Fox Point Lake

2017 Water Quality Monitoring Report

Prepared for

Municipality of the District of Chester

Water Quality Monitoring Committee (Mill Cove)

By

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1. Introduction

1.1 Project Background

In 2014, the Municipality of the District of Chester created the Fox Point Lake Water Quality Monitoring Committee to monitor the health of Fox Point Lake (FPL). Residents of the lake have expressed concerns about the potential water quality impacts from a large development project within the lake's catchment area. The development, Aspotogan Ridge, is a 550-acre family lifestyle community which includes over 350 residential units and an 18-hole golf course. At the onset of golf course construction, the residents of FPL observed several sedimentation plumes entering the lake through the southern inlet stream following periods of rainfall and overland run-off, leading to concerns over the impacts of the development project on the health of the lake and its drainage basin.

In 2015, Coastal Action was contracted by the Municipality of the District of Chester to work with the Fox Point Lake Water Quality Monitoring Committee on the development of a monitoring program which would document water quality conditions and track any changes in the health of the lake over the course of the development project. Coastal Action has trained a small, dedicated group of volunteers to conduct various monitoring activities at the lake with the support of the Coastal Action Project Manager. A description of the monitoring program can be found in the *Fox Point Lake Water Quality Monitoring Program (2015)* and results from the first two years of monitoring can be found in the *Fox Point Lake Water Quality Monitoring Report (2015)* and in the *Fox Point Lake 2016 Water Quality Monitoring Report*, all available on request from the Municipality of the District of Chester.

The goals and objectives of the monitoring program remain unchanged from those stated in 2015 and are as follows:

Program Goals:

1. *Establish a baseline of the water quality conditions and trophic status of Fox Point Lake based on an initial monitoring period of May-October 2015, with the understanding that conditions may already be degraded to a certain degree as a result of development activities.*
2. *Monitor the water quality conditions and trophic status of Fox Point Lake throughout the course of the multi-year Aspotogan Ridge development project.*

Program Objectives:

a) Monitor various biological, chemical, and physical water quality parameters in Fox Point Lake to establish a baseline of these indicators and track any changes as a result of development.

b) Determine the current trophic status of Fox Point Lake based on results of the initial monitoring period (May-October 2015), using the following key parameters: total phosphorus, total nitrogen, chlorophyll a, and Secchi disk depths.
c) Monitor the trophic status of Fox Point Lake throughout the course of development for signs of cultural eutrophication.
d) Monitor the water depth of Fox Point Lake throughout the course of development as an indicator of sediment in-filling or altered drainage basin hydrology.
e) Monitor precipitation amounts throughout the course of development to track local rainfall patterns and the severity of associated siltation events in Fox Point Lake.
f) Monitor stream flow discharge in two inlet streams and one outlet stream of Fox Point Lake throughout the course of development as an indicator of altered hydrology within the drainage basin.
g) Monitor and document siltation events and algal blooms occurring in Fox Point Lake throughout the course of development.
h) Monitor thermal stratification of Fox Point Lake by conducting temperature/ dissolved oxygen profiles to track the influence of increased nutrient loading on the algal and dissolved oxygen conditions of the lake.

Fox Point Lake, the largest lake on the Aspotogan Peninsula at 1.4 km^2, is long and shallow with 11 small islands and an average depth of 4.9 m (Beanlands, 1980). The lake has a drainage area of 8 km^2, with two inlet streams and one outlet. The northern inlet drains a heavily forested area and flows through a wetland before entering FPL, while the southern inlet flows through the Aspotogan Ridge development site draining the southern end of the lake's drainage basin. A single outlet stream flows out of the southeast corner of the lake draining directly into St. Margaret's Bay.

The Fox Point Lake Water Quality Monitoring Program was designed to be carried out primarily by volunteer lake residents, with the assistance of the Coastal Action Project Manager. Easily accessible sample sites were chosen which would allow volunteers to monitor the conditions of the north and south inlet streams, the outlet stream, and within the lake itself. A monitoring station was established on a volunteer's property where water level and rainfall amounts were recorded daily (see Fig. 1).

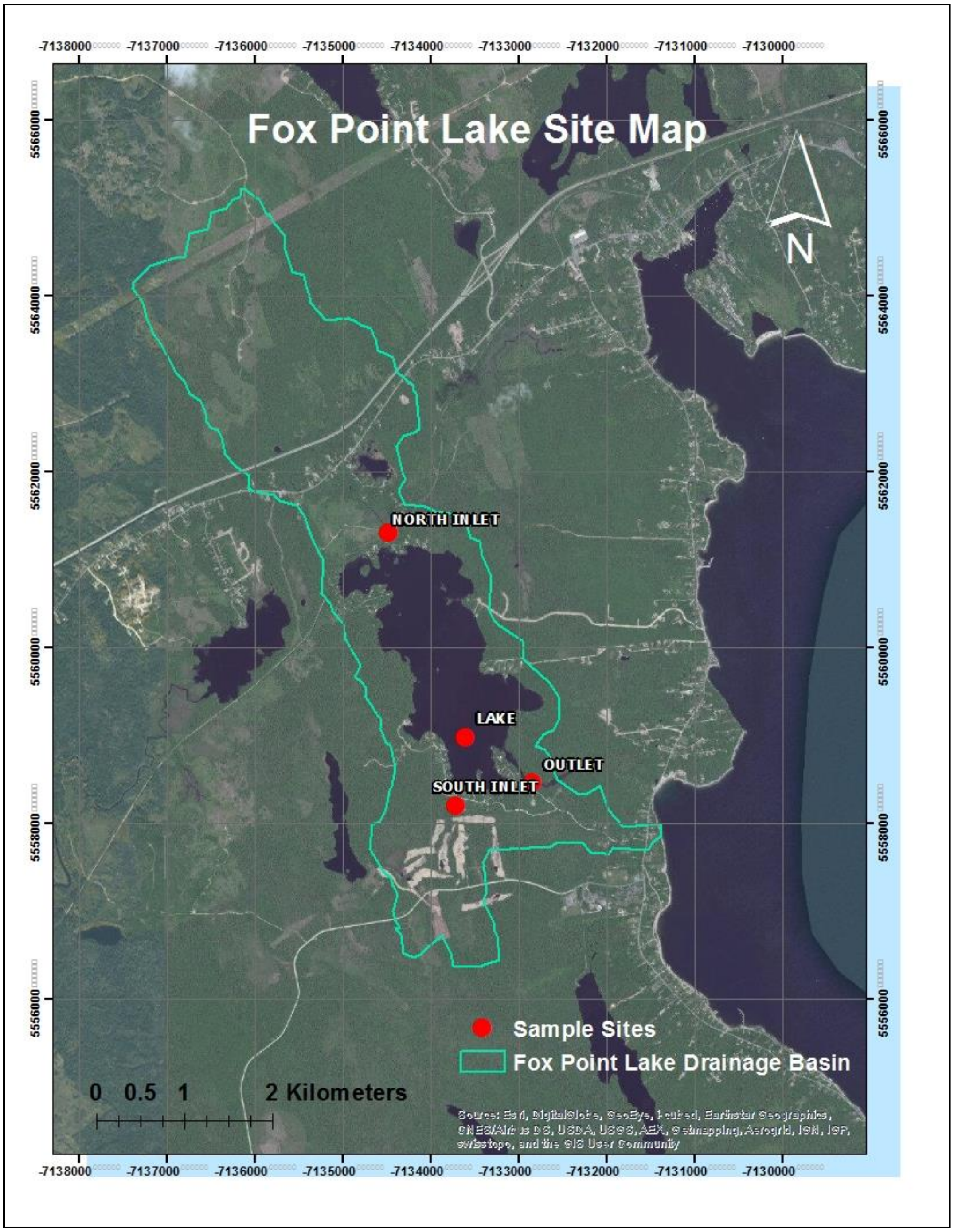

Figure 1 – Map of the Fox Point Lake drainage basin and four water quality monitoring sites.

1.2 Review of the 2016 Fox Point Lake Water Quality Monitoring Report

Residents of Fox Point Lake reported that the water clarity was better than they had seen for many years during the summer of 2016. Nova Scotia, in particular the southwestern region of the province, experienced a severe drought during the summer of 2016, which meant there were very few rainfall events carrying run-off (as well as sediment, nutrients, bacteria, and other contaminants) into streams and lakes. No construction activity took place at the Aspotogan Ridge development site during the 2016 monitoring period and the golf course was not active.

The trophic status of FPL was determined to be oligotrophic and approaching mesotrophic in both 2015 and 2016, meaning that there had not been any major change in the biological productivity of the lake between 2015 and 2016.

Thermal stratification was monitored at two locations in the lake in 2016, with both sites displaying dissolved oxygen depletion at concentrations < 3 mg/L in the bottom waters of the lake.

An algae bloom occurred in June of 2016 and water sample analysis confirmed the presence of microcystin-LR, which is a toxin produced by cyanobacteria. The confirmation of cyanobacterial toxins in FPL 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 (phosphorus and nitrogen) were found to exceed water quality guidelines at the South Inlet sample site only, which is consistent with the 2015 monitoring results. The south inlet stream appears to be suffering from excessive nutrient loading.

1.3 Changes to the 2017 Fox Point Lake Water Quality Monitoring Program

In 2016, two lake sites were monitored for thermal stratification. Results indicated that there was little variation between these two sites and the monitoring of this second lake site added a significant amount of sampling time for volunteers; therefore, the second lake site was removed from the program for the 2017 monitoring season.

Phosphorus and nitrogen concentrations in the south inlet stream have indicated that this stream suffers from anthropogenic sources of excessive nutrient loading. Additional monitoring activities were recommended for this stream, which included the collection of a sediment sample from the stream bottom and an assessment of stream conditions along the entire length of the stream. This assessment included a visit to the Aspotogan Ridge Golf Course.

1.4 Aspotogan Ridge Golf Course Visit

On October 4, 2017, two Coastal Action staff members were given a tour of the golf course grounds by Ged Stonehouse, owner of the Stonehouse Golf Group and Project Coordinator for the new owners of the Aspogotan Ridge development project. The purpose of this visit was to investigate the conditions of the stream that flows through the development site and into the southwest cove of Fox Point Lake. A full stream assessment, including in-stream and riparian health assessments and habitat measurements, was not performed; however, in-situ water quality parameters were assessed at several locations along the stream using a YSI Professional Plus water meter. Results of these spot-tests were consistent with the water quality conditions observed downstream of the golf course at the South Inlet sample site, with the most notable result being low dissolved oxygen concentrations in many spots.

The majority of the stream's riparian habitat, as it runs through the golf course property, has been maintained as a good quality buffer zone between the golf course greens and the stream itself. Several sediment control measures were noted in areas of potential overland run-off, which is important for the protection of the stream from sedimentation issues in the future as development continues.

2. Water Quality Monitoring Results

The following section provides an analysis of the 2017 monitoring program. Several water quality parameters will be compared to guidelines which have been established by the Canadian Council of Ministers of the Environment (CCME), Health Canada, or through other research bodies.

As in the summer of 2016, the Aspotogan Ridge development project was not active during the 2017 monitoring period and residents of FPL did not report any visible impacts on water quality in the lake (sedimentation plumes) near the south inlet stream or any other locations in the lake. The 2017 monitoring period began on May 25 and ended on October 31, comprising a total of 10 sampling days.

