Sherbrooke Lake
2018 Water Quality Monitoring Report

Prepared for

Municipality of Chester

Municipality of the District of Lunenburg

Sherbrooke Lake Stewardship Committee

By

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1. Introduction

1.1. Sherbrooke Lake Background

Sherbrooke Lake (SL) is located in the headwaters of the LaHave River watershed, in Southern Nova Scotia. Sherbrooke Lake covers 16.94 km^2 – the largest waterbody within the LaHave watershed – and has a 285 km^2 drainage basin (Figure 1). Although SL is fed by 14 inlet streams, many are less than 1 km in length. Sherbrooke River is the largest inlet stream feeding SL, while North Branch is the only outlet stream of the lake - located on the South-Southwest side of the lake.

The water quality of the LaHave River watershed has been monitored by Coastal Action since 2007. The program monitors 15 sites throughout the watershed, including the Sherbrooke River which feeds the lake, and the lake's outlet downstream. A water quality index (WQI) report card of the status of the watershed and the individual sites is reported annually and available at the Coastal Action website (http://coastalaction.org/Wordpress/).

Forestry, silviculture, and agriculture dominate the LaHave River watershed and SL sub-watershed. Rural communities are also located throughout, with cottages and camps found along the edge of SL.

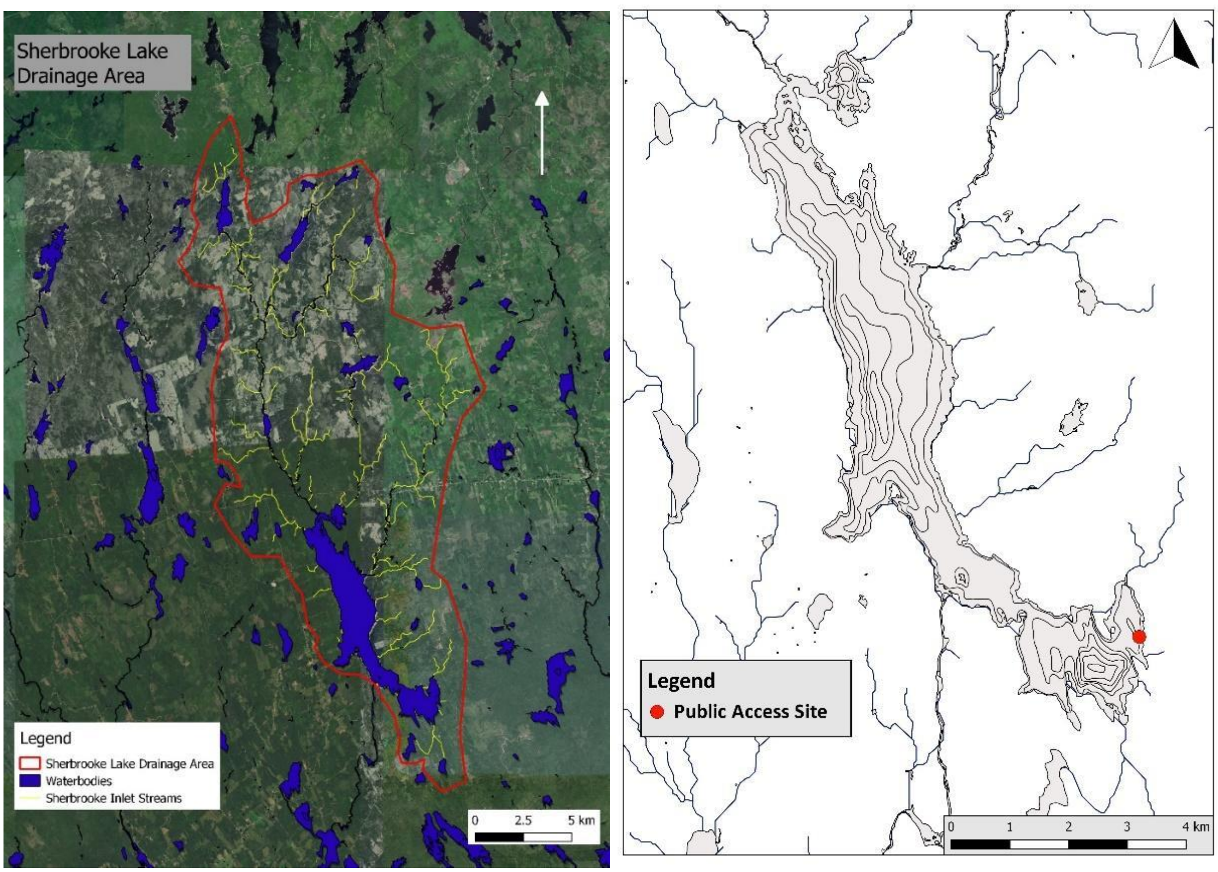

Figure 1: Left - Streams (yellow) and drainage boundary (red) of Sherbrooke Lake. Right – Bathymetry of Sherbrooke Lake and proposed public access site (red circle).

In 2015, the Municipality of the District of Lunenburg (MODL) began investigating ways to allow public access to the lake by appointing the Sherbrooke Lake Access Advisory Committee (SLAAC). SLAAC was to present options for accessing SL, and to obtain community advice and input throughout the process. After public consultations, held by UPLAND Planning + Design, a section of land on the South-Eastern side of the lake was determined to be the public access site (Figure 1). In the report provided to SLAAC by UPLAND Planning + Design, the implementation of a water quality committee for Sherbrooke Lake was recommended.

1.2. Program Background

As a result of the planned public access site at SL, the Sherbrooke Lake Stewardship Committee (SLSC) was formed. The SLSC, a joint commitment between MODL and the Municipality of Chester (MOC), is comprised of one Bluenose Coastal Action Foundation (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 Sherbrooke Lake prior to 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.

Although a preliminary monitoring program was implemented in 2017, the full Sherbrooke Lake Water Quality Monitoring Program began in May 2018. The 2018 monitoring program consisted of three lake sites monitored for various chemicals monthly from May to October, two additional lake sites monitored during the summer months for chlorophyll *a*, four streams monitored bimonthly from May to October, seven streams monitored once after a rainfall event (>20 mm rainfall within 24 hours), two lake sites and one stream site where one-time sediment samples were obtained for analyses, and two lake sites where one-time lake profiles and nutrients at-depth were obtained for analyses (Figure 2, Table 1). The 2018 monitoring program incorporated trained volunteers to collect the water and sediment samples throughout the field season, while Coastal Action coordinated the sampling and analyzed the data (for full methodology please refer to the *Sherbrooke Lake Water Quality Monitoring Program* available upon request from either the Municipality of Chester or the Municipality of the District of Lunenburg).

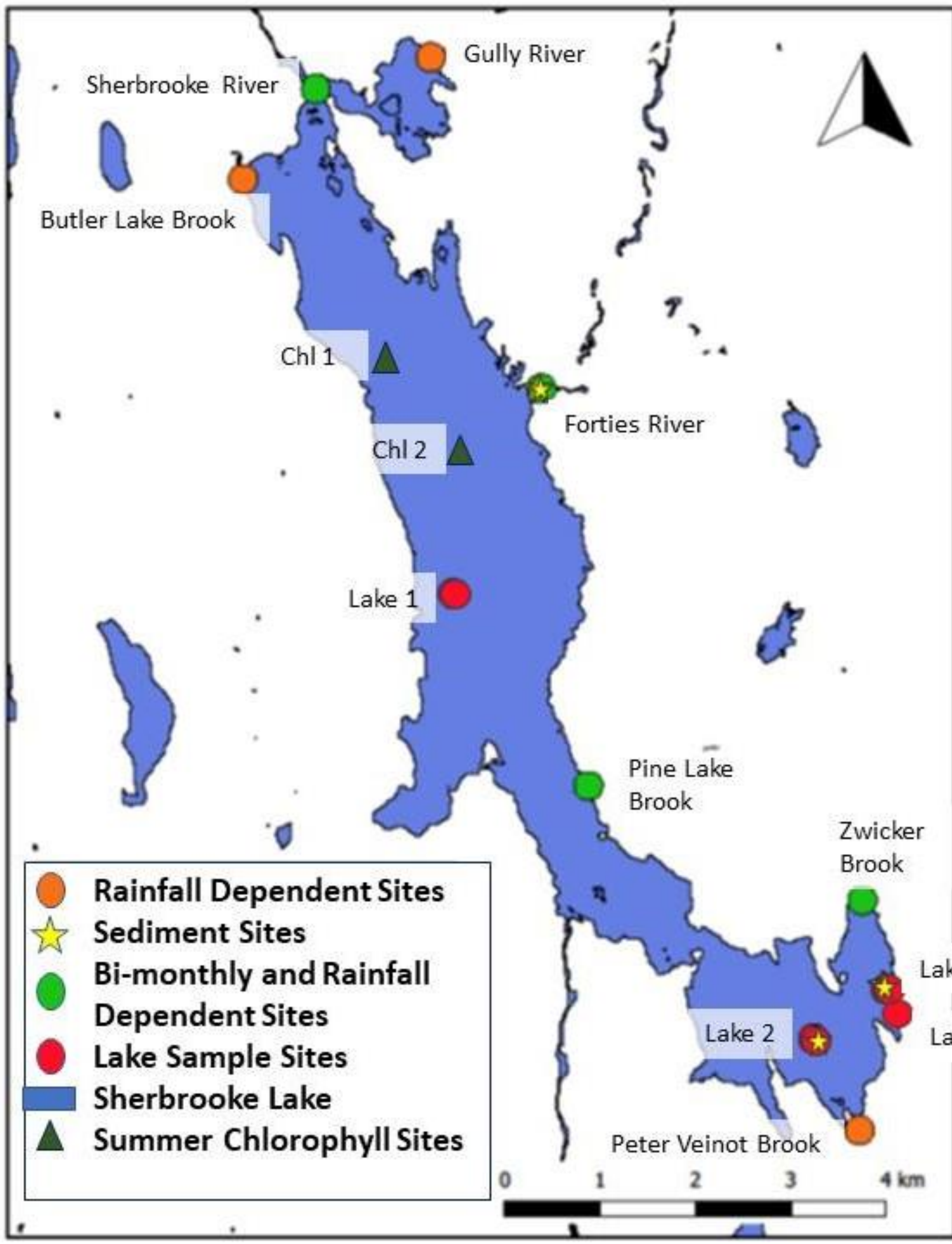

Figure 2: Sherbrooke Lake 2018 Water Quality Monitoring Program sampling locations.

Table 1: Monitoring program parameters, site locations, and sampling frequencies for the 2018 Sherbrooke Lake Water Quality Monitoring Program. New coordinates to access river sites via road are in blue.

Sample Site Name	Site Coordinates (UTM Zone 20T)	Sampling Frequency	Parameters Sampled
Lake 1	372287 E, 4947688 N	Monthly (May-Oct.)	YSI⁺, hydrocarbons, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a*, Secchi disk depth. One-time depth profile.
Lake 2	376072 E, 4943018 N	Monthly (May-Oct.)	YSI, hydrocarbons, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a*, Secchi disk depth. One-time dept profile and sediment grab.
Lake 3 (Public Access)	376831 E, 4943540 N	Monthly (May-Oct.)	YSI, hydrocarbons, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a*, Secchi disk depth. One-time sediment grab.
Lake 4* (Public Access Boat Launch)	376844 E, 4943371 N	Monthly (Sept – Oct.)	YSI, hydrocarbons, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a.*
Chl 1	371682 E, 4949984 N	Monthly (June-Aug.)	YSI, chlorophyll *a*, Secchi disk depth.
Chl 2	372466 E, 4949027 N	Monthly (June-Aug.)	YSI, chlorophyll *a*, Secchi disk depth.
Butler Lake Brook	370079 E, 4952036 N	One-time, rainfall-dependent	YSI, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a.*
Sherbrooke River	370845 E, 4952984 N 369774 E, 4954072 N	Bi-monthly (May, July, Sept.) & rainfall-dependent	YSI, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a.*
Gully River	372050 E, 4953315 N 372246 E, 4953404 N	One-time, rainfall-dependent	YSI, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a.*
Forties River	373210 E, 4949840 N 373539 E, 4949823 N	Bi-monthly (May, July, Sept.) & rainfall-dependent	YSI, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a.* One-time sediment grab.
Pine Lake Brook	373705 E, 4945670 N	Bi-monthly (May, July, Sept.) & rainfall-dependent	YSI, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a.*
Zwicker Brook	376582 E, 4944469 N	Bi-monthly (May, July, Sept.) & rainfall-dependent	YSI, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a.*
Peter Veinot Brook	376552 E, 4942058 N 376507 E, 4941558 N	One-time, rainfall-dependent	YSI, total suspended solids, total phosphorus, total nitrogen, fecal coliform, chlorophyll *a.*

⁺YSI is a multi-parameter water quality device that measures the physical characteristics (temperature, dissolved oxygen, pH, total dissolved solids, salinity, pressure, and specific conductivity) of the water at the time of sampling.
*Lake 4 site added in September 2018 after a Sherbrooke Park Design Meeting to obtain water quality specifically at the lake site near the planned boat launch.

1.3. Objectives and Scope of Work

The objective of this program is to provide a water quality overview for Sherbrooke Lake, which can help the SLSC provide evidence-based advice to both MODL and MOC. Within the SLSC, Coastal Action's scope of work included:

- Designing and writing the Sherbrooke Lake 2018 Water Quality Monitoring Program
- Ordering and ensuring correct bottles from Maxxam Analytics
- Creating and printing waterproof field sheets for each sampling month
- Implementing two days of volunteer training
- Calibrating and caring for the MODL-MOC YSI monthly
- Ensuring volunteers obtained all required field equipment for field work
- Transferring data from field sheets and Maxxam into a database and analyzing data
- Attending SLSC meetings and presenting water quality results
- Preparing this report to summarize results and recommendations for water quality related to Sherbrooke Lake

2. Water Quality Monitoring Results

2.1. Physical Water Parameters

2.1.1. Surface Water Temperature

Water temperature is a key parameter in understanding and assessing the health and productivity of an aquatic environment, as it directly impacts organisms, while also affecting other physical and chemical parameters. Water temperature can impact the presence and survival of fish, where temperatures outside of a species' optimal range can negatively affect fish survival (NSSA, 2014); 20°C is the maximum acceptable temperature for salmon and trout (Alabaster and Lloyd, 1982). In addition, increased water temperature decreases a waterbody's capacity to hold oxygen, thereby limiting available oxygen to aquatic organisms.

In the lake sites, temperatures ranged from 10.2-26.7°C, while streams ranged from 13-26.5°C (Figures 3 and 4). The lake sites exceeded 20°C between June to August 2018, while the stream sites exceeded 20°C in July and August 2018. In the lake, surface temperatures exceeding 20°C will not greatly affect organisms, as aquatic life can take refuge in the cooler deep waters below; however, this is not the case for streams. The highest water temperatures were recorded at Sherbrooke River and Forties River. The lower temperatures observed at Pine Lake Brook and Zwicker Brook may be due to higher percentage of shade covering the waters (from tree canopies) due to smaller stream widths (compared to Sherbrooke and Forties). Pine Lake Brook and Zwicker Brook exceeded that 20°C threshold only once (by 0.1°C in July 2018) – these streams appear to provide a suitable habitat for aquatic organisms year-round.

Following the one-time rainfall sampling event, 5/7 streams were below 20°C, with only Sherbrooke and Forties exceeding the threshold.

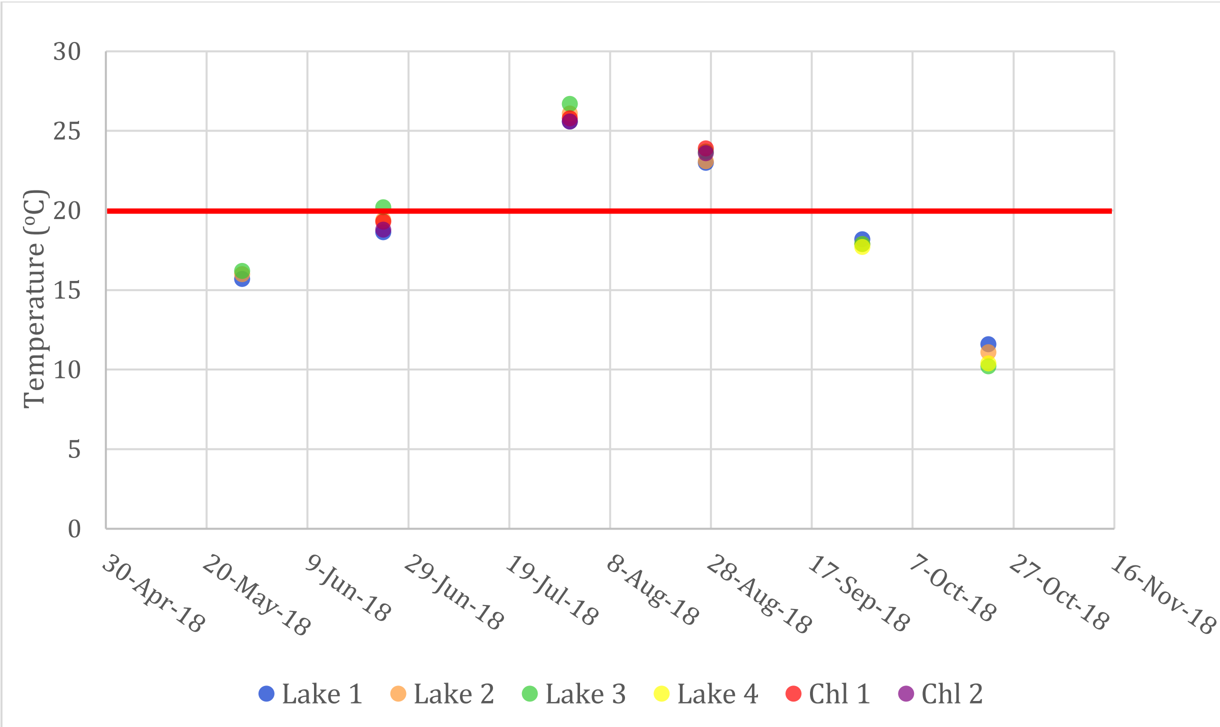

Figure 3: Water temperatures at four monthly lake sites (Lake 1-4), and two summer-only sites (Chl 1 and Chl 2) during the May-October 2018 SL water quality field season. Red line indicates the 20ºC limit for survival of aquatic organisms.

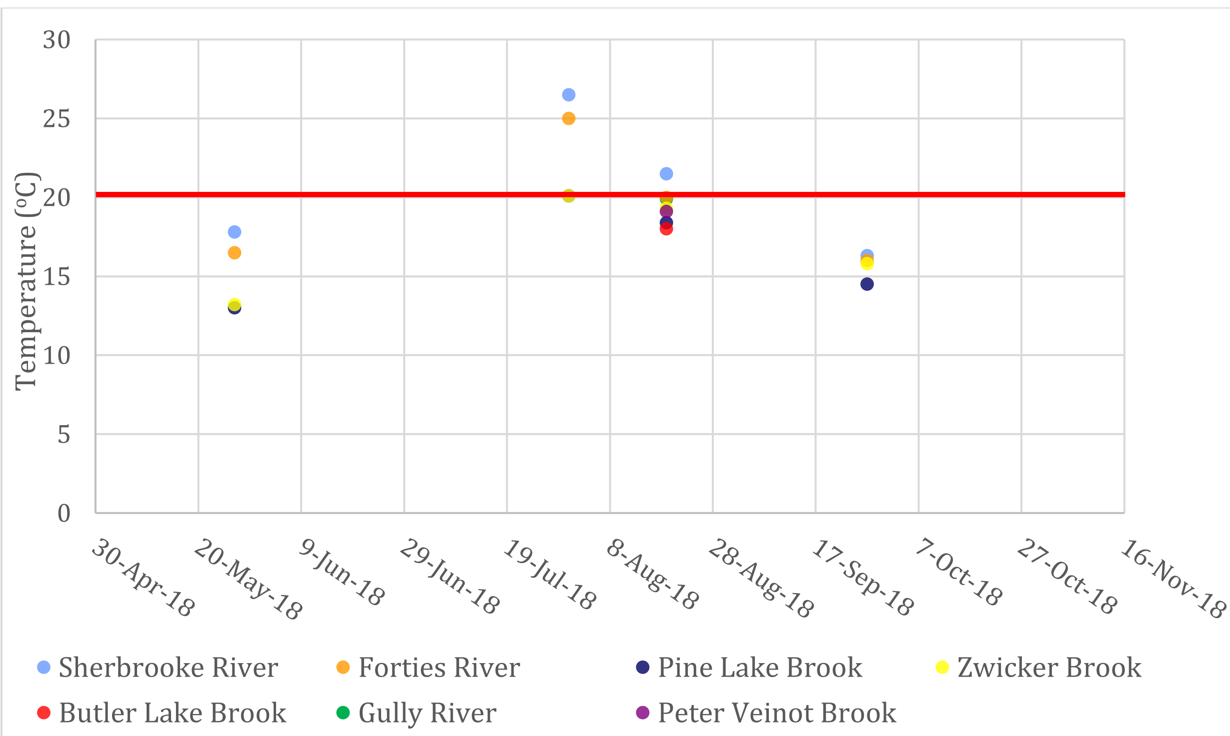

Figure 4: Water temperatures at four bimonthly and rainfall-dependent stream sites (Sherbrooke River, Forties River, Pine Lake, and Zwicker Brook), in addition to three rainfall-dependent stream sites (Butler Lake Brook, Gully River, and Peter Veinot Brook). Red line indicates the 20ºC limit for survival of aquatic organisms.

2.1.2. Surface Dissolved Oxygen

Dissolved oxygen (DO) is another key physical water parameter, as it is required for the survival of aquatic organisms and affects how nutrients are cycled and released within lake waterbodies. The Canadian Council of Ministers of the Environment (CCME) set a guideline at ≥6.5 mg/L for the protection of aquatic life for cold water species – species found in lakes such as Sherbrooke (CCME, 1999). DO not only affects aquatic organisms, but also is controlled by organisms (due to consumption), water temperature, and the waterbody's ability to mix and engulf DO (wind and waves increase dissolved oxygen into the water).

Of the lake and stream sites, only one stream site had DO below 6.5 mg/L throughout the 2018 field season (Figures 5 and 6). The six lake sites monitored in SL were always >7 mg/L, even as DO decreased during summer months due to biological demand. The high DO concentrations may be attributed to the sampling depths for these monthly and bimonthly samples, as only surface water was monitored and therefore influenced by the DO engulfment via winds and waves. The seven stream sites also appear to be well oxygenated and suitable for aquatic life – even the Peter Veinot Brook measurement below 6.5 mg/L was only 0.09 mg/L below the threshold.

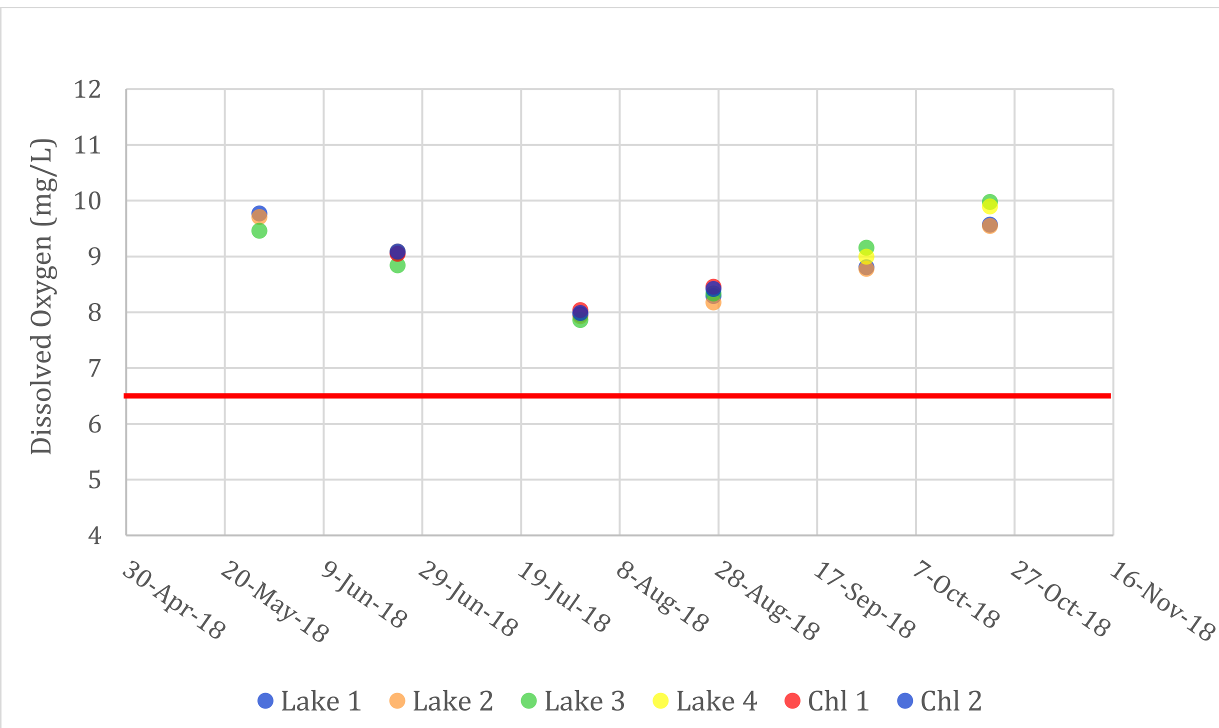

Figure 5: DO at four monthly lake sites (Lake 1-4), and two summer-only sites (Chl 1 and Chl 2) during the May-October 2018 SL water quality field season. Red line indicates CCME's 6.5 mg/L DO minimum-threshold for survival of aquatic organisms.

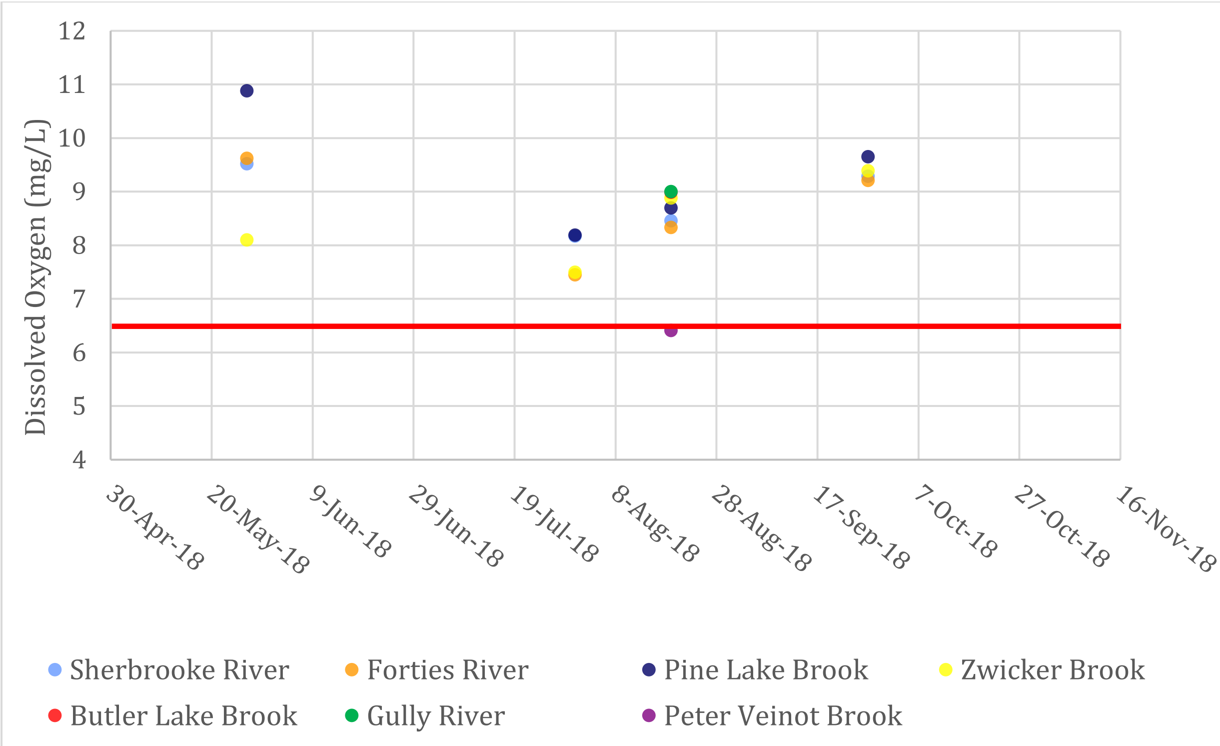

Figure 6: DO at four bimonthly and rainfall-dependent stream sites (Sherbrooke River, Forties River, Pine Lake, and Zwicker Brook), in addition to three rainfall-dependent stream sites (Butler Lake Brook, Gully River, and Peter Veinot Brook). Red line indicates CCME's 6.5 mg/L DO minimum-threshold for survival of aquatic organisms.

2.1.3. Depth Profiles

2.1.3.1. At-Depth Water Temperature

The water profile at lake sites 1 and 2 in August 2018 indicate that both sites have a thermal stratification – Lake 2 having a stronger stratification than Lake 1 (Figure 7). Stratification begins at a shallower depth (5 m) for Lake 2 than Lake 1 (8 m). Lake 2's thermocline is 8 m thick, separating the >20°C surface waters from the <10°C deep waters. Lake 1's thermocline is only 2 m thick, with ~5°C separation between surface and deep waters. The presence of a thermocline at both lake sites indicates that the nutrient-rich, cold deep waters are not mixing with the nutrient-limited, warm surface waters during the summer months; mixing and redistribution of nutrients within the lake is therefore only occurring during spring and fall turnover, when water temperature is uniform at all depths and no density-differences inhibit mixing.

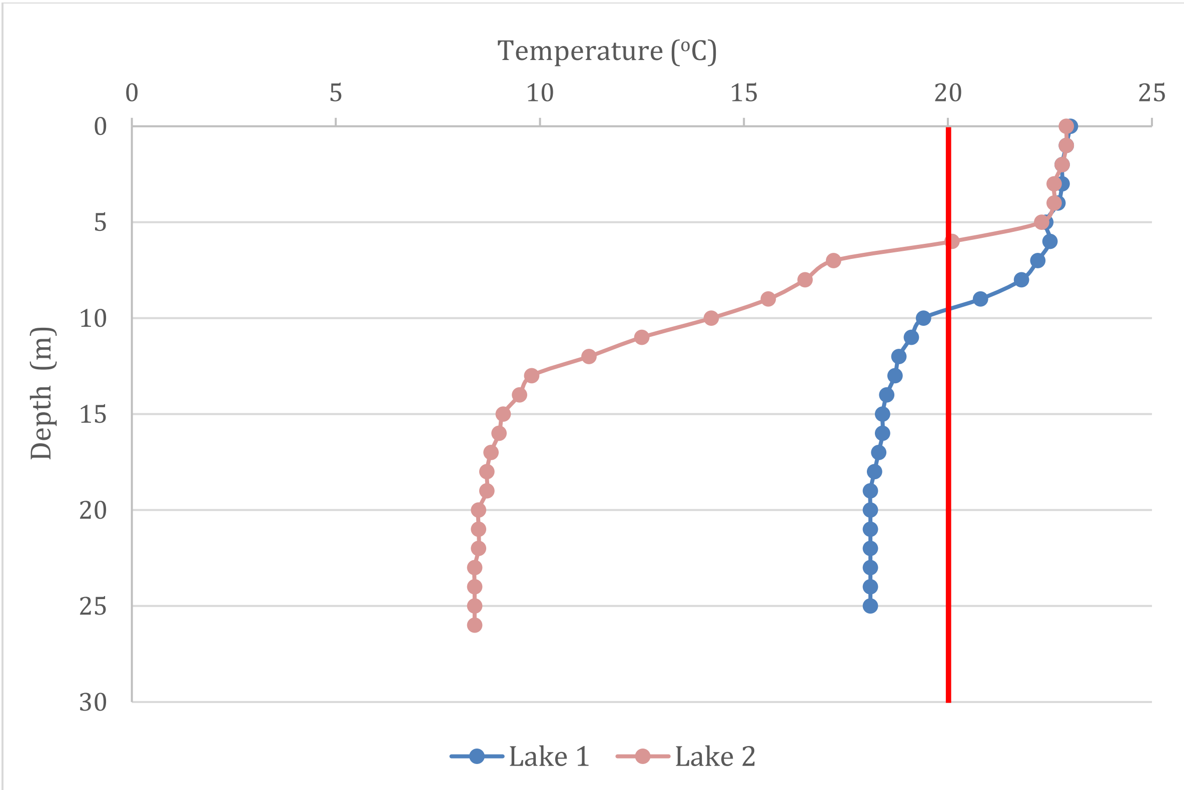

Figure 7: Water temperature depth profile from two lakes during the August 2018 sampling of SL. Red line indicates the 20ºC limit for survival of aquatic organisms.

2.1.3.2. At-Depth Dissolved Oxygen

In addition to the thermocline that is present in the lake sites' depth profiles, DO is also stratified at the two sites (Figure 8). Of the four common DO profiles in lakes (Figure 9), Lake 1 presents a clinograde curve, where DO is highest in the surface waters and lowest in the deep waters. Clinograde curves often occur in mesotrophic and eutrophic lakes, where microbial decomposition uses and depletes the lake's DO. Lake 2 appears to have a negative heterograde curve. Negative heterograde curves have a distinct reduction in DO at depth – this may be due to increased organic matter trapped within the thermocline, acting as a source of food for microbes and increasing DO depletion from microbial decomposition. DO increases past the decomposition depth due to the lack of food encouraging microbial decomposition. There is a drop of DO at the base of the lake in Lake 2 - this may be due to increased microbial presence – again due to increased nutrients available (decaying organisms and litter would sink to the sediment, acting as a food source of microbes).

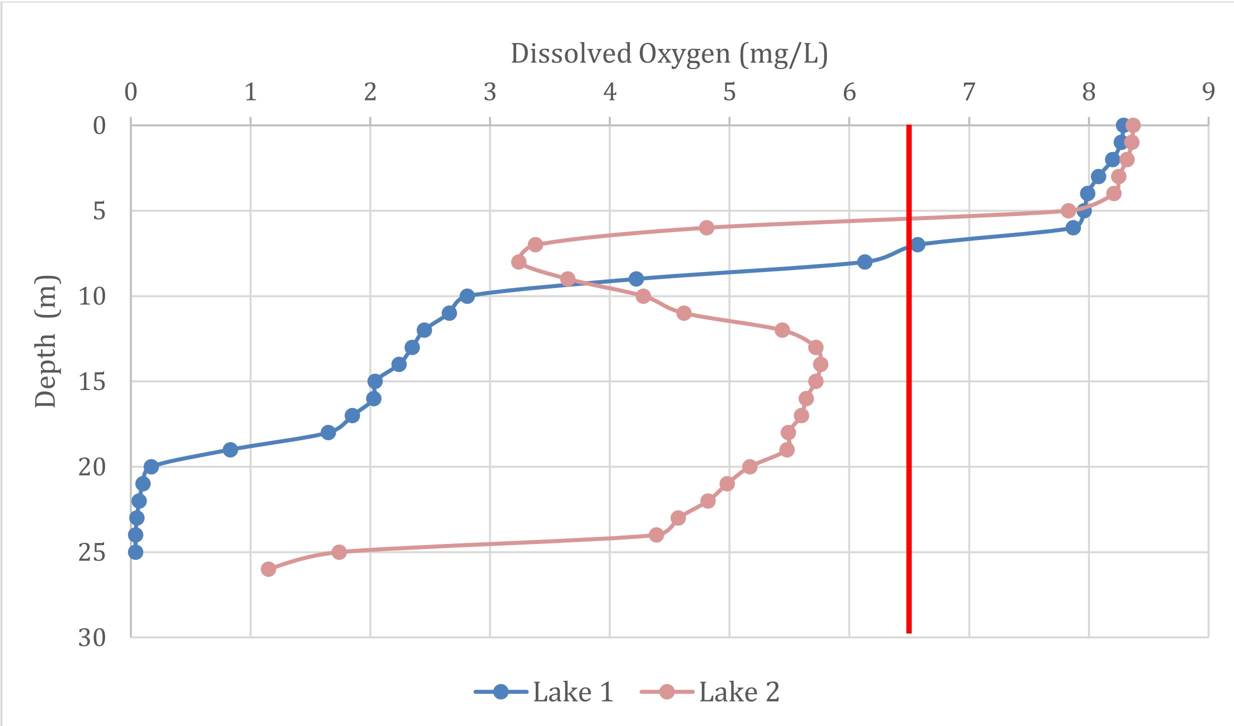

Figure 8: DO depth profile from two lake sites during the August 2018 sampling of SL. Red line indicates CCME's 6.5 mg/L DO minimum-threshold for survival of aquatic organisms.

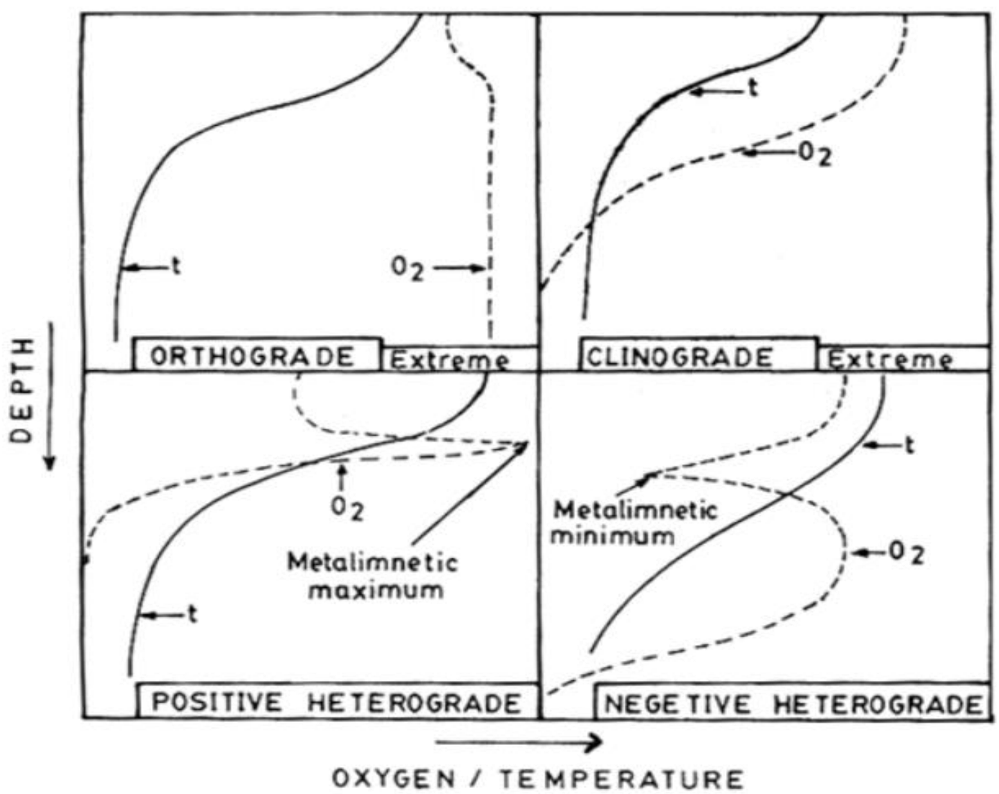

Figure 9: Four common water temperature and DO depth profiles, from Hutchinson, 1957.

Due to the stratification of the lake sites 1 & 2, no summer mixing occurs, resulting in a finite supply of DO for organisms below the thermocline until fall turnover. At depths below 7 m for Lake 1, DO falls below the CCME 6.5 mg/L guideline, while depths below 5 m at Lake 2 also have <6.5 mg/L of DO available. As microbes continue to consume the finite supply of DO in the deep lake waters, the stress of low-DO on aquatic organisms will only increase until the water's DO is replenished during fall turnover.

It appears at the bottom of the lake at both Lake 1 and Lake 2, waters become hypoxic (<2 mg/L) and anoxic (<1 mg/L) and have decreased capacity to support aquatic life (USGS, 2014; Brylinsky, 2004). As oxygen is necessary for aquatic life, anoxic conditions can be harmful and even kill organisms that pass through anoxic waters. In addition, anoxic conditions can cause phosphorus locked in the sediment to change states and be released into the water column, potentially over-enriching the waters with new nutrients and causing algal blooms.

2.1.4. pH

pH is a parameter used to access the acidity of a substance, with pH being the negative logarithmic of the hydrogen ion concentration of the solution (Equation 1). The pH scale ranges from 0 (most acidic) to 14 (most basic), with 7 being the neutral point. In natural waters, due to the dissolution of carbon dioxide, water pH is slightly more acidic than neutral (~6.5), with geology, organic materials, and rain inputs also affecting the water's natural pH state; due to such natural variations, the CCME has set a pH range of 6.5-9.0 as a guideline for the protection of aquatic life (CCME, 2007).

Equation 1: $$pH = -\log([H^+])$$

Particularly in Nova Scotia, natural organic matter, acid rock drainage from specific bedrock formations, and decades of acid precipitation have lowered the pH of waters in the province and negatively affected fish populations. Although the CCME has set a threshold of 6.5, many aquatic organisms have adjusted to Nova Scotia's acidic waters, with trout species surviving in waters as low as 4.7 (NSSA, 2014). Although organisms can survive in acidic conditions, Harvey and Lee (1982) reported fish kills associated with exposure to highly acidic waters from hours to days, while Courtney and Clements (1998) reported significant reductions in invertebrates after seven days of exposure to acidic conditions (pH 4.0).

pH within the lakes and rivers of the 2018 SL monitoring program varied between 3.2-6.6 (Figures 10 and 11). Lake 3 consistently had the highest pH values, while only Lake 2 and Lake 4 fell below 5.5 (4.22 and 3.24, respectively). It is unclear what caused Lake 4's pH to drop to 3.24 during the October sampling, and more data is required to understand if the pH of this site is commonly acidic, or if this was an anomaly. Of the stream sites, the lowest recorded pH was 5.05 at Pine Lake Brook – Pine Lake Brook was consistently one of the lowest pH sites during the 2018 field season.

Even with pH values below the CCME's 6.5-pH threshold at lake and river sites, the data suggest that pH would not negatively affect aquatic life in the streams and most lake sites. For the stream sites, pH >5.0 is adequate for the survival of fish and invertebrates (Morris, Taylor, and Brown, 1989). Of the lake sites, only Lake 2 and Lake 4 pose a threat to aquatic life; however, as the length of the low-pH conditions are unknown – due to the monthly sampling frequency of the program – it is unclear if these conditions pose short-term or long-term concerns to aquatic life.

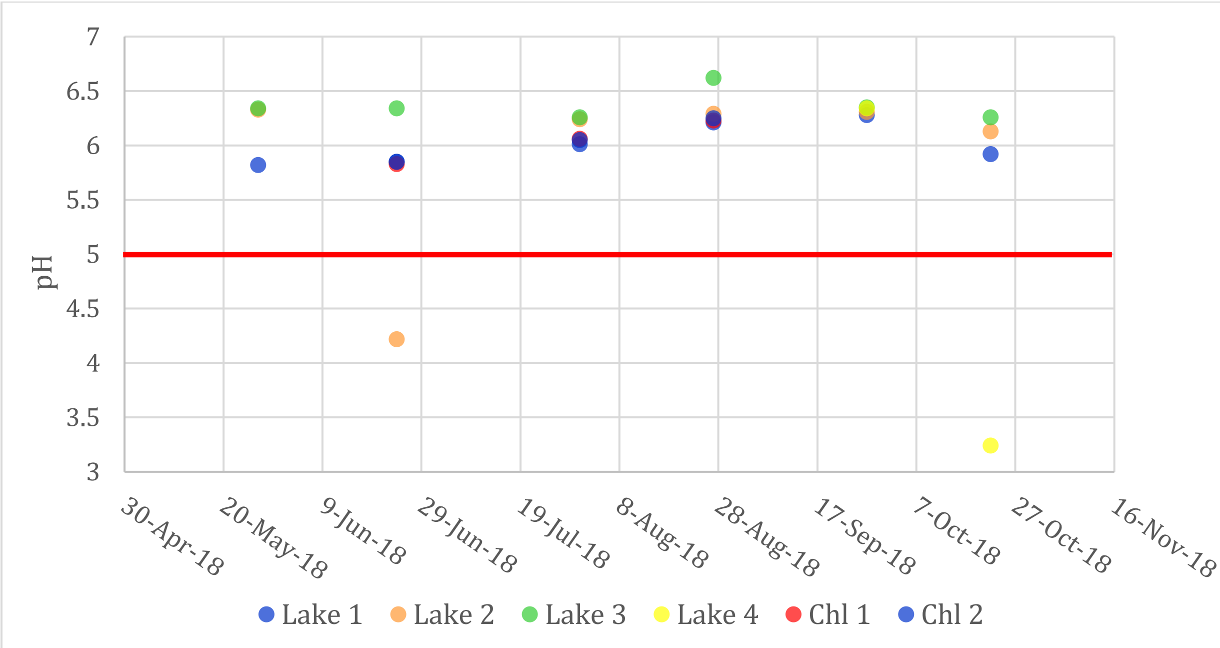

Figure 10: pH at four monthly lake sites (Lake 1-4), and two summer-only sites (Chl 1 and Chl 2) during the May-October 2018 SL water quality field season. Red line indicates the 5.0-pH minimum threshold for survival of fish and invertebrates (Morris, Taylor, and Brown, 1989).

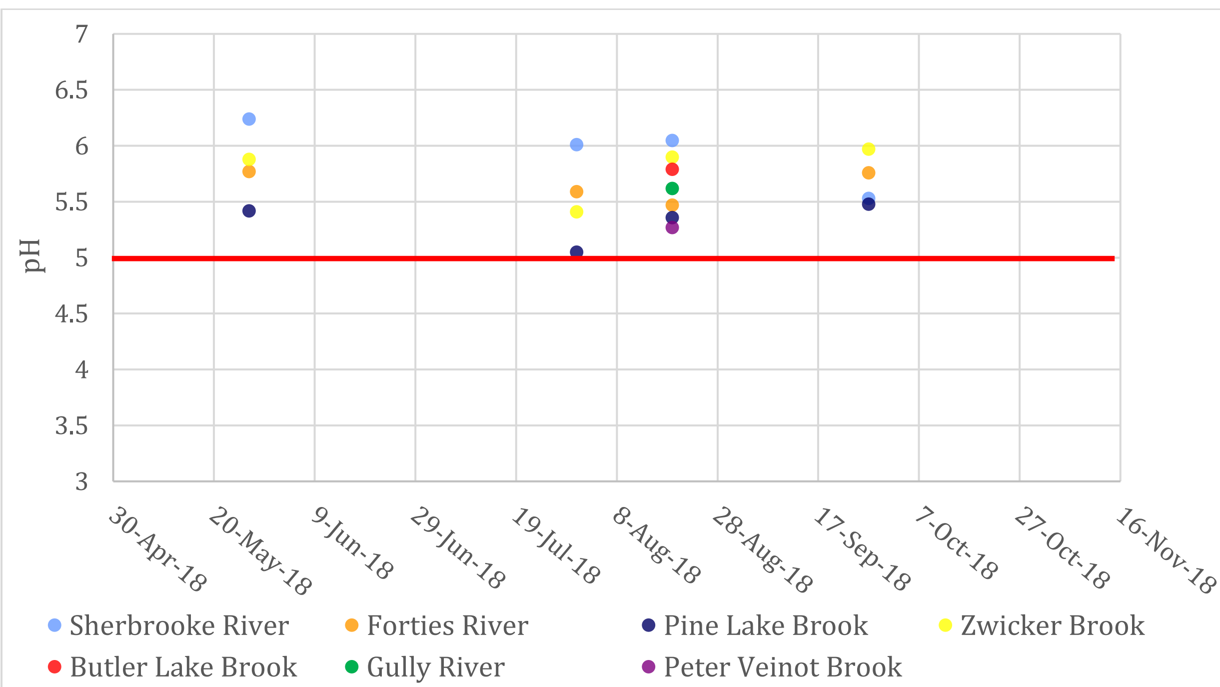

Figure 11: pH at four bimonthly and rainfall-dependent stream sites (Sherbrooke River, Forties River, Pine Lake, and Zwicker Brook), in addition to three rainfall-dependent stream sites (Butler Lake Brook, Gully River, and Peter Veinot Brook). Red line indicates the 5.0-pH minimum threshold for survival of fish and invertebrates (Morris, Taylor, and Brown, 1989).

2.1.5. Total Dissolved Solids

Total dissolved solids (TDS) – a measurement of dissolved materials in water – is an invaluable parameter. TDS can be influenced by construction, deforestation, sewage effluent, urban and agricultural run-off, industrial waste, road salts, forest fires, and rainfall/flooding events, and therefore provides insight into potential pollution issues affecting the water. Although there is no CCME guideline for TDS, high concentrations of TDS can affect a water's taste, colour, and clarity (NSSA, 2014), and reductions in clarity can decrease the depth of light penetration and affect rooted vegetation. For most of Nova Scotia's lakes, TDS ranges from 5 to 235 mg/L (Nova Scotia Lake Inventory Program, 2017).

TDS of the six SL lake sites never exceeded 20.0 mg/L, while most streams had TDS concentrations >20 mg/L (Table 2, Figures 12 and 13). TDS was very similar between lake sites, while streams had slightly more TDS concentration variation between sites. Of the four bimonthly stream sites monitored, no site indicated an increase in TDS during the rainfall sampling event. Butler Brook had the highest recorded TDS concentration (39 mg/L), which is consistent with its 2017 preliminary data (33.8 mg/L), suggesting that the brook has naturally high TDS concentrations. TDS concentrations from SL fall along the lower end of the TDS range for Nova Scotia's lakes.

Table 2: Mean and maximum TDS concentrations from lake and river sites during the 2018 SL field season.

Site Type	Site	Mean TDS (mg/L)	Maximum TDS (mg/L)
Lake	Lake 1	18.8	20.0
	Lake 2	18.2	19.0
	Lake 3	18.2	19.0
	Lake 4	18.5	19.0
	Chl 1	19.0	20.0
	Chl 2	18.3	19.0
Stream	Sherbrooke River	21.3	23
	Forties River	19.0	24
	Pine Lake Brook	17.9	21
	Zwicker Brook	19.0	23
	Butler Brook	-	39
	Gully River	-	14
	Peter Veinot Brook	-	21

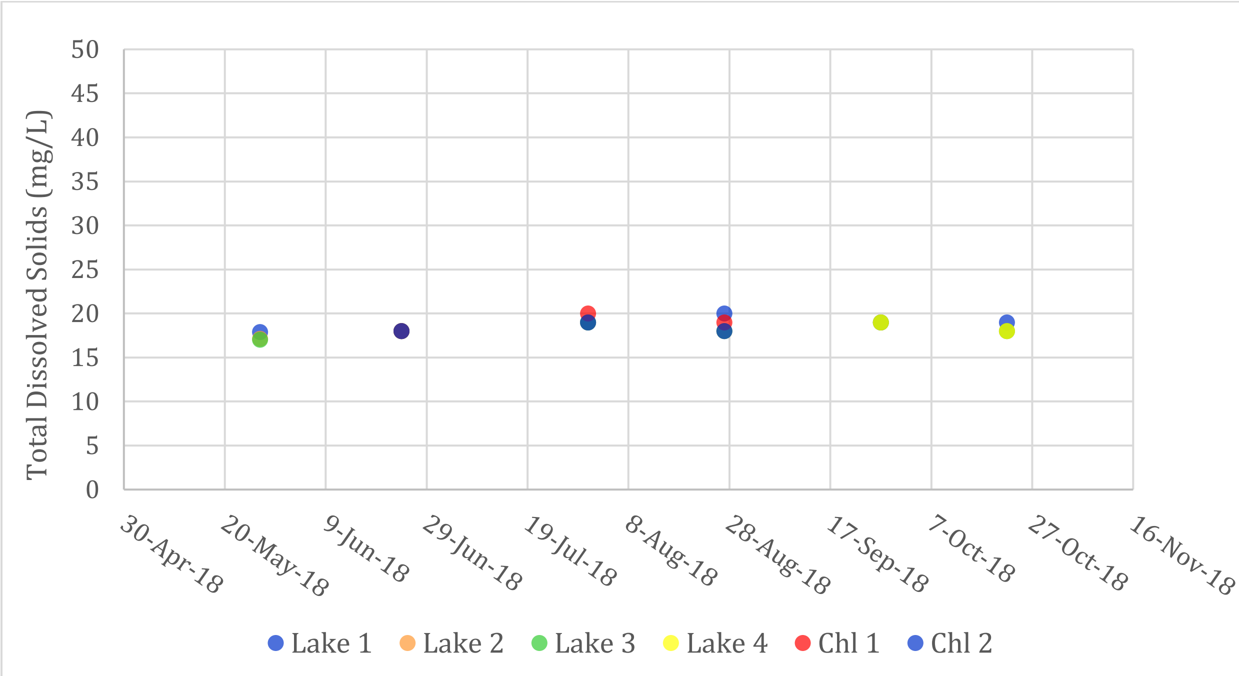

Figure 12: TDS at four monthly lake sites (Lake 1-4), and two summer-only sites (Chl 1 and Chl 2) during the May-October 2018 SL water quality field season.

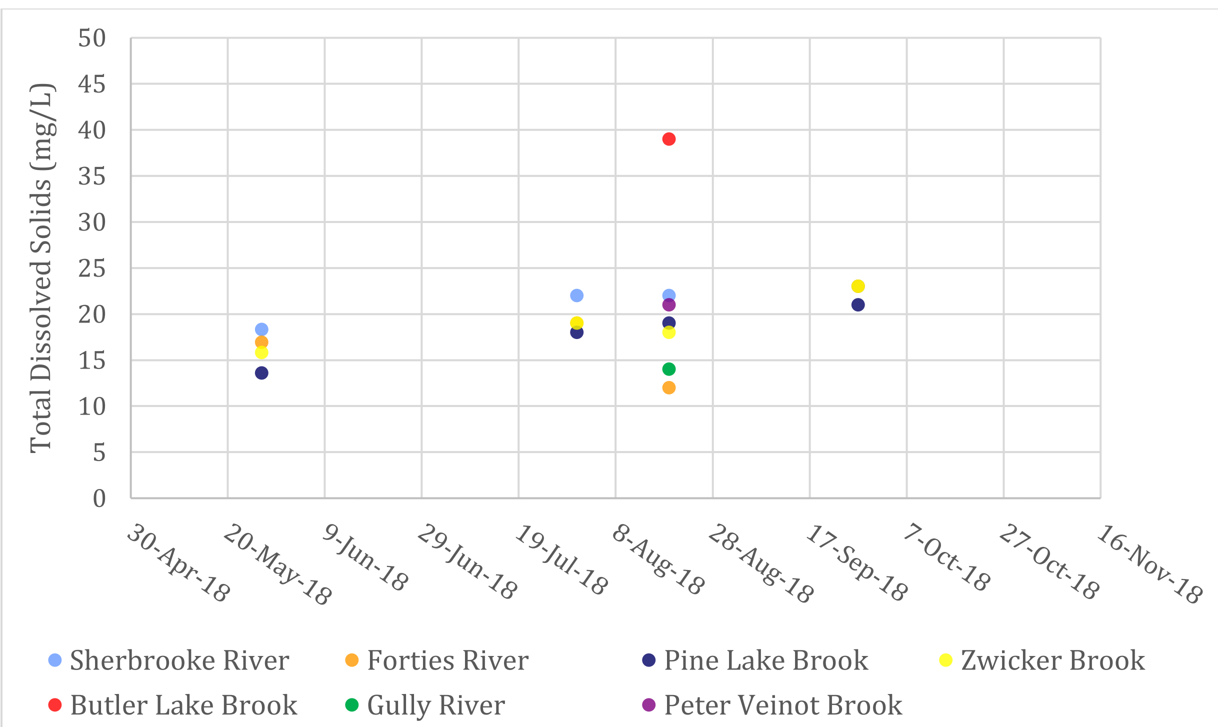

Figure 13: TDS at four bimonthly and rainfall-dependent stream sites (Sherbrooke River, Forties River, Pine Lake, and Zwicker Brook), in addition to three rainfall-dependent stream sites (Butler Lake Brook, Gully River, and Peter Veinot Brook).

2.2. Chemical Water Parameters

2.2.1. Total Suspended Solids

Total suspended solids (TSS) is a measurement of all suspended materials in the water column. Increases in TSS can be natural due to erosion or general disturbance of land upstream or can be unnatural (release of substance from deforestation, mining, etc.). According to the Nova Scotia Environment Act (1994-95), '*No person shall release or permit the release into the environment of a substance in an amount, concentration or level of at a rate of release that causes or may cause adverse effect, unless authorized by an approval of the regulations*'; by monitoring and obtaining an initial reference point of TSS and other water quality parameters prior to future potential land disturbances, the SLSC can address and mitigate any possible substance release events.

TSS concentrations ranged from <1 mg/L to 3.4 mg/L for SL lake and river sites (Figures 14 and 15). Most lake sites had <1 mg/L of TSS during the field season, with minimal differences between lake sites. For the stream sites, Zwicker Brook had, in general, the highest TSS concentrations; however, Sherbrooke River did have the highest TSS of the 2018 field season (3.4 mg/L). The high TSS concentration at Sherbrooke River coincides with the rainfall-dependent event; however, no other stream experienced increased TSS during the rainfall event. In Nova Scotia, TSS in lakes ranges from 0.8 to 15 mg/L (Nova Scotia Lake Inventory Program, 2017); SL TSS concentrations fall along the lower end of this range.

Secchi disk depth – the depth to which a black and white disk just is barely visible within a waterbody – can act as a proxy for TSS in lakes. In SL, Secchi disk depths were measured for sites Lake 1-4. Lake 1 was visible to a maximum depth of 2.65 m, with a mean depth of 2.21 m. Lake 2 had a maximum visible depth of 2.84 m and mean depth of 2.43 m. At Lake 3 and 4, the Secchi depths were equivalent to the depth of water, due to the shallowness of the sites (mean depth of 1.78 m and 2.38 m, respectively). Although Secchi depth provides an indication of light penetration into waterbodies, the measurements can be skewed due to an individual's eyesight, and different individuals performing the measurement on different days.

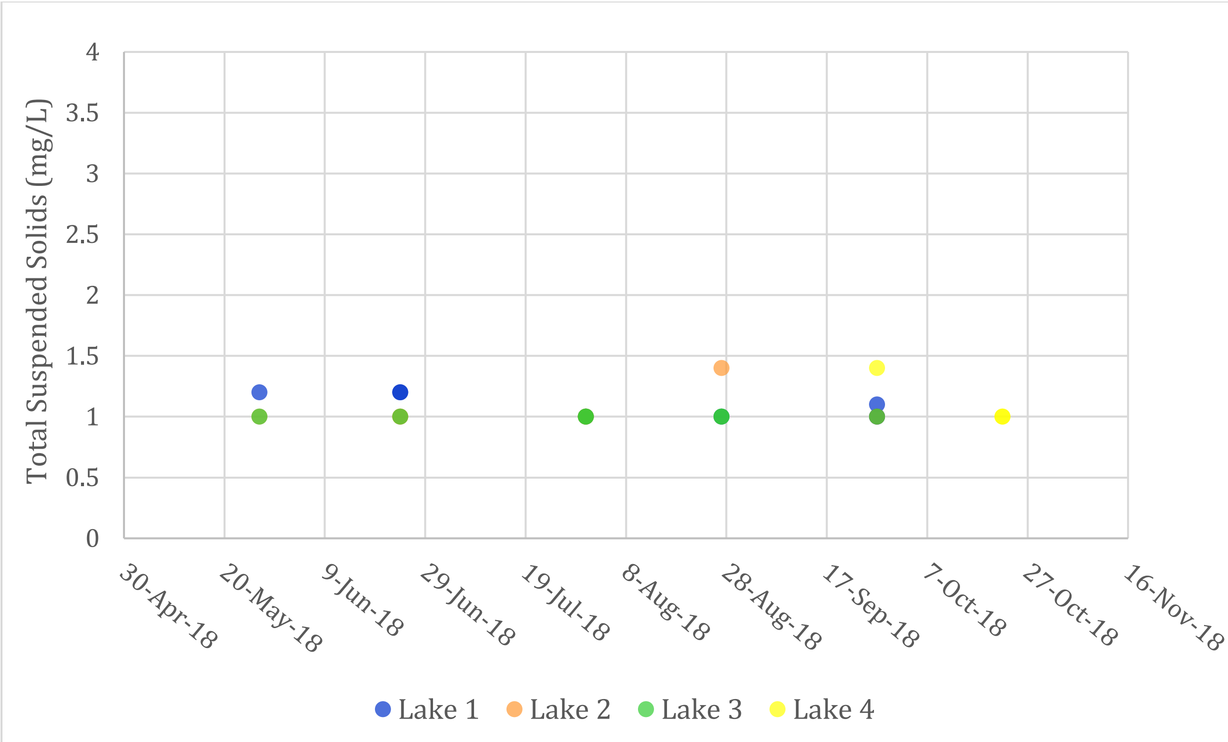

Figure 14: TSS at four monthly lake sites (Lake 1-4) during the May-October 2018 SL water quality field season.

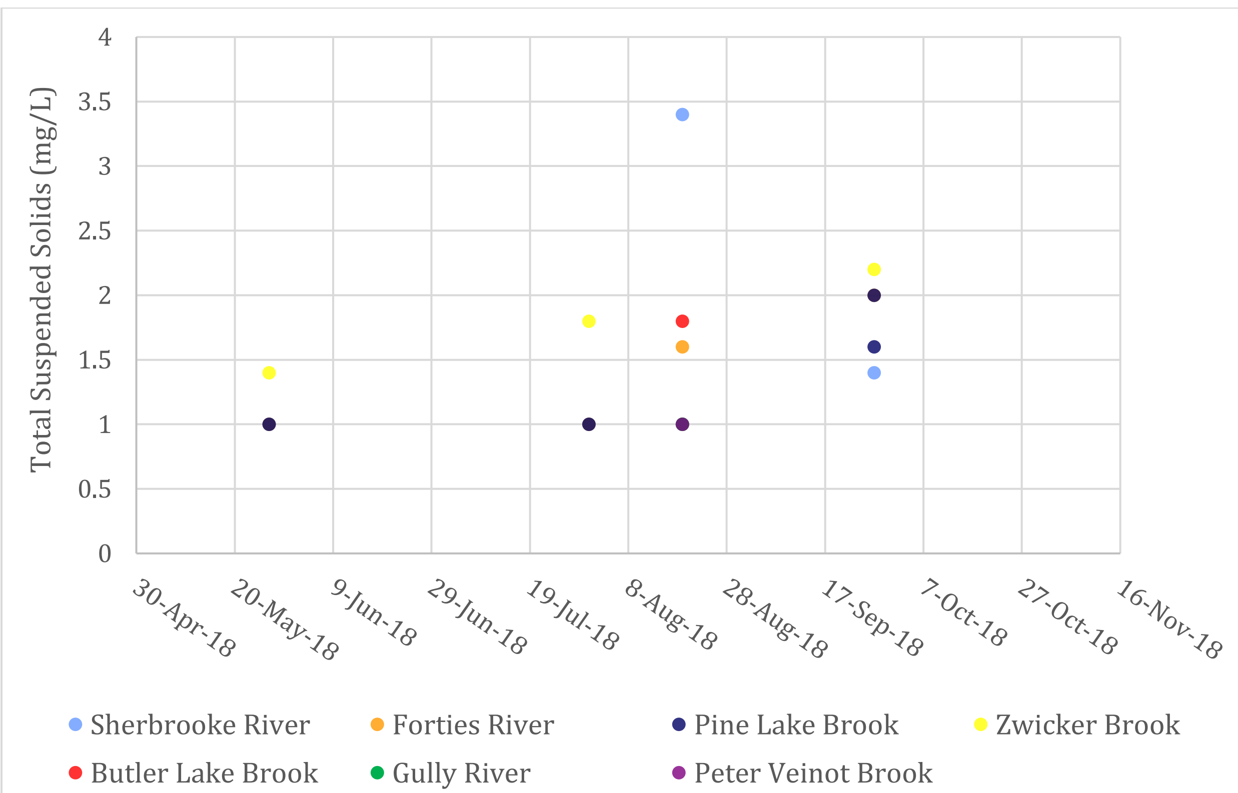

Figure 15: TSS at four bimonthly and rainfall-dependent stream sites (Sherbrooke River, Forties River, Pine Lake, and Zwicker Brook), in addition to three rainfall-dependent stream sites (Butler Lake Brook, Gully River, and Peter Veinot Brook).

2.2.2. Total Phosphorus

Phosphorus concentrations (both organic and inorganic) are extremely important in healthy ecosystems; phosphorus acts as a nutrient to various organisms and plants within watersheds. Due to minimal natural sources of phosphorus and high demand of phosphorus by plants, phosphorus concentrations are low in aquatic environments and therefore a growth-limiting factor. As phosphorus is a key nutrient in freshwater environments, and not considered a toxic substance, the CCME does not have set guidelines; however, Ontario's Ministry of Environment and Climate Change (MOECC) has set a total phosphorus guideline of ≤0.02 mg/L for lakes, and ≤0.03 mg/L for rivers and streams (MOE, 1979). By monitoring phosphorus, pollution sources can be located due to 'pockets' of elevated phosphorus concentrations. In addition, by monitoring phosphorus below a lake's thermocline, we can assess how nutrients are being used/supplied in deeper waters, and if nutrient-enrichment will be a problem once the waters mix during fall and spring turnover.

Lake sites were consistently lower than streams (Figures 16 and 17, Table 3). Lake phosphorus concentrations ranged from <0.004 mg/L to 0.017 mg/L, while streams ranged from 0.011 mg/L to 0.04 mg/L. No lake phosphorus concentrations exceeded the MOECC lake guideline of 0.02 mg/L, while three stream sites exceeded the MOECC stream guideline of 0.03 mg/L. Zwicker Brook, Forties River, and Sherbrooke River all exceeded the guideline by 0.01 mg/L, while Pine Lake Brook, Butler Lake Brook, and Gully River were at the threshold (0.03 mg/L). Phosphorus concentrations increased at the four bimonthly streams during the rainfall event; phosphorus concentrations were also elevated at the three rainfall-dependent sites, but as these sites were not sampled more than once, it is unclear if these phosphorus concentrations are elevated or natural. Due to the increase in phosphorus of the bimonthly streams, it is reasonable to assume that the rainfall caused increased flushing of phosphorus into the streams. As the monthly sampling for August did not occur until 10 days after the rainfall event, the effects of the stream phosphorus flushing on lake sites would be minimal.

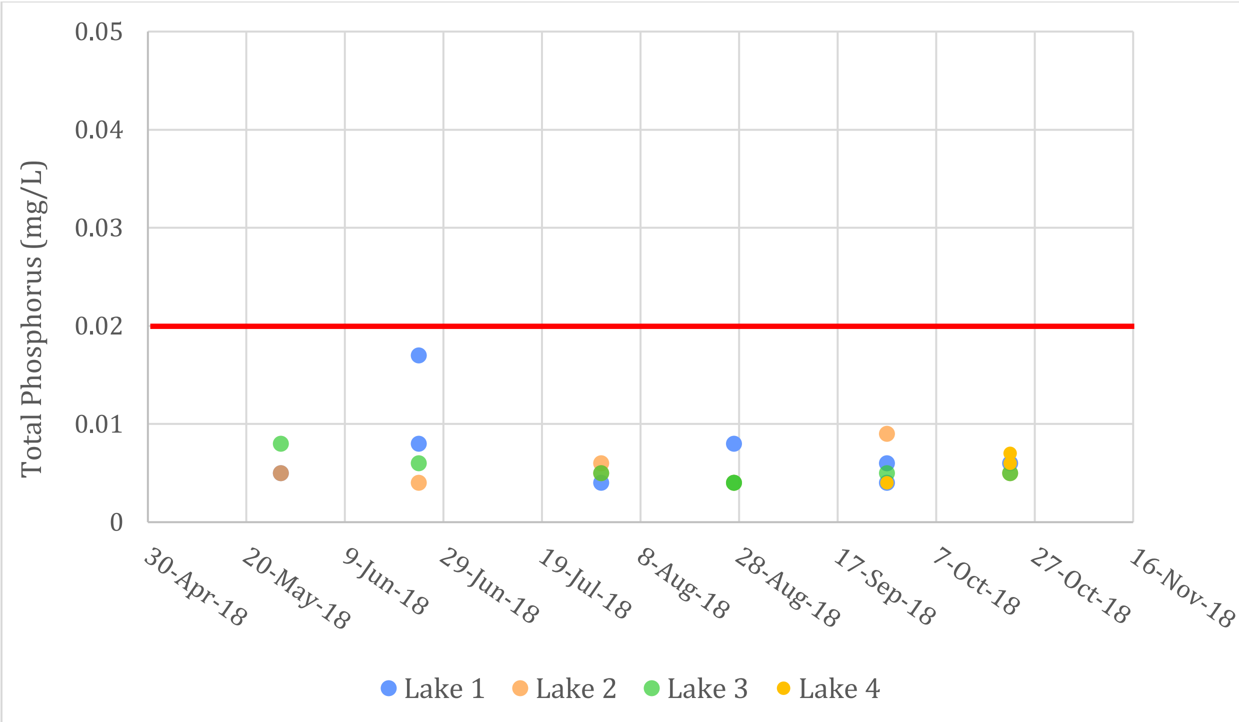

Figure 16: Total phosphorus at four monthly lake sites (Lake 1-4) during the May-October 2018 SL water quality field season. Red line indicates the MOECC 0.02 mg/L guideline for phosphorus in lakes.

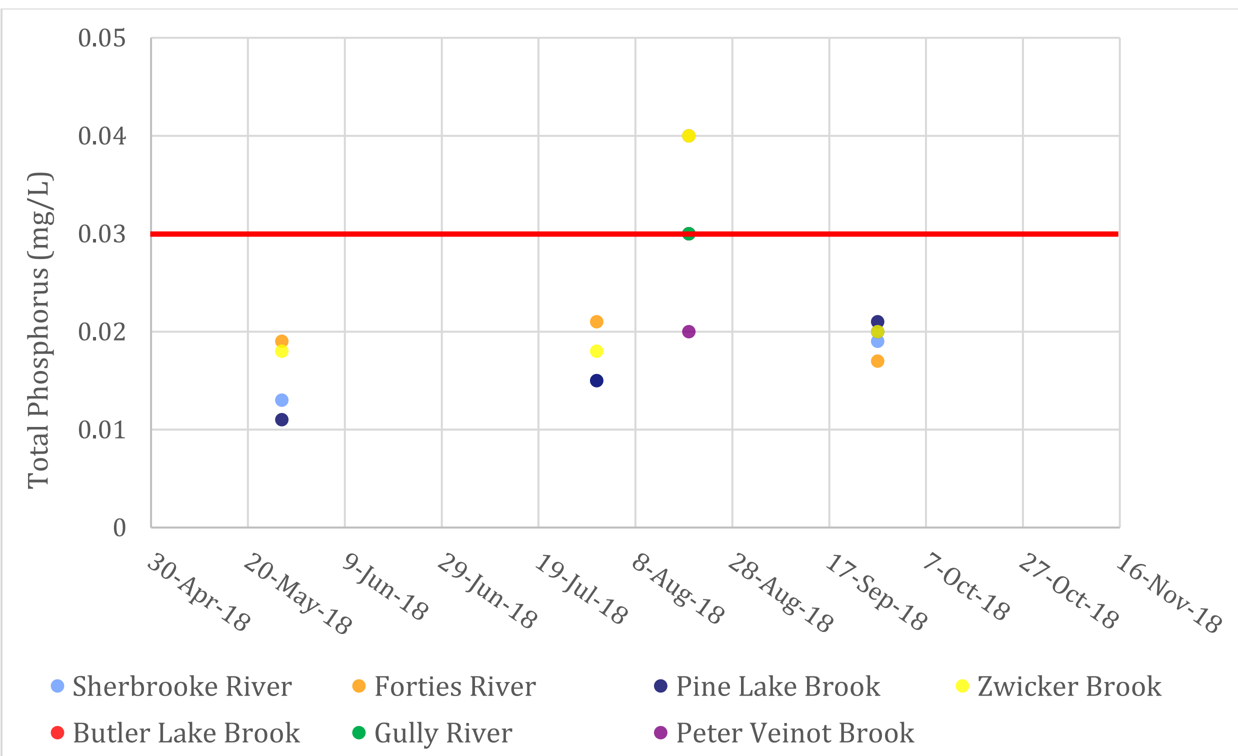

Figure 17: Total phosphorus at four bimonthly and rainfall-dependent stream sites (Sherbrooke River, Forties River, Pine Lake, and Zwicker Brook), in addition to three rainfall-dependent stream sites (Butler Lake Brook, Gully River, and Peter Veinot Brook). Red line indicates the MOECC 0.03 mg/L guideline for phosphorus in streams.

Phosphorus concentrations during the 2018 field season differ at several sites compared to the 2017 preliminary data (Table 3). Phosphorus concentrations are similar for all lake sites, while all stream sites have increased phosphorus concentrations. The difference between the stream concentrations may be due to the weather differences during sampling events, as the 2017 samples were collected on a day without rain, while the 2018 samples collected during the same month (August) were collected during the rainfall-dependent event.

Table 3: Range in total phosphorus concentrations between 2017 and 2018; July-August for lake samples, August for river samples.

Site	2017 Range	2018 Range
Lake 1	0.005-0.008	0.004-0.008
Lake 2	0.004-0.005	0.004-0.009
Lake 3	No data	0.004-0.005
Lake 4	No data	0.004-0.007
Sherbrooke River	0.007	0.04
Forties River	0.016	0.04
Pine Lake Brook	0.019	0.03
Zwicker Brook	0.024	0.04
Butler Lake Brook	0.013	0.03
Gully River	0.01	0.03
Peter Veinot Brook	0.01	0.02

Elevated phosphorus concentrations below the thermocline may indicate a possible nutrient-enrichment event during fall turnover, with a potential for eutrophication and algal blooms. In SL, phosphorus concentrations below the thermocline ('phosphorus at-depth') were not significantly lower than surface concentrations (Table 4). Phosphorus at-depth was 0.001 mg/L lower than Lake 1 surface waters, while Lake 2 saw an increase of 0.021 mg/L between surface and at-depth concentrations. High phosphorus concentrations in the deeper lake waters suggests that the thermocline is not allowing nutrient mixing within the lake profile, and that there is minimal assimilation of phosphorus at-depth. Although no algal bloom occurred during fall turnover in SL, caution should be advised to residents of SL during the fall, as the mixing of elevated phosphorus concentrations increases the risk of a fall algal bloom in the future.

Table 4: Total phosphorus concentrations from two lake sites, obtained both at the surface and below the thermocline, in August for the SL 2018 Water Quality Monitoring Program.

Site	Surface Phosphorus (mg/L)	Phosphorus At-Depth (mg/L)
Lake 1	0.008	0.007
Lake 2	0.004	0.025

2.2.3. Total Nitrogen

Like phosphorus, nitrogen concentrations are also key and limiting nutrients for plants and other organisms in freshwater environments. No CCME guidelines exist for nitrogen; however, Dodds and Welch (2000) have established a ≤0.9 mg/L guideline for freshwater environments, while Underwood and Josselyn (1979) reported a guideline of ≤0.3 mg/L for oligotrophic waterbodies.

Lake nitrogen concentrations ranged from 0.18 mg/L to 0.359 mg/L, while stream nitrogen concentrations ranged from 0.35 mg/L to 0.883 mg/L (Figures 18 and 19, Table 5). Total nitrogen, just as total phosphorus, was lower in lake sites than stream sites, and total nitrogen increased at all stream sites compared to the 2017 preliminary sampling data – possibly due to a difference in sampling event types. No stream or lake site exceeded the Dodds and Welch (2000) 0.9 mg/L threshold; however, the Lake 1 site did exceed the Underwood and Josselyn (1979) 0.3 mg/L threshold for oligotrophic waterbodies once – 0.359 mg/L on July 31st, 2018.

Exceedance of the oligotrophic threshold, in addition to the elevated nitrogen concentrations at all seven streams during the rainfall event suggests that nitrogen pollution may be a problem in SL in the future, and that rainfall may be a key driver of how pollutants enter the lake. Of the bimonthly streams monitored during the sampling program, all four streams had increases in total nitrogen during the rainfall-dependent sampling. Of the lake sites sampled during the monthly August event, nitrogen concentrations only increased at Lake 2, while Lake 1 and 3 dropped from the July concentrations – as sampling occurred 10 days after the rainfall-dependent sampling, it is possible that the influx of nitrogen from the inlet streams had been assimilated by plants, and therefore the lake's elevated nitrogen concentrations associated with the rainfall event may have been missed.

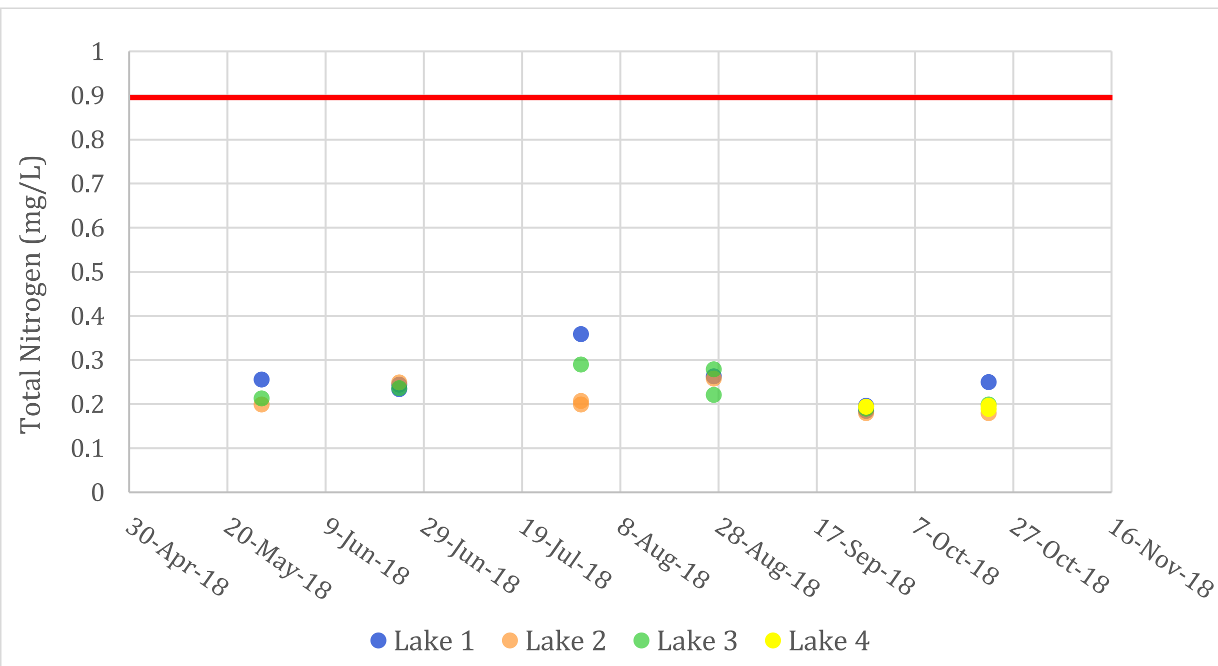

Figure 18: Total nitrogen at four monthly lake sites (Lake 1-4) during the May-October 2018 SL water quality field season. Red line indicates the Dodds and Welch (2000) 0.9 mg/L nitrogen threshold for freshwaters.

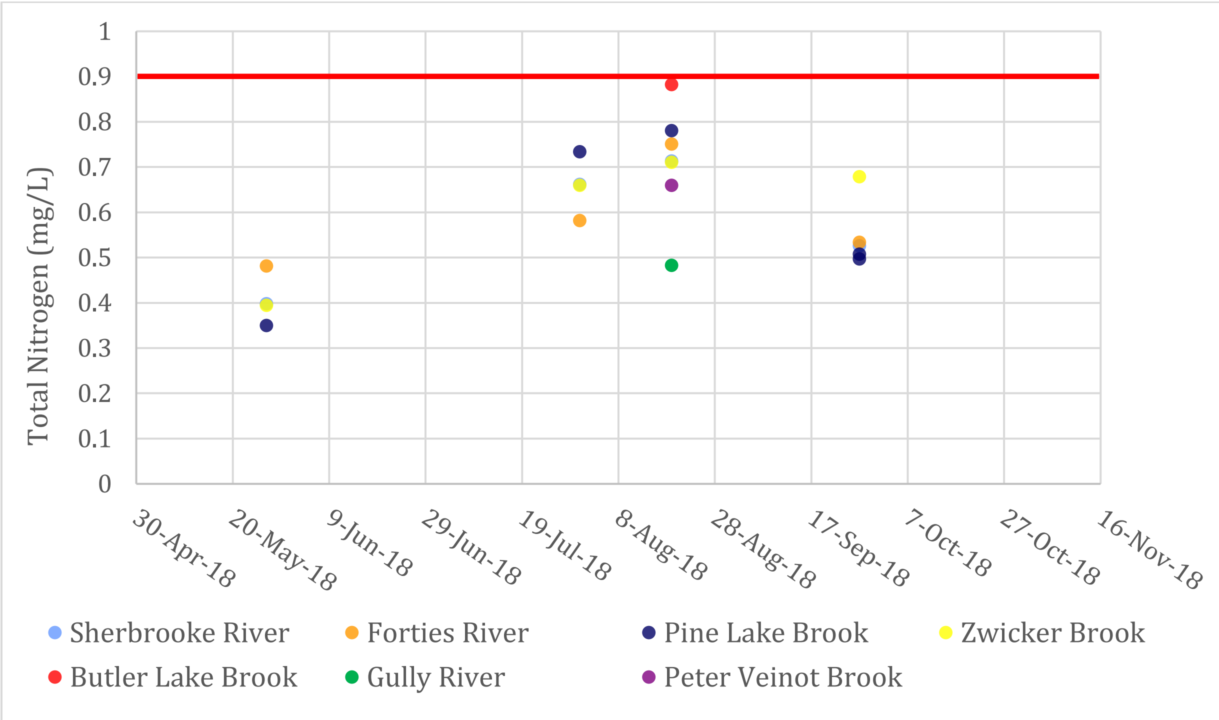

Figure 19: Total nitrogen at four bimonthly and rainfall-dependent stream sites (Sherbrooke River, Forties River, Pine Lake, and Zwicker Brook), in addition to three rainfall-dependent stream sites (Butler Lake Brook, Gully River, and Peter Veinot Brook). Red line indicates the Dodds and Welch (2000) 0.9 mg/L nitrogen threshold for freshwaters.

Table 5: Range in total nitrogen concentrations between 2017 and 2018; July-August for lake samples, August for river samples.

Site	**2017 Range**	**2018 Range**
Lake 1	0.258-0.36	0.185-0.359
Lake 2	0.234-0.324	0.18-0.258
Lake 3	No data	0.19-0.29
Lake 4	No data	0.189-0.196
Sherbrooke River	0.511	0.714
Forties River	0.685	0.751
Pine Lake Brook	0.629	0.781
Zwicker Brook	0.592	0.711
Butler Lake Brook	0.434	0.883
Gully River	0.441	0.483
Peter Veinot Brook	0.374	0.66

Just as with phosphorus, elevated nitrogen concentrations below the thermocline may indicate a possible nutrient-enrichment event during fall turnover, with a potential for eutrophication and algal blooms. In SL, nitrogen concentrations at-depth were not significantly lower than surface concentrations (Table 6). Lake 2 had almost double the surface nitrogen concentration in the waters below the thermocline. With elevated phosphorus and nitrogen concentrations below the thermocline, SL fall turnover is essential for nutrient dispersal – and a concern for eutrophication. Although no algal bloom occurred in fall 2018 in SL, caution should be taken in the future, especially at Lake 2 where nutrients are particularly high.

Table 6: Total nitrogen concentrations from two lake sites, obtained both at the surface and below the thermocline, in August for the SL 2018 Water Quality Monitoring Program.

Site	Surface Nitrogen (mg/L)	Nitrogen At-Depth (mg/L)
Lake 1	0.263	0.223
Lake 2	0.258	0.46

2.2.4. Hydrocarbons

Hydrocarbons are chains of carbon and hydrogen molecules which are the main components of natural gases and petroleum products. Monitoring hydrocarbons provides insight to whether anthropogenic activities are influencing water quality in the region - such as boating and combustion of petroleum products causing atmospheric deposition of polycyclic aromatic hydrocarbons (PAHs) (Das, Routh, and Roychoudhury, 2008; Andren and Strand, 1979).

No hydrocarbons were detectable at any lake sites during either the preliminary-2017 and full-2018 SL Water Quality Monitoring Program. Hydrocarbons should continue to be monitored at all lake sites to monitor for changes in detectable amounts of hydrocarbons – especially at sites Lake 3 and 4, where a public boat launch is proposed, which would see an increase in boat traffic, and by association, increases in the potential for hydrocarbon releases into the lake. As hydrocarbons commonly form particulate complexes that settle out of solution, collecting sediment hydrocarbon samples at sites Lake 3 and 4 may also be useful in developing a reference point prior to the installment of the SL public access site.

2.2.5. Chlorophyll *a*

Chlorophyll *a* is a parameter used as a proxy for biological activity within water and can be an indicator for potential algal blooms if it increases to elevated levels (Stumpf, 2001). For SL, chlorophyll *a* never exceeded 7 µg/L (Figure 20). Chlorophyll *a* decreased over the 2018 sampling season and plateaued from August to October. The highest chlorophyll *a* concentration was observed at Lake 1 in May 2018, while Lake 3 consistently had the lowest chlorophyll *a* concentrations. The low chlorophyll *a* concentrations throughout the 2018 field season, and no increase in chlorophyll *a* during the fall turnover, coincide with the lack of algal blooms observed within the lake.

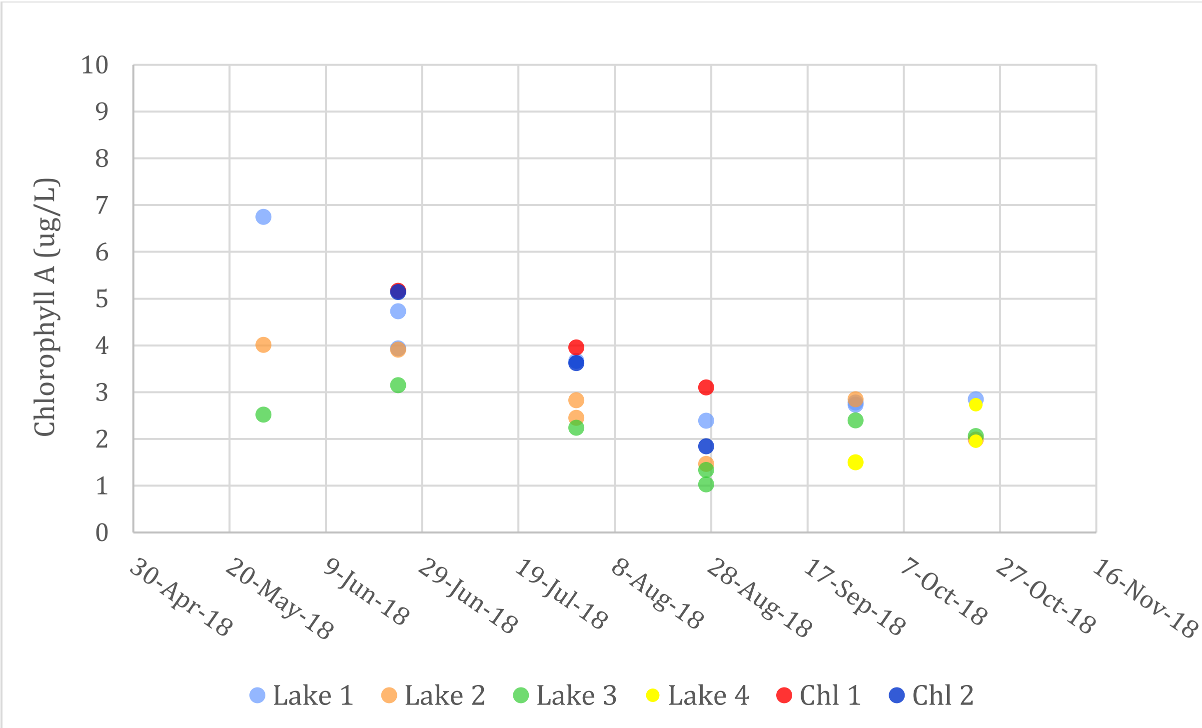

Figure 20: Chlorophyll a at four monthly lake sites (Lake 1-4), and two summer-only sites (Chl 1 and Chl 2) during the May-October 2018 SL water quality field season.

2.2.6. Fecal Coliform Bacteria

Fecal coliform bacteria are found in the waste of warm-blooded animals and used as indicators of fecal pollution within freshwater environments. Sources of bacteria can include agricultural lands – due to the spreading of manure on crops, stream crossings by livestock, and livestock feces (Stephenson and Street, 1978; Hunter et al., 1999; Crane et al., 1983), domestic and wild animal feces, leachate from landfills (Maqbool et al., 2011), malfunctioning septic systems, illegal straight-pipes, and stormwater run-off (both urban areas and overland flow in rural regions).

In recreational waters, the presence of fecal pollution presents a risk to the public, as the possible presence of pathogenic microorganisms can infect humans and animals and cause serious illnesses. As testing for the hundreds of disease-causing microorganisms is costly and impractical, this program uses fecal coliforms measured in coliform forming units per 100 mL (CFU/100mL) as an indicator of fecal pollution. Fecal coliforms act as a proxy for *Escherichia coli* (*E. coli*), Health Canada's indicator bacteria for fecal contamination in freshwaters, under the assumption that 90% of fecal coliforms are *E. coli*. For recreational waters, Health Canada has set a limit of < 400 CFU/100 mL of fecal coliforms and *E. coli* during primary contact activities (activities where the body, face, or trunk are submersed, and it is likely that water will be swallowed, such as: swimming, surfing, canoeing, etc.) (Health Canada, 2012). Although the presence of fecal coliforms indicates the presence of fecal contamination, the absence of fecal coliforms should not be interpreted to mean that all pathogenic organisms are absent.

In the four lake sites and seven inlet stream sites monitored during the 2018 field season, no site exceeded the Health Canada primary contact limit (Figures 21 and 22). The highest fecal coliform count within the lake sites was 20 CFU/100 mL, found at Lake 2 in July 2018. Samples were below laboratory detection limits for all eight Lake 1 samples, six of seven Lake 2 samples, six of seven Lake 3 samples, and two of three Lake 4 samples. For the streams, concentrations ranged from <10 CFU/100 mL to 350 CFU/100 mL. The highest bacteria concentration was recorded at Butler Lake Brook (350 CFU/100 mL), during the rainfall-dependent event.

Elevated stream bacteria concentrations were recorded during both the August rainfall-dependent event and September bimonthly event – these elevated concentrations may be due to flushing of bacteria on land into the streams, as both samples coincided with heavy rainfall. Increases in bacteria in waterbodies following rainfall is commonly reported in the literature (Rodgers et al., 2003; Hunter, McDonald, and Beven, 1992; Stephenson and Street, 1978); however, it appears that the increases did not affect lake water quality. Although the rainfall-dependent sampling did not include sampling lake sites, the September sampling event coincided with heavy rainfall and required both lake and bimonthly sampling of the four primary inlet streams. Though the four streams had elevated September bacteria concentrations, no increase in bacteria concentrations was recorded at any lake site. Caution should still be maintained by the public after rainfall events, to avoid exposure to high fecal bacteria concentrations, especially around streams and where streams and the lakes intersect. In addition, caution should be taken in streams that have known bacteria sources upstream.

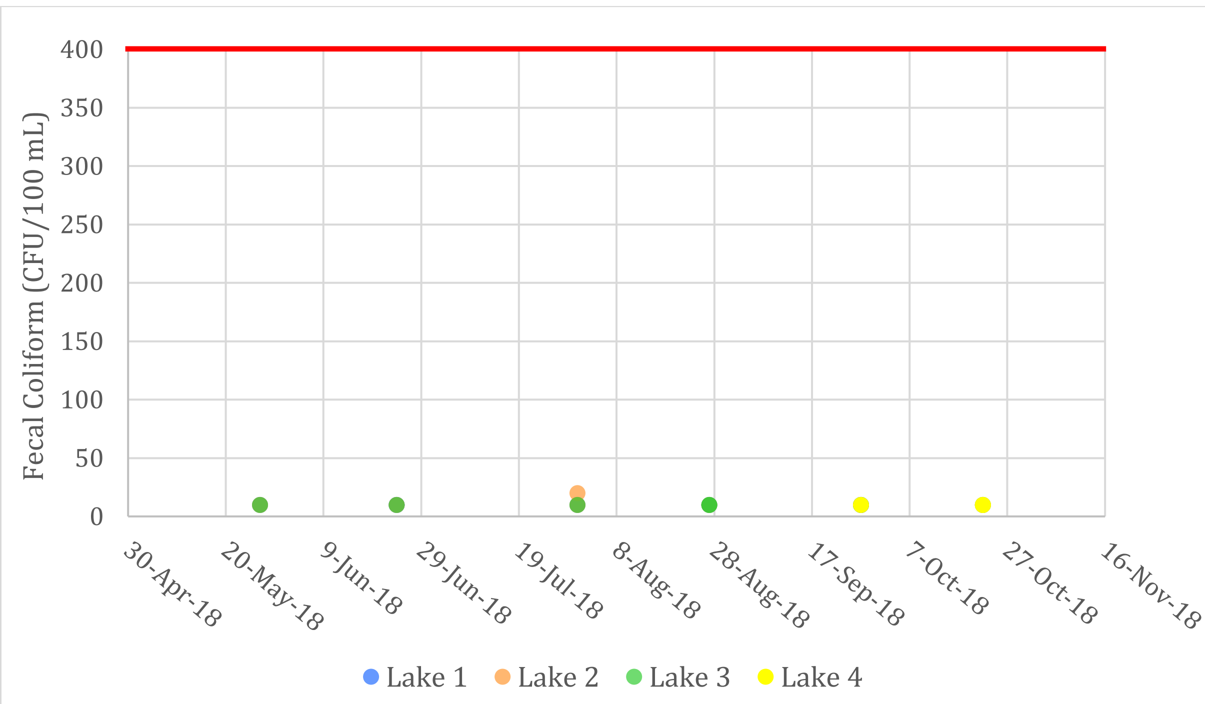

Figure 21: Fecal coliform at four monthly lake sites (Lake 1-4) during the May-October 2018 SL water quality field season. Red line indicates Health Canada's fecal coliform concentration limit for recreation in freshwaters (400 CFU/100 mL).

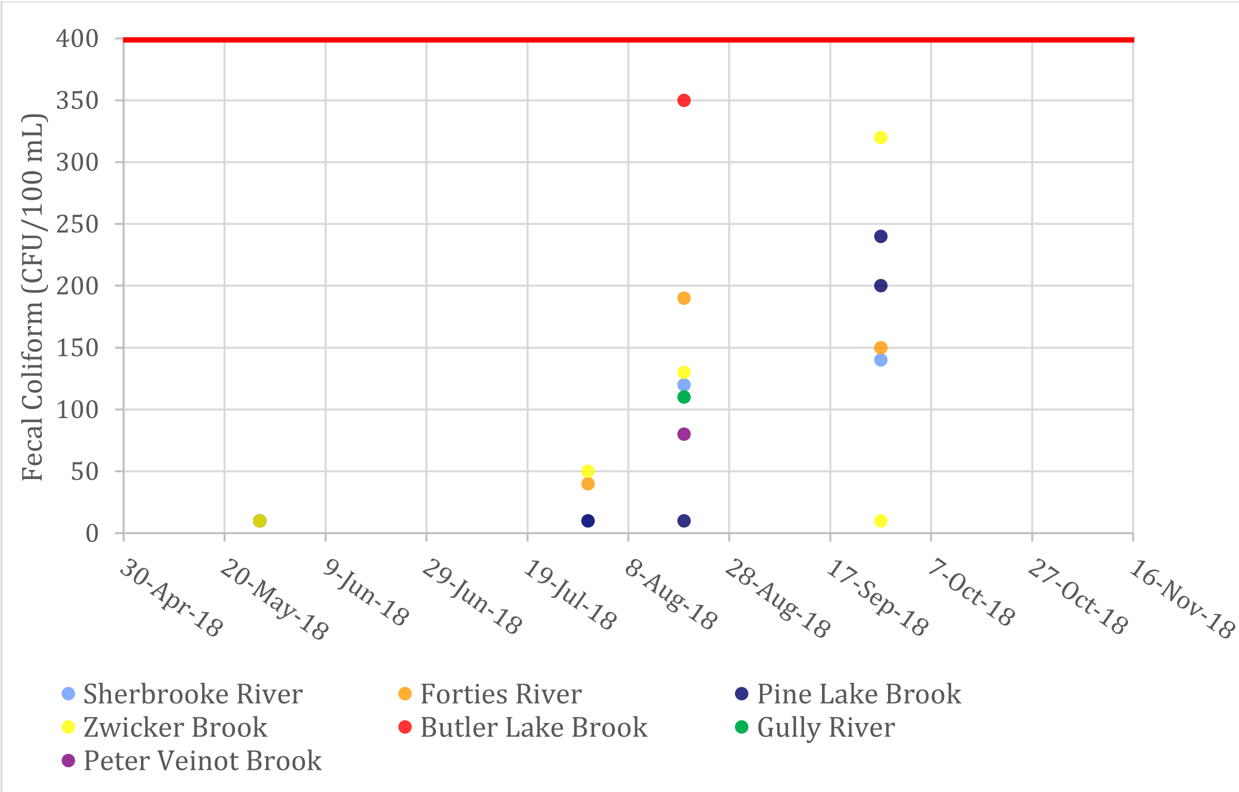

Figure 22: Fecal coliform at four bimonthly and rainfall-dependent stream sites (Sherbrooke River, Forties River, Pine Lake, and Zwicker Brook), in addition to three rainfall-dependent stream sites (Butler Lake Brook, Gully River, and Peter Veinot Brook). Red line indicates Health Canada's fecal coliform concentration limit for recreation in freshwaters (400 CFU/100 mL).

2.3. Sediment Sampling

Sediments can have adverse effects on water quality in lakes and rivers, as sediment acts as a reservoir for metals, nutrients, and organisms. During turbulence in streams, chemicals held within sediment can be released, causing an influx of more than just TSS and TDS, but increases in metals, bacteria, organic matter, and nutrients (Reddy et al., 1999; Brylinsky, 2004) – all of which can negatively affect a lake's fragile chemical equilibrium.

For sediments found at the bottom of lakes, resuspension is less likely; however, sediments can affect bottom-feeding organisms due to high concentrations of metals which settle out of suspension and accumulate on the lake bottom (Guthrie and Perry, 1980). Affecting bottom-feeders thereby affects other organisms due to bioaccumulation of chemicals through the food-chain (Fishar and Ali, 2005; Chen and Chen, 1999). In addition, different forms of phosphorus held in sediments can greatly affect lakes. Orthophosphate is a bioavailable form of phosphorus which 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; Howell, 2010). 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 turnover, when nutrient-rich bottom waters are mixed throughout the lake, providing new food sources for organisms.

High concentrations of metals within the lake bottom sites, unlike the Forties River site, may negatively affect aquatic life (Table 7). Within the Lake 2 and 3 sites, arsenic, cadmium, lead, and mercury exceed the CCME interim sediment quality guidelines (ISQG). In addition, manganese and selenium concentrations appear to be close to CCME sediment guidelines and should be monitored (CCME, 2001). Lake 2 has more exceedances of metal guidelines than Lake 3 – this may be due to the increased depth and greater slope of Lake 2. Water depth and slope are associated with increased metal concentrations due to funneling of particulate matter towards deeper lake-bottom pockets, as observed by Hakanson (1977) in Lake Vanern, Sweden.

Sediment metal concentrations at both SL lake sites are comparable to metal concentrations found in four Kejimkujik lakes monitored from 2000-2009. Sediment samples were collected by Environment and Climate Change Canada from Hichemakaar Lake, Big Dam East, Cobrielle Lake, and Peskowesk between 2000 and 2009 (Kirk, 2018). Although the SL and Kejimkujik lakes have comparable sediment metal concentrations, many of these metals' concentrations exceed CCME guidelines. The high metal concentrations at Lake 2 are greater than the mean metal concentrations found at Kejimkujik for arsenic, cadmium, lead, manganese, and mercury (Table 8). In addition, the concentration of cadmium in sediment at Lake 2 and 3 is greater than the maximum cadmium concentration found in the four Kejimkujik lakes. Although Lake 1 sediment was not sampled during the 2018 monitoring program, it is recommended that sediment sampling be done at the site in the future, due to the high metal concentrations recorded at the Lake 2 and 3 sites.

As Forties River does not exceed any guidelines, it does not appear to be a significant influence on metal concentrations within the lake sites. It is possible that one (or multiple) of the other 13 inlet streams is affecting metal concentrations within the lake sediments; the lake sediments may also just be the accumulation over time from metal inputs from other inlet streams. Expanding sediment analyses to slowly assess sediment quality from the other six main inlet streams would help determine whether one or multiple streams are influencing lake sediments accumulation quantities.

Table 7: Concentration of metals within site sediment samples sampled on August 27th, 2018. Interim sediment quality guideline (ISQG) is the recommendation by CCME of total concentrations of chemicals in surficial sediment, while the probable effect level (PEL) is the CCME upper value in which adverse effects are expected (CCME, 2001). Nova Scotia environmental quality standards (NSEQS) are sediment guidelines specifically set by the Nova Scotia Environment (NSE, 2014). Light yellow indicates parameters approaching one of the guidelines, while dark yellow indicates an exceedance of one of the guidelines.

		Sediment Sample Concentrations				**Concentration Guidelines**		
Metal	**UNITS**	**Lake 2**	**Lake 3**	**Forties River**	**RDL***	**ISQG**	**PEL**	**NSEQS**
Acid Extractable Aluminum (Al)	mg/kg	22000	6700	4300	10	-	-	-
Acid Extractable Antimony (Sb)	mg/kg	ND*	ND	ND	2.0	-	-	-
Acid Extractable Arsenic (As)	mg/kg	16	8.3	2.7	2.0	5.9	17	17
Acid Extractable Barium (Ba)	mg/kg	42	26	26	5.0	-	-	-
Acid Extractable Beryllium (Be)	mg/kg	ND	ND	ND	2.0	-	-	-
Acid Extractable Bismuth (Bi)	mg/kg	ND	ND	ND	2.0	-	-	-
Acid Extractable Boron (B)	mg/kg	ND	ND	ND	50	-	-	-
Acid Extractable Cadmium (Cd)	mg/kg	1.0	1.5	ND	0.30	0.6	3.5	3.5
Acid Extractable Chromium (Cr)	mg/kg	14	4.6	4.7	2.0	37.3	90	90
Acid Extractable Cobalt (Co)	mg/kg	8.8	6.8	2.3	1.0	-	-	-
Acid Extractable Copper (Cu)	mg/kg	15	13	ND	2.0	35.7	197	197
Acid Extractable Iron (Fe)	mg/kg	14000	10000	8300	50	-	-	47,766
Acid Extractable Lead (Pb)	mg/kg	49	13	3.3	0.50	35	91.3	91.3
Acid Extractable Lithium (Li)	mg/kg	10	11	20	2.0	-	-	-
Acid Extractable Manganese (Mn)	mg/kg	480	1000	200	2.0	-	-	1,100
Acid Extractable Mercury (Hg)	mg/kg	0.27	0.16	ND	0.10	0.17	0.486	0.486
Acid Extractable Molybdenum (Mo)	mg/kg	ND	ND	ND	2.0	-	-	-
Acid Extractable Nickel (Ni)	mg/kg	7.5	5.7	2.3	2.0	-	-	75
Acid Extractable Phosphorus (P)	mg/kg	1900	400	180	100	-	-	-
Acid Extractable Rubidium (Rb)	mg/kg	6.3	4.7	17	2.0	-	-	-
Acid Extractable Selenium (Se)	mg/kg	1.8	ND	ND	1.0	-	-	2
Acid Extractable Silver (Ag)	mg/kg	ND	ND	ND	0.50	-	-	1
Acid Extractable Strontium (Sr)	mg/kg	13	ND	ND	5.0	-	-	-
Acid Extractable Thallium (Tl)	mg/kg	0.26	0.34	0.12	0.10	-	-	-
Acid Extractable Tin (Sn)	mg/kg	3.0	2.0	ND	2.0	-	-	-
Acid Extractable Uranium (U)	mg/kg	5.7	1.7	0.52	0.10	-	-	-
Acid Extractable Vanadium (V)	mg/kg	30	11	11	2.0	-	-	-
Acid Extractable Zinc (Zn)	mg/kg	93	96	20	5.0	123	315	315
Orthophosphate (P)	mg/kg	0.067	0.26	0.33	0.050	-	-	-

*RDL = Reportable Detection Limit; ND = Not Detected

Table 8: Comparison of 2018 sediment metal concentrations from SL Lake 2, Lake 3, and Forties River to the range and mean metal concentrations from four Kejimkujik Lakes (Hilchemakaar, Big Dam East, Cobrielle, and Peskowesk) monitored from 2000-2009 (Kirk, 2018).

Metal	Unit	Lake 2	Lake 3	Forties River	Kejimkujik Range	Kejimkujik Mean Concentration
Acid Extractable Arsenic (As)	mg/kg	16	8.3	2.7	3.55-27.1	10.50
Acid Extractable Cadmium (Cd)	mg/kg	1.0	1.5	ND*	0.1-0.4	0.26
Acid Extractable Lead (Pb)	mg/kg	49	13	3.3	43-62.5	48.40
Acid Extractable Manganese (Mn)	mg/kg	480	1000	200	28.7-666	273.40
Acid Extractable Mercury (Hg)	mg/kg	0.27	0.16	ND	0.14-0.345	0.22
Acid Extractable Selenium (Se)	mg/kg	1.8	ND	ND	1.39-3.17	2.24

*RDL = Reportable Detection Limit; ND = Not Detected

Regarding the phosphorus levels within the lake and river sediment (Table 9), although Lake 2 has the highest amount of phosphorus in sediment, Forties River has the highest orthophosphate to phosphorus ratio. All three sites had low orthophosphate to phosphorus ratios (<0.2% each), indicating that the bioavailable orthophosphate is being quickly assimilated by organisms and therefore most of the phosphorus in the sediment is in non-bioavailable forms. Although there is no sediment phosphorus guideline set by the CCME, Ontario's Provincial Sediment Quality Guidelines have a 600-2000 mg/kg range, where 2000 mg/kg of phosphorus in sediment is the 'severe effect level' (Ontario MOE, 2008). Lake 3 and Forties River are below the Ontario guidelines, suggesting minimal influence by pollution and no negative effects on aquatic organisms; however, Lake 2 is close to the 2000 mg/kg severe effect level (1900 mg/kg at Lake 2) and therefore may indicate pollution affecting the lake, and a potential for internal loading for phosphorus in the lake causing algal blooms. Lake 2 should be considered a 'site of concern' and be continued to be monitored due to high potential for nutrient-enrichment, eutrophication, and algal blooms.

Table 9: Phosphorus concentrations in sediment samples from lake and river sites sampled on August 27th, 2018.

	Lake 2	Lake 3	Forties River
Orthophosphate in sediment (mg/kg)	0.0067	0.26	0.33
Acid extractable phosphorus in sediment (mg/kg)	1900	400	180

3. Discussion

3.1. Trophic State of Sherbrooke Lake

Trophic states describe the productivity of a waterbody which can aid in tracking how a waterbody changes over time. Trophic states range from oligotrophic (low productivity and minimal biomass) to hypereutrophic (high productivity and maximum biomass). The trophic state index (TSI), proposed by Carlson (1977), uses the depth of transparency (Secchi disk), and concentrations of chlorophyll *a* and phosphorus to apply a number to the waterbody's state (Equations 2, 3, and 4) – associated with its trophic state. Tracking a waterbody's TSI allows comparison between years using the same methods.

Equation 2: $$TSI\ (Secchi\ disk) = 60 - 14.41 \times \ln(Mean\ Secchi\ disk\ [m])$$

Equation 3: $$TSI\ (chlorophyll\ A) = 30.6 + 9.81 \times \ln\left(Mean\ chlorophyll\ A\ \left[\frac{\mu g}{L}\right]\right)$$

Equation 4: $$TSI\ (total\ phosphorus) = 4.15 + 14.42 \times \ln\left(Mean\ total\ phosphorus\ \left[\frac{\mu g}{L}\right]\right)$$

In SL, the lake's TSI could be based on sites Lake 1 and Lake 2, therefore a TSI was created for both sites (Table 10; Figure 23). Both sites indicate mainly mesotrophic conditions, with phosphorus concentrations towards oligotrophic status. Concern should be minimal for the Secchi disk/water transparency eutrophic-approaching indices, as water transparency is not an exact indication of a waterbody's productivity, and can be influenced by factors other than biomass, such as suspended particles within the water column (NSSA, 2014; EPA, 2002). For 2018, the SL trophic status should be considered borderline oligotrophic-mesotrophic.

Table 10: Carlson (1977) 2018 SL TSI scores and trophic states for total phosphorus, chlorophyll A, and Secchi disk for Lake 1 (red) and Lake 2 (blue).

TSI Score	Trophic State	Phosphorus	Chlorophyll A	Secchi Disk
< 40	Oligotrophic	33.3 28.6		
40-50	Mesotrophic		42.3 40.7	48.6 47.38
> 50	Eutrophic			

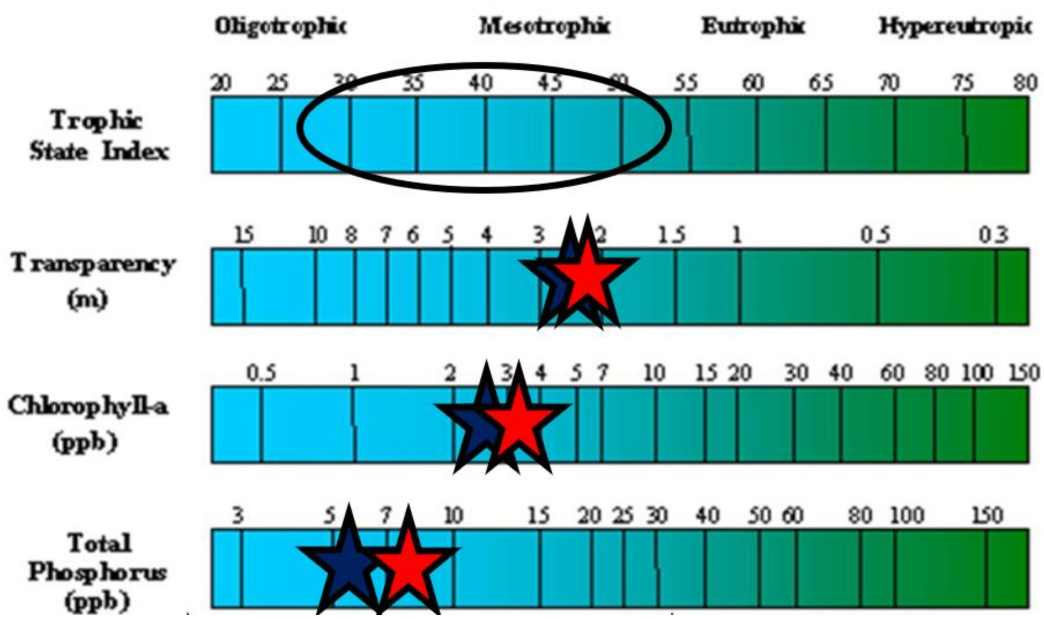

Figure 23: Carlson TSI for lakes, with TSI ranks for SL Lake 1 (red star) and Lake 2 (blue star). Transparency determined using Secchi disk depth. From Carlson (1977).

3.2. Algal Blooms

An algal bloom is the rapid increase and accumulation of microscopic plankton algae (phytoplankton) in water bodies and can be detrimental of ecosystems (Hallegraeff, 2003). Ecosystems have a fragile balance, where biomass is sustained and limited by available nutrients; however, when excess nutrients enter an ecosystem, biomass can expand (Heisler et al., 2008). In waterbodies, excess nutrients allow algae to flourish, exceeding normal densities and assimilating all nutrients. The increased biomass presence causes decreased water transparency – blocking off the depth of which sunlight penetrates a waterbody – and as the algae decay, increased microbial decomposition reduces dissolved oxygen – leading to hypoxic and anoxic conditions (Paerl et al., 2001).

In addition to the detrimental environmental effects, algae blooms can pose a risk to humans and animals if they consist of cyanobacteria. Cyanobacteria, commonly referred to as blue-green algae, can emit toxins into the water, causing serious illness and even death in humans (Lawton and Codd, 1991). Aside from humans, cyanobacteria blooms have also been associated with fish kills (Rodger et al., 1994), and the death of dogs (Backer et al., 2013). Although not all cyanobacteria are toxic, it is important to test each bloom to confirm which strains are present and if toxins are a threat within the waterbody.

For SL, algal blooms have been reported in previous years; however, no bloom was sampled and confirmed during the 2018 field season. Chlorophyll *a* – a proxy for biomass and indicator of potential blooms – remained low throughout the summer and did not spike after fall turnover when nutrients increased. In addition, algal blooms can occur in pockets, and it is possible that a bloom did occur, but not at the sampling sites. Although no algal bloom was detected in 2018, the literature suggests an increase in both size and frequency of algae blooms in the future (Michalak et al., 2013), therefore SL may still experience algae blooms in years to come.

3.3. Pollution

Based on the low nutrient and bacteria concentrations, lack of detectable hydrocarbons and algal blooms, and an oligotrophic-mesotrophic state of the lake, pollution appears to be minimal within SL. Rainfall appears to be the biggest threat to water quality within the lake – affecting the seven inlet streams via bacteria and nutrient levels. Though no effect was observed within the lake during the rainfall events, the continued input from these streams may influence long-term productivity of the lake.

Heavy metals within the lake sediments suggests that some degree of pollution does exist within the lake. Although heavy metals do have natural sources, and the metal concentrations from SL sediment are comparable to nearby sediment in Kejimkujik, concentrations for mercury, arsenic, cadmium, and lead exceed CCME guidelines for aquatic life. The accumulation of heavy metals in SL sediment may be exacerbated by development and atmospheric inputs originating from industry.

As the SL water quality is not heavily affected by human pollution – aside from long-term sediment contamination - it is important to continue monitoring and highlighting changes in water quality within the lake and its inlet streams, to ensure issues are identified and best management practices are applied. In addition, as high metal concentrations have been found within SL sediment, sediment analyses should also be included in long-term monitoring and management plans of SL.

4. Recommendations

The following recommendations are suggested for the SL Water Quality Monitoring Program, based on the 2018 water quality results:

- The SL Water Quality Monitoring Program should continue in 2019 and beyond, as construction of the public access site - and expected increased lake-usage - is expected to continue into future years, and this program was developed to establish a water quality baseline to aid in evidence based decisions concerning the development of the properties acquired by MODL for public use.
    - Sampling of the seven inlet streams should continue during rainfall-dependent events, to determine how rainfall events are affecting inlet streams. Sampling of one lake site during the rainfall-dependent event would also add information regarding how the streams are influencing the lake during rainfall events.
    - The program should consider purchasing a rainfall and water level gauge, to be set up and monitored by volunteers, to provide volunteers greater decision-making tools when trying to capture a rainfall-dependent sampling event.
- The Lake 4 site should be added to the 2019 water quality monitoring program, with a minimum of hydrocarbons being sampled at the location.
- The addition of monitoring hydrocarbons in the sediment of sites Lake 3 and 4 should be considered to track hydrocarbon loading at the lake bottom in areas with projected high traffic and potential high contamination.
- The 2019 stream sediment sample should be obtained from a different inlet stream, to gather more spatial information about nutrient and metal loading from the different streams discharging into the lakes, especially to locate if one stream is contributing excess pollutants and highly influencing lake sediment.
- Fecal bacteria testing should be switched from fecal coliforms to *E. coli*, as *E. coli* is Health Canada's primary indicator of fecal contamination.
- Monitoring of Chl 1 and Chl 2 sites should be ceased, as Lake 1 is close enough to both sites that duplication of sampling should be avoided.
- Monitoring of Lake 1 bottom sediments should be undertaken to determine the levels of phosphorus and metals in bottom sediments.
- Residents of SL should continue to be supplied with laboratory-certified bottles and sampling procedures for the collection of water samples during an algae bloom.
    - There should be emphasis in public education about the SL monitoring program, with increased awareness of what blooms are, how they occur, what they look like, and actions to take in the event of a bloom. Information should be shared with both residents of the lake, and at the public access site for visitors of the lake.
    - Caution should be advised to SL users during the fall, due to fall turnover and high potential for an algal bloom – especially at the Lake 2 site.

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