# Sherbrooke Lake 2022 Water Quality Monitoring Report

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Sherbrooke Lake Stewardship Committee

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Sherbrooke Lake 2022 Water Quality Monitoring Report

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## Executive Summary

This report outlines the activities and results of the 2022 Sherbrooke Lake (SL) water quality monitoring program. This project began in response to the planned development of a municipal public access site at Sherbrooke Lake. The program's goal was to determine a baseline understanding of water quality conditions within SL before construction of the public access site, monitor water quality during and after the construction, and provide evidence-based advice to MODL and MOC regarding ways to address water quality changes and concerns within the lake.

In June, August and September 2022, volunteers collected water samples at three lake sites and three stream sites. Lake 3, a site that has previously been sampled, was not included in the 2022 sample schedule except for *Escherichia coli (E. coli)*. On December 1, 2022, Coastal Action staff collected samples at seven stream sites following a rainfall event (rain >25 mm). Sediment samples were also taken at the lake and one stream site once in the season. An at-depth sample, taken below the thermocline at lake sites, was analyzed for total phosphorus and total nitrogen.

Factors measuring or contributing to the production of algae in freshwater, including phycocyanin, total phosphorus and total nitrogen, did not exceed guidelines set by the World Health Organization or Ontario's Ministry of Environment and Climate Change guidelines, except for Pine Lake Brook, which exceeded the threshold of 0.03 mg/L for total phosphorus in rivers and streams in August.

Surface water temperatures of all lake and stream sites exceeded or approached the 20°C temperature threshold for cold-water fish species (NSSA 2014) during August.

Dissolved oxygen at all lake sites stayed above the minimum threshold of 6.5 mg/L set by the Canadian Council of Ministers of the Environment (CCME) for cold-water species (CCME 1999). Some of the stream sites fell below this threshold in both August and September.

pH measurements for most sites fell below the 6.5-pH threshold set by the CCME (2002); however, the acidity of SL waters is not uncommon for southwest NS lakes, which generally have lower pH values than the 6.5 threshold. It appears that most of the time, the acidity of the waters at SL poses minimal threat to organisms, except for some stream sites.

*E. coli* levels in the lake sites did not exceed or approach recreational guidelines. Sherbrooke River approached the primary recreational guideline of *E. coli* (400 CFU/100 mL) in August. In the rainfall-dependent sample, Pine Lake Brook and Zwicker Brook approached the primary guideline, while Peter Veinot Brook exceeded it.

Arsenic, cadmium, and mercury levels were elevated at all lake sites in the sediment samples. Lead levels were low at most lake sites, except Lake 2 which exceeded Interim Sediment Quality Guideline (ISQG). Metal concentrations in the stream site did not approach any of the guidelines.

The water quality of Sherbrooke Lake and its tributaries did not identify any significant water quality issues in 2022.

Based on the mean depth of transparency (Secchi disk), and mean concentrations of chlorophyll-α and phosphorus, a Trophic State Index (TSI) score has been calculated annually to assess biological productivity. Trophic states range from oligotrophic (low productivity and minimal biomass) to hypereutrophic (high productivity and maximum biomass). The trophic state of SL in 2018 and 2019 was oligotrophic-mesotrophic. The transition from oligotrophic to mesotrophic is a TSI score of 40. In 2018 and 2019, the TSI was less than a 10$^{th}$ of a decimal over 40, therefore classifying the lake as mesotrophic. In 2021, the TSI score was 39.4, putting the lake into an oligotrophic state. The trophic state remained oligotrophic in 2022, with a TSI score of 39.11. SL appears to be maintaining a steady TSI score over the four years this data has been collected.

Coastal Action recommends that the project continues in 2023, following the same program structure as 2022, with bi-monthly monitoring of lake and stream sites; sediment sampling; sampling regular stream sites and rainfall-dependent stream sites after rainfall exceeding 25 mm; and volunteers supplied with algae sampling equipment.

## 1.0 Introduction

The following report summarizes the results of the 2022 Sherbrooke Lake Water Quality Monitoring Program. Monitoring activities were conducted at Sherbrooke Lake (SL) by trained volunteers with support from Coastal Action in June, August and September 2022.

This marks the fourth year of the monitoring program, which began in 2018. Monitoring activities did not occur in 2020 due to COVID-19 restrictions.

This program receives financial support from both the Municipality of the District of Lunenburg (MODL) and the Municipality of Chester (MOC).


*Figure 1. Sherbrooke Lake Water Quality Monitoring Program 2022 monitoring sites.*

## 1.1 Monitoring Program Background

Following several years of consultations regarding the development of a municipal public access site at Sherbrooke Lake, the Sherbrooke Lake Stewardship Committee (SLSC) was formed. The SLSC, a joint commitment between MODL and MOC, is comprised of one Coastal Action staff, two residents of MODL, two residents of MOC, a water quality expert, and supporting municipal staff.

The SLSC was tasked with developing and implementing a water quality monitoring program to: determine a baseline understanding of water quality conditions within SL before construction of the public access site, monitor water quality during and after the construction, and provide evidence-based advice to MODL and MOC regarding ways to address water quality changes and concerns within the lake.

Coastal Action acts as technical support for a group of trained volunteers, who conduct the monthly sampling, and Coastal Action collect samples at seven stream sites following rainfall exceeding 25 mm within 24 hours. Sampling after a significant rainfall monitors the potential effect of runoff from land (i.e., nutrients, bacteria, sediment), which may impact water quality. Following preliminary ground-truthing activities in 2017, the full Sherbrooke Lake Water Quality Monitoring Program was conducted in 2018, 2019, 2021 and 2022.

Further details on the program can be found in the *Sherbrooke Lake Water Quality Monitoring Program*, and the *Sherbrooke Lake Water Quality Monitoring Report* (2018, 2019 & 2021); all are available upon request from either MOC or MODL.

## 1.2 Review of the 2021 Sherbrooke Lake Water Quality Monitoring Report

In 2018 and 2019, the overall trophic state of Sherbrooke Lake was oligotrophic-mesotrophic, indicating that the biological productivity of the lake did not change during that period. In 2021, the trophic state of the lake was oligotrophic. The overall trophic state index (TSI) scores have remained relatively steady over the three years this data has been collected. The monitoring program did not identify any significant issues with the water quality of SL in 2018, 2019 and 2021.

An algal bloom was detected at the outlet to Gully Lake on July 7, 2021. Volunteers collected and submitted a water sample to BV Labs. No Microcystin-LR was detected in the sample.

None of the SL sites exceeded the phosphorus guideline of 0.02 mg/L in 2021. All stream sites remained under the 0.03 mg/L MOECC stream guidelines for phosphorus.

Sediment was sampled at Lake sites 1, 2, and 4, and at the mouth of Sherbrooke River to test for metal concentrations. At Lake 2 and 4, arsenic exceeded the ISQG (Interim Sediment Quality Guidelines). At Lake 4, arsenic and cadmium exceeded the ISQG. Lake 1 had no metals exceeding ISQG; however, mercury was approaching the ISQG. Sherbrooke River displayed low concentrations of metals with no parameter exceeding or approaching any of the sediment guidelines.

# 2.0 2022 Water Quality Monitoring Results

## 2.1 Physical Water Quality Parameters

### 2.1.1. Chlorophyll-α, and Phycocyanin

In 2021, a ProDSS Total Algae PC Sensor was purchased by MODL to use on the ProDSS YSI unit owned jointly by MOC and MODL. This probe measures concentrations of chlorophyll-α and phycocyanin present in water. Phycocyanin is a pigment found in cyanobacteria, or blue-green algae, and provides an estimate of total cyanobacteria production. Chlorophyll-α is a pigment produced by all types of algae and provides an estimate of total algae production.

Collecting this data over multiple seasons will provide baseline concentrations of phycocyanin in SL, which can vary across waterbodies. Long-term monitoring with this probe, paired with the collection of Microcystin-LR water samples during blooms, will help to identify spikes in phycocyanin concentrations and build a predictive curve for the relationship between the concentrations of these algal pigments and the occurrence of algal blooms in SL.

Algal concentrations are measured as Relative Fluorescence Units (RFU). Phycocyanin RFU units were converted to the total number of cells (Genzoli and Kann 2016). World Health Organization (WHO) provides two guideline levels, ‘alert level 1’ is reached when 20,000 phycocyanin cells/mL are observed, and ‘alert level 2’ is reached when 100,000 phycocyanin cells/mL are observed. At no point were the WHO guidelines exceeded or approached (Figure 2, Figure 3, Figure 4). The data was not collected before, during, or immediately after any known algae blooms.

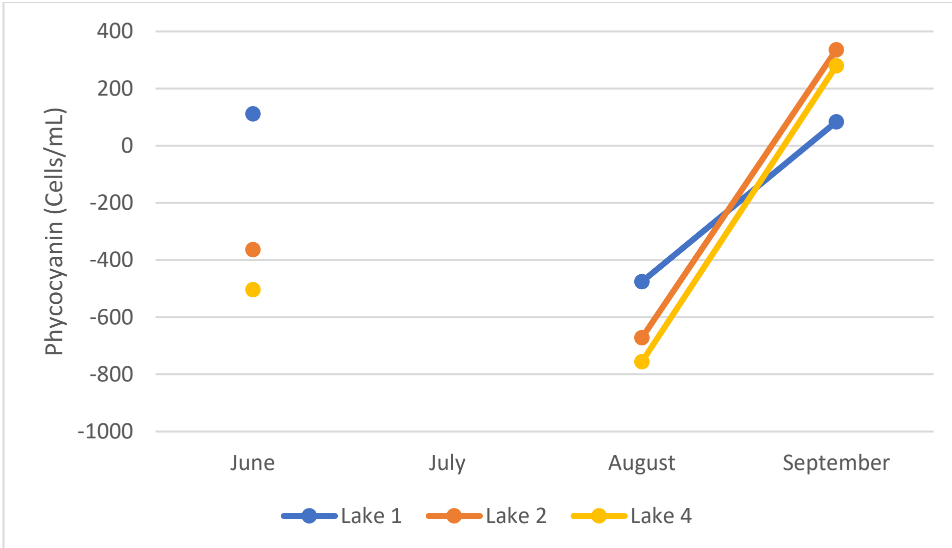



*Figure 2. Phycocyanin (cells/mL) levels from the 2022 monthly sampling events at the lake sites. The WHO provides two guidelines; Alert level 1 at 20,000 cells/mL, and Alert level 2 at 100,000 cells/mL.*

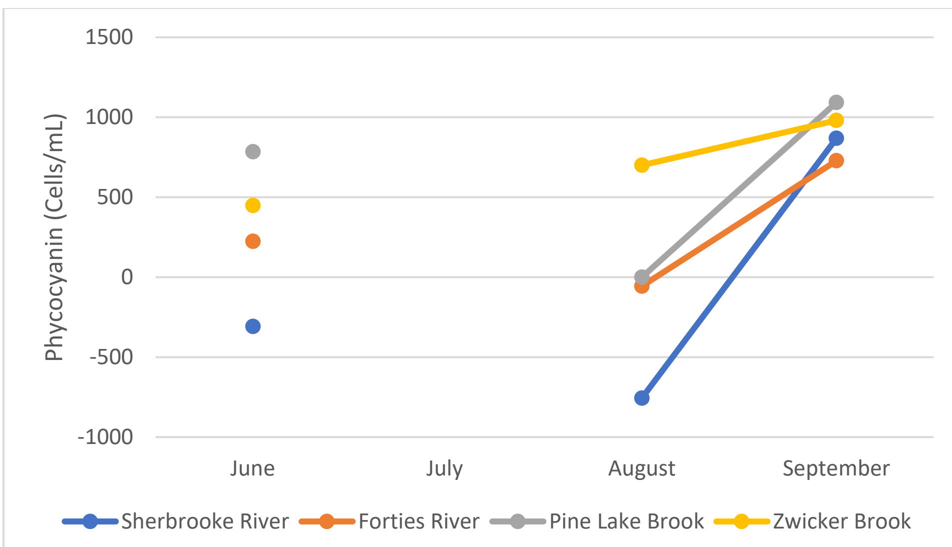



*Figure 3. Phycocyanin (cells/mL) levels from the 2022 sampling events at the stream sites. The WHO provides two guidelines; Alert level 1 at 20,000 cells/mL, and Alert level 2 at 100,000 cells/mL.*

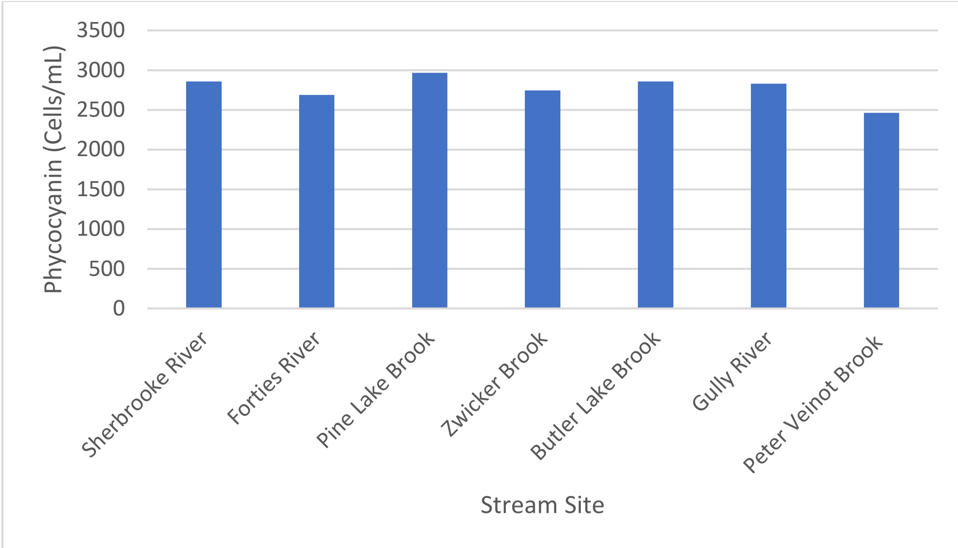



*Figure 4. Phycocyanin (cells/mL) levels from the 2022 rainfall dependent sampling event at the stream sites, including the additional, rainfall-specific sites. The WHO provides two guidelines; Alert level 1 at 20,000 cells/mL, and Alert level 2 at 100,000 cells/mL. Rainfall dependent samples were taken December 1, 2022.*

### 2.1.2. Surface Water Temperatures

Water temperatures were recorded in June, August and September at all lake sites, except Lake 3 which was only sampled for *Escherichia coli (E. coli)* in the 2022 field season. The stream sites were sampled in June, August, and September. Temperature readings were also taken during a rainfall dependent event in December at all stream sites, including the additional rainfall-specific sites. Temperatures at the lake sites ranged from 18.3°C to 24.2°C (Figure 5). The highest temperature recorded was at Lake 4 in August, but all other lake sites had similar temperatures during this time. Lake sites 2 and 4 exceeded the 20$^{o}$C temperature threshold for cold-water fish species in June, while all lake sites exceeded this threshold in August (Nova Scotia Salmon Association [NSSA] 2014). All sites were below the threshold in September.

The stream sites showed cooler temperatures than the lake, ranging from 12.5°C to 22.5°C (Figure 6). The highest temperature recorded was at Sherbrooke River in August. Sherbrooke River exceeded the 20°C temperature threshold for cold-water fish species in June and August. Forties River and Zwicker Brook both exceeded the threshold in August, while Pine Lake Brook was just below at 19.9°C.

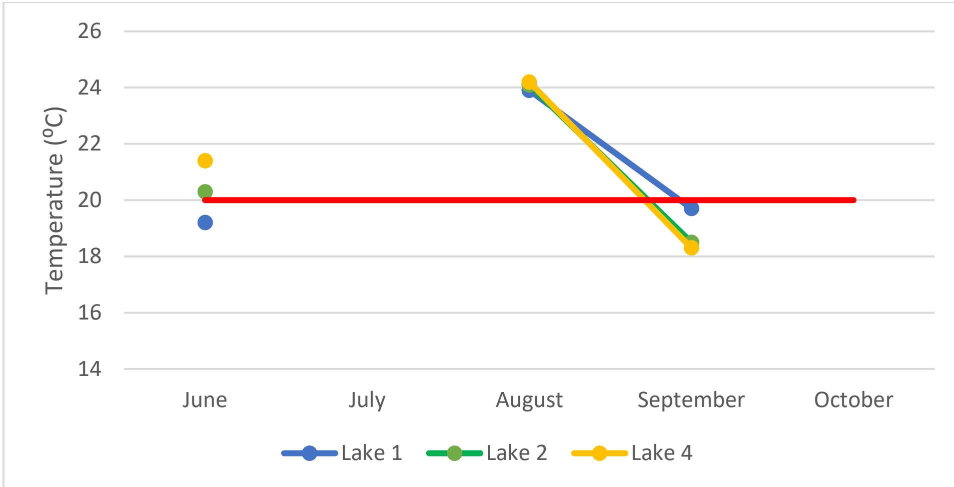



*Figure 5. Temperature (°C) readings from the 2022 monthly sampling events at the lake sites. The red line indicates the 20°C threshold for cold-water fish set by NSSA. In August Lake 2 was 24.1$^0$C and Lake 4 was 24.2$^0$C; in September Lake 2 was 18.5$^0$C and Lake 4 was 18.3$^0$C.*

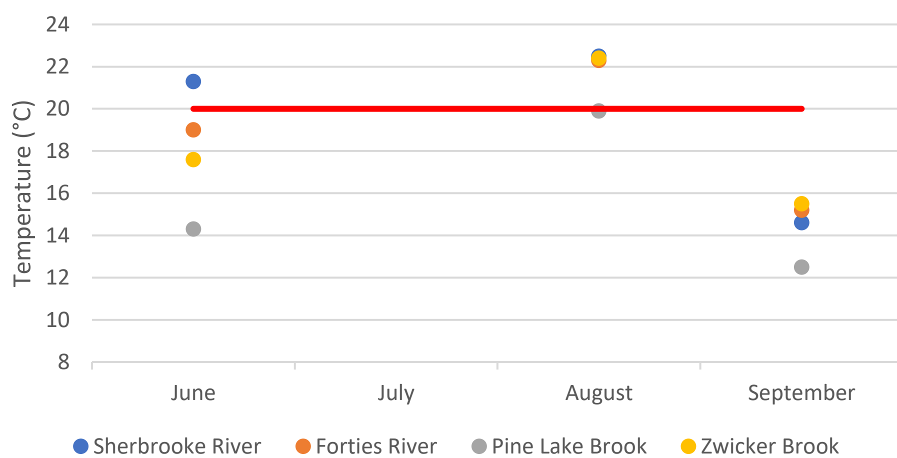



*Figure 6. Temperature (°C) readings from the 2022 sampling events at the stream sites. The red line indicates the 20°C threshold for cold-water fish set by NSSA.*

Surface water temperature readings were taken during the rainfall dependent sampling on December 1, 2022, at each of the stream sites, including three additional sites not included in the regular monthly samples. These samples were taken later than usual in the year due to a lack of significant rainfall during the summer and fall months which led to low water flow following rainfall events and staff safety for sampling following significant rainfall from Hurricane Fiona. Temperatures from the rainfall sampling range from 5°C to 7.3°C (Figure 7).

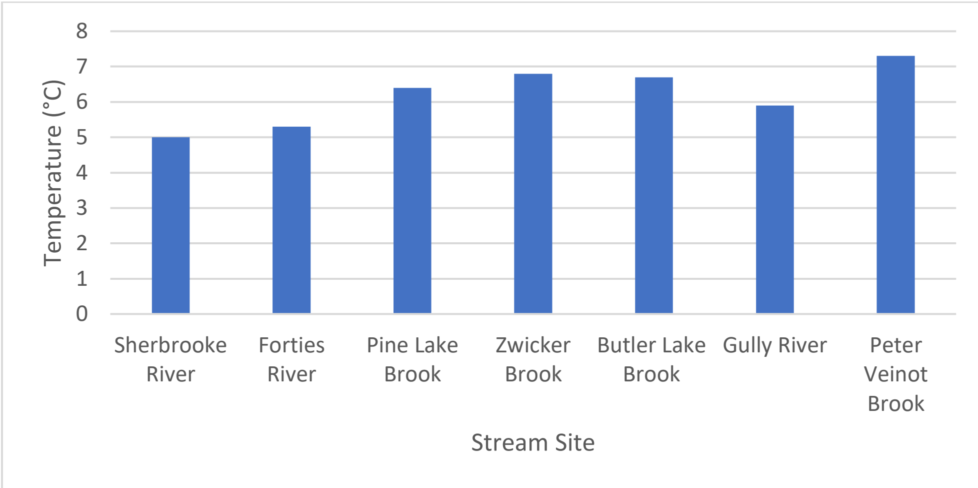



*Figure 7. Temperature (°C) readings from the 2022 rainfall dependent sampling at the stream sites, including the additional, rainfall-specific sites.*

### 2.1.3 Surface Dissolved Oxygen

Dissolved oxygen (DO) was recorded in June, August and September at all lake and stream sites, except Lake 3 which was not sampled. DO readings were also taken during the rainfall dependent sampling in December at all stream sites, including the additional rainfall-specific sites. DO readings at the lake sites ranged from 8.18 mg/L to 9.94 mg/L (Figure 8). The lowest reading was taken at Lake 4 in August. DO is a requirement for the survival of aquatic organisms, with a minimum threshold of 6.5 mg/L set by the Canadian Council of Ministers of the Environment (CCME) for cold-water species (CCME 1999). No readings below this threshold were recorded at any regularly monitored lake site in 2022.

DO readings at the stream sites ranged from 3.42 mg/L to 10.10 mg/L (Figure 9). Forties River and Pine Lake Brook were below the 6.5 mg/L threshold in both August and September. Forties River was below the threshold in September.

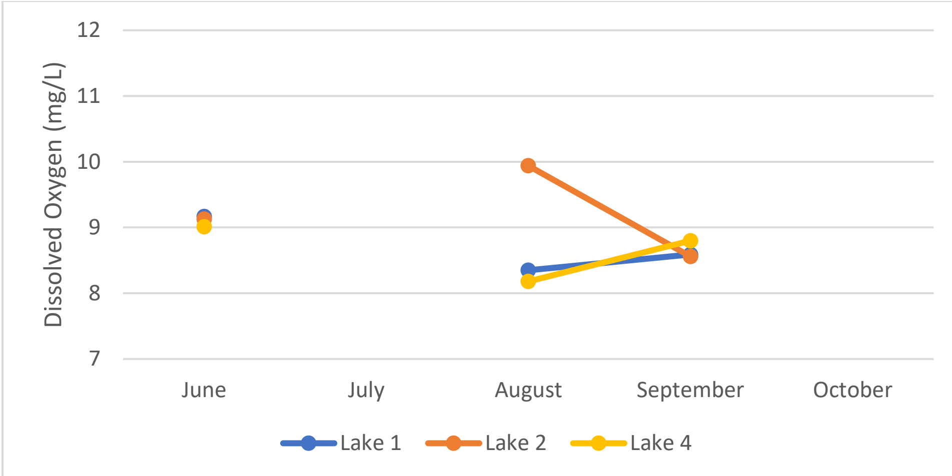



*Figure 8. Dissolved Oxygen (mg/L) readings from the 2022 monthly sampling events at the lake sites.*

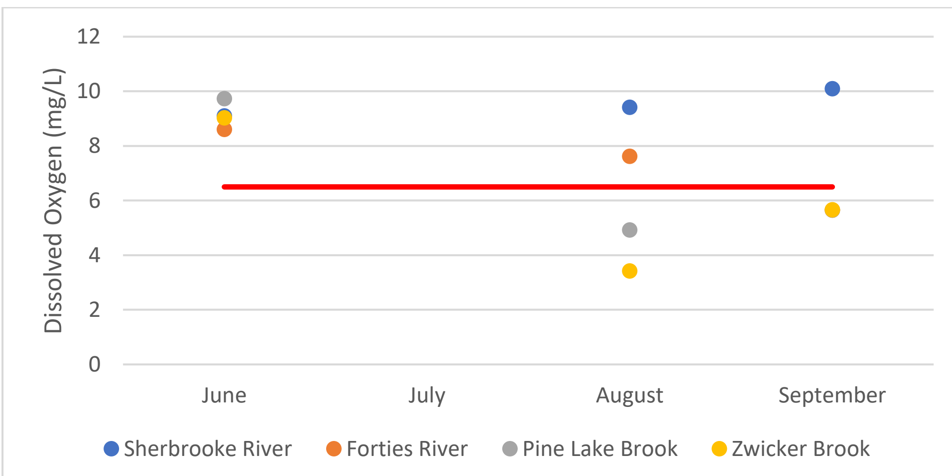



*Figure 9. Dissolved Oxygen (mg/L) readings from the 2022 sampling events at the stream sites.*

Dissolved oxygen readings were taken during the rainfall dependent sampling event on December 1, 2022, at each of the stream sites, including three additional sites not included in the regular monthly samples. DO levels ranged from 10.55 mg/L to 12.56 mg/L (Figure 10). None of the readings were below the 6.5 mg/L threshold.

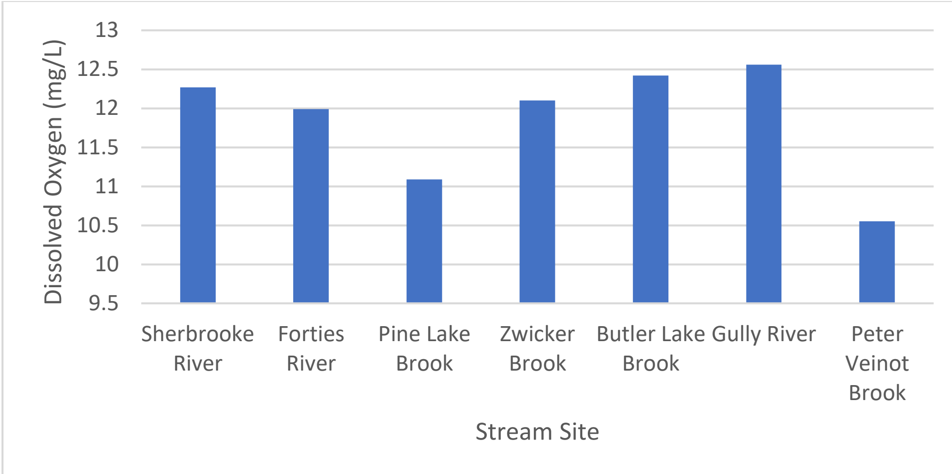



*Figure 10. Dissolved Oxygen (mg/L) readings from the 2022 rainfall dependent sampling event at the stream sites, including the additional, rainfall-specific sites.*

### 2.1.4 pH

pH, a measurement of the acidity of a liquid, was recorded in June, August and September at all lake and stream sites, except Lake 3 which was not sampled. pH readings were also taken during a rainfall dependent sampling event in December at all stream sites, including the additional, rainfall-specific sites. Although the pH measurements for most sites fell below the 6.5-pH threshold set by the CCME (CCME 2002), the acidity of SL waters is not uncommon for southwest NS lakes. As Nova Scotia has experienced high amounts of acid precipitation in the past, and its geology limits the replenishment of base cations to soils (NSSA 2015), surface waters in southwest Nova Scotia are generally lower than the 6.5-pH threshold. In addition, though the Sherbrooke Lakes' pH values are lower than 6.5 pH, many fish species can survive in waters >5.0-pH (NSSA 2014) and therefore it appears that most of the time, the acidity of the waters at SL poses minimal threat to organisms, except for some stream sites.

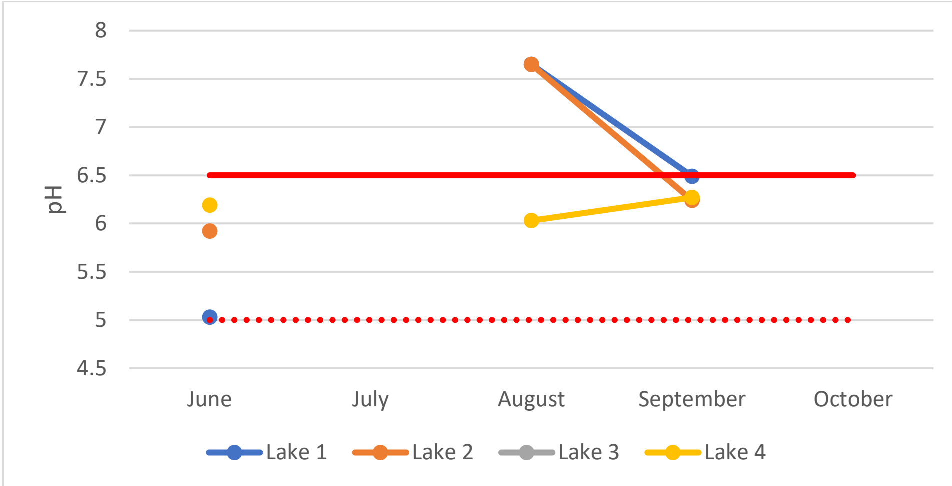



*Figure 11. pH readings from the 2022 monthly sampling events at the lake sites. The solid red line indicates the 6.5 pH threshold set by CCME, and the dotted red line indicates the 5.0 pH threshold identified by NSSA.*

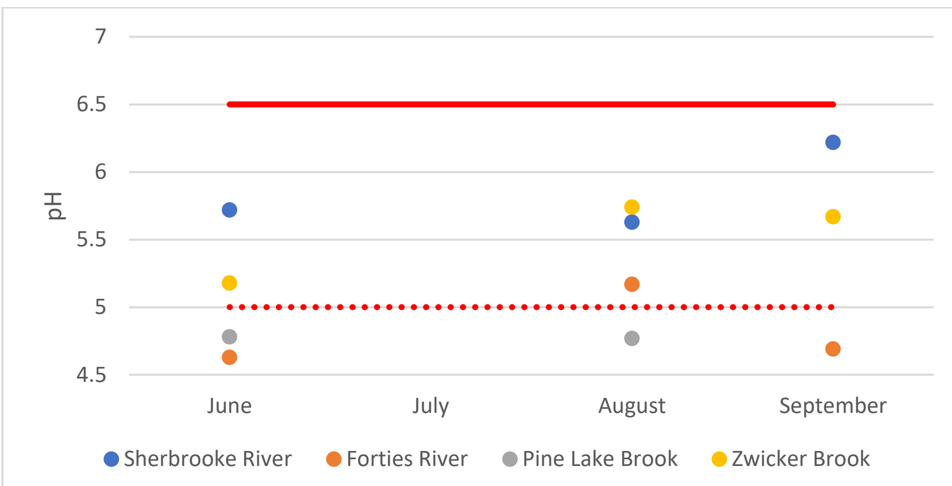



*Figure 12. pH readings from the 2022 sampling events at the stream sites. The solid red line indicates the 6.5 threshold set by CCME, and the dotted red line indicates the 5 threshold identified by NSSA.*

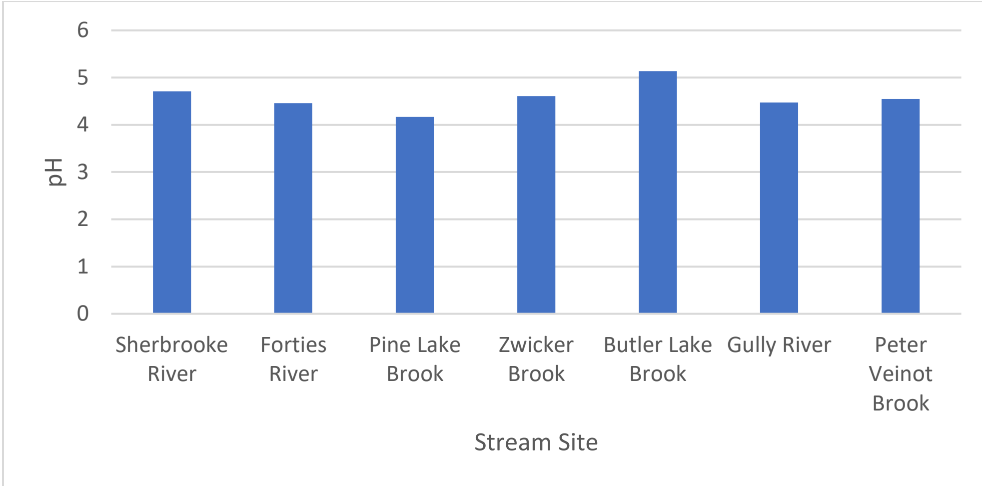



*Figure 13. pH readings from the 2021 rainfall dependent sampling event at the stream sites, including the additional, rainfall-specific sites.*

### 2.1.5 Total Dissolved Solids

Total Dissolved Solids (TDS) were recorded in June, August and September at all lake and stream sites, except Lake 3 which was not sampled. TDS readings were also taken during a rainfall dependent sampling event in December at all stream sites, including the additional, rainfall-specific sites. TDS readings at the lake sites ranged from 14 mg/L to 16 mg/L (Figure 14), and 2 mg/L to 27 mg/L at the stream sites (Figure 15). The highest reading of all lake sites was taken in August, and the highest reading of the stream sites was taken at Zwicker Brook in August.

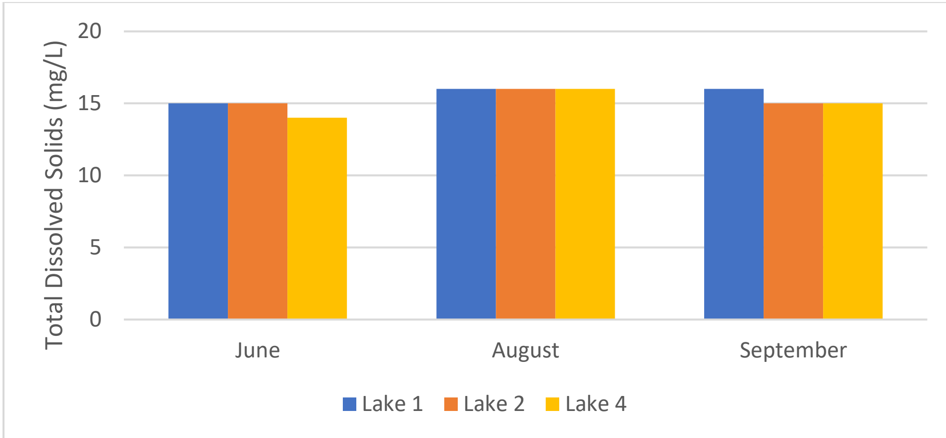



*Figure 14. Total Dissolved Solids (mg/L) readings from the 2022 monthly sampling events at the lake sites.*

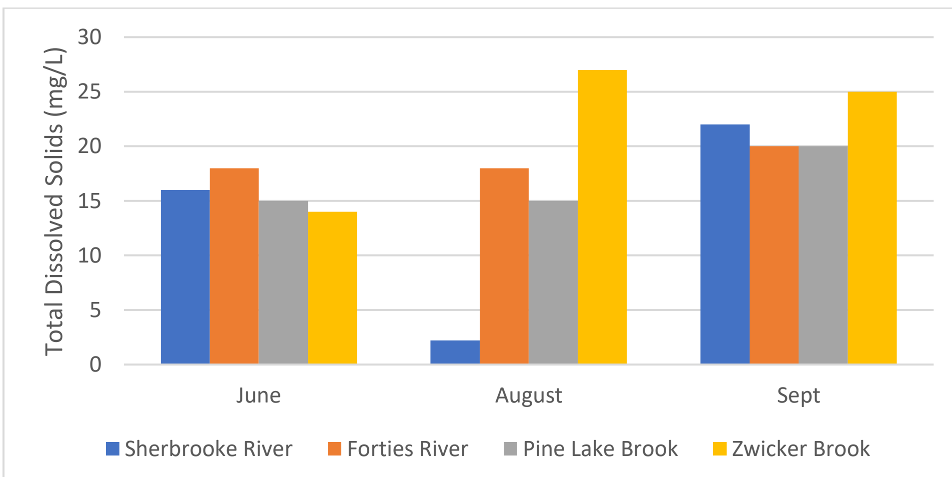



*Figure 15. Total Dissolved Solids (mg/L) readings from the 2022 sampling events at the stream sites.*

Total Dissolved Solids readings were taken during a rainfall dependent sampling event on December 1, 2022, at each of the stream sites, including three additional sites not included in the regular monthly samples. TDS levels ranged from 19.5 mg/L to 27.3 mg/L (Figure 16).

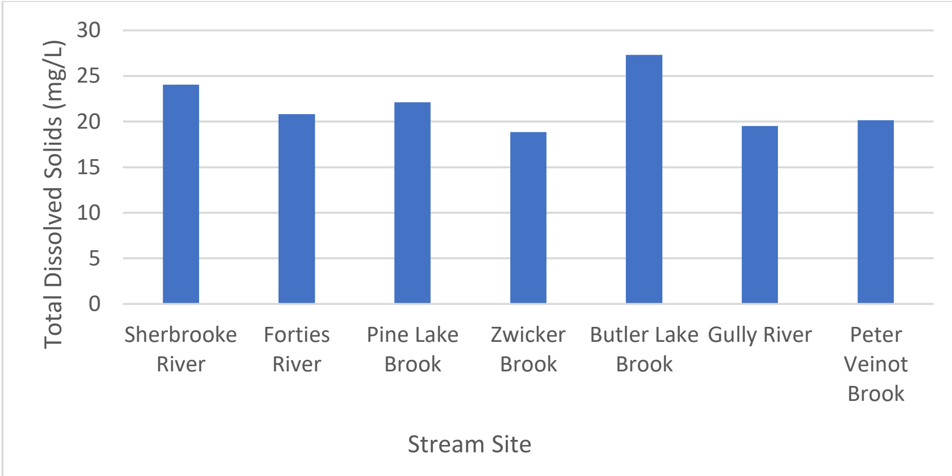



*Figure 16.Total Dissolved Solids (mg/L) readings from the 2022 rainfall dependent sampling event at the stream sites, including the additional, rainfall-specific sites.*

There is no guideline for TDS set by the CCME for the protection of aquatic health; however, Hinch and Underwood (1985) found that pristine Nova Scotian lakes had an average of 20 mg/L. The presence of high TDS is not necessarily harmful as dissolved materials can be from both anthropogenic and natural sources. As TDS does not have a guideline for the protection of aquatic organisms, TDS concentrations do not appear to be detrimental to Sherbrooke Lake.

## 2.2 Chemical Water Quality Parameters

### 2.2.1 Total Suspended Solids

Total Suspended Solids (TSS) were measured as the value of solids suspended in a water column that do not pass through a 45 µm glass fibre filter. Samples were recorded in June, August, and September at all lake sites, except Lake 3 which was not sampled (Figure 17). The stream sites were also sampled in June, August, and September (Figure 18). TSS samples were also taken during a rainfall dependent sampling event in December at all stream sites, including the additional, rainfall-specific sites. In some cases, TSS concentrations were so low that lab results displayed a 'not detected' (ND) reading. The TSS samples from the lake sites ranged from ND to 1.2 mg/L, and from ND to 25 mg/L at the stream sites.

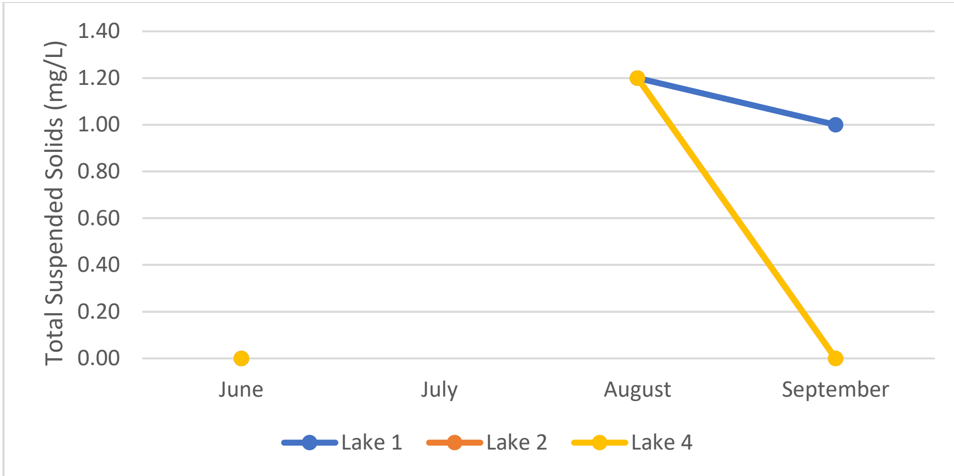



*Figure 17. Total Suspended Solids (mg/L) readings from the 2022 monthly sampling events at the lake sites. Lake 1, Lake 2 and Lake 4 had readings of 1.2 mg/L in August. Values of 0 are not detected.*

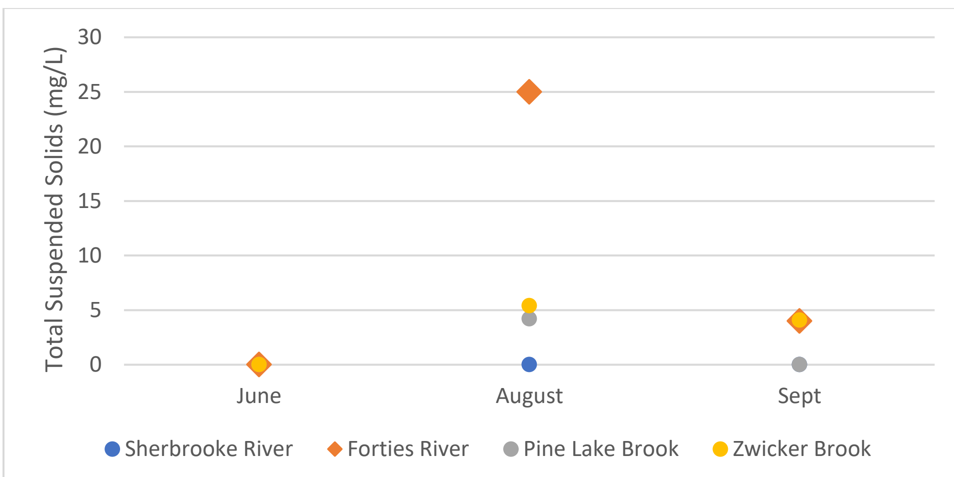



*Figure 18. Total Suspended Solids (mg/L) readings from the 2022 sampling events at the stream sites. Values of 0 are not detected.*

Total Suspended Solids samples were taken during a rainfall dependent sampling event on December 1, 2022, at each of the stream sites, including three additional sites not included in the regular monthly samples. TSS levels ranged from ND to 2.4 mg/L (Figure 19).

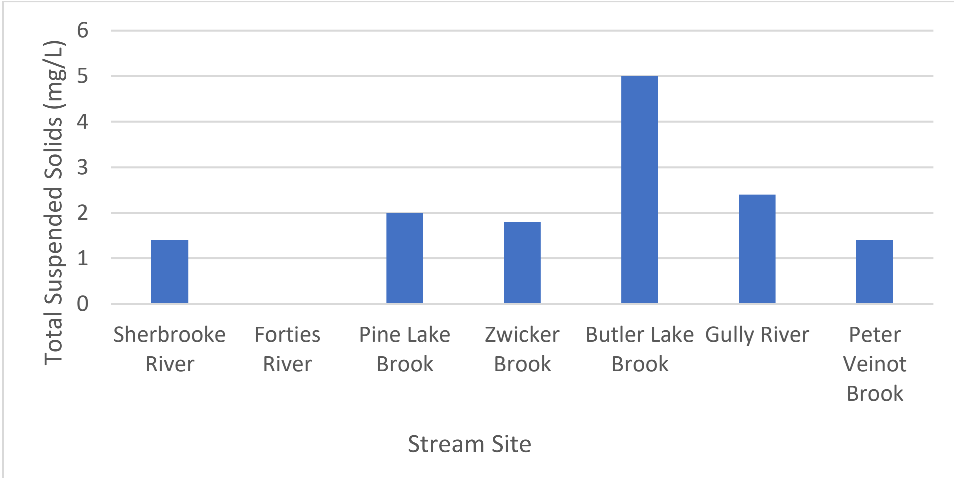


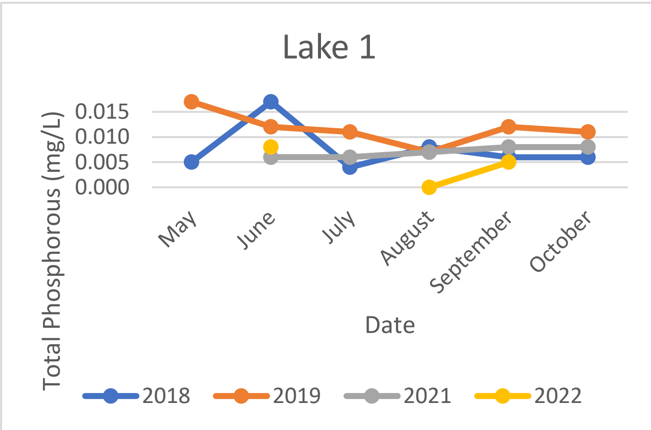

*Figure 19. Total Suspended Solids (mg/L) readings from the 2021 rainfall dependent sampling event at the stream sites, including the additional, rainfall-specific sites. TSS was not detected at Forties River.*

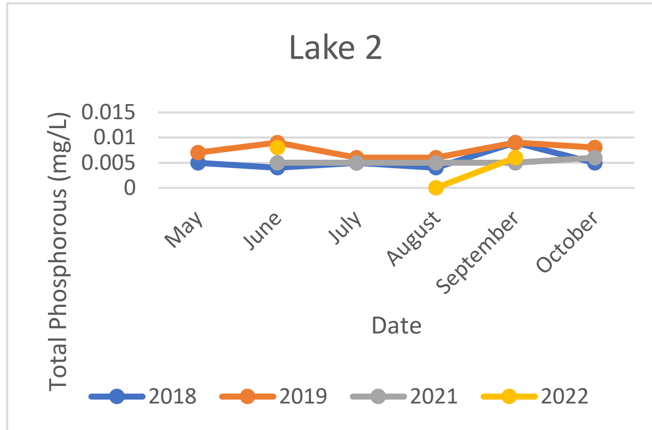
As the CCME has a guideline of a 10 mg/L allowable increase from baseline in waterbodies with TSS ≤ 100 mg/L (CCME 2002), the levels observed in 2022 are not a threat to aquatic organisms.

### 2.2.2 Total Phosphorus

Total phosphorus (TP) levels were recorded in June, August and September at all lake and stream sites, except Lake 3 which was not sampled. TP readings were also taken during a rainfall dependent sampling event in December at all stream sites, including the additional, rainfall-specific sites. TP readings at the lake sites ranged from not detected (ND) to 0.008 mg/L, and 0.012 mg/L to 0.033 mg/L at the stream sites. The highest lake concentration was observed at all lake sites in August, and the highest concentration of the stream sites was observed at Pine Lake Brook in August. Compared to the previous years, TP levels in the Lake sites have been less varied, and lower in 2022; however, data from May, July, September and October are missing for 2022 (Figure 20).

Ontario's Ministry of Environment and Climate Change (MOECC) has established two guidelines for phosphorus in water bodies: ≤ 0.02 mg/L for lakes, and ≤ 0.03 mg/L for rivers and streams (Ontario's Ministry of Environment [MOE] 1979). TP concentrations in the lake did not exceed the MOECC guidelines. Pine Lake Brook exceeded the threshold of 0.03 mg/L in August.



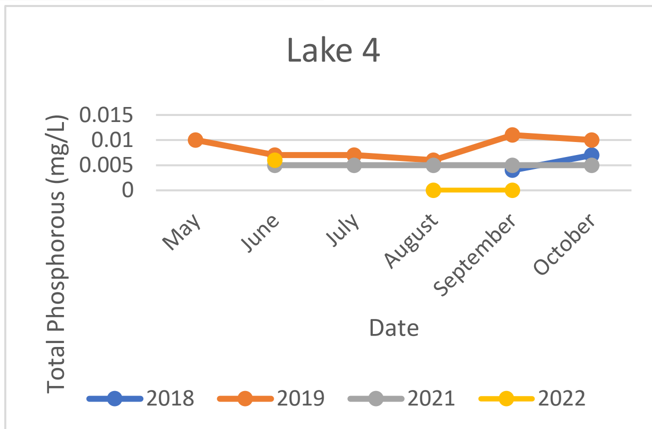




*Figure 20. Total Phosphorus (mg/L) levels from Lake 1, 2, and 4 from 2018, 2019, 2021, and 2022.*

Total phosphorus samples were taken during a rainfall dependent sampling event on December 1, 2022, at each of the stream sites, including three additional sites not included in the regular monthly samples. TP levels ranged from 0.007 mg/L to 0.015 mg/L (Figure 22).

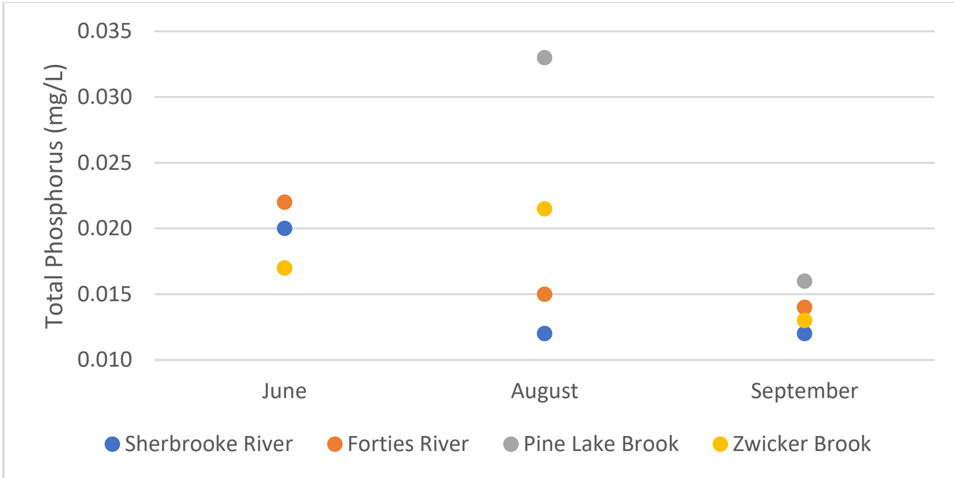



*Figure 21. Total Phosphorus (mg/L) readings from the 2022 sampling events at the stream sites.*

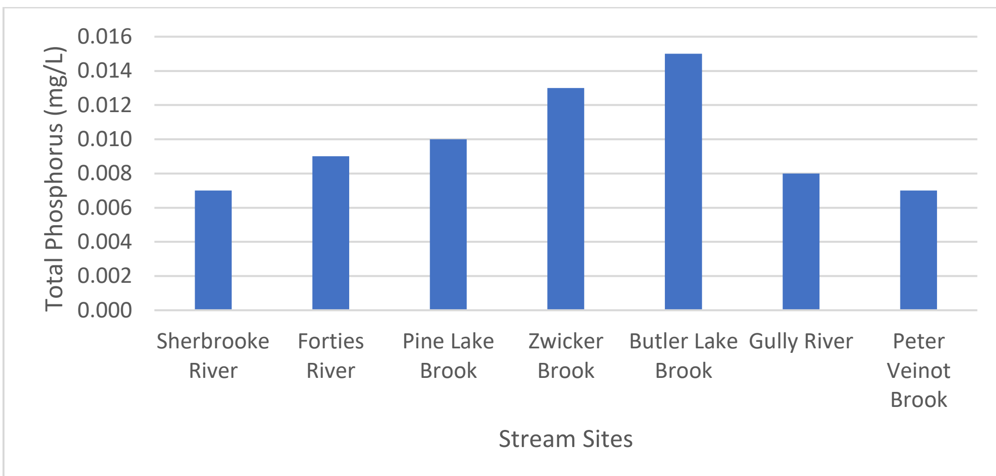



*Figure 22. Total Phosphorus (mg/L) readings from the 2022 rainfall dependent sampling event at the stream sites, including the additional, rainfall-specific sites.*

In September, Total Phosphorus samples were taken below the thermocline at Lake 1 and Lake 2. Results show 0.008 mg/L at Lake 1, and 0.006 mg/L at Lake 2. These results do not exceed the MOECC guidelines and are similar to the surface Total Phosphorus levels.

### 2.2.3 Total Nitrogen

Total Nitrogen (TN) levels were recorded in June, August and September at all lake and stream sites, except Lake 3 which was not sampled. TN readings were also taken during a rainfall dependent sampling event in December at all stream sites, including the additional, rainfall-specific sites. TN readings at the lake sites ranged from 0.201 mg/L to 0.238 mg/L (Figure 23), and 0.396 mg/L to 0.781 mg/L at the stream sites (Figure 24). The highest concentration at the lake sites occurred at Lake 2 in August, and the highest stream concentration occurred at Pine Lake Brook in August.

Total Nitrogen samples were taken during a rainfall dependent sampling event on December 1, 2022, at each of the stream sites, including three additional sites not included in the regular monthly samples. TN levels ranged from 0.386 mg/L to 0.510 mg/L (Figure 25). Dodds and Welch (2000) have established a guideline for nitrogen in waterbodies of 0.9 mg/L. This guideline was not approached or exceeded by any sites.

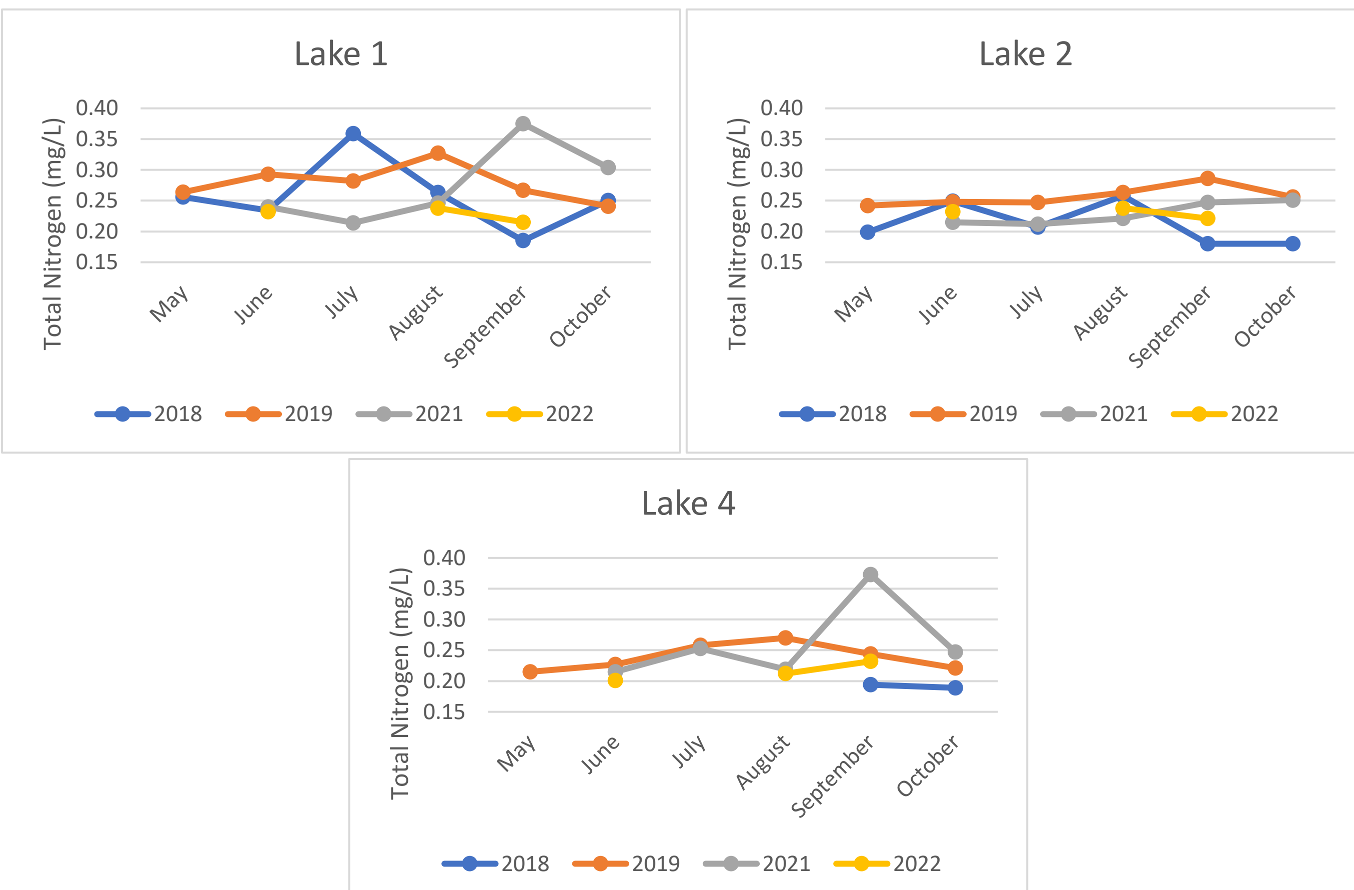



*Figure 23. Total Nitrogen (mg/L) levels from Lake 1, 2, and 3 from 2018, 2019, and 2021.*

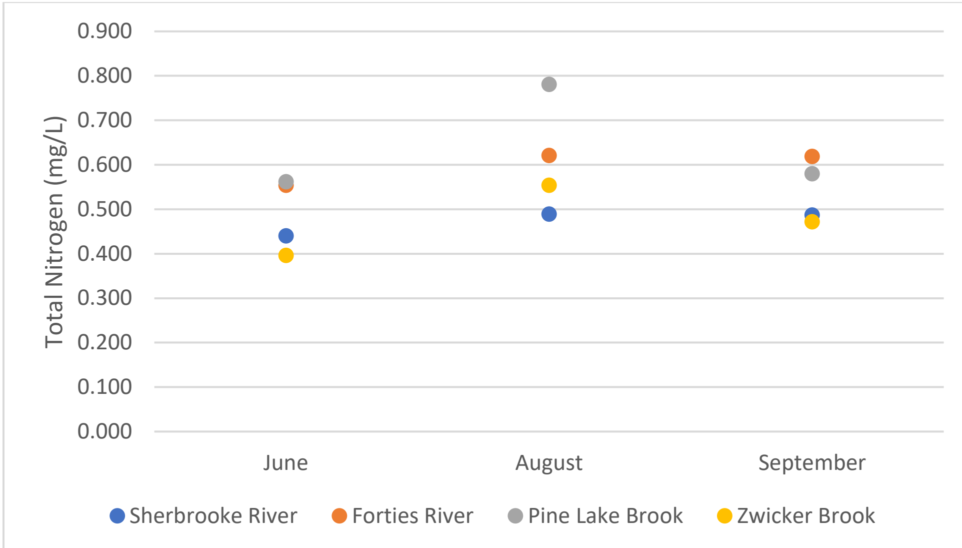



*Figure 24. Total Nitrogen (mg/L) readings from the 2022 sampling events at the stream sites.*

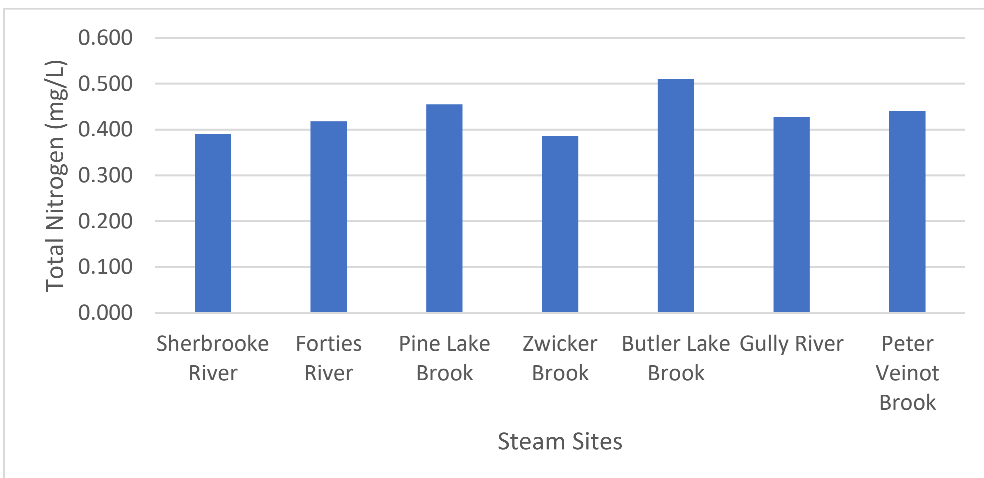



*Figure 25. Total Nitrogen (mg/L) readings from the 2022 rainfall dependent sampling event at the stream sites, including the additional, rainfall-specific sites*

Total Nitrogen concentrations were measured below the thermocline at Lake 1 and Lake 2. Results show 1.47 mg/L at Lake 1, and 0.361 mg/L at Lake 2. The results from Lake 1 exceeded the Dodds and Welch guideline of 0.9 mg/L. Higher nitrogen concentrations below the thermocline may indicate a possible nutrient-enrichment event during fall turnover, with a potential for eutrophication and algal blooms.

## 2.3 Biological Water Quality Parameters

### 2.3.1 Fecal Bacteria

*E. coli* samples were taken in June, August, and September at all lake and stream sites. Readings were also taken during a rainfall dependent sampling event in December at all stream sites, including the additional, rainfall-specific sites. *E. coli* readings at the lake sites ranged from not detected (ND) to 2 CFU/100 mL, and not detected to 370 CFU/100 mL at the stream sites (Figure 27). Of the 12 total *E. coli* samples taken at the lake sites, only four showed any detectable concentrations. The samples collected in August at Lake 1, Lake 3, and Lake 4, as well as Lake 4 in September, showed 2 CFU/100 mL. All other samples did not detect any *E. coli.* The highest concentration was observed at Sherbrooke River in August (Figure 26).

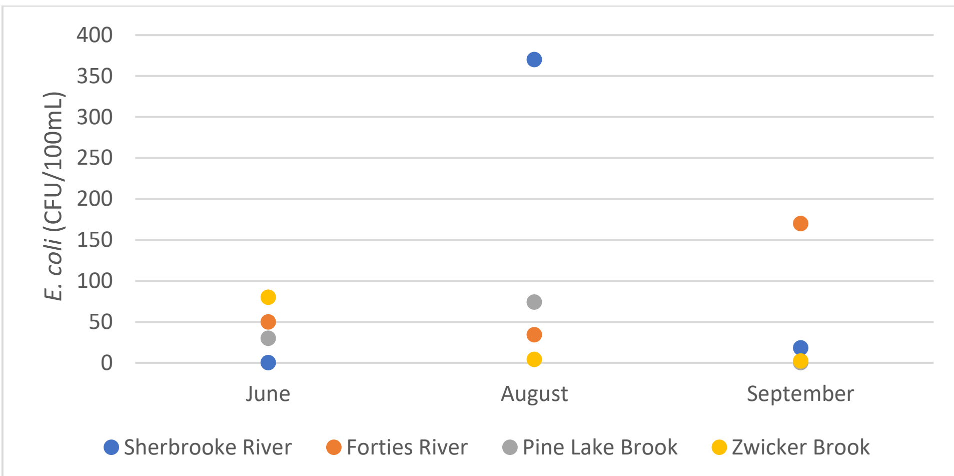



*Figure 26. E. coli (CFU/100 mL) readings from the 2022 sampling events at the stream sites.*

*E. coli* samples were taken during a rainfall dependent sampling event on December 1, 2022, at each of the stream sites, including three additional sites not included in the regular monthly samples. *E. coli* concentrations ranged from 30 CFU/100 mL to 550 CFU/100 mL (Figure 27).

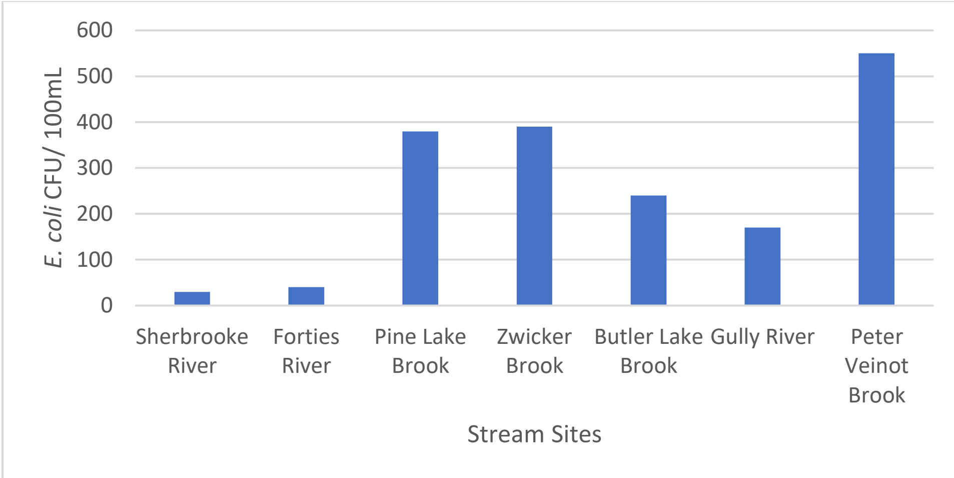



*Figure 27. E. coli (CFU/100 mL) readings from the 2022 rainfall-dependent sampling event at the stream sites, including the additional, rainfall-specific sites.*

Health Canada has set primary and secondary recreational contact guidelines for *E. coli* in freshwaters, ≤400 CFU/100 mL and ≤1000 CFU/100 mL, respectively (Health Canada 2012). Sherbrooke River approached this guideline in August. Pine Lake Brook and Zwicker Brook also approached this guideline in the rainfall dependent sample. Peter Veinot Brook exceeded the primary guideline of 400 CFU/100 mL in the rainfall-dependent sample.

### 2.3.2 Microcystin-LR & Algal Blooms

The recreational guideline for cyanobacterial toxins – Microcystin-LR is 10 µg/L (Health Canada 2012). This guideline is meant to protect against exposure to microcystins and other toxins that may be present in an algal bloom. Microcystin-LR can persist in aquatic environments after a visible bloom has dissipated (Jones and Orr 1994).

Not all algal blooms are toxic cyanobacteria blooms, and Microcystin-LR is only one of the possible toxins in a cyanobacteria bloom. For this reason, every algal bloom should be treated with caution and reported to Nova Scotia Environment (NSE).

An algal bloom was reported at the North East section of the lake along the shoreline of Sherbrooke Forest in 2022. This bloom dissipated before volunteers could sample it.

## 2.4 Sediment Sampling

Sediment sampling at sites Lake 1, 2, and 4 has occurred each year since 2018. Sediment samples are collected from one stream each year. In 2022, the bottom substrate was analyzed for metals, phosphorus, and orthophosphate, to assess the risk of internal nutrient loading within the lake and the potential risk from the accumulation of metals within the sediments.

### 2.4.1 Metals

Three guidelines are used for sediment analysis; the CCME's recommended Interim Sediment Quality Guideline (ISQG), the CCME's Probable Effect Levels (PEL), and the Nova Scotia Environmental Quality Standards (NSEQS) contamination threshold. Sediment samples are collected annually from the lake sites and one stream site. In 2018, Lake 2, Lake 3, and Forties River were sampled. In 2019, and 2021 Lake 1, Lake 2, and Lake 4 were sampled. The 2019 stream was Zwicker Brook and the 2021 stream was Sherbrooke River.

Arsenic concentrations were noticeably high and exceeded the ISQG guidelines at all lake sites every year except at Lake 1 in 2021. In 2018 and 2019, Lake 2 had the highest recorded levels of arsenic, with 2018 levels approaching the PEL & NSEQS guidelines. Increased arsenic levels reduce the abundance of benthic invertebrates, the main food source for many aquatic species (CCME 2002). Of the four stream sites sampled, none have arsenic levels of concern, and no metal concentrations show levels approaching any of the guidelines. Arsenic levels increased from 2021 to 2022 at Lakes 1 and 2, whereas Lake 4 had a slight decrease of 1.5 mg/kg.

Cadmium levels exceeded the ISQG guidelines at all lake sites in all years except at Lake 1 and Lake 2 in 2021. The highest cadmium concentration recorded was 1.5 mg/kg at Lake 3 in 2018. Like arsenic, cadmium reduces the abundance of benthic invertebrates and damages aquatic species. However, cadmium levels are generally low at all sites and were not detected at any of the stream sites. The highest concentration recorded only exceeded the ISQG guidelines by 0.9 mg/kg.

Lead levels were low at all sites each year, with only the ISQG guideline being exceeded in 2018 and 2022 at Lake 2. At Lake 1 in 2019, the ISQG guideline was approached but not exceeded with a level of 34 mg/kg. Lead levels at the stream sites were very low in all years. Lead can reduce the abundance of benthic invertebrates, and depending on the physicochemical conditions, can be harmful to other aquatic organisms (CCME 2002).

Mercury levels are relatively high at all lake sites. The ISQG guideline was either exceeded or approached at each lake site each year except Lake 4 in 2019. The level of mercury increased at each site from 2021 to 2022. Mercury was not detected at any of the stream sites.

Selenium levels approached the NSEQ guideline at Lake 2 in 2018, 2021, and 2022, and at Lake 4 in 2021. Selenium was undetected at all stream sites.

*Table 1. Concentrations of metals within Lake site sediment samples. Light yellow indicates parameters approaching one of the guidelines, orange indicates an exceedance of ISQG, and red indicates an exceedance of either the PEL or NSEQS guidelines.*

| | **UNITS** | **Lake 1** | | | **Lake 2** | | | | **Lake 3** | **Lake 4** | | | **Concentration Guidelines** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Metals** | | 2019 | 2021 | 2022 | 2018 | 2019 | 2021 | 2022 | 2018 | 2019 | 2021 | 2022 | **ISQG** | **PEL** | **NS** |
| Acid Extractable Aluminum (Al) | mg/kg | 22000 | 12000 | 18000 | 22000 | 25000 | 16000 | 18000 | 6700 | 7200 | 22000 | 20000 | | | |
| Acid Extractable Antimony (Sb) | mg/kg | ND | ND | <2 (ND) | ND | ND | ND | <2 (ND) | ND | ND | ND | <2 (ND) | | | 25 |
| Acid Extractable Arsenic (As) | mg/kg | 8.4 | 4.8 | 6.8 | 16 | 12 | 6.8 | 12 | 8.3 | 8.1 | 9.8 | 8.3 | 5.9 | 17 | 17 |
| Acid Extractable Barium (Ba) | mg/kg | 49 | 26 | 42 | 42 | 50 | 30 | 35 | 26 | 17 | 35 | 33 | | | |
| Acid Extractable Beryllium (Be) | mg/kg | ND | ND | 1.5 | ND | 2.1 | ND | 1.6 | ND | ND | ND | 1.5 | | | |
| Acid Extractable Bismuth (Bi) | mg/kg | ND | ND | <2 (ND) | ND | ND | ND | <2 (ND) | ND | ND | ND | <2 (ND) | | | |
| Acid Extractable Boron (B) | mg/kg | ND | ND | <50 (ND) | ND | ND | ND | <50 (ND) | ND | ND | ND | <50 (ND) | | | |
| Acid Extractable Cadmium (Cd) | mg/kg | 0.76 | 0.31 | 0.69 | 1 | 0.99 | 0.46 | 0.81 | 1.5 | 0.76 | 0.63 | 0.66 | 0.6 | 3.5 | 3.5 |
| Acid Extractable Chromium (Cr) | mg/kg | 15 | 8 | 13 | 14 | 14 | 8.7 | 11 | 4.6 | 5.1 | 14 | 12 | 37.3 | 90 | 90 |
| Acid Extractable Cobalt (Co) | mg/kg | 9 | 4.3 | 5.7 | 8.8 | 11 | 5.2 | 5.7 | 6.8 | 4.1 | 6.6 | 6.2 | | | |
| Acid Extractable Copper (Cu) | mg/kg | 12 | 6 | 9.3 | 15 | 10 | 6.1 | 8.7 | 13 | 3.1 | 9.5 | 8.4 | 35.7 | 197 | 197 |
| Acid Extractable Iron (Fe) | mg/kg | 14000 | 6600 | 9300 | 14000 | 15000 | 9100 | 11000 | 10000 | 9400 | 9000 | 8400 | | | 47,766 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Acid Extractable Lead (Pb) | mg/kg | 34 | 8.8 | 30 | 49 | 24 | 8 | 43 | 13 | 13 | 8.9 | 17 | 35 | 91.3 | 91.3 |
| Acid Extractable Lithium (Li) | mg/kg | 17 | 8 | 15 | 10 | 9.7 | 4.9 | 8.9 | 11 | 14 | 13 | 12 | | | |
| Acid Extractable Manganese (Mn) | mg/kg | 540 | 230 | 260 | 480 | 1300 | 430 | 380 | 1000 | 290 | 460 | 420 | | | 1,100 |
| Acid Extractable Mercury (Hg) | mg/kg | 0.27 | 0.15 | 0.25 | 0.27 | 0.2 | 0.12 | 0.21 | 0.16 | ND | 0.12 | 0.14 | 0.17 | 0.486 | 0.486 |
| Acid Extractable Molybdenum (Mo) | mg/kg | ND | ND | <2 (ND) | ND | 2 | ND | <2 (ND) | ND | ND | 2 | <2 (ND) | | | |
| Acid Extractable Nickel (Ni) | mg/kg | 10 | 4.9 | 8 | 7.5 | 6.9 | 4.3 | 5.8 | 5.7 | 4.6 | 8.7 | 7.2 | | | 75 |
| Acid Extractable Phosphorus (P) | mg/kg | 1900 | | 1600 | 1900 | 2200 | | 1600 | 400 | 490 | | 1700 | | | |
| Acid Extractable Rubidium (Rb) | mg/kg | 11 | 5.9 | 9.5 | 6.3 | 6.2 | 3.5 | 5.2 | 4.7 | 5.5 | 7 | 6.5 | | | |
| Acid Extractable Selenium (Se) | mg/kg | 1.3 | 0.89 | 1.2 | 1.8 | 1.8 | 1.1 | 1.5 | ND | ND | 1.7 | 1.5 | | | 2 |
| Acid Extractable Silver (Ag) | mg/kg | ND | ND | <0.5 (ND) | ND | ND | ND | <0.5 (ND) | ND | ND | ND | <0.5 (ND) | | | 1 |
| Acid Extractable Strontium (Sr) | mg/kg | 13 | 6.1 | 9.3 | 13 | 13 | 8.1 | 9.6 | ND | ND | 8.7 | 7.8 | | | |
| Acid Extractable Thallium (Tl) | mg/kg | 0.26 | 0.13 | 0.18 | 0.26 | 0.24 | 0.13 | 0.17 | 0.34 | 0.11 | 0.31 | 0.21 | | | |
| Acid Extractable Tin (Sn) | mg/kg | 2.5 | ND | 2 | 3 | 1.5 | ND | 2.1 | 2 | ND | ND | 1.1 | | | |
| Acid Extractable Uranium (U) | mg/kg | 4.3 | 2.6 | 3.5 | 5.7 | 6.5 | 3.7 | 4.3 | 1.7 | 2 | 7.3 | 5.7 | | | |
| Acid Extractable Vanadium (V) | mg/kg | 23 | 12 | 17 | 30 | 34 | 21 | 25 | 11 | 12 | 24 | 22 | | | |
| Acid Extractable Zinc (Zn) | mg/kg | 87 | 46 | 71 | 93 | 89 | 48 | 70 | 96 | 66 | 110 | 100 | 123 | 315 | 315 |
| Orthophosphate (P) | mg/kg | 0.15 | 0.39 | 0.51 | 0.067 | 0.086 | 0.27 | 0.24 | 0.26 | 0.24 | 0.24 | 0.26 | | | |

*Table 2. Concentrations of metals within stream site sediment samples.*

| | UNITS | Forties River | Zwicker Brook | Sherbrooke River | Pine Lake Brook | Concentration Guidelines | | |
|---|---|---|---|---|---|---|---|---|
| **Metals** | | 2018 | 2019 | 2021 | 2022 | **ISQG** | **PEL** | **NS** |
| Acid Extractable Aluminum (Al) | mg/kg | 4300 | 4700 | 3300 | 730 | | | |
| Acid Extractable Antimony (Sb) | mg/kg | ND | ND | ND | ND | | | 25 |
| Acid Extractable Arsenic (As) | mg/kg | 2.7 | ND | ND | ND | 5.9 | 17 | 17 |
| Acid Extractable Barium (Ba) | mg/kg | 26 | 18 | 18 | ND | | | |
| Acid Extractable Beryllium (Be) | mg/kg | ND | ND | ND | ND | | | |
| Acid Extractable Bismuth (Bi) | mg/kg | ND | ND | ND | ND | | | |
| Acid Extractable Boron (B) | mg/kg | ND | ND | ND | ND | | | |
| Acid Extractable Cadmium (Cd) | mg/kg | ND | ND | ND | ND | 0.6 | 3.5 | 3.5 |
| Acid Extractable Chromium (Cr) | mg/kg | 4.7 | 4 | 4 | ND | 37.3 | 90 | 90 |
| Acid Extractable Cobalt (Co) | mg/kg | 2.3 | 2.2 | 1.9 | ND | | | |
| Acid Extractable Copper (Cu) | mg/kg | ND | 4.2 | ND | ND | 35.7 | 197 | 197 |
| Acid Extractable Iron (Fe) | mg/kg | 8300 | 6800 | 5800 | 1200 | | | 47,766 |
| Acid Extractable Lead (Pb) | mg/kg | 3.3 | 3.3 | 4.2 | 1 | 35 | 91.3 | 91.3 |
| Acid Extractable Lithium (Li) | mg/kg | 20 | 21 | 16 | 4.1 | | | |
| Acid Extractable Manganese (Mn) | mg/kg | 200 | 110 | 150 | 40 | | | 1,100 |
| Acid Extractable Mercury (Hg) | mg/kg | ND | ND | ND | ND | 0.17 | 0.486 | 0.486 |
| Acid Extractable Molybdenum (Mo) | mg/kg | ND | ND | ND | ND | | | |
| Acid Extractable Nickel (Ni) | mg/kg | 2.3 | 3.1 | 2.2 | ND | | | 75 |
| Acid Extractable Phosphorus (P) | mg/kg | 180 | 190 | | ND | | | |
| Acid Extractable Rubidium (Rb) | mg/kg | 17 | 7.8 | 11 | 3.1 | | | |
| Acid Extractable Selenium (Se) | mg/kg | ND | ND | ND | ND | | | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Acid Extractable Silver (Ag) | mg/kg | ND | ND | ND | ND | | | 1 |
| Acid Extractable Strontium (Sr) | mg/kg | ND | ND | ND | ND | | | |
| Acid Extractable Thallium (Tl) | mg/kg | 0.12 | ND | ND | ND | | | |
| Acid Extractable Tin (Sn) | mg/kg | ND | ND | ND | ND | | | |
| Acid Extractable Uranium (U) | mg/kg | 0.52 | 0.77 | 0.46 | 0.17 | | | |
| Acid Extractable Vanadium (V) | mg/kg | 11 | 9 | 7.3 | ND | | | |
| Acid Extractable Zinc (Zn) | mg/kg | 20 | 34 | 20 | ND | 123 | 315 | 315 |
| Orthophosphate (P) | mg/kg | 0.28 | 0.38 | 0.36 | 0.79 | | | |

*Table 3. Summary of guideline exceedances of metals in sediment samples. Light yellow indicates parameters approaching one of the guidelines, orange indicates an exceedance of the ISQG, and red indicates an exceedance of either the PEL or NSEQS guidelines*

| | **UNITS** | **Lake 1** | | | **Lake 2** | | | | **Lake 3** | **Lake 4** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Metals** | | 2019 | 2021 | 2022 | 2018 | 2019 | 2021 | 2022 | 2018 | 2019 | 2021 | 2022 |
| Acid Extractable Arsenic (As) | mg/kg | 8.4 | 4.8 | 6.8 | 16 | 12 | 6.8 | 12 | 8.3 | 8.1 | 9.8 | 8.3 |
| Acid Extractable Cadmium (Cd) | mg/kg | 0.76 | 0.31 | 0.69 | 1 | 0.99 | 0.46 | 0.81 | 1.5 | 0.76 | 0.63 | 0.66 |
| Acid Extractable Lead (Pb) | mg/kg | 34 | 8.8 | 30 | 49 | 24 | 8 | 43 | 13 | 13 | 8.9 | 17 |
| Acid Extractable Mercury (Hg) | mg/kg | 0.27 | 0.15 | 0.25 | 0.27 | 0.2 | 0.12 | 0.21 | 0.16 | ND | 0.12 | 0.14 |

## 2.4.2 Sediment Phosphorus and Orthophosphate

Concentrations of both acid-extractable (total) phosphorus and bioavailable orthophosphate in sediment were analyzed from 2018 to 2022, with total phosphorus being excluded from the 2021 sample.

*Table 4. Orthophosphate and Total Phosphorus levels from the annual sediment samples at the Lake and Stream Sites. FR = Forties River; ZB = Zwicker Brook; SR = Sherbrooke River; PLB = Pine Lake Brook.*

| | **Lake 1** | | | **Lake 2** | | | | **Lake 3** | **Lake 4** | | | **FR** | **ZB** | **SR** | **PLB** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter (Units)** | **2019** | **2021** | **2022** | **2018** | **2019** | **2021** | **2022** | **2018** | **2019** | **2021** | **2022** | **2018** | **2019** | **2021** | **2022** |
| Orthophosphate in sediment (mg/kg) | 0.15 | 0.39 | 0.51 | 0.0067 | 0.086 | 0.27 | 0.24 | 0.26 | 0.24 | 0.24 | 0.26 | 0.33 | 0.38 | 0.36 | 0.79 |
| Acid extractable phosphorus in sediment (mg/kg) | 1900 | | 1600 | 1900 | 2200 | | 1600 | 400 | 490 | | 1700 | 180 | 190 | | ND |

Orthophosphate levels increased at all sites in 2022, except for Lake 2, which had a decrease of 0.03 in 2022. The sample results from Pine Lake Brook showed higher levels of orthophosphate than the three other stream sites sampled in previous years. According to Ontario's provincial sediment quality guidelines, pollution can range from clean/marginally polluted ('lowest effect level') at 600 mg/kg of phosphorus to heavily contaminated ('severe effect level') at >2000 mg/kg of phosphorus in sediment (Ontario MOE 2008). These guidelines have previously been approached and exceeded at Lake 1, Lake 2, and Lake 4, but not Lake 3 or stream sites.

Orthophosphate is a bioavailable form of phosphorus that tends to be in lower concentrations due to high demand by plants; however, as plants decompose, orthophosphate is released back into the environment (CCME 2004). For phosphorus held into complexes with metals, anoxic conditions facilitate the dissolution of complexes and release of phosphorus from sediments (Hayes, Reid, and Cameron 1985). Increased levels of phosphorus released from sediments into the water (internal phosphorus loading) can cause nutrient-enrichment and potential eutrophication and algal blooms (Sondergaard, Jensen, and Jeppesen 2003) – this is particularly susceptible during a turnover when nutrient-rich bottom waters are mixed throughout the lake, providing new food sources for organisms.

# 3.0 Discussion

Similar to 2018, 2019, and 2021 monitoring results, the water quality of Sherbrooke Lake and its tributaries did not identify any significant water quality issues in 2022. Only one bloom was reported in SL in 2022; however, sampling blooms and determining their toxicity remains a challenge. All visible blooms should be treated with caution and ongoing efforts will continue to improve the reporting and advisory process.

## 3.1 Algae Blooms in Sherbrooke Lake

NS Environment's current system of notifying lake residents of potentially harmful algae blooms is reactive and can be ineffective. NSE responds to reports of suspected blooms but inspectors are not always able to respond in time to witness the bloom. NSE rarely collects water samples for analysis and often has to post precautionary advisories based on the appearance of a bloom in photographs from residents. Lake closure advisories are posted via Twitter and other online locations.

Microcystin-LR is not the only toxin produced by cyanobacteria. Anatoxins, Cylindrospermopsins, Nodularins, Saxitoxins, Dermatoxtoxins, and other irritant toxins are also produced by cyanobacteria (Health Canada 2012). The majority of commercial labs in Canada do not test for these toxins. This means that the absence of Microcystin-LR in a water sample does not mean that a bloom does not contain other toxins. Because of this, lake residents should be made aware of all blooms and treat all blooms with the same level of caution.

As algal blooms can be induced and intensified by increases in nutrients to ecosystems (whether naturally from the mixing of waters or anthropogenically from pollution), trends in algal blooms are hard to predict and can vary spatially. The literature predicts increases in both size and frequency of blooms, globally, in the future (Michalak et al. 2013). Although nitrogen and phosphorus levels remain low, algal blooms should continue to be monitored and tested within Sherbrooke Lake, with residents made aware of algal bloom causes, health effects, precautions to take, and the reporting procedure if a bloom occurs.

## 3.2 Trophic State of Sherbrooke Lake

The biological productivity of SL has been assessed and monitored for changes over time by identifying its trophic state annually. Based on the mean depth of transparency (Secchi disk), and mean concentrations of chlorophyll-α and phosphorus, a Trophic State Index (TSI) score can be calculated using the Carlson (1977) equations (Equations 1, 2, and 3). Trophic states range from oligotrophic (low productivity and minimal biomass) to hypereutrophic (high productivity and maximum biomass). The following information was based on data collected from Lake sites 1, 2, and 4 in June, August and September of 2022.

$$Equation\ 1{:}\ TSI\ (Secchi\ disk) = 60 - 14.41 \times ln(Mean\ Secchi\ disk\ [m])$$

$$Equation\ 2{:}\ TSI\ (Chlorophyll\ A) = 30.6 + 9.81 \times ln(Mean\ Chlorophyll\ a\ \left[\frac{\mu g}{L}\right])$$

$$Equation\ 3{:}\ TSI\ (Total\ Phosphorus) = 4.15 + 14.42 \times ln(Mean\ Total\ Phosphorus\ \left[\frac{\mu g}{L}\right])$$

*Table 5. TSI values for all lake sites in 2022 for three parameters.*

| **Parameter** | **Calculated TSI Value** |
|---|---|
| Secchi disk (transparency) | 40.85 |
| Chlorophyll-α | 45.37 |
| Total Phosphorus | 31.11 |
| **TSI Value** | **39.11** |

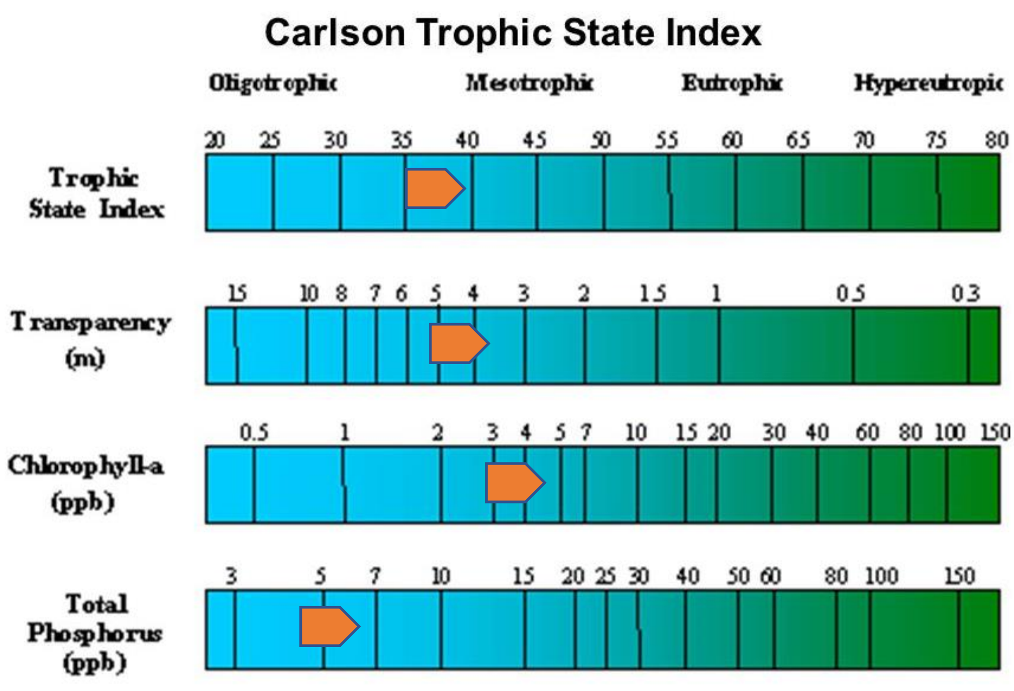



*Figure 28. Carlson TSI for Sherbrooke Lake in 2022 using the mean Secchi disk depth (transparency), mean chlorophyll α concentration and mean total phosphorus concentration. (Carlson 1977)*

The trophic state of SL in 2018 and 2019 was oligotrophic-mesotrophic. The transition from oligotrophic to mesotrophic is a TSI score of 40. In 2018 and 2019, the TSI was less than a 10th of a decimal over 40, therefore classifying the lake as mesotrophic. In 2021, the TSI score was 39.4, putting the lake into an oligotrophic state. The trophic state has remained oligotrophic in 2022, with a TSI score of 39.11. SL appears to be maintaining a steady TSI score over the four years this data has been collected (Figure 29). The Total Phosphorus remains the lowest of all TSI scores every year, while the Chlorophyll-a TSI score is the highest. Secchi depth readings are highly influenced by several factors; therefore, the TSI score for Total Phosphorus should be considered the most accurate reflection of biological productivity in SL, resulting in an oligotrophic status.

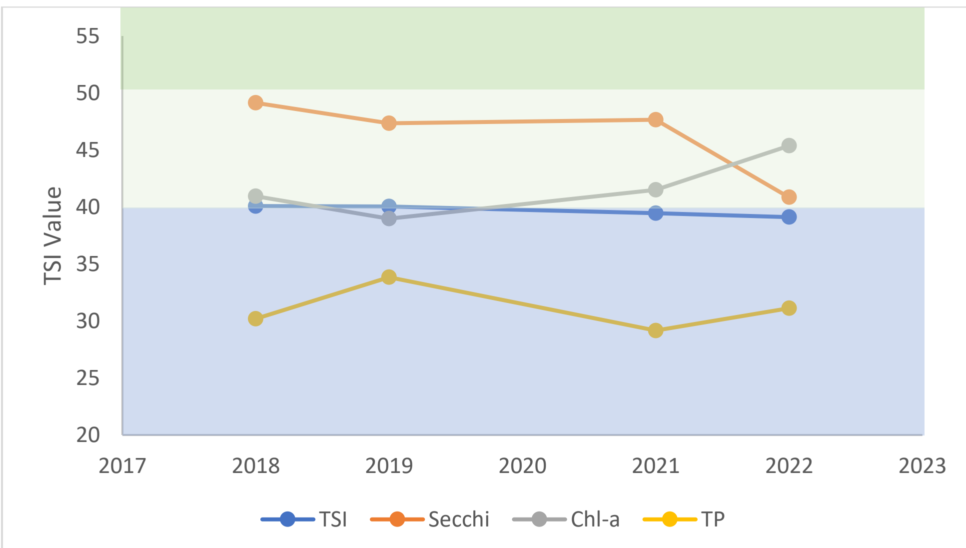



*Figure 29. Comparison of Lake site TSI scores from 2018 to 2022 using the Carlson (1977) trophic equations for total phosphorus, chlorophyll α, and Secchi disk (2020 excluded).*

## 4.0 Recommendations

The following recommendations are suggested for the Sherbrooke Lake Water Quality Monitoring Program:

1. The Sherbrooke Lake Water Quality Monitoring Program should continue in 2023 as this program was developed to establish a water quality baseline to aid in evidence-based decisions concerning the development of the public access property acquired by MODL for public use. Development at this site has yet to begin, meaning that further monitoring will continue to establish a baseline understanding of SL water quality before the potential impacts of this development start. The 2023 monitoring program will be the 5$^{th}$ and final year of baseline monitoring, as outlined in the initial project proposal.

2. When MODL decides to move forward with the park development and if they decide to re-establish the public access site planning committee, this committee should meet with the SLSC members to receive an update on the water quality program that was managed by SLSC and to discuss future monitoring activities that should be conducted. Any recommendations from these two committees would need to be presented to both the MODL and MODC councils.

3. Attempts should be made to identify a lake resident willing and able to host the SL weather station. The station should be installed as early as possible in the monitoring season and checked monthly to ensure it is working properly.

4. Monitoring of the seven inlet streams should continue during rainfall-dependent events, to determine how rainfall is affecting inlet streams.

5. Volunteer monitors should continue to be supplied with bottles for Microcystin-LR sample collection.

6. Algae blooms should continue to be monitored, recorded, and reported to Nova Scotia Environment. Efforts should continue to improve the reporting and advisory process between the NS Department of Environment and Climate Change, municipal units, and SL cottage associations.

7. Depth profiles at all lake sites should be continued during regular monitoring activity given the varying strength and depth of the thermocline observed at these sites in previous years and considering the elevated nutrient concentrations observed in deeper waters.

8. Sediment total phosphorus should be included in the final year of sampling. BV labs now require a separate analysis for this parameter.

## 5.0 Acknowledgements

This project is funded by the Municipality of the District of Lunenburg (MODL) and the Municipality of Chester (MOC). Coastal Action would like to thank the volunteers and Sherbrooke Lake Stewardship Committee for their contributions that made for a successful 2022 field season.

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