%	2%	1%	0%	4%	8%	6%	12%	18%	6%	9%	18%	18%	18%	18%
LAK042	9%	6%	6%	1%	2%	36%	44%	81%	76%	60%	55%	60%	0%	0%	2%	4%	6%	5%	1%	2%	0%	13%	23%	21%	14%	4%
LAK044	0%	1%	0%	0%	0%	1%	0%	4%	6%	13%	4%	2%	0%	0%	3%	3%	4%	1%	1%	0%	0%	0%	1%	4%	4%	0%
Less Sensitive Lakes																										
LAK016 [2]	7%	7%	2%	3%	2%	97%	81%	81%	99%	70%	75%	72%	0%	0%	1%	4%	7%	2%	4%	1%	0%	6%	28%	32%	18%	5%
Control Lakes																										
DCAS14A [2]	1%	10%	5%	2%	2%	68%	75%	99%	56%	14%	16%	53%	0%	0%	1%	11%	7%	4%	1%	6%	0%	12%	50%	52%	43%	12%
NC184 [2]	10%	43%	46%	30%	18%	58%	69%	86%	50%	15%	6%	19%	5%	4%	17%	28%	30%	26%	19%	28%	14%	19%	48%	48%	34%	23%
NC194 [2]	n/a	n/a	n/a	n/a	n/a	1%	1%	2%	12%	4%	5%	11%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	12%	4%	17%	62%	71%	49%	38%

[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 averaging period used in the CR), whereas the subsequent Annual Reports apply a 3-year averaging period for the current 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 and the underlying values are compiled in Table 4-4. A lake may appear in different parts of the evidentiary framework depending on whether we use CBANC or pH as criteria (CBANC is the KPI and pH is an informative indicator). To be precautionary, we consider the lake's appropriate assignment to be the furthest position into the evidentiary framework. Results show that: a) 1 sensitive lake (LAK044) and all 3 control lakes[3] land within the first box, "smelter not causally linked to changes in lake chemistry"; b) 4 sensitive lakes (LAK006, LAK012, LAK023, and LAK042) and 1 less sensitive lake (LAK016) land within the second box, "lake is healthy, and not acidifying"; and c) 2 sensitive lakes (LAK022 and LAK028) land within the third box, "some evidence of acidification; closely monitor". The situation for the lakes landing in the third box is expanded upon below.

For LAK028, this classification is based on: a) values for the current averaging period below the *level of protection* for both CBANC and pH, and b) moderate support for a decline in CBANC (67% belief) and pH (43% belief), with moderate support for exceedance of the *change limit* threshold for CBANC (45% belief) and low support for exceedance of the *change limit* threshold for pH (18%). For CBANC, the overall result is the same as last year but the support for exceedance of the *change limit* threshold increased from low (6% belief) to moderate (45% belief), as driven by the low CBANC values observed in 2024 (described in greater detail earlier in this report). For pH, the overall result is the same as last year and the percent belief values for both any change in pH as well as exceedance of the *change limit* threshold are very similar.

For LAK023, this classification is based on pH only. LAK022 shows: a) a moderate belief in exceeding the *level of protection* for pH (27% belief), and b) moderate support for declines in pH (26% belief), with low support for exceedance of the *change limit* threshold (7% belief). Although this is the same overall result as last year, the level of support has declined notably – from 75% to 27% for exceedance of the *level of protection* threshold for pH (from the high end to the low end of the moderate range), from 50% to 26% for declines in pH, and from 32% to 7% for exceedance of the *change limit* threshold for pH. For CBANC, there continues to be a 0% belief in LAK022 being below the *level of protection*.

There are no lakes that have acidification exceedances.

The changes in lake classification from last year's Annual Report include four lakes that have "moved up" a step in the evidentiary framework. Three lakes (LAK006, LAK023, and LAK042) all moved from the yellow box to the second green box because of the support for a decline in pH decreasing from 21-24% belief to 9-11%. Those changes are not large in absolute terms but moved all three lakes from the very low end of the moderate range squarely into the middle of

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[3] 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. In both 2022 and 2023, all three control lakes showed a low percent belief in SO_4 changes since 2013 (Table 4-3). In 2019-2021 two of the control lakes (DCAS14A and NC184) showed moderate to high beliefs in SO_4 change (Table 4-3), but the magnitude of changes over time were very small (see graphs for Control Lakes in Appendix 2).

the low range. LAK012 remained in the same classification but changed to the earlier entry point for pH (which was already the case for CBANC) – i.e., from having moderate support (44% belief) for being below the *level of protection* threshold for pH but low support for any decline in pH, to having low support (18% belief) in being below the *level of protection* threshold.

The only changes of >25% belief in the underlying results for the sensitive lakes were: a) for LAK028, the percent belief in exceeding the *change limit* for CBANC increased by 39%; b) for LAK022, the percent belief for exceeding the *level of protection* and *change limit* thresholds for pH decreased by 48% and 25%, respectively; and c) for LAK012, the percent belief for exceeding the *level of protection* for pH decreased by 26%. For control lake DCAS14A, the percent belief in an increase in sulphate increased by 37% and the percent belief in an exceedance of the *change limit* threshold decreased by 31%; however, all three control lakes are classified in the first box regardless of potential increase in sulphate because any such increases cannot be causally linked to the smelter due to their location well outside of the smelter plume.

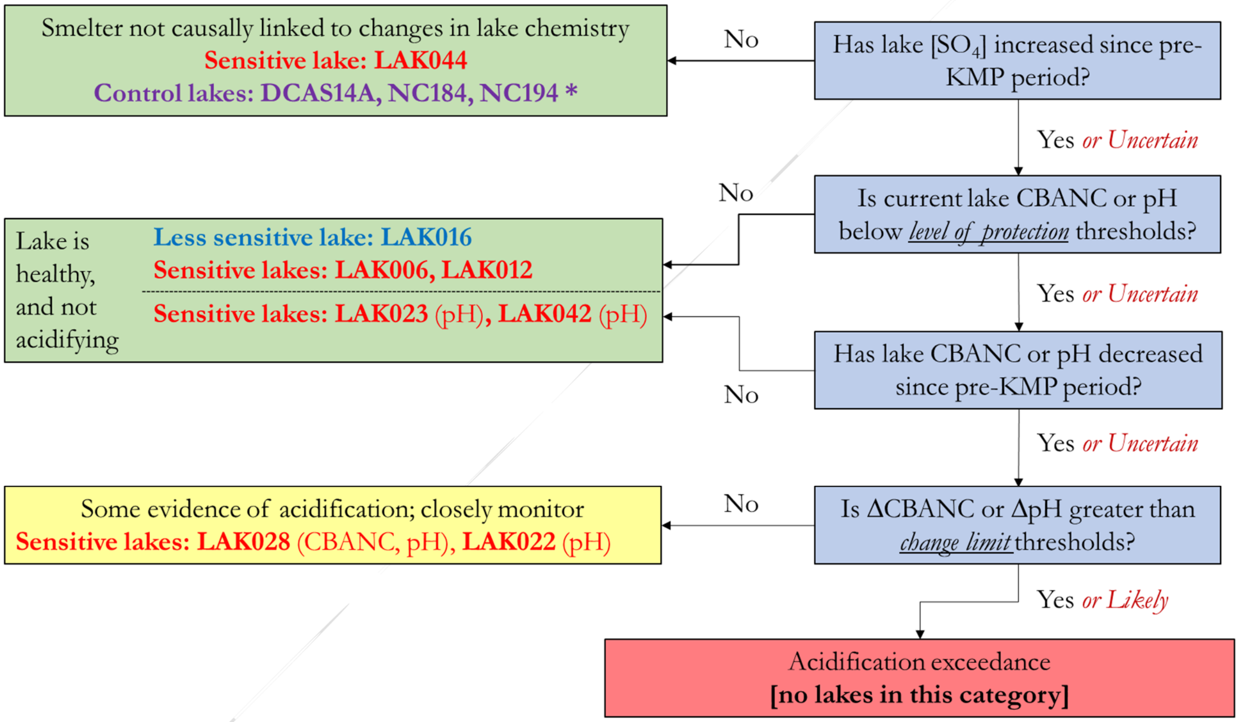

Figure 4-1. Classification of EEM lakes according to the simplified evidentiary framework. To be precautionary, we consider the lake's appropriate assignment to be the furthest position into the evidentiary framework, based on CBANC or pH. LAK028 has moderate support for declines in CBANC and pH with moderate and low support for exceeding the *change limit* thresholds, respectively. LAK022 has moderate support for declines in pH with low support for exceeding the *change limit* thresholds; however, it is still above the CBANC *level of protection*. * One of the control lakes shows moderate support for increases in SO_4 (DCAS14A); however, all three are classified in the first box regardless of potential increase in sulphate because any such increases cannot be causally linked to the smelter due to their location well outside of the smelter plume.

Table 4-4. Results used in the application of the simple evidentiary framework. The first four columns are identical to 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. "Current" refers to the current averaging period (2022-2024).

LAKE	**Changes in SO_4** (% belief in SO_4 increase / decrease)	**State of current CBANC** (% belief that CBANC *level of protection* threshold exceeded)	**State of current 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	78%	0%	11%	2%	2%	4%	9%
LAK012	62%	0%	18%	49%	4%	82%	10%
LAK022	71%	0%	27%	6%	7%	17%	26%
LAK023	52%	0%	98%	5%	3%	21%	11%
LAK028	80%	100%	100%	45%	18%	67%	43%
LAK042	60%	0%	100%	2%	4%	9%	10%
LAK044	2%	100%	100%	0%	0%	0%	3%
Less Sensitive Lakes							
LAK016	72%	0%	0%	2%	5%	22%	24%
Control Lakes							
DCAS14A	53%	0%	4%	2%	12%	5%	67%
NC184	19%	0%	66%	18%	23%	28%	38%
NC194	11%	0%	0%	n/a	38%	21%	60%

5 Recommendations

We do not recommend sampling LAK027 again. As discussed in Section 4.1, the data collected over the past four years indicate that LAK027 has a low acidification risk, which confirms the conclusions of the STAR for this lake. Despite anomalous conditions in different years, the multiple years of resampling across a diversity of conditions have achieved the original intent of the resampling.

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

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Appendix 1: Water Chemistry Data from Annual Sampling, 2012-2024

The two tables below show the sample results for each of the EEM lakes and control lakes from annual monitoring conducted from 2012 to 2024, 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, 2019-2024). 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 (BASL)	SE	pH (ALS)	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)	SE	∑ Anions (μeq/L)	SE
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	*2.1*	84.2	*2.3*
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	*2.3*	135.7	*5.3*

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 (BASL)	SE	pH (ALS)	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)	SE	∑ Anions (µeq/L)	SE
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	4.4	93.0	2.9
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	
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	0.5	77.0	0.6
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	4.8	140.3	7.3
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	1.8	83.0	2.6
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	2.3	74.0	1.4
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	1.5	115.7	1.7
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	1.3	80.8	2.1
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	11.7	179.1	9.1
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	1.9	78.8	2.0
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	0.6	27.7	0.8
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	0.5	71.4	1.6
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	6.6	117.5	5.1
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	

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 (BASL)	SE	pH (ALS)	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)	SE	∑ Anions (µeq/L)	SE
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	*2.5*	71.3	*3.0*
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	*15.3*	199.2	*16.7*
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	*3.9*	80.8	*5.0*
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	*0.4*	26.2	*1.7*
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	*1.3*	82.1	*1.9*
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	*1.5*	112.3	*1.0*
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	
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	*0.6*	78.6	*2.0*
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	*1.9*	147.4	*2.7*
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	*1.0*	74.4	*0.9*
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	*0.2*	27.5	*1.3*
LAK006	2019	63.8	*2.2*	31.6	*2.7*	40.0	*1.1*	49.7	*1.8*	6.1	*0.0*	6.2	*0.0*	6.5	*0.1*	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	*1.8*	74.1	*3.8*
LAK007	2019	1443.5		1374.5		1496.3		1445.4		8.1		8.0		8.1		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*	6.2	*0.0*	6.6	*0.1*	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	*0.7*	121.4	*5.8*
LAK016	2019	129.8		90.8		100.9		111.2		6.6		6.6		7.1		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		6.2		6.4		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*	6.0	*0.0*	6.3	*0.1*	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	*2.1*	79.4	*2.6*
LAK024	2019	570.7		496.9		548.7		566.0		7.7		7.3		7.7		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*	5.1	*0.0*	5.4	*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	*1.7*	200.1	*6.1*
LAK034	2019	196.8		148.9		166.9		173.8		6.4		6.6		7.0		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*	5.4	*0.0*	5.6	*0.1*	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	*2.3*	77.1	*3.7*
LAK044	2019	14.8	*0.6*	6.1	*0.4*	6.6	*0.3*	5.7	*1.2*	5.5	*0.0*	5.7	*0.0*	5.9	*0.1*	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	*0.6*	32.0	*1.7*
LAK006	2020	70.3	*1.5*			44.7	*1.3*	48.1	*3.8*			6.1	*0.0*	6.3	*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	*2.0*	91.4	*2.5*
LAK007	2020																																		
LAK012	2020	142.1	*6.4*			93.1	*9.0*	101.4	*4.9*			6.1	*0.0*	6.4	*0.1*	8.8	*0.3*	15.6	*4.0*	9.3	*0.3*	5.0	*0.1*	97.5	*3.0*	28.1	*0.0*	7.8	*0.4*	24.5	*0.2*	157.9	*2.4*	165.7	*6.3*
LAK016	2020																																		
LAK022	2020																																		
LAK023	2020	66.6	*0.5*			29.6	*1.6*	37.6	*2.8*			6.0	*0.0*	6.1	*0.0*	6.4	*0.7*	13.9	*0.8*	5.1	*0.0*	4.8	*0.1*	49.0	*0.7*	15.7	*0.7*	3.7	*0.3*	12.2	*0.1*	80.6	*0.2*	80.5	*4.7*
LAK024	2020																																		

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 (BASL)	SE	pH (ALS)	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)	SE	∑ Anions (µeq/L)	SE
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	3.6	193.3	5.6
LAK034	2020																																		
LAK042	2020	79.5	0.4			-10.0	3.6	-13.2	0.9			4.7	0.1	4.8	0.2	19.2	0.1	7.6	0.5	6.5	0.6	2.5	0.2	23.6	1.5	33.2	0.6	2.9	0.5	27.5	0.2	87.2	0.1	102.9	1.8
LAK044	2020	14.5	0.9			2.4	1.6	8.1	1.1			5.6	0.0	5.7	0.1	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	0.7	21.8	0.5
LAK006	2021	67.8	3.6			39.1	0.8	46.0	3.8			5.9	0.0	6.3	0.1	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	3.2	91.3	3.3
LAK007	2021																																		
LAK012	2021	101.2	2.6			58.7	6.9	68.1	4.1			5.8	0.0	6.3	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	3.0	133.3	0.6
LAK016	2021	138.1				95.9		97.9				6.2		6.7		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				5.5		5.4		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			5.7	0.0	6.1	0.1	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	4.1	82.0	2.8
LAK024	2021																																		
LAK028	2021	11.7	1.9			-5.7	0.9	-31.9	2.5			4.8	0.0	4.9	0.1	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	6.1	141.1	7.1
LAK034	2021																																		
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	3.3	100.5	3.2
LAK044	2021	17.1	1.4			5.4	1.9	9.5	1.6			5.5	0.0	5.5	0.1	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	1.6	25.6	1.2
LAK006	2022	70.1	1.3			44.1	1.7	52.2	1.7			6.3	0.0	6.5	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	1.0	84.7	2.1
LAK007	2022																																		
LAK012	2022	112.4	1.1			81.9	1.6	90.2	2.2			6.3	0.0	6.7	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	0.8	115.9	2.7
LAK016	2022	141.4				113.1		123.2				6.6		7.0		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				6.2		6.3		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			6.1	0.0	6.2	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	0.6	72.0	1.8
LAK024	2022																																		
LAK028	2022	19.3	4.0			10.4	1.9	-10.6	3.6			5.2	0.1	5.3	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	2.4	139.4	1.5
LAK034	2022																																		
LAK042	2022	52.8	1.3			15.4	1.7	15.6	2.2			5.5	0.0	5.6	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	1.2	65.7	1.8
LAK044	2022	16.8	0.4			7.3	0.5	10.9	1.6			5.8	0.0	5.8	0.1	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	0.4	22.1	1.5
LAK006	2023	68.2	1.3			41.4	1.2	52.7	1.7			6.2	0.1	6.4	0.0	3.8	0.2	14.0	0.6	5.6	0.2	3.8	0.1	41.7	0.5	17.2	0.2	4.1	0.2	19.3	0.5	82.4	0.9	78.3	0.9
LAK007	2023																																		
LAK012	2023	92.2	0.8			62.4	1.1	75.2	0.5			6.3	0.0	6.4	0.1	4.0	0.1	7.3	0.6	5.0	0.1	4.2	0.1	55.1	0.3	19.0	0.2	3.9	0.3	21.7	0.2	99.7	0.5	95.4	0.9
LAK016	2023	128.1				93.9		112.2				6.6		6.6		3.8		42.8		6.8		7.3		116.5		23.8		8.4		22.4		171.1		162.6	
LAK022	2023	81.4				40.0		57.6				6.2		6.2		5.4		32.3		7.3		5.1		66.1		19.4		4.4		23.9		113.8		106.5	
LAK023	2023	57.0	1.0			27.3	0.8	36.3	0.8			6.1	0.0	6.1	0.0	4.8	0.0	16.2	0.9	4.8	0.2	4.9	0.1	43.5	0.5	14.2	0.1	3.8	0.1	11.9	0.2	73.4	0.7	71.0	1.6
LAK024	2023																																		
LAK028	2023	12.8	3.5			7.3	1.7	-6.1	3.1			5.3	0.0	5.2	0.1	4.4	0.2	82.4	2.2	6.0	0.2	16.9	0.4	65.0	1.0	15.7	0.4	2.7	0.1	14.3	0.4	97.8	1.6	115.4	2.2
LAK034	2023																																		

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 (BASL)	SE	pH (ALS)	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)	SE	∑ Anions (µeq/L)	SE
LAK042	2023	57.2	0.5			15.9	2.5	13.4	2.5			5.4	0.0	5.5	0.0	9.4	0.5	5.8	0.2	6.4	0.2	2.4	0.2	10.8	0.2	24.1	0.4	2.6	0.1	25.6	0.4	63.1	0.5	75.1	4.7
LAK044	2023	16.7	0.4			7.4	0.8	11.2	0.6			5.7	0.0	5.8	0.0	1.7	0.1	3.1	0.2	6.3	0.2	2.0	0.1	8.2	0.1	4.0	0.1	7.0	0.2	0.7	0.1	19.9	0.5	20.0	0.8
LAK006	2024	61.2	0.6			33.3	1.0	44.9	1.0			6.1	0.0	6.4	0.0	3.9	0.2	19.2	0.5	6.3	0.2	3.9	0.1	40.1	0.4	17.1	0.2	3.9	0.2	19.6	0.3	80.7	0.8	80.8	1.4
LAK007	2024																																		
LAK012	2024	92.8	2.1			55.5	4.1	67.4	4.1			6.0	0.1	6.4	0.1	5.7	1.0	24.3	7.0	7.8	0.6	4.0	0.1	67.7	6.5	22.2	1.6	5.2	0.6	22.2	0.6	117.3	8.9	121.0	9.7
LAK016	2024	132.3				88.3		111.9				6.4		6.6		4.7		71.0		10.2		7.8		142.3		28.3		9.7		25.0		205.4		207.0	
LAK022	2024	70.2				24.0		42.6				6.0		6.1		6.2		54.6		9.6		5.5		74.0		22.4		4.7		23.8		124.9		129.0	
LAK023	2024	47.5	1.8			20.7	3.9	28.3	0.5			5.9	0.0	6.1	0.0	4.5	0.3	31.6	1.4	6.4	0.1	4.9	0.1	49.6	1.8	15.0	0.6	3.7	0.0	11.6	0.4	79.8	2.7	84.1	2.3
LAK024	2024																																		
LAK028	2024	-8.8	4.6			-3.6	2.5	-34.4	6.2			5.0	0.1	5.0	0.1	5.8	0.4	146.8	10.5	8.8	0.8	22.3	1.3	91.4	5.4	24.8	1.7	3.2	0.2	19.6	0.8	139.1	7.5	187.0	12.1
LAK034	2024																																		
LAK042	2024	61.2	0.8			3.6	4.6	1.6	4.3			5.0	0.1	5.0	0.1	12.6	1.0	14.1	0.7	7.3	0.5	2.4	0.1	17.8	0.9	29.2	0.7	2.5	0.1	25.9	0.4	75.5	1.6	93.1	3.4
LAK044	2024	16.1	0.4			5.3	0.7	9.4	0.7			5.7	0.0	6.1	0.3	2.0	0.2	3.9	0.3	6.7	0.1	1.7	0.1	8.3	0.1	4.1	0.1	7.0	0.0	0.6	0.2	20.1	0.2	23.6	0.7
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			
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	5.9	0.0	6.1	0.1	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	1.5	114.5	1.8
NC194	2019	46.7	0.6	30.4	5.3	41.4	0.2	44.7	0.4	6.4	0.0	6.5	0.0	6.6	0.1	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	0.8	50.0	6.3
DCAS14A	2019	81.1	1.5	58.6	5.9	73.0	0.3	78.3	1.4	6.6	0.1	6.6	0.0	6.8	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	1.7	138.6	13.6
NC184	2020																																		
NC194	2020																																		

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 (BASL)	SE	pH (ALS)	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)	SE	∑ Anions (µeq/L)	SE
DCAS14A	2020																																		
NC184	2021	61.2				9.2		6.4				5.2		5.1		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				6.0		6.2		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				6.0		6.6		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				5.9		6.1		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				6.4		6.5		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				6.5		6.8		1.2		30.7		5.4		0.3		71.2		11.4		10.1		9.1		101.7		98.5	
NC184	2023	111.5				67.1		80.4				6.5		6.5		6.9		4.2		23.7		0.3		80.0		18.6		4.0		13.2		115.7		131.1	
NC194	2023	43.1				34.2		42.4				7.0		6.5		0.8		1.2		7.1		0.3		27.6		4.3		4.2		8.3		44.4		47.1	
DCAS14A	2023	84.2				68.7		81.4				6.6		6.8		1.2		32.2		7.1		0.3		82.1		12.8		10.9		10.7		116.5		109.1	
NC184	2024	82.3				24.4		30.6				5.6		5.6		11.0		5.6		19.5		0.3		51.2		18.1		3.0		15.6		87.9		114.7	
NC194	2024	39.7				26.0		37.9				6.2		6.3		1.0		2.7		6.5		0.3		25.2		4.5		4.2		8.7		42.6		48.0	
DCAS14A	2024	75.4				69.9		72.0				6.4		6.6		1.3		39.7		8.5		0.3		81.0		12.6		11.1		10.6		115.2		119.9	

[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

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	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
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

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)
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
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

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)
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
LAK006	2023		2.1		6.4	6.3	3.4	9.3	0.7	0.2	0.1	2.5	5.8	0.8	0.2	0.2	0.6	0.0	0.0	0.0
LAK012	2023		3.1		6.4	6.3	4.0	10.6	0.4	0.2	0.1	2.5	2.5	1.1	0.2	0.2	0.6	0.1	0.0	0.0
LAK016	2023		4.7		6.6	6.6	3.8	19.3	2.1	0.2	0.1	2.5	8.5	2.3	0.3	0.3	0.6	0.0	0.0	0.0
LAK022	2023		2.0		6.2	6.2	5.4	13.1	1.6	0.3	0.1	2.5	2.5	1.3	0.3	0.2	0.7	0.1	0.1	0.0
LAK023	2023		1.4		6.1	6.1	4.8	8.0	0.8	0.2	0.1	2.5	2.5	0.9	0.2	0.2	0.4	0.0	0.1	0.0
LAK028	2023		0.3		5.3	5.3	4.1	16.3	4.2	0.2	0.3	2.5	4.7	1.3	0.2	0.1	0.5	0.1	0.4	0.0
LAK042	2023		0.8		5.5	5.4	9.4	8.0	0.3	0.2	0.0	2.5	2.5	0.2	0.3	0.1	0.7	0.2	0.3	0.0
LAK044	2023		0.4		5.8	5.7	1.7	3.6	0.2	0.2	0.0	2.5	3.5	0.2	0.1	0.3	0.1	0.0	0.0	0.0
LAK006	2024		1.8		6.4	6.0	3.8	9.4	0.9	0.2	0.1	2.5	6.4	0.8	0.2	0.2	0.6	0.0	0.0	0.0
LAK012	2024		2.8		6.4	6.0	5.7	13.4	1.2	0.3	0.1	4.0	4.0	1.4	0.3	0.2	0.7	0.2	0.1	0.0
LAK016	2024		4.4		6.6	6.4	4.7	23.4	3.5	0.4	0.1	30.9	15.3	2.9	0.4	0.4	0.8	0.0	0.1	0.0
LAK022	2024		1.2		6.1	6.0	6.2	15.2	2.7	0.3	0.1	2.5	2.5	1.5	0.3	0.2	0.7	0.1	0.1	0.0
LAK023	2024		1.0		6.1	5.9	4.5	10.2	1.6	0.2	0.1	10.0	25.0	1.0	0.2	0.1	0.4	0.0	0.1	0.0
LAK028	2024		-0.6		4.8	4.8	6.8	30.0	8.6	0.4	0.5	33.2	2.5	2.2	0.4	0.1	0.7	0.1	0.8	0.0
LAK042	2024		0.2		5.0	5.0	12.6	11.8	0.7	0.3	0.0	2.5	9.3	0.4	0.4	0.1	0.7	0.3	0.4	0.0
LAK044	2024		0.3		6.1	5.7	2.0	3.5	0.2	0.2	0.0	2.5	6.9	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																			

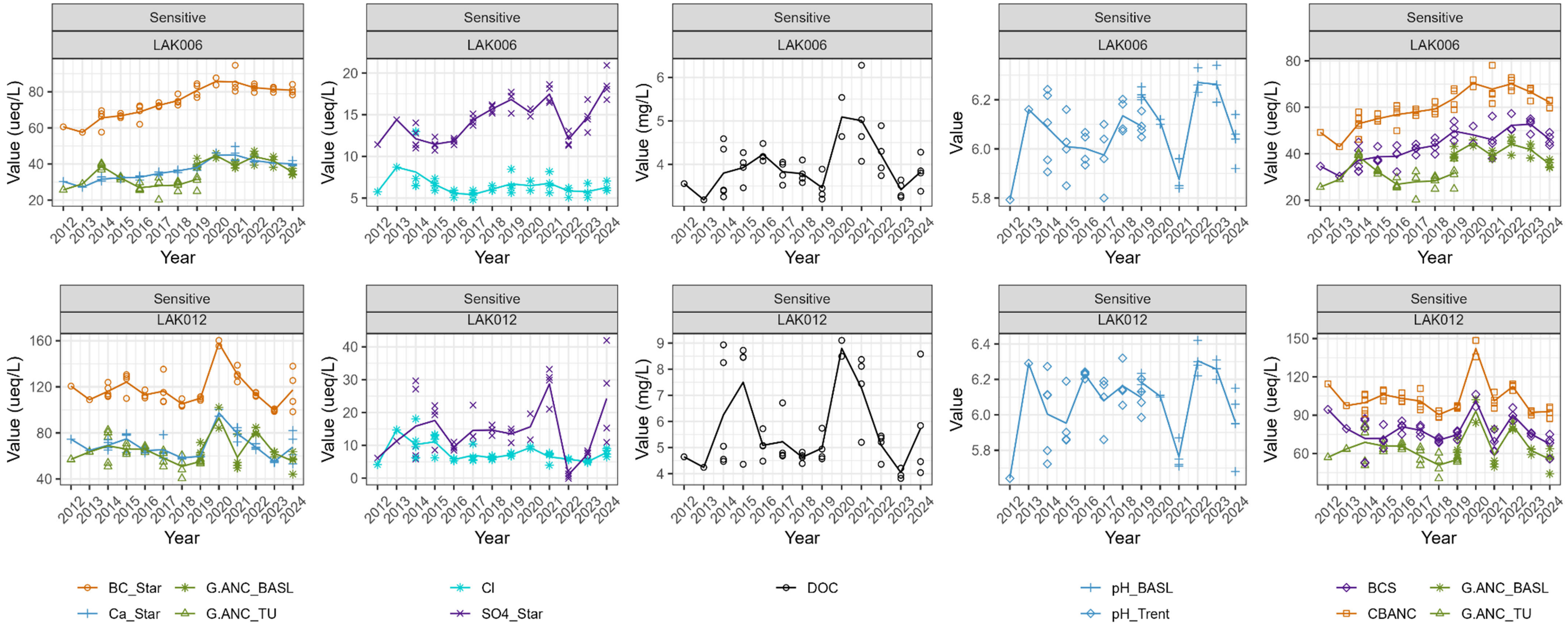
Lake	Year	Gran Alkalinity (mg/L) (Trent)	Gran Alkalinity (mg/L) (BASL)	pH (Trent)	pH (ALS)	pH (BASL)	DOC (mg/L)	Conductivity (µS/s)	SO4 (mg/L)	Cl (mg/L)	F (mg/L)	NO3 (µg/L)	NH4 (µg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)
DCAS14A	2014																			
NC184	2015	0.9		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
NC184	2023		3.4		6.5	6.5	6.9	13.9	0.3	0.8	0.0	2.5	2.5	1.6	0.3	0.2	0.8	0.1	0.2	0.0
NC194	2023		1.7		6.5	7.0	0.8	5.3	0.1	0.3	0.0	2.5	2.5	0.6	0.1	0.2	0.3	0.0	0.0	0.0
DCAS14A	2023		3.4		6.8	6.6	1.2	13.6	1.6	0.3	0.0	2.5	2.5	1.7	0.2	0.4	0.4	0.0	0.0	0.0
NC184	2024		1.2		5.6	5.6	11.0	11.6	0.4	0.7	0.0	2.5	2.5	1.0	0.3	0.1	0.7	0.1	0.3	0.0
NC194	2024		1.3		6.3	6.2	1.0	5.0	0.2	0.2	0.0	2.5	2.5	0.5	0.1	0.2	0.3	0.0	0.0	0.0
DCAS14A	2024		3.5		6.6	6.4	1.3	14.1	2.0	0.3	0.0	2.5	13.8	1.6	0.2	0.4	0.4	0.0	0.0	0.0

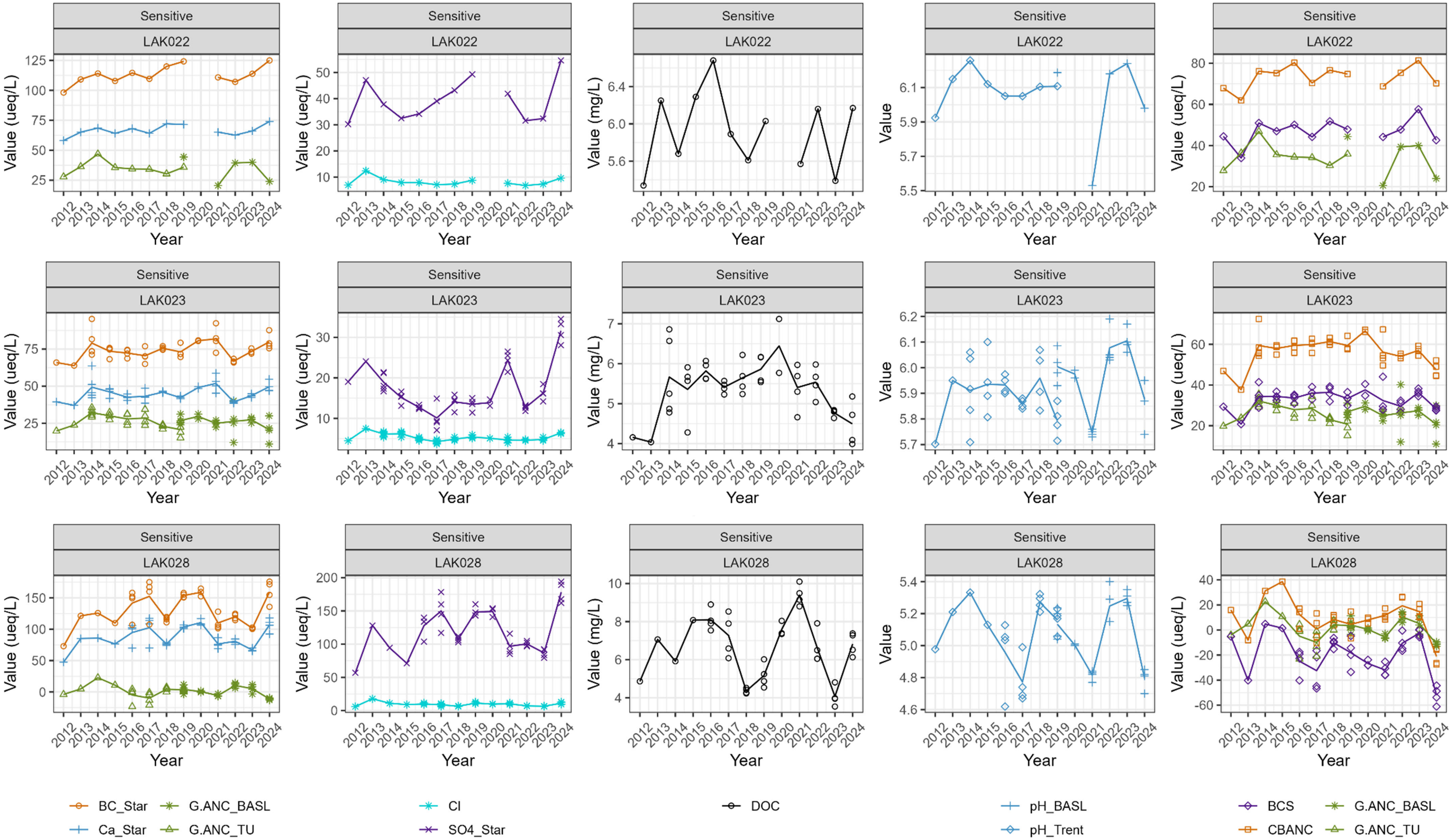
Appendix 2: Changes in Ion Concentrations from 2012 to 2024

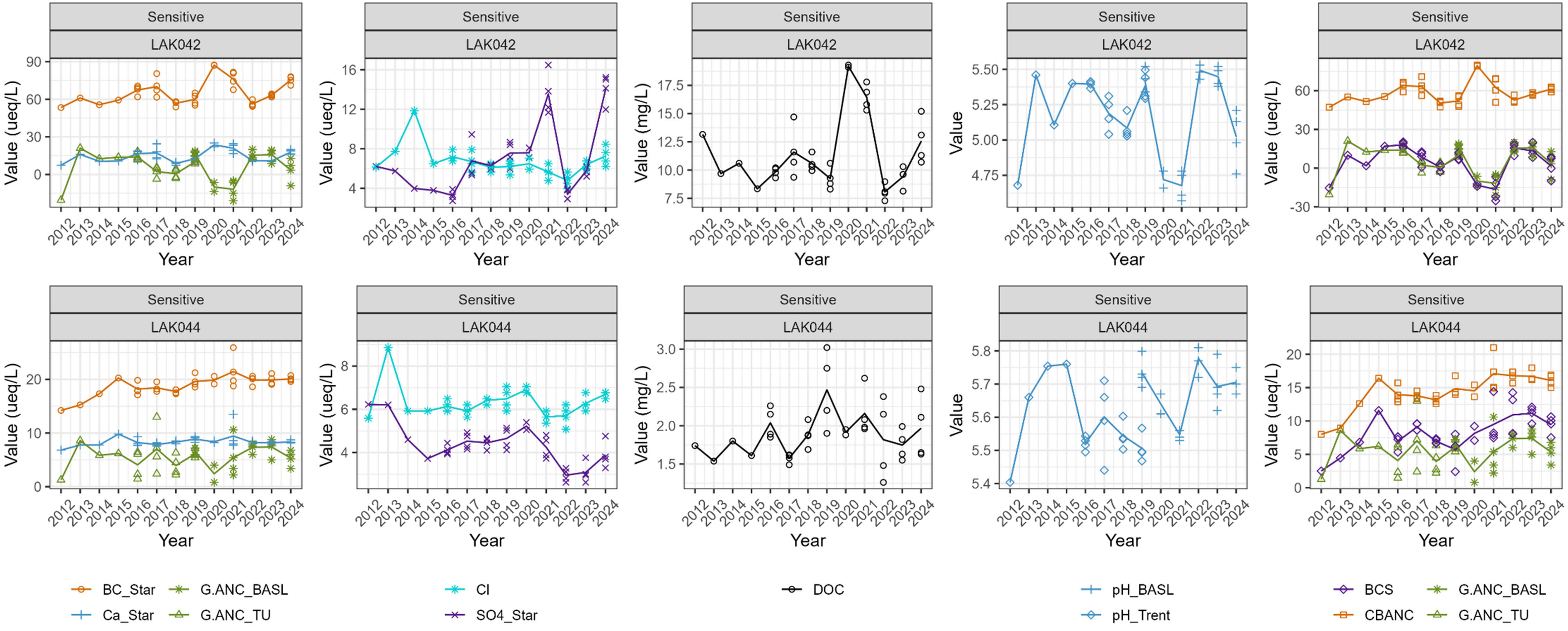
For each of the EEM lakes, the figures in this appendix show the inter-annual changes in six major water chemistry metrics from 2012 to 2024: Gran ANC, base cations and calcium (left panel), sulfate and chloride (centre-left panel), dissolved organic carbon (centre panel), CBANC, Gran ANC, and BCS (centre-right panel), and pH (right panel). The selection of each set 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 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 that were taken within the fall index period. 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.

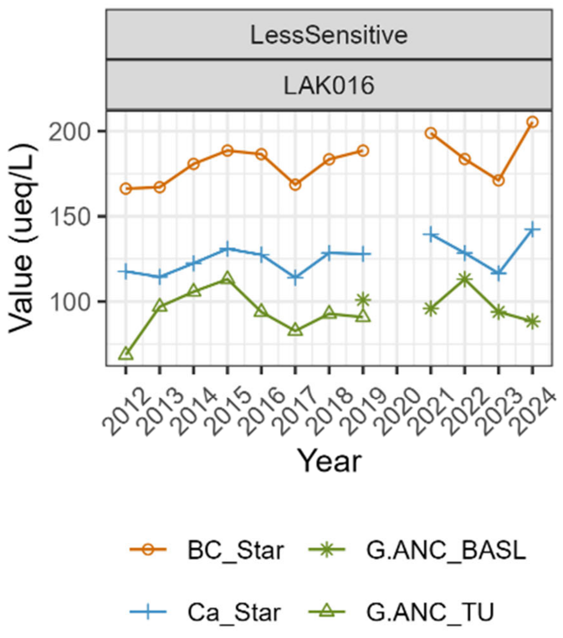
Sensitive Lakes

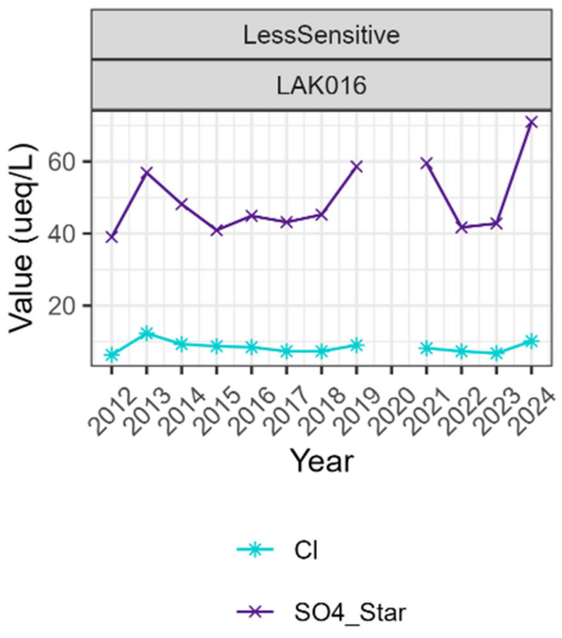


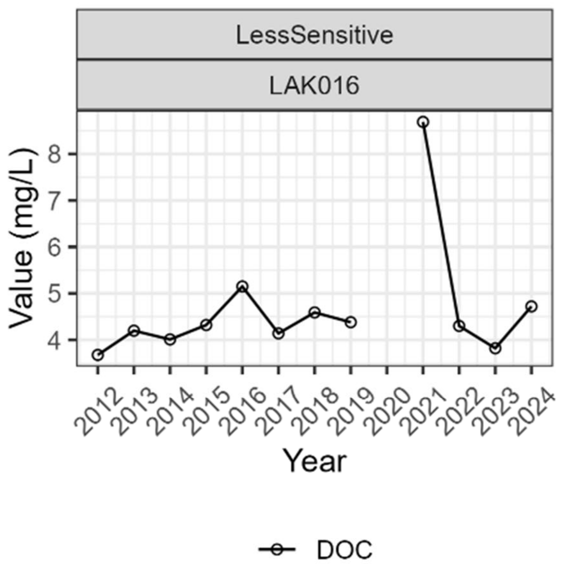

Sensitive
LAK022
LAK023
LAK028
Value (ueq/L)
Value (mg/L)
Value
Year
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
BC_Star
Ca_Star
G.ANC_BASL
G.ANC_TU
Cl
SO4_Star
DOC
pH_BASL
pH_Trent
BCS
CBANC
G.ANC_BASL
G.ANC_TU

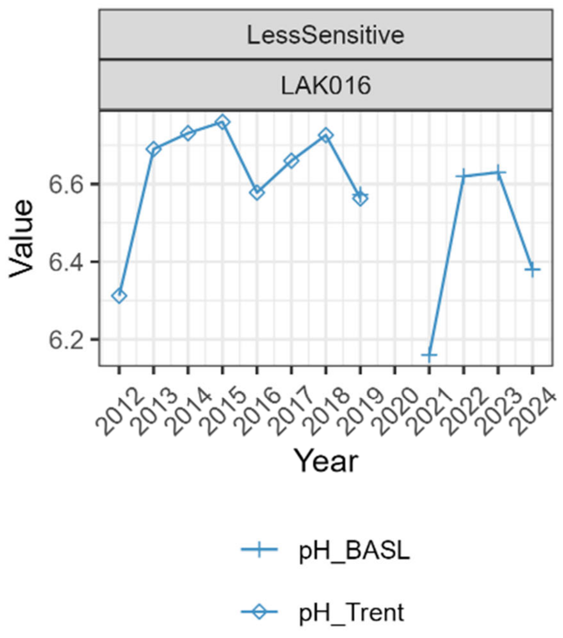

Sensitive
LAK042
Sensitive
LAK044
Value (ueq/L)
Value (mg/L)
Value
Year
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
90
60
30
0
16
12
8
4
17.5
15.0
12.5
10.0
7.5
5.50
5.25
5.00
4.75
60
30
0
-30
20
10
0
8
6
4
3.0
2.5
2.0
1.5
5.8
5.7
5.6
5.5
5.4
20
15
10
5
0
BC_Star
Ca_Star
G.ANC_BASL
G.ANC_TU
Cl
SO4_Star
DOC
pH_BASL
pH_Trent
BCS
CBANC
G.ANC_BASL
G.ANC_TU

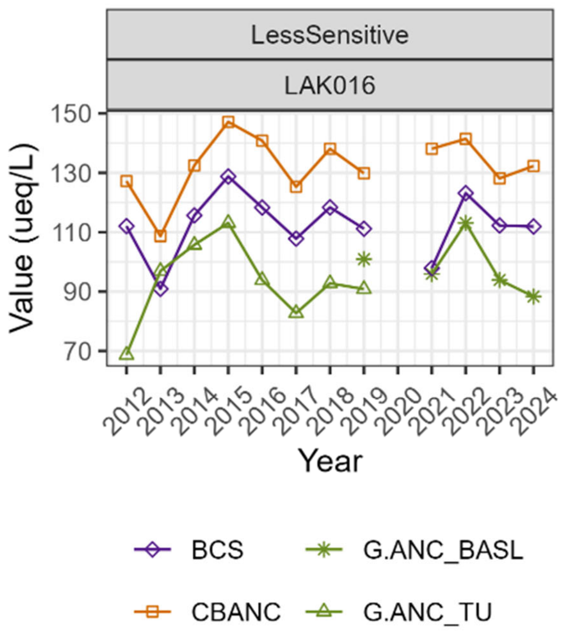
Less Sensitive Lakes



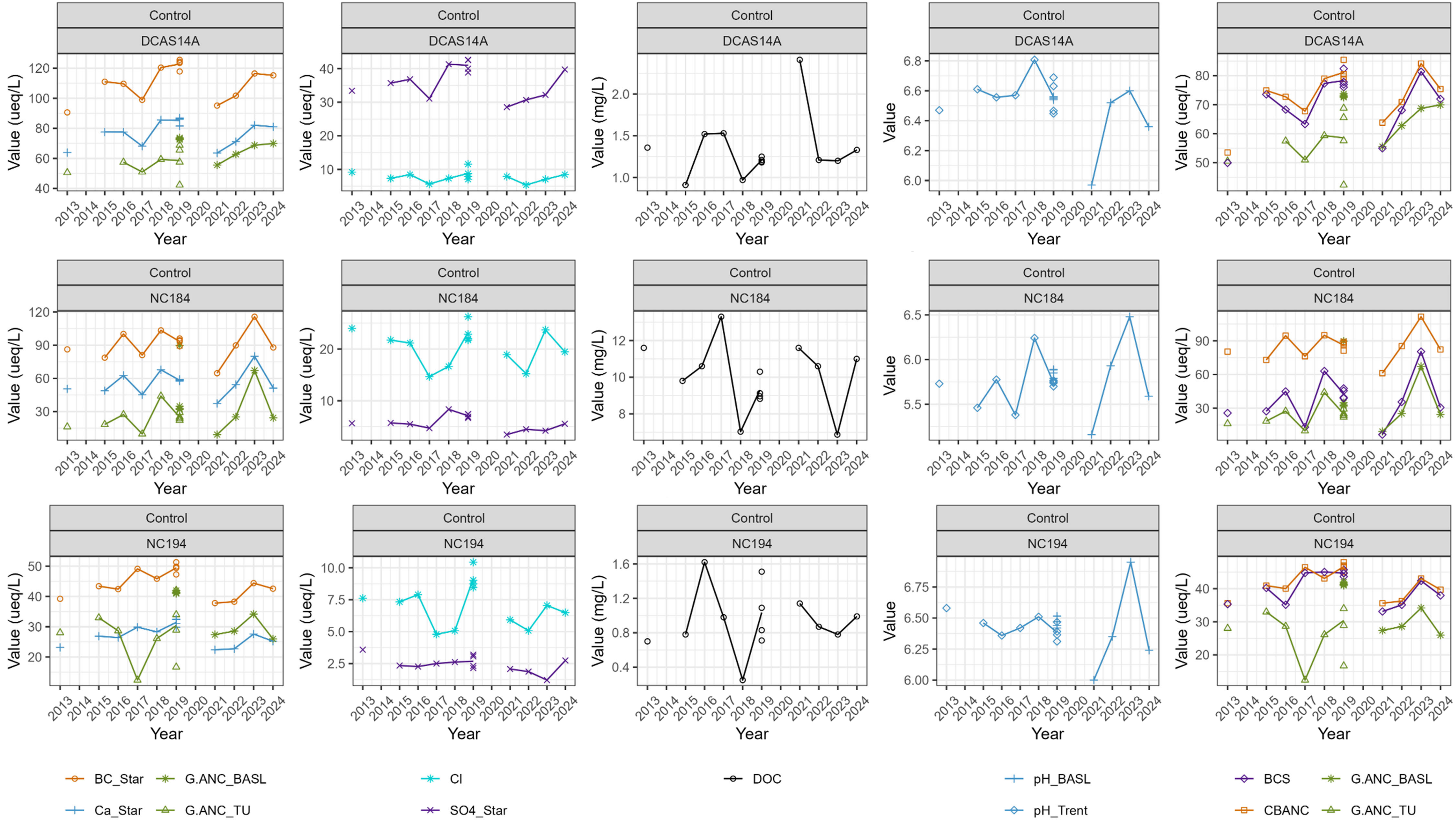






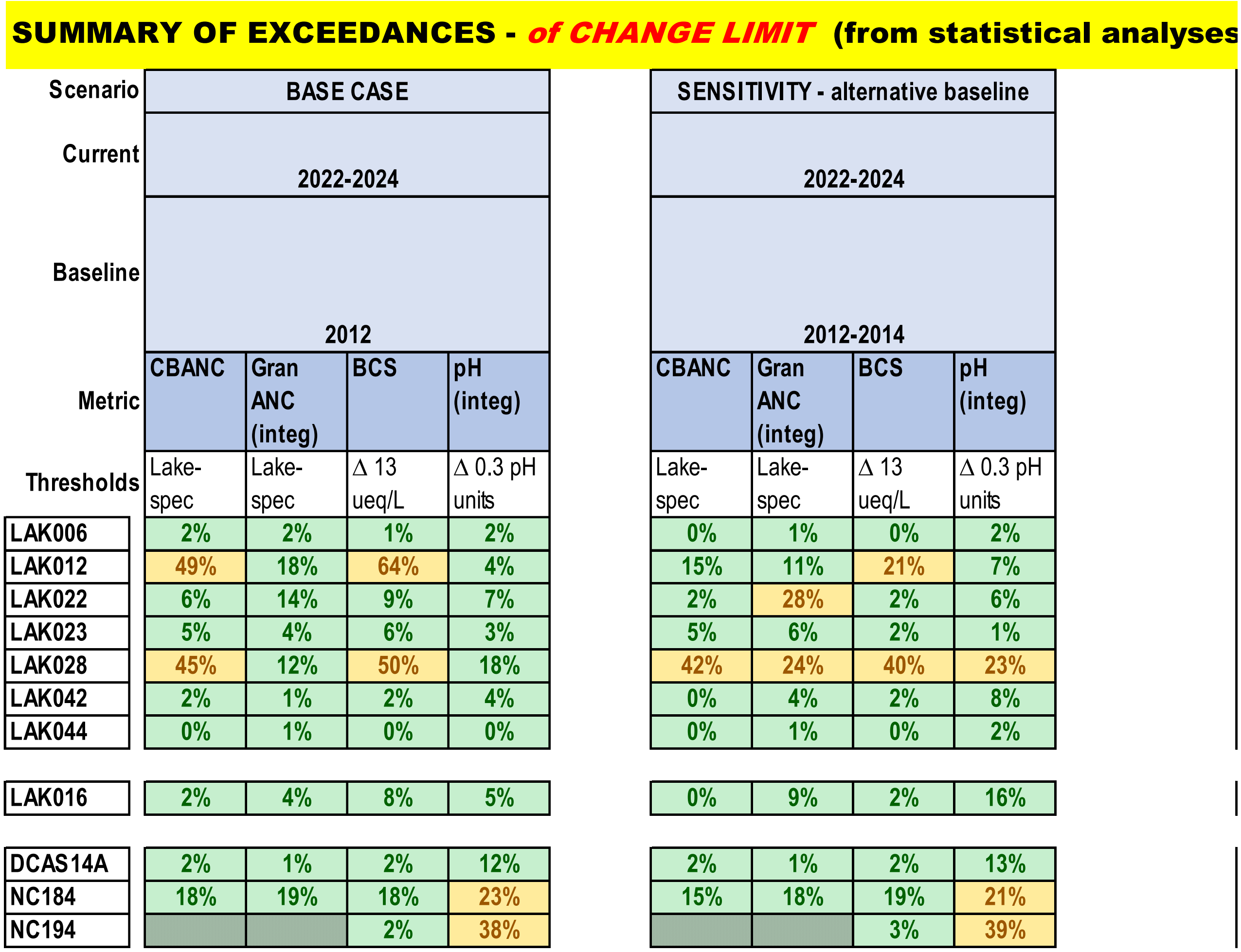


Control Lakes



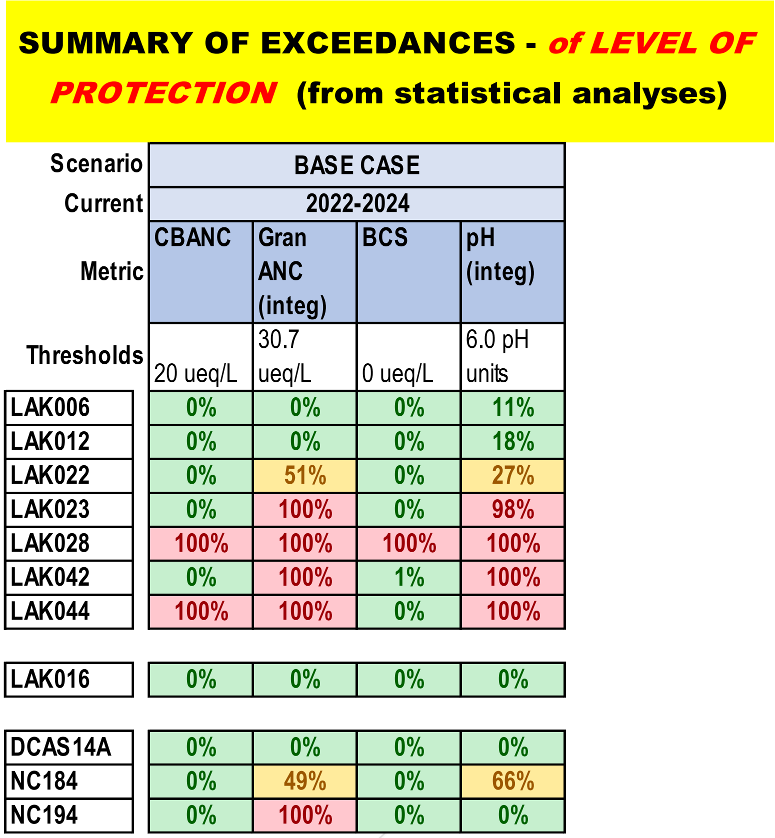
Appendix 3: Sensitivity Analyses for Statistical Analyses of Changes in Lake Chemistry

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

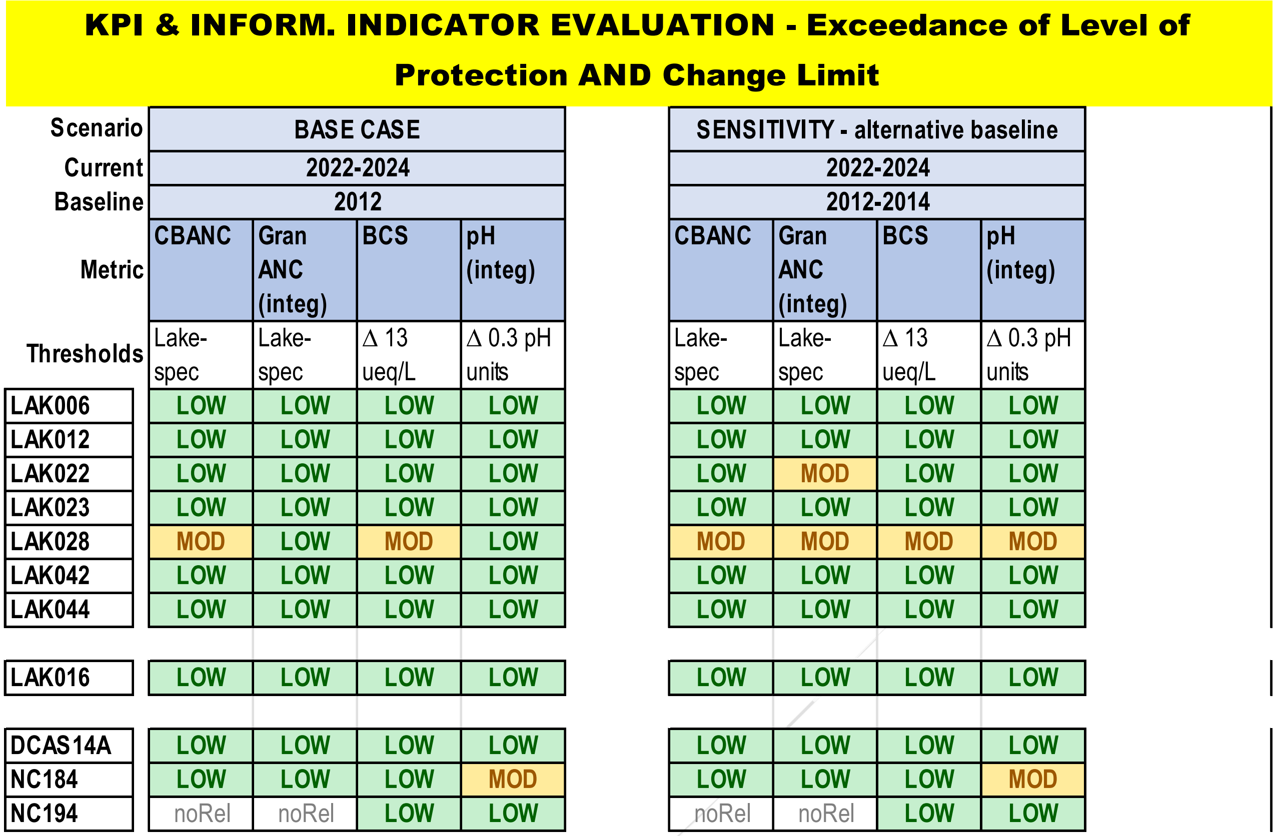
Scenario	BASE CASE				SENSITIVITY - alternative baseline			
Current	2022-2024				2022-2024			
Baseline	2012				2012-2014			
Metric	CBANC	Gran ANC (integ)	BCS	pH (integ)	CBANC	Gran ANC (integ)	BCS	pH (integ)
Thresholds	Lake-spec	Lake-spec	Δ 13 ueq/L	Δ 0.3 pH units	Lake-spec	Lake-spec	Δ 13 ueq/L	Δ 0.3 pH units
LAK006	2%	2%	1%	2%	0%	1%	0%	2%
LAK012	49%	18%	64%	4%	15%	11%	21%	7%
LAK022	6%	14%	9%	7%	2%	28%	2%	6%
LAK023	5%	4%	6%	3%	5%	6%	2%	1%
LAK028	45%	12%	50%	18%	42%	24%	40%	23%
LAK042	2%	1%	2%	4%	0%	4%	2%	8%
LAK044	0%	1%	0%	0%	0%	1%	0%	2%
LAK016	2%	4%	8%	5%	0%	9%	2%	16%
DCAS14A	2%	1%	2%	12%	2%	1%	2%	13%
NC184	18%	19%	18%	23%	15%	18%	19%	21%
NC194			2%	38%			3%	39%



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

Scenario	BASE CASE			
Current	2022-2024			
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%	11%
LAK012	0%	0%	0%	18%
LAK022	0%	51%	0%	27%
LAK023	0%	100%	0%	98%
LAK028	100%	100%	100%	100%
LAK042	0%	100%	1%	100%
LAK044	100%	100%	0%	100%
LAK016	0%	0%	0%	0%
DCAS14A	0%	0%	0%	0%
NC184	0%	49%	0%	66%
NC194	0%	100%	0%	0%

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 current 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.

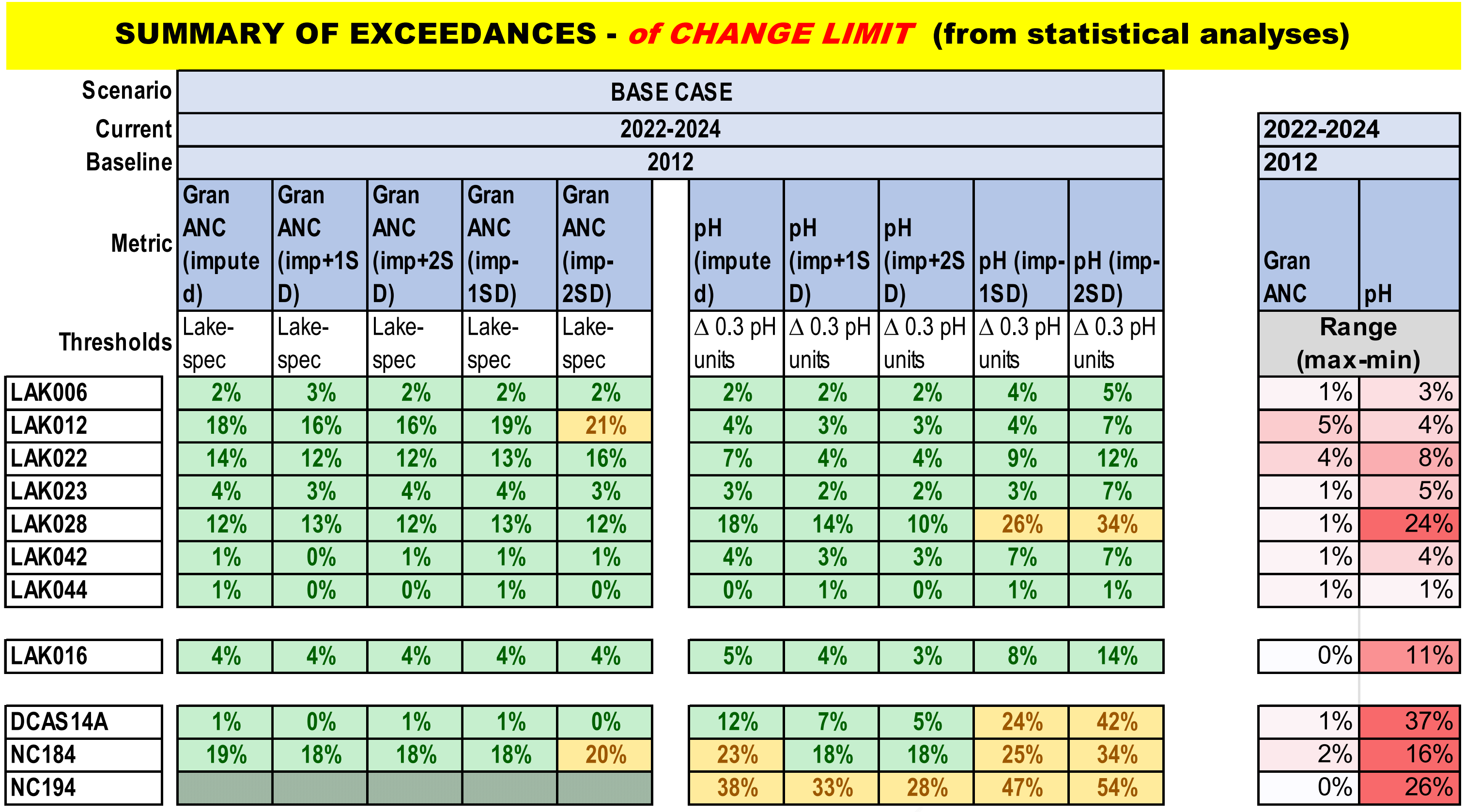


KPI & INFORM. INDICATOR EVALUATION - Exceedance of Level of Protection AND Change Limit

Scenario	BASE CASE				SENSITIVITY - alternative baseline			
Current	2022-2024				2022-2024			
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	LOW	LOW	LOW	LOW	MOD	LOW	LOW
LAK023	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
LAK028	MOD	LOW	MOD	LOW	MOD	MOD	MOD	MOD
LAK042	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
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	LOW	LOW	MOD	LOW	LOW	LOW	MOD
NC194	noRel	noRel	LOW	LOW	noRel	noRel	LOW	LOW

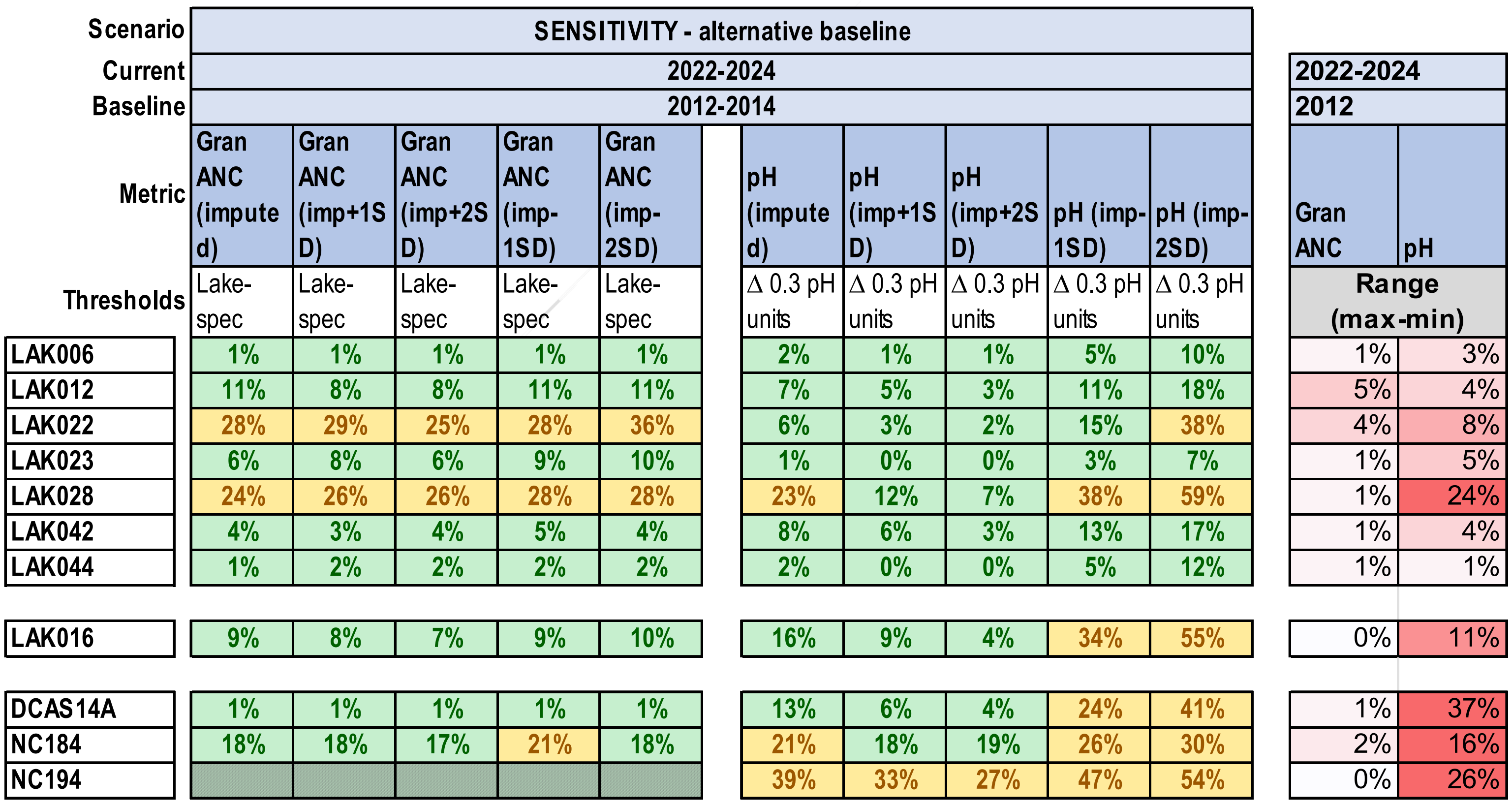
Appendix 4: Sensitivity Analyses on Imputation of Gran ANC and pH Values for Integrated Time Series

This appendix includes the results of the Bayesian statistical analyses for Gran ANC and pH using alternate values for the imputed 2020, 2021, 2022, 2023 and 2024 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 and the alternative baseline 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.*

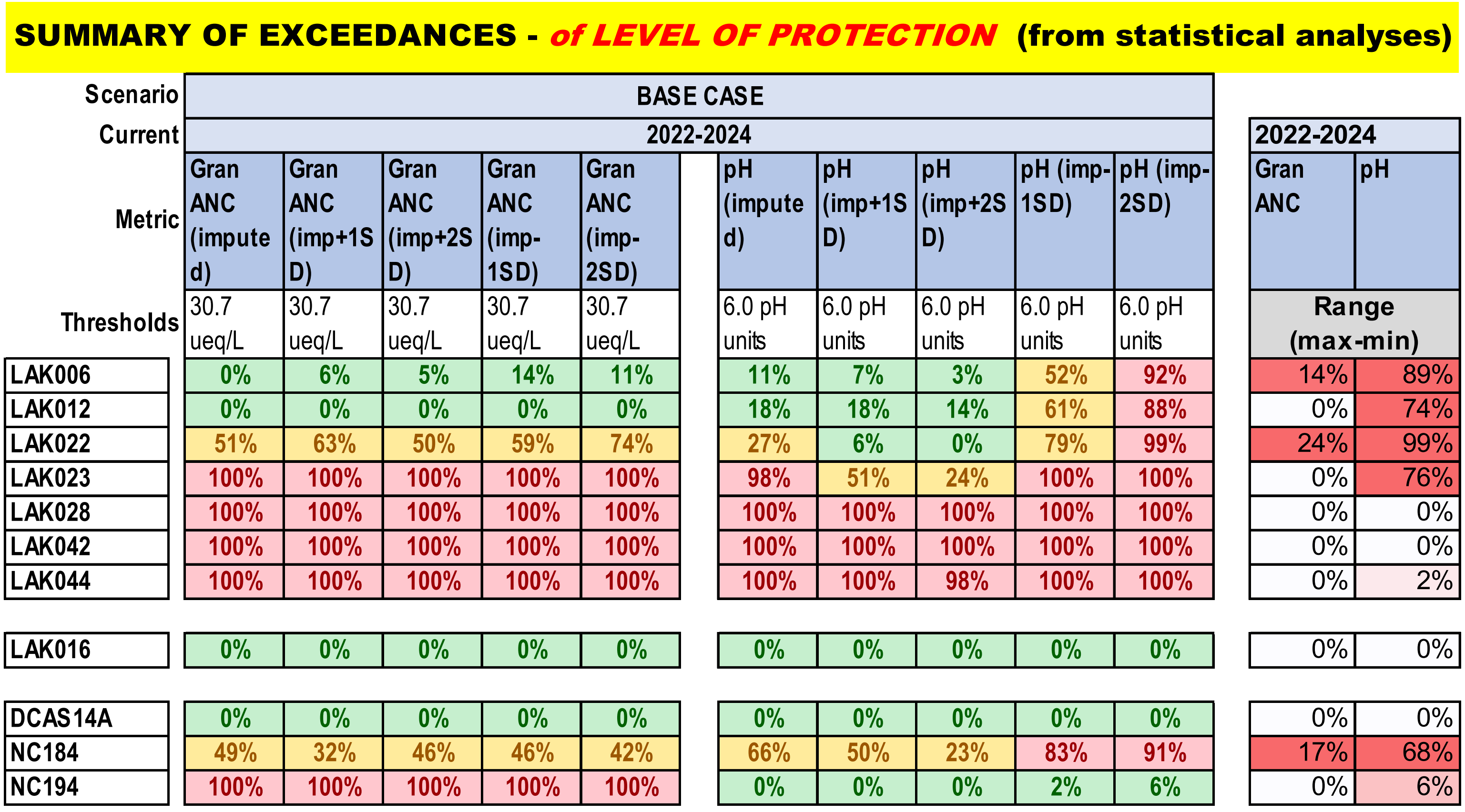


SUMMARY OF EXCEEDANCES - *of CHANGE LIMIT* (from statistical analyses)

Scenario	BASE CASE											
Current	2022-2024										2022-2024	
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	2%	3%	2%	2%	2%	2%	2%	2%	4%	5%	1%	3%
LAK012	18%	16%	16%	19%	21%	4%	3%	3%	4%	7%	5%	4%
LAK022	14%	12%	12%	13%	16%	7%	4%	4%	9%	12%	4%	8%
LAK023	4%	3%	4%	4%	3%	3%	2%	2%	3%	7%	1%	5%
LAK028	12%	13%	12%	13%	12%	18%	14%	10%	26%	34%	1%	24%
LAK042	1%	0%	1%	1%	1%	4%	3%	3%	7%	7%	1%	4%
LAK044	1%	0%	0%	1%	0%	0%	1%	0%	1%	1%	1%	1%
LAK016	4%	4%	4%	4%	4%	5%	4%	3%	8%	14%	0%	11%
DCAS14A	1%	0%	1%	1%	0%	12%	7%	5%	24%	42%	1%	37%
NC184	19%	18%	18%	18%	20%	23%	18%	18%	25%	34%	2%	16%
NC194						38%	33%	28%	47%	54%	0%	26%



Scenario	SENSITIVITY - alternative baseline											
Current	2022-2024										2022-2024	
Baseline	2012-2014										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	1%	1%	1%	1%	1%	2%	1%	1%	5%	10%	1%	3%
LAK012	11%	8%	8%	11%	11%	7%	5%	3%	11%	18%	5%	4%
LAK022	28%	29%	25%	28%	36%	6%	3%	2%	15%	38%	4%	8%
LAK023	6%	8%	6%	9%	10%	1%	0%	0%	3%	7%	1%	5%
LAK028	24%	26%	26%	28%	28%	23%	12%	7%	38%	59%	1%	24%
LAK042	4%	3%	4%	5%	4%	8%	6%	3%	13%	17%	1%	4%
LAK044	1%	2%	2%	2%	2%	2%	0%	0%	5%	12%	1%	1%
LAK016	9%	8%	7%	9%	10%	16%	9%	4%	34%	55%	0%	11%
DCAS14A	1%	1%	1%	1%	1%	13%	6%	4%	24%	41%	1%	37%
NC184	18%	18%	17%	21%	18%	21%	18%	19%	26%	30%	2%	16%
NC194						39%	33%	27%	47%	54%	0%	26%



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

Scenario	BASE CASE											
Current	2022-2024										2022-2024	
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%	6%	5%	14%	11%	11%	7%	3%	52%	92%	14%	89%
LAK012	0%	0%	0%	0%	0%	18%	18%	14%	61%	88%	0%	74%
LAK022	51%	63%	50%	59%	74%	27%	6%	0%	79%	99%	24%	99%
LAK023	100%	100%	100%	100%	100%	98%	51%	24%	100%	100%	0%	76%
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%	98%	100%	100%	0%	2%
LAK016	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
DCAS14A	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NC184	49%	32%	46%	46%	42%	66%	50%	23%	83%	91%	17%	68%
NC194	100%	100%	100%	100%	100%	0%	0%	0%	2%	6%	0%	6%

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.

Appendix D: Technical Report of Lake Monitoring in 2024

The following pages contain the full **Rio Tinto BC Works SO_2 Environmental Effects Program: Monitoring of Lakes in 2024, Final Report**, in PDF format.

Citation: Limnotek. 2025. Rio Tinto SO_2 Environmental Effects Program: Monitoring of Lakes in 2024. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Ltd. 62 pp.

Rio Tinto BC Works SO_2 Environmental Effects Program: Monitoring of Lakes in 2024

Final Report

May 31, 2025

LIMNOTEK

Rio Tinto BC Works SO_2 Environmental Effects Program: Monitoring of Lakes in 2024

Final Report

Submitted to

Rio Tinto BC Works Ltd.
Kitimat, B.C.

Prepared by

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May 31, 2025

Citation: Limnotek. 2025. Rio Tinto SO_2 Environmental Effects Program: Monitoring of lakes in 2024. Report prepared by Limnotek Research and Development Inc. for Rio Tinto Ltd. 54pp.

Cover photo: Foreshore and dock at the Rio Tinto smelter in Kitimat, September 28, 2024
Photo credit, Chris Perrin.

EXECUTIVE SUMMARY

Chemical measurements among selected lakes near Kitimat and Terrace, British Columbia were completed in 2024 as part of ongoing environmental effects monitoring (EEM) of SO_2 emissions from the Rio Tinto smelter in Kitimat. Lake sampling and related data analysis is the aquatic component of a larger EEM program that also includes atmospheric SO_2 and acidic deposition, human health, vegetation, and soils monitoring. This report presents quality control measurements and selected limnological interpretations in support of the continued EEM program. Detailed analysis of the EEM data is presented in a separate report by ESSA Technologies Ltd. on behalf of Rio Tinto.

The lake monitoring includes annual sampling of eleven lakes for a range of chemical attributes that are used to assess risk of acidification from smelter emissions. More frequent and detailed sampling each year of a subset of the lakes is used to examine limnological processes contributing to time course change in lake function and seasonality of lake chemistry.

Quality assurance testing in 2024 showed high accuracy and precision among analytes, indicating continued excellent repeatability of sample handling and analysis procedures.

pH is a particularly important indicator of time course change in lake acidification. It supports Gran ANC as a key performance indicator in the Rio Tinto EEM program. pH was measured from all lakes in three ways in 2024 and prior years: in samples submitted to ALS Environmental in Burnaby, B.C., in samples submitted to the Biogeochemical Analytical Service Laboratory at the University of Alberta (a speciality chemistry lab), and using a field WTW pH meter. Additionally, pH at two of the lakes was measured continuously using pH loggers. Two factors affect pH measurement assuming instruments and electrodes are operating correctly and filled sample bottles are capped without air space. First is duration that a water sample is exposed to air before pH is measured (a CO_2 degassing effect on pH) and second is duration of electrode immersion in a water sample before pH is measured (time for voltage stabilization across the electrode glass bulb). Unlike observations in earlier years of the EEM, controlled trials in 2024 showed these factors were not statistically significant in affecting recorded pH. Despite this finding, pH values coming from ALS were significantly and consistently greater than pH from the other sources. This high bias at ALS was also found in earlier years of monitoring. While the “correct” pH value is not known among paired contrasts, calibration with fresh standards and other quality control was well established and known with use of the WTW, the loggers, and at BASL. The same must be true at ALS but loss of CO_2 from the samples at ALS must be occurring in greater amounts than is happening with use of the other instruments and methods to result in high pH bias. Cause of that bias is unknown based on testing to date.

To avoid further trials looking for cause of this method effect on pH, a standard method is presented for routine and reliable long term pH measurement in the EEM program. It includes discontinued pH measurement at ALS but continued pH measurement of pH using the other methods. BASL pH will be used for long term trend analysis. Logger data will be used for resolving seasonal pH variation. Field pH data from the WTW meter will be used as backup given its long-term record and high accuracy as measured against frequent calibrations.

Meromixis (lack of mixing of a chemically distinct bottom layer) is known in one of the lakes called LAK028, which is located within the northward path of emissions from the Rio Tinto smelter. This lake has a steep chemocline in the bottom few meters. Sulfur-reducing bacteria (bacteria that use sulfur as an electron donor for their metabolism) and phototrophic sulfur bacteria are thought to be present in the chemocline using an ample supply of sulfur deposited on the lake surface in precipitation. Oxidizing conditions are present above the chemocline and strong reducing conditions are present within the chemocline resulting in lower pH at the surface compared to the bottom. While minor entrainment from the chemocline into surface water can occur, it is not enough to change surface chemistry. The chemocline has remained stable and isolated for practical purposes from surface water at least since chemical stratification was detected in 2017. This stability means that sampling of the surface water in LAK028 is acceptable and representative of an acid-sensitive lake within the EEM program. Water column chemistry must continue to be monitored in LAK028 to ensure that confounding by unexpected disruption of meromixis does not affect interpretation of time course change in critical load of acidity that is examined annually by ESSA Technologies on behalf of Rio Tinto.

Increased sensitivity of chemical profiling that was implemented in 2024 with the use of a high accuracy CTD (RBR Maestro) revealed minor entrainment of bottom water into surface waters of LAK028. As noted above it was not enough to change pH of surface water. The CTD also detected a short-lived spring algal bloom in LAK028, which has not been previous found.

ACKNOWLEDGEMENTS

Several people contributed to this project. Work was managed by Chris Perrin. Field operations were run by Shauna Bennett with site logistics and safety organization provided by Fred Seiler. Chris Perrin and Shauna Bennett were authors of this report. Rio Tinto safety planning and oversight was managed by Shawn Zettler (Rio Tinto). Personnel who assisted in the field were Dwayne Ridler and Jared Sanders, both with Wai Wah Environmental GP Ltd. that was on contract with Rio Tinto. Chemical analysis of water samples was provided by the Biogeochemical Analytical Service Laboratory (BASL) at the University of Alberta (managed by Dr. Mingsheng Ma) and ALS Environmental in Burnaby, B.C. with account management from Thomas Chang. Safety check-in was provided by Jason Bennett for ground-based sampling and by Shawn Zettler (Rio Tinto) for sampling by helicopter. Special thanks go to David Marmorek (ESSA Technologies Ltd.), Shawn Zettler (Rio Tinto), and Alex Hall (ESSA Technologies Ltd.) for their ongoing communications with the authors during the project.

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1 INTRODUCTION

At the end of March 2016, Rio Tinto completed modernization of its smelter in Kitimat, British Columbia to increase production of aluminum. The modernization, hereafter called the Kitimat Modernization Project or KMP, increased emissions of SO_2 , which could potentially change the acidity of precipitation affecting downwind watersheds and communities, including Terrace, Kitimat, and Kitamaat Village (village of the Haisla Nation). ESSA et al. (2013a) estimated that the acidic deposition may exceed the critical load of acidity for some lakes. Critical load (CL) is defined as “a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge” (Nilsson and Grennfelt 1988). An environmental effects monitoring program (EEM) was developed by ESSA et al. (2013b) in consultation with representatives of Rio Tinto, the Haisla Nation, and the BC Ministry of Environment. The monitoring plan was implemented and has been ongoing annually. It includes indicators of atmospheric SO_2 and acidic deposition, SO_2 thresholds for human health, vegetation, soils, water chemistry, and aquatic biota. In the water and aquatic biota component, indicators include charge balance ANC (CBANC) as a Key Performance Indicator (KPI), and a set of informative indicators (Gran ANC, base cation surplus (BCS), pH). Additional indicators (dissolved organic carbon (DOC), and the concentration of major anions and cations) are used to perform QA/QC checks and evaluate year on year changes (ESSA 2022). The focus of annual water monitoring has been on lakes potentially exposed to acid deposition. Chemical measurements in streams downstream of a lake closest to the smelter have also been conducted, but less frequently than the lake sampling. In 2015, the annual water sampling expanded to include three control lakes (called DCAS14A, NC184 and NC194) that are not within the smelter-influenced airshed. A comprehensive review of the EEM data collected during 2013 – 2018 showed no evidence of exceedances of pH or ANC thresholds (ESSA et al. 2019). This outcome showed that ambient base cation supply was sufficient to offset acid loading among lakes and streams of local drainages affected by smelter emissions, thus limiting change in ANC and pH. A ten-year comprehensive review will be completed by ESSA in 2026.

This report presents measurements collected from lakes that were sampled in 2024 in support of the continued EEM program. Nine tasks were as follows:

1. Sampling of water from 12 lakes on September 28, 2024 followed by analytical chemistry as part of the ongoing annual lake sampling. The sampling was completed using helicopter techniques that were developed in early years of the EEM by Limnotek. The lakes included seven *acid-sensitive* lakes (LAK006 (LAK006), LAK012 (Little LAK006), LAK022, LAK023 (West Lake), LAK028, LAK042, and LAK044), one *less acid-sensitive* lake (LAK016), three *control* lakes (DCAS14A, NC184, NC194) and one non-EEM lake (LAK027 Bowbyes Lake, added at the request of BC Environment).

2. Monthly water sampling during May through September 2024 in LAK006 (LAK006) and LAK028 and to describe basic limnology and to provide data for later analysis of spring and summer variability among values of chemical analytes. These two selected lakes were representative of acid – sensitive lakes in the study area.
3. Addition of three sampling episodes in late September through late October for later analysis of variability among chemical analytes during the fall sampling period in LAK006, LAK012, LAK023, LAK028, LAK042, and LAK044. This sampling supplemented the annual EEM sampling in Task 1.
4. Quality assurance testing of the 2024 water chemistry results.
5. Time course monitoring of pH and water level using data loggers in LAK006 and LAK028 in May through October 2024 to supplement Task 2.
6. Full year temperature monitoring at several depths in LAK028 from October 2023 through to October 2024. This sampling started in 2018 to examine physical differences between surface and bottom layers in LAK028 that are associated with meromixis that was detected in 2017.
7. Operation of a pH logger at the surface and bottom of LAK028 and a pH logger near the surface in LAK006 to examine seasonal variation in pH and provide insight into meromixis in LAK028.
8. Full year conductivity monitoring at several depths in LAK028 from October 15, 2023 through to October 15, 2024 to examine and interpret long term physical stability of the chemocline.
9. Maintenance of an instrument raft on LAK028 (Figure 1). The raft supported temperature and pH moorings. Tripods that were secured to the raft deck hosted air samplers that were part of the SO_2 sampler network in the Terrace-Kitimat valley (ESSA et al. 2022).

All data were supplied to ESSA Technologies Ltd. to update analyses needed for the EEM program.

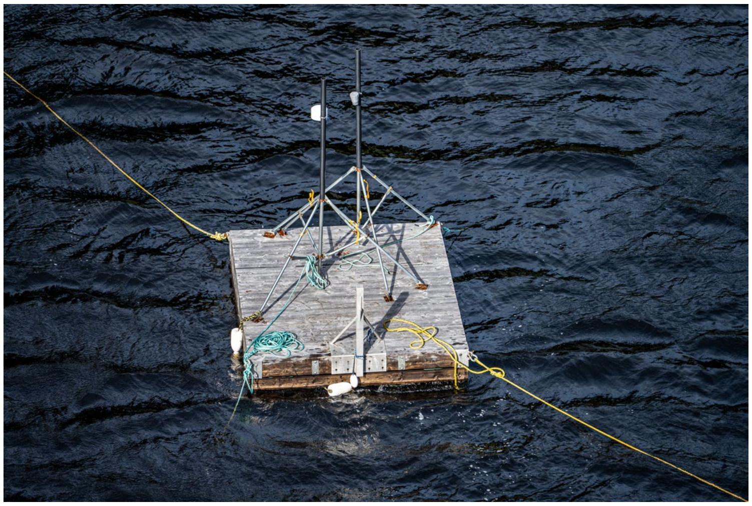

Figure 1. Image of the instrument raft on LAK028. The temperature and conductivity moorings and pH loggers (surface and bottom) were suspended from the raft. The tripods supported air sampling equipment that is described elsewhere.

2 METHODS

2.1 Sampling sites

Twelve lakes were included in the 2024 EEM following recommendations by ESSA et al. (2020a) and BC Environment (Table 1). The lakes included seven *acid-sensitive* lakes (LAK006 (LAK006), LAK012 (Little LAK006), LAK022, LAK023 (West Lake), LAK028, LAK042, and LAK044), one *less acid-sensitive* lake (LAK016), three *control* lakes (DCAS14A, NC184, NC194) and one non-EEM lake (LAK027 Bowbyes Lake) (Figure 2). Bowbyes Lake (LAK027) was added in 2021 following a request from BC Environment to sample another lake in the high SO_2 deposition zone.

Table 1. List of 11 EEM lakes and one non-EEM lake sampled in 2024.

Number of water body	Lake or stream name	Lake area (ha)	Lake designation[a]	UTM zone	Easting	Northing	Sampling activity in the EEM program[b]
LAK006	LAK006	10.25	Sensitive	9U	524155	6020661	SWC, F
LAK012	Little LAK006	2.30	Sensitive	9U	524145	6021028	SWC, F
LAK022		5.74	Sensitive	9U	524185	6022796	SWC
LAK023	West Lake	6.77	Sensitive	9U	522750	6018850	SWC, F
LAK028		1.02	Sensitive	9U	519139	5993425	SWC[c]
LAK042		1.46	Sensitive	9U	520911	6048362	SWC
LAK044		2.01	Sensitive	9U	522541	6050321	SWC, F
LAK016		2.58	Less sensitive	9U	523347	6018243	SWC, F
DCAS14A	Allistair Lake	717.2	Control	9U	488170	5994898	SWC
NC184		6.8	Control	9U	512321	5933333	SWC
NC194		35.6	Control	9U	522119	5949616	SWC
LAK027	Bowbyes Lake	19.5	Non-EEM lake	9U	518232	5995394	N/A

a. There are three sets of lakes in ESSA et al (2020a) defined as: ***"Less sensitive lakes"****. These lakes were expected to show changes in lake SO_4^{2-} if exposed to increased deposition of S, but no biologically significant changes in pH of Gran ANC due to their greater ability to neutralize acidic deposition,* ***Sensitive lakes:*** *seven lakes that were predicted to decrease in pH >0.1 units under maximum future emission levels, and* ***Control lakes****: three sensitive lakes located well outside of the deposition plume from Rio Tinto. The control lakes were added in 2015 but had sampling data from 2013 KAEEA program[1]."*

b. EEM sampling activities have included surface water chemistry (SWC) and fish (F)

c. Fish sampling was conducted in LAK028 in 2017, but it was not part of the original EEM program.

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[1] ESSA et al 2014

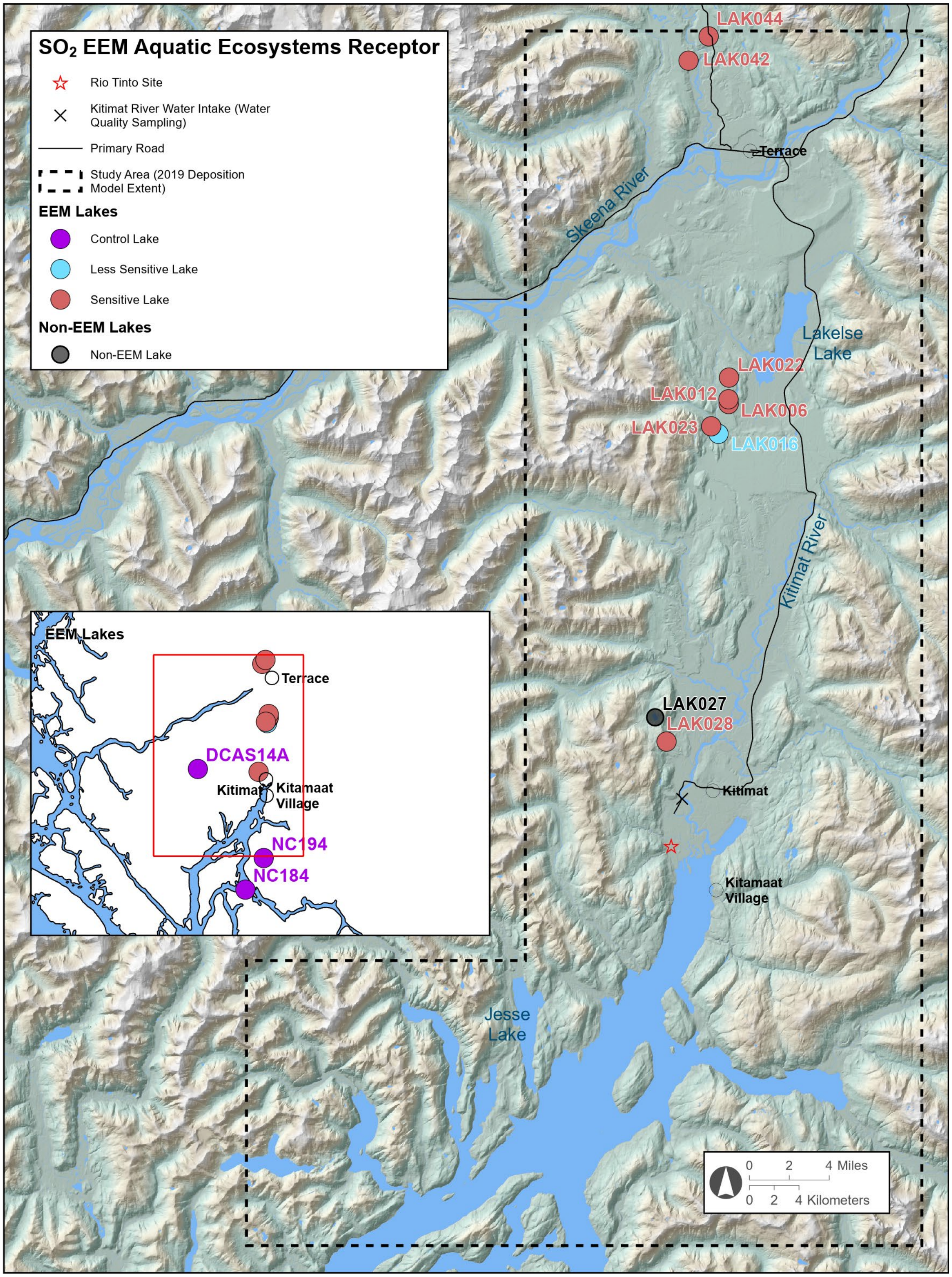

Figure 2. Layout of 12 lakes sampled in 2024.

2.2 Annual lake water sampling, 2024

The one – day annual sampling of the EEM lakes was completed on September 28, 2024. At each lake, instruments were deployed, and water was collected from a Twinstar helicopter in a hover position approximately 4 m above the water surface using a crew of three people plus the pilot. The crew leader in the front seat recorded data on a standard field sheet, took site photos, double-checked the global positioning system (GPS) waypoint location, and provided overall direction of sampling activities. The other two crew members worked together in the back seat to take instrument readings and collect the water samples. The pilot made all decisions related to safety. Crew members and the pilot were always in communication via headsets. Lab-supplied vinyl gloves were worn by crew members handling the instruments and water bottles.

The following sampling procedure was followed at each lake. As the helicopter approached a lake, the crew leader (front seat) provided the pilot with general guidelines about where the sampling station should be located, which was usually at an expected deep point. The pilot decided on the actual location. Station coordinates from the helicopter GPS were logged on the field form. Once on station in a stable hover, the sliding back door of the helicopter was opened, a weighted transducer was lowered into the lake just under the water surface and the water depth and temperature was measured using a Lowrance Mark-5X portable depth sounder. The sounder transducer was retrieved. The data were recorded on a field sheet (Table 2). A 5 L VanDorn water bottle (Wildlife Supply Co. Yulee, FL) was lowered to a depth of 1 m, triggered with a messenger to collect a water sample and retrieved.

At LAK028, a second water sample from a depth of 13 m was also collected by helicopter in three steps. A 13 m depth mark was placed on the haul line. The Van Dorn water bottle was lowered to the point where the 13 m mark on the haul line was at the water surface. The messenger for the Van Dorn was then released to trigger the closing mechanism on the Van Dorn, which was then hauled back into the helicopter. This method resulted in the collection of a sample from a depth of approximately 13 m based on the haul line mark. Due to movement of the helicopter in a hover position, that sampling depth may have been plus or minus 1m.

Samples at all lakes were dispensed from the VanDorn bottle into the following bottles on board the helicopter:

- two 250 mL pre-cleaned polyethylene bottles,
- one 125 mL precleaned amber glass bottle precharged with sulfuric acid preservative (H_2SO_4),
- two precleaned 125 mL polyethylene bottles,
- one 1 L precleaned polyethylene bottle, and
- at LAK028 only, an additional 60 mL polyethylene bottle pre-charged with preservative (sodium hydroxide and zinc acetate) was filled.

After filling all bottles at a given lake, the sample bottles were placed in a plastic bag labelled with the lake number and packed on ice in a cooler that was carried in the helicopter skid basket. At the end of the day of sample collections, water samples from each site were handled as follows:

- H_2SO_4 preserved sample in the 125 mL amber glass bottle was packed on ice, and shipped to ALS Environmental in Burnaby, B.C. for fluorometric analysis of NH_4-N concentration, total phosphorus (TP), and total nitrogen (TN) by standard methods (APHA 2011).
- Sample in one of the 125 mL polyethylene bottles was preserved with HNO_3 by dispensing the HNO_3 contents of a plastic vial prepared by the lab into the sample bottle. The sample bottle was packed on ice with other samples from the day of sampling and shipped to ALS for analysis of total base cation (Ca, K, Mg, Na, Sr, Al, Mn, Fe) concentrations using inductively coupled plasma – mass spectrometry (ICPMS).
- From the second 125 mL polyethylene bottle, ALS measured pH using a 10-minute electrode immersion time, as requested by Limnotek in 2020 for application to low ionic strength waters. This method was identical to the standard pH method (see below) with the exception that the instrument did not time out after 3-minutes but was allowed to stabilize for up to 10-minutes before a pH value was recorded. Field tests in 2019 showed that immersion of the electrode for 10-minutes provided stable pH readings (Limnotek 2020).
- Sample in the 60 mL polyethylene bottle that was pre-charged with sodium hydroxide and zinc acetate preservative (collected at LAK028 only) was packed on ice and shipped to ALS for analysis of total sulfide (as H_2S and S) by colourimetry (APHA 2011).
- The first 250 mL polyethylene bottle was packed on ice and shipped to Biogeochemical Analytical Service Laboratory (BASL) at the University of Alberta in Edmonton, Alberta, for analysis of pH and Gran ANC by titration on a PC-titration Plus system (https://mantech-inc.com/analysis-systems/automated-titration-analysis/). Detailed methods for this procedure are available upon request. Note that prior to 2020, these samples were shipped to Trent University in Ontario. After a cross-lab comparison using paired samples collected in October 2019 (Limnotek 2020), this transition from Trent to BASL was implemented in 2020. The change in labs was due to Trent not having the capacity to provide lab services beyond 2019.
- The second 250 mL poly bottle was packed on ice and shipped to ALS for analysis of anion (HCO_3, Cl, SO_4, F, NO_3-N) concentrations by ion chromatography, total dissolved solids by gravimetric analyses, specific conductivity using an automated bench top conductivity meter, dissolved inorganic carbon by combustion (lab filtered), soluble reactive phosphorus (SRP)

by standard methods (APHA 2011), and pH using a Skalar Sp2000 auto-titrator system (https://www.skalar.com/analyzers/sp2000-robotic-analyzers-turnkey-or-custom-made-automation-solutions/) or a Metrohm 848 Titrino Plus system (https://www.metrohm.com/en/products/titration/titrino-plus/28480010). The Metrohm system included stirring of the sample during pH measurement. These instruments recorded a stable signal if the pH changed less than 0.05 pH units in five consecutive readings that were five seconds apart. The instruments timed out after 3-minutes, which means that even if a stable signal was not found before 3-minutes of electrode immersion, a pH value was recorded.

- Aliquots from the 1 L polyethylene bottle were handled as follows:
    - At the field lab in Terrace, B.C. a 40 mL aliquot was dispensed in smooth flow without bubbles to a 50 mL polyethylene flask pre-rinsed with sample water for immediate pH measurement using a WTW Multi 3510 IDS Portable pH meter equipped with a Sentix 940 pH combination electrode (Xylem Analytics, Weilheim, Germany) prior to any other aliquots being dispensed to minimize degassing of CO_2 from the sample prior to pH measurement. This field pH measurement followed procedures in EPA method 150.3 (EPA 2017) that is followed by the Canadian federal agencies (*e.g.* https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-ph.html#a42 , CCME 2011). No stirring of the sample was done during electrode stabilization to avoid degassing of CO_2 from the samples as recommended by Busenberg and Plummer (1987) for measurement of pH in very low conductivity waters. The field pH meter was purchased new in May 2024 as a replacement for the WTW ProfiLine 3210 portable pH meter with Sentix 41 pH sensor that had been used in all previous years.
    - A 125 mL aliquot was filtered (0.45 µm) and preserved with HNO_3, packed on ice, and shipped to ALS for analysis of dissolved base cation (Ca, K, Mg, Na, Sr, Al, Mn, Fe) concentrations using ICPMS.
    - A 125 mL aliquot was filtered into a pre-charged glass amber bottle (H_2SO_4), packed on ice, and shipped to ALS for analysis of total dissolved phosphorus (TDP) and dissolved organic carbon (DOC) concentration by standard methods (APHA 2011).
    - All filtrations were done using a Sartorius Minisart® syringe filter (28 mm, 0.45 µm Hydrophilic Teflon DIGIFilter) in a filtration stand (Figure 3). Each filter was washed with 60 mL of deionized water followed by 20 mL of sample water before filtering into the sample container to minimize contamination, particularly for DOC (Tisserand et al., 2024).

Figure 3. Example of a filtration stand for use in minimizing user contact with the syringe plunger during water filtrations in the field. Image source: “ALS EnviroMail 06 December 2017. Best practices to prevent false positives and negatives for dissolved metals”. Note that vinyl gloves are preferred over nitrile gloves that may host metals contamination.

Measurements of descriptive variables were compiled on a field data at each lake. The listing of these variables and how they were measured is provided in Table 2. These data provided supportive evidence of lake conditions that could later assist with interpretation of lake water chemistry.

Table 2. List of descriptive variables and associated methods of calculation that were recorded on the field data sheet.

Habitat or other descriptive variable	**Units**	**Description and method**
Lake name	No units	Station label
Site ID	No units	Preassigned site identification number
Date	No units	Date of sampling
Time on station	24-hour clock	Time of arrival at station
Time off station	24-hour clock	Time of departure from station
Field Crew	No units	Names of field crew
Northing	UTM	UTM northing recorded with a Garmin GPSmap 76CSx GPS receiver
Easting	UTM	UTM easting recorded with a Garmin GPSmap 76CSx GPS receiver
Weather	No units	Coding for present conditions and conditions in past 24 hours and past week
Riparian Vegetation	%	Estimate (%) of each type, totaling 100% including: unvegetated, grasses/ferns/herbs, shrubs, deciduous forest, coniferous forest, and wetland
Water depth at sampling station	m	Water depth at the sampling station measured using the Lowrance Mark-5XDSI portable depth sounder.
Water sample depth	m	Depth of sample collection recorded from the calibrated line used to deploy the VanDorn water bottle.
Temperature	ºC	Instantaneous surface temperature in all lakes measured with the Lowrance Marck 5XSDI portable depth sounder.
pH	Relative units	Measurement taken with the WTW Multi 3510 IDS Portable pH meter in a field lab on the day of sample collection from each lake. The WTW meter was calibrated with fresh pH buffers on the day of measurement.
Secchi depth[a]	m	A black and white disc (Secchi disc) is lowered on the shaded side of the boat until it is no longer visible. The depth is on the haul line is noted. The disc is then slowly raised until it is visible again. The depth on the haul line is noted. The average of the two depths is the Secchi depth.

a. Secchi depth was added to the field sheet on September 25th, 2023. It was measured during work conducted from the boat, not during work conducted from the helicopter.

2.3 Time course lake water sampling, 2024

2.3.1 Overview

Time course sampling of selected lakes (specified in following sections) was done during spring through fall, 2024 to provide data for later analysis by ESSA Technologies. The lakes were LAK006, LAK012, LAK023 LAK028, LAK042, and LAK044. All lakes were sampled at the surface except LAK028 where samples were collected from both surface and 2 m off bottom. The added sampling at LAK028 was done to describe meromixis that was not present in the other lakes. Analytes were the same as those measured during the single date annual water sampling (Section 2.2).

An Onset (Bourne, MA) MX2501 pH and temperature logger (hereafter referred to as an “Onset”) was installed at a water depth of 2 m in LAK006 and at depths of 2 m and 13 m in LAK028 during 2024 to continuously record pH. Data from the deep Onset in LAK028 assisted with continued interpretation of meromixis that was detected in 2017. Prior to 2021, electrodes were changed every 2-3 months in the field. In 2024, new instruments were installed in each lake at the beginning of the year and every two months, new electrodes were installed on spare instruments the day prior to the field visit, and the whole instrument was replaced on the field day. All loggers had an anti-biofouling ring on the pH electrode, which prevented growth of a biofilm on the electrodes. Methods for the water sampling at all lakes and lab procedures are described in the following sub-sections.

On each sampling date, temperature, specific conductivity, turbidity, dissolved oxygen, chlorophyll a (fluorescence), photosynthically active radiation (PAR) and fine dissolved organic matter (FDOM) concentration profiles were completed using a RBR Maestro CTD (RBR Ltd. Ottawa, Canada). CTD is a generic term given to an instrument that measures conductivity (the “C” part of CTD) and temperature (the “T” part of CTD) amongst other parameters over a depth (the “D” part of CTD) profile. The CTD casts were done in LAK028 and LAK006, the two acid-sensitive lakes receiving detailed sampling. After a 2-minute electrode stabilization period just under the surface, the instrument was lowered at a rate of 20 $cm \cdot s^{-1}$ until it reached the lake bottom, while logging 4 readings per second (4 Hz) from all sensors to instrument memory. Logged data were uploaded to a computer on the day of sampling.

Scripts in R (www.**r**-project.org) were used to produce line or colour filled plots of the temperature, conductivity, dissolved oxygen, turbidity, and chlorophyll-a profiles over time from the profiling data. FDOM data were not summarized in this report but are available for later use if needed. Depth of the thermocline during stratification and chemocline in LAK028 was captured from these images as the range of depths where water temperature or other physical attributes changed more rapidly with depth than it did in stable layers above and below.

2.3.2 LAK028

Time course water sampling of LAK028 occurred on May 22, June 18, July 15, Aug. 12, Sept. 9, Sept. 25, Oct. 8, and Oct. 17, 2024. Access was by truck off the Wedeene forest service road (FSR) for 2 km until the Mt. Claque trailhead. From there, the field crew hiked 750 m up the steep Mt. Claque trail and then another 550 m from the Mt. Claque trail to the edge of LAK028. Once at the lake, the crew unlocked and launched a 12 foot aluminum Marlon jon boat from the lake edge (which had been slung into LAK028 via helicopter in October 2016) and paddled to the centre of the lake where the raft was anchored. The boat was tied to the raft for water sampling and servicing of instruments. On all samping dates, water samples were collected from the surface and from a depth of 13 m (roughly 2 m off bottom) using a Van Dorn sampler. Sampling depth was exact using this method. On all dates, the water samples were analyzed for all parameters described in Section 2.2.

After each day of water sampling, the boat was pulled out of the water and locked to a tree. The crew hiked out with the water samples, which were packed on ice in a soft cooler nested in a backpack. The total return trip time from the parking area on the Wedeene FSR was 5 hours. After the final sampling event in 2024, the boat was chained and locked to a tree in an upright, inverted position to shed snowfall.

A temperature mooring was installed in LAK028 in 2019 and maintained to the present to examine mixing patterns needed to interpret the stability of meromixis that was used for interpretation of time course change in pH and Gran ANC at the lake surface. Ten Onset TidBit temperature loggers were distributed from surface to bottom on a vertical line that was attached to the raft and weighted with a 10 lb. dumbbell. Logger depths (m) were 1, 3, 6, 8, 9, 10, 11, 12, 13, and 14 m. The mooring and loggers were installed on June 13, 2019. Data were recorded in 30-minute intervals. Temperature loggers were replaced with new loggers in July, 2022 at depths (m) of 3, 6, 9, 11, and 13. Temperature data at the remaining depths was from conductivity loggers installed in July 2022. In 2024, data were uploaded from the temperature loggers on May 22, Sept. 9, Oct. 17 and on Nov. 1 before the line was reset for the winter. Each winter since 2019, the temperature mooring has been set up independent from the raft using a weighted line and floats to overwinter in the centre of the lake.

On May 22, 2024 an Onset pH logger was clipped onto the mooring at a depth of 2 m and another at 13 m. Pre-and post-calibration checks were performed and calibrations were conducted on each sampling date using a two point calibration with standard buffers of pH 4 and 7 via a bluetooth application on a cell phone. The loggers were removed at the end of sampling on November 1, 2024, and data were uploaded to computer. The logger electrodes were cleaned using a Q-tip at the time of calibration if needed. Battery replacement on the Onsets was not required.

A conductivity mooring consisting of one logger situated at each of 1, 8, 10, 12, and 14 m on a vertical line was installed in July, 2022. Loggers were removed and reinstalled the following day each May and October of all years. The loggers were left to overwinter on the same mooring as the temperature loggers. In 2024, the conductivity loggers were removed on May 22, data were uploaded at the field lab, and loggers were reinstalled on May 23, with logging interval set to once every 30 minutes on all loggers. An additional conductivity logger was installed on July 15, 2024 at a depth (m) of 13 to increase sensitivity in the chemocline. The loggers were removed for downloading a second time in 2024 on Oct. 17, and reinstalled on Oct. 18. The conductivity loggers shared the same vertical line as the temperature loggers, which was set up independent of the raft using a weighted line and floats to overwinter in the centre of the lake.

2.3.3 LAK006

Time course water sampling of LAK006 (Figure 4) occurred on May 21, June 17, July 16, Aug. 13, Sept. 10, Sept. 24, Oct. 6, and Oct. 15. Access was by truck and sampling was done from a 10 foot long inflatable boat equipped with 2.2hp outboard engine. Water samples were collected from the surface using a Van Dorn bottle and were analyzed for all parameters described in Section 2.2.

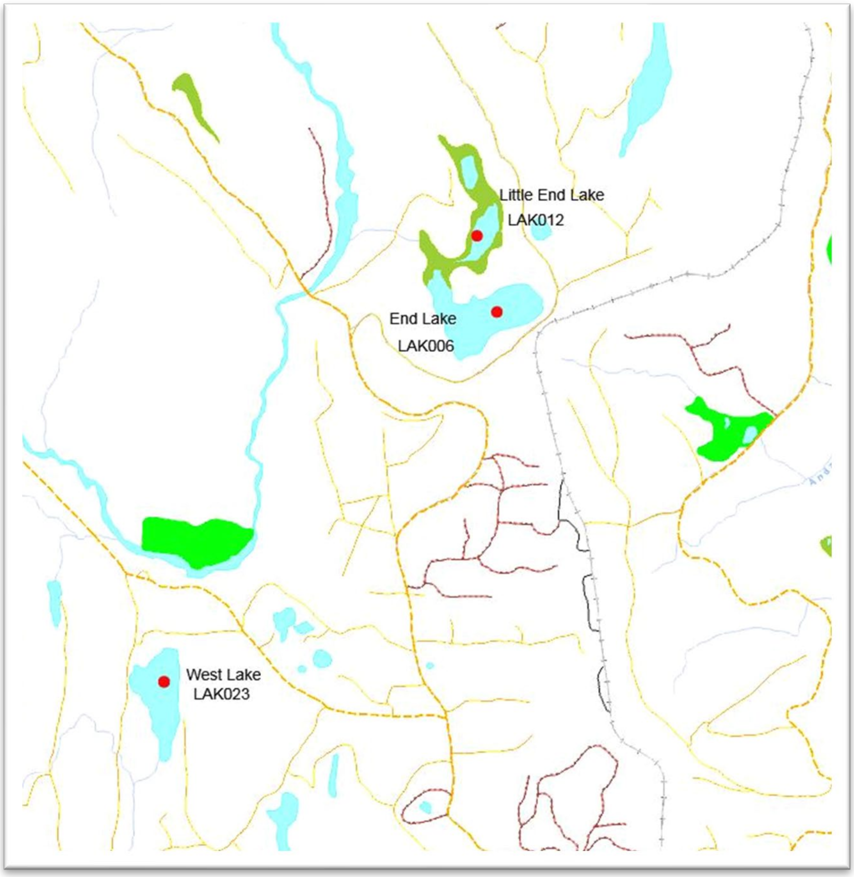

Figure 4. Location of LAK006, LAK012, and West lake (LAK023) with water sampling locations shown as red solid circles. General location of the lakes is shown in Figure 2. The yellow dotted lines represent roads or ATV trails.

An Onset pH logger was installed on a submerged mooring line in LAK006. Weights anchored the mooring. The line length was 1 m less than water depth at the chosen site. The line was held vertical through the water column with submerged floats. The Onset was attached to the line 1 m beneath the floats using a locking carribiner. During instrument calibrations that occurred on each of the water sampling dates, the submerged floats were captured using a boat hook, pulled to the surface, and another float was clipped onto the vertical mooring using a tag line. This arrangement allowed easy access to the mooring for redeployment of the instruments after calibration on the boat.

For servicing on each visit, the Onset logger was clipped off the mooring line, pre- and post-calibration checks were run using solutions of known pH, data were downloaded, and a two point calibration was run using standard buffers of pH 4 and 7 via a bluetooth application on a cell phone as was done in LAK028 (Section 2.3.2). All this was done on the boat.

2.3.4 LAK012, LAK023, LAK042, and LAK044

Time course water sampling of LAK012 and LAK023 occurred on Sept. 24, Oct. 6 and Oct. 15 and at LAK042 and LAK044 it occurred on Sept. 26, Oct. 10 and Oct. 16, 2024. Access to LAK042 was via a spur road to a wood waste dump off the Kalum West FSR approximately 7 kilometers north of Hwy 16. A small inflatable boat, paddles and PFD's were carried down to the lake along with the water sample bottles and sampling equipment (roughly 300 m). The boat was launched from the edge of the lake and paddled out to the centre, where water samples were collected. On one occasion (Oct 9), a valve malfunction on the boat prevented sample collection from the designated deep station. As an alternative, a sample was taken from the lake's edge at a depth of 0.5 m. This deviation from standard protocol should be considered when interpreting the data, as the nearshore conditions may differ from deep-water characteristics. Following the collection of samples, the gear and boat were packed back to the truck. Access to LAK044 was by truck and then by hiking 40 meters with the inflatable boat. The crew paddled the boat to the centre of the lake, where water samples were collected. Access to LAK012 and LAK023 was by truck close to the lake shore. Sampling was done from a depth of 2 m using the VanDorn water bottle and all water samples were analyzed of the full suite of analytes described in Section 2.2.

2.4 Quality of chemical data

2.4.1 Blanks and duplicates

A blank and blind duplicate water sample were collected on each sampling date for calculation of precision and accuracy. Blanks were deionized water provided by ALS Environmental and handled the same way as all test samples including water transfers to sample bottles, filtrations, storage, and shipping. Duplicates were water samples collected from a randomly selected station on each sampling date and again handled the same way as test samples. The presence of cations and anions in the blank samples indicated contamination during sample processing and the chemical concentration showed the amount of contamination.

2.4.2 Precision

Precision (D_f) was calculated as relative percent difference of an analyte concentration between a sample and its corresponding duplicate using the following equation recommended in the BC Field Sampling Manual (MOECCS 2024):

$$D_f = \left(\frac{sample\ result - duplicate\ result}{(sample\ result + duplicate\ result)/2}\right) * 100 \qquad \text{Equation 1}$$

where ‘sample result’ is the concentration of an analyte in the original sample, and ‘duplicate result’ is the concentration of the same analyte in the duplicate sample. Precision decreases as a parameter values approach the method detection limit (MDL) (MOECCS 2024). Therefore, relative percent difference was only calculated if the original or duplicate sample had a value greater than 5 times the MDL, following procedures reported by the BC Field Sampling Manual (MOECCS 2024).The measurement of precision was associated with field and lab processes because it integrated sample collection, processing in the field, transport to the lab, and processing of samples in the labs.

2.4.3 Accuracy

Lab accuracy was tested by calculating percent recovery on solutions of known concentrations. Accuracy was determined as percent recovery (R_p) according to the following equation:

$$R_p = \left(\frac{B}{A}\right) * 100 \qquad \text{Equation 2}$$

where B is the recovered concentration and A is the known concentration of a given analyte in a solution. A solution containing the known analyte concentration was prepared in each lab using inorganic standards. The average value from up to 9 separate spiked samples was used to show average percent recovery from known standards of each cation and anion. Tests of percent recovery were limited to analytical values that were more than five times greater than the method detection limit, where the method detection limit was the concentration above which there was a high probability that a substance could be detected, following procedures reported by the BC Field Sampling Manual (MOE 2013).

2.5 Method effect on pH measurement

2.5.1 Instrument comparisons

The following instruments and sample handling procedures were used to measure pH.

- Onset pH logger installed at a depth of 2 m in each of LAK006 and LAK028 and another one installed at a depth of 2 m off bottom (13 m from the surface) in LAK028 with a new Onset instrument and pH electrode at the start of the season. A new electrode was installed in a spare instrument (also new in spring 2023) that replaced the existing instrument at the lake station every two months. The purpose of replacing the entire instrument was to avoid electrode replacements in the field which may result in moisture entering the instrument electronics during inclement weather. The two-month period for electrode replacement was based on monitoring the electrode offset value during calibrations to avoid logging and calibration errors associated with the end of electrode life. In the low conductivity waters of LAK006 and surface water of LAK028, the electrode life is less than the manufacturer's recommendation.
- The WTW Multi 3510 portable pH meter (described in Section 2.2). Measurements were made in the field laboratory within 5 hours of water sample collection during both the annual sampling of all lakes on September 28 and the time course sampling of LAK028 and LAK006. There was no air space in sample bottles thus minimizing effects of CO_2 degassing on pH between the time of sample collection and pH measurement.
- Two samples were shipped to ALS Environmental located in Burnaby, B.C. for pH measurement using a bench top automated pH meter during both the annual sampling of all lakes on September 28 and the time course sampling of LAK028 and LAK006. On average, there were 3 days between sampling and measurement. The pH in one sample was measured using a 3-minute electrode stabilization period (hereafter called ALS-3) and the other was measured with up to 10-minute electrode stabilization (hereafter called ALS-10). There was no air space in the sample bottle thus minimizing effects of CO_2 degassing on pH. If tests showed that the effect of electrode immersion time on pH was statistically significant, the pH value from the longer immersion period was used in describing pH over time in LAK006 and LAK028.
- Bench top automated pH meter in the lab at BASL in Edmonton within 16 days after sampling during both the annual sampling of all lakes on September 28 and the time course sampling of LAK028 and LAK006. Measurement was done on a Mantech PC automatic titrator (Mantech Inc. Guelph, Ontario).

During the time course sampling of LAK006 and LAK028 there were 9 dates of measurement (see Section 2.3.2 for LAK028 and Section 2.3.3 for LAK006).

A repeated measures design was used to test the hypothesis that a pH measurement by a given instrument at a lake was more similar to its corresponding measurement by one of the other instruments than to samples from other dates. Measurements from the four instruments were compared using a repeated measures one-way ANOVA run on data from each lake. There were four levels (Onset, WTW, ALS-10, BASL) followed by post hoc tests between the instrument pairs. The significance level for the overall test of instrument effect was 0.05 adjusted using the Bonferroni correction for multiple comparisons to avoid the influence of random effects on those comparisons. The statistical analyses were run in R (R Core Team 2022).

A paired T-test run on pH data from the single day annual sampling of all lakes in previous years was discontinued in 2024. A concern was possible strong influence of pH variability among lakes on calculation of the T value that may mask an instrument effect and introduce either Type I or Type II errors. This analysis was compromised by lack of replication of pH in each lake. Even if that replication was present for the single day of sampling (e.g. more than one sample from a lake), it would represent pseudoreplication that would invalidate a conclusion of presence or absence of an instrument effect.

2.5.2 Exposure of a sample to air

Water samples were collected from the surface of LAK006 on August 15, 2024 and LAK028 on November 1, 2024, to test the effect of duration a sample is exposed to air prior to pH measurement on the pH of lake water samples. On each date, 60 water samples (125 mL each) were collected using two Van Dorn hauls from the lake surface. The HDPE bottles were filled completely to eliminate headspace, immediately capped and stored on ice in a cooler for transport to the Terrace field laboratory. At the lab, samples were randomly assigned to one of two treatment groups; Cap-on and Cap-off. In the Cap-on group, bottles remained sealed until the time of pH measurement while in the Cap-off group, all bottles were uncapped at time zero and exposed to ambient air for varying durations. Time zero was defined as the time of first pH measurement, which occurred 5 to 10 hours after sample collection. At each subsequent time point, pH was measured in three replicates from each treatment group (n = 3 per treatment group per time point). Cap-on bottles were uncapped immediately prior to measurement to minimize exposure to air. Cap-off bottles remained open from time zero onward. Time points were selected based on staff availability but constrained to a maximum of 72 hours (4320 minutes), consistent with laboratory processing times at ALS (Limnotek 2024). Measurements of pH were conducted using a WTW Multi 3510 pH meter, calibrated daily according to manufacturer instructions. All measurements were taken at room temperature. The same instrument and calibration procedures were used for both lakes to ensure comparability.

All statistical analyses were conducted in R (R Core Team 2022). The normality of pH values was assessed using the Shapiro-Wilk test. A two-way analysis of variance

(ANOVA) was used to evaluate the effects of treatment group (Cap-on vs. Cap-off) and time (categorical variable) on pH, as well as their interaction (time x treatment). Means and standard deviations of pH were calculated for each treatment group at each time point and plotted to visualize trends. If the ANOVA indicated a significant effect of treatment group ($p < 0.05$), but no significant effect of time or the time x treatment interaction, we concluded that duration of exposure to air after uncapping rather than the total time elapsed since sample collection, was the primary factor influencing pH.

2.5.3 Electrode immersion time

Paired water samples were collected from all sites and dates to examine the effect of electrode immersion time on pH at ALS, as has been done in previous years. Each sample pair was dispensed from the same water sample collected with the VanDorn into two separate bottles. Both bottles were shipped to ALS, where each of ALS-3 and ALS-10 methods were used to measure pH. The Shapiro-Wilk test was run to test for normality of the sample distribution. If significant ($p<0.05$), the non-parametric Wilcoxon test was used to test for significance of paired differences. If the Shapiro-Wilk test was not significant, a paired t-test was run to test for significance of paired differences. There was no control for this test (no known values of pH for each pair). If the test showed a method effect on pH, the assumption was that the pH values using ALS-10 would be more accurate than ALS-3. If the test for paired differences was not significant ($p<0.05$), we concluded there would be no evidence to support use of ALS-10. If the P value for a paired t-test or Wilcoxin test was less than 0.05, the mean difference between paired values reported by the two methods that were contrasted was considered significantly different from zero. The statistical analyses were run in R (R Core Team 2022).

2.6 Onset pH logger electrode drift

Output drift of a pH electrode was examined on each of the Onsets. Drift is caused by the slow passage of hydrogen ions across the glass bulb which leads to dilution of the reference solution. Drift was the difference between observed and expected pH values following a period of operation. The expected value was pH in a standard buffer solution of pH 4.0 and 7.0. The observed value was the pH in that buffer solution before calibration to the buffer value.

2.7 Precipitation and water surface elevation in LAK006 and LAK028

Regional precipitation and water surface elevation of LAK006 and LAK028 were used to describe wetting and drying trends that may affect lake chemistry.

Precipitation data were downloaded from Environment and Natural Resources Canada websites for the study region. Data from three stations were available:

- Terrace airport (Station ID 1068134, 54°28’07.000”N, 128°34’42.000”W, Hourly Data Report for May 03, 2024 - Climate - Environment and Climate Change Canada)
- Terrace PCC (also known as Braun’s Station) was near the Skeena River adjacent to Terrace (Station ID 1068131, 54°30’07.000”N, 128°37’29.000”W, Daily Data Report for May 2024 - Climate - Environment and Climate Change Canada)
- Kitimat at Forest Ave. (Station ID 1064324, 54°03’13.025”N, 128°38’01.087”W, Daily Data Report for May 2024 - Climate - Environment and Climate Change Canada.

Water surface elevation was monitored in LAK006 (May 21 through October 31, 2024) and LAK028 (June 30 to August 30, 2024 and October 8 to November 1, 2024). The LAK028 level logger was new but found to be faulty after installation on June 30. The break in LAK028 data between August 30 and October 8 was due to time needed to replace that instrument. The measurement interval was 30 minutes at both lakes. Instrumentation included a standard staff gauge for manual water level readings and a Onset Hobo water level logger. The logger in both lakes was model MX2001-04 equiped with automatic compensation for atmospheric pressure (new in 2022 in LAK006 and in 2024 in LAK028). Each logger was suspended using a 1 m length of aircraft cable inside a 2 inch PVC stand-pipe. The pipe was fitted with a grated cover on the lower end, and had holes drilled in it to allow free water movement. The staff gauge and logger assembly was secured to a 2.7 m length of angle iron that was bolted into a shoreline tree (Figure 5, Figure 6), thus providing a fixed station for readings of water level at each lake. In LAK006, a simple 3-point survey with a rod and level was completed on the day of logger installation and day of removal to fix the monitoring location and determine if position of the staff gauge and logger housing shifted or was moved during the period of data logging. In 2024, there was no shift in position between May and November.

During water sampling visits to each lake, water depth on the staff gauge was recorded and the logger installations were checked for signs of tampering or vandalism.

Figure 5. Photo showing the installed water level staff gauge and 2-inch PVC pipe that housed the water level logger in LAK006.

Figure 6. Photo showing the installed water level staff gauge and 2-inch PVC pipe that housed the Hobo water level logger in LAK028.

3 RESULTS

3.1 Overview

All water sampling and measurements were completed as planned. There were no safety incidents, and all work was completed on time within the planned schedule. All field and laboratory data were compiled into csv files ready for import into R data analysis software (R Core Team 2022). Those files were sent to ESSA Technologies for further analysis.

3.2 Quality of chemical data

3.2.1 Field blanks and duplicates

A total of 20 blank and 20 duplicate samples were collected in 2024. Nine positive blanks were observed; five in filtered blanks and four in unfiltered blanks (Table 3). Blank concentrations of NH_4-N, total Si, DIC and DOC were significantly lower than concentrations found in lake water samples, and therefore not a concern. Single-incident blank concentrations of total arsenic and total dissolved phosphorus (TDP) were close to average concentrations in lake water samples, which may indicate potential sensitivity issues or the need for tighter QC. The absence of the similar anomalies in the lake water samples collected on the same dates shows any contamination was limited to the blanks.

Of particular concern, the blank concentration of dissolved zinc on Oct 6, 2024 was 0.0053 mg/L, more than twice the average lake concentration of 0.0022 mg/L. However, three of four lake samples collected on the same date had concentrations of dissolved zinc below detection limit, and no other contamination issues were observed. This suggests the contamination issue was limited to the blank and points towards a lab error rather than a filtration or sample handling issue.

Table 3. Incidence of positive blanks (deionized water having an analyte concentration above the method detection limit) and comparison of analyte concentrations in positive blanks with analyte concentrations in lake water samples, 2024.

Analyte	Method detection limit ($mg \cdot L^{-1}$)	Number of positive blanks (maximum possible is 20)	Average concentration in positive blanks ($mg \cdot L^{-1}$) (range in brackets if applicable)	Average concentration in lake samples in 2024 ($mg \cdot L^{-1}$)
Ammonium, (NH_4-N)	0.005	3	0.0102 (0.0066 - 0.0136)	0.4770
Arsenic, total	0.0001	1	0.00012	0.000112
DIC	0.5	1	0.51	2.15
DOC	0.5	1	0.94	6.49
Phosphorus, total dissolved	0.002	1	0.0033	0.0057

Analyte	Method detection limit ($mg \cdot L^{-1}$)	Number of positive blanks (maximum possible is 20)	Average concentration in positive blanks ($mg \cdot L^{-1}$) (range in brackets if applicable)	Average concentration in lake samples in 2024 ($mg \cdot L^{-1}$)
Silicon, dissolved	0.05	1	0.134	1.08
Zinc, dissolved	0.001	1	0.0053	0.0022

3.2.2 Precision

Precision is considered high among field duplicates when relative percent difference (RPD) is less than 20% (MOE 2013). Values of RPD >20% indicate a possible problem and > 50% indicate a definite problem potentially including sample contamination or a lack of sample representativeness (high heterogeneity) (MOE 2013). In 2024, the average RPD between replicate pairs of samples was < 9% (Table 4) except for TIC that had an average RPD of 31% based only on a single pair of samples. Those samples were obtained from two separate casts collected from the deep station at LAK028 and likely reflects the greater natural heterogeneity of repeat samples taken within the chemocline.

Table 4. Relative percent difference of analyte concentration, or relative difference in pH units, between surface replicates in 2024. Data are shown only for sample pairs having analyte concentrations greater than five times the method detection limit (except pH) (MOECCS 2024).

Analyte	Average value of relative percent differences between replicate pairs of samples (%)
Aluminum, dissolved	3 (n=20)
Aluminum, total	4 (n=20)
Ammonium-N	9 (n=3)
Calcium, total	3 (n=17)
Chloride	1 (n=2)
Conductivity	2 (n=12)
Conductivity (BASL)	1 (n=20)
Dissolved Inorganic Carbon	8 (n=2)
Dissolved Organic Carbon	7 (n=16)
Fluoride	3 (n=16)
Gran ANC (BASL)	7 (n=19)
Iron, dissolved	4 (n=7)
Iron, total	6 (n=16)
Magnesium, dissolved	2 (n=20)
Magnesium, total	2 (n=20)
Manganese, dissolved	3 (n=18)

Analyte	Average value of relative percent differences between replicate pairs of samples (%)
Manganese, total	2 (n=20)
Nitrate-N	5 (n=2)
Nitrogen, total	5 (n=8)
Orthophosphate, dissolved	no values >5X MDL
pH (ALS)	0.014 pH units (n=20)
pH (ALS low ionic strength method)	0.005 pH units (n=20)
pH (BASL)	0.002 pH units (n=20)
pH Field (WTW)	0.012 pH units (n=20)
Phosphorus, total	7 (n=4)
Phosphorus, total dissolved	8 (n=1)
Potassium, dissolved	8 (n=4)
Sodium, total	2 (n=17)
Solids, total dissolved	4 (n=1)
Strontium, dissolved	2 (n=20)
Strontium, total	3 (n=20)
Sulfide (as S)	4 (n=2)
Sulfide (as H2S)	4 (n=2)
Sulphate	1 (n=15)
Total Inorganic Carbon	31 (n=1)
Total Organic Carbon	7 (n=12)

3.2.3 Accuracy

Average percent recovery in spiked and certified reference samples tested at the ALS lab ranged from 93% to 110% among all analytes, with an overall average percent recovery of 99% among all analytes (Table 5). These results show high accuracy.

Table 5. Percent recovery of analyte concentrations in lab control and spiked samples for the test of lab accuracy in 2024.

Analyte	Known concentration ($mg \cdot L^{-1}$ unless otherwise noted)	Average recovered concentration ($mg \cdot L^{-1}$ unless otherwise noted)	Sample size	Average percent recovery
Aluminum, dissolved	0.10 – 1.0	0.09 – 1.0	15	97
Aluminum, dissolved	2.00	2.00	16	100
Aluminum, total	0.10 - 0.40	0.09 – 0.41	15	94
Aluminum, total	0.1 – 1.0	0.09 – 2.15	19	100
Ammonium-N	0.2	0.197	21	99
Ammonium-N	0.100	0.100	18	100

Analyte	**Known concentration (mg·L^{-1} unless otherwise noted)**	**Average recovered concentration (mg·L^{-1} unless otherwise noted)**	**Sample size**	**Average percent recovery**
Calcium, dissolved	50.0	48.7	16	97
Calcium, dissolved	4.0	3.7	4	93
Calcium, total	4.0	3.8	6	95
Calcium, total	50.0	49.0	16	98
Chloride	100	99.9	21	100
Chloride	100	101.3	18	101
Conductivity (µS/cm)	147	146	21	99
Dissolved Inorganic Carbon	5.0	5.1	15	103
Dissolved Inorganic Carbon	8.0	8.3	20	104
Dissolved Organic Carbon	5	5.16	12	103
Dissolved Organic Carbon	8.57	8.81	21	103
Fluoride	1.00	0.99	21	99
Fluoride	1	0.98	18	98
Iron, dissolved	1.00	0.98	16	98
Iron, dissolved	0.05 - 4.0	0.04 - 3.74	16	95
Iron, total	1.00	1.00	16	100
Iron, total	0.05 – 4.0	0.05 – 3.81	18	97
Magnesium, dissolved	1	0.97	5	97
Magnesium, dissolved	50	50.3	16	101
Magnesium, total	1 – 2.5	0.94 – 2.67	9	99
Magnesium, total	50	50.5	16	103
Manganese, dissolved	0.012 - 0.04	0.02 - 0.04	10	96
Manganese, dissolved	0.012 – 0.25	0.02 – 0.26	19	100
Manganese, total	0.012 - 0.20	0.01 – 0.02	12	97
Manganese, total	0.012 – 0.25	0.01 – 0.27	19	101
Nitrate-N	2.50	2.49	19	101
Nitrate-N	2.5 - 50.0	2.3 – 48.4	19	101
Nitrogen, total	0.40	0.39	11	97
Nitrogen, total	0.500	0.485	21	97
Orthophosphate, dissolved	0.030	0.030	21	100
Orthophosphate, dissolved	0.030	0.030	21	98
pH	7.00	7.02	40	100
Phosphorus, dissolved	10	10.04	16	100
Phosphorus, dissolved	0.5 - 20	0.53 – 19.9	19	101
Phosphorus, total	0.050	0.047	21	94
Phosphorus, total	0.050	0.048	14	96

Analyte	**Known concentration (mg·L^{-1} unless otherwise noted)**	**Average recovered concentration (mg·L^{-1} unless otherwise noted)**	**Sample size**	**Average percent recovery**
Phosphorus, total dissolved	0.03 - 0.05	0.028 - 0.048	22	96
Phosphorus, total dissolved	0.050	0.048	19	96
Potassium, dissolved	4.00	3.92	15	98
Potassium, dissolved	50.0	50.9	16	102
Potassium, total	4.00	3.88	14	97
Potassium, total	50	50.7	16	101
Sodium, dissolved	2.00	2.00	9	100
Sodium, dissolved	50.0	51.3	16	102
Sodium, total	2.00	1.99	8	100
Sodium, total	50.0	51.3	16	102
Strontium, dissolved	0.02	0.02	5	98
Strontium, dissolved	0.25	0.253	16	101
Strontium, total	0.02	0.02	5	98
Strontium, total	0.25	0.255	16	102
Sulfate	100.0	101.0	21	101
Sulfate	100.0	101.2	18	101
Sulfide (as S)	0.085	0.086	9	101
Sulfide (as S)	1.00	1.05	9	95
Total Dissolved Solids	1000	1040	22	104
Total Inorganic Carbon	8	8.34	16	104
Total Inorganic Carbon	5	5.5	6	110
Total Organic Carbon	8.57	8.57	17	100
Total Organic Carbon	5	5.06	12	101

3.3 Method effect on pH measurement

3.3.1 Instrument comparisons

The Onset pH loggers were installed and retrieved in LAK006 and LAK028 according to the schedule shown in Table 6. There were no logger failures. A continuous record of data from the loggers was May 21, 2024 to October 31, 2024 in LAK006 and May 21, 2024 to November 1, 2024 at the two depths in LAK028. Mean daily pH from each Onset pH logger was plotted with discrete pH values from the other instruments (WTW, ALS-10, and BASL) for each of LAK006 and LAK028 surface and LAK028 deep and shown in Figure 7, Figure 8 and Figure 9 respectively.

There was often a drop in pH after calibration at the LAK028 deep station, including June 30 when the onset was calibrated but no water samples were collected. This may have been a result of a temporary environmental disturbance caused by resetting of the weighted instrument line at a depth close to the lake-sediment interface. Further evidence supporting this theory is absence of any change in pH on Sept. 28, when samples were collected by helicopter and the Onset instrument remained in place, without being removed for calibration.

Repeated measures ANOVA showed a method effect on pH was present at LAK006 (Figure 10) and LAK028-D (Figure 12) but not at LAK028-S (Figure 11). Where the effect was detected, pH was highest using ALS-10 compared to lower pH values measured with other instruments.

Table 6. Schedule of Onset pH instruments deployment and removal from LAK006 and LAK028 in 2024.

pH Instrument Location	pH Instrument and Serial Number	Instrument commissioning date	2024 Installation Date	2024 Retrieval Date	Number of continuous days	Maximum electrode offset (mV)[1]
LAK006, 2 m depth	21874259	2024-05-20	2024-05-21	2024-07-16	56	-17.8
	21909667	2024-07-16	2024-07-16	2024-09-10	56	-17.5
	21874259	2024-05-20	2024-09-10	2024-10-31	51	-17.8
LAK028, 2 m depth	21952347	2024-05-21	2024-05-22	2024-07-15	54	-14.1
	21952346	2024-07-14	2024-07-15	2024-09-09	56	-14.6
	21952347	2024-05-21	2024-09-09	2024-11-01	53	-17.7
LAK028, 13 m depth	21839688	2024-05-21	2024-05-22	2024-07-15	54	-9.5
	21909669	2024-07-14	2024-07-15	2024-09-09	56	-14.7
	21839688	2024-05-21	2024-09-09	2024-11-01	53	-15.0

[1] Maximum electrode offset (MEO) is a value from the instrument that is used to assess electrode function. If the MEO exceeds +30mV or is less than -30mV, the sensor needs replacing. All MEO values show excellent electrode performance.

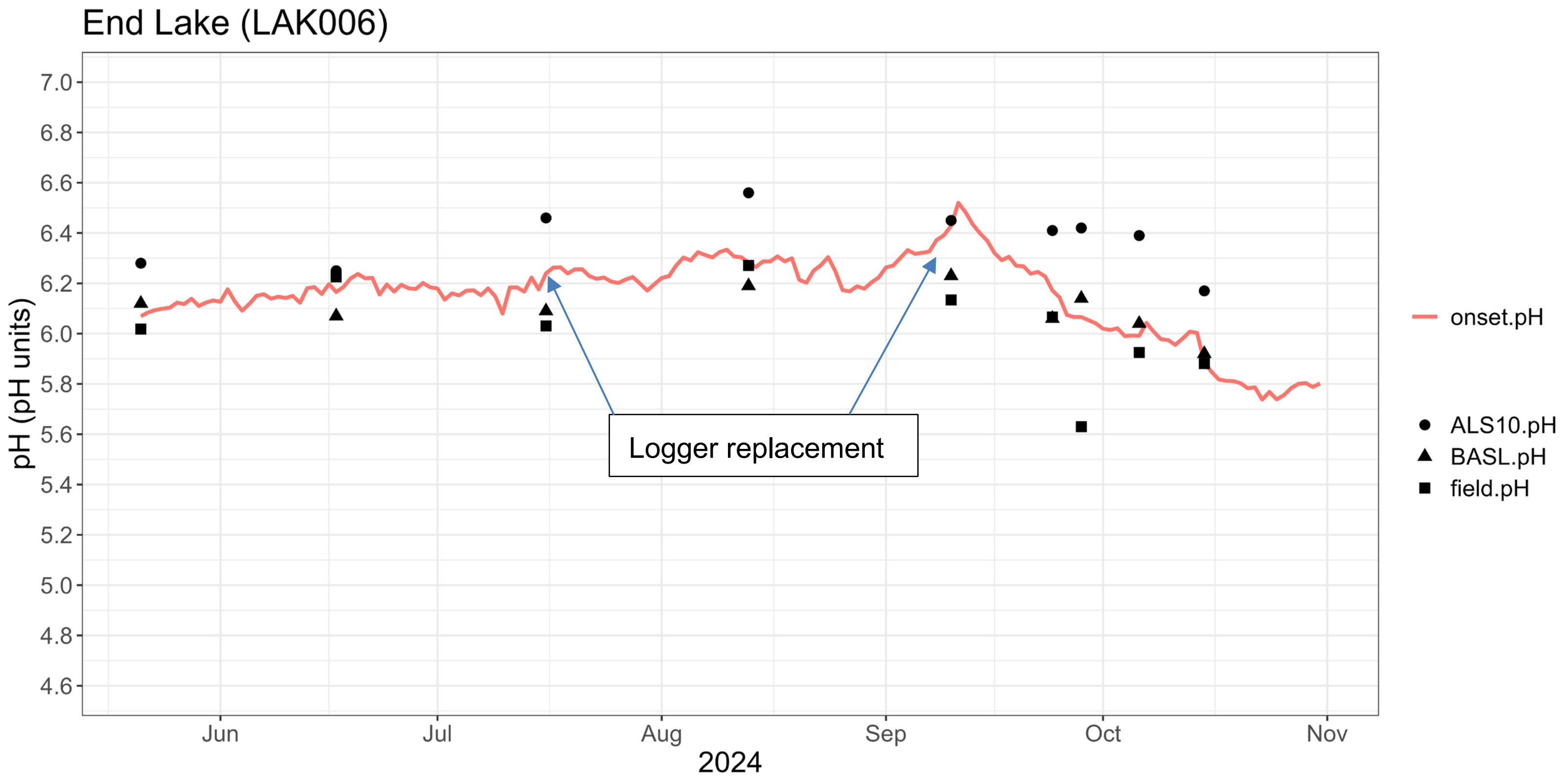

Figure 7. Mean daily pH recorded by the Onset logger in LAK006 (continuous red line) shown with discrete pH measurements using other instruments in 2024. Field.pH is WTW meter, ALS10.pH is a bench top meter used at ALS labs in Burnaby using a 10-minute electrode immersion time, and BASL.pH is the Mantech PC-titration Plus system used at BASL. Discrete sampling dates correspond to dates when the Onset logger was calibrated except on Sept. 28th when the lake was sampled from a helicopter.

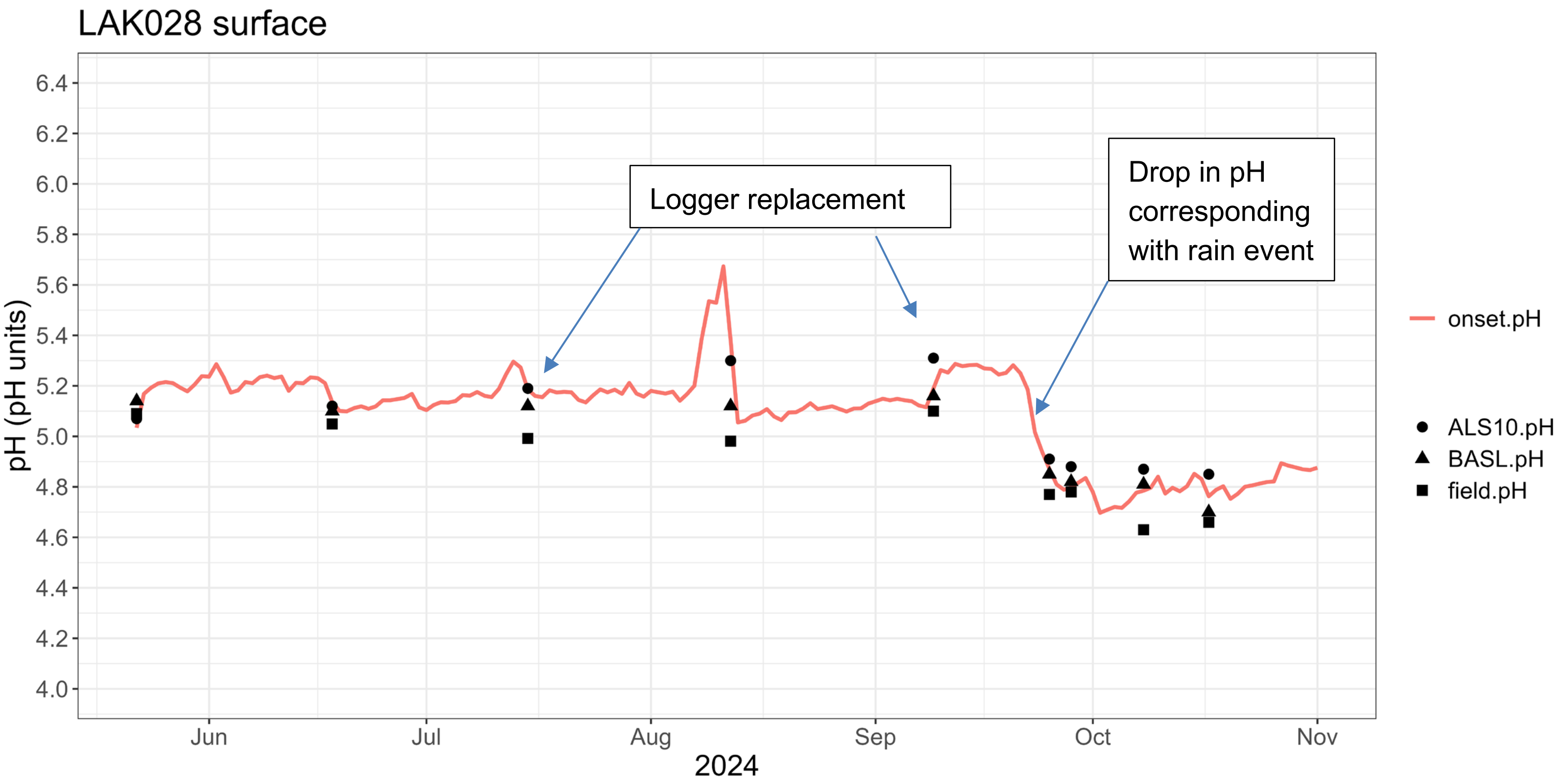

Figure 8. Mean daily pH for Onset pH logger in LAK028 deployed at a depth of 2 m (continuous red line) shown with discrete pH measurements in samples from the same depth using other instruments in 2024. Field.pH is the WTW meter, ALS10.pH is a bench top meter used at ALS using a 10-minute electrode immersion time, and BASL.pH is the Mantech PC-titration Plus system used at BASL. Discrete sampling dates correspond to dates when the Onset logger was calibrated except on Sept. 28th when the lake was sampled from a helicopter and on June 30th when the Onset logger was calibrated but no water samples were collected.

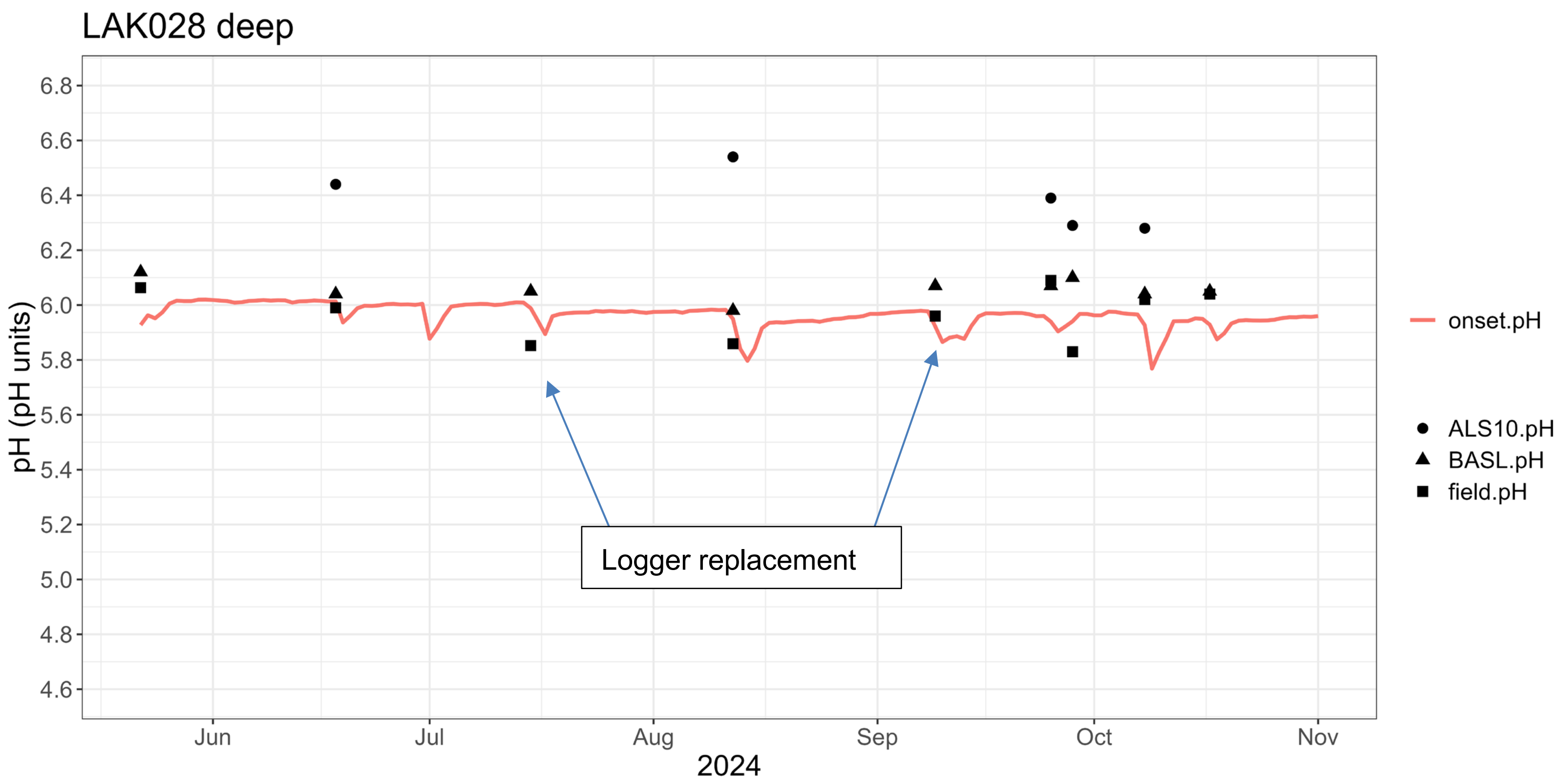

Figure 9. Mean daily pH for Onset pH logger in LAK028 deployed at a depth of 13 m (continuous red line) shown with discrete pH measurements in samples from the same depth using other instruments in 2024. Field.pH is the WTW meter, ALS10.pH is a bench top meter used at ALS using a 10-minute electrode immersion time, and BASL.pH is the Mantech PC-titration Plus system used at BASL. Discrete sampling dates correspond to dates when the Onset logger was calibrated except on Sept. 28th when the lake was sampled from a helicopter and on June 30th when the Onset logger was calibrated but no water samples were collected.

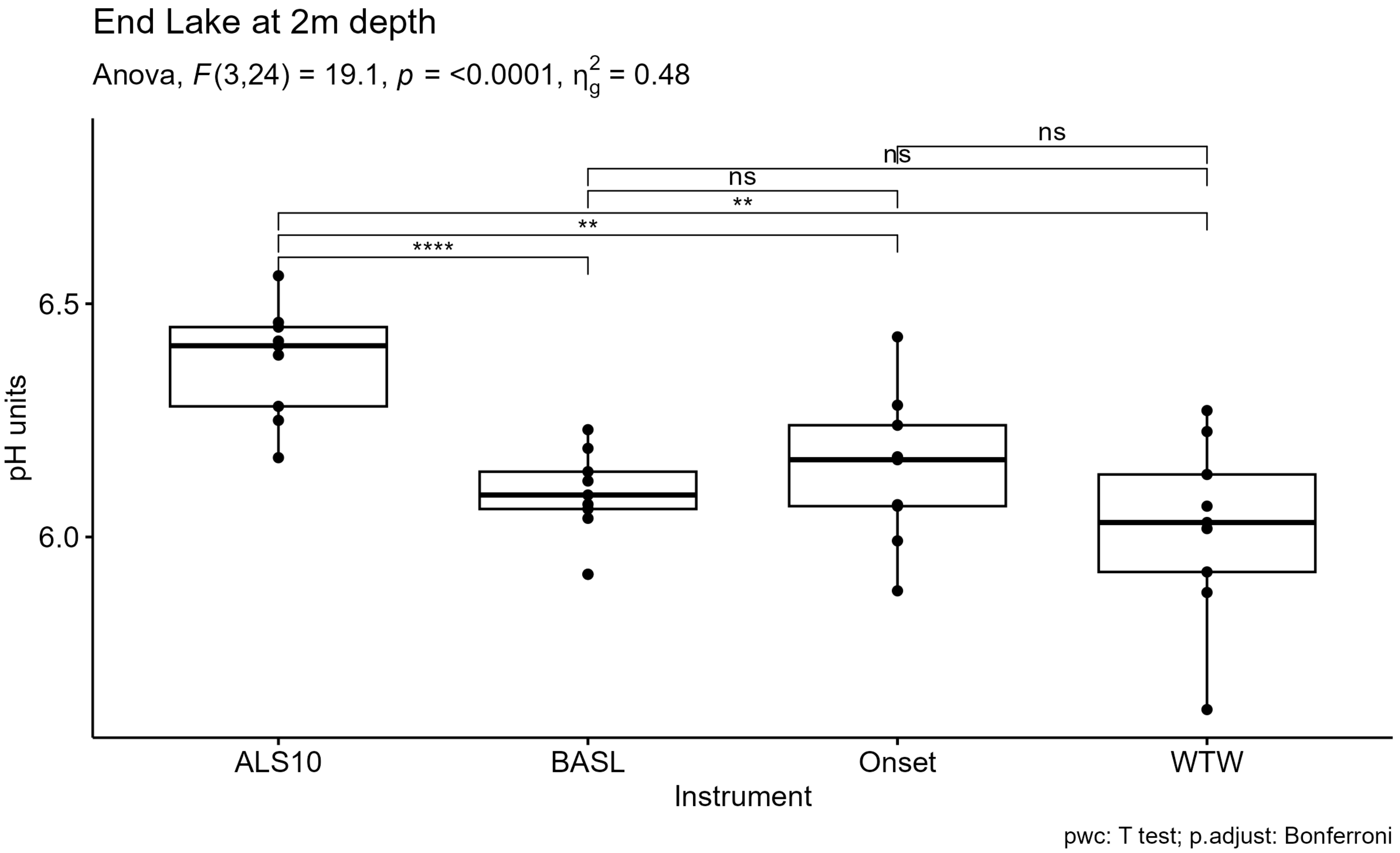

Figure 10.Box plot showing difference in pH in LAK006 between all combinations of instrument pairs during sampling in May through October 2024 (n=9). Instrument names are ALS10 (instrument at the ALS lab using 10-minute electrode immersion time), BASL (instrument at the BASL lab), Onset (in situ pH logger), and WTW (field pH meter). Horizontal bars at the top of the box plot span instrument pairs being tested along with symbols indicating significance of a difference in pH using repeated measures ANOVA. The * or ** or **** indicates a significant mean difference and “ns” indicates no significant difference in pH between the paired instruments.

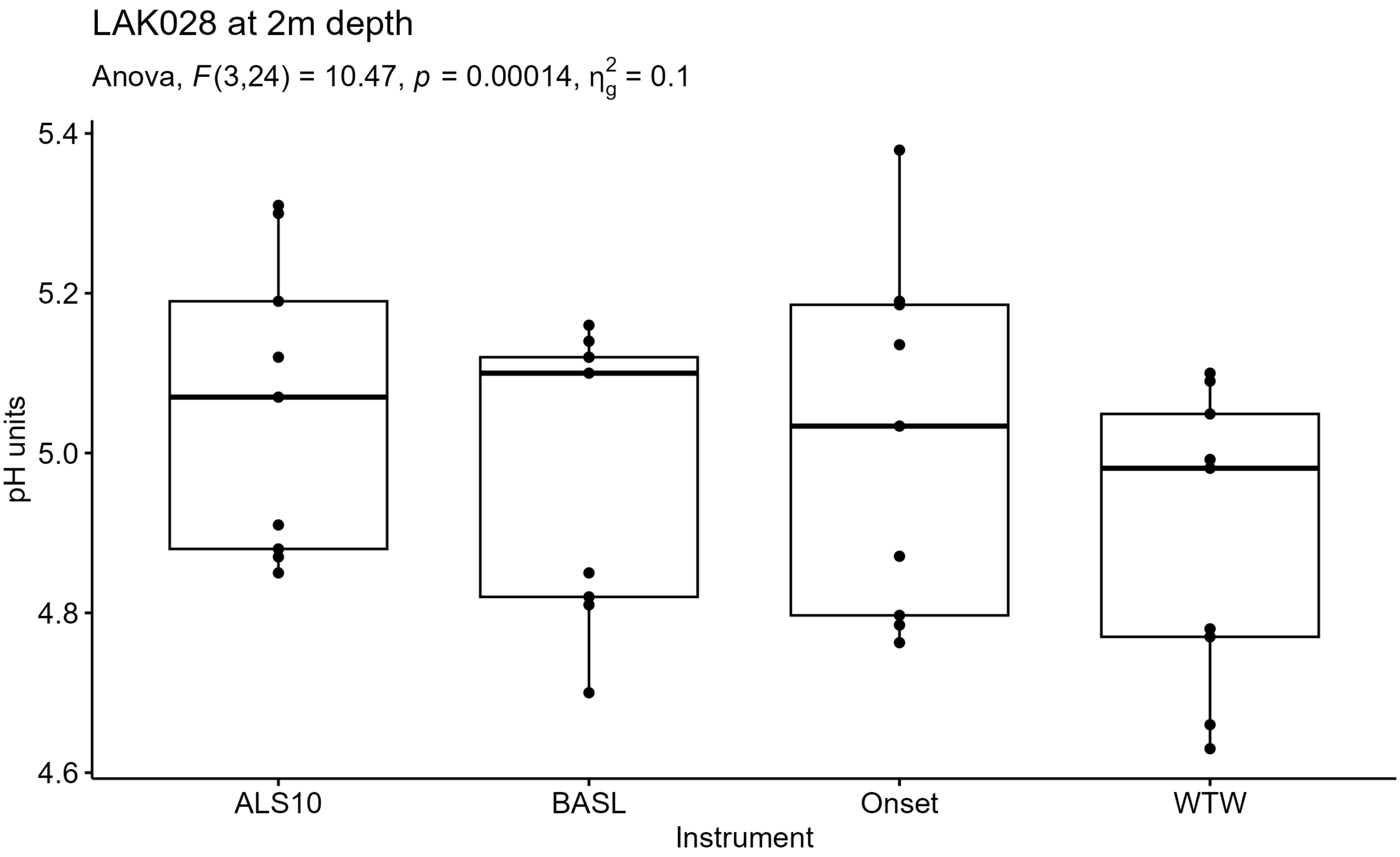

Figure 11. Box plot showing difference in pH in LAK028 (2 m depth) between all combinations of instrument pairs during sampling in May through October 2024 (n=9). Instrument names are ALS10 (instrument at the ALS lab using 10-minute electrode immersion time), BASL (instrument at the BASL lab), Onset (in situ pH logger), and WTW (field pH meter). There were no significant differences in pH between instrument pairs using repeated measures ANOVA.

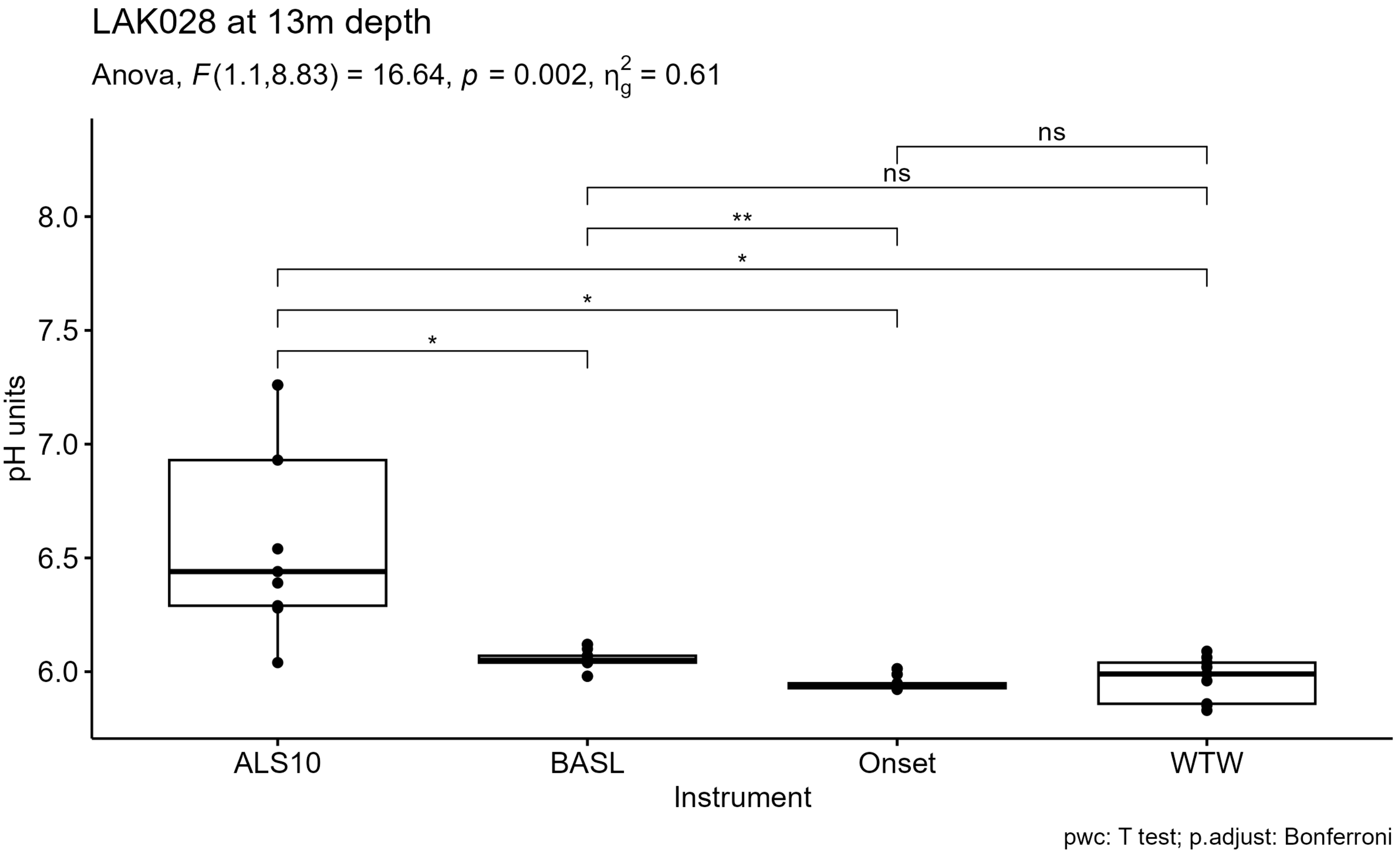

Figure 12. Box plot showing difference in pH in LAK028 (13 m depth) between all combinations of instrument pairs during sampling in May through October 2024 (n=9). Instrument names are ALS10 (instrument at the ALS lab using 10-minute electrode immersion time), BASL (instrument at the BASL lab), Onset (in situ pH logger), and WTW (field pH meter). Horizontal bars at the top of the box plot span instrument pairs being tested along with symbols indicating significance of a difference in pH using repeated measures ANOVA. The * or ** indicates a significant mean difference and “ns” indicates no significant difference in pH between the paired instruments.

3.3.2 Exposure of a sample to air

Neither the duration of exposure to air prior to measurement of pH nor treatment (Cap-on vs. Cap-off) had a statistically significant effect on pH for samples collected at LAK006 on August 15, 2024 ($F_{1,38}$ = 0.53, p = 0.47), treatment group ($F_{1,38}$ = 1.90, p = 0.18), interaction ($F_{1,38}$ = 0.09, p = 0.76) (Figure 13).

The two-way ANOVA for LAK028 (sampled on November 1, 2024) revealed a significant time effect on pH ($F_{1,38}$ = 16.62, p = <0.001) (Figure 14). Neither the treatment group ($F_{1,38}$ = 1.040, p = 0.31) nor the time × treatment interaction ($F_{1,38}$ = 3.695, p = 0.06) was statistically significant. The time course change in pH in both groups at LAK028 was less than 0.1 pH unit.

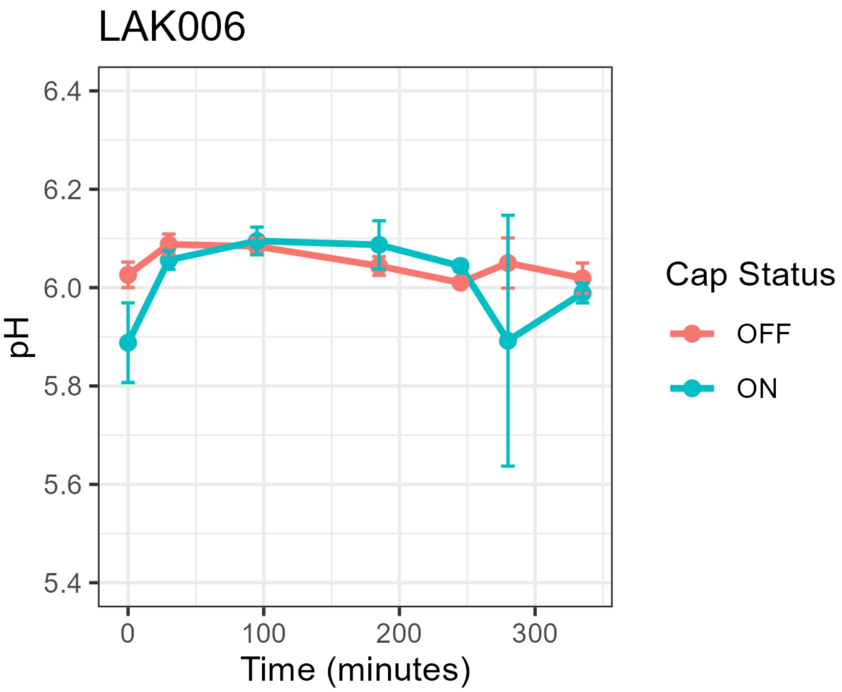

Figure 13 Time course change in pH stratified by the two treatments of sample exposure to air (cap on and cap off) using water collected from LAK006 on August 15, 2024. The values are mean pH ± standard deviation.

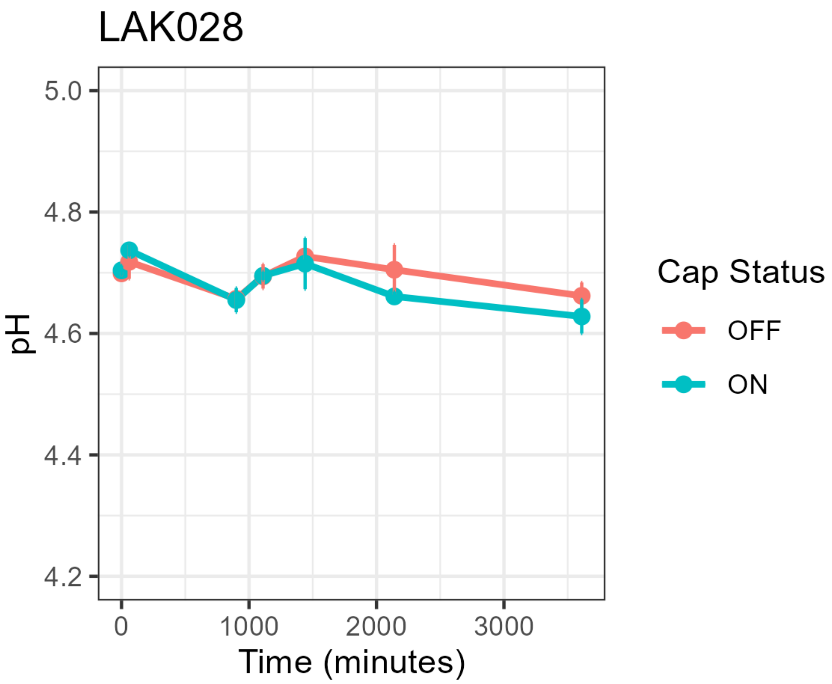

Figure 14 Time course change in pH stratified by the two treatments of sample exposure to air (cap on and cap off) using water collected from LAK028 on November 1, 2024. The values are mean pH ± standard deviation.

3.3.3 Electrode immersion time

The distribution of paired differences of pH between ALS-3 and ALS-10 did not meet the assumption of normality (Shapiro-Wilk p value <0.001), so the non-parametric Wilcoxin test was used to test for an effect of electrode immersion time on pH. Differences in pH between the methods was not significantly different from zero (p value = 0.71).

3.4 Onset pH electrode drift

Mean drift in pH logged by each of the LAK006 and LAK028 Onsets (the difference between observed and expected values in pH readings taken in solutions of a known pH) was 0.01 – 0.03 pH units immediately after calibration (a measure of calibration accuracy), increasing to 0.02 - 0.04 pH units up to a month of operation in LAK006 and LAK028 (Figure 15) without time course trend or pattern (Figure 16). The magnitude of electrode drift in 2024 remained among the lowest recorded over the full duration of continuous pH monitoring in LAK006 and LAK028, consistent with observations in 2022 and 2023 (Limnotek 2024).

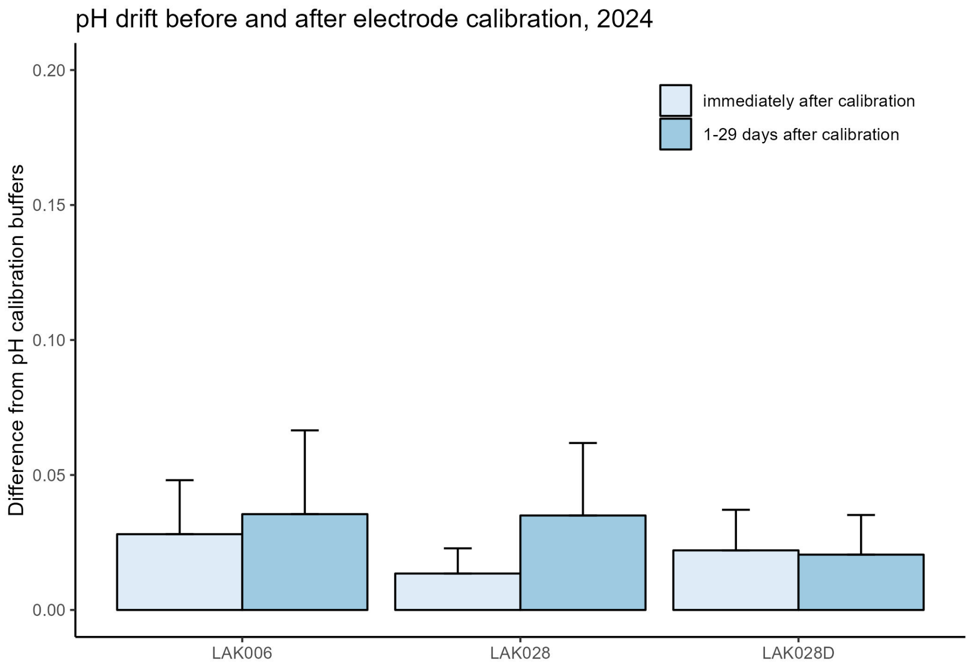

Figure 15. Onset pH electrode drift, shown as the mean difference (± standard deviation) between observed pH (field measured value of a buffer solution) and expected pH (certified pH value of a buffer solution) measured immediately after calibration and after a period up to 29 days in LAK006 and LAK028 in 2024.

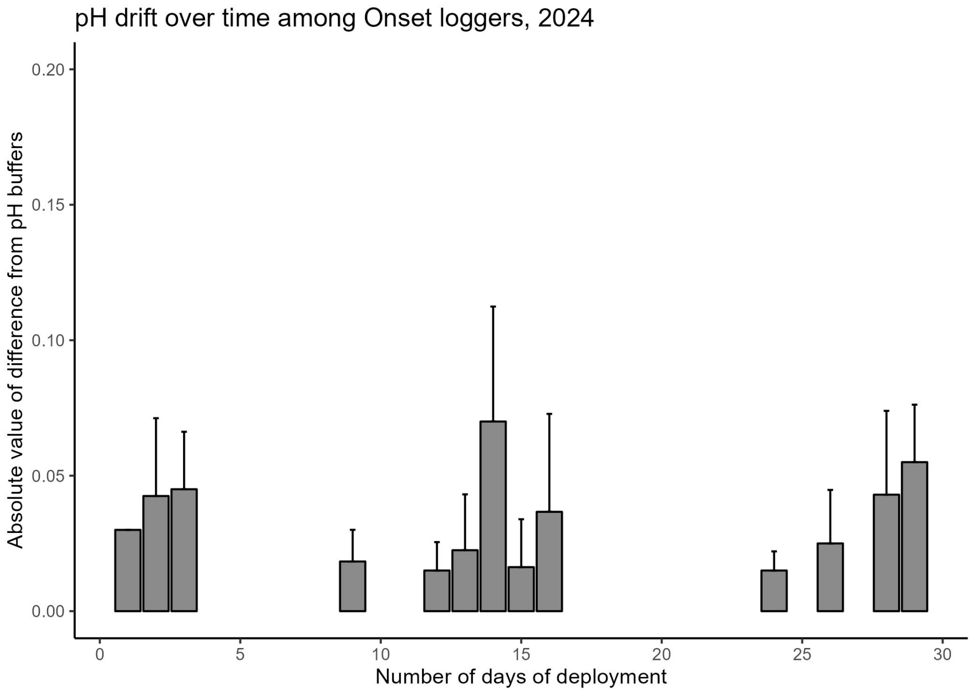

Figure 16. Onset pH electrode drift (the difference between observed pH (field measured value) and expected pH (certified pH value of a solution) after varying times of deployment following calibrations in 2024. Data were pooled for all Onset instruments in LAK006 and LAK028.

3.5 Precipitation and water surface elevation in LAK006 and LAK028.

There were no signs of tampering or vandalism of the staff gauges or water level loggers in 2024.

Water surface elevation varied by 40 cm in LAK006 and by 47 cm in LAK028 in 2024 (Figure 17 and Figure 18). At LAK028, the water level logger failed on August 30 and was replaced on Oct 8. The period of missing data corresponded with heavy rainfall in late September following a dry period in July and August (Table 7, Figure 18). Differences in change of water surface elevation between the two lakes are attributed to spatial variation in rainfall, lake morphometry, and basin hydrology. Total rainfall in Kitimat was almost double that in Terrace during the 2024 study period (Table 7).

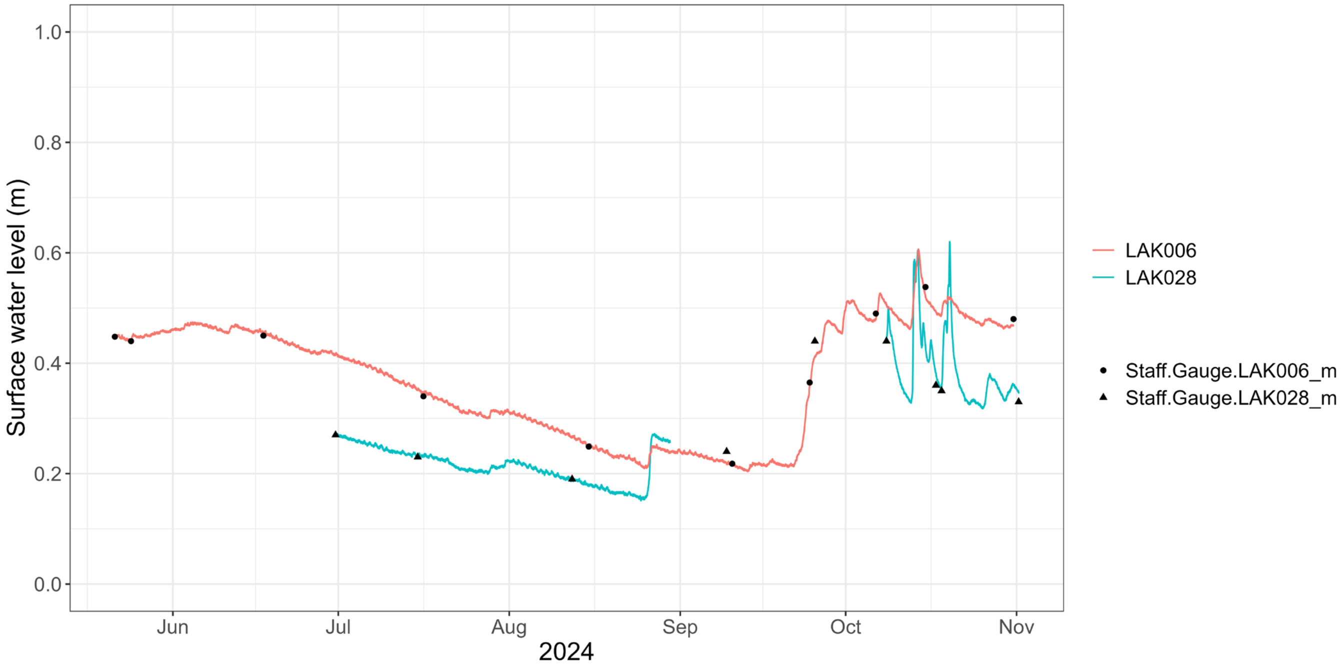

Figure 17. Surface water level (cm) in LAK006 and LAK028 in 2024 (measured every 30 minutes). Note that water level is relative to a benchmark at each lake, not to a common benchmark. The missing data in LAK028 from Aug 30 to Oct 8 was due to logger failure.

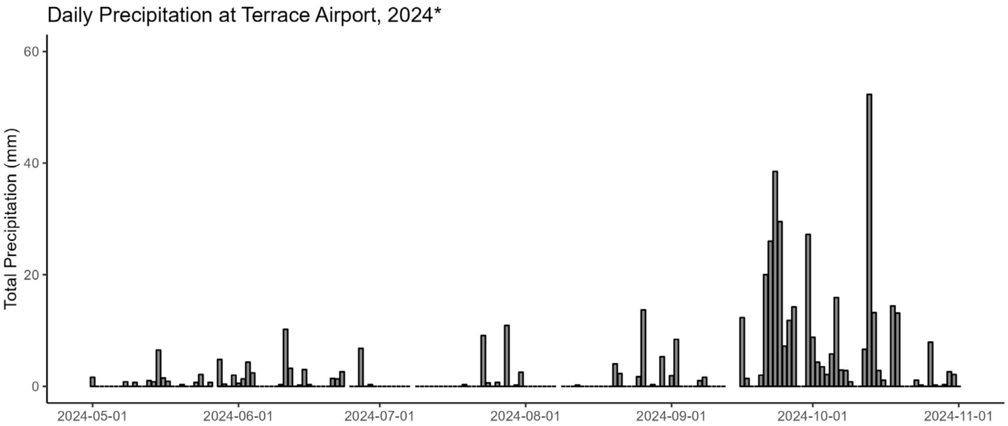

Figure 18 Total daily rainfall reported by Environment and Natural Resources Canada at the Terrace Airport (Terrace A) for May through October 2024. *Rainfall data was unavailable from the Terrace Airport station for Sep 12 to 24, so data from the Braun's Island station in Terrace was substituted for those days.

Table 7. Total rainfall by month during the water sampling period in 2024 reported by Environment and Natural Resources Canada at Terrace and Kitimat stations.

Month	**Total rainfall in 2024 (mm)**	
	Terrace (Station 1068134 at the airport or Station 1068131 at Braun's Island)	**Kitimat at Forest Ave. (Station 1064324)**
May	25	56
June	38	61
July	24	42
Aug	28	53
Sept	203*	291
Oct	165	382
May to Oct	**483**	**885**

*from Braun's Island

3.6 Limnology of LAK006

Temperature stratification was present in LAK006 throughout monitoring in 2024 (Figure 19). A surface warm layer (epilimnion) was present above 3 m in May which deepened to 6 m in October. Temperature of the hypolimnion (bottom layer) was 4ºC for the entire monitoring period. Surface temperature peaked at 22.5ºC on July 16, 2024.

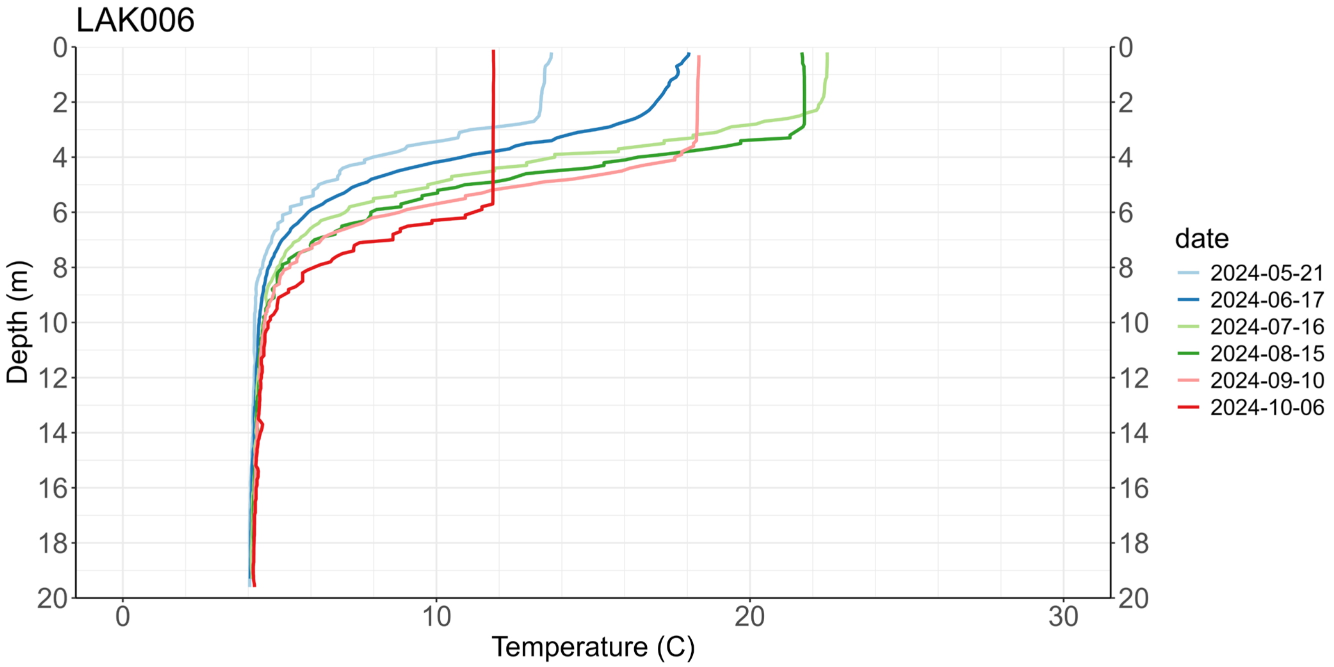

Figure 19 LAK006 water temperature from CTD casts in 2024. Each line represents a monthly measurement.

Dissolved oxygen (DO) concentrations showed a distinct pattern over time and depth (Figure 20). High values in spring declined sequentially through August and were characterized by pronounced mid-depth DO maxima, corresponding with mid-depth chlorophyll-a maxima (Figure 21). In September and October, surface DO concentrations remained high but mid-depth maxima were absent, likely associated with less oxygen produced from mid-depth primary production. High surface values in the fall may be attributed to wind and wave action from storm activity. A steep oxycline was present at 4 – 8 m in all months, coinciding with thermocline depths. Below the thermocline, dissolved oxygen concentrations were less than 5 mg/L and they declined with increasing depth. Hypolimnetic (below 8 m) dissolved oxygen concentrations were highest in the spring and lowest in the fall, reflecting well oxygenated conditions in the spring and increasing oxygen demand through the biological growing season.

Conductivity increased linearly with depth among all months, showing increasing solute concentrations from surface to bottom, particularly at depths below the thermocline. Highest conductivity that was found at the water – sediment interface can be attributed to diffusion of solutes from the sediment.

Turbidity occurred in a narrow range of 1 – 1.5 FTU except in May near the thermocline. The mid-depth peak corresponded with peak chlorophyll-a concentrations and corresponding phytoplankton cell density that would affect light scattering measured by the turbidity sensor. Lack of time course turbidity anomalies near the surface showed no inflow turbidity events.

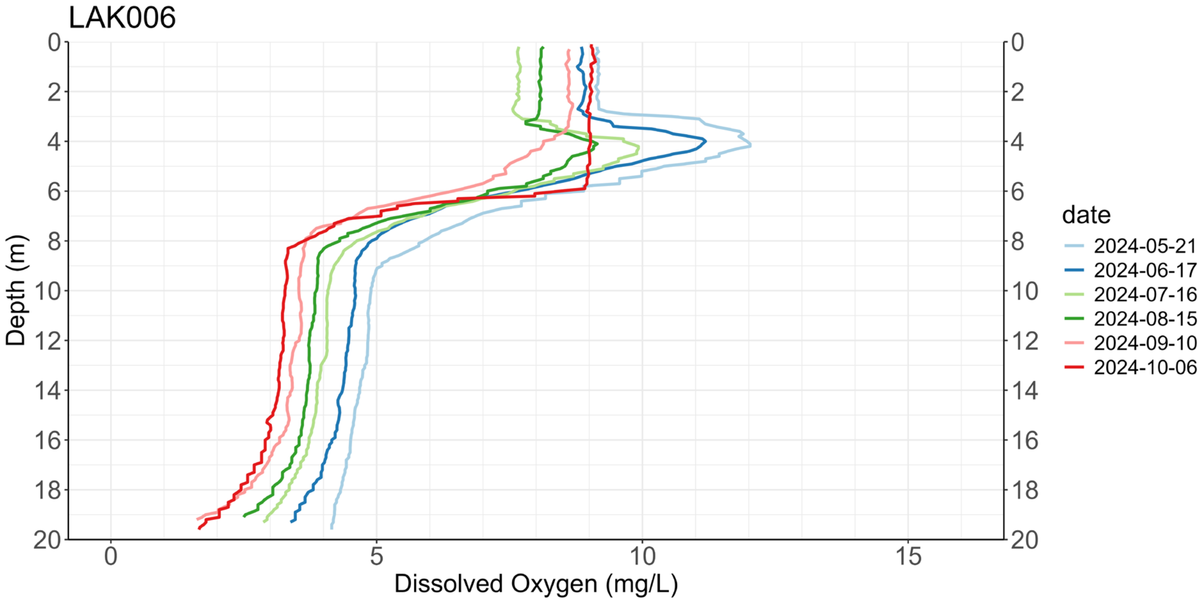

Figure 20 LAK006 dissolved oxygen concentrations from CTD casts in 2024. Each line represents a monthly measurement.

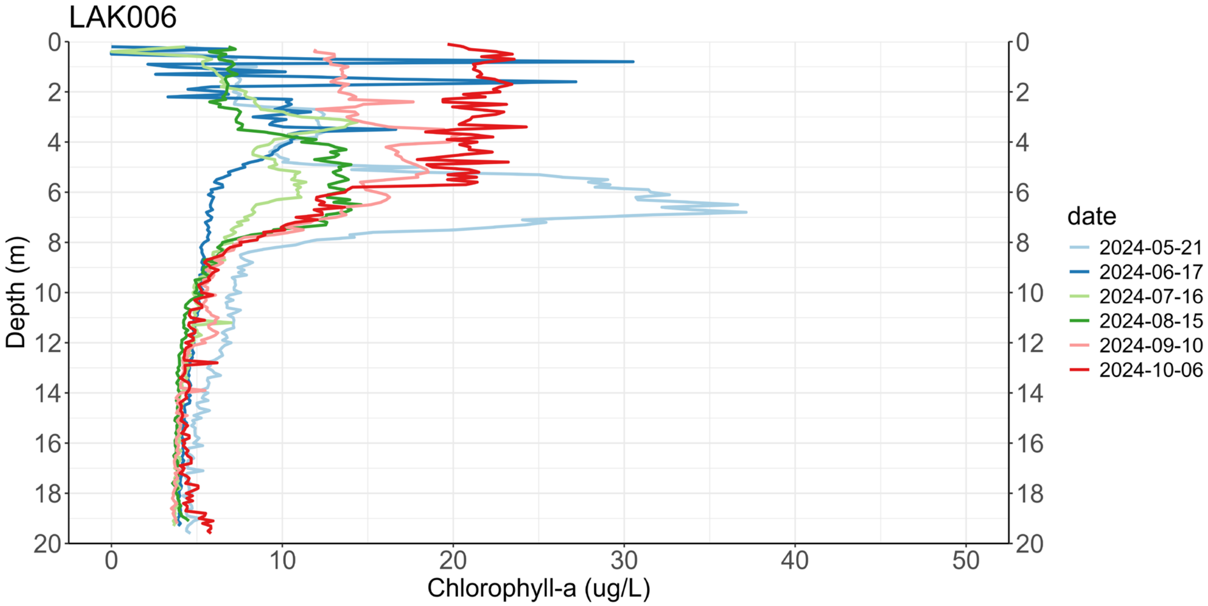

Figure 21 LAK006 chlorophyll-a concentrations (from fluorescence) from CTD casts in 2024. Each line represents a monthly measurement.

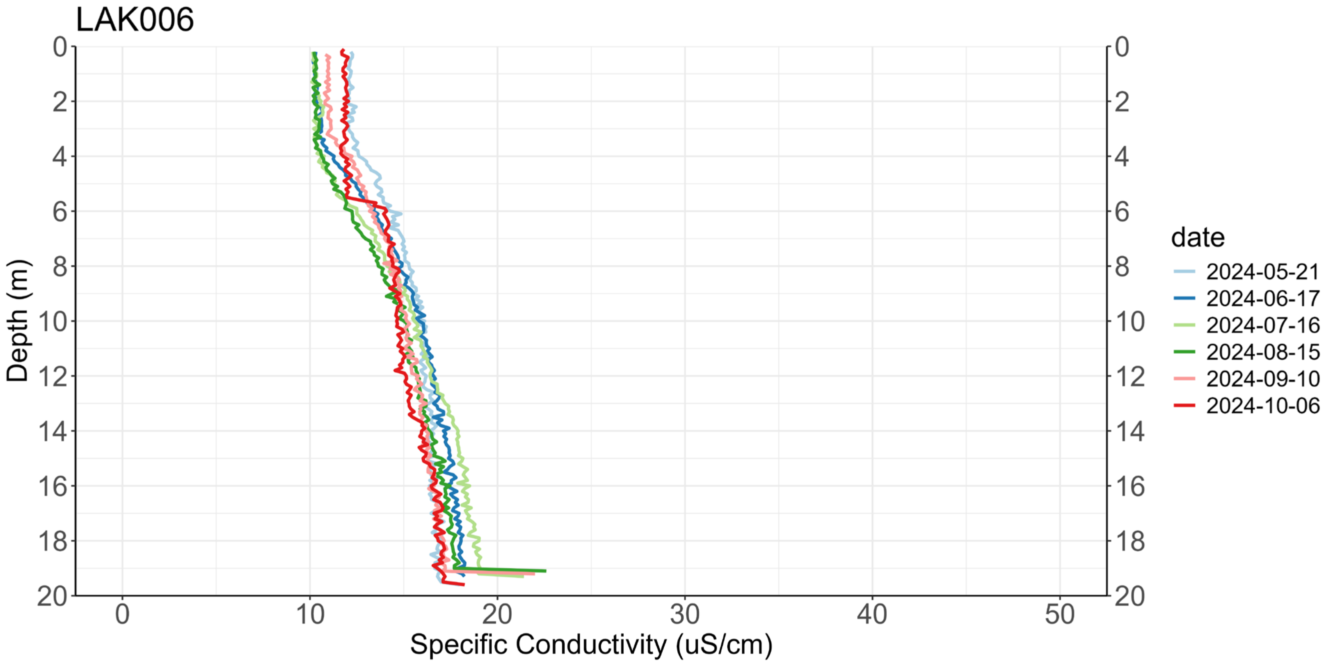

Figure 22 LAK006 specific conductivity from CTD casts in 2024. Each line represents a monthly measurement.

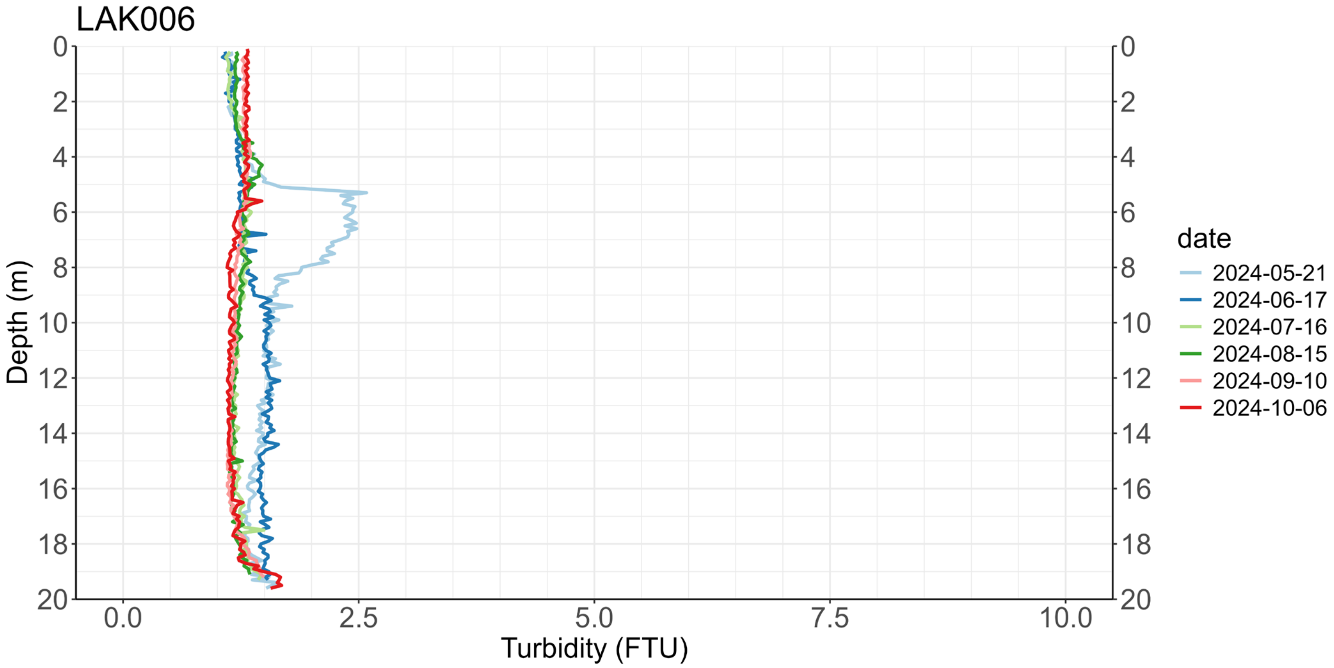

Figure 23 LAK006 turbidity from CTD casts in 2024. Each line represents a monthly measurement.

3.7 Limnology of LAK028

Three temporal phases were found in the logged LAK028 temperature data (Figure 24). Isothermal conditions occurred in November, 2023 through January, 2024 (Figure 24). They were followed by mid-winter inversion when surface temperatures were lower than those at depth, likely due to presence of surface ice. The 1 m logger ceased operation on February 13, 2024, and remained inactive until May 23, 2024. Despite this gap, warming of surface waters was detected in mid-April at the 3 m depth. A third phase in late May through late September, 2024, showed surface heating producing an epilimnion and hypolimnion separated by a thermocline (Figure 24 and Figure 25). Resistance to mixing declined in October 2024 as surface waters cooled. The peak surface temperature was 23.7°C, occurring on July 20, compared to 23.6°C in early July, 2023 and 21.7 °C in mid-August of 2022 (Limnotek 2024). At water depths >10 m, temperature was consistently near 4°C (at which point water has highest density).

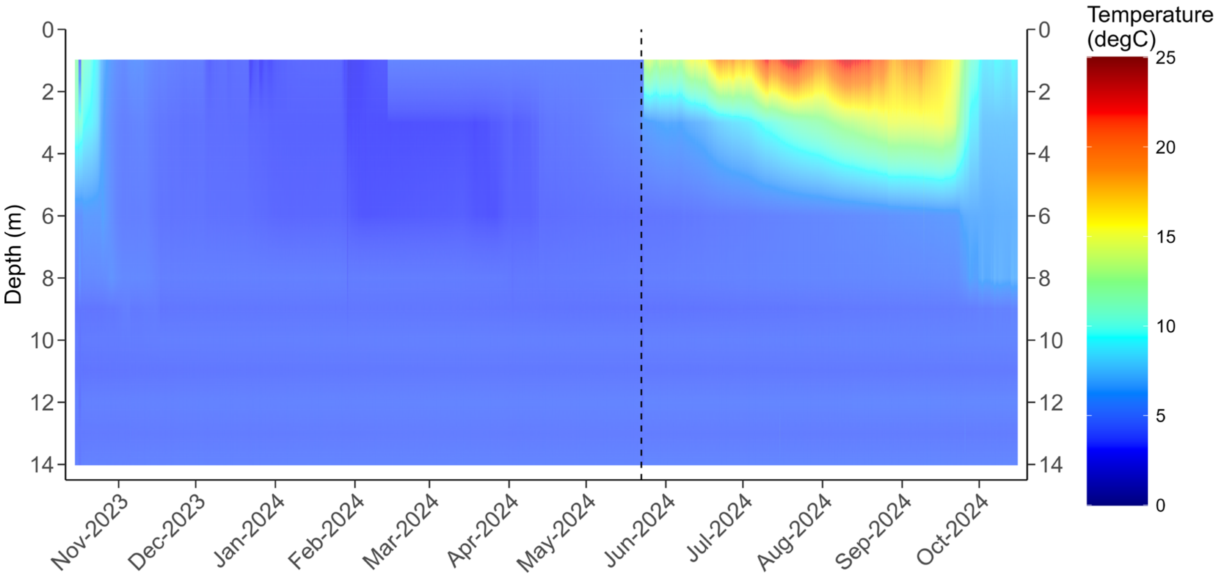

Figure 24 Temperature over time and depth from the mooring in Lak028 during October 15, 2023 through October 16, 2024. Measurements were taken at 10 depths every 30 minutes and data between those depths and times were linearly interpolated.

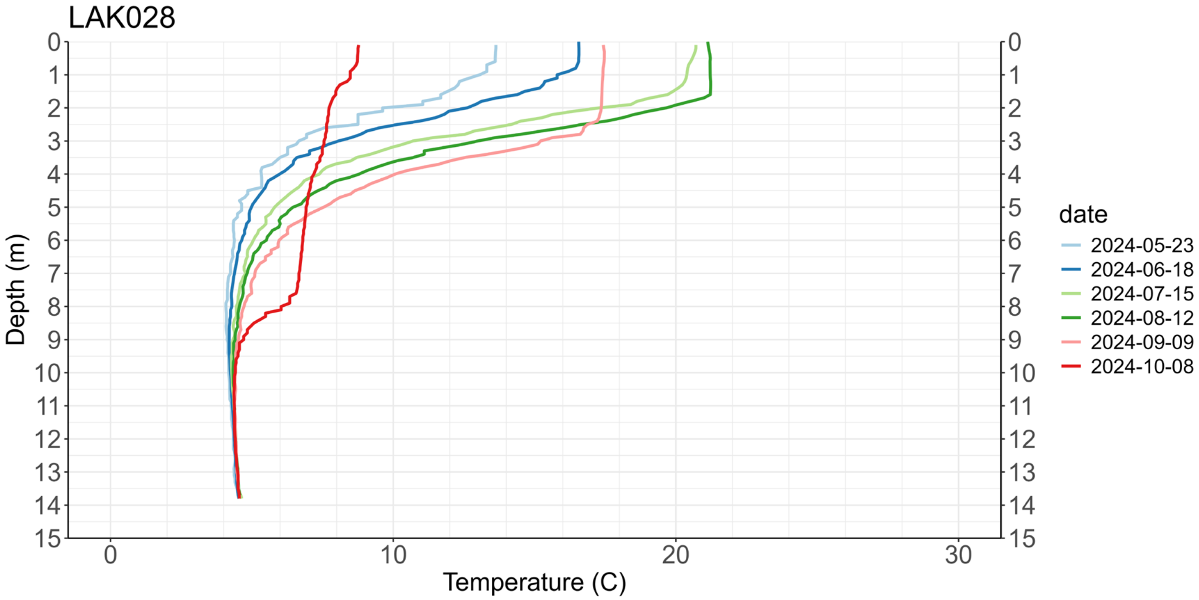

Figure 25 Detail of water temperature over time and depth during May through October 2024 in LAK028.

High DO concentrations in spring declined sequentially through August with mid-depth DO maxima, corresponding with chlorophyll-a concentrations (Figure 26 and Figure 27), as was found in LAK006 (Figure 20 and Figure 21). In September and October, surface DO concentrations remained high but mid-depth maxima were absent, likely showing less oxygen produced from mid-depth primary production. A steep oxycline was present at 7 – 9 m in all months, which, unlike in LAK006, was below the thermocline. At water depths greater than 9 m, DO concentrations were <1 mg/L.

Unlike LAK006, a surface algal bloom was detected in LAK028 in July, 2024 with chlorophyll-a concentrations exceeding 40 µg/L (Figure 27). The bloom was absent thereafter. Mid-depth chlorophyll maxima were common in all other months at less than half of the surface peak chlorophyll-a concentrations in July. Chlorophyll-a variability in the epilimnion and through the thermocline declined at a depth near 9 m resulting in common values among months of 12 µg/L at 9 m increasing to 19 µg/L near the lake bottom.

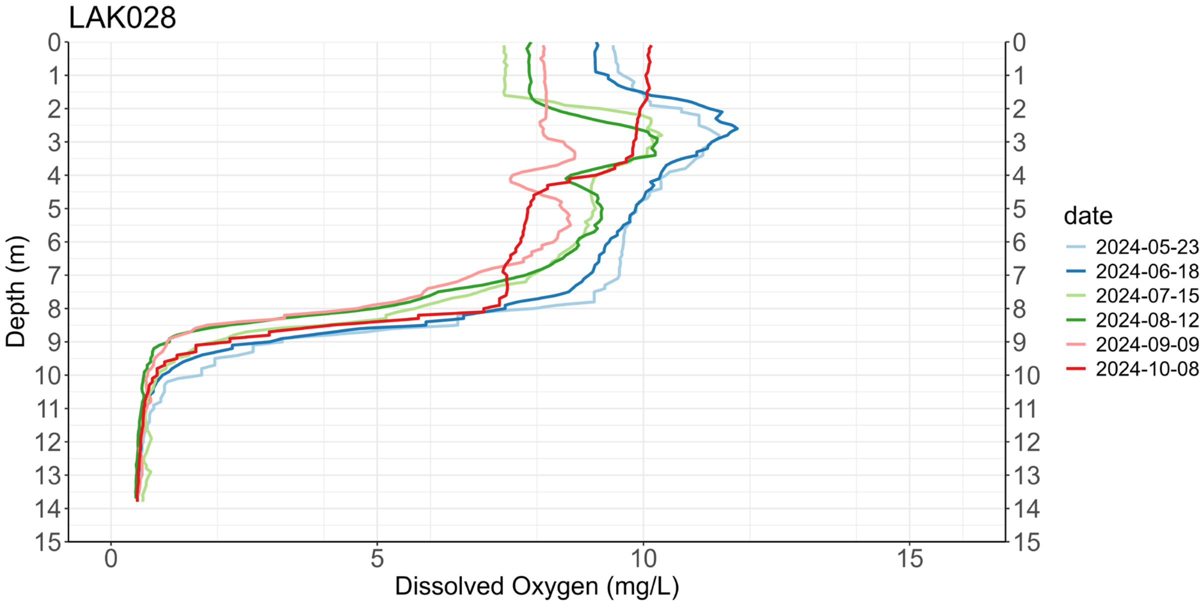

Figure 26 Dissolved oxygen concentrations from CTD casts among dates and depths in LAK028 at the raft station in 2024. Each coloured line represents a monthly cast.

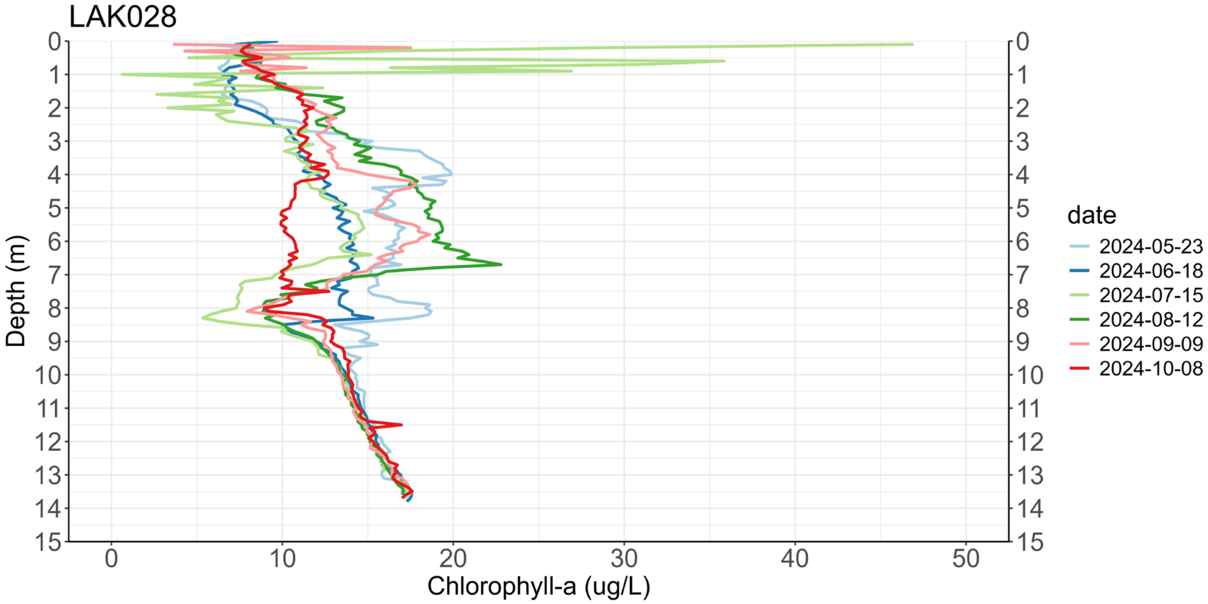

Figure 27 Chlorophyll-a concentrations from CTD casts among dates and depths in LAK028 at the raft station in 2024. Each coloured line represents a monthly cast.

A stable chemocline near the lake bottom was found in 2024 (Figure 28) as in previous years (Limnotek 2024). Conductivity was 25 – 35 µS/cm from the lake surface to a depth of 10 m. It increased at depths >10 m, exceeding 150 µS/cm near the water – sediment interface (Figure 29). The temporally consistent curvilinear change in conductivity with depth was inverse to the decline in DO with depth. Conductivity increased in the near surface waters in October compared to May through September, coinciding with cooling and inferred decline in resistance to mixing in the fall. That mixing may have allowed entrainment due to shear and convection in the upper part of the chemocline to affect surface waters (e.g. Ushijima and Yoshikawa 2022).

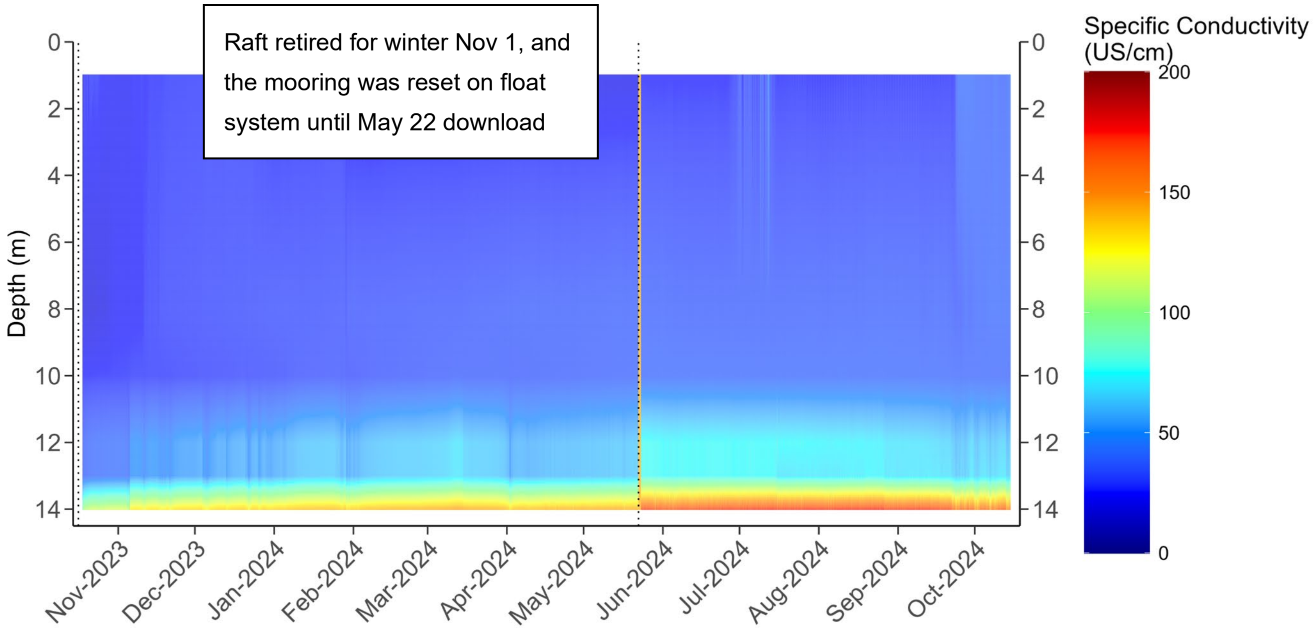
Raft retired for winter Nov 1, and the mooring was reset on float system until May 22 download

Figure 28 Specific conductivity from the LAK028 mooring among dates and depths in 2024. The vertical dotted line in November 2023 indicates the date the mooring was reset from the raft to the float system. The vertical line in May 2024 shows a one-day removal of the mooring for data download. The conductivity loggers were placed at water depths of 1 m, 8 m, 10 m, 12 m and 14 m on the mooring. On July 15, a sixth conductivity logger was added at a water depth of 13 m to increase resolution in the chemocline. Data between those depths were linearly interpolated.

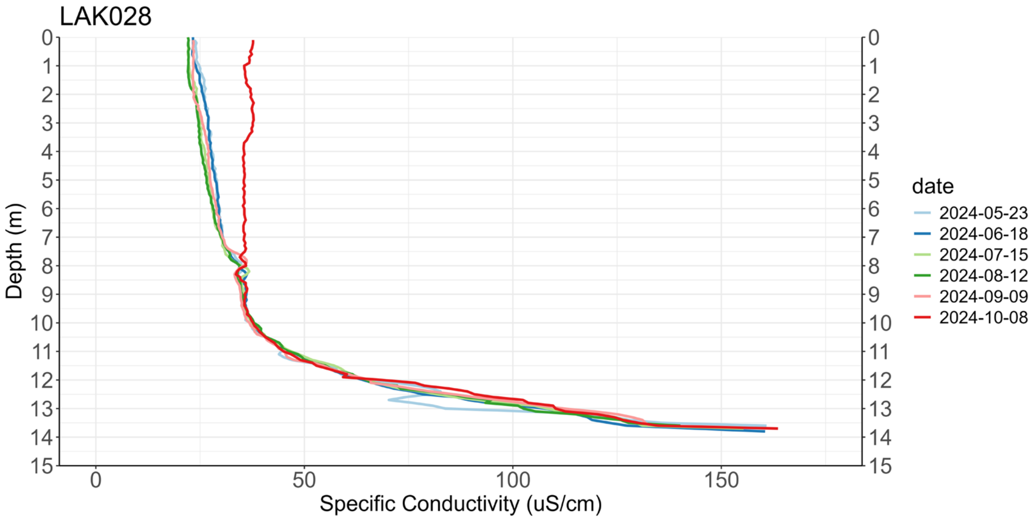

Figure 29 Specific conductivity (uS/cm) from CTD casts among dates and depths in LAK028 at the raft station in 2024. Each line represents a monthly measurement.

Conductivity at the standard 13 m water sampling depth in 2024 was lower than in 2020 to 2022 (67 uS/cm), but higher than in 2023 (Figure 30). In 2023, there was contraction of the reduced layer near the sediment – water interface compared to earlier years.

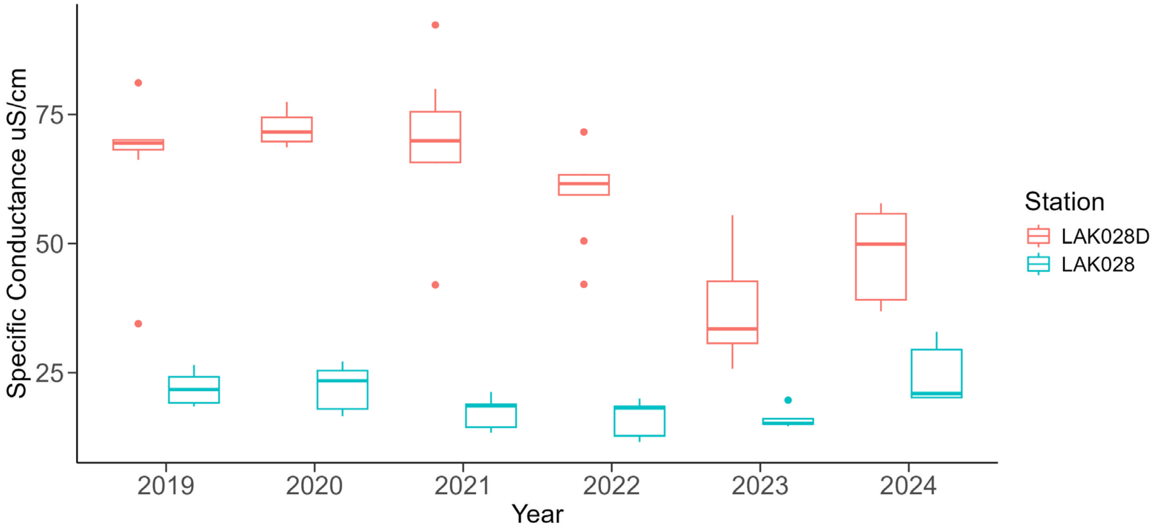

Figure 30 Boxplot of specific conductivity (uS/cm) from water samples collected May to October at two depths in LAK028 at the raft station from 2019 to 2024 (n=8 in 2019 and 2020, n=9 in all other years).

Three different processes were evident in the LAK028 turbidity profiles. Relatively high surface turbidity that declined through the epilimnion in July corresponded with the algal bloom occurring at the same time. Smaller turbidity spikes were found at the thermocline among all months, showing mid-depth particle accumulation potentially caused by resistance to particle settlement at the thermocline. Further turbidity spikes at a water depth of 12 m may be linked to bacterial communities in the low-oxygen or anoxic and nutrient-rich zone of the chemocline, a classic condition in meromictic lakes (*e.g.* Tonolla et al 2014).

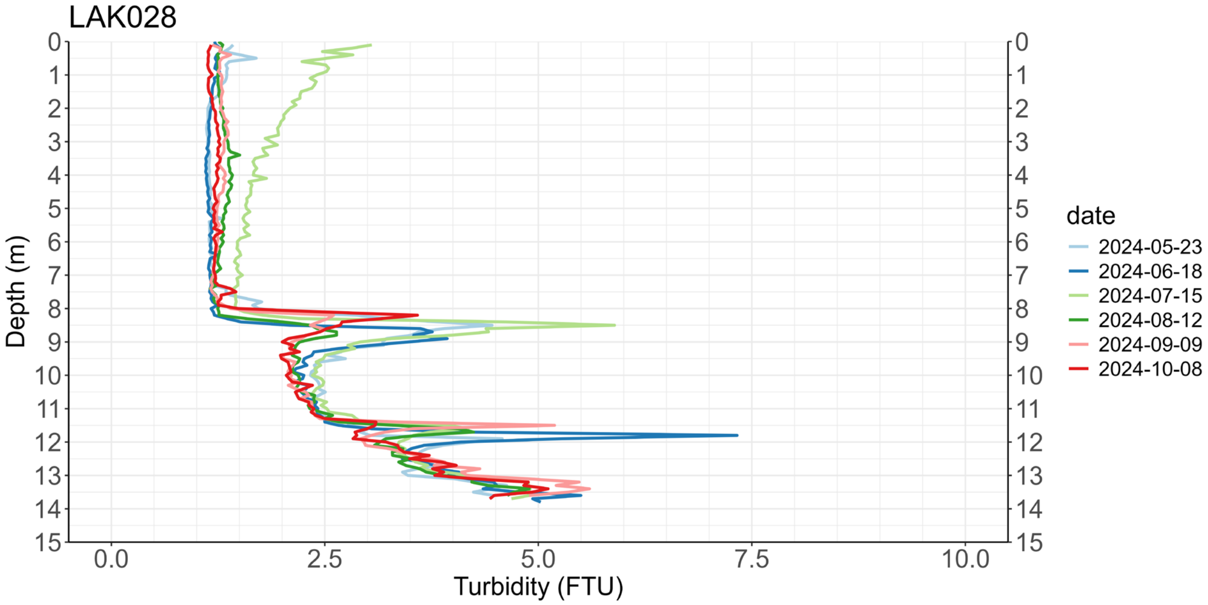

Figure 31 Turbidity from CTD casts across dates and depths in LAK028 at the raft station in 2024. Each line represents a monthly measurement. Values expressed as FTU (formazin turbidity units), as shown in this figure, are the same as those expressed as NTU (nephelometric turbidity units).

Details of the chemical differences between surface water that is sampled for the ongoing EEM and water that is 2 m off bottom is shown in Table 8 for 2024. Sulfate concentrations were greater at the surface than near the bottom while total sulfide concentrations were greater near the bottom than at the surface. The same inverse pattern was found for NH_4-N (greater near the bottom) and NO_3-N (greater at the surface). The greater conductivity at bottom than at the surface (Figure 28, Figure 29, Figure 30) was related to higher concentrations of all nutrients, total and dissolved carbon, and Gran ANC near the bottom compared to the surface resulting in lower pH at the surface than at bottom. All of these differences were related to oxidizing conditions at the surface and reducing conditions at the bottom (Figure 26). These differences prevailed regardless of the presence or absence of density stratification (Figure 24, Figure 25).

Table 8 Average values of chemical attributes at water depths of 2 m and 13 m in LAK028 in May through October, 2024.

Analyte	**Units**	**Mean value or concentration ± standard deviation in LAK028**	
		Surface (n=9)	**Deep (2 m off bottom) (n=9)**
SO_4 (sulfate)	$mg \cdot L^{-1}$	7.1 ± 1.5	0.2 ± 0.2
Sulfide (as H_2S)	$mg \cdot L^{-1}$	<0.01	0.9 ± 0.1
Specific conductivity	$\mu S \cdot cm^{-1}$	25 ± 5	48 ± 8
Total dissolved solids	$mg \cdot L^{-1}$	30 ± 8	60 ± 12
pH- WTW field meter	pH units	4.9 ± 0.2	6.0 ± 0.1
pH - BASL	pH units	5.0 ± 0.2	6.1 ± 0.0
pH - ALS (low ionic strength method)	pH units	5.1 ± 0.2	6.6 ± 0.4
Gran Alkalinity – BASL	$mg \cdot L^{-1}$ as $CaCO_3$	0.2 ± 0.4	21.8 ± 4.9
NH_4-N (total ammonia as N)	$\mu g \cdot L^{-1}$	< 5	2814 ± 834
NO_3-N (nitrate as N)	$\mu g \cdot L^{-1}$	18 ± 18	<5
TN (total nitrogen)	$\mu g \cdot L^{-1}$	136 ± 28	2673 ± 1285
SRP (soluble reactive phosphorus)	$\mu g \cdot L^{-1}$	<1	<1
TDP (total dissolved phosphorus)	$\mu g \cdot L^{-1}$	2.4 ± 0.7	16.9 ± 3.1
TP (total phosphorus)	$\mu g \cdot L^{-1}$	4 ± 1	32 ± 5
DOC (dissolved organic carbon)	$mg \cdot L^{-1}$	5.8 ± 1.3	14.1 ± 2.3
DIC (dissolved inorganic carbon)	$mg \cdot L^{-1}$	0.6 ± 0.1	8.9 ± 3.5
TOC (total organic carbon)	$mg \cdot L^{-1}$	5.8 ± 1.4	13.8 ± 1.4
TIC (total inorganic carbon)	$mg \cdot L^{-1}$	0.7 ± 0.4	9.1 ± 3.4

4 DISCUSSION AND RECOMMENDATIONS

4.1 Data compilation

Data from 2024 were appended to those from previous years (2012 to 2023) to provide an up-to-date compilation of chemical and other descriptive information for further analysis by ESSA Technologies. This process of continuous updates provides a single source of data for review, analysis, and reporting over time. Formatting is structured as a data frame for reading in R (R Core Team 2022).

4.2 Quality of chemical data

High precision and excellent percent recovery among analytes in 2024 provided confidence in the repeatability and accuracy of output from the commercial laboratories (e.g. BASL and ALS).

Of the 20 blanks submitted to ALS, nine showed detectable concentrations of one or more analytes—five in filtered blanks and four in unfiltered blanks. For most parameters, including NH_4-N, total silicon (Si), dissolved inorganic carbon (DIC), and dissolved organic carbon (DOC), concentrations in blanks were well below ambient lake levels and did not compromise data quality. Positive blanks for total arsenic and total dissolved phosphorus (TDP) were found at concentrations greater than ambient lake levels. These anomalies were limited to the blank and not mirrored in lake samples collected on the same day. Dissolved zinc contamination in one blank at a concentration of 0.0053 mg/L was twice the average lake concentration of 0.0022 mg/L, yet three of four lake samples from the same date were below detection limits, possibly indicating a laboratory artifact rather than field contamination.

Tisserand et al. (2024) provide evidence that filters can contribute to blank contamination (e.g. DOC) but pre-washing filters with at least 20 mL of ultrapure (e.g. deionized) water can minimize this source of error. This practice was implemented beginning in August 2024 after four positive blanks were found in dissolved samples, and only one positive blank for a dissolved parameter was detected after implementing the filter wash, showing marked improvement with the added DI filter wash technique.

Collectively, these findings support the overall reliability of the dataset while emphasizing the importance of regular blank monitoring to detect and investigate rare contamination events. Discussion and tracking of blank anomalies with the lab helps reduce the risk of false positives or data misinterpretation.

Among the field duplicates, precision was excellent (RPD <9%) for all paired samples, except for one pair of TIC values, where RPD was 31%. The sample and duplicate were collected using two different Van Dorn hauls from the deep station (13m). The water collection may have occurred at slightly different depths that could strongly affect the water chemistry in different hauls because of the heterogenous nature of the narrow chemocline. Differences in pH of samples and their blind paired field duplicates showed excellent precision ranged from 0.002 to 0.014 pH units. BASL had the highest agreement between pairs and ALS-3 had the lowest. There was higher precision for ALS-10 (0.005 pH units) than for ALS-3 (0.014 pH units) providing support for continuing with ALS-10 for pH measurement.

To ensure continued data reliability and further minimize the risk of contamination, the following field and lab recommendations are made:

1. Use Sartorius Minisart® syringe filter (28 mm, 0.45 µm Hydrophilic Teflon DIGIFilter) or similar product for all sample filtrations to prevent DOC

contamination associated with cellulose ester filters. Larger diameter Teflon filter may also be used in the Swinnex systems for high-volume samples.

2. Pre-rinse each filter with 20 mL of DI water followed by 10 mL of sample water to reduce contamination introduced by the filter housing or membrane.
3. Use lab-certified vinyl gloves for low-level metals sampling instead of nitrile gloves. Employ a filtration stand to reduce repeated handling of the syringe, which can occur when multiple filters are needed per sample. An example filtration stand is shown in Figure 3.
4. Handle total sulfide bottles (precharged with zinc acetate and NaOH) separately from all other sample bottles. Change gloves after filling or labeling these bottles to prevent transfer of preservative residues, and store the total sulphide samples in a sealed ziplock bag, physically separated from other samples to prevent cross-contamination during storage and transport.

4.3 Method effect on pH measurement

Paired differences in pH between labs and instruments have been tested annually to define a clear and standard approach for obtaining accurate pH among lakes and sampling times. Findings showed that pH from ALS is significantly greater than pH from the other methods (Limnotek 2024). Results from 2024 were consistent with this finding, except in paired comparisons from the 2 m depth in LAK028, an outlier among contrasts.

Two factors potentially contributing to this method effect on pH are variation in electrode immersion time and duration of sample exposure to air prior to measurement. Both were shown to be potentially important in earlier years (Limnotek 2024).

The 2024 testing did not support those earlier observations. There was no effect of electrode immersion time among measurements at ALS and there was no effect of duration of exposure of a sample to air prior to measurement. These conflicting findings between years show that unknown factors are contributing to greater pH at ALS compared to the other sources of measurement.

To avoid further trials looking for a cause of method effect, it is recommended that a standard method be adopted for the acquisition of pH data that is consistent with past measurements and can be defended. Five recommendations forming that standard method are as follows:

1. Always fill sample bottles so there is no air space. No air space ensures no gas exchange with the sampled solution that can change pH of the sample.
2. Discontinue pH measurement at ALS. The ALS pH values are almost always greater than paired values from the other measurement methods. While the “correct” pH value is not known among paired contrasts, calibration with fresh

standards and other quality control is well established and known with use of the field instruments and at BASL. Robust quality control is applied at ALS but something there gives us pause when all of the other instruments give similar results that are different from those at ALS. Given that ALS pH is greater than pH from the other instruments, loss of CO_2 from the samples at ALS must be occurring in greater amounts than is happening with use of the other instruments and methods. Cause of that CO_2 loss is unknown based on testing to date.

3. Use pH data from BASL for statistical analyses of long-term trends, building on the time series of prior pH measurements from Trent University.
4. Use pH logger data to examine seasonal trends in pH in LAK006 (surface only) and LAK028 (surface and near bottom), the two acid – sensitive lakes having a long-term data record. Start each field season with five new loggers and six new electrodes for the three points of measurement. This instrument and electrode renewal is needed to avoid failure (Limnotek 2024). Calibrate the instruments and download data a minimum of once per month. Every second month assemble a new logger/electrode combination, test it in the lab, and use it to replace the existing logger the following day. Using this procedure in 2023 and 2024, there were no logger failures due to moisture in the instrument since all electrodes replacements were done in the lab.
5. Use pH data from the WTW field pH meter as backup to all other pH measurements. There are only a few minutes between opening a bottle and taking a pH measurement with the WTW, thus minimizing an effect of gas exchange on pH. The WTW instrument informs the operator when a stable reading is attained. Use this feature to avoid personal bias in selecting a reading to record. These features make for high accuracy pH coming from the WTW meter. Data from this make of meter also dates to the beginning of the project, thus providing reliable backup data in case lab data is interrupted at some time.

4.4 Meromixis in LAK028

LAK028 exhibits meromixis with a stable chemocline. The pothole lake shape having a small surface area relative to depth and low wind exposure inhibits mixing and favours chemocline persistence. Accumulation of salts near the lake bottom likely results from organic matter decomposition that creates oxygen demand, release of solutes at the sediment-water interface, and limited upward diffusion due to the chemocline. The lake also has an ample supply of SO_4 originating at the lake surface that eventually is taken up and settles to sediments via photosynthetic and assumed bacterial processes.

The stable chemocline allows for reliable interpretation of surface water chemistry that is used to follow change in pH and Gran ANC as part of the Rio Tinto EEM of SO_2 emissions over years of monitoring.

Continued monitoring of thermal and chemical stratification profiles is essential for proper interpretation of long-term trends. The conductivity and temperature mooring data are the most valuable among all measurements in tracking mixing in LAK028 and need to continue to ensure surface water data are not confounded by potential entrainment of reduced bottom waters.

Increased sensitivity of chemical profiling that was implemented in 2024 with the use of the RBR Maestro revealed minor entrainment of bottom water into surface waters of LAK028. As noted in Section 3.7, it was not enough to change pH of surface water. The CTD also detected the short-lived spring algal bloom in LAK028, which has not been previous found.

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Appendix E: Vascular Plant and Cyanolichen Biodiversity Monitoring Program, Forth Annual Report: 2024 Field Season

The following pages contain the full **Vascular Plant and Cyanolichen Biodiversity Monitoring Program, Forth Annual Report: 2024 Field Season,** in PDF format.

Citation: Balanced Ecological Management Co. 2024. Vascular Plant and Cyanolichen Biodiversity Monitoring Program, Forth Annual Report: 2024 Field Season. Report prepared by Balanced Ecological Management Co. for Rio Tinto Ltd. 58 pp.

Vascular Plant and Cyanolichen Biodiversity Monitoring Program Fourth Annual Report: 2024 Field Season

Prepared for Rio Tinto B.C. Works (Kitimat, BC)

Prepared by Amanita Coosemans, Balanced Ecological Management Co.,

with

Dr. Carl James Schwarz

DECEMBER 23rd, 2024

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Glossary and Abbreviations

BC or B.C.	British Columbia, Canada
Cyanolichen plot	Plot (defined below) plus the adjacent area included during the one-hour timed search at each location during each assessment.
Deposition Zones	Deposition Zones are based on the 42 tonne per day No Background scenario currently available: Low is <7.5; Medium is 7.5 to <20; High is 20+ (units: kg SO_4^{2-}/ha/year).
$F_{(g)}$	Gaseous fluoride
IER column	Atmospheric ion exchange resin column.
Mg	Megagram (equivalent to 1000 kilograms, or a metric tonne)
mm	Millimeter
ENV	British Columbia Ministry of Environment and Climate Change Strategy
NYA	Not yet available.
OGMA	Old Growth Management Area: Defined areas that contain, or are managed to attain, specific structural old-growth attributes and that are delineated and mapped as fixed areas, legally designated under the BC *Land Act* and the *Forest and Range Practices Act*.
PCMP	Vascular Plant and Cyanolichen Biodiversity Monitoring Program.
Plot	A site assessment undertaken at a particular site at a particular time (i.e., year). Plot naming convention is site identifier (e.g., B04), followed by two letters (typically initials of lead ecologist, or coding for "special" plot type) and 2-digit year, e.g., "B04AC21."
QP	Qualified professional.
RT	Rio Tinto Alcan Inc.
RTBC	Rio Tinto B.C. Works smelter site, south of Kitimat, BC
SE	Standard Error
Site	A permanent sample location identifier (e.g., "B04") whose geographic coordinates are fixed. The standard PCMP site is 20x20m, oriented along cardinal directions, for a total 400m^2. Note that cyanolichen search area, while centered on it, may extend away from the site (SEe "Cyanolichen plot," above).
SO_2	Sulphur dioxide
tpd	Metric tonnes per day.

Introduction

This Annual Report was prepared to fulfill part of the submissions required for the Rio Tinto's waste discharge authorization #100183 (Section 4.2.4 for SO_2 Environmental Effects Monitoring Program (SO_2 EEM) and section 8.7 for vegetation monitoring). This report follows the Annual Report template as provided in the *Terms of Reference for Reporting and Consultation Deliverables Required under the SO_2 EEM Plan, Draft V.4* (ESSA Technologies *et al*. 2022). The 2024 field data presented in this report include the first remeasurement of sites within the Vascular Plant and Cyanolichen Biodiversity Monitoring Program ("the Program," or "PCMP").

Background

In 2019, the Comprehensive Review of the SO_2 EEM recommended discontinuing the previous Vegetation Line of Evidence that was comprised of the biennial health inspection of vegetation as well as the annual foliar analysis of sulphur in western hemlock needles. The Comprehensive Review also recommended that a new vegetation monitoring program be integrated with the terrestrial line of evidence in order to achieve a more holistic environmental effects monitoring program. The reason for the recommended change was that, based on actual measurements of emissions and deposition, and on updated dispersion modelling, any potential effects were likely to be subtle and mediated through soil or substrate acidification.

In 2020 a new plan to monitor cyanolichens and vascular plant communities was developed and submitted to the British Columbia Ministry of Environment and Climate Change Strategy (BC ENV) (Laurence *et al*. 2020), and was subsequently accepted and integrated into the Terrestrial Line of Evidence of the SO_2 EEM program. The plan, referred to as the Vascular Plant and Cyanolichen Biodiversity Monitoring Program ("the Program," or "PCMP") is designed to detect more subtle effects of SO_2 and sulphate deposition. Per this plan, we built on the work of Williston and Perkins (2019), where feasible using their established cyanolichen sites and including new sites to a total of 34 sample locations that will be assessed on a rotating basis. In addition, Rio Tinto (RT) added and assessed two reference sites in the Kemano Valley in 2022 (which may have an offset schedule of reassessment differing from the other sites). All sites are located in mature forest with no obvious history of commercial logging and with at least some trees in excess of 100 years old, across modelled SO_4^{2-} Deposition Zones, from reference areas to areas predicted to be close to, or perhaps exceeding, the soil critical load under the modelled 42 tonnes SO_2 per day emission scenario. At all sites that comprise the PCMP, we monitor cyanolichen biodiversity, as well as metrics of plant abundance, health, and a selection of other ecological variables. In 2021, Year 1 of the PCMP was implemented. 2024 represented the fourth continuous year of the Program, and includes the remeasurement of the ten sites initially assessed during Year 1, as well as the assessment of an additional site—taken from the pool of alternate (inactive) sites that are part of the Program—to bring the total of sites in this rotation up to eleven.

Purpose

The Program is designed to detect potential differential trends in the biodiversity (species richness and abundance) of vascular plants in the low shrub and forb layers, and of arboreal cyanolichens, in forest ecosystems of the Kitimat Valley and Lakelse Watersheds. The Program focuses on detecting potential mid- to long- term effects on plants and cyanolichens associated with acidification due to emissions of SO_2 from the Rio Tinto BC Works (RTBC) south of Kitimat. The details of the Program are found in Laurence *et al.* (2020).

Current Status

2024 represents Year 4 for the Vascular Plant and Cyanolichen Biodiversity Monitoring Program. The ten sites first assessed in 2021 were remeasured for the first time in 2024, and an additional site—taken from the pool of alternate (inactive) sites that are part of the Program—was assessed in order to bring the total of sites in this rotation up to eleven. Taken with the twelve regular sites assessed in 2022 and the eleven sites assessed in 2023, we now have 34 sites measured at least once as part of the regular PCMP. In addition, RT voluntarily added and assessed two Kemano reference sites in 2022, for a total of 36 PCMP sites measured at least once. Note that the Kemano sites are ancillary to the Program and their monitoring schedule remains discretionary; as such, they may not follow the three-year monitoring schedule of the sites in the Kitimat valley. Further information on the Kemano site additions is found in the "Adjustments to the PCMP" section of this document.

The modelled Deposition Zones of all sites were adjusted in 2022 from the original plan to reflect corrected deposition modelling data (based on the *42-tpd No Background* scenario), and thus the reader will note that the deposition classification of some sites has changed from the 2021 reporting (Coosemans, Doyle and Grossmann 2021) and the original plan to monitor (Laurence *et al*. 2020). It is important to highlight that actual depositions vary depending on operational conditions, and thus will differ from modelled depositions: As a result, Deposition Zone boundaries should be viewed as useful constructs rather than fixed zones, and may be reviewed in future years. Regardless of actual deposition, the pattern of deposition—a high to low gradient of deposition generally radiating outward and northward up the Valley from the smelter—is expected to be consistent.

Also of note, 2024 represents the final set of PCMP data without additional *operational* emissions from the new LNG-Canada facility, which has been under construction since October of 2018[1]. Between August 29th and September 5th, 2024, the LNG-Canada facility received and introduced its first natural gas, and began flaring as part of its start-up activities[2].

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[1] LNG Canada "One Year Later" project update October 01, 2019: https://www.lngcanada.ca/news/one-year-later/

[2] LNG Canada "Community Notification: Taking Receipt of Natural Gas Ahead of Flaring" and "Community Notification: Low-level Flaring has Commenced" project updates, August 29th, 2024 and September 5th, 2024: https://www.lngcanada.ca/news/

Activities Conducted During the Reporting Period

Schedule of measurements

Sites assessed during 2024 are presented in Figure 1. Eleven sites were assessed (Table 1), from June 29 to July 5, 2024, during which the following activities were conducted:

- General site information (using Plot Site Data Form) data collected;
- Vascular plant biodiversity assessment (using Plot Vegetation Data and Line Transect Vegetation Data forms);
- Cyanolichen biodiversity assessment (Plot Cyanolichen Data form), including cyanolichen health assessment; and
- Plant health assessment (using Plot Site Data and Vegetation Health Assessment forms).

Note that no sites required soil sampling (soil samples were collected and analysed for these sites in 2022).

Having a bank of alternate sites that can be substituted in, as needed, is a critical component of the Program, such that suitable sites are available in each of the Deposition Zones in the event additional sites are needed to replace others that may become inaccessible or no longer suitable owing to disturbance. Alternates are identified with an “A” prefix in this report and our data workbook (Attachment 1), while sites that are part of the active Program have a “B” (the regular Program sites) or a “K” (Kemano sites) prefix.

Reconnaissance in 2024 added two alternate sites to the Program, and one site was moved from the alternate bank to the active bank during 2024 assessments (formerly, “A36”; now “B36”), to increase the total number of sites assessed in this rotation to eleven (only ten were completed in 2021, owing to a combination of factors encountered during the 2021 field season that prevented an eleventh site from being assessed during that first year of the Program). The two alternate sites added to the Program this year are A53 and A54; the two alternate sites identified in 2022 were A36 and A40; and the eight identified in 2023 were labelled A43 through A52. With the conversion of A36 into an active site, there is currently a total of eleven alternate sites. Of these, five are in the Low Deposition Zone, three are in the Medium, and three are in the High.

Please note that, for Table 1 and all other tables in this document, colour-coding indicates the modelled deposition zone: green = Low (<7.5 kg/ha/yr); orange = Medium (7.5 - <20 kg/ha/yr); and red = High (20+ kg SO_4^{2-}*/ha/yr). The pattern of colour-coding may differ for certain figures, where noted.*

Table 1: 2024 site assessment dates and general location information.

Site	Plot	Sample Event	Site location description	Date of Assessment
B04	B04AC24	2	Connector Rd. between FSR and Kitimaat Village Road	2024-06-28
B09	B09AC24	2	NW Dyke near Kitimat Service Centre	2024-06-28
B10	B10AC24	2	Emsley Creek	2024-07-02
B12	B12AC24	2	Bish Cove	2024-07-02
B17	B17AC24	2	Enzo Forest Rec Site on Wedeene FSR	2024-07-03
B20	B20AC24	2	Mailbox Point, upland side of Beam Stn. Rd.	2024-07-04
B22	B22AC24	2	Mt Herman area, west side of Beam Stn. Rd.	2024-07-04
B26	B26AC24	2	Below 6km Bish Mainline	2024-07-02
B30	B30AC24	2	Past Hirsch Creek bridge, off Hirsch Trail	2024-07-05
B32	B32AC24	2	Weedeene 16.5km FSR	2024-07-03
B36	B36AC24	1	OGMA on Kitimat River floodplain	2024-07-05

All assessed plots were conducted by a minimum crew of four persons, variably composed of Meagen Grossmann and Grace Jeon (Rio Tinto); Dwayne Riddler, Sarah Peden and Maria Otto (Wai Wah Environmental); and Amanita Coosemans and Frank Doyle (Balanced Ecological Management Company).

- Meagen assisted in all aspects of data collection, and was primarily responsible for the Line Transect Vegetation Data form. Meagen also mentored new Rio Tinto and Wai Wah Environmental staff in site data collection.
- Grace observed and participated in all aspects of data collection.
- Dwayne, Sarah and Maria assisted in all aspects of data collection, and were primarily responsible for the Line Transect Vegetation Data form.
- Frank assisted in all aspects of data collection, and was primarily responsible for the Plot Cyanolichen Data form, plant and cyanolichen health assessments, and participated in alternate site reconnaissance work.
- Amanita acted as lead ecologist/Vegetation QP, generally overseeing data collection, and primarily responsible for Plot Site Data form collection/verification, Plot Vegetation Data (plot abundances, distribution, vigour and phenology), and Vegetation Health Assessments; she assisted Line Transect Vegetation Data completion, Plot Cyanolichen Data collection, and led the reconnaissance for new alternate sites.

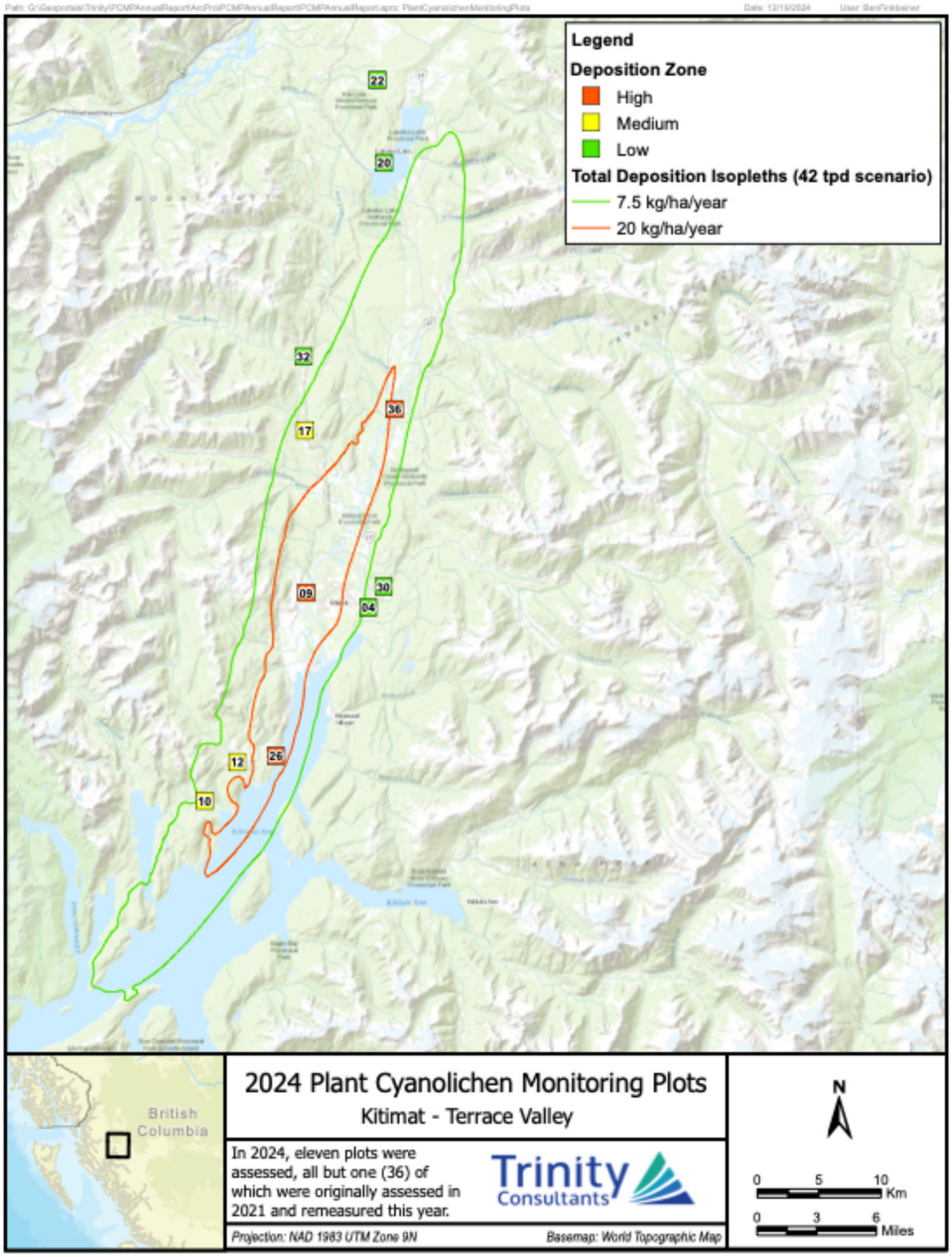

Figure 1: Map showing sites assessed during 2024 in relation to modeled sulphate Deposition Zones (note that isopleths are based on the 2016-2018 meteorological year average).

Variance from planned activities

In 2024, one plot was added to the Program that had not been scheduled; additional line transects were added to plots that had limited vegetation cover; and several new abundance variables were collected during cyanolichen assessments: These variances, described below, represent the only changes made to planned activities in 2024.

Plots lost

No plots were lost or removed from the PCMP in 2024 for any reason, including access issues, human- or natural- disturbances.

Plots added

One unscheduled plot was added during the 2024 PCMP year: In 2024, the plot scheduling included the ten sites initially scheduled for 2024, *plus one additional site location (B36)* to increase the sampling to eleven total sites. The additional site was originally in the set of alternate sites, and its inclusion during the 2024 sampling increases the number of active sites in the Program to 34, rather than 33 (not including Kemano reference sites).

Variables added and measured

In an effort to improve the ability to detect change over time, we added line transects on the south and west boundary lines for sites that had low covers of low shrub and herbaceous vegetation.

Similarly, in an effort to improve the ability to meaningfully analyse potential changes in cyanolichen abundance data, we tested two additional metrics of abundance during 2024: 1) a tally of estimated 1-gram amounts, and 2) a measure of total estimated surface area. These data were collected for each cyanolichen occurrence on suitable substrate (standing living or dead conifer) in the searchable area (ground-level to 2m height) within the vegetation site boundaries. These two metrics will be evaluated over the coming years for whether they may be useful permanent additions or not.

Variables not measured

There were no variables that were omitted in 2024.

Other changes of note

No other changes of note are relevant for the 2024 PCMP year.

Adjustments to the PCMP

Few adjustments have made to the approved SO_2 EEM Plan and Field Manual since the first year of the Program. This section of the report provides a compilation of deviations that have been carried over from year to year since the first assessments were undertaken in 2021, but does not include any variations made during the current year. Adjustments to-date are described in the following subsections.

Sites lost

No plots have been lost to human- or natural- disturbances during the PCMP to-date; however, two sites, B13 and B16, were removed from the PCMP in 2022 and 2021, respectively, for reasons related to access, safety, and/or suitability:

- In 2021, Site B16 was lost from the Program owing to access difficulties.
- In 2022, Site B13 was lost because of active bear use, poor visual site lines and difficult egress. The team decided to drop this site from the Program owing to the likelihood that these site factors would be problematic in future years, and also in light of the difficulty associated with undertaking this plot without impacting the fragile, overlapping vegetation at the site (*i.e.*, a highly complex, layered site with an abundance of wet pockets and skunk cabbage).

No sites were lost during the 2023 or 2024 PCMP years.

Sites added

In 2022, RT voluntarily contributed two additional “reference” sites to the PCMP. The sites, K33 and K34, are located in the Kemano valley, approximately 69+ kilometers southeast of Kitimat, BC, and are well-removed from any significant source of emissions. While these two sites were added and assessed during 2022, the Kemano sites are difficult to access and are not intended to be part of the regularly scheduled Program, but instead were established as control plots in reference areas. These sites allow us to potentially augment our understanding of regional factors such as climate change, and how such factors could differentially act on sites in the region. A schedule of measurements for these two sites is yet to be determined.

Note that, while several other sites have been added to the Program since 2021, these do not constitute adjustments to the PCMP, as they simply represent the fulfillment of the planned suite of sites (including alternates) intended for the Program.

Variables added and measured

As noted in previous annual reports, “one time” collection and chemical analysis of the lichen, *Lobaria oregana*, was undertaken at/near all plots where it was found to be sufficiently abundant (either growing on trees or recently fallen), and where its collection was deemed that it would not materially impact PCMP assessments or analysis in future years. While analysis (for metals and SO_2 concentration) was undertaken and results archived, the results were not included in annual PCMP reports (as it lies outside the scope of the PCMP); results were tied to PCMP initial assessments at sites where collected. As mutually agreed upon with ENV at the time of this addition, baseline opportunistic collection of *L. oregana* is not continuing through this second cycle of the Program.

During soil sampling, mineral samples were opportunistically collected, where possible, from the 10-20cm depth, in addition to the previously agreed 0-10cm sample, and the depth of the humus layer was also recorded. These adjustments will continue should additional soil sampling be required.

Variables not measured or dropped

Several variables were identified and noted in the annual reports as variables that could not be effectively measured as originally described, and constitute adjustments to the approved SO_2 EEM Plan (ESSA Technologies *et al*. 2023) and original Field Manual (Coosemans and Laurence 2021). Note that no other such variables were identified in 2023 or 2024. Variables not measured or dropped, as adjustments to the Program, include the following:

1) **Counts of individuals have proven impractical and will not be included in plot data**. The original Plan indicated that such counts would be included, "for those species with growth habits that support this metric" (Laurence *et al*. 2020).
2) **Alaskan blueberry (*Vaccinium alaskaense*) and oval-leaved blueberry (*V. ovalifolium*) species will be combined for abundance and richness measurements** owing to difficulties in distinguishing the two species.
3) **Similarly, at sites where other species cannot be readily distinguished in the field, species will be combined.** This originally emerged as an issue at site K33 in 2022, when the field team was not able to reliably separate two species in cover estimates; both species were noted as present, but were combined in the abundance data. Where this or a similar issue occurs in future plots, a similar approach will be used.
4) **Canadian bunchberry (*Cornus canadensis*) and Alaskan bunchberry (*C. unalaschkensis*), to be separated based solely on subzone location** (CWHws1—*C. canadensis;* CWHvm1— *C. unalaschkensis*), owing to difficulties in distinguishing the two species. **In data summaries, the two species will be combined.**
5) At one site (B06), the organic soil layer exceeded 100cm depth, and mineral soil samples could not be acquired for this site. **Soil samples will not be collected for any site where the organic soil layer exceeds 100cm.**
6) While rare, on occasion a data point was not recorded in the field; where this occurs, data fields are left blank and/or noted.

Other changes of note

No changes of note are relevant for the reporting year.

Results

Current (Version 14; Province of BC 2020) plant species codes and tree codes were utilized for data entry and presentation, including the files *BC Flora Checklist 2020*; *B.C. Tree Code List Version 2020*; and *List of All Species List Changes (2001 to 2020)*.

For results from this year's Program, note that we have generally presented data without pooling species (except in cases where they could not be separated); presented analyses are thus, likewise, based on the raw, unpooled data. While we anticipate that pooling of data is ultimately likely to be more informative for the Program, the author has chosen to offer less "worked" data for the annual report, and will delay presentation of pooled analyses until the end-of-cycle.

Vascular plant biodiversity measurements

Species richness

Species richness in the low shrub and herb layers—including otherwise pooled or combined species as unique species—was found to include five conifer tree species, zero deciduous tree species, 15 [non-tree] shrub species, and 34 herbaceous species across all eleven plots undertaken in 2024 (see attached Excel workbook for complete species details).

Species richness and averages of species richness are broken down by plot and by Deposition Zone in Table 2. For species richness within plots, species that could not be reliably distinguished were combined.

Table 2: Species Richness in the low shrub and herb layers at each plot (VACCALA/VACCOVL combined)

Plot	# Tree spp. in low shrub layer	# Non-tree shrub spp.	# Herb spp.	Total # spp. (richness)
B04AC24	2	6	7	15
B09AC24	1	6	9	16
B10AC24	3	5	9	17
B12AC24	4	4	9	17
B17AC24	4	5	11	20
B20AC24	3	4	6	13
B22AC24	2	5	8	15
B26AC24	1	3	4	8
B30AC24	3	7	16	26
B32AC24	4	6	13	23
B36AC24	1	5	10	16
Average (range) for Low Deposition Plots (5)	2.80 (2-4)	5.60 (4-7)	10.00 (7-16)	18.4 (13-26)
Average (range) for Med Deposition Plots (3)	3.67 (3-4)	4.67 (4-5)	9.67 (9-11)	18.00 (17-20)
Average (range for High Deposition Plots (3)	1.00 (1-1)	4.67 (3-6)	7.67 (4-9)	13.33 (8-16)

Percent cover

Percent cover of low shrub and herbaceous species is calculated both for each 400m^2 plot and for the sum of the line transects that run along site boundaries at each plot: In most plots, line transects were undertaken along only the north and east plot boundaries, for a total ~40m in transect length per plot, depending on terrain; however, transects were also undertaken along south and west boundaries in three sites (B20, B22, and B26) where low covers warranted additional transects, and in which the total transect length is therefore ~80m.

Not unexpectedly, percent cover in the plots for the various species ranged considerably, as it did in the line transects; however, this variability does not impact the analysis, as trends within plots—not between plots—are the subject of this Project. Data are presented in full for 2024 in Attachment 1.

Calculation of slope

2024 represents the first year when calculation of slope for percent cover data is possible, with the completion of a second set of measurements obtained in 2024 for ten sites originally assessed in 2021.

While slopes for individual species at individual sites can be viewed as the thin lines in Figures 8 and 9 (Appendix A), we caution that these slopes are based on two points only, have no standard error associated with them, and are therefore not particularly meaningful. The slopes become more meaningful when they combine across sites and are compared across deposition zones (viewed as thick lines in Figures 8 and 9, Appendix A).

Change in biodiversity profiles

Diversity profiles were introduced to the Program in the first end-of-cycle reporting (Coosemans, Grossmann and Schwarz 2024) for each of the plots that had been measured once between 2021 and 2023. In brief, diversity profiles provide a means of examining biodiversity across a continuum of diversity measures and indices, with the far left of the profile (scale 0) showing species richness, and, with increasing values of q, the effective number of species becoming increasingly dominated by common species. Parallel profiles have equivalent evenness; a diversity profile that remains above another across the whole profile is more diverse; diversity profiles that cross one another cannot be ranked in terms of diversity, but one can draw conclusions as to whether richness or evenness are higher for one compared with another.

For 2024, diversity profiles are presented in Figures 2 and 3 for the ten remeasured sites, both for transect-based data and for plot-based data, respectively. From the figures, we see that, in both cases, most of the sites do not show notable change between the diversity profiles for the two years of measurement; however, transect data in B04 and in B26 do show notable differences between the years. In the case of B04, the authors suspect the cause is likely related to a small shift in the physical location of the transect between the years, and that the change is thus an artefact, not a “real” change; this is supported by the associated diversity profile from plot-based information (Figure 3), which shows that B04’s profiles are very similar between years. In the case of B26, two additional transects were added to this low cover plot, thus 2024 captured species presence while 2021 data had no species recorded on transects.

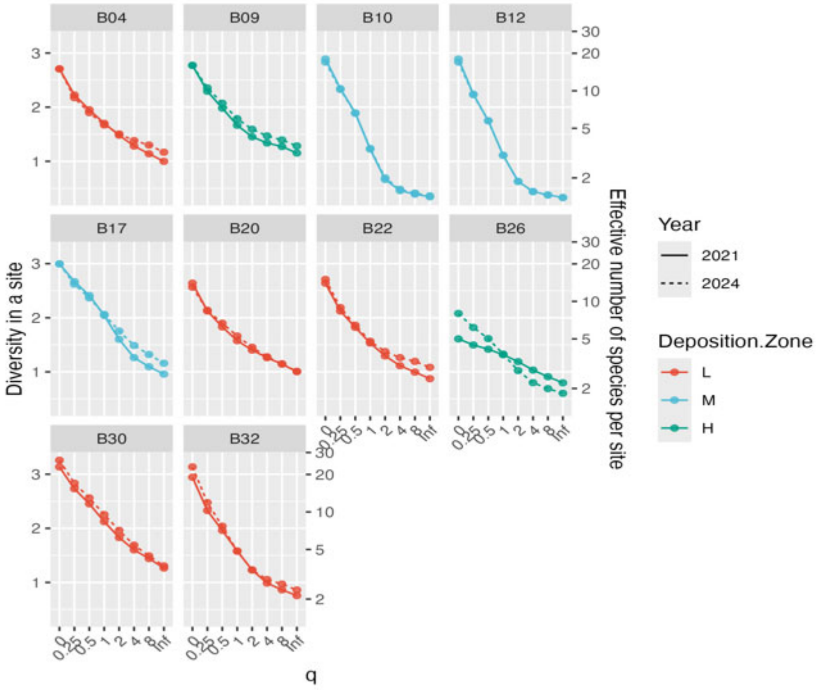

Figure 2: Diversity profiles based on [unpooled] transect data for 2021 and 2024 (note that Deposition Zone colour-coding differs from standard coding in this report).

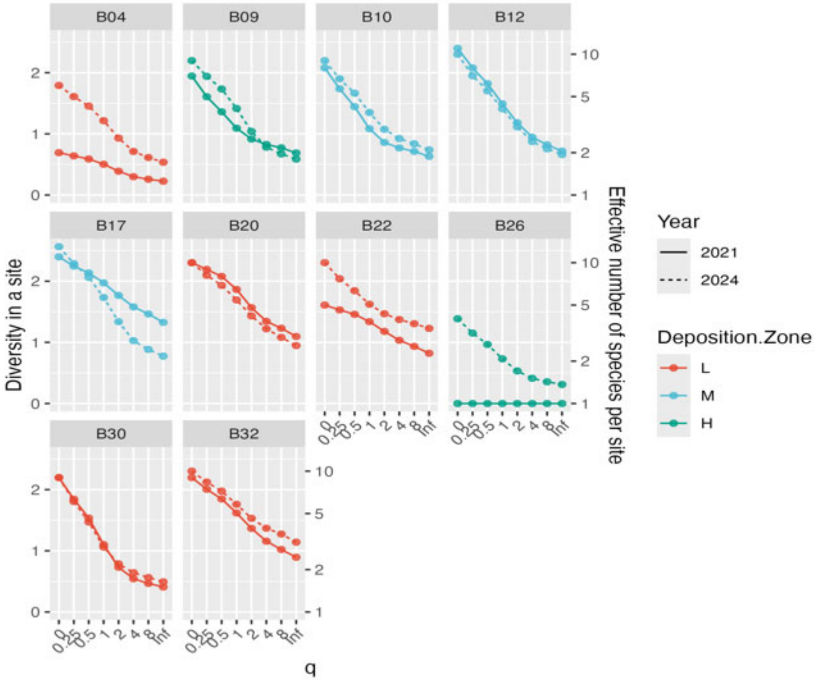

Figure 3: Diversity profiles from [unpooled] plot-based data for 2021 and 2024 (note that Deposition Zone colour-coding differs from standard coding in this report).

Trends for acid-sensitive and culturally important species

2024 represents the first year when trend analyses based on the calculation of slope (above) in relation to Deposition Zone are possible for the ten sites originally assessed in 2021 and remeasured in 2024. Species included in this subsection are those deemed acid-sensitive and/or culturally important in the Modified Table 1 of Appendix D in the B.C. Works' Sulphur Dioxide Environmental Effects Monitoring Program – Phase III Plan for 2019 to 2025 (ESSA Technologies et al. 2023).

Figures 8 and 9 (Appendix A) show trend information for species based on transects and plots, respectively. Figure 9 also shows trend information for both the compiled low shrub (B2) and herbaceous (C) layers. For individual species, only those species with a minimum coverage (0.01%) across remeasurement years were included, as below this level the data cannot be meaningfully plotted. The figures present change in percent cover (on the logit scale) over time by Deposition Zone. Individual lines show the pair of repeated measures at each of the ten sites remeasured between 2021 and 2024, while thick lines show average change by Deposition Zone for these sites (where [a] thick line[s] lie[s] at the bottom of the scale in Figures 8 and 9, it indicates that the species had zero cover in 2021/2024). Note that points are jittered to prevent overplotting, and that data from 2022 and 2023 (as well as data from the first measurement at site B36 in 2024) are included to provide a sense of the variability in a species or group, but do not contribute to the trend lines presented.

A test of the hypothesis of "no common trend" (*i.e.*, species have no common directional trend across all deposition classes) and "no differential trend" across deposition classes is found in Tables 9 and 10 of Appendix A (transect information and plot information, respectively). There is no evidence of change over time, nor of a differential trend by deposition class. Sample sizes are small, because we are so early in the Program.

Finally, estimated slopes for the trend lines by both deposition class and species are presented in table form (Tables 11 and 12, Appendix A) and in figure form (Figures 4 and 5), below, for transect- and plot- based information, respectively. Because of the small number of plots with remeasurements and only a single remeasurement, estimates of the slopes have large Standard Error (SE) and it is difficult to distinguish among them (see Tables 11 and 12, Appendix A, for SE values).

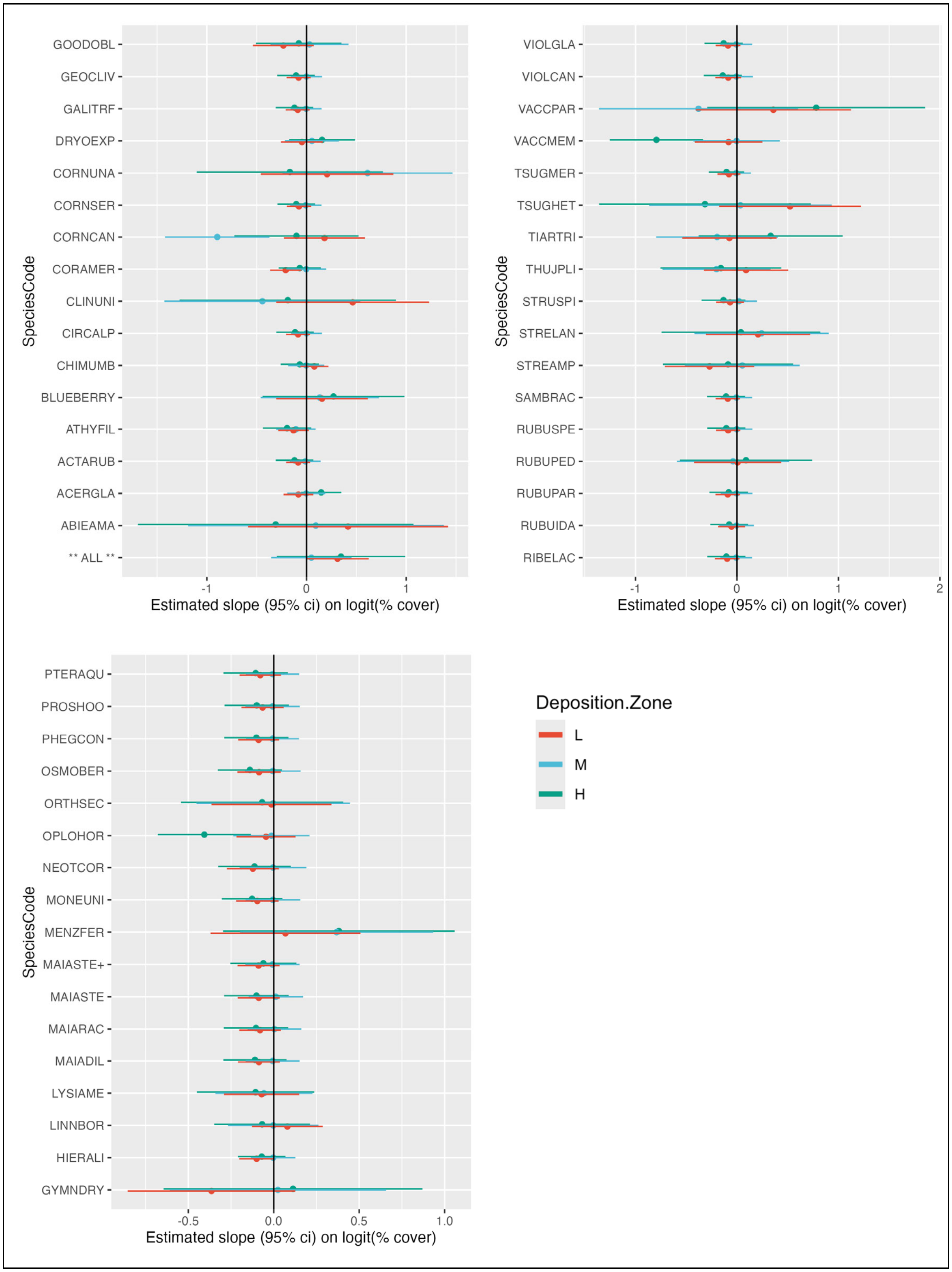

Figure 4: Estimated slopes (SE) of trend line by deposition class and species using transect-based data (note that Deposition Zone colour-coding differs from standard coding in this report).

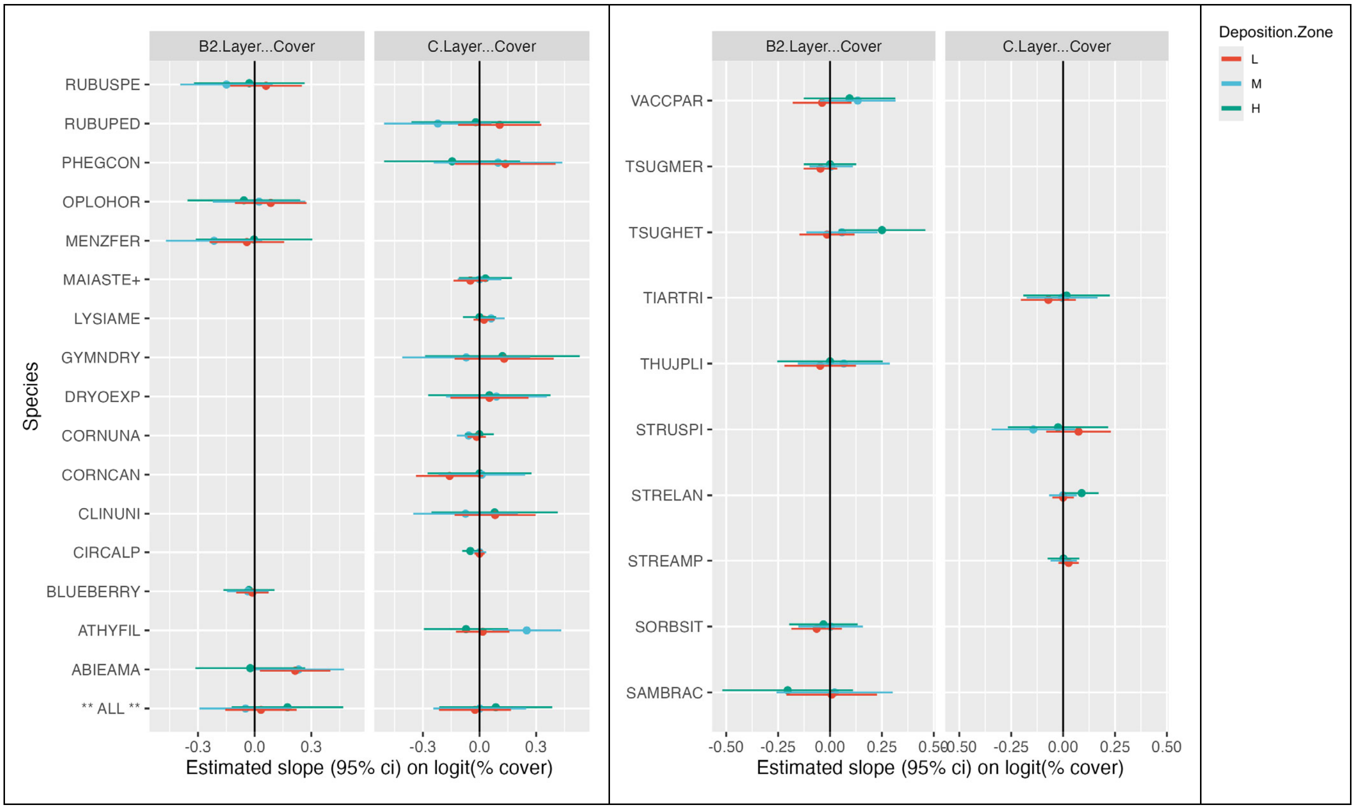

Figure 5: Estimated slopes (SE) of trend line by deposition class and species using plot-based data (note that Deposition Zone colour-coding differs from standard coding in this report).

Cyanolichen biodiversity measurements

Species richness

Cyanolichens only contribute to species richness data if they occur on standing, live or dead conifer hosts, but do not contribute to this metric if they occur on deciduous hosts, as the bark of the deciduous hosts has acid-buffering capacity (per direction from Patrick Williston (pers. comm. March 17th 2021), and methodology of Williston and Perkins (2019), which informed the PCMP cyanolichen monitoring). If cyanolichen species were observed on a deciduous host, they were noted in the comments, but are not recorded with the other data. The same is true (per the Field Manual for this program: Coosemans and Laurence 2022) for cyanolichens occurring loosely fallen from the canopy or on downed wood in the search area, including fallen branches.

For the purpose of cyanolichen biodiversity measurements, "cyanolichen plot" refers to the standard PCMP plot (20x20m) *plus the adjacent area included during the one-hour timed search* at each location, unless otherwise specified.

A total of 15 unique cyanolichen species (richness) were observed growing on standing conifer stems across all cyanolichen plots in 2024 (Table 3). No cyanolichen species were recorded at two of the eleven cyanolichen plots undertaken in 2024 (B09 & B26, both located in the High Deposition Zone).

Table 3: Cyanolichen species recorded in 2024 PCMP cyanolichen plots, by Deposition Zone.

Species Latin name	**Provincial Listing**	**Species Code**	**Low Deposition Plots**	**Medium Deposition Plots**	**High Deposition Plots**
*Leptogium cyanescens**	Red	LEPTCYA	(0)	(0)	B36
L. linita	Yellow	LOBALIN	B04, B22, B30	(0)	B36
L. oregana	Yellow	LOBAORE	B04, B20, B30	(0)	B36
L. pulmonaria	Yellow	LOBAPUL	B20, B22	(0)	(0)
Melanohalea elegantula	Yellow	MELAELA	(0)	B17	B36
Nephroma bellum	Yellow	NEPHBEL	B04, B20, B30	(0)	B36
N. helveticum ssp. *sipeanum*	Yellow	NEPHHEL2	B04, B20, B22, B30	B12	B36
N. occultum	Blue	NEPHOCC	B22	(0)	(0)
N. parile	Yellow	NEPHPAR	B20, B22, B30	(0)	B36
N. resupinatum	Yellow	NEPHRES	B22	(0)	(0)
Peltigera britannica	Yellow	PELTBRI	B32	(0)	(0)
Pseudocyphellaria anomala	Yellow	PSEUANO	B20, B22	(0)	B36
Sticta fuliginosa	Yellow	STICFUL	B20, B30	(0)	(0)

*voucher specimen yet to be confirmed for this potential new species.

During the 2024 sampling event, two species (the red-listed *Leptogium cyanescens* (species voucher not yet confirmed), and yellow-listed *Nephroma bellum*) were unique to site B36, which is classified as a High deposition site, near the boundary with the Medium Deposition Zone. *Lobaria pulmonaria* and *Sticta fuliginosa* occurred only in two Low deposition sites, and *Nephroma occultum* (a blue-listed species), as well as *N. resupinatum* and *Peltigera britannica*, were found in a single Low deposition site this year. *Peltigera neopolydacylum* was found on log substrate or the ground at B04, B22, B12 and B17 (Low, Low, Medium and Medium deposition sites, respectively) and were therefore not counted; similarly, *L. oregana* and *L. pulmonaria* were found on a fallen dead tree-top at B20 (a Low deposition site) and were not counted.

Species tallies and relative abundance ratings (within plot boundaries)

Species tallies and associated relative abundance rating categories (based on the number of individuals or colonies detected per plot) are compared in Table 4 for species that occurred *inside plot boundaries*, between measurement years at each of the ten sites that was assessed for a second time this year. This includes ten species over a total of just seven sites, as three sites (B09, B17 and B26; in High, Medium and High Deposition Zones, respectively) had zero cyanolichen occurrences inside plot boundaries in both 2021 and 2024.

Table 4: Comparison of cyanolichen tallies and abundance ratings inside plots between 2021 and 2024, by species.

Site	Species Code	Tally Inside Plot (individuals or colonies)			Abundance Rating Inside Plot		
		2021	2024	Change?	2021	2024	Change?
B04	LOBALIN	>15	10	Decrease	3	3	No
B12	LOBALIN	2	0	Decrease	1	0	Decrease
B22	LOBALIN	3	0	Decrease	2	0	Decrease
B30	LOBALIN	>15	30	No	3	3	No
B04	LOBAORE	1	20	Increase	1	3	Increase
B10	LOBAORE	4	0	Decrease	2	0	Decrease
B12	LOBAORE	1	0	Decrease	1	0	Decrease
B20	LOBAORE	4	5	Increase	2	2	No
B30	LOBAORE	>15	10	Decrease	3	3	No
B22	LOBAPUL	0	2	Increase	0	1	Increase
B04	NEPHBEL	10	5	Decrease	2	2	No
B10	NEPHBEL	8	0	Decrease	1	0	Decrease
B30	NEPHBEL	>15	1	Decrease	3	1	Decrease
B04	NEPHHEL2	>15	5	Decrease	3	2	Decrease
B10	NEPHHEL2	4	0	Decrease	1	0	Decrease
B30	NEPHHEL2	>15	1	Decrease	3	1	Decrease
B30	NEPHPAR	0	2	Increase	0	1	Increase
B20	NEPHRES	1	0	Decrease	1	0	Decrease
B32	PELTBRI	1	1	No	1	1	No
B04	PSEUANO	1	0	Decrease	1	0	Decrease
B04	STICFUL	1	0	Decrease	1	0	Decrease
B30	STICFUL	0	2	Increase	0	1	Increase

Slopes cannot be calculated for cyanolichen species abundance using the current metrics of tallies and relative abundance classes. Additional information collected on a trial basis beginning in 2024 may allow more refined future analyses. We note in Table 4 a decrease in four species in two Medium deposition sites, and species/sites with increases, decreases and no change in the Low deposition category. With the limited amount of data available for 2024, no clear pattern has emerged.

Change over time

This (2024) is the fourth year of the PCMP and associated cyanolichen assessment; however, similar assessments were undertaken by Patrick Williston in 2016/2017 (Williston and Perkins 2019; Williston 2020), and repeated in 2020 (Williston 2020) at or near 27 of the cyanolichen plots undertaken during the PCMP assessments. Although not strictly comparable as methods/locations were not precisely the same, the data are, nonetheless, an informative part of the baseline for each site. Table 5 shows comparative cyanolichen species richness measured at Williston's plots and those undertaken as part of the PCMP in 2021 and 2024: The reader will note that, for 2024, all but one site (B36) had previous data from both Williston and PCMP 2021. The reader will note that the sites appear relatively stable—though individual assessments may be variable from one to the other—over the entire assessment period.

Table 5: Cyanolichen richness recorded at assessed sites 2016/17, 2020, and 2023.

Site	Cyanolichen richness 2016/17*	Cyanolichen richness 2020*	Cyanolichen richness 2021 PCMP	Cyanolichen richness 2024 PCMP
B04	6	7	6	4***
B09	0	0	0	0
B10	4	4	5	5
B12**	2	2	4	1***
B17	0	0	0	1***
B20	10	6	10	7***
B22	5	2	2	7***
B26	0	0	0	0
B30	6	10	4	6
B32	2	2	0	1
B36	N/a	N/a	N/a	8

*from Williston (2020); **B12 was moved from the original ENV plot to another area in the same stand; ***additional cyanolichen species on non-countable substrates were, however, observed at sites B04, B12 & B20 in 2024 (see description in Species Richness subsection, above).

Plant and Cyanolichen health assessment

Plant and cyanolichen health information was recorded at each plot assessed in 2024. Plants at the PCMP sites are assessed for symptoms of insect infestation, plant disease, and abiotic factors such as drought, frost, mechanical injury, and air pollutants.

The timing of our 2024 PCMP vegetation health assessments occurred June 28th - July 5th. The study area experienced relatively normal—but slightly (0.1-0.3 °C) lower—daily average temperatures in the growing season months (April – June) leading up to the PCMP assessment period. Temperatures remained close to seasonal norms throughout 2024, but were 1.0 – 1.9 °C elevated for the remainder of the growing season (July-September) (Figure 6). While temperatures were very close to normal during the growing season leading up to and including the assessments, precipitation levels were in a significant deficit: 2023 ended with a deficit of 157mm (~12%) compared with its normal total precipitation, and the deficit in the first six months of 2024 leading into the PCMP assessment period was an additional 264mm. This deficit has continued to increase throughout 2024, with the notable exception of September, which was the only month in 2024 that was wetter than normal (by 24.6mm) (Figure 7). (Government of Canada 2024a & 2024b: Terrace Airport weather station data for 2024 and historical averages, respectively).

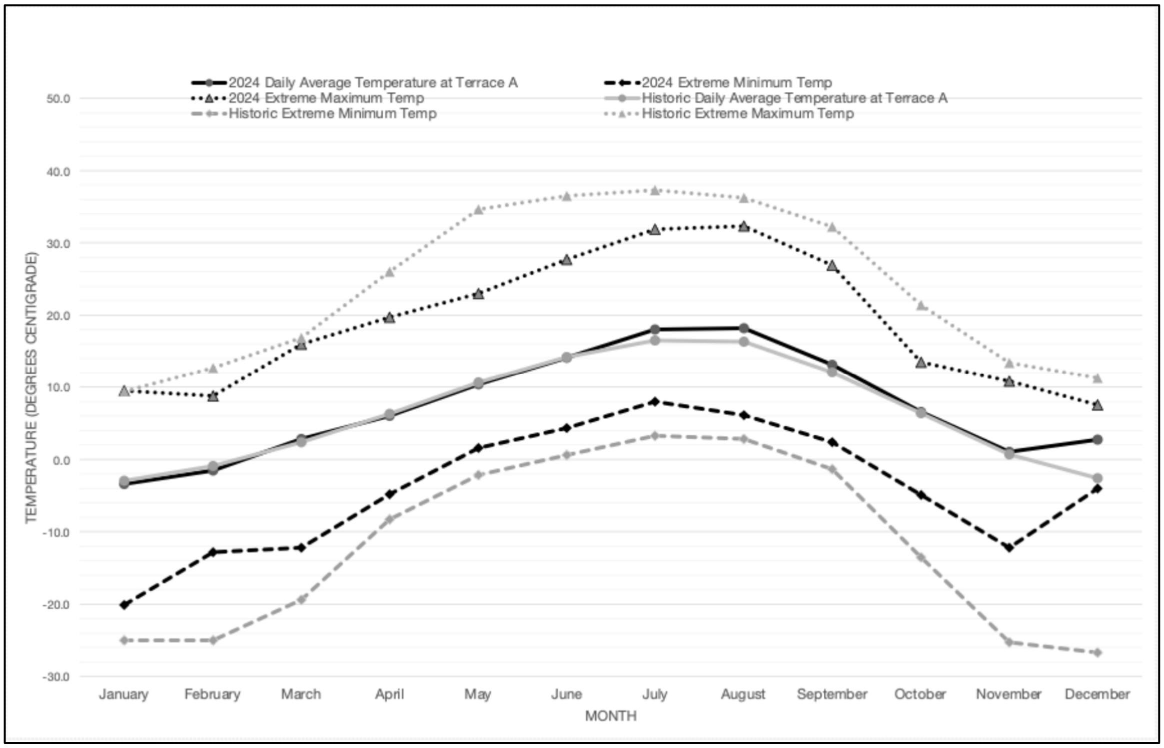

Figure 6: 2024 and Historical daily average, extreme minimum and extreme maximum temperatures (note that December data for 2024 is incomplete, ending on Dec. 8, and does not therefore reflect the final values for the month).

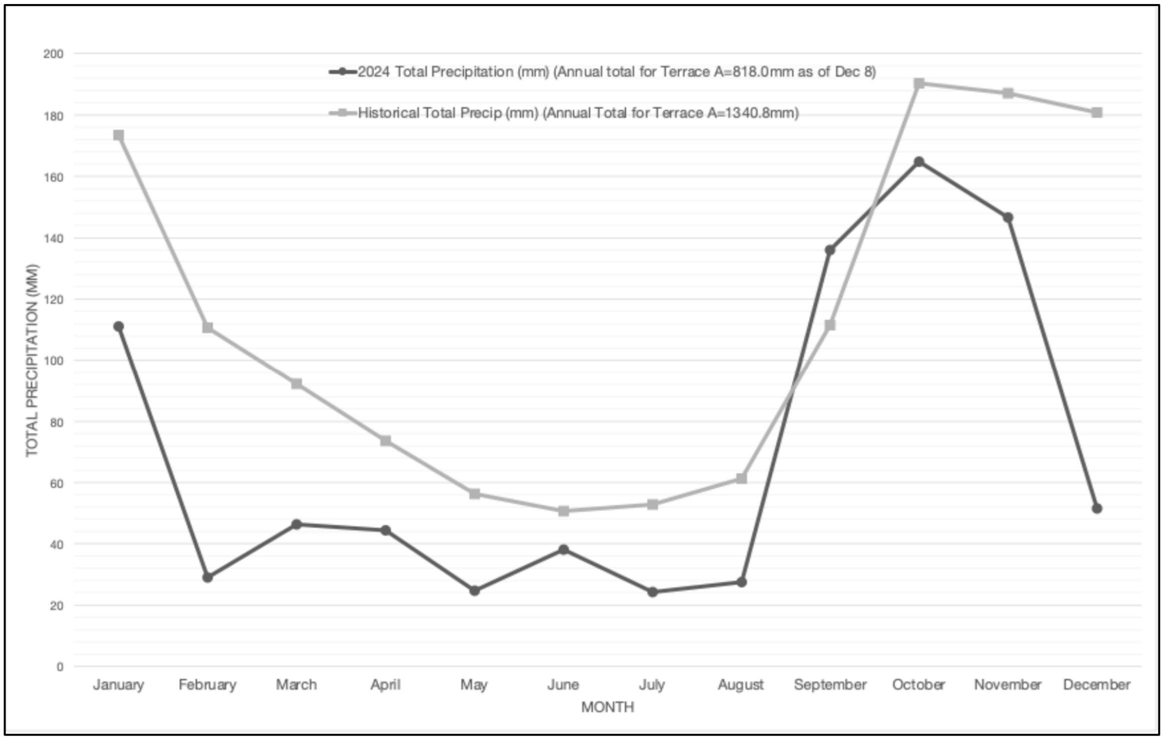

Figure 7: 2024 and Historical monthly precipitation (note that December data for 2024 is incomplete, ending on Dec. 8, and does not therefore reflect the total 2024 precipitation for the month).

Plant health data collected at and near plots are summarized in Table 6, below.

Table 6: Plant health assessment for each plot undertaken in 2024.

Plot	Visual health inspection (overall)	General vegetation health site conditions or other comments*	Additional Health Form?
B04AC24	Green healthy	No unusual symptoms. Several MENZFER have died since last visit: presumed cause is repeated insect feeding (leaf miner), based on low vigour noted previously, though frost may have been another blow to these plants.	Y
B09AC24	Green healthy	No unusual symptoms. Minor insect/fungal damage on most species. Possible frost damage from previous year(s) significant, particularly on OPLOHOR: dead stems/tops noted.	Y
B10AC24	Green healthy	No unusual symptoms; some apparent frost damage from previous year(s) on OPLOHOR & RUBUSPE: dead stems/tops noted.	Y
B12AC24	Green healthy (physical damage)	No unusual symptoms, but with some small tree-fall inside plot and significant frost (?) damage/death on blueberry & other shrubs.	Y
B17AC24	Green healthy	No unusual symptoms. Variety of insect (& trace fungal) damage on most species, but minor. Possible frost damage/kill of OPLOHOR tops.	Y
B20AC24	Green healthy	No unusual symptoms; some apparent frost damage from previous year(s) on most mature shrubs. Apparent frost (?) damage/death on ABIEAMA, TSUGHET & MENZFER.	Y
B22AC24	Green healthy	No unusual symptoms; some apparent frost damage from previous year(s) on most mature shrubs.	Y
B26AC24	Green healthy	No unusual symptoms: Bare plot with some leaf-miner causing necrosis on MENZFER and insect feeding on most spp. Lack of light is the major factor on veg health at this site.	Y
B30AC24	Green healthy	No unusual symptoms; some apparent frost damage from previous year(s) on shrubs (esp. OPLOHOR): dead stems/tops.	Y
B32AC24	Green healthy (physical damage)	Generally healthy and mature veg (no unusual symptoms), but most shrubs have suffered significant recent years' frost (?) damage & have die-back.	Y
B36AC24	Green healthy	No unusual symptoms; some frost(?)-killed OPLOHOR and RUBUSPE; minor insect feeding on most species.	Y

*see Province of BC (2020) or tabs “USysAllSpec” and “BC_Flora_2020_Spp_Subtaxa” on attached Excel spreadsheet for plant species codes.

As shown in Table 6, an additional full Vegetation Health Data form was populated for all sites visited in 2024. All vegetation health details are presented in Attachment 1.

With respect to cyanolichen health, assessors examine specimens noting whether they appear Normal, Stressed or Injured in terms of growth (relative to typical for the region), changes in morphology, colour (e.g., signs of bleaching), or presence of necrotic tissue. In 2024, only one lichen species at one site was identified as stressed: *Peltigera brittanica* at B32 (a Low deposition site) appeared in poor health, dry and of low vigour. At two sites (B10 and B22; Medium & Low deposition sites, respectively), it was noted that lichens were dry but otherwise healthy. Full cyanolichen health information for 2024 is presented in Attachment 1.

Biotic factors

Biotic factors were responsible for plant health issues at all sites assessed during the 2024 PCMP program, including fungal damage, and feeding damage from both mammals and insects. Nonetheless, both fungal and insect damage were minor in severity.

Fungal pathogens such as leaf spot were nearly absent across sites and, where they occurred, were of a very minor nature in 2024; this is in line with expectations, considering the dryness of the growing season period leading up to the assessment (Figure 7).

Across the region in 2024, insect feeding symptoms were generally minor and there was nothing that appeared notable at any of the sites examined. For this reason, the "Insect Infestation" category for the overall Visual Health Inspection (Column 2 in Table 6) was not used in 2024, as the plots in these cases still appeared generally healthy (vigorous and bright green).

Biotic factors could not always be distinguished from environmental ("abiotic") factors for occasional discolouration, chlorosis, or necrosis noted in various shrub and herb species, nor for the cause of the one "stressed" cyanolichen species noted above.

Abiotic factors including natural or human disturbance

During 2024 assessments, we noted a significant impact on low shrubs from what appears to have been a late frost event—an appraisal supported by the author's earlier field observations of significant frost damage to shrubs and saplings across the valley and the region in early April, 2024. In two sites (B12 and B32), frost damage was considered significant enough to warrant a bracketed "Physical Damage" notation in the overall Visual Health Inspection field (Column 2 in Table 6). In addition to those occurrences where frost damage is noted as the probable cause, some of the damage to herbaceous species could not be determined and may also be attributable to frost. As noted in the preceding subsection, we were not always able to distinguish between abiotic and biotic factors affecting the appearance and vigour of some species.

While we did make observations of dry cyanolichens at several sites during our 2024 assessments, these observations were not noted to be causing significant stress, and the cyanolichens were deemed "Normal" in terms of growth (relative to typical for the region), changes in morphology, colour (e.g., signs of bleaching), or presence of necrotic tissue. As described in the previous subsections, a single observation was made of a cyanolichen deemed to be "Stressed" (*Peltigera brittanica* at plot B32 in the Low Deposition Zone): it was noted that the lichen was in poor health, dry and of low vigour. Necrotic tissue or bleaching—more typical indicators of injury—were not reported. While its poor vigour may be related to extended dry conditions, the cause of the stress could not be determined with confidence.

With regard to injury due to air pollution, no symptoms of visible injury due to either gaseous fluoride ($F_{(g)}$) or sulphur dioxide (SO_2) appeared on plants (or cyanolichens) observed at the 2024 PCMP vegetation health assessment sites. Symptoms of injury occur as a *repeated pattern* that holds at a given site, the pattern being maintained on individual plants and across individuals of a species irrespective of growing conditions or other site factors.

Symptoms specific to $F_{(g)}$ may include chlorosis, anthocyanosis, and necrosis, most commonly at the margins of broadleaf plants or "tipburn" on conifers. There may also be deformation of leaves (e.g., leaf tip necrosis resulting in notched tips and resulting "cupping" due to altered leaf expansion). Lodgepole pine, mugo pine, and willows are species found locally that are sensitive to $F_{(g)}$ and have shown injury pre-KMP. We also note western redcedar's conical growth form as this shape seems to be related to proximity to the smelter, though the exact cause of the altered form is unknown.

Symptoms of injury specific to SO_2 include interveinal bleaching and/or necrosis (if acute), or chlorosis. On conifers, needles may have chlorotic spots, bands, or brown tips. Among our local species, lodgepole pine is known to be sensitive to SO_2, as are violets, plantain, aspen, apple, and many pea family species, such as clover. Injury caused by SO_2 has not been observed in recent memory (at least 20 years; Dr. John Laurence, pers. comm. 2024).

Patterns observed

No patterns were observed in the 2024 dataset, nor in previous years of the Program. There did not appear to be substantial differences in the degree of insect feeding or the incidence and severity of plant diseases related to the location of the sites with respect to Rio Tinto BC Works or Deposition Zone.

Levels of insect activity, fungal pathogens, and frost impacts across sites were similar to those observed by the author throughout the region in 2024. A single observation of stressed cyanolichens occurred in a Medium Deposition Zone plot, and cyanolichens showed no health or injury patterns across the sites of the PCMP for 2024 or in previous years.

Soil [and IER] analysis

Soil sampling was completed for all established sites possible in 2022, including those sampled initially in 2021 and the alternate site that was converted to the regular Program this year (B36).

The "one-time" approach was identified in the 2021 annual report as a means of garnering the greatest consistency in analysis, while satisfying the intent of the Plan (Laurence *et al*. 2020); the 2022 soil sampling and analysis so far includes all 36 (including Kemano) active sites in the Program. The Program's requirements for soil sampling have thus been fulfilled to the degree possible, for all established sites, and no further sampling is scheduled to occur unless a new, previously unsampled site is added to the Program.

As described in the Plan (Laurence *et al*. 2020), "[t]he purpose of sampling is to assess the sensitivity of the soils to acidification, not to measure and detect differential changes in soil chemistry over time."

Similarly, in accordance with the Plan (Laurence *et al*. 2020), Ion Exchange Resin (IER) columns have not been deployed at any of the PCMP sites in any year. Use of IER columns would be triggered if necessary to establish causality if biologically significant differential changes in vascular plant or cyanolichen communities are detected between low and high S deposition sites: In that case, they will be planted vertically in the soil to measure SO_4^{2-}, base cations, and aluminum. Additionally, if triggered as described, above-ground IER columns "may be used at selected locations to quantify actual S deposition depending on the risk of soil acidification. These measurements will help characterize that risk."

RT BC Works Data

Rio Tinto's BC Works data are not yet available for the entire year. Available information has been provided in the subsections, below.

SO_2 emissions

Sulphur dioxide emissions for 2024 are shown in Table 7, along with aluminum production. On average, 26.4 kg of SO_2 were emitted for every thousand kilograms (i.e., Megagrams (Mg)) of aluminum produced (ranging from 22.33 kg/Mg in November to 28.17 kg/Mg in March). SO_2 emissions were relatively stable throughout 2024, ranging from 24.9 Mg/day in November to as high as 33.3 Mg/day in March, and averaging 30.3 Mg/Day for the first eleven months of 2024 for which data are available.

Metal production

Aluminum production for 2024 is provided in Table 7, along with sulphur dioxide emissions. Total aluminum production was relatively stable in 2024, ranging from 33,453 Mg produced in November to 36,645 Mg in March; the total production of aluminum for the year-to-date (excluding December) was 384,771 Mg.

Table 7: Average monthly sulphur dioxide emissions and aluminum production in 2024

2024	Plant $S0_2$ Emissions (average Mg/day)	Plant $S0_2$ Emissions (kg/Mg Aluminum)	Aluminum Production (Mg)
January	30.4	25.89	36,400
February	32.5	27.72	34,001
March	33.3	28.17	36,645
April	29.7	24.98	35,669
May	30.8	26.20	36,443
June	33.0	28.12	35,206
July	31.1	27.33	35,276
August	27.7	25.07	34,252
September	30.8	27.76	33,285
October	29.3	26.84	33,841
November	24.9	22.33	33,453
December	NYA	NYA	NYA
Average Annual Emissions and Total Production*:	**30.3**	**26.4**	**384,771**

*excluding December

3-Year annual average ambient SO_2 concentration

Monitored and modelled concentrations for 2024 and the 3-year average, are provided in Table 8. Data are not yet available (NYA) as of the writing of this report.

Table 8: Annual (2024) and 3-Year average ambient SO_2 monitored and modelled concentrations.

Site	Monitored concentration (ppb)	Modelled Concentration (ppb)	Monitored concentration (ppb)	Modelled Concentration (ppb)
	2024		3 year average	
Haul Road	NYA	NYA	NYA	NYA
Kitamaat Village	NYA	NYA	NYA	NYA
Riverlodge	NYA	NYA	NYA	NYA
Whitesail	NYA	NYA	NYA	NYA

3-Year annual wet and dry deposition

Data are not yet available.

Discussion and Interpretation

Logistics

The field team did not experience any notable logistical problems during 2024.

The two methods of abundance data collection—plot-based and transect-based—for the low shrubs and herbs provide different levels of accuracy and precision, but both contribute to a more complete view of plant community complexity and sensitivity to change over time. As expected, practical difficulties in the collection of highly accurate abundance data within the 400m^2 plots results in a predictable level of variation, or "noise" in the data; this is especially true of sites with high species diversity and/or cover, and in species with high cover. Noise is minimized through consistency in team members, and comparing estimates among team members during cover assessments where there is greater uncertainty; uncertainty is expected to be greater during the first year of data collection than in subsequent assessments, when crews may have greater site familiarity. In contrast, the line-intercept data are expected to more precisely document changes in species cover over time—but they cover a far smaller total area, and thus provide narrower picture of a site's plant community over time. As, however, transect lines themselves are not physically fixed in place (other than corner posts) and must be re-hung for each measurement, we also note that some degree of year-to-year variation is inevitably introduced through this factor.

As noted in previous reports, sites that have the required attributes for this Program are uncommon in the study area (i.e., safe, practical, legal and long-term access; no history of industrial logging; whenever possible, the presence of at least one tree >100 years in age; sufficient and practical—that is, not overly fragile—vegetation layers available for monitoring). Unfortunately, because of pre-existing circumstances and the overall rarity of old growth in the valley, several of the sites do have some history of disturbance (primarily the severe, stand-initiating hemlock/saddleback looper disturbances that were widespread in the Kitimat area in 1960-61, causing extensive mortality, and again, but less severely, in 1969): Though none of these sites have obvious indications of industrial logging, as stands they continue to be maturing, and have not yet achieved the structure of an old forest. In such stands, we frequently see limited forest floor vegetation until light levels increase and there has been sufficient time for vegetation to re-establish. We therefore expect the site-level vegetation to mature and generally increase as these stands open up, though any species-specific patterns associated with deposition are still expected to hold at these sites. From a logistical perspective, while we would prefer to have uniformly structurally-mature sites compose the Program, we have struggled to find sufficient such sites that also provide a distribution across the Study Area.

The distribution of sites in the modelled Deposition Zones currently sits at fifteen Low (including two reference sites at Kemano), ten Medium, and eleven High. Although the distribution is weighted to Low and reference sites, the reader is reminded that the Deposition Zones are a based on the modelled *42 tpd No Background* scenario, prepared using 2016-2017 monitoring data and may or may not represent actual deposition in subsequent years. The authors are aware that the Deposition Zones currently classified as Low (including Reference), Medium or High (based on the modelled 42 tpd scenario) could be reviewed in case of any future adjustments to the model, or through use of actual—in contrast to modelled—scenarios. Sites for the Program have thus been selected and established across the deposition continuum that radiates outwards from the Kitimat Works smelter, with an aim to ensuring that the Program and its analyses are robust under a variety of potential Deposition Zone scenarios.

Trends in vascular plant biodiversity

In 2024, with the first plot re-measurement at ten sites, it is now possible to examine potential trends in species richness (e.g., gain or loss of species) and abundance (e.g., increase or decrease in a species' abundance), through examination of slopes for abundance measures of species and species groups, and through mapping diversity profiles over time. When these are linked to Deposition Zone, we are able to examine whether there are significant trends in biodiversity related to deposition. As shown in the Results section of this report, no trends in vascular plant biodiversity are apparent, with no significant differences between Low, Medium or High Deposition Zones for all measured vascular species combined; for low shrub (B2-layer) species combined; herbaceous (C-layer) species combined; or for any species of shrub or herb individually examined (i.e., those acid-sensitive or culturally important species identified in the Modified Table 1 of the EEM PIII Plan (Appendix D in ESSA Technologies *et al*. 2023). Furthermore, there were no notable, unexplained differences in the biodiversity profiles of 2021 and 2024.

Related to emissions

Currently, no relationship between Deposition Zone and vascular plant biodiversity at the sites remeasured during 2024 was detected.

Unrelated to emissions

No relationship was detected between Deposition Zone and vascular plant biodiversity at the sites that were remeasured during 2024. This is the first year where remeasurements are available, so sample sizes are limited.

Trends in cyanolichen biodiversity

This year, 2024, is the first year that comparable trends in cyanolichen biodiversity can be generated. Previously, we were able to compare only with ENV's previous work at the sites (Williston and Perkins 2019; Williston 2020), which did not collect any abundance ratings, but did allow a coarse assessment of cyanolichen plot variability over time.

Our use of tallies of the number of colonies of each species within plot boundaries continued during the 2024 [re-]measurements. In 2024, we also introduced two additional measures of cyanolichen abundance—estimates of the area (in square centimeters) covered by lichen species, and estimates of total weight (in grams) of lichen species—in order to test their ability to broaden our analytical options and reduce some of the limitations inherent in the original method (*i.e.*, tallies).

Based on the tally and associated cyanolichen abundance class information collected at ten plots in 2021 and repeated in 2024, we note from Table 4 that tallies and abundance classes uniformly decreased at Medium deposition species-specific comparisons between 2021 and 2024, while species-specific comparisons included decreases, no change and increases for Low deposition sites. It is important to note that very few repeat records are available for individual species at specific sites, and the reasons for a "significant" decrease in lichen abundance naturally include the variability inherent in the annual assessments, as well as important stochastic changes such as the loss of colonies from the sample through host death/decay. The data do not [yet] lend themselves to meaningful statistical analysis. An examination of the results does not strongly suggest any differential trend in cyanolichen biodiversity between the zones, outside of continuing to demonstrate the legacy effect of historical fluoride deposition that severely impacted cyanolichen distribution (see Richards 1986 and Bunce 1978).

Related to emissions

The obvious differences observed in cyanolichen biodiversity between Deposition Zones are not unexpected, as much previous study in the valley has shown the effects of historic pollutants, which extirpated lichens close to the source of historical emissions (Richards 1986; Bunce 1978). In terms of its geographic spread, the deposition plume related to the modernized smelter emissions is expected to behave similarly as that of historical emissions; therefore, historic impacts will continue to show patterns that overlap with—but may well be different from—modern impacts. The design of the PCMP, with its within-site comparisons, will allow trends emerging from modernized smelter emissions to be teased apart from historical impacts, albeit with lower power in the High Deposition Zone owing to a generally reduced baseline.

One site, currently falling within the High Deposition Zone category, is at odds with the historic pattern: At site B36 (a new site added this year from the bank of alternate sites), a total of eight cyanolichen species were observed, which was the most for any site visited in 2024. At over 21 kilometers' distance from the smelter, this site is the farthest of the High Deposition Zone sites in the Program, and lies at the boundary of the Medium – High (i.e., 20 kg/ha/year) isopleth (see Figure 1).

Of the ten sites that were re-assessed for the first time in 2024, no clear species-specific trends or changes in cyanolichen biodiversity were observed.

Unrelated to emissions

Annual variability in cyanolichen species richness (Table 5) emphasizes the stochastic nature of cyanolichen searches, suggesting important changes such as tree death, tree decay, tree fall, and the impossibility of searching precisely all the same potential substrates each year. A site changes naturally from year to year, and with it potential cyanolichen substrate and searchability. In addition, the assessments are influenced by the assessor, and their previous experience (if any) with lichen searches at the site which will influence their "intuitive wander" while conducting the timed search. Variability between plots is thus, at least in part, a product of circumstances other than emissions.

Of the ten sites that were re-assessed for the first time in 2024, no clear species-specific trends or changes in cyanolichen biodiversity were observed.

Plant and cyanolichen health assessment

Overall, the health of plants and cyanolichens examined this year was good, as shown in Table 6.

Related to emissions

Currently, no relationship between Deposition Zone and plant or cyanolichen health was detected.

Unrelated to emissions

Little evidence of fungal pathogens was noted by the authors both in plots and in the region as a whole, presumably owing to the dry conditions. Similarly, feeding damage from insects and mammals was minimal during 2024, though some damage was observed in individuals in all plots, and, as such, all eleven sites assessed for vegetation health showed evidence of biotic stresses on plant health (Table 6).

While overall health of the sites examined this year was good, dry (but not "Stressed") cyanolichens were noted at several sites, as may be expected in relation to the persistent dry conditions experienced in the region. A designation of "Stressed," however, was given for just one cyanolichen species (*Peltigera britannica*) at a single site, B32, located in the Low Deposition Zone. While it is uncertain whether the low vigour observed was fully or only partially attributable to the dry conditions, there was no indication that it was related to emissions. While the drought conditions for 2024 were significant, the timing of the PCMP relatively early in the season allowed plants to benefit from snow-melt and subsequent [partial] recharge of groundwater, and thus stress was not apparent at the time of assessment. As an additional factor, seasonal temperatures that were typical, rather than elevated, mitigated the consequences of the dry conditions during Program activities in 2024.

The major health factor of note in 2024 was the substantial amount of damage and death caused to shrubs from a [presumed] late frost throughout the study area. It appears that shrubs—and possibly also herbaceous species—had left their dormant winter state when they experienced a damaging frost event, and that this affected species throughout the valley, both in exposed areas and under mature forest canopy.

Soil analysis and risk of acidification

No soil samples were collected in 2024, with all active sites in the Program having been sampled in 2022.

It is not yet relevant to consider risk of acidification owing to increased SO_2 emissions from Rio Tinto Kitimat smelter's modernization.

Conclusions and Recommendations

Overall, this fourth year—and first re-measurement year—of PCMP plot assessments went smoothly and according to plan. With the addition this year of one site (such that eleven sites were fully assessed, ten of which were re-measured), there is now a total complement of 34 regular, active sites that constitute the Program, as well as an additional two reference sites in the Kemano valley, for a combined total of 36 sites that have been assessed at least once.

As noted in previous years, the authors emphasise the importance of undertaking the plots at a similar time each year, and, as much as possible, without interruption: This ensures both comparability from year to year and plot to plot, as well as ensures greater consistency and flow in the field team's work. Notwithstanding this important consideration, however, for 2024 the field timing was scheduled towards the latter part of the Program's timing period, as per the recommendations from previous years. This latter period allows greater certainty that the Program captures later-emerging species, without compromising the benefits of the Program's early-season assessment period. Timing for 2024 (June 28th – July 5th) was effective, and generally aligned with previous years, though was later than Year 1, when the ten plots were first measured (June 14th – July 2nd, 2021). Generally, vegetation was found to be fully developed (or near to it), and not yet fading, and we continue to recommend that, in future years, crews endeavor to conduct field assessments as much as possible during the latter part of the Program's timing period in best efforts to capture later-emerging species without compromising the benefits of the Program's early-season assessment period (e.g., lower likelihood of impact on species richness and abundance from extreme weather/climatic events, insect damage, etc.).

As discussed here and in the previous annual reports, combining of some species is sometimes required owing to difficulties in reliably distinguishing highly similar morphologies. *While we recommend that, wherever possible, species other than blueberry continue to be recorded separately*, we also note that there may be considerable value in pooling some species groups when future end-of-cycle reporting is completed: This may be particularly useful when ecologically similar species may occupy different biogeoclimatic zones (e.g., bunchberry or lily species) and thus would otherwise appear to correlate with Deposition Zones (which extend from the more maritime area near the smelter site to more interior as one moves northward, up the valley).

Finally, in the first end-of-cycle report recommendations (Coosemans, Grossman and Schwarz 2024), two broad concerns relating to data analysis emerged: 1) plots and transects with low percent covers provide limited interest as their ability to show change is severely limited and unidirectional; and 2) cyanolichen abundance measures were inadequate to make statistical inferences. To answer the first concern, in 2024 we introduced additional transects for sites that have low cover, in an effort to increase the power to detect change at these sites. This change did result in greater amount of data, and we recommend continuing with this strategy. Another recommendation made at that time was to examine the possibility of assessing low-cover sites less frequently, and substituting other sites into the Program, which would increase the power to detect change: We recommend that this possibility be investigated as an option for the Program in future years. To answer the second concern, in 2024 we trialed two additional metrics of cyanolichen abundance: We provided an estimate of both area (square centimeters) and mass (grams) of each cyanolichen species that was observed on suitable substrate within site boundaries. Because this is the first year the metrics have been used, it is not possible to use these data to map trends at this stage; however, they do appear to present a satisfactory approach from both a logistical and analytical perspective, and we recommend continuing to add these metrics to the coming years of data collection before determining whether they should become a permanent addition to (or possible replacement for some of) the cyanolichen data collection.

Overall, the authors are satisfied with the data collected and the overall implementation of the first cycle of re-measurement in the Program.

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Additional Archived Materials

The complete Excel data set and VPro Access Database, as well as photos, are archived with Rio Tinto, BC Works (Kitimat).

Notes on Attachments

Attachment 1: 2024 PCMP data

The attached Excel workbook, “PCMP Annual Report_2024_Attachment 1_2024 PCMP Data.xlsx”, contains all 2024 PCMP data, organized into a set of tabs. In each tab, “keys” are highlighted in yellow.

Tab Name	Description
TabKey	List of Workbook names, information contained in each, notes, and column headings.
Site info_Fixed	Plot (site) information that is not expected to change substantially from year to year, including location information and relatively fixed environmental variables, as well as assigned deposition zone based on modelled 42-tpd No Background scenario. May be updated from time to time if new information is obtained (e.g. soil pit) or if time (or events such as disturbance or management intervention) is sufficient to change successional status, structural stage, etc.
Plot info_Changeable	Plot information that is expected to change during each assessment, such as sample event #, date, surveyors, canopy/layer closure/cover.
Transect Info	Each TRANSECT (typically North and East for each plot) location with start point, end point, length and surveyors.
Spp abundance_transect	TRANSECT-based abundance data, linking to transect ID & Direction, with line length for each species. IF no species on transect, there are no lines of data in this tab for that transect.
Spp abund_coding_plot	PLOT-based abundance data, separated by layer (B2 or C), including distribution, vigour and phenology coding for each species in plot.
Veg health	Vegetation health inspection for each plot, including overall health of vegetation (not cyanolichens) at plot, description of site condition at assessment, and whether there is an additional health form completed for plot.
AdditionalVegHealth	Detailed species-specific vegetation health assessment, including symptom/cause, area affected, etc. Optional additional form (not always completed at each plot assessment).
Cyanolichen Plot Data	Lichen Plot information collected during each assessment, including search time/location in/out of plot boundary, # cyanolichen species current/historical, and overall cyanolichen health in plot.
Cyanolichen_SppData	Species identified in plots with detailed data collected for each species, including abundance, conifer host(s), and health. If no cyanolichen species meeting criteria for inclusion, no lines for plot.
USysAllSpec	List of all species codes used in BC, including genera without species (for use with Unknowns), old code (if applicable), lifeform, climate/environment type information
BC_Flora_2020_Spp_Subtaxa	List of all known species and subspecies in BC, with codes (inc. tree codes), lifeform, and whether native (N) or exotic (E).
Lobaria Samples	Listing of all lichen samples collected for lab analysis.
Lobaria LabResult_summ	Summarized laboratory results (2022).
Soil Samples	Listing of all soil samples collected.
Soil LabResult_summ	Summarized laboratory results (2022).

Appendix A: Data Analysis

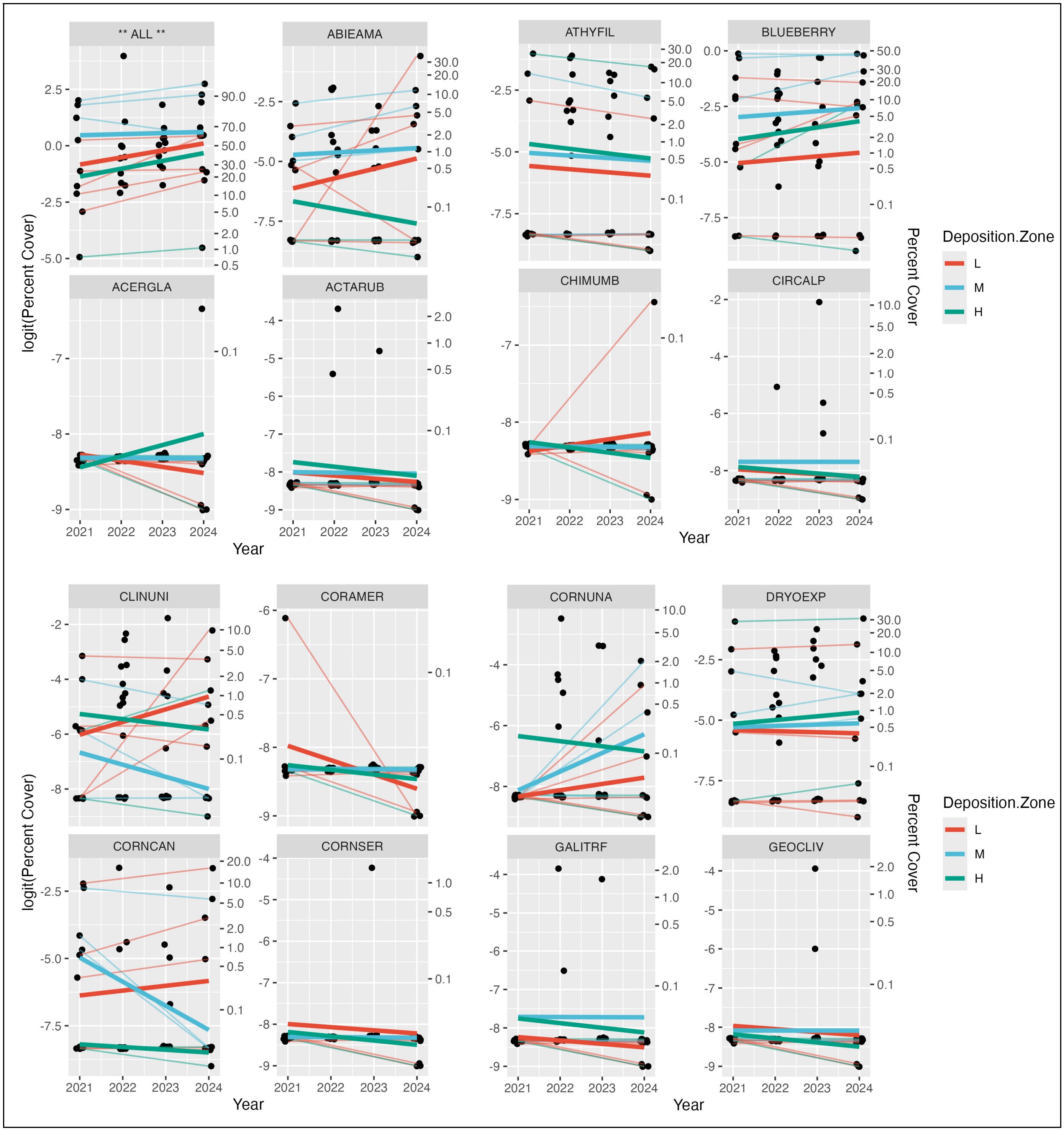
The following tables and figures provide a summary of data analysis not included directly in the body of this report.

Table 9: Hypothesis tests (ANOVA) for no common trend and no differential trend by deposition class for select species using transect-based data.

Species Code	No Common Trend	No Differential Trend	Species Code	No Common Trend	No Differential Trend	Species Code	No Common Trend	No Differential Trend
** ALL **	p = 0.075	p = 0.451	GYMNDRY	p = 0.640	p = 0.387	RIBELAC	p = 0.116	p = 0.541
ABIEAMA	p = 0.839	p = 0.648	HIERALI	p = 0.098	p = 0.450	RUBUIDA	p = 0.354	p = 0.806
ACERGLA	p = 0.667	p = 0.153	LINNBOR	p = 0.966	p = 0.639	RUBUPAR	p = 0.175	p = 0.585
ACTARUB	p = 0.101	p = 0.570	LYSIAME	p = 0.299	p = 0.966	RUBUPED	p = 0.893	p = 0.940
ATHYFIL	p = 0.021	p = 0.799	MAIADIL	p = 0.127	p = 0.567	RUBUSPE	p = 0.134	p = 0.534
BLUE-BERRY	p = 0.240	p = 0.934	MAIARAC	p = 0.168	p = 0.533	SAMBRAC	p = 0.120	p = 0.538
CHIMUMB	p = 0.960	p = 0.398	MAIASTE	p = 0.181	p = 0.472	STREAMP	p = 0.489	p = 0.594
CIRCALP	p = 0.126	p = 0.503	MAIASTE+	p = 0.231	p = 0.656	STRELAN	p = 0.349	p = 0.886
CLINUNI	p = 0.822	p = 0.259	MENZFER	p = 0.088	p = 0.535	STRUSPI	p = 0.210	p = 0.457
CORAMER	p = 0.071	p = 0.186	MONEUNI	p = 0.104	p = 0.495	THUJPLI	p = 0.501	p = 0.560
CORNCAN	p = 0.066	p = 0.014 **	NEOTCOR	p = 0.134	p = 0.555	TIARTRI	p = 0.893	p = 0.434
CORNSER	p = 0.157	p = 0.627	OPLOHOR	p = 0.026	p = 0.063	TSUGHET	p = 0.727	p = 0.330
CORNUNA	p = 0.336	p = 0.421	ORTHSEC	p = 0.805	p = 0.973	TSUGMER	p = 0.107	p = 0.560
DRYOEXP	p = 0.444	p = 0.490	OSMOBER	p = 0.107	p = 0.487	VACCMEM	p = 0.011	p = 0.017 **
GALITRF	p = 0.107	p = 0.495	PHEGCON	p = 0.130	p = 0.571	VACCPAR	p = 0.314	p = 0.216
GEOCLIV	p = 0.155	p = 0.563	PROSHOO	p = 0.192	p = 0.671	VIOLCAN	p = 0.109	p = 0.489
GOODOBL	p = 0.351	p = 0.491	PTERAQU	p = 0.142	p = 0.604	VIOLGLA	p = 0.095	p = 0.491

Table 10: Hypothesis tests (ANOVA) for no common trend and no differential trend by deposition class for combined B2 layer, combined C layer, and select species using plot data.

Species Code	No Common Trend	No Differential Trend	Species Code	No Common Trend	No Differential Trend	Species Code	No Common Trend	No Differential Trend
ALL B2	p = 0.407	p = 0.432	GYMNDRY	p = 0.493	p = 0.540	RUBUSPE	p = 0.537	p = 0.337
ALL C	p = 0.740	p = 0.771	LYSIAME	p = 0.155	p = 0.451	SAMBRAC	p = 0.482	p = 0.507
ABIEAMA	p = 0.049	p = 0.272	MAIARAC	p > .999	p > .999	SORBSIT	p = 0.443	p = 0.757
ACERGLA	p > .999	p > .999	MAIASTE	p > .999	p > .999	STREAMP	p = 0.528	p = 0.723
ACTARUB	p > .999	p > .999	MAIASTE+	p = 0.846	p = 0.516	STRELAN	p = 0.118	p = 0.136
ADENBIC	p > .999	p > .999	MENZFER	p = 0.209	p = 0.393	STRUSPI	p = 0.547	p = 0.193
ATHYFIL	p = 0.194	p = 0.062	MONEUNI	p > .999	p > .999	THUJPLI	p = 0.908	p = 0.649
BLUE-BERRY	p = 0.373	p = 0.913	OPLOHOR	p = 0.784	p = 0.645	TIARTRI	p = 0.655	p = 0.646
CIRCALP	p = 0.108	p = 0.120	ORTHSEC	p > .999	p > .999	TSUGHET	p = 0.055	p = 0.104
CLINUNI	p = 0.680	p = 0.564	PHEGCON	p = 0.730	p = 0.380	TSUGMER	p = 0.618	p = 0.612
CORNCAN	p = 0.412	p = 0.344	POLYMUN	p > .999	p > .999	VACCMEM	p > .999	p > .999
CORNSER	p > .999	p > .999	RIBEBRA	p > .999	p > .999	VACCPAR	p = 0.202	p = 0.239
CORNUNA	p = 0.157	p = 0.368	RIBELAC	p > .999	p > .999	VIBUEDU	p > .999	p > .999
DRYOEXP	p = 0.359	p = 0.964	RUBUPAR	p > .999	p > .999			
GALITRF	p > .999	p > .999	RUBUPED	p = 0.541	p = 0.169			


** ALL **
ABIEAMA
ATHYFIL
BLUEBERRY
ACERGLA
ACTARUB
CHIMUMB
CIRCALP
CLINUNI
CORAMER
CORNUNA
DRYOEXP
CORNCAN
CORNSER
GALITRF
GEOCLIV
logit(Percent Cover)
Percent Cover
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Deposition.Zone
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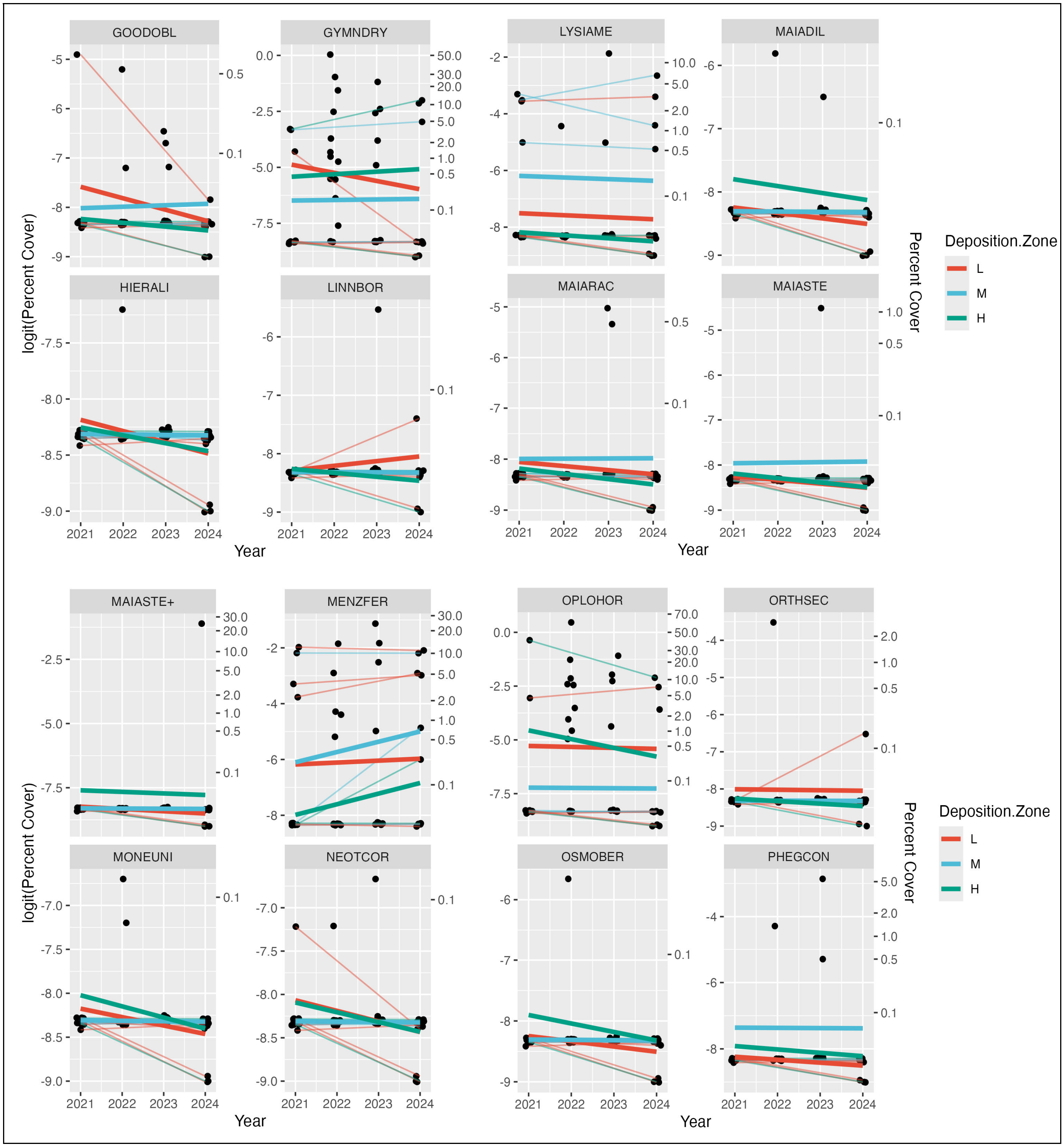

GOODOBL
GYMNDRY
LYSIAME
MAIADIL
HIERALI
LINNBOR
MAIARAC
MAIASTE
MAIASTE+
MENZFER
OPLOHOR
ORTHSEC
MONEUNI
NEOTCOR
OSMOBER
PHEGCON
logit(Percent Cover)
Percent Cover
Year
2021
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Deposition.Zone
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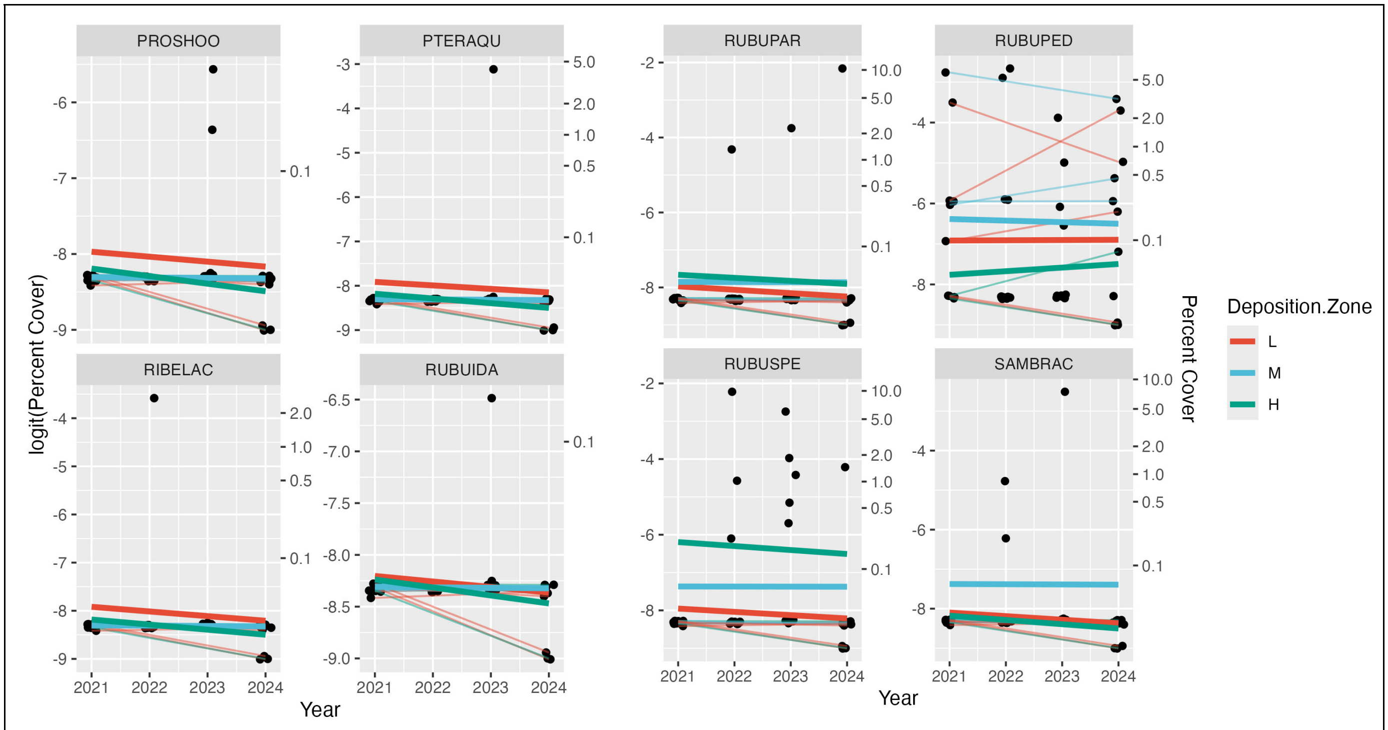
PROSHOO
PTERAQU
RUBUPAR
RUBUPED
RIBELAC
RUBUIDA
RUBUSPE
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Percent Cover
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Deposition.Zone
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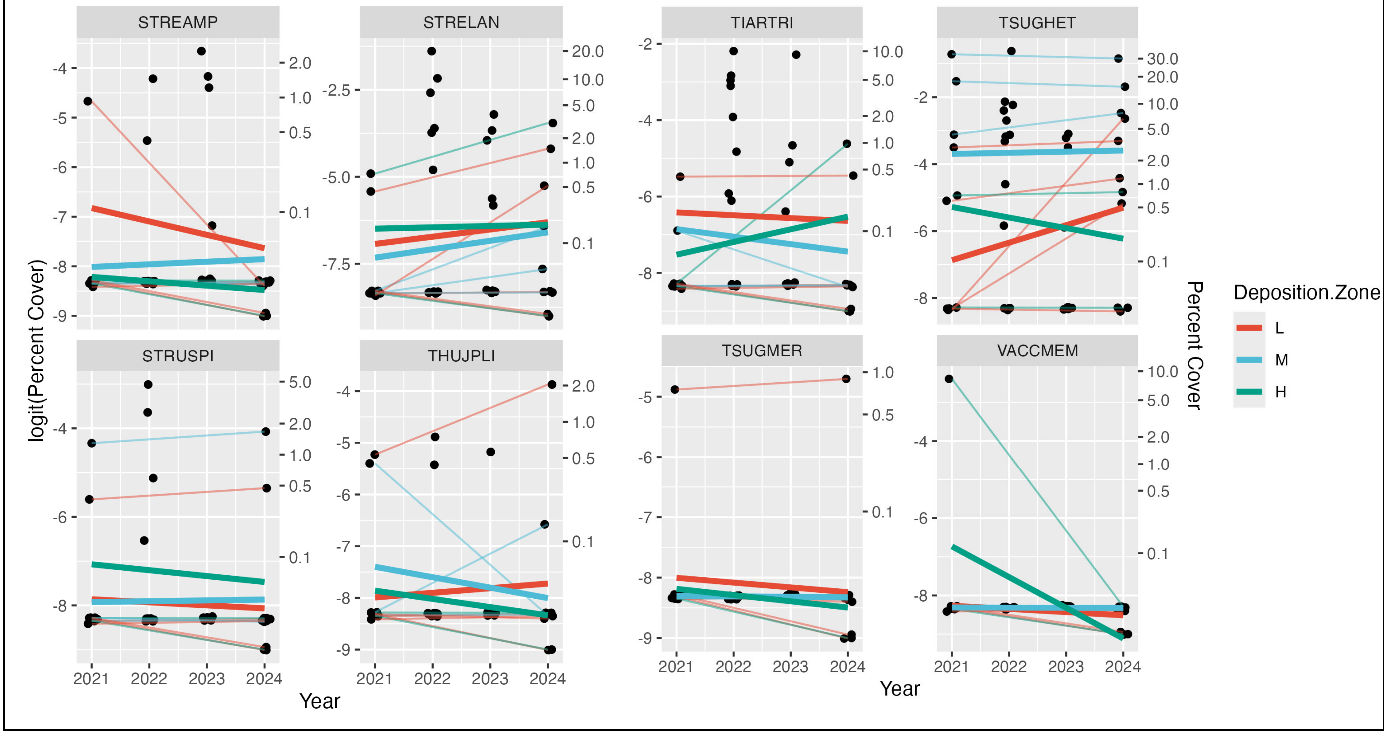
STREAMP
STRELAN
TIARTRI
TSUGHET
STRUSPI
THUJPLI
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VACCMEM
logit(Percent Cover)
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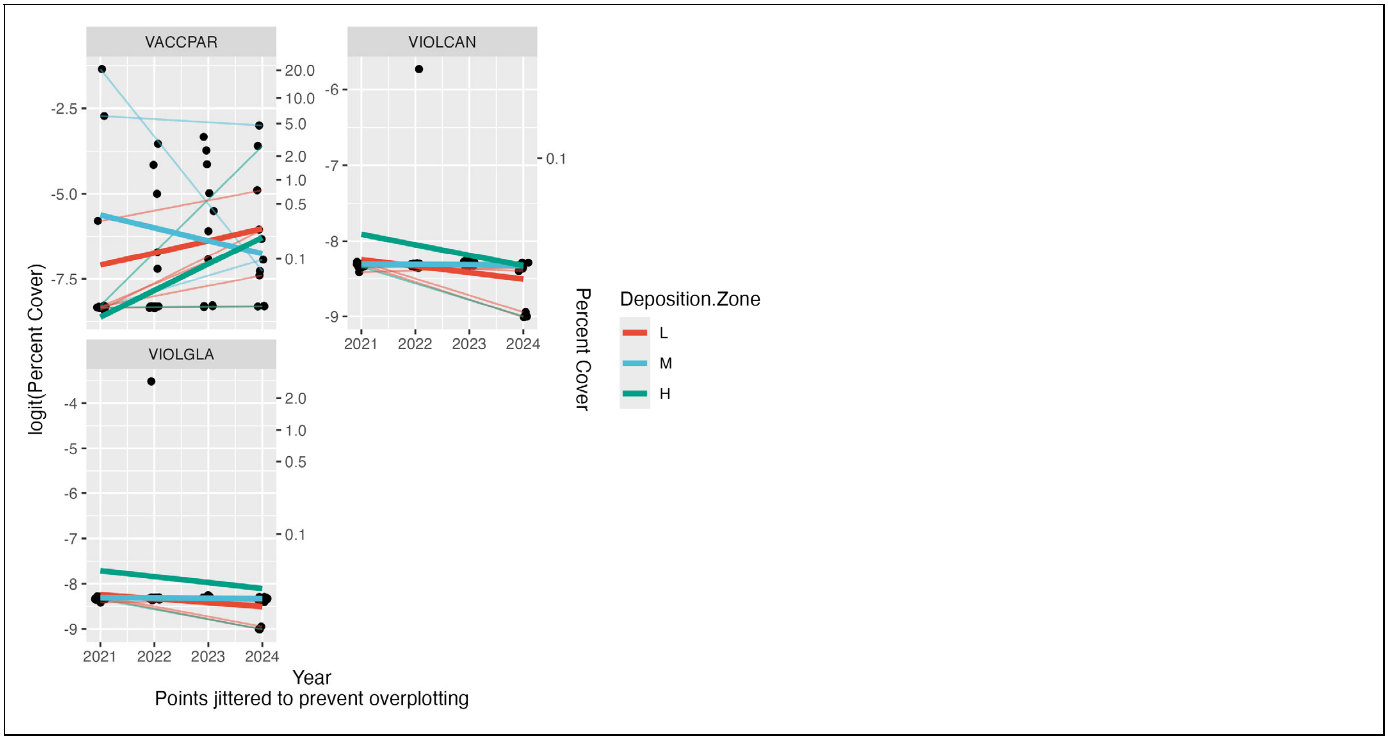
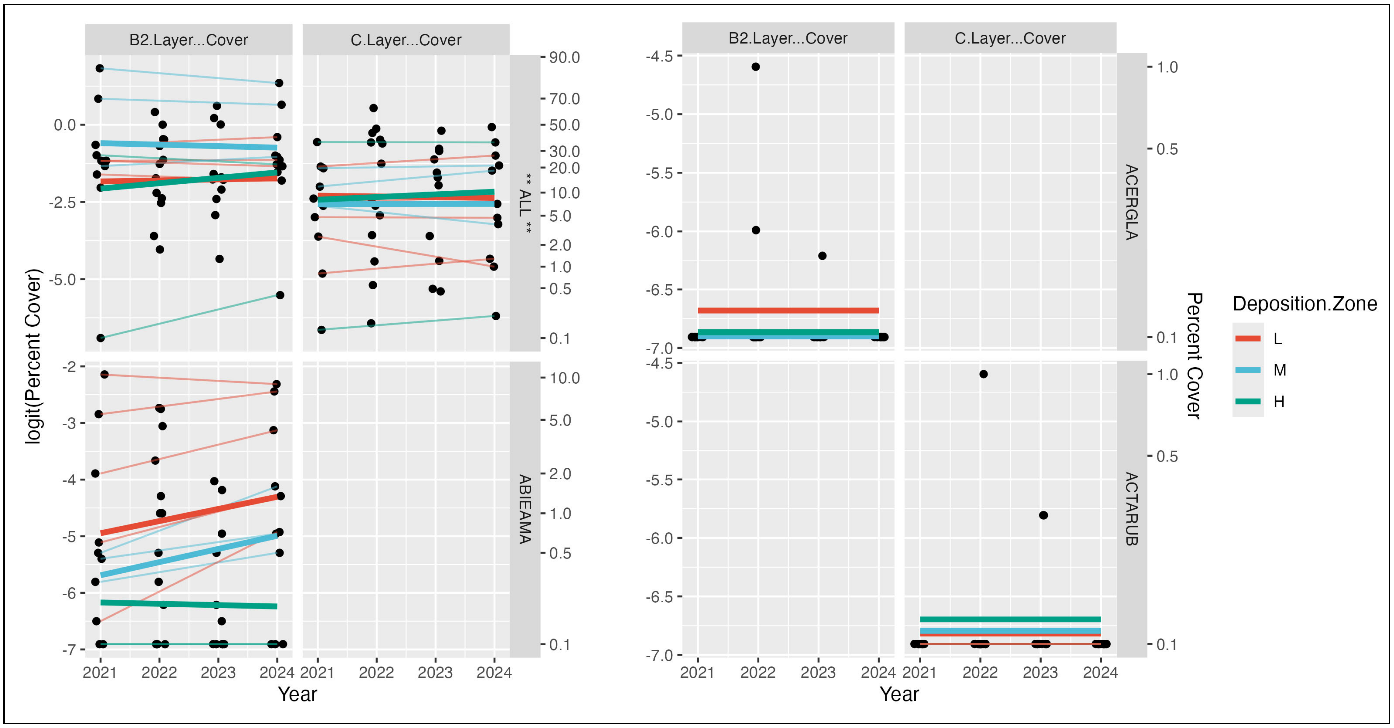
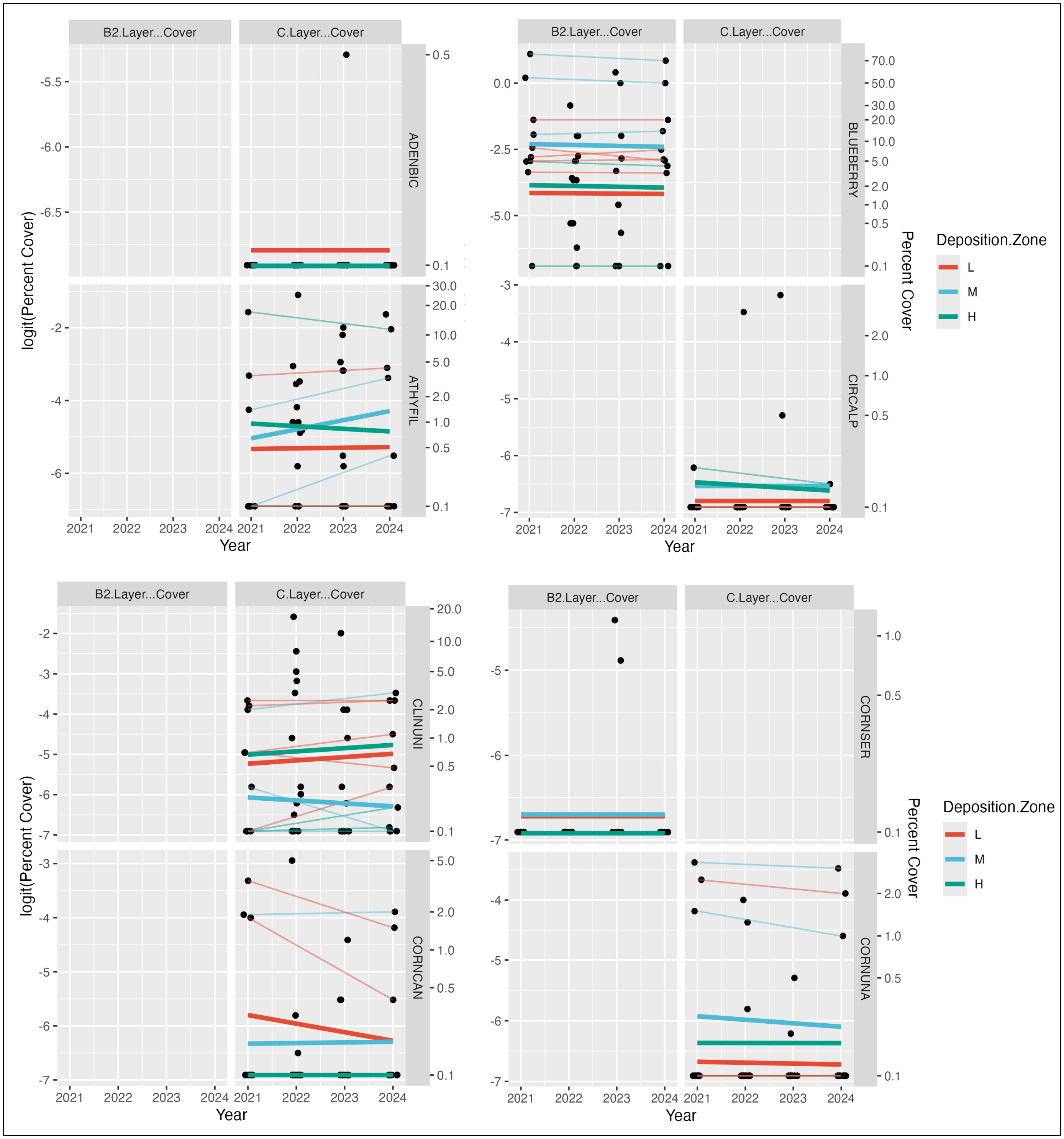


Points jittered to prevent overplotting

Figure 8: Changes in logit (total percent cover) for select and combined species measured from transect data (note that Deposition Zone colour-coding differs from standard coding in this report).




B2.Layer...Cover
C.Layer...Cover
ADENBIC
ATHYFIL
BLUEBERRY
CIRCALP
CLINUNI
CORNCAN
CORNSER
CORNUNA
logit(Percent Cover)
Percent Cover
Year
2021
2022
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2024
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-5.5
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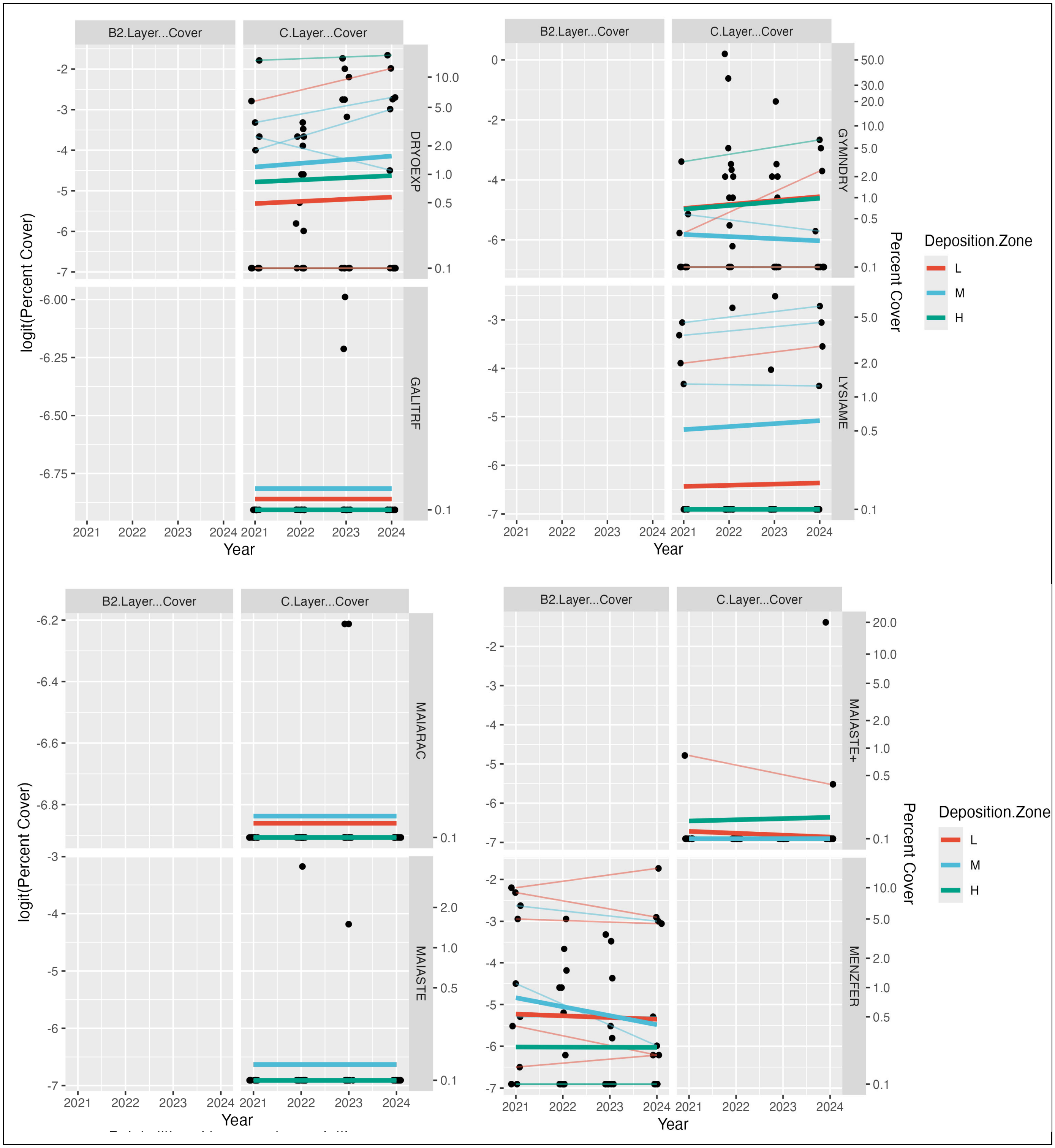
B2.Layer...Cover
C.Layer...Cover
DRYOEXP
GALITRF
GYMNDRY
LYSIAME
MAIARAC
MAIASTE
MAIASTE+
MENZFER
logit(Percent Cover)
Percent Cover
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Deposition.Zone
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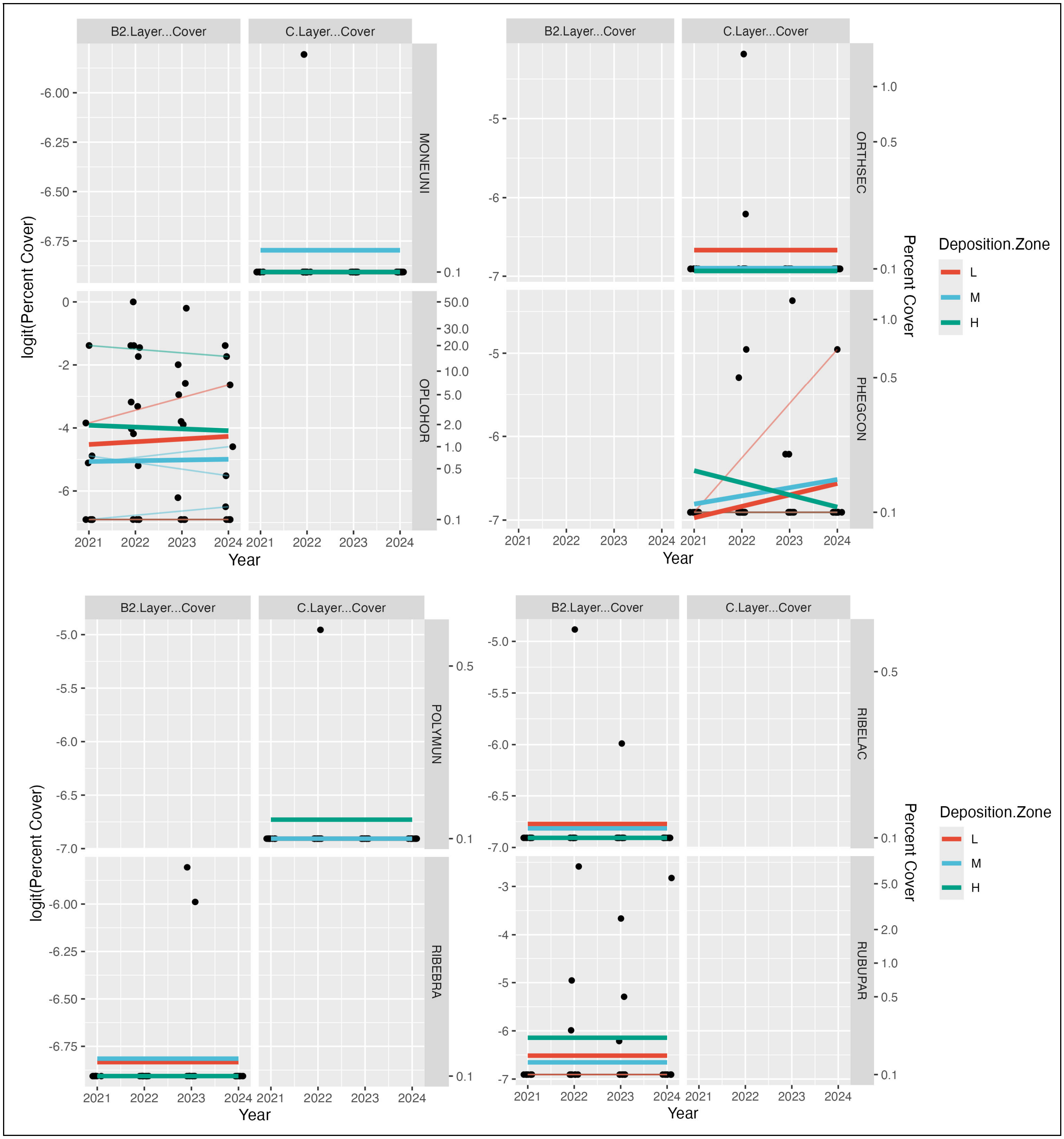
B2.Layer...Cover
C.Layer...Cover
MONEUNI
OPLOHOR
ORTHSEC
PHEGCON
POLYMUN
RIBEBRA
RIBELAC
RUBUPAR
logit(Percent Cover)
Percent Cover
Year
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-6.00
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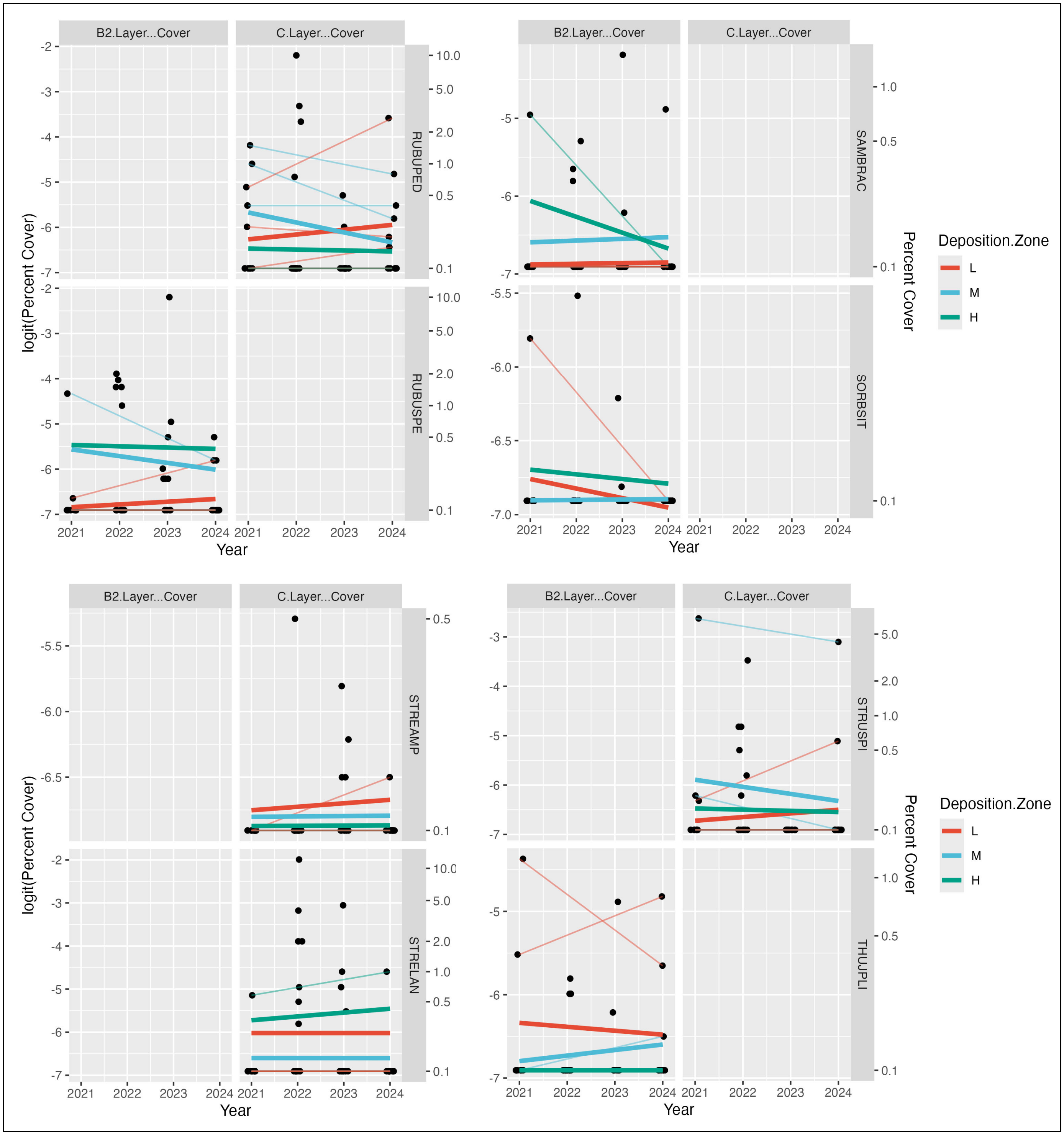
B2.Layer...Cover
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RUBUPED
RUBUSPE
SAMBRAC
SORBSIT
STREAMP
STRELAN
STRUSPI
THUJPLI
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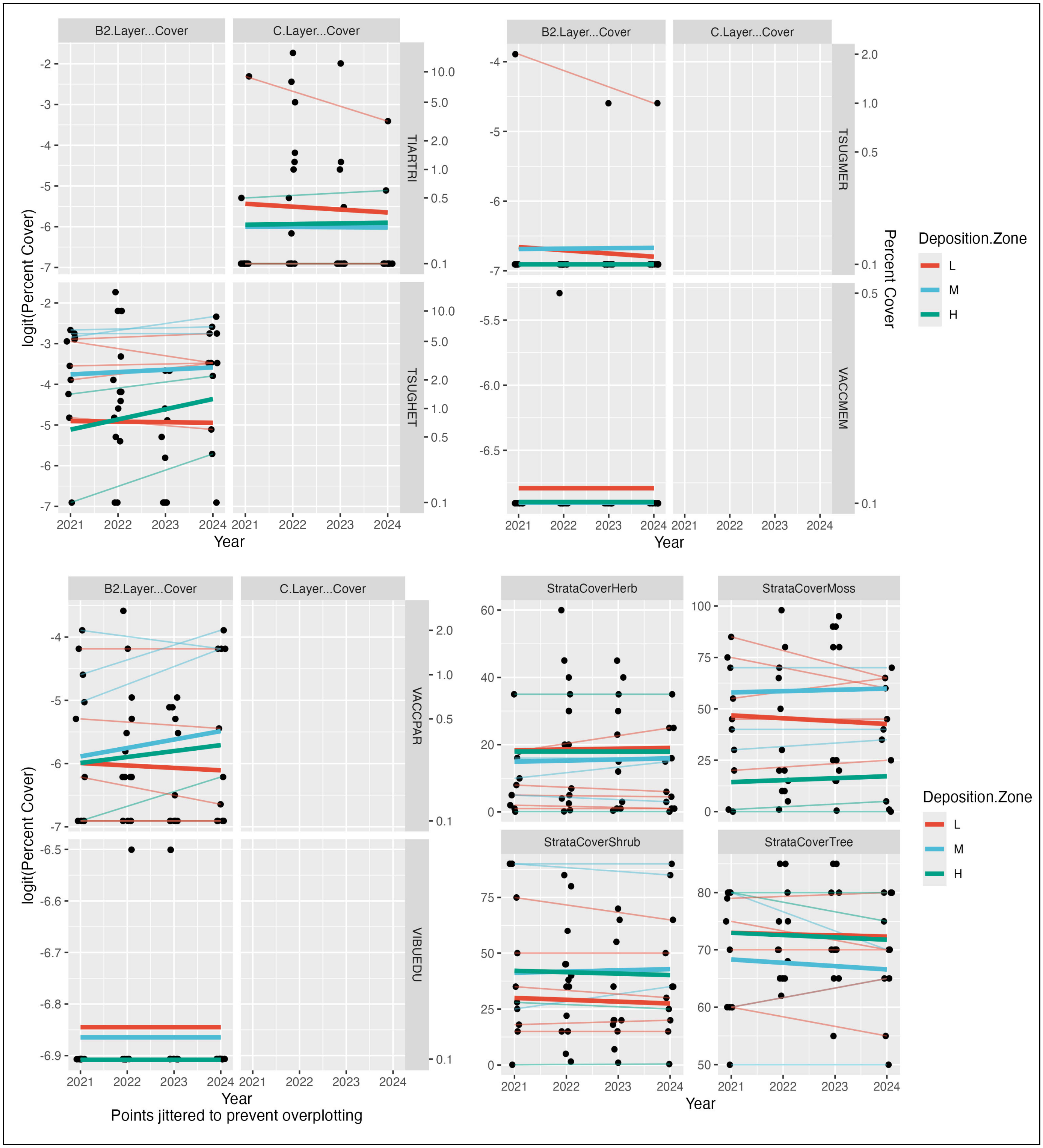


Figure 9: Changes in logit (total percent cover) for select and combined species and layers (strata), measured from plot data (note that Deposition Zone colour-coding differs from standard coding in this report).

Table 11: Estimated slopes (SE) of trend line by deposition class using transect-based data.

Species	Deposition Zone			Species	Deposition Zone			Species	Deposition Zone		
	L	M	H		L	M	H		L	M	H
** ALL **	0.31 (SE 0.13)	0.05 (SE 0.17)	0.35 (SE 0.28)	GYMNDRY	-0.36 (SE 0.21)	0.02 (SE 0.27)	0.11 (SE 0.33)	RIBELAC	-0.10 (SE 0.05)	-0.01 (SE 0.07)	-0.10 (SE 0.08)
ABIEAMA	0.42 (SE 0.45)	0.09 (SE 0.58)	-0.31 (SE 0.65)	HIERALI	-0.10 (SE 0.05)	-0.00 (SE 0.06)	-0.07 (SE 0.07)	RUBUIDA	-0.05 (SE 0.06)	-0.00 (SE 0.08)	-0.08 (SE 0.09)
ACERGLA	-0.08 (SE 0.07)	-0.00 (SE 0.09)	0.15 (SE 0.10)	LINNBOR	0.08 (SE 0.10)	-0.00 (SE 0.12)	-0.07 (SE 0.13)	RUBUPAR	-0.09 (SE 0.05)	-0.00 (SE 0.07)	-0.08 (SE 0.08)
ACTARUB	-0.08 (SE 0.05)	-0.01 (SE 0.07)	-0.12 (SE 0.08)	LYSIAME	-0.07 (SE 0.09)	-0.06 (SE 0.12)	-0.11 (SE 0.15)	RUBUPED	0.01 (SE 0.18)	-0.04 (SE 0.24)	0.09 (SE 0.29)
ATHYFIL	-0.13 (SE 0.06)	-0.11 (SE 0.08)	-0.20 (SE 0.10)	MAIADIL	-0.09 (SE 0.05)	-0.01 (SE 0.07)	-0.11 (SE 0.08)	RUBUSPE	-0.09 (SE 0.05)	-0.00 (SE 0.07)	-0.11 (SE 0.08)
BLUEBERRY	0.16 (SE 0.20)	0.13 (SE 0.25)	0.27 (SE 0.31)	MAIARAC	-0.08 (SE 0.05)	0.00 (SE 0.07)	-0.10 (SE 0.08)	SAMBRAC	-0.09 (SE 0.05)	-0.01 (SE 0.07)	-0.11 (SE 0.08)
CHIMUMB	0.08 (SE 0.07)	-0.00 (SE 0.08)	-0.07 (SE 0.09)	MAIASTE	-0.09 (SE 0.05)	0.01 (SE 0.07)	-0.10 (SE 0.08)	STREAMP	-0.27 (SE 0.19)	0.05 (SE 0.25)	-0.09 (SE 0.29)
CIRCALP	-0.08 (SE 0.05)	-0.00 (SE 0.07)	-0.11 (SE 0.08)	MAIASTE+	-0.09 (SE 0.05)	-0.01 (SE 0.07)	-0.06 (SE 0.08)	STRELAN	0.21 (SE 0.22)	0.24 (SE 0.28)	0.04 (SE 0.34)
CLINUNI	0.46 (SE 0.34)	-0.44 (SE 0.44)	-0.19 (SE 0.50)	MENZFER	0.07 (SE 0.19)	0.37 (SE 0.24)	0.38 (SE 0.29)	STRUSPI	-0.07 (SE 0.06)	0.02 (SE 0.08)	-0.13 (SE 0.09)
CORAMER	-0.21 (SE 0.07)	-0.00 (SE 0.09)	-0.07 (SE 0.10)	MONEUNI	-0.10 (SE 0.05)	-0.00 (SE 0.07)	-0.13 (SE 0.08)	THUJPLI	0.09 (SE 0.18)	-0.20 (SE 0.23)	-0.16 (SE 0.27)
CORNCAN	0.18 (SE 0.17)	-0.90 (SE 0.22)	-0.10 (SE 0.27)	NEOTCOR	-0.12 (SE 0.07)	-0.00 (SE 0.09)	-0.11 (SE 0.10)	TIARTRI	-0.07 (SE 0.20)	-0.20 (SE 0.26)	0.33 (SE 0.31)
CORNSER	-0.08 (SE 0.05)	-0.01 (SE 0.07)	-0.10 (SE 0.08)	OPLOHOR	-0.05 (SE 0.07)	-0.01 (SE 0.09)	-0.41 (SE 0.12)	TSUGHET	0.52 (SE 0.30)	0.03 (SE 0.39)	-0.32 (SE 0.46)
CORNUNA	0.21 (SE 0.30)	0.61 (SE 0.38)	-0.17 (SE 0.43)	ORTHSEC	-0.01 (SE 0.16)	-0.00 (SE 0.21)	-0.07 (SE 0.23)	TSUGMER	-0.08 (SE 0.05)	-0.01 (SE 0.06)	-0.10 (SE 0.08)

DRYOEXP	-0.05 (SE 0.09)	0.05 (SE 0.11)	0.16 (SE 0.14)	**OSMOBER**	-0.09 (SE 0.05)	-0.01 (SE 0.07)	-0.14 (SE 0.08)	**VACCMEM**	-0.08 (SE 0.15)	-0.00 (SE 0.19)	-0.79 (SE 0.22)
GALITRF	-0.09 (SE 0.05)	-0.00 (SE 0.07)	-0.12 (SE 0.08)	**PHEGCON**	-0.09 (SE 0.05)	-0.01 (SE 0.07)	-0.10 (SE 0.08)	**VACCPAR**	0.36 (SE 0.34)	-0.38 (SE 0.44)	0.78 (SE 0.50)
GEOCLIV	-0.08 (SE 0.05)	-0.00 (SE 0.07)	-0.11 (SE 0.08)	**PROSHOO**	-0.07 (SE 0.05)	-0.01 (SE 0.07)	-0.10 (SE 0.08)	**VIOLCAN**	-0.09 (SE 0.06)	-0.01 (SE 0.07)	-0.14 (SE 0.08)
GOODOBL	-0.23 (SE 0.14)	0.03 (SE 0.17)	-0.08 (SE 0.20)	**PTERAQU**	-0.08 (SE 0.05)	-0.01 (SE 0.07)	-0.11 (SE 0.08)	**VIOLGLA**	-0.09 (SE 0.05)	-0.01 (SE 0.07)	-0.13 (SE 0.08)

Table 12: Estimated slopes (SE) of trend line by deposition class using plot-based data.

Species	Deposition Zone			Species	Deposition Zone		
	L	M	H		L	M	H
****ALL B2 Layer****	0.03 (SE 0.08)	-0.05 (SE 0.10)	0.17 (SE 0.13)	**OPLOHOR**	0.09 (SE 0.08)	0.02 (SE 0.10)	-0.06 (SE 0.13)
****ALL C Layer****	-0.02 (SE 0.08)	0.00 (SE 0.10)	0.09 (SE 0.13)	**PHEGCON**	0.14 (SE 0.12)	0.10 (SE 0.16)	-0.15 (SE 0.17)
ABIEAMA	0.21 (SE 0.08)	0.23 (SE 0.10)	-0.02 (SE 0.12)	**RUBUPED**	0.11 (SE 0.09)	-0.22 (SE 0.12)	-0.02 (SE 0.15)
ATHYFIL	0.02 (SE 0.06)	0.25 (SE 0.08)	-0.07 (SE 0.09)	**RUBUSPE**	0.06 (SE 0.08)	-0.15 (SE 0.10)	-0.03 (SE 0.13)
BLUEBERRY	-0.01 (SE 0.04)	-0.04 (SE 0.05)	-0.03 (SE 0.06)	**SAMBRAC**	0.01 (SE 0.10)	0.02 (SE 0.12)	-0.20 (SE 0.14)
CIRCALP	0.00 (SE 0.01)	0.00 (SE 0.01)	-0.05 (SE 0.02)	**SORBSIT**	-0.06 (SE 0.06)	0.00 (SE 0.07)	-0.03 (SE 0.08)
CLINUNI	0.08 (SE 0.09)	-0.07 (SE 0.12)	0.08 (SE 0.14)	**STREAMP**	0.03 (SE 0.02)	0.00 (SE 0.03)	0.00 (SE 0.03)
CORNCAN	-0.16 (SE 0.08)	0.01 (SE 0.10)	-0.00 (SE 0.12)	**STRELAN**	-0.00 (SE 0.02)	-0.00 (SE 0.03)	0.09 (SE 0.03)
CORNUNA	-0.02 (SE 0.02)	-0.06 (SE 0.03)	-0.00 (SE 0.03)	**STRUSPI**	0.07 (SE 0.07)	-0.14 (SE 0.09)	-0.02 (SE 0.10)
DRYOEXP	0.05 (SE 0.09)	0.09 (SE 0.11)	0.05 (SE 0.14)	**THUJPLI**	-0.05 (SE 0.07)	0.07 (SE 0.10)	-0.00 (SE 0.11)
GYMNDRY	0.13 (SE 0.11)	-0.07 (SE 0.14)	0.12 (SE 0.18)	**TIARTRI**	-0.07 (SE 0.06)	-0.00 (SE 0.07)	0.02 (SE 0.09)
LYSIAME	0.02 (SE 0.02)	0.06 (SE 0.03)	0.00 (SE 0.04)	**TSUGHET**	-0.01 (SE 0.06)	0.06 (SE 0.07)	0.25 (SE 0.09)

MAIASTE+	-0.05 (SE 0.04)	-0.00 (SE 0.05)	0.03 (SE 0.06)	**TSUGMER**	-0.05 (SE 0.03)	0.01 (SE 0.04)	0.00 (SE 0.05)
MENZFER	-0.04 (SE 0.08)	-0.22 (SE 0.11)	-0.00 (SE 0.13)	**VACCPAR**	-0.04 (SE 0.06)	0.13 (SE 0.08)	0.09 (SE 0.09)

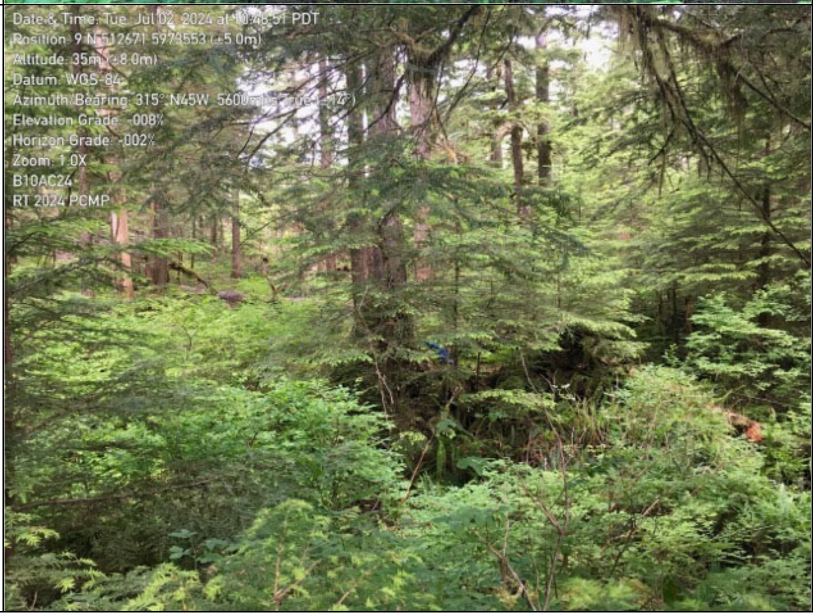
Appendix B: Plot Photos

A complete set of high-resolution photos has been archived for this Project in 2024. For this annual summary report, only four photos—taken from plot centre towards the northeast (~45°), southeast (~135°), southwest (~225°) and northwest (~315°) corners—are presented for each plot.

Plot B04AC24

Plot B09AC24

Plot B10AC24



Plot B12AC24

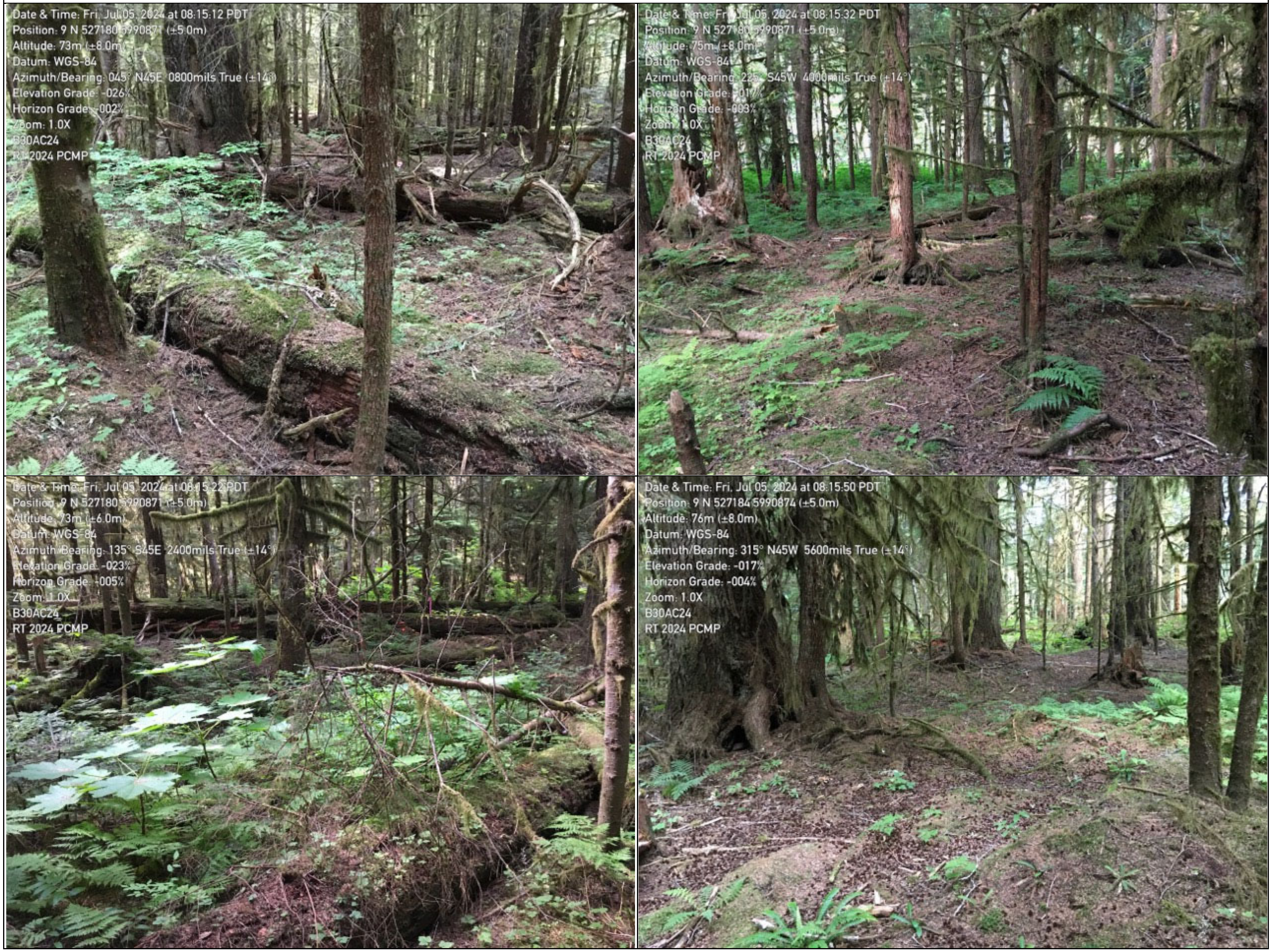
Plot B17AC24

Plot B20AC24

Plot B22AC24

Plot B26AC24

Plot B30AC24



Plot B32AC24

Plot B36AC24