2.1 Algae Bloom in Fox Point Lake

An algae bloom was observed in Fox Point Lake on June 13, 2017. A water sample was collected in a laboratory-certified bottle by 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 this sample indicated a concentration of microcystin-LR of 0.71 µg/L. This concentration is lower than that found in the sample collected last year on June 22, 2016 during an algae bloom (microcystin-LR of 1.25 µg/L). Both samples displayed concentrations which fell below the drinking water guideline for microcystin-LR which is 1.5 µg/L (Health Canada, 2010).

There is no simple method to distinguish a toxic bloom from a non-toxic bloom; therefore, every algal bloom which occurs in a waterbody should be treated with caution. Cyanobacteria toxins can persist in a waterbody for several weeks after a visible bloom has dissipated. Exposure to these toxins occurs most often through the consumption of drinking water; however, minor exposure can occur through recreational activities and domestic water uses. Inadvertent ingestion of water or skin contact through recreational activities can, in rare cases, result in headache, fever, vomiting, skin and eye irritation, muscle pain, and weakness (WHO, 2003; Federal-Provincial-Territorial Committee on Drinking Water, 2002).

2.2 Trophic State of Fox Point Lake

Trophic state describes the biological productivity of a waterbody and can be used as a benchmark from which to assess changes in the health of a lake due to anthropogenic activities within the lake and its drainage basin. Oligotrophic lakes have low productivity and relatively pristine conditions, mesotrophic lakes display moderate biological productivity, while eutrophic lakes exhibit high densities of plant biomass and high productivity. The natural, long-term process of waterbodies progressing from lower trophic states to higher ones is termed eutrophication; whereas, cultural eutrophication refers to an acceleration of this process towards higher trophic states due to anthropogenic activities within the drainage basin of a waterbody. Symptoms of cultural eutrophication include excessive nutrient loading, increased growth of rooted aquatic plants and algae, and low dissolved oxygen (Brown & Simpson, 1998; Brylinsky, 2004).

Trophic state is determined through the analysis of key water quality parameters: total phosphorus, total nitrogen, chlorophyll *a*, and Secchi disk depth. Results for these parameters are compared to means and ranges established by Vollenweider and Kerekes (1982) as well as entered into formulas for the calculation of the Carlson Trophic State Index (TSI) (Carlson, 1977).

Table 1 – Mean and range values for key parameters from the Lake sample site in Fox Point Lake from May to October 2017.

	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Chlorophyll *a* (µg/L)	Secchi Disk Depth (m)
Mean	7.0	236.2	1.97	2.71
Range	5.0 – 10.0	213.0 – 276.0	0.98 – 3.31	2.03 – 3.72

Table 2 – Mean and range values associated with trophic levels in lakes (Brown & Simpson, 1998).

Table 1. Ranges of Variable Values Associated with Trophic Levels in Lakes (adapted from Vollenweider and Kerekes, 1980)			
Water Quality Variable	**Oligotrophic**	**Mesotrophic**	**Eutrophic**
Total Phosphorus			
Mean	8	27	84
Range	3-18	11-96	16-390
Total Nitrogen			
Mean	660	750	1,900
Range	310-11600	360-1400	390-6100
Chlorophyll *a*			
Mean	1.7	4.7	14
Range	0.3-4.5	3-11	2.7-78
Peak Chlorophyll *a*			
Mean	4.2	16	43
Range	1.3-11	5-50	10-280
Secchi Depth (m)			
Mean	9.9	4.2	2.4
Range	5.4-28	1.5-8.1	0.8-7.0
Note: Units are Ug/l (or mg/m^3), except Secchi depth; means are geometric annual means (log 10), except peak chlorophyll a.			

Comparing the means and ranges for these key parameters from FPL in 2017 (see Table 1) to those established by Vollenweider and Kerekes (1982) (see Table 2) identifies the trophic state of FPL as oligotrophic and approaching mesotrophic. Further analysis using the Carlson Trophic State Index will provide numerical scores which can be compared from one year to the next.

Secchi disk:	TSI(SD) = 60 – 14.41 ln(SD)	**TSI(SD) = 45.5**
Chlorophyll *a*:	TSI(CHL) = 9.81 ln(CHL) + 30.6	**TSI(CHL) = 37.3**
Total phosphorus:	TSI(TP) = 14.42 ln(TP) + 4.15	**TSI(TP) = 32.2**
(ln = natural log)		

Figure 2 – Formulas used for the calculation of three Trophic State Indices and the TSI scores for 2017.

Table 3 – TSI scores for Secchi disk (SD), chlorophyll *a* (CHL), and total phosphorus (TP) for the Lake sample site in Fox Point Lake from 2015 to 2017.

	2015	**2016**	**2017**
TSI (SD)	49	45.7	45.5
TSI (CHL)	34	41.5	37.3
TSI (TP)	37	31.8	32.2

TSI scores less than 40 indicate an oligotrophic lake, while mesotrophic lakes display TSI scores between 40 and 50, and eutrophic lakes have TSI scores greater than 50. Priority is often given to the TSI score for chlorophyll *a* as it provides the most accurate prediction of algal biomass and biological productivity (Brown & Simpson, 1998).

Using the TSI scores for both chlorophyll *a* and total phosphorus, Fox Point Lake is classified as an oligotrophic lake. The TSI scores for Secchi disk depth fall within the mesotrophic range; however, Secchi depths can be influenced by more than just biological productivity levels, such as sediment, silt, and other suspended particles in the water column (NSSA 2014; EPA 2002).

The trophic state of Fox Point Lake has held steady from 2015 to 2017 in the range of oligotrophic approaching mesotrophic, meaning that the lake displays low to moderate biological productivity.

2.3 Thermal Stratification of Fox Point Lake

Thermal stratification of a waterbody involves the separation of the water column into layers of different densities based on changing water temperatures. Spring turnover occurs when water temperatures are consistent from top to bottom, and wind and currents draw dissolved oxygen into bottom waters and pull nutrients to the surface. As surface water warms in early summer, three density layers begin to form in the water column. The epilimnion is the warm surface layer where wind circulates water, adding dissolved oxygen. The metalimnion, or thermocline, displays rapid changes in water temperature with depth. The hypolimnion is the bottom layer consisting of the coldest, densest water (see Fig. 3).

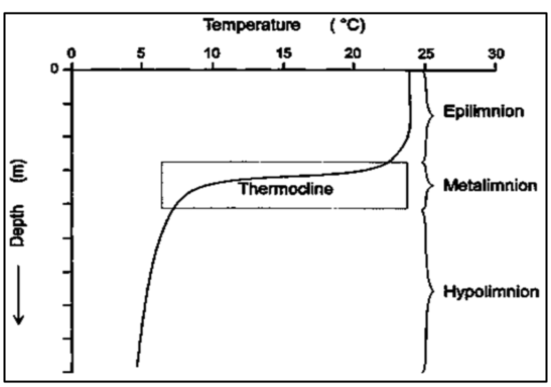

Figure 3 – Thermal stratification of a water column with three layers of varying densities and temperatures (Chowdhury et al., 2014).

There is little to no mixing between these layers of water, which means that the hypolimnion no longer receives dissolved oxygen from the surface once stratification is established. This finite supply of oxygen can be depleted over the course of the summer as organic material sinks to the bottom and microbial decomposition uses the available oxygen to break this material down. This can lead to hypoxic (<2 mg/L dissolved oxygen) or anoxic (<1 mg/L dissolved oxygen) conditions in the bottom waters and a decreased ability to support aquatic life (USGS 2014; Brylinsky, 2004).

Thermal stratification breaks down with fall turnover, when water temperatures once again become uniform from top to bottom. This allows water to mix and replenish the bottom waters with dissolved oxygen (see Fig. 4).

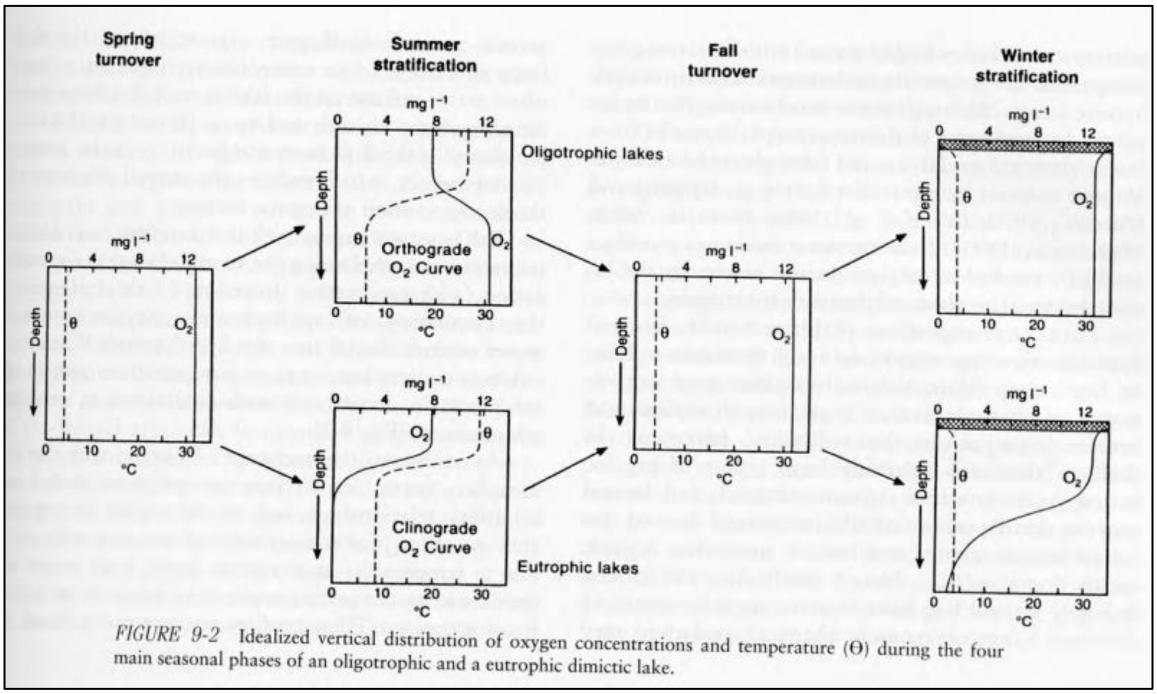

FIGURE 9-2 Idealized vertical distribution of oxygen concentrations and temperature (Θ) during the four main seasonal phases of an oligotrophic and a eutrophic dimictic lake.

Figure 4 – Thermal stratification represented by dissolved oxygen/water temperature depth profile curves (Wetzel, 2001).

There are four types of dissolved oxygen depth profile curves that can be observed during thermal stratification, depending on the trophic state of a waterbody (see Fig. 5). Orthograde profiles occur in oligotrophic lakes when dissolved oxygen concentrations increase in the hypolimnion (bottom layer). Clinograde profiles occur in mesotrophic and eutrophic lakes when dissolved oxygen concentrations decrease in the hypolimnion due to microbial decomposition. Heterograde profiles occur when dissolved oxygen concentrations change at unlikely depths. Negative heterograde profiles display low dissolved oxygen concentrations in the thermocline due to an accumulation of decomposing organic material caught in the density boundary.

Positive heterograde profiles display high dissolved oxygen concentrations in the thermocline, usually due to a high concentration of photosynthesizers at that depth (Mackie, 2004).

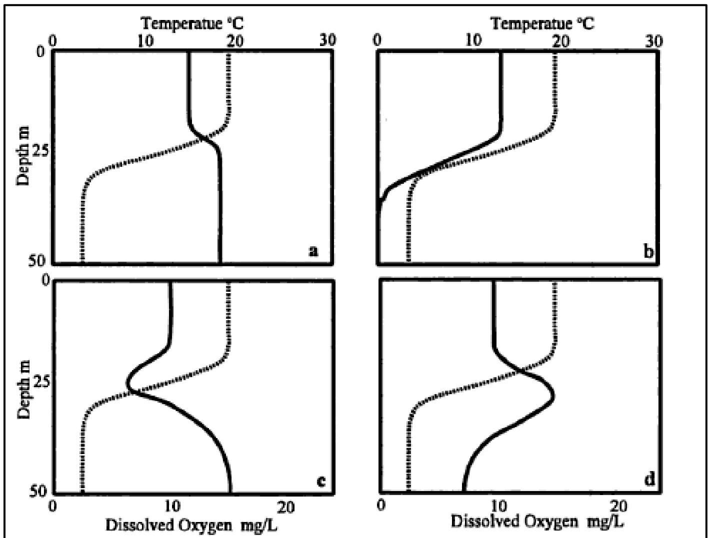

Figure 5.2. Common summer vertical oxygen profiles in lakes. (a) Orthograde. (b) Clinograde. (c) Negative heterograde. (d) Positive heterograde.

Figure 5 – Common dissolved oxygen depth profiles observed in thermally stratified lakes (Mackie, 2004).

Depth profiles were conducted at the Lake sample site from May 25 to October 31 in 2017 (see Fig. 6). Thermal stratification was established in the lake at some point between the June 11 and June 28 sampling days, with an initial thermocline depth of approximately 4 m. Throughout the months of July and August, dissolved oxygen concentrations displayed negative heterograde profiles, meaning there was likely an accumulation of organic material in the thermocline and microbial decomposition was consuming dissolved oxygen at that depth. Dissolved oxygen concentrations in the hypolimnion consistently fell below the CCME Guideline for the Protection of Aquatic Life for cold-water species (≥ 6.5 mg/L) from July until October.

There appears to have been a partial breakdown of stratification around September 13 with both the water temperature and dissolved oxygen curves staying consistent from the surface to a depth of 14 m. This partial breakdown of stratification was not enough to cause mixing with the bottom hypolimnion layer as dissolved oxygen concentrations remained very low in September and October. Dissolved oxygen concentrations dropped as low as 1.3 mg/L in September and October; whereas, the lowest concentration observed in 2016 was 2.7 mg/L.

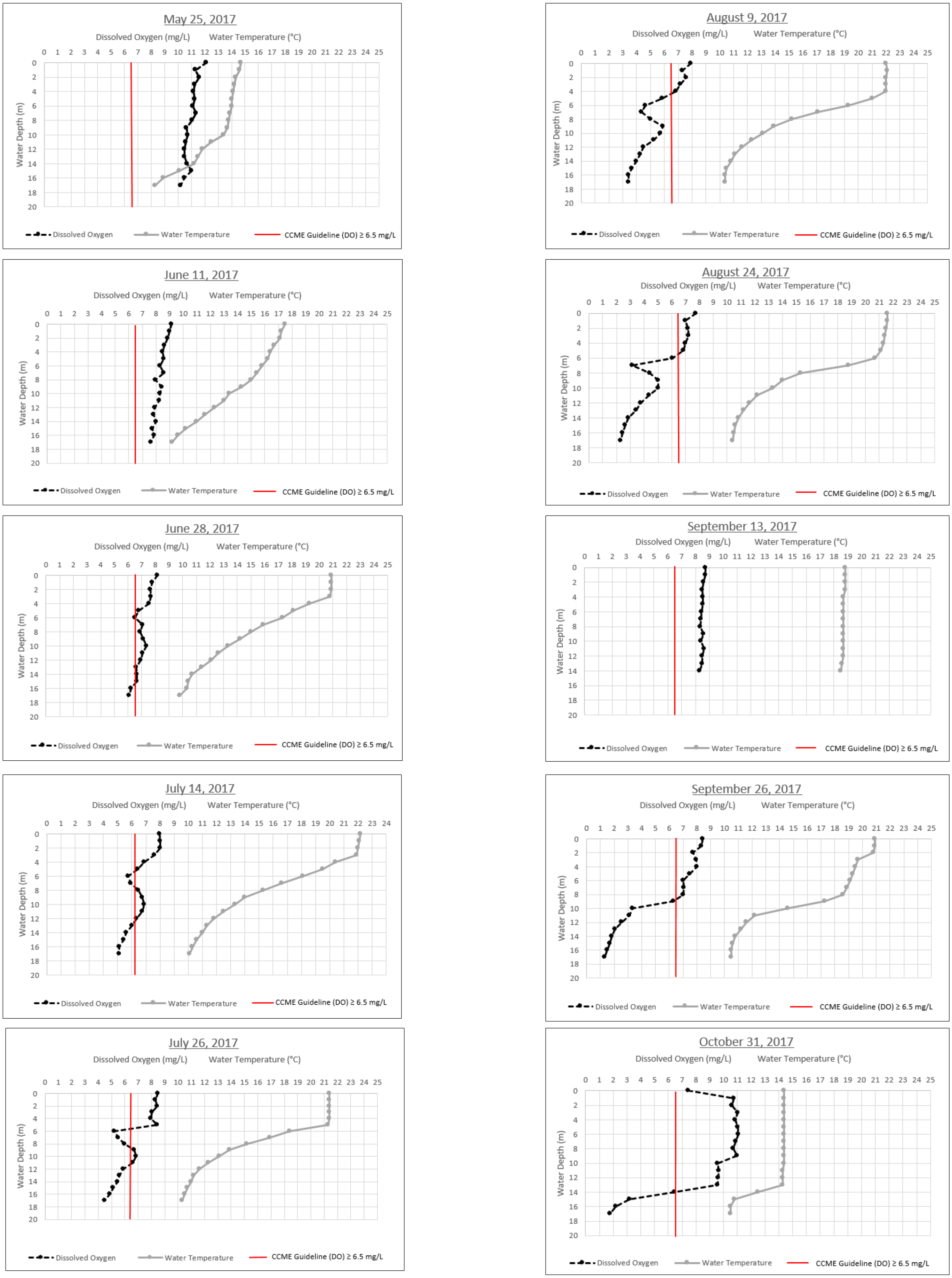

Figure 6 – Dissolved oxygen/water temperature depth profiles in Fox Point Lake in 2017.

2.4 Sediment Sampling in Fox Point Lake (southwest cove) and the South Inlet Stream

Sediment samples were collected from the stream bottom at the South Inlet sample site and from the lake bottom in the southwest cove of Fox Point Lake (UTM Zone 20T 414024 E, 4938846 N) on October 31, 2017 using an Ekman dredge sampling device. This sampling device collected sediment to a depth of 10-15 cm. The sediment sample collected from the South Inlet sample site was analyzed for a full suite of metals, as well as phosphorus and orthophosphate, while the sediment from the Southwest Cove sample site was analyzed for phosphorus and orthophosphate only (see Table 4). Due to laboratory error, phosphorus concentrations in the overlying water column were not analyzed on October 31, 2017.

Sediment sampling was recommended for these sites due to the severe sedimentation run-off events that occurred during the initial construction activities at the Aspotogan Ridge development site, which coincided with large sediment plumes flowing through the south inlet stream and into Fox Point Lake. The south inlet stream suffers from excessive nutrient loading and a significant degree of sedimentation. The southwest cove of FPL is the location where the south inlet stream enters the lake and where sedimentation plumes were most severe. This cove is likely the area where much of this sediment would have settled to the lake bottom. Determining phosphorus concentrations in these bottom sediments is necessary to understand the potential for internal phosphorus loading (phosphorus release from sediment) in the south inlet stream and FPL, which can contribute to eutrophication, anoxic conditions, and algae blooms.

When phosphorus enters an aquatic environment, it undergoes several complex transformations which are influenced by the physical, biological, and chemical conditions of that aquatic system. This process is called phosphorus cycling and involves the uptake and release of phosphorus from sediments and the continuous conversion of phosphorus between inorganic, organic, dissolved, and particulate forms (Howell, 2010; Brylinsky, 2004). Phosphorus occurs in four forms in an aquatic environment: dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP), particulate inorganic phosphorus (PIP), and particulate organic phosphorus (POP) (Reddy et al., 1999). The dissolved inorganic form of phosphorus (DIP), also called orthophosphate, is the bioavailable form and the only form which plants are able to assimilate. Because orthophosphate is taken up by plants so quickly, it tends to be present in lower concentrations compared to other forms. Once assimilated by plants, orthophosphate transforms into the particulate phosphorus form, which constitutes the largest proportion of total phosphorus in an aquatic environment. When this plant material dies and decomposes, phosphorus is released back into the environment as the bioavailable orthophosphate form (CCME, 2004; Howell, 2010).

The retention capacity of a stream refers to its ability to remove phosphorus from the water column and transform it into non-bioavailable forms, thus decreasing the phosphorus loading of downstream waterbodies. Retention depends on many factors including stream velocity, water depth, the assimilation of phosphorus into vegetation, microorganisms, and sediment, and the concentration of elements with the capacity to bind and release phosphorus (Abu-Hmeidan et al., 2018). Anoxic conditions can facilitate the release of sediment-bound phosphorus from complexes with metals such as iron, aluminum, and magnesium through oxidation reduction processes (Hayes et al., 1985). In addition, phosphorus can be rapidly released from sediment and transported downstream during high-flow storm events (Reddy et al., 1999; Brylinsky, 2004).

The South Inlet sample site displayed a phosphorus concentration of 460 mg/kg and an orthophosphate concentration of 0.51 mg/kg, meaning that orthophosphate constitutes just 0.11 % of the total phosphorus load in the stream sediment. Elevated concentrations of aluminum and iron in the sediment from the South Inlet sample site suggest that a significant proportion of the non-bioavailable phosphorus may be complexed with metals (see Table 5).

The Southwest Cove sample site displayed a phosphorus concentration of 850 mg/kg and an orthophosphate concentration of 0.17 mg/kg, with orthophosphate constituting 0.02% of the total phosphorus load in the lake sediment. This indicates that orthophosphate is being rapidly assimilated by aquatic plants and that the majority of the phosphorus load in the sediment is comprised of other non-bioavailable forms.

Ontario's Provincial Sediment Quality Guidelines have established a guideline for total phosphorus in sediment for the protection of the aquatic environment. This guideline is set at a 'lowest effect level' of 600 mg/kg, and a 'severe effect level' of 2,000 mg/kg. Lowest effect level represents clean to marginally polluted sediment which can be tolerated by sediment-dwelling aquatic organisms, while the severe effect level represents heavily contaminated sediment which is detrimental to most sediment-dwelling aquatic organisms (Ontario MOE, 2008).

The total phosphorus concentration in the South Inlet sample site sediment falls below the lowest effect level of 600 mg/kg, while the Southwest Cove sample site sediment falls within the range of 600-2000 mg/kg, closer to the lowest effect level end of the guideline spectrum.

Table 4 – Orthophosphate and phosphorus in sediment at the South Inlet sample site and Southwest Cove sample site on October 31, 2017.

	South Inlet site	**Southwest Cove Fox Point Lake**
Orthophosphate in sediment (mg/kg)	0.51	0.17
Acid extractable phosphorus in sediment (mg/kg)	460	850

Table 5 – Metals in sediment at the South Inlet sample site on October 31, 2017, and Nova Scotia Environmental Quality Standards for Sediments (NSE, 2014).

Metals (in soil)	**Units**	**South Inlet site**	**N.S. Freshwater Sediment Quality Standards (mg/kg)**	**RDL (mg/kg)**
Acid Extractable Aluminum (Al)	mg/kg	4400	-	10
Acid Extractable Antimony (Sb)	mg/kg	ND	25	2.0
Acid Extractable Arsenic (As)	mg/kg	7.9	17	2.0
Acid Extractable Barium (Ba)	mg/kg	30	-	5.0
Acid Extractable Beryllium (Be)	mg/kg	ND	-	2.0
Acid Extractable Bismuth (Bi)	mg/kg	ND	-	2.0
Acid Extractable Boron (B)	mg/kg	ND	-	50
Acid Extractable Cadmium (Cd)	mg/kg	ND	3.5	0.30
Acid Extractable Chromium (Cr)	mg/kg	3.2	90	2.0
Acid Extractable Cobalt (Co)	mg/kg	1.9	-	1.0
Acid Extractable Copper (Cu)	mg/kg	7.4	197	2.0
Acid Extractable Iron (Fe)	mg/kg	5900	43,766	50
Acid Extractable Lead (Pb)	mg/kg	17	91.3	0.50
Acid Extractable Lithium (Li)	mg/kg	6.8	-	2.0
Acid Extractable Manganese (Mn)	mg/kg	330	1100	2.0
Acid Extractable Mercury (Hg)	mg/kg	0.12	0.486	0.10
Acid Extractable Molybdenum (Mo)	mg/kg	ND	-	2.0
Acid Extractable Nickel (Ni)	mg/kg	2.7	75	2.0
Acid Extractable Phosphorus (P)	mg/kg	460	-	100
Acid Extractable Rubidium (Rb)	mg/kg	7.1	-	2.0
Acid Extractable Selenium (Se)	mg/kg	ND	2	1.0
Acid Extractable Silver (Ag)	mg/kg	ND	1	0.50
Acid Extractable Strontium (Sr)	mg/kg	12	-	5.0
Acid Extractable Thallium (Tl)	mg/kg	ND	-	0.10
Acid Extractable Tin (Sn)	mg/kg	ND	-	2.0
Acid Extractable Uranium (U)	mg/kg	6.9	-	0.10
Acid Extractable Vanadium (V)	mg/kg	6.1	-	2.0
Acid Extractable Zinc (Zn)	mg/kg	30	315	5.0
RDL = Reportable Detection Limit **ND = Not Detected**				

2.5 Water Temperature

Water temperature is one of the most important indicators of water quality and plays a significant role in the health and productivity of aquatic ecosystems, effecting many physical, biological, and chemical factors within a waterbody. Water temperature influences dissolved oxygen concentrations, another critical parameter in aquatic ecosystem health, as cold water holds more oxygen than warm water.

Aquatic organisms have varying levels of sensitivity to temperature as well as optimal temperature ranges. Extreme temperature fluctuations outside of those optimal ranges, both acute and chronic, can cause physiological stress, relocation, or death (NSSA, 2014). Salmonids, such as Atlantic salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis*), require cold water for survival. Brook trout, known to populate Fox Point Lake, are one of the most temperature-sensitive salmonid species, and will begin to experience physiological stress if water temperatures exceed 20°C. In response to high temperatures, fish will seek out areas of thermal refugia, such as spring/groundwater-fed streams and streams with deep cold-water pools (MacMillan et al., 2005).

Water temperature was monitored bi-weekly at all four sample sites from May 25 to October 31 2017. Surface water temperatures exceeded the 20°C threshold for cold-water fish species at the Lake sample site from June 28 to August 24 and again on September 26. The Outlet sample site displayed water temperatures very close to the 20°C threshold and exceeded this temperature on July 14 and August 24. Both the North Inlet and South Inlet sample sites did not exceed this threshold at any time throughout the monitoring period (see Fig. 7)

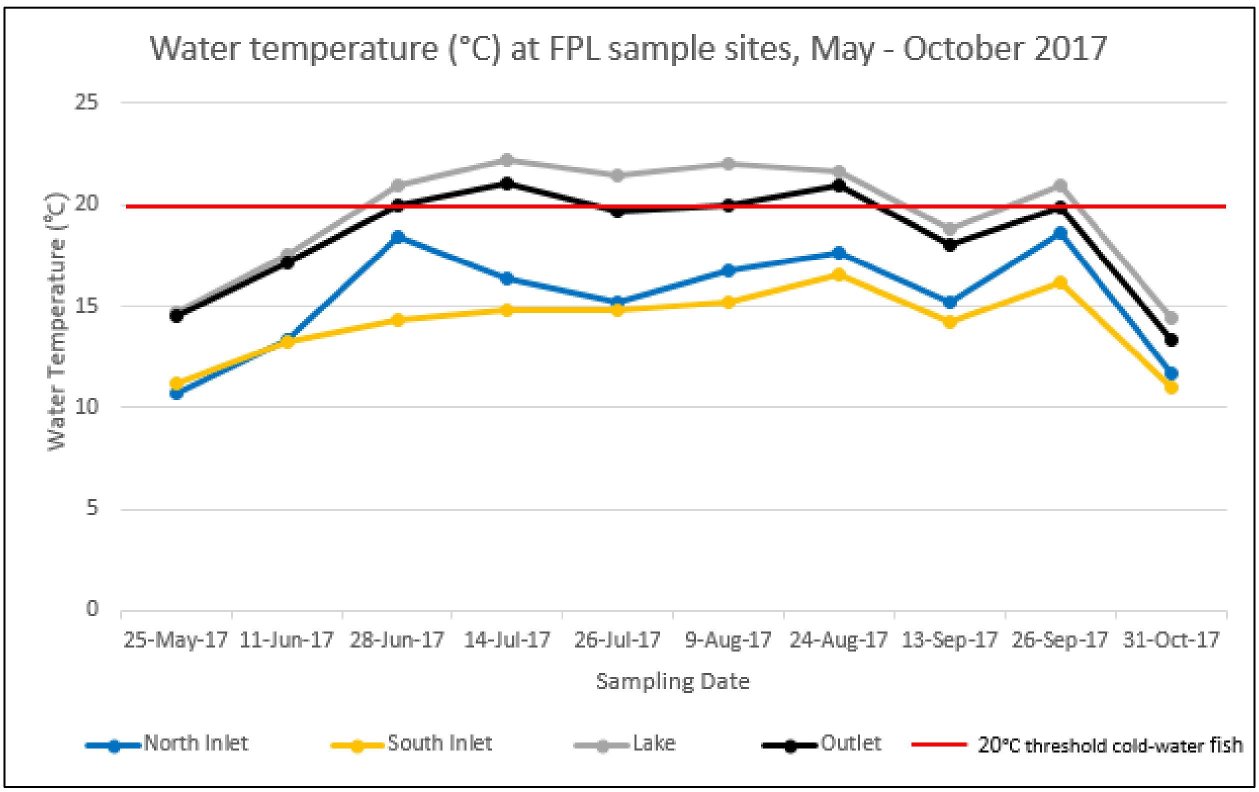

Figure 7 – Water temperature at four FPL sample sites from May to October 2017.

2.6 Dissolved Oxygen

Dissolved oxygen is one of the most important indicators of water quality and aquatic ecosystem health. Oxygen enters water through wind and wave action, rainfall, cascading water, and photosynthesis by aquatic vegetation. Dissolved oxygen concentrations in a waterbody can be influenced by several factors including thermal stratification, water temperature, algae and aquatic plant growth, and the oxygen content of inlet streams (EPA, 2002).

The CCME Guideline for the Protection of Aquatic Life for dissolved oxygen is ≥ 6.5 mg/L for cold-water species and ≥ 5.5 mg/L for warm-water species (CCME, 1999).

Both the Lake and Outlet sample sites maintained dissolved oxygen concentrations above the CCME Guideline for the Protection of Aquatic Life (for cold-water species) throughout the entire monitoring period (see Fig. 8). The North Inlet sample site fell below this guideline from June 28 to September 26, which is similar to the previous monitoring period, with this site falling below the guideline from July 4 to September 30 in 2016.

In 2016, dissolved oxygen concentrations fell below the guideline at the South Inlet sample site from July 4 to September 9, and displayed a seasonal (July-September) mean concentration of 5.63 mg/L. In 2017, the dissolved oxygen conditions at the South Inlet sample site showed a slight improvement, with concentrations falling below the guideline on two sampling dates, August 24 and September 26, and the seasonal (July-September) mean increased to 6.70 mg/L (see Table 6).

Statistical analysis, using paired t-tests with a significance threshold of 95%, determined that there are no significant differences between dissolved oxygen concentrations in 2015 and 2017 for all four sample sites (North Inlet p-value = 0.814, South Inlet p-value = 0.878, Lake p-value = 0.673, Outlet p-value = 0.918).

Table 6 – Mean and minimum summer dissolved oxygen concentrations from July to September 2017, with 2015 and 2016 results for comparison.

	North Inlet	**South Inlet**	**Lake**	**Outlet**
Mean summer dissolved oxygen (mg/L) *(2015/2016)*	3.59 *(2.25/3.36)*	6.70 *(6.31/5.63)*	8.21 *(7.88/8.02)*	7.66 *(7.05/6.97)*
Minimum summer dissolved oxygen (mg/L) *(2015/2016)*	1.93 *(1.38/2.31)*	5.38 *(5.86/3.92)*	7.75 *(7.33/7.43)*	6.80 *(5.75/5.61)*

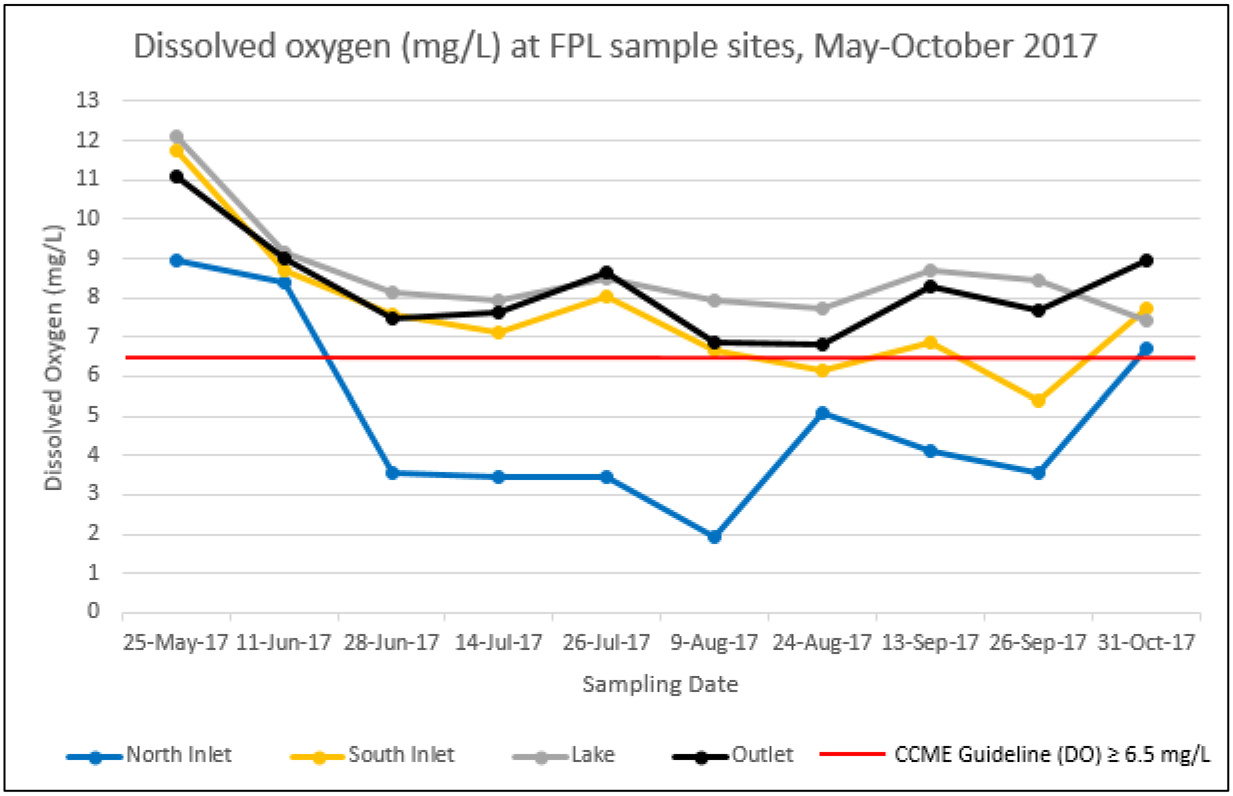

Figure 8 – Dissolved oxygen concentrations at four FPL sample sites from May to October 2017.

2.7 pH

pH is a measurement of the hydrogen-ion concentration in water which is expressed on a logarithmic scale from 0 to 14. A pH of 0 is the most acidic, pH of 7 is neutral, and a pH of 14 is the most basic. The CCME Guideline for the Protection of Aquatic Life for pH is within the range of 6.5-9.0 (CCME, 2002). Natural variation in pH occurs as a result of soil and bedrock composition, drainage from coniferous forests, and aquatic vegetation and organic material biomass. Anthropogenic influences on pH include wastewater discharge, increased atmospheric carbon dioxide, and acid precipitation (B.C. MOE, 1998).

Nova Scotia has lost the greatest percentage of fish habitat due to acid precipitation in all of North America. The province is positioned directly downwind from high emission-polluting areas of central Canada and the Midwestern United States. Southwestern Nova Scotia suffers significantly from the effects of acid precipitation due to the poor buffering capacity of the soils in this region, which are unable to neutralize the effects of the acids (NSSA, 2015). Fish and other aquatic organisms experience negative physiological impacts in water with pH < 5.0. Salmon can withstand pH as low as 5.0, and trout species are slightly hardier and can withstand pH as low as 4.7 (NSSA, 2014).

The North Inlet, South Inlet, and Outlet sample sites all fell below the CCME Guideline for the Protection of Aquatic Life throughout the entire monitoring period, which is consistent with the 2015 and 2016 monitoring periods (see Fig. 9). The Lake sample site maintained pH levels within the CCME guideline range for most of the monitoring period, falling below the guideline on two sampling days (August 24 and September 26). Statistical analysis, using paired t-tests with a significance threshold of 95%, confirmed that the Lake sample site has shown a significant increase in pH from 2015 to 2017 (p-value = 0.0001727).

Table 7 – Mean and minimum pH results from May to October 2017, with 2015 and 2016 results for comparison.

	North Inlet	South Inlet	Lake	Outlet
Mean pH ***(2015/2016)***	4.98 *(4.56/5.17)*	5.23 *(5.08/5.64)*	6.95 *(6.11/6.39)*	5.49 *(5.45/5.74)*
Minimum pH ***(2015/2016)***	4.49 *(3.88/4.36)*	4.78 *(4.10/4.85)*	6.10 *(5.66/6.08)*	5.08 *(5.04/5.59)*

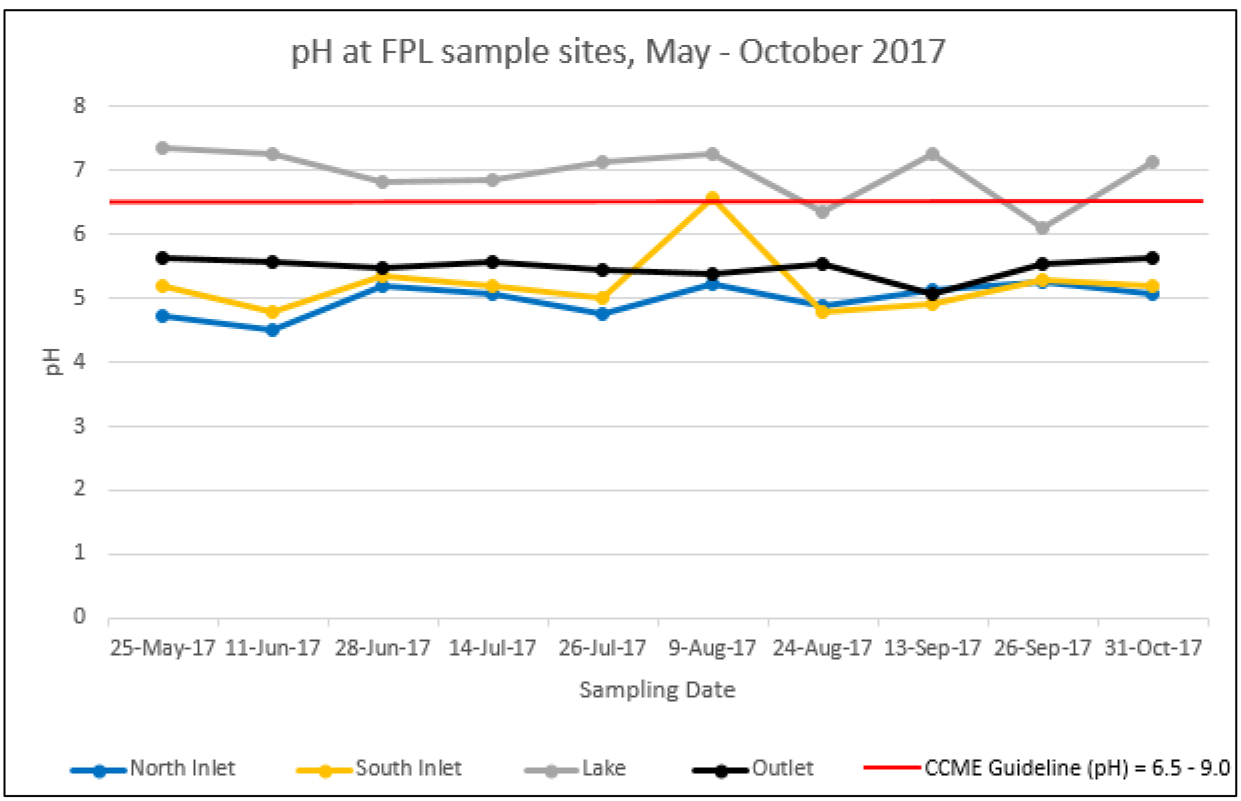

Figure 9 – pH results at four FPL sample sites from May to October 2017.

2.8 Total Dissolved Solids

Total dissolved solids is a measure of dissolved materials in water such as calcium, magnesium, chloride, sodium, sulphate, nitrate, and bicarbonate. Sources of dissolved solids include natural sources in the environment, sewage effluent, urban and agricultural run-off, industrial wastewater, and road salts. High concentrations of dissolved solids can influence the taste, color, and clarity of water (B.C. MOE, 1998; NSSA, 2014). There is no CCME guideline for dissolved solids in terms of the protection of aquatic life; however, Health Canada has established a drinking water guideline of ≤ 500 mg/L (Health Canada, 1991), and the average total dissolved solids concentration for pristine lakes in Nova Scotia is 20 mg/L (Hinch & Underwood, 1985).

The Lake sample site displayed a mean total dissolved solids concentration of 30.62 mg/L in 2017 (see Table 8). The Lake and Outlet sample sites display very similar total dissolved solids concentrations throughout the monitoring period. The North Inlet sample site displays the highest total dissolved solids levels of the four sites, with a mean concentration of 49.29 mg/L, while the South Inlet sample site displays the lowest mean concentration of 25.91 mg/L (see Fig. 10).

Table 8 – Total dissolved solids from May to October 2017, with 2015 and 2016 results for comparison.

	North Inlet	South Inlet	Lake	Outlet
Mean total dissolved solids (mg/L) ***(2015/2016)***	49.29 (43.36/46.73)	25.91 (25.16/28.93)	30.62 (27.50/29.74)	30.88 (27.82/30.14)
Maximum total dissolved solids (mg/L) ***(2015/2016)***	58.50 (52.65/52.65)	31.20 (37.05/37.05)	31.85 (27.95/30.55)	31.85 (28.60/31.20)

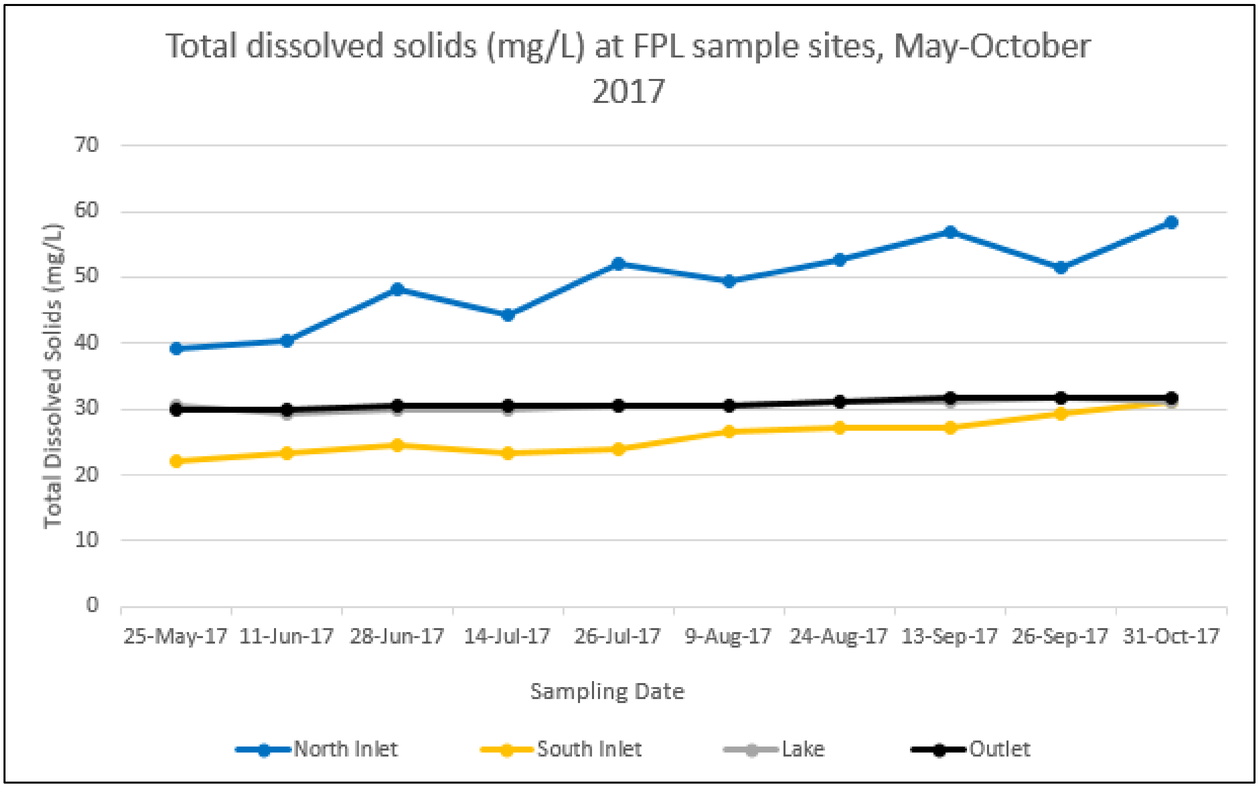

Figure 10 – Total dissolved solids at four FPL sample sites from May to October 2017.

2.9 Total Suspended Solids

Total suspended solids is a measure of the solids suspended in a water column which do not pass through a 45µm glass fiber filter. These solids include silt, clay, plankton, microscopic organisms, and fine organic and inorganic particles. Total suspended solids is one of the most visible indicators of water quality, as it provides a measure of water clarity and sedimentation, and it is strongly influenced by precipitation and overland run-off. Sources of suspended solids include natural geological erosion, agriculture, forestry, construction, and wastewater discharge. High concentrations of suspended solids can cause an increase in surface water temperatures as particles in the water column absorb solar radiation, as well as a decrease in dissolved oxygen as particles decrease light penetration and photosynthesis rates (CCME, 2002).

The average background concentration in Nova Scotia lakes is 3.0 mg/L (Hinch & Underwood, 1985). The CCME Guideline for the Protection of Aquatic Life is dependent on the baseline concentrations of suspended solids in each individual waterbody. When baseline concentrations are ≤ 100 mg/L, the maximum allowable increase is 10 mg/L above baseline levels. When baseline concentrations are > 100 mg/L, the maximum allowable increase is 10% of baseline levels (CCME, 2002).

Total suspended solids concentrations at the Lake sample site did not exceed the average background concentration in Nova Scotia lakes (3.0 mg/L) throughout the entire monitoring period in 2017, which is consistent with the 2015 and 2016 monitoring periods (see Table 9).

A spike in total suspended solids was observed at the South Inlet sample site on October 31, with a concentration of 21 mg/L. The validity of this sample was confirmed by a laboratory duplicate as part of Maxxam Analytics' quality control procedures.

Table 9 – Total suspended solids (mg/L) from May to October 2017.

	North Inlet	South Inlet	Lake	Outlet
May 25, 2017	1.4	1.6	1.8	2.2
June 28, 2017	3.6	2.2	1.6	2.0
July 26, 2017	2.5	2.4	1.0	1.2
August 24, 2017	4.4	1.8	1.4	1.0
September 26, 2017	2.0	1.8	ND (RDL = 1.0)	ND (RDL = 1.0)
October 31, 2017	1.0	21	ND (RDL = 1.0)	2.0

* ND = Not Detected, RDL = Reportable Detection Limit

2.10 Total Phosphorus

Total phosphorus is a measure of both organic and inorganic forms of phosphorus. Phosphorus is an essential nutrient for plant growth, and is usually the limiting factor for the growth of algae and aquatic plants in freshwater systems. Phosphorus has few natural sources in the environment, meaning that elevated concentrations in a waterbody are likely caused by anthropogenic activities. Natural sources of phosphorus include the weathering and erosion of rocks and the decomposition of organic matter. Anthropogenic sources of phosphorus include industrial effluent, sewage effluent, and run-off from urban, agricultural, or forestry land-use activities (B.C. MOE, 1998).

Lakes that are not significantly impacted by anthropogenic activities typically display total phosphorus concentrations of < 0.01 mg/L (B.C. MOE, 1998). CCME has not established a guideline for total phosphorus because it is not a 'toxic substance', but rather it has secondary effects in the environment such as eutrophication and dissolved oxygen depletion (CCME, 2004). Provincial guidelines have been established in some provinces, but not in Nova Scotia. Ontario's Ministry of Environment and Climate Change (MOECC) have established widely-recognized guidelines for both stream and lake habitats. The total phosphorus guideline for lakes is ≤ 0.02 mg/L, while the guideline for rivers and streams is ≤ 0.03 mg/L (MOECC, 1979).

Total phosphorus concentrations at the Lake sample site did not exceed the MOECC lake guideline of ≤ 0.02 mg/L throughout the entire monitoring period. The Outlet sample site did not exceed the MOECC stream guideline of ≤ 0.03 mg/L throughout the entire monitoring period, while the North Inlet sample site narrowly exceeded this guideline on one sample date (July 26, 2017) with a concentration of 0.034 mg/L (see Fig. 11).

The South Inlet sample site exceeded the MOECC stream guideline throughout the entire monitoring period with a mean concentration of 0.088 mg/L (see Table 10). This sample site has exceeded the MOECC stream guideline for total phosphorus on every sampling occasion in 2015, 2016, and 2017. The mean total phosphorus concentrations have decreased over the three years, with a mean of 0.164 mg/L in 2015, 0.149 mg/L in 2016, and 0.088 mg/L in 2017; however, this decrease is not statistically significant (p-value = 0.1208).

Table 10 – Mean and maximum total phosphorus concentrations from May to September 2017, with 2015 and 2016 results for comparison.

	North Inlet	**South Inlet**	**Lake**	**Outlet**
Mean total phosphorus (mg/L) (2015/2016)	0.021 *(0.020/0.018)*	0.088 *(0.164/0.149)*	0.007 *(0.010/0.007)*	0.007 *(0.008/0.012)*
Maximum total phosphorus (mg/L) (2015/2016)	0.034 *(0.030/0.031)*	0.120 *(0.240/0.320)*	0.010 *(0.014/0.008)*	0.008 *(0.008/0.027)*

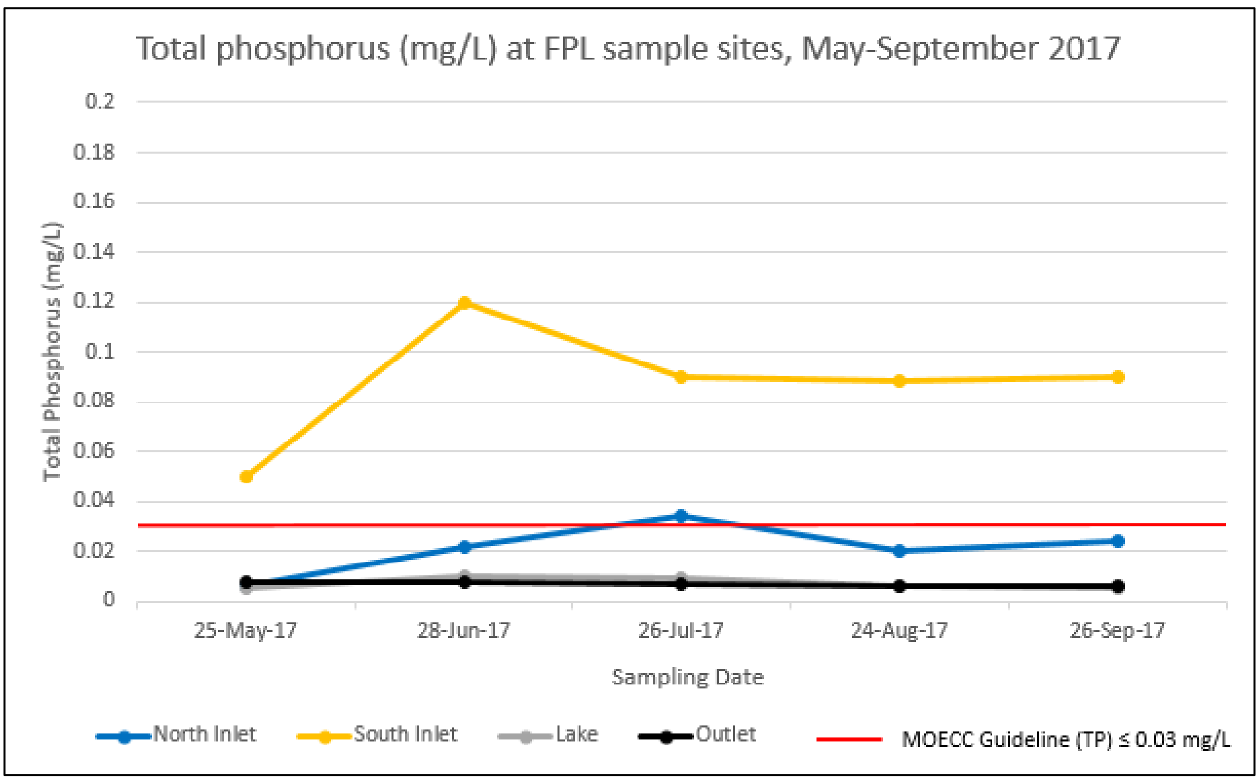

Figure 11 – Total phosphorus concentrations at four FPL sites from May to September 2017.

2.11 Total Nitrogen

Total nitrogen is a measure of all forms of organic and inorganic nitrogen. Nitrogen, like phosphorus, is an essential nutrient for plant growth, and is usually the limiting factor for the growth of aquatic plants and algae in marine environments. Anthropogenic sources include sewage effluent, urban and agricultural run-off, and industrial effluent (B.C. MOE, 1998). As with total phosphorus, CCME has not established a guideline for total nitrogen, as it is not considered to be a 'toxic substance', rather one that has secondary effects on the environment such as eutrophication and dissolved oxygen depletion (CCME, 2004). Recommended guidelines have emerged through extensive research on the fate of nitrogen in freshwater environments. Dodds and Welch (2000) have established a total nitrogen guideline of ≤ 0.9 mg/L for freshwater environments in which excessive nutrient loading and eutrophication are likely to occur. Underwood and Josselyn (1979) have reported a total nitrogen concentration guideline of ≤ 0.3 mg/L for oligotrophic waterbodies.

All four sample sites fell below the Dodds and Welch (2000) guideline of ≤ 0.9 mg/L for the entire monitoring period (see Fig. 12). The Lake sample site has fallen below the Underwood and Josselyn (1979) guideline of ≤ 0.3 mg/L for all sampling events from 2015 to 2017, supporting the trophic state classification of Fox Point Lake as oligotrophic (see Table 11).

Statistical analysis, using paired t-tests with a significance threshold of 95%, has shown a significant decrease in total nitrogen concentrations at the South Inlet sample site from 2015 to 2017 (p-value = 0.01228).

Table 11 – Mean and maximum total nitrogen concentrations from May to September 2017, with 2015 and 2016 for comparison.

	North Inlet	**South Inlet**	**Lake**	**Outlet**
Mean total nitrogen (mg/L) (2015/2016)	0.478 *(0.530/0.481)*	0.595 *(1.22/0.612)*	0.236 *(0.234/0.214)*	0.244 *(0.365/0.236)*
Maximum total nitrogen (mg/L) (2015/2016)	0.605 *(0.624/0.584)*	0.683 *(2.01/0.763)*	0.276 *(0.266/0.266)*	0.264 *(0.696/0.298)*

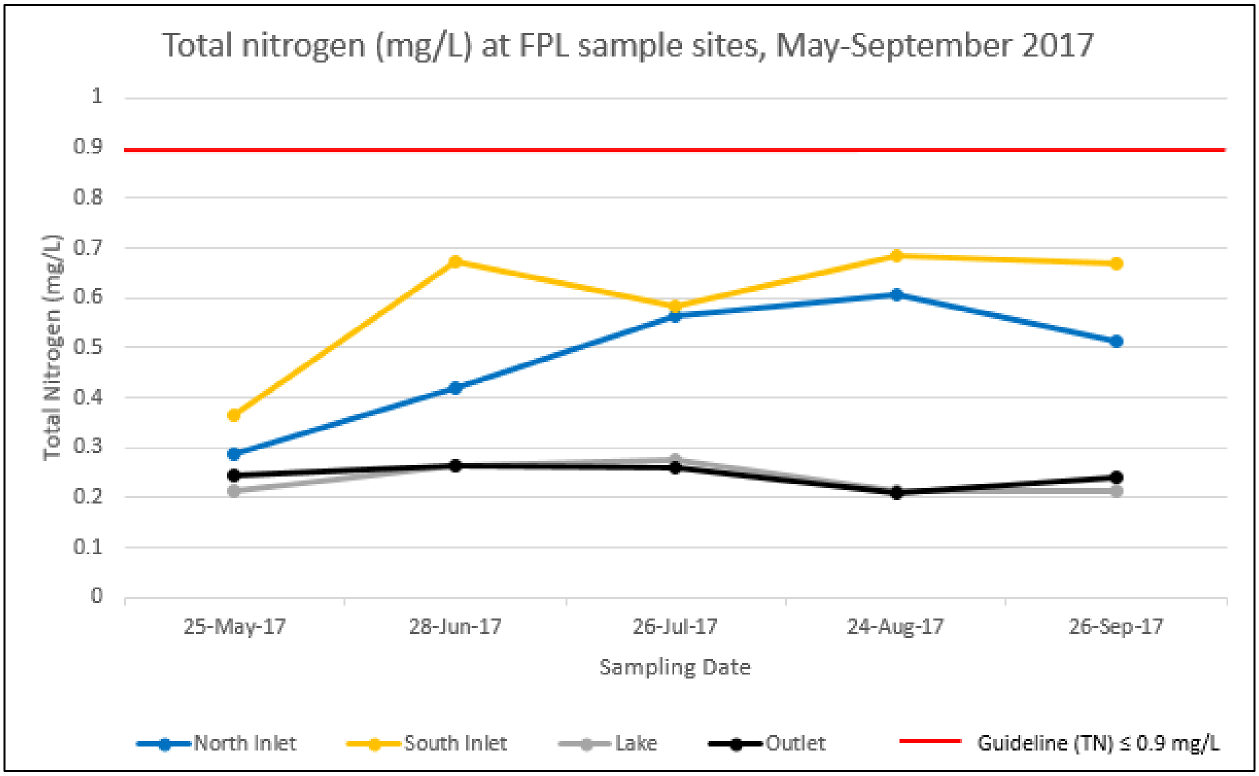

Figure 12 – Total nitrogen concentrations at four FPL sample sites from May to September 2017.

2.12 Fecal Coliform Bacteria

Fecal coliform bacteria are found in the waste of warm-blooded animals and are used as an indicator of fecal contamination in the environment. With hundreds of types of pathogenic bacteria, viruses, protozoa and other harmful microorganisms, it is not practical to test for all of them in the environment. Non-pathogenic bacteria species are used as indicators of the possible presence of pathogenic organisms.

Sources of fecal bacteria include stormwater run-off, straight pipe septic systems, malfunctioning septic systems, livestock, wildlife, domestic animals, and agricultural run-off. Exposure to water contaminated with fecal bacteria poses a significant risk to public health and can cause illnesses such as gastroenteritis, hepatitis, respiratory infections, as well as eye, skin, and ear infections (B.C. MOE, 1998; Health Canada, 2012).

Health Canada has established guidelines for the protection of human health during water-based recreation activities. Separate guidelines have been developed, depending on the level of water contact and the likelihood of ingesting water during certain types of water-based activities.

Primary contact: Activities in which the whole body or the face and trunk are frequently immersed, or the face is frequently wetted by spray, and where it is likely that some water will be swallowed (e.g., swimming, surfing, waterskiing, whitewater canoeing/rafting/kayaking, windsurfing, subsurface diving).

Secondary contact: Activities in which only the limbs are regularly wetted and in which greater contact (including swallowing water) is unusual (e.g., rowing, sailing, canoe touring, fishing).

(Health Canada, 2012)

The primary contact guideline for E. coli is ≤ 400 cfu/100 mL, and the secondary contact guideline for E. coli is ≤ 1,000 cfu/100 mL. Fecal coliforms are used as a proxy measurement for E. coli, as the majority of a fecal coliform sample is comprised of E. coli bacteria; therefore, the fecal coliform results from FPL will be compared to the Health Canada E. coli guidelines.

All four sample sites fell below the Health Canada guideline for primary contact throughout the entire monitoring period. The South Inlet sample site displayed an elevated fecal bacteria concentration of 380 cfu/100 mL on June 28 but did not exceed the primary contact guideline of ≤ 400 cfu/100 mL (see Table 12).

Table 12 – Fecal coliform (cfu/100 mL) results at four FPL sample sites from May to October 2017.

	North Inlet	**South Inlet**	**Lake**	**Outlet**
May 25, 2017	ND (RDL = 10)	40	ND (RDL = 10)	ND (RDL = 10)
June 28, 2017	90	380	ND (RDL = 10)	60
July 26, 2017	100	20	ND (RDL = 10)	30
August 24, 2017	100	30	ND (RDL = 10)	20
September 26, 2017	ND (RDL = 10)	10	ND (RDL = 10)	ND (RDL = 10)
October 31, 2017	60	10	ND (RDL = 10)	130

* ND = Not Detected, RDL = Reportable Detection Limit

2.13 Precipitation and Lake Water Level

Precipitation and the water level of FPL were monitored daily from June 10 to October 30 during the 2017 monitoring period. A record of precipitation events is important for the interpretation of water quality data, as many parameters are strongly influenced by rainfall and overland run-off. Daily monitoring of lake water level captures the natural variability and seasonal fluctuations of the lake and creates an important baseline for the identification of significant changes which may be attributable to anthropogenic activities such as watercourse and wetland alterations, irrigation water usage, vegetation removal, or topographic alterations (Fisheries and Oceans Canada, 2006).

The total precipitation amount at Fox Point Lake from June 10 to October 30 was 483.6 mm. Over the course of the 2016 monitoring period, as southwest Nova Scotia suffered from a significant drought, the precipitation amount totalled just 163 mm from June 22 to October 21.

Water level was recorded from a fixed-elevation staff gauge on a shoreline dock structure. The water level of FPL fluctuated between 0.58 m – 0.78 m, which is consistent with the fluctuation range of 0.63 m – 0.78 m measured in 2016, and 0.61 m – 0.80 m in 2015 (see Fig. 13).

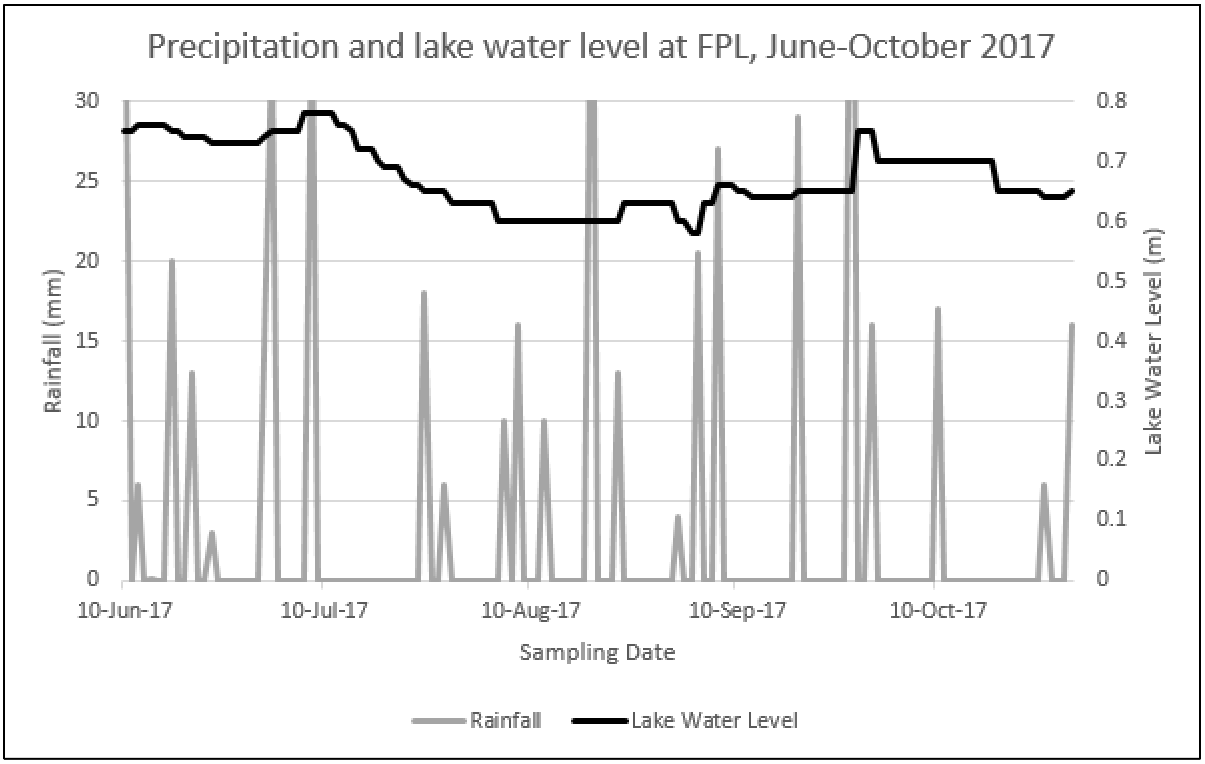

Figure 13 – Precipitation and water level at Fox Point Lake from June to October 2017.

2.14 Stream Discharge

Stream discharge rates were monitored at the North Inlet, South Inlet, and Outlet sample sites on a bi-weekly basis from May to October in 2017. Stream discharge is a product of water velocity times the depth and width of the water flowing in a stream. Anthropogenic activities within a drainage basin which effect hydrologic conditions may result in altered stream discharge rates (Meals & Dressing, 2008).

The Outlet sample site displayed the most variability in discharge rates as well as the highest mean discharge rate of 0.608 m^3/s, as this is the only outlet stream draining Fox Point Lake (see Fig. 14). The South Inlet sample site displayed a mean discharge rate of 0.060 m^3/s, which is more than double the mean discharge rate observed at this site in 2016 (0.027 m^3/s). The North Inlet sample site displayed a mean discharge rate of 0.157 m^3/s, a lower rate than that observed in 2016 (0.213 m^3/s) (see Table 13).

Table 13 – Mean and range stream discharge rates from May to October, with 2015 and 2016 results for comparison.

	North Inlet	South Inlet	Outlet
Mean stream discharge rate (m^3/s) *(2015/2016)*	0.157 *(0.428/0.213)*	0.060 *(0.036/0.027)*	0.608 *(0.235/0.178)*
Range of stream discharge rate (m^3/s) *(2015/2016)*	0.104-0.195 *(0.202-0.701/0.161-0.271)*	0.015-0.106 *(0.021-0.058/0.012-0.035)*	0.254-0.930 *(0.052-0.749/0.032-0.540)*

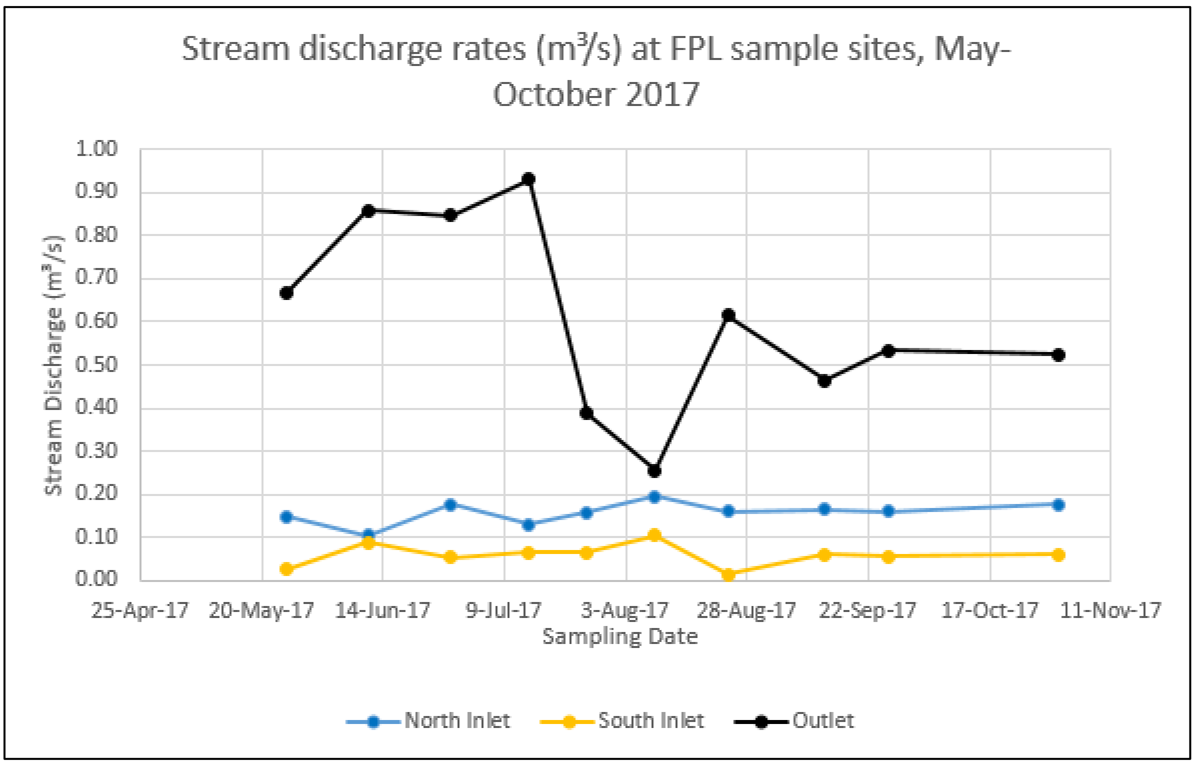

Figure 14 – Stream discharge rates at three FPL sample sites from May to October 2017.

3. Time Series Data from 2015 to 2017

Several important water quality parameters have been plotted as a time series, representing the data from the Fox Point Lake Water Quality Monitoring Program from 2015 to 2017. With three years of water quality data collected, important changes in parameters and relationships between sample sites can be identified through statistical analysis.

As seen in Figure 15, the pH of the Lake sample site has been consistently higher than the pH levels of the inlet and outlet streams. The Lake sample site has shown a statistically significant increase in pH from 2015 to 2017 (p-value = 0.0001727).

Total phosphorus concentrations have been consistently higher at the South Inlet sample site compared to the other three sample sites. Total phosphorus concentrations have decreased at the South Inlet sample site from 2015 to 2017; however, this decrease is not statistically significant. Total nitrogen concentrations have shown a statistically significant decrease at the South Inlet sample site from 2015 to 2017 (p-value = 0.01228). Nutrient levels between the South Inlet sample site and the North Inlet sample site have shown statistically significant differences for both total phosphorus (p-value = 0.000065) and total nitrogen (p-value = 0.014) for 2015, 2016, and 2017.

The South Inlet sample site has been found to be significantly different from the Lake sample site for all parameters tested in 2015, 2016, and 2017.

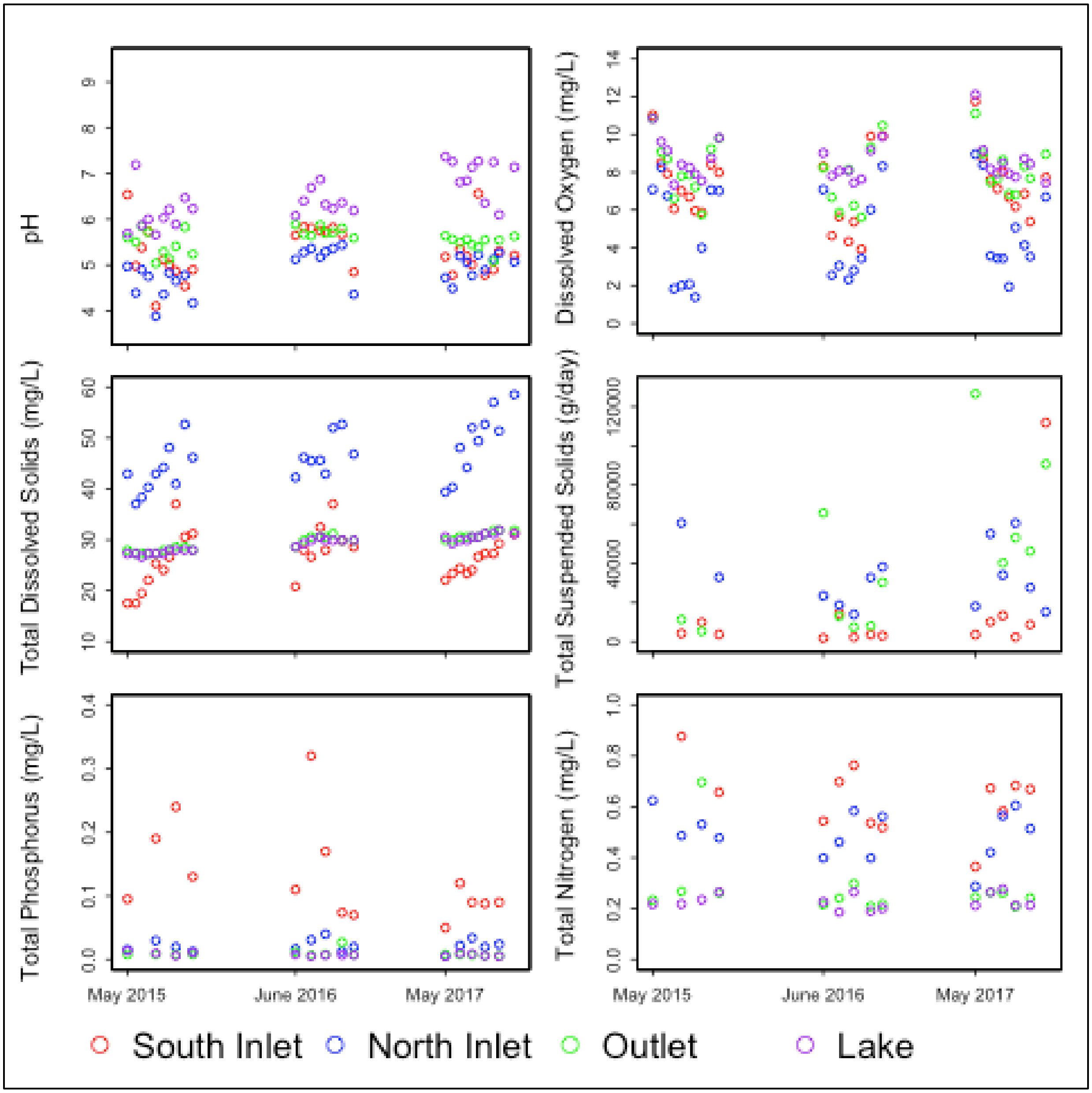

Figure 15 – Time series data for key water quality parameters at four FPL sample sites from 2015 to 2017.

4. Discussion

Fox Point Lake has experienced an algal bloom during the month of June in both 2016 and 2017. Analysis of water samples from both blooms has confirmed the presence of a cyanobacterial toxin, microcystin-LR, at a concentration of 1.25 µg/L in 2016 and 0.71 µg/L in 2017. Both microcystin-LR concentrations fall below the Health Canada drinking water guideline of 1.5 µg/L (Health Canada, 2010). Cyanobacteria blooms tend to recur in the same waterbody year after year, thus highlighting the importance of limiting external inputs of nutrients into Fox Point Lake as well as maintaining adequate dissolved oxygen concentrations in the hypolimnion layer in order to prevent an increase in the frequency and severity of algae blooms in the lake. Exposure to cyanobacteria toxins through the consumption of water, and in rare cases, recreational skin contact with water, does pose a risk of illnesses such as fever, vomiting, stomach cramps, and eye or skin irritation (WHO, 2003; Federal-Provincial-Territorial Committee on Drinking Water, 2002). As such, the residents of Fox Point Lake should be provided with educational materials about algal blooms and the associated risks and appropriate preventative measures. In addition, all lake residents should be notified in the case of a confirmed algal bloom, as the bloom may not be visible in all parts of the lake and cyanobacterial toxins can persist in the water for several weeks after a visible bloom has dissipated.

Fox Point Lake has not experienced any measurable increase in trophic state from 2015 to 2017, with the classification holding steady at oligotrophic approaching mesotrophic throughout each annual monitoring period. In 2017, the chlorophyll *a* and total phosphorus TSI scores indicated an oligotrophic state, meaning the lake has low biological productivity. The TSI score for Secchi disk depth indicated a mesotrophic state, which suggests that the Secchi disk depths may be more strongly influenced by the presence of suspended particles, such as sediment or silt, than by algal biomass.

Thermal stratification was established in the deepest part of the lake by mid-June in 2017, with a thermocline depth of 4-6 m. Dissolved oxygen concentrations were severely depleted in the hypolimnion layer, with hypoxic conditions (< 2 mg/L) being observed in September and October. Dissolved oxygen concentrations in the hypolimnion reached a minimum of 1.3 mg/L in 2017, compared to a low of 2.7 mg/L in 2016. This oxygen depletion is indicative of the level of microbial decomposition of organic material, which consumes the available oxygen and can lead to the release of the bioavailable form of phosphorus. In addition, the low dissolved oxygen conditions in the stratified parts of the lake pose a risk of internal phosphorus loading through the release of phosphorus from bottom sediments where it is bound to metals such as aluminum and iron (Brylinsky, 2004).

Fox Point Lake has displayed a reduction in acidification over the three annual monitoring periods. The Lake sample site has shown a statistically significant increase in pH from 2015 to 2017 (p-value = 0.0001727). Several studies have shown that lakes are recovering from acidification as a result of stricter sulphur dioxide emission regulations. Research on Nova Scotia lakes has shown an increase in pH, as well as biodiversity and dissolved organic carbon, without an associated increase in nutrients, which suggests that N.S. lakes are experiencing some level of recovery from acidification (Anderson et al., 2017).

The South Inlet sample site displayed an unusually high concentration of total suspended solids (21 mg/L) on October 31, 2017. The analysis of a laboratory duplicate confirmed the validity of this result. A rainfall amount of 16 mm was measured on October 30; however, rainfall is likely not the cause of this spike in suspended solids as similar rainfall amounts have occurred prior to other sampling days without a corresponding spike in total suspended solids. It is possible that some form of wildlife caused an upstream disturbance of bottom sediments prior to the collection of water samples.

As in 2015 and 2016, nutrient concentrations exceeded guidelines at only one site: the South Inlet sample site. This site exceeded total phosphorus guidelines throughout the entire monitoring period in 2017. Mean annual total phosphorus concentrations have shown a decrease from 2015 to 2017; however, this decrease is not statistically significant. The South Inlet site has shown a significant decrease in total nitrogen concentrations from 2015 to 2017 (p-value = 0.01228).

While the south inlet stream does suffer from excessive nutrient loading, the Lake sample site has not exceeded nutrient guidelines. Lakes which are not significantly impacted by anthropogenic activities normally display total phosphorus concentrations of < 0.01 mg/L (B.C. MOE, 1998). Annual mean total phosphorus concentrations at the Lake sample site have not exceeded 0.01 mg/L. Underwood and Josselyn (1979) have reported a total nitrogen guideline of ≤ 0.3 mg/L for oligotrophic lakes. The Lake sample site has never exceeded this guideline, supporting the classification of Fox Point Lake as predominantly oligotrophic.

Sediment from the stream bottom at the South Inlet sample site displayed a total phosphorus concentