Fox Point Lake

2018 Water Quality Monitoring Report

Prepared for

Municipality of Chester

Water Quality Monitoring Committee (Mill Cove)

By

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1. Introduction

1.1. Fox Point Lake Background

Fox Point Lake (FPL) is a 1.4 km^2 lake located on the Aspotogan Peninsula, within the Municipality of Chester, Nova Scotia (Figure 1). FPL contains 11 small islands and has an average depth of 4.9 m (Beanlands, 1980). The lake drains an area of 8 km^2, with two inlet streams – the north and south - and one outlet draining into St. Margaret's Bay. The northern inlet drains a forested region, crossing a wetland before reaching the lake, while the southern inlet runs through the Aspotogan Golf Course. Residential properties, both year-round and seasonal, line the lake perimeter.

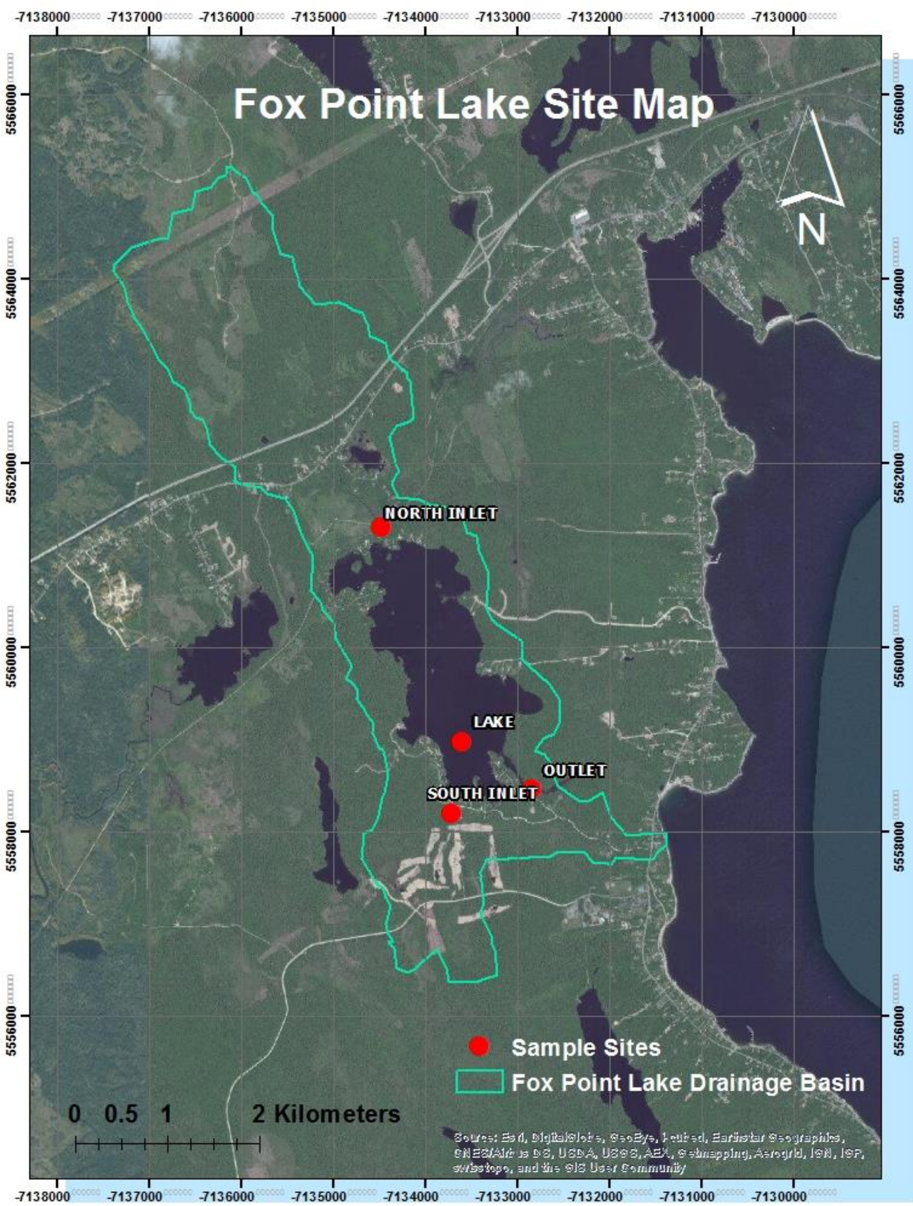

Figure 1: Drainage basin and sampling sites of Fox Point Lake.

1.2. Program Background

In 2014, due to concerns from residents about the water quality of FPL, the Municipality of Chester created the Fox Point Lake Water Quality Monitoring Committee (WQMC). Due to development around the lake by Aspotogan Ridge – a 550-acre community with development plans for 344 residential units and an 18-hole golf course – the rate of rainfall-induced sedimentation plumes in FPL spiked. The sedimentation events, occurring near the southern inlet which drains from the golf course, raised concerns for the health of FPL by citizens.

To monitor the water quality conditions and track changes within the lake, Coastal Action was contracted in 2015 by the Municipality of Chester to join the WQMC and develop and implement a water quality program. The program focuses on four site locations (Figure 1) chosen to monitor water quality incoming, within, and exiting the lake. Monitoring activities within the program are conducted by a small group of trained volunteers, with the support of the Coastal Action Project Manager.

Further details on the program can be found in the *Fox Point Lake Water Quality Monitoring Program (2015)*, and program results are found in the *Fox Point Lake Water Quality Monitoring Reports* from 2015-2017; all are available on request from the Municipality of Chester.

1.3. Objectives and Scope of Work

The objective of this program is to provide a multi-year water quality baseline of Fox Point Lake, and monitor changes and the lake's trophic state, to help inform decisions made regarding development in the region and its effects on water quality. Within the WQMC, Coastal Action's scope of work includes:

- Designing and writing the Fox Point Lake 2018 Water Quality Monitoring Program
- Ordering and ensuring correct bottles from Maxxam Analytics
- Creating and printing waterproof field sheets for each sampling month
- Calibrating and caring for the MODL-MOC YSI monthly
- Coordinating with volunteers for sampling days
- Coordinating the volunteer-collected water level and rainfall measurements
- Conducting one-time rainfall-dependent sampling with volunteers
- Conducting one-time field sediment sampling with volunteers
- Conducting field water sampling monthly with volunteers
- Conducting algal bloom sampling with volunteers
- Dropping off water samples at Maxxam Analytics in Bedford, NS
- Transferring data from field sheets, Maxxam, and volunteers into a database and analyzing data

- Attending WQMC-MC meetings and presenting water quality results
- Preparing this report to summarize results and recommendations for water quality related to Fox Point Lake

1.4. Review of the 2017 Fox Point Lake Water Quality Monitoring Report

The trophic state of FPL was determined to be oligotrophic and approaching mesotrophic in 2015, 2016, and 2017; this indicates that there have not been any major changes in the biological productivity of the lake from 2015-2017.

Thermal and oxygen profiles were conducted at one lake site in 2017. Thermal stratification of the lake was observed during the temperature profile, while dissolved oxygen indicated a depletion of oxygen at depth, with concentrations below 3 mg/L at the bottom waters of the lake.

An algae bloom occurred in June of 2017 and water sample analysis confirmed the presence of microcystin-LR, which is a toxin produced by cyanobacteria. The 2017 algal bloom occurred at approximately the same time as the 2016 bloom – in mid- to late-June. The confirmation of cyanobacterial toxins in FPL in 2016 and 2017 highlights the need for residents to be aware of the risks associated with algae blooms and informed as to the proper precautions to take during a bloom.

Nutrients (both phosphorus and nitrogen) were found to exceed water quality guidelines at the North and South Inlets; however, the South Inlet site had decreases in both mean and maximum concentrations of phosphorus and nitrogen compared to 2015 and 2016. The South Inlet stream appears to be recovering from excessive nutrient loading but is still exceeding guidelines.

1.5. Changes to the 2018 Fox Point Lake Water Quality Monitoring Program

In 2017, physical water parameters (temperature, dissolved oxygen, pH, and total dissolved solids) were measured bimonthly; however, due to the minimal differences between bimonthly measurements and the significant amount of sampling time required from volunteers, sampling was reduced to monthly.

In addition, the 2018 program added a one-time sampling event to measure total nitrogen and total phosphorus below the thermocline of the lake. Sampling below the thermocline was added to inform whether the lake may have excessive nutrients within the bottom waters, which could cause an algal bloom or eutrophication during the fall's lake-turnover.

One blank and one replicate per month at a randomly-selected sampling site were added to the program in 2018 for quality assurance and quality control.

Finally, as the program did not begin until June in 2018, the sampling costs for May's sampling were used for a one-time rainfall-dependent sampling event, where water samples were collected and analyzed within 48 hours of a >20 mm rainfall event.

2. Water Quality Monitoring Results

2.1. Water Sampling

2.1.1. Physical Water Quality Parameters

2.1.1.1. Precipitation and Water Level

Precipitation and water level of FPL were monitored by FPL volunteers daily from June to October, 2018 – except the month of September as data collection was unavailable (Figure 2).

Between June 5th and October 17th, 2018, FPL received 433 mm of rain – this rainfall amount is a minimum value, as the September data are not available. This precipitation amount is comparable to the 483.6 mm of rain in 2017, and higher than the drought-inducing 163 mm in 2016.

Water level was recorded from a fixed-elevation staff gauge on a shoreline dock structure. The FPL water level fluctuated between 0.57 and 0.78 m during 2018 – this is also consistent with previous years' data (0.58-0.78 m in 2017, 0.63-0.78 m in 2016, and 0.61-0.80 m in 2015). Water level within the lake decreased below 0.6 m within the month of August, coinciding with a period of drought.

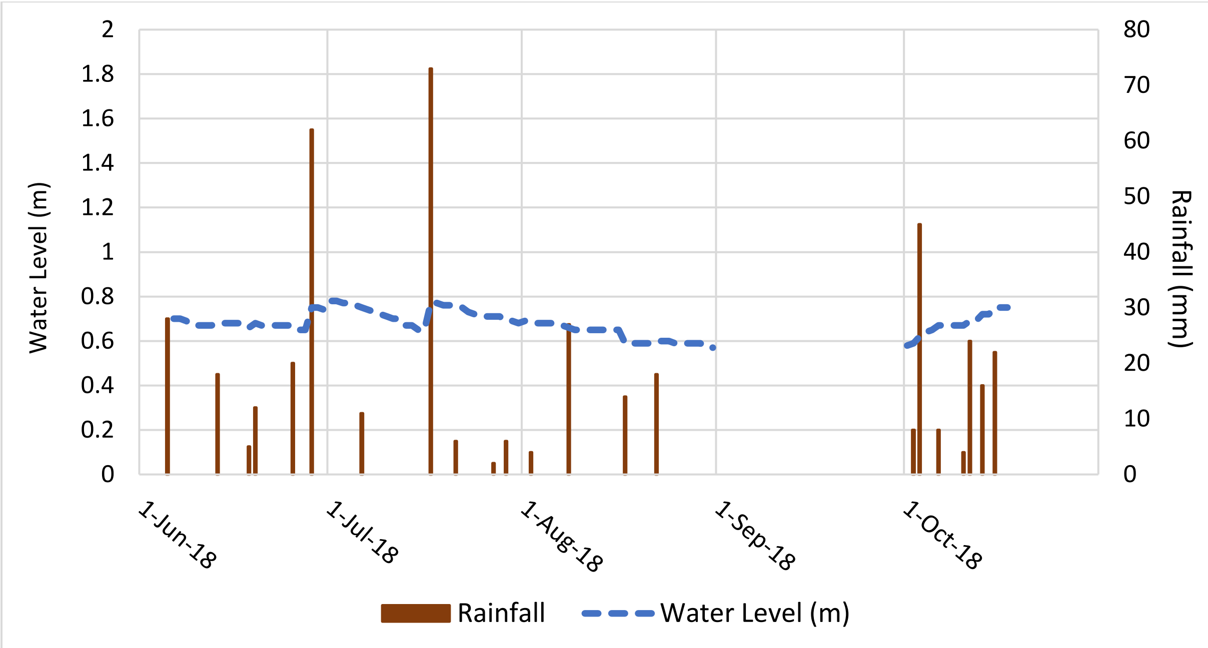

Figure 2: Daily water level and rainfall monitored at FPL from June-October, 2018. No data was collected during the month of September.

2.1.1.2. Stream Discharge

Stream discharge rates were monitored at the two inlet sites – North and South – and the Outlet site monthly from June to October, 2018 (Figure 3). As stream depth and width can affect stream discharge, each stream's depth, width, velocity, and discharge are measured and calculated on an individual basis.

Discharges from the two inlet sites were, on average, lower than that of the outlet (Figure 3, Table 1). The Outlet provided the greatest rate variability, ranging between 0.005 to 0.610 m^3/s; however, both the Outlet and the South Inlet sites' range and mean discharge for 2018 are comparable to previous years. The discharge at the outlet is the highest of all three steam sites, which is expected as it is the sole outlet draining the lake.

The North Inlet had the greatest variability in discharge direction. The negative directions recorded at the North Inlet are associated with the strong influence from wind and the lake's waves, causing the stream to appear to be moving backwards. The effects of the wind and waves on the North Inlet site appears to be due to the change in site location, as previous years did not record negative discharges.

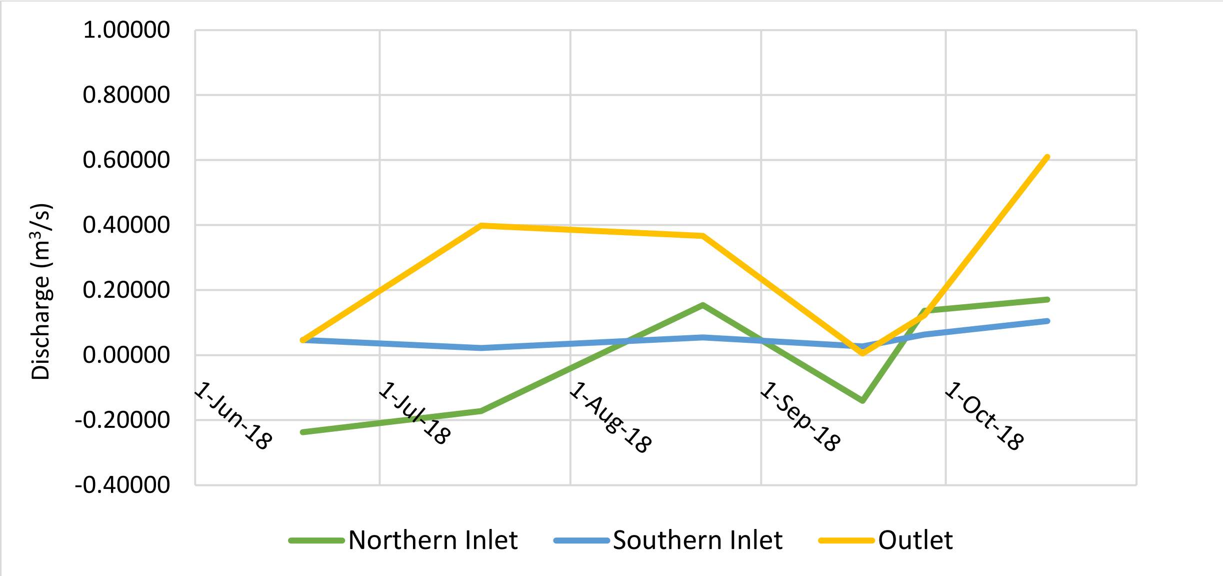

Figure 3: One-time monthly water discharges from the three streams monitored at FPL from June-October, 2018.

Table 1: Mean and range of stream discharge rates from June-October, 2018 at the three stream sites, with 2015, 2016, and 2017 results for comparison.

	North Inlet	**South Inlet**	**Outlet**
Mean Stream Discharge Rate (m³/s) ***(2015/2016/2017)***	-0.015 *(0.428/0.213/0.157)*	0.053 *(0.036/0.027/0.053)*	0.26 *(0.235/0.178/0.608)*
Range of Stream Discharge Rates (m³/s) ***(2015/2016/2017)***	-0.237-0.171 *(0.2002-0.701/0.161-0.271/0.104-0.195)*	0.022-0.105 *(0.021-0.058/0.012-0.035/0.015-0.106)*	0.005-0.610 *(0.052-0.749/0.032-0.540/0.254-0.930)*

2.1.1.3. Water Temperature and Stratification of Fox Point Lake

Water temperatures from the four FPL sites were recorded monthly during the 2018 program; temperatures ranged from 9.1 to 23.7ºC (Figure 4). Water temperatures were consistently colder at the North and South Inlet sites than the Lake and Outlet. As streams are commonly cooler than lakes, the cooler temperatures recorded at the inlet streams are expected. In addition, as the Outlet is the point of drainage for the lake, the temperatures in the stream are highly dependent on the lake temperatures and would therefore be elevated higher than the two inlet streams.

Water temperatures increased from July to September, with the Lake and Outlet sites exceeding 20ºC – the temperature threshold for cold-water fish species (Nova Scotia Salmon Association [NSSA], 2014). Although the two sites exceeded the 20ºC threshold, the deeper waters within the lake, deep cold-water pools within the Outlet, and the two colder inlet streams provide ample thermal refuge for fish during the hotter months.

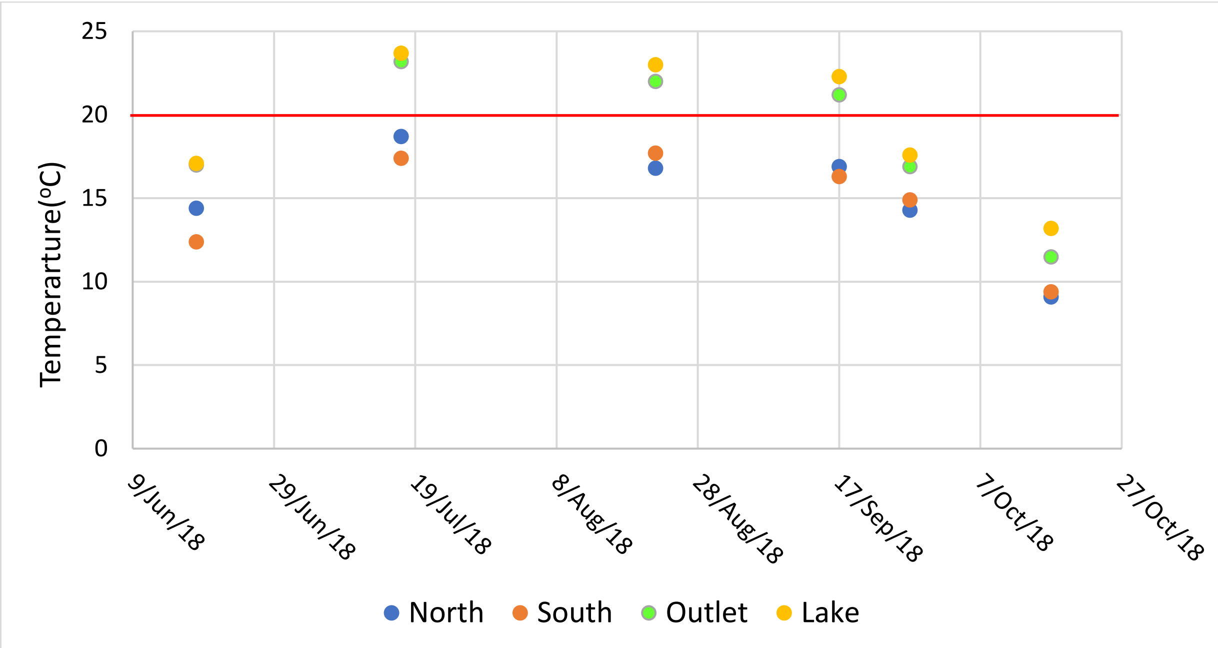

Figure 4: Monthly water temperature from the lake and three stream sites at FPL from June-October, 2018. Red line indicates the 20°C water temperature threshold for cold-water fish species.

During the 2018 FPL program, a monthly water profile was conducted within the lake (Figure 5). Between June to September, the profile shows the development and establishment of a stratified water column, with warmer waters remaining at the surface (epilimnion) and the cooler, more-dense waters settling to the lake bottom (hypolimnion). The thermocline – the depth at which the water temperature rapidly changes – is located at the 6 to 10-m lake depth. Although the surface waters of the lake exceeded the 20°C threshold for cold-water fish, temperatures were below the threshold at depths >6 m.

Due to the density-differences between the epilimnion and hypolimnion, little mixing occurs within the thermally-stratified parts of the lake. By the end of September (during the rainfall event), we can see the deterioration of the stratification (Figure 5), as the surface temperatures lower and the thermocline covers a smaller area. October has minimal thermocline, with temperatures staying consistent down to a depth of 13 m. Fall turnover of the lake is expected to occur in October when the lack of stratification encourages mixing of the waters at all depths.

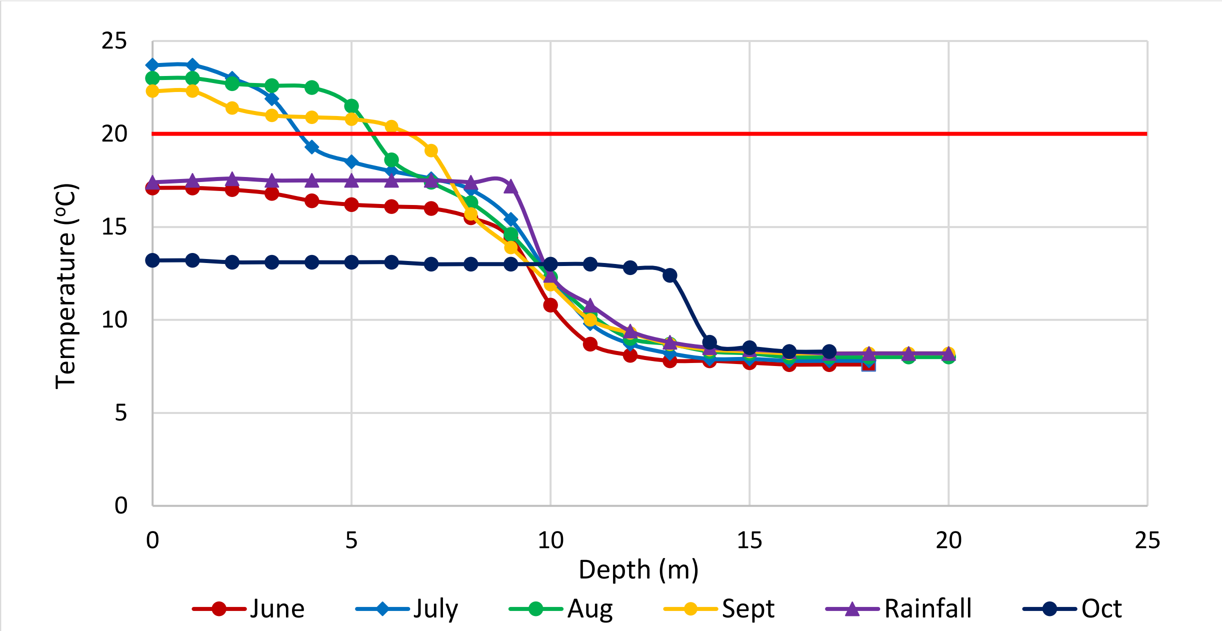

Figure 5: Monthly water temperature depth-profiles from the lake site at FPL from June-October, 2018. Red line indicates the 20°C water temperature threshold for cold-water fish species.

2.1.1.4. Dissolved Oxygen and Stratification of Fox Point Lake

Dissolved oxygen (DO) within the water was recorded monthly at all four sites, from June to October, 2018 (Figure 6). DO ranged from 0.22 mg/L to 10.39 mg/L. The North inlet consistently had the lowest DO concentrations, while the highest concentrations were recorded within the lake. The low velocity and minimal incline of the North inlet stream may be factors in the low DO measurements, as these factors limit the water's ability to engulf oxygen from the air.

The low DO in the North inlet may negatively affect aquatic organisms. DO is a requirement for the survival of aquatic organisms, with a minimal threshold of 6.5 mg/L set by the Canadian Council of Ministers of the Environment (CCME) for cold-water species (CCME, 1999). Of the four sites, the lake was never below 6.5 mg/L, the Outlet minimally fell below the threshold once in September (6.38 mg/L), the South inlet fell below the threshold three times (5.55 mg/L, 6.26 mg/L, and 3.02 mg/L on July 17th, August 22nd, and September 17th, respectively), and the North inlet was below the 6.5 mg/L threshold every month except October. Although fish can survive in low-DO environments for short periods of time, the continuous low-DO environment in the North inlet may be causing physiological stress to fish in that stream.

Although the low-DO concentrations in the North inlet is concerning, it is consistent with previous years (Table 2). The summer 2018 DO concentrations (July-September) at the North inlet are lower than previous years; however, when comparing the entire field seasons of 2017 and 2018, the DO measurements are not significantly different at 95% (p-value: 0.09 according to the Wilcoxon Test). The reduction in DO during the summer is a consistent annual trend due to the decreased ability for warmer waters to dissolve oxygen and the higher DO demand during the growing season.

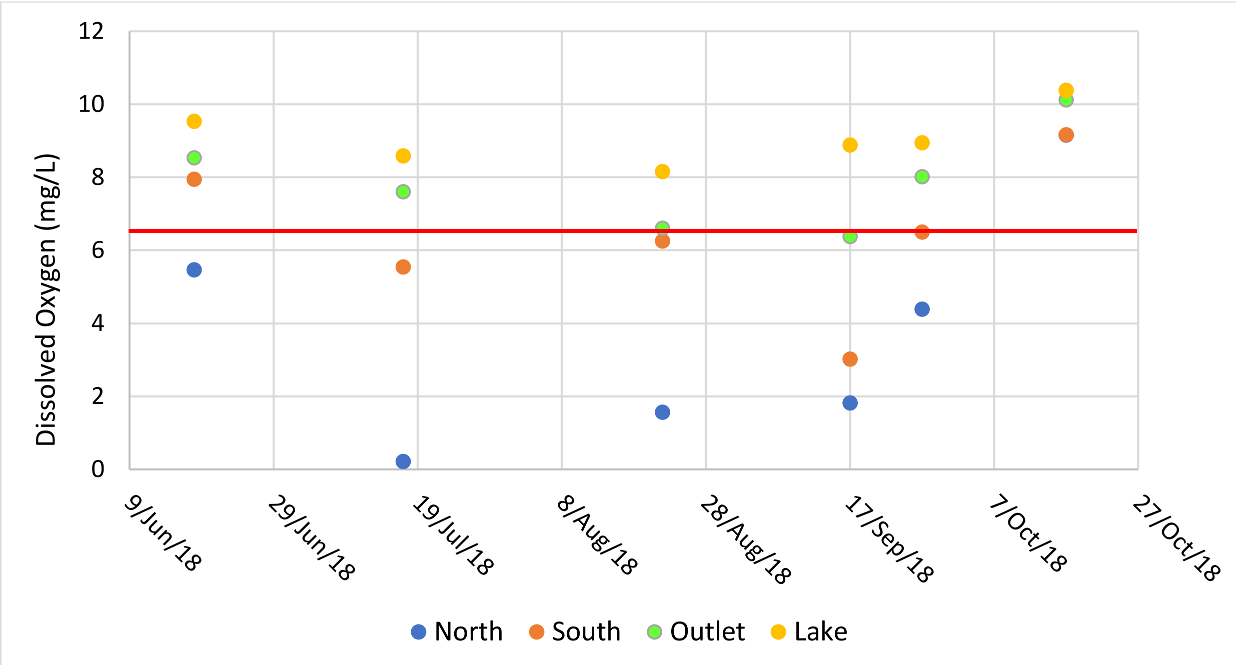

Figure 6: Monthly DO from the lake and three stream sites at FPL from June-October, 2018. Red line indicates the 6.5 mg/L DO minimum for aquatic organisms, as set by the CCME.

Table 2: Mean and minimum summer DO concentrations from July-September, 2018 at the four sites, with 2015, 2016, and 2017 results for comparison.

	North Inlet	South Inlet	Outlet	Lake
Mean Summer DO (mg/L) ***(2015/2016/2017)***	2.0 *(2.25/3.36/3.59)*	5.33 *(6.31/5.63/6.70)*	7.16 *(7.05/6.97/7.66)*	8.65 *(7.88/8.02/8.21)*
Minimum Summer DO (mg/L) ***(2015/2016/2017)***	0.22 *(1.38/2.31/1.93)*	3.02 *(5.86/3.92/5.38)*	6.38 *(5.75/5.61/6.80)*	8.16 *(7.33/7.43/7.75)*

DO was measured within the lake during the monthly water depth-profiles (Figure 7). There is no difference in DO concentrations at depth in June, and minimal difference in July. By August, there appears to be an established stratified DO column in the lake, which remains for the rest of the sampling period. The reduction of DO concentrations within the hypolimnion is associated with minimal mixing of the water column due to the presence of a thermocline in the lake (refer to section 2.1.1.3). The lack of mixing and therefore minimal DO inputs from the epilimnion, and the continued oxygen demand from organisms, result in the decline in DO concentrations in the hypolimnion until the water column mixes again during fall turnover (Smith and Bella, 1973).

The DO depth-profile within the lake appears to be a clinograde curve, with a negative heterograde curve occurring in August. Of the four types of DO curves that can be observed (orthograde, clinograde, negative heterograde, and positive heterograde), a clinograde curve occurs when DO decreases in the hypolimnion layers due to microbial decomposition and other oxygen demands. A negative heterograde curve can occur, with a pocket of low DO occurring mid-profile, due to the accumulation and high oxygen demand of decomposing organic matter being caught in the density boundary (Mackie, 2004). A negative heterograde curve has been confirmed in previous years in FPL, with the clinograde curve occurring most predominantly during the fall prior to the lake's turnover.

The summer stratification of the lake may cause stress to organisms within the lake. During the August-October monthly profiles, the hypolimnion's DO concentrations fall below 6.5 mg/L. August appears to be the most concerning, as the decline in DO concentrations below the threshold occurs at shallow depth (6 m) and remains below the threshold for all depths >6 m. Although the subsequent months do not fall below the threshold until after 6-m, their hypolimnion waters have lower DO concentrations than in August, becoming hypoxic (<2 mg/L) and anoxic (<1 mg/L) – conditions which can reduce the ability to support aquatic life (United States Geological Survey [USGS], 2014; Brylinsky, 2004).

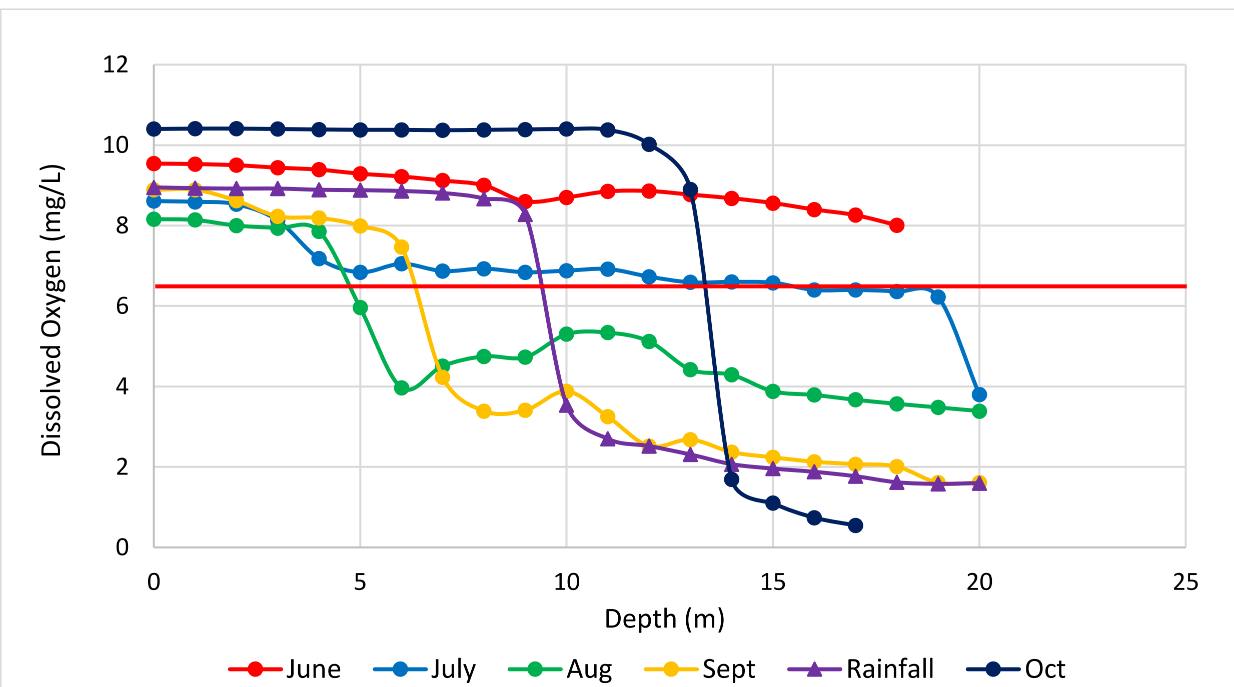

Figure 7: Monthly dissolved oxygen depth-profiles from the lake site at FPL from June-October, 2018. Red line indicates the 6.5 mg/L DO minimum for aquatic organisms, as set by the CCME.

2.1.1.5. pH

pH, a measurement of the acidity of a liquid, was measured monthly at each of the four FPL sites (Figure 8). Mean pH concentrations for the sites ranged from 5.15-pH at the North inlet, to 6.71-pH within the Lake (Table 3). pH values fell as low as 4.40-pH, occurring at the North inlet on October 17th; however, pH values at the North inlet were not statistically significant from the 2017 values (p-value: 0.33 at 95% confidence using the Wilcoxon Test). The highest recorded pH – 9.75 on September 27th within the lake – occurred following a heavy rainstorm and may be influenced by more basic water entering the lake via rainwater and overland flow.

Although most pH measurements fell below the 6.5-pH threshold set by the CCME (CCME, 2002), the acidity of the FPL waters is not a concern. Of the measurements taken, only one sample – 9.75 on September 27th within the Lake – met the 6.5-pH threshold. 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 within the province are generally lower than the 6.5-pH threshold. In addition, though the FPL sites' 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 the majority of the time (save for the low sub-5.0 pH measurements in the North and South inlets on October 17th) the acidity of the waters at FPL pose minimal threat to organisms.

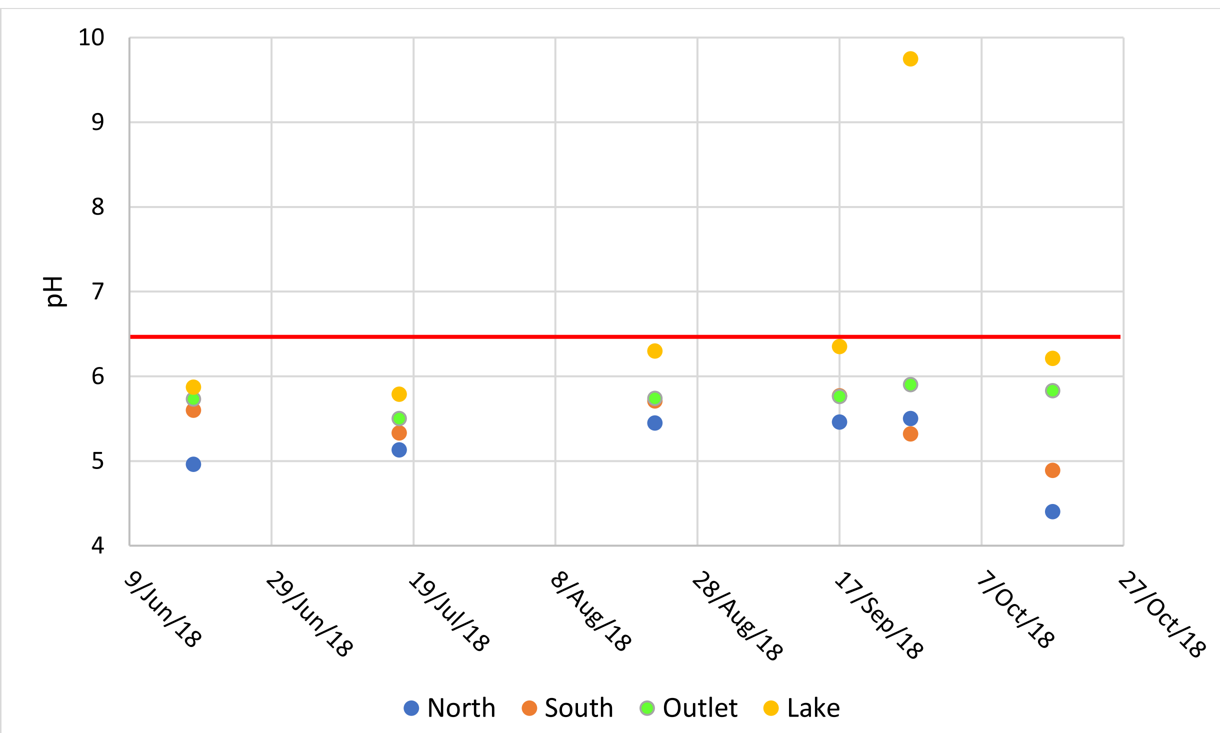

Figure 8: Monthly pH from the lake and three stream sites at FPL from June-October, 2018. Red line indicates the 6.5-pH minimum for aquatic organisms, as set by the CCME.

Table 3: Mean and minimum pH values from June-October, 2018 at the four sites, with 2015, 2016, and 2017 results for comparison.

	North Inlet	**South Inlet**	**Outlet**	**Lake**
Mean pH ***(2015/2016/2017)***	5.15 *(4.52/5.17/5.01)*	5.44 *(4.96/5.64/5.23)*	5.74 *(5.45/5.74/5.47)*	6.71 *(6.17/6.39/6.91)*
Minimum pH ***(2015/2016/2017)***	4.40 *(3.88/4.36/4.49)*	4.89 *(4.1/4.85/4.78)*	5.50 *(5.04/5.59/5.08)*	5.79 *(5.66/6.08/6.10)*

2.1.1.6. Total Dissolved Solids

Total dissolved solids (TDS) from the four FPL sites sampled monthly from June-October 2018 ranged from 25 mg/L to 59 mg/L (Figure 9). The highest TDS concentrations were consistently measured within the North inlet, while the remaining three sites never exceeded 34 mg/L.

Although TDS concentrations within FPL are higher than other locations and previous years, TDS does not appear to be a problem for aquatic organisms. There is no set guideline for TDS 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 lake site within the FPL program had an average of 33.2 mg/L in 2018, suggesting that the lake is not pristine and to some extent affected by sedimentation. In addition, the lake site's 2018 TDS concentrations were significantly higher than the 2017 concentrations (p-value: 0.007 at 95% confidence based on the Wilcoxon Test). Although TDS did increase within the lake compared to 2017, 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 and has only a 2.15 mg/L maximum difference from the 2017 values, TDS concentrations do not appear to be detrimental to FPL.

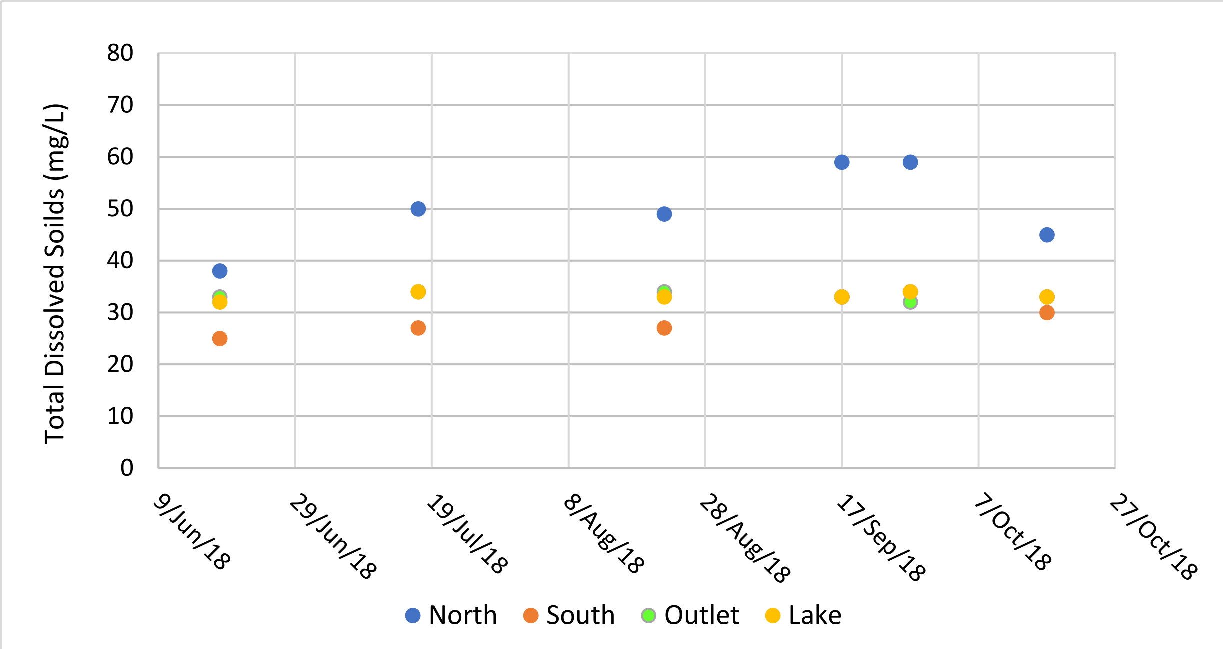

Figure 9: Monthly total dissolved solids from the lake and three stream sites at FPL from June-October, 2018.

2.1.2. Chemical Water Quality Parameters

2.1.2.1. Total Suspended Solids

Total suspended solids (TSS) were measured, at Maxxam Analytics Laboratory for each site monthly, as the value of solids suspended in a water column which do not pass through a 45 µm glass fiber filter. For FPL, TSS ranged from <1 mg/L to 3 mg/L (Figure 10). The South inlet had the highest maximum and mean TSS concentrations, 3.0 mg/L and 2.09 mg/L respectively. Only the South inlet was significantly different from the Lake at 95% confidence (p-value: 0.005 based on Wilcoxon Test); the stream sites were not significantly different from each other at 95% confidence. An increase in TSS concentrations were recorded within the Lake and South inlet sites during the scheduled September and rainfall-dependent sampling events.

Although rainfall appears to influence TSS within FPL, concentrations are not a concern and are consistent with Nova Scotian lakes and previous FPL sampling years. Following several rainfall events in mid-September, both the monthly and the rainfall-dependent samples from the Lake and South inlet increased; increases may be associated with overland flow influences adding sediment to both the stream and the lake. The elevated TSS concentrations were only 0.91 mg/L and 0.5 mg/L greater than mean concentrations for the South inlet and Lake, respectively. 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 increases observed in FPL do not appear to be a threat to aquatic organisms. The TSS measurements are consistent with past sampling, as no 2018 FPL site's TSS concentrations were significantly different than the 2017 measurements (at 95%

confidence based on the Wilcoxon Test). In addition, the mean Lake TSS concentration was 1.10 mg/L, well below the average 3.0 mg/L background concentration of Nova Scotia lakes reported by Hinch and Underwood (1985).

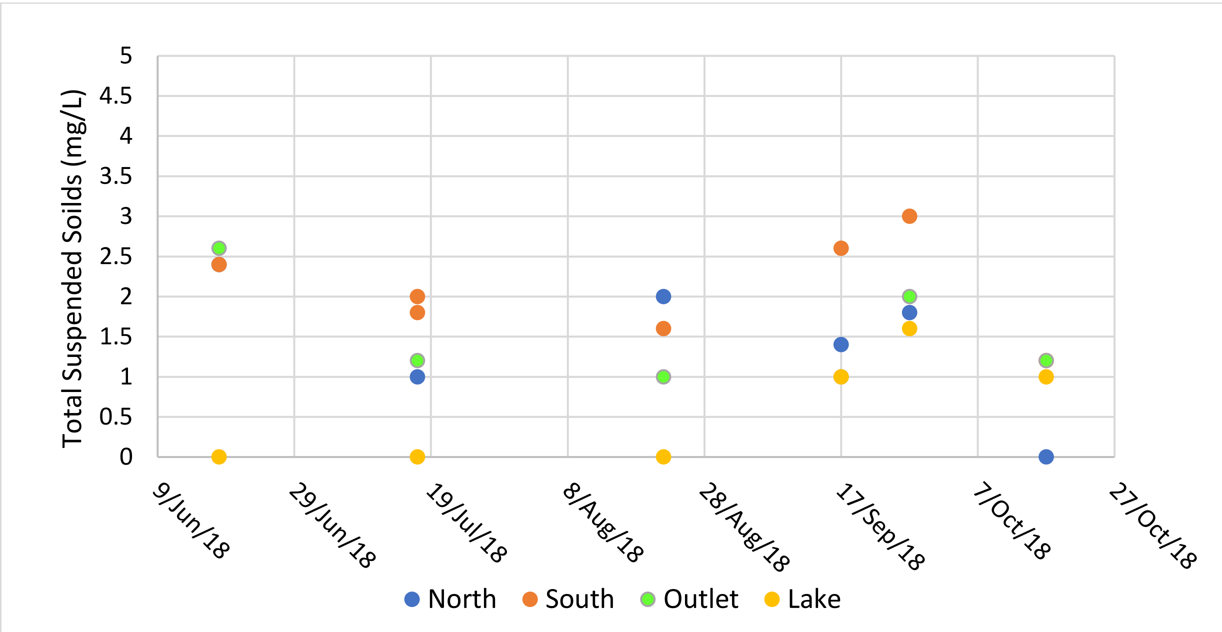

Figure 10: Monthly total suspended solids from the lake and three stream sites at FPL from June-October, 2018.

2.1.2.2. Total Phosphorus

Total phosphorus within FPL, monitored and analyzed at Maxxam monthly from June-October 2018, ranged from <0.004 mg/L to 0.1 mg/L (Figure 10, Table 4). The highest phosphorus concentrations were consistently measured at the South inlet, and were significantly different from the North inlet, Outlet, and Lake sites (p-values: 0.003 for all sites, at 95% confidence based on the Wilcoxon Test). The phosphorus concentration obtained at-depth, below the thermocline, was 0.025 mg/L.

Three of the four FPL sites did not exceed phosphorus guidelines in 2018. Ontario's Ministry of Environment and Climate Change (MOECC) has established two guidelines for phosphorus in waterbodies: ≤ 0.02 mg/L for lakes, and ≤ 0.03 mg/L for rivers and streams (Ontario's Ministry of Environment [MOE], 1979). The lake's phosphorus concentrations never exceeded 0.02 mg/L, with 0.013 mg/L between the threshold and the highest recorded 2018 lake phosphorus concentration. Phosphorus concentrations also did not exceed the 0.03 mg/L stream threshold for the North inlet and Outlet.

The South inlet site exceeded the 0.03 mg/L MOECC stream guideline for phosphorus during the entire 2018 sampling season. This sample site has exceeded the MOECC stream guideline for phosphorus for each sample obtained during the 2015, 2016, 2017, and 2018 field seasons. As there are few natural phosphorus inputs into the environment, elevated concentrations indicate an anthropogenic source; the South inlet site is downstream of the Aspotogan golf course, which may be acting as a contributing source to the inlet's phosphorus concentrations.

Although the South inlet exceeded MOECC stream phosphorus guidelines, phosphorus concentrations within the stream appear to be declining. The maximum recorded phosphorus concentration in 2018 was 0.1 mg/L, the lowest maximum value recorded since the inception of the program (Table 4). In addition, the 2018 samples also had the lowest mean concentration compared to 2015, 2016, and 2017. Although phosphorus concentrations in the South inlet are the highest of the four FPL sampling sites, the reduction in phosphorus concentrations suggests that the stream is recovering from nutrient enrichment and that the control measures placed along any developments feeding the South inlet are working.

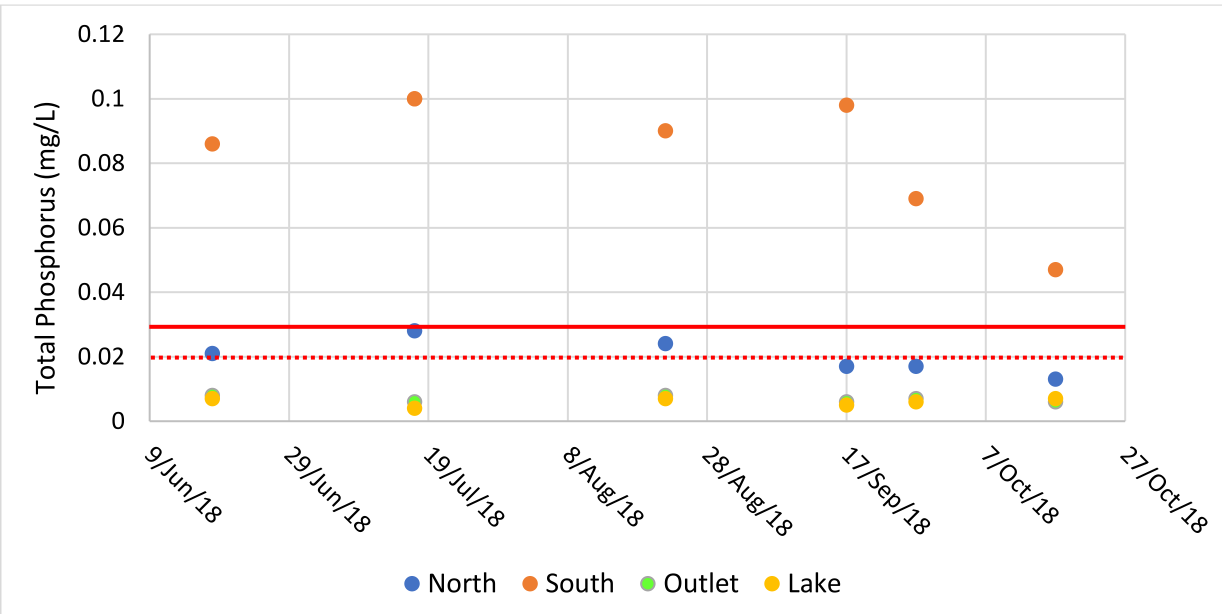

Figure 11: Monthly total phosphorus concentrations from the lake and three stream sites at FPL from June-October, 2018. Red solid line indicates the 0.03 mg/L MOECC guideline for streams and rivers, while the red dotted line indicates the 0.02 mg/L MOECC guideline for lakes.

Table 4: Mean and maximum phosphorus concentrations from June-October 2018 at the four sites, with 2015, 2016, and 2017 results for comparison.

	North Inlet	South Inlet	Outlet	Lake
Mean Total Phosphorus (mg/L)	0.020	0.084	0.007	0.006
(2015/2016/2017)	*(0.020/0.018/0.021)*	*(0.164/0.149/0.088)*	*(0.008/0.012/0.007)*	*(0.010/0.007/0.007)*
Maximum Total Phosphorus (mg/L)	0.028	0.100	0.008	0.007
(2015/2016/2017)	*(0.030/0.031/0.034)*	*(0.240/0.320/0.120)*	*(0.008/0.027/0.008)*	*(0.014/0.008/0.010)*

2.1.2.3. Total Nitrogen

Total nitrogen was measured at Maxxam monthly from June-October 2018 for all four FPL sites (Figure 12). Total nitrogen ranged from 0.167 mg/L to 0.66 mg/L; the highest nitrogen concentration was recorded at the North inlet, while the highest mean nitrogen concentration occurred at the South inlet (Table 5). No sites' 2018 concentrations were significantly different from the 2017 concentrations (at 95% confidence based on the Wilcoxon Test). The nitrogen concentration obtained at-depth, below the thermocline, was 0.460 mg/L.

Nitrogen concentrations do not appear to be a problem in FPL. The CCME does not have a set guideline for nitrogen in waters, as nitrogen is an essential nutrient to ecosystems; however, Dodds and Welch (2000) established a 0.9 mg/L threshold for freshwater environments to avoid excessive nutrient loading and eutrophication of the ecosystem. In addition, Underwood and Josselyn (1979) have a 0.3 mg/L guideline for nitrogen concentrations in oligotrophic waters. All four sample sites fell below the 0.9 mg/L threshold, while the Lake site exceeded the 0.3 mg/L guideline once – the first exceedance of the oligotrophic guideline since the beginning of the program. As this exceedance occurred on September 27th, on the rainfall-dependent sampling date, it is possible that the elevated concentration is due to overland flow, as the two inlet streams minimally changed from their mean concentrations and therefore do not appear to be factors in the increase of nitrogen within the lake during this sampling event. As all four sites are under the nutrient-loading threshold, and the lake is generally within oligotrophic nitrogen levels, the risk of nutrient enrichment via nitrogen appears to be minimal for FPL.

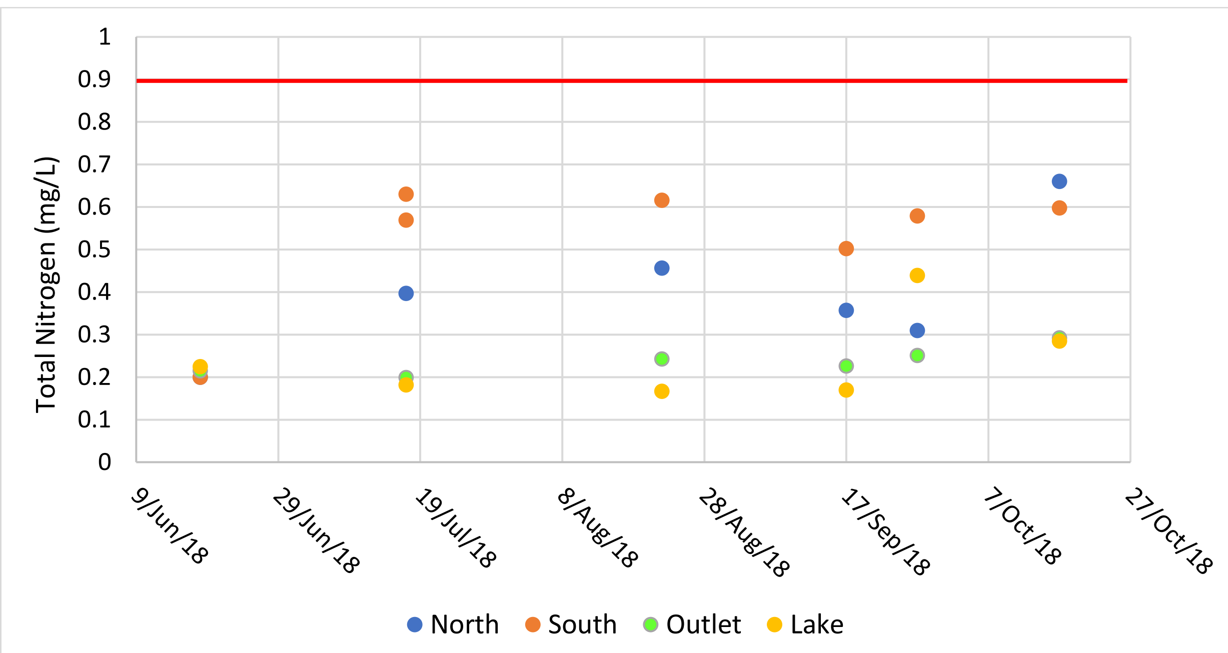

Figure 12: Monthly total nitrogen concentrations from the lake and three stream sites at FPL from June-October, 2018. Red line indicates the 0.9 mg/L guideline for freshwater environments, as set by Dodds and Welch (2000).

Table 5: Mean and maximum nitrogen concentrations from June-October, 2018 at the four sites, with 2015, 2016, and 2017 results for comparison.

	North Inlet	South Inlet	Outlet	Lake
Mean Total Nitrogen (mg/L) **(2015/2016/2017)**	0.397 *(0.530/0.481/0.478)*	0.528 *(1.22/0.612/0.595)*	0.238 *(0.365/0.236/0.244)*	0.245 *(0.234/0.241/0.236)*
Maximum Total Nitrogen(mg/L) **(2015/2016/2017)**	0.660 *(0.624/0.584/0.605)*	0.630 *(2.01/0.763/0.683)*	0.292 *(0.696/0.298/0.264)*	0.439 *(0.266/0.266/0.276)*

2.1.3. Biological Water Quality Parameters

2.1.3.1. Fecal Coliform Bacteria

Although Heath Canada uses *Escherichia coli* (*E. coli*) as the fecal bacteria indicator, this program uses fecal coliform as a proxy. 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). Prior to the use of *E.coli*, fecal coliform was used as an indicator for fecal contamination in freshwaters and was therefore included in the FPL program. As the FPL program has tested for fecal coliform since the program began in 2015, the 2018 field season continued the fecal coliform sampling to allow for comparison with previous years. Fecal coliform concentrations are used as a proxy to *E. coli* concentrations and compared to Health Canada's *E. coli* guidelines.

Fecal coliform samples were collected from each FPL site monthly during the 2018 field season (Figure 13). Samples ranged from <10 CFU/100 mL to 840 CFU/100 mL. The South inlet had the highest mean fecal coliform concentration of 187.1 CFU/100 mL. The South inlet had a median value of 50 CFU/100 mL for 2018, indicating that extreme values are skewing the 2018 statistical mean at the site; however, the South inlet's median value remains the highest of the four sites.

During the rainfall-dependent sampling event, bacteria concentrations spiked in the two inlets and resulted in the sole exceedance of Health Canada's primary contact recreational guideline during the sampling period. The North inlet increased from 20 CFU/100 mL during the monthly September sampling event to 170 CFU/100 mL following the rainfall event; the South inlet also saw an increase from 20 CFU/100 mL to 840 CFU/100 mL. The North inlet increase did not exceed any Health Canada guidelines; however, the South inlet sample exceeded the primary contact guideline, while falling 160 CFU/100 mL below the secondary contact guideline. The increases in bacteria during the rainfall event may be due to drought conditions before the rain, as bacteria concentrate in pools during the low-discharge period and then these bacteria-rich pools are flushed during rainfall events (Caruso, 2001). It should be noted that the raised bacteria concentrations during this storm were not the highest bacteria concentrations recorded during the FPL program (Figure 14), and that drought-induced bacteria concentrations have been shown to be dominated by wildlife sources rather than human sources – though this has not been confirmed in FPL (Shehane et al., 2005).

Lake bacteria concentrations throughout the sampling period were well below primary recreation Health Canada guidelines. Throughout the 2018 sampling period, the lake fecal coliform concentrations never exceeded 10 CFU/100 mL. Although the North and South inlets had increased bacteria concentrations during the September 27th sampling event, the lake bacteria concentrations do not appear to be affected, as concentrations raised from below the lab's detection limit to just at the detection limit (10 CFU/100 mL). The last – and only – sample to exceed 10 CFU/100 mL was October 23rd, 2015.

During the 2018 field season, construction of a house and barn occurred just below the South inlet sampling site. If the barn on the property were to house animals, this would increase the risk of fecal bacteria contamination of the South inlet due to the increased presence and potential leaching of animal feces into the water from overland flow. Moving the South inlet site, or adding a secondary site below the development, may be needed to monitor changes in water quality along the inlet.

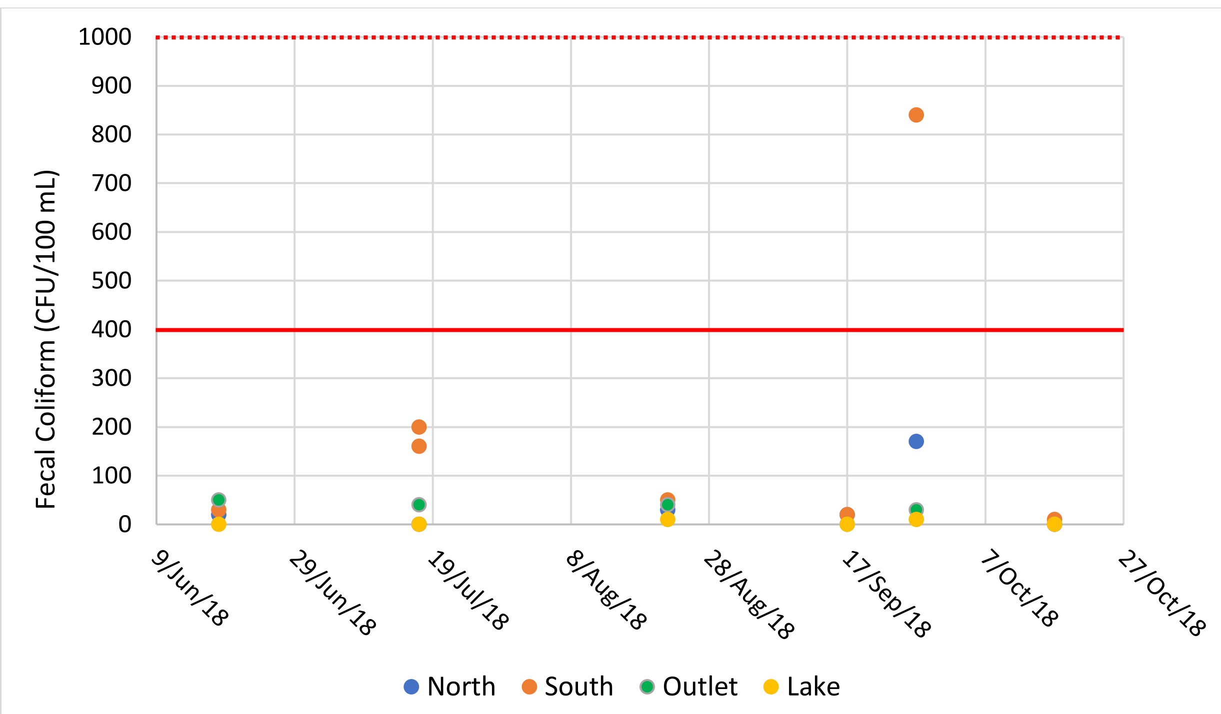

Figure 13: Monthly fecal bacteria concentrations from the lake and three stream sites at FPL from June-October, 2018. Red solid line indicates the Health Canada 400 CFU/100 mL limit for primary recreation in freshwaters; red dotted line indicates the Health Canada 1000 CFU/100 mL limit for secondary recreation in freshwaters.

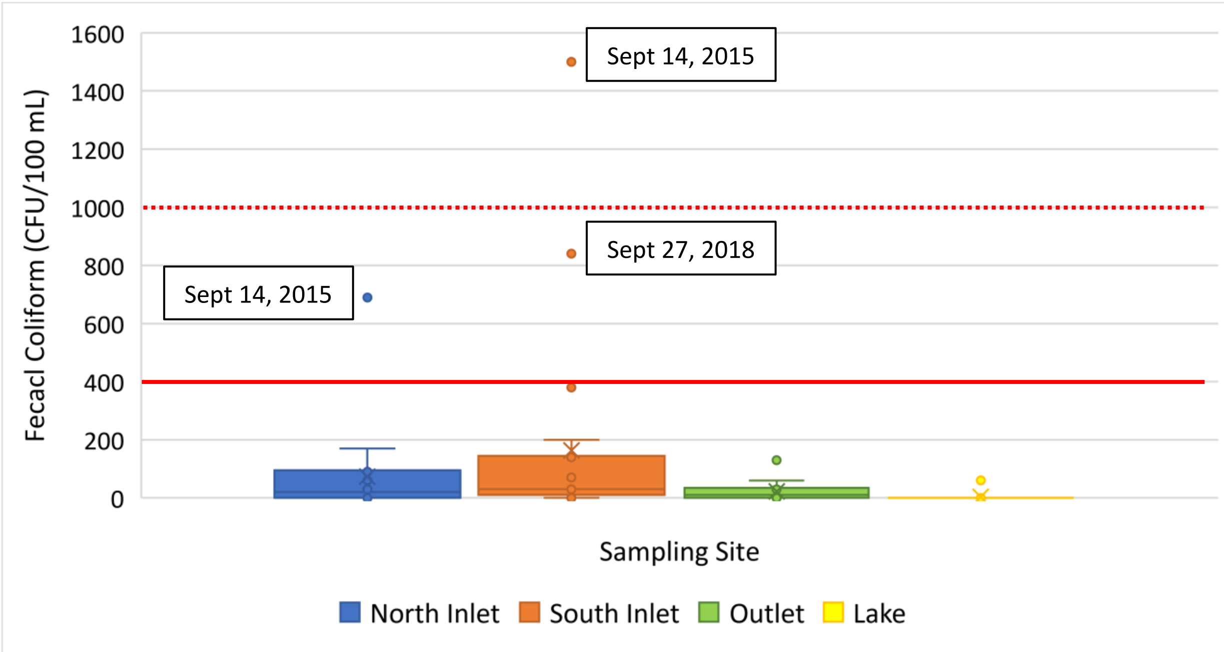

Figure 14: Monthly fecal bacteria concentrations from the lake and three stream sites at FPL from 2015-2018. Red solid line indicates the Health Canada 400 CFU/100 mL limit for primary recreation in freshwaters; red dotted line indicates the Health Canada 1000 CFU/100 mL limit for secondary recreation in freshwaters.

2.1.3.2. Microcystins and Algal Blooms

An algae bloom was not observed in Fox Point Lake in 2018; however, suspicious algae were noted and sampled on August 22, 2018. A water sample was collected in a laboratory-certified bottle by Coastal Action and a member of the FPL volunteer group, delivered to Maxxam Analytics laboratory in Bedford, then shipped to Nautilus Environmental laboratory in Calgary, Alberta for analysis of microcystin-LR, a cyanobacteria (blue-green algae) toxin.

Analysis of the sample indicated a microcystin-LR concentration of 0.16 µg/L, significantly lower than the 20 µg/L threshold set by Health Canada for recreational water-based activities (Health Canada, 2012). The 2018 microcystin-LR sample was also lower than previous years: 0.71 µg/L in 2017 and 1.25 µg/L in 2016.

2.2. Sediment Sampling

Sediment sampling from the Southwest side of the lake (known as 'SW Cove') and from the South inlet occurred on September 27th, 2018. The substrate from both sites were analyzed for metals, phosphorus, and orthophosphate, to assess the risk of internal nutrient loading within the lake and potential risk from accumulation of metals within the sediments (Tables 6 & 7).

Within the lake, the substrate indicates minimal risk for bioaccumulation. Of the three guidelines used for comparison – the CCME's recommended interim sediment quality guideline

(ISQG), the CCME's probable effect level (PEL), and the Nova Scotia Environmental Quality Standards (NSEQS) contamination threshold – only arsenic exceeded a threshold (CCME, 2001; Nova Scotia Environment [NSE], 2014). Acid extractable arsenic was 0.1 mg/kg greater than the ISQG, but still below the PEL and NSEQS thresholds. As arsenic is still below concentrations believed to have adverse effects to organisms, and is the only metal exceeding guidelines, FPL sediments appear to be of good quality and pose minimal threat to organisms.

Within the South inlet, metal concentrations within sediment were greater than those found within the lake sediment. Arsenic and mercury concentrations both exceeded ISQG thresholds, while lead appears to be approaching the ISQG threshold. All three of these metals are higher than the 2017 concentrations (7.9, 0.12, and 17 mg/kg in 2017, respectively). Although no metal concentration exceeded PEL or NSEQS thresholds, the increase in metals within one year is alarming. Organisms living within this stream should be considered at-risk for bioaccumulation. Any fisheries should be limited to the lake, where the inputs from the South inlet are diluted and do not appear to affect the overall sediment quality within the lake.

As discussed in Section 2.1.3.1, development along the South inlet may be detrimental to water quality. The development of the downstream property may pose issues with water quality within the remaining stretch of the South inlet. As the South inlet's sediment is contaminated with heavy metals, disturbance of the sediment can result in the release and contamination of metals into the water, thereby affecting water quality and organisms.

Table 6: Concentration of metals within site sediment samples sampled on September 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 for contaminated sites 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**		
Metals	**Units**	**SW Cove**	**South Inlet**	**RDL***	**ISQG**	**PEL**	**NSEQS**
Acid Extractable Aluminum (Al)	mg/kg	1700	6100	10			
Acid Extractable Antimony (Sb)	mg/kg	ND*	ND	2.0			25
Acid Extractable Arsenic (As)	mg/kg	6.0	10	2.0	5.9	17	17
Acid Extractable Barium (Ba)	mg/kg	14	50	5.0			
Acid Extractable Beryllium (Be)	mg/kg	ND	ND	2.0			
Acid Extractable Bismuth (Bi)	mg/kg	ND	ND	2.0			
Acid Extractable Boron (B)	mg/kg	ND	ND	50			
Acid Extractable Cadmium (Cd)	mg/kg	ND	0.40	0.30	0.6	3.5	3.5
Acid Extractable Chromium (Cr)	mg/kg	ND	4.5	2.0	37.3	90	90
Acid Extractable Cobalt (Co)	mg/kg	1.2	2.0	1.0			
Acid Extractable Copper (Cu)	mg/kg	2.2	8.5	2.0	35.7	197	197
Acid Extractable Iron (Fe)	mg/kg	4000	7000	50			47,766
Acid Extractable Lead (Pb)	mg/kg	2.6	33	0.50	35	91.3	91.3
Acid Extractable Lithium (Li)	mg/kg	6.6	7.8	2.0			
Acid Extractable Manganese (Mn)	mg/kg	230	270	2.0			1,100
Acid Extractable Mercury (Hg)	mg/kg	ND	0.21	0.10	0.17	0.486	0.486
Acid Extractable Molybdenum (Mo)	mg/kg	ND	ND	2.0			
Acid Extractable Nickel (Ni)	mg/kg	ND	3.8	2.0			75
Acid Extractable Phosphorus (P)	mg/kg	110	640	100			
Acid Extractable Rubidium (Rb)	mg/kg	4.3	7.9	2.0			
Acid Extractable Selenium (Se)	mg/kg	ND	1.1	1.0			2
Acid Extractable Silver (Ag)	mg/kg	ND	ND	0.50			1
Acid Extractable Strontium (Sr)	mg/kg	ND	24	5.0			
Acid Extractable Thallium (Tl)	mg/kg	ND	ND	0.10			
Acid Extractable Tin (Sn)	mg/kg	ND	ND	2.0			
Acid Extractable Uranium (U)	mg/kg	1.5	11	0.10			
Acid Extractable Vanadium (V)	mg/kg	2.8	8.4	2.0			
Acid Extractable Zinc (Zn)	mg/kg	16	43	5.0	123	315	315

*RDL = Reportable Detection Limit; ND = Not Detected

Concentrations of both acid extractable phosphorus and bioavailable orthophosphate were analyzed within both sites' substrates (Table 7). Within the SW Cove, orthophosphate constituted just 0.58% of total phosphorus. This is an increase from the 0.02% from 2017; however, this increase is due to the change in phosphorus stores within the sediment, where total phosphorus fell from 850 mg/kg in 2017 to 110 mg/kg in 2018, and orthophosphate rose from 0.17 mg/kg in 2017 to 0.64 mg/kg in 2018. Within the South inlet, orthophosphate makes up 0.20% of total phosphorus, an increase of 0.09% compared to 2017. This increase suggests that there is more bioavailable phosphorus within the lake and South inlet sediment in 2018 than 2017, which can result in nutrient enrichment during fall turnover if the available orthophosphate stores increase and are not assimilated.

Although orthophosphate concentrations have increased, total phosphorus concentrations within the sediment of both sites suggest minimally polluted sediment. According to Ontario's provincial sediment quality guidelines, pollution can range from clean/marginally polluted ('lowest effect level') at 600mg/kg to heavily contaminated ('severe effect level') at >2000 mg/kg of phosphorus in sediment (Ontario MOE, 2008). The SW Cove falls within the lowest effect level – with a large decrease in total phosphorus from 850mg/kg in 2017. The South inlet is marginally polluted, falling slightly above the 600 mg/kg boundary, and increasing its status from the lowest effect level due to an increase of 180 mg/kg since 2017.

Table 7: Phosphorus concentrations in sediment samples from lake and river sites sampled on September 27th, 2018.

	SW Cove	South Inlet
Orthophosphate in sediment (mg/kg)	0.64	1.3
Acid extractable phosphorus in sediment (mg/kg)	110	640

3. Discussion

3.1. Algae Blooms in Fox Point Lake

For FPL, algal blooms have been reported and sampled during the previous two monitoring years; however, no bloom occurred in the lake during 2018. The lack of algal blooms in FPL is consistent with other lakes in Nova Scotia (Sherbrooke Lake – see Sherbrooke Lake 2018 Water Quality Monitoring Report available from the Municipality of the District of Lunenburg and the Municipality of Chester) and across the country (Bergot, 2018).

It appears that 2018 was an anomaly for algal blooms, as the literature predicts increases in both size and frequency of blooms in the future (Michalak et al., 2013). As algal blooms can be induced and intensified by increases in nutrients to ecosystems (whether naturally from mixing of waters or anthropogenically from pollution), trends in algal blooms are hard to predict and can vary spatially. Although no bloom occurred in FPL during 2018, algal blooms should continue to be monitored and tested, with residents around FPL made aware of algal bloom causes, health effects, and precautions to take if a bloom occurs.

3.2. Trophic State of Fox Point Lake

Using various water parameters, the biological productivity of a lake can be assessed and monitored for changes over time. Based on the mean depth of transparency (Secchi disk), and mean concentrations of chlorophyll *a* and phosphorus, a Trophic State Index (TSI) score can be calculated using the Carlson (1977) equations (Equations 1, 2, and 3). By calculating a TSI of a waterbody, we can assess the biological state (trophic state) of the water and monitor how it changes over time. Trophic states range from oligotrophic (low productivity and minimal biomass) to hypereutrophic (high productivity and maximum biomass).

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

For FPL, the trophic state has consistently been recorded as oligotrophic approaching mesotrophic from 2015-2018 (Table 8). Phosphorus and chlorophyll *a* concentrations are within the oligotrophic range, while the Secchi disk score falls within the mesotrophic range (Table 8, Figure 15). The status of FPL should be considered more oligotrophic than mesotrophic, as water transparency via Secchi disk 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; United States Environmental Protection Agency [US EPA], 2002).

Table 8: 2018 FPL TSI scores (red) and trophic states, using the Carlson (1977) trophic equations, for total phosphorus, chlorophyll a, and Secchi disk compared to previous years (black italicized).

TSI Score	**Trophic State**	**Phosphorus** *(2015/2016/2017)*	**Chlorophyll *a*** *(2015/2016/2017)*	**Secchi Disk** *(2015/2016/2017)*
< 40	Oligotrophic	29.99 *(37/31.8/32.2)*	39.09 *(34/41.5/37.3)*	
40-50	Mesotrophic			47.55 *(49/45.7/45.5)*
> 50	Eutrophic			

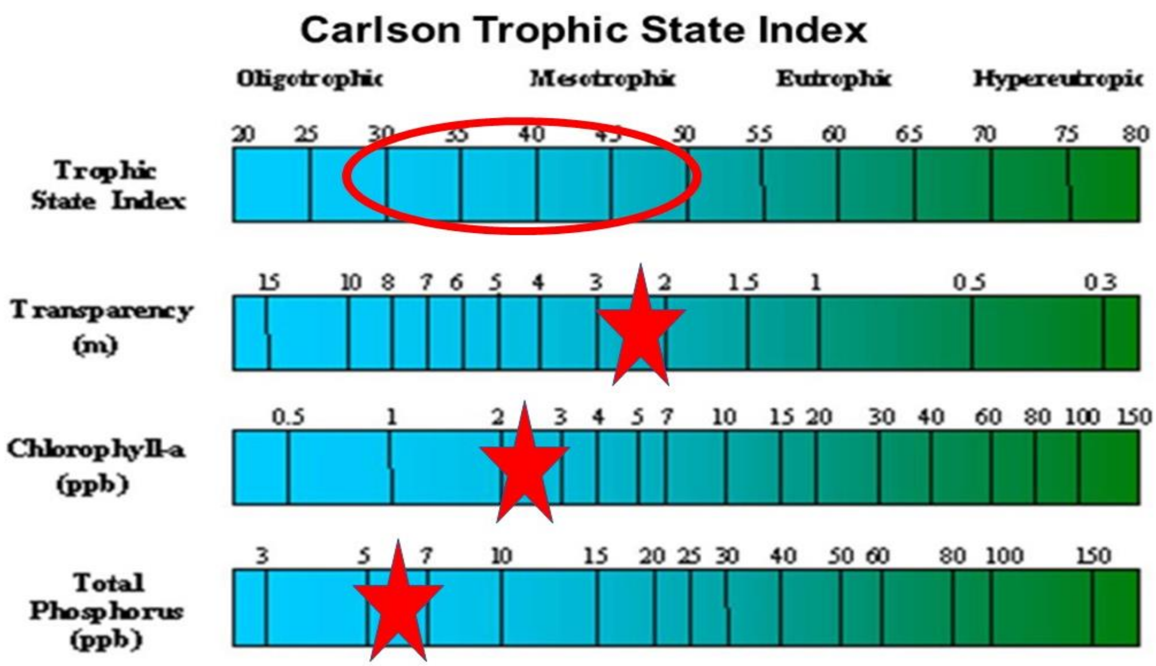

Figure 15: Carlson TSI for FPL using the mean Secchi disk depth (transparency), mean chlorophyll a concentration and mean total phosphorus concentration within FPL in 2018. From Carlson, 1977.

3.3. Potential for Nutrient Enrichment of Fox Point Lake

Excessive nutrients entering FPL can be detrimental to the health of the lake and will change the lake's trophic status. Nutrient enrichment can be from both external and internal loading sources. External sources can be natural (animal waste, plant decomposition, etc.) or anthropogenic (septic tank malfunction, fertilizer application, composter leachate, etc.) (Sereda et al., 2008; Wetzel, 1990; Dion et al., 1983). Internal sources come from within the lake, whether nutrients trapped within the lake substrate (like orthophosphate) or nutrients trapped in the water below the thermocline and therefore can't be mixed and dispersed throughout the lake (Sondergaard et al., 2003; Kennedy and Walker, 1990).

Within FPL, external loading appears to affect the inlet streams more than the lake. Both inlet streams had greater nitrogen and phosphorus concentrations compared to the lake. Concentrations of nitrogen also increased within the two inlets following a rainfall event. The elevated nutrient concentrations of these two inlet streams suggests a level of pollution related to nutrients, particularly phosphorus entering the South inlet from nearby sources. Nutrient loading within the two inlets is further increased during rainstorms via overland flow. Although the lake appears to be unaffected by the current influx of nutrients coming from both inlet streams, further increases in nutrients from either stream may affect the delicate balance within the lake and cause eutrophication.

Internal loading poses a risk to nutrient enrichment and eutrophication in FPL. Within the water column, there is an increase in phosphorus and nitrogen concentrations below the thermocline than within the surface waters (Table 9); when fall turnover occurs, the redistribution of these elevated levels of nutrients results in a source of internal loading and may cause eutrophication of the lake. Nutrients in sediments is an additional internal loading source. Although orthophosphate makes up only 0.58% of total phosphorus in the SW Cove sediment, the increase from the 0.02% in 2017 suggests an increase in pollution. In addition, the release of phosphorus from sediment is not limited to lakes, but also streams; the South inlet's marginally phosphorus-polluted stream acts as an additional source of nutrients which may impact the lake. As the percent of bioavailable phosphorus increases within the lake and stream sediment, there is greater risk in the future for nutrient enrichment via internal loading within the lake.

Table 9: Nutrient concentrations from surface and depth waters (below the thermocline) within FPL, obtained on September 27th, 2018.

	Surface Waters	**At-Depth Waters**
Phosphorus Concentrations (mg/L)	0.006	0.025
Nitrogen Concentrations (mg/L)	0.439	0.460

The development occurring along the South inlet may influence the risk of nutrient enrichment within FPL. The barn located on the property may be used to house animals, with the means of feeding and disposing their waste unknown. As animal waste contains bacteria and nutrients (Vanni, 2002), these can be flushed into the South inlet and eventually the lake. The increase in nutrients within the lake can result in possible eutrophication and algae blooms, as the presence of key nutrients stops limiting the growth of organisms within the lake.

4. Recommendations

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

- The FPL Water Quality Monitoring Program should continue in 2019 and beyond.
    - The program should continue to collect monthly water samples from all four sites.
    - The program should continue to obtain one-time sediment samples from the SW Cove and South inlet, as arsenic and mercury may pose a risk to aquatic organisms' health and should be monitored.
    - One-time lake water samples from below the thermocline should continue to be monitored to assess the risk associated with internal loading and potential late-season algal blooms.
    - The program should continue to supply FPL residents with certified bottles to sample and test for the presence of microcystins-LR during future possible algal blooms.

  - Although previous years have analyzed fecal coliform, future water quality within FPL should switch to testing for *E. coli*, as it is Health Canada's indicator of choice and has set primary and secondary recreational thresholds.
- Due to the expected increases in droughts and rainfall events associated with climate change, the one-time rainfall-dependent sampling event should be adopted, and at least one monthly sampling event should be aimed to capture the effects of a drought.
- Due to development occurring below the golf course along the South inlet, moving the current site or adding an additional site should be investigated. Samples should be obtained, between the current South inlet site and the lake, after a rainstorm to determine if the development is affecting water quality.
- Due to the interference of winds affecting the ability to calculate flow within the North inlet throughout the 2018 season, the placement of the North inlet site should be reconsidered and relocated.
- As the FPL Water Quality Monitoring Program has been ongoing since 2015, the WQMC should implement a communications plan to inform community members and visitors of the water quality work in FPL. The plan should include tips to be water-friendly, information to increase awareness of water quality and degradation within the area, and a way for citizens to contact the committee. This may act as a source of additional members becoming involved and volunteering with the committee and sampling team and will increase the spatial coverage volunteers have when monitoring the lake for algal blooms.

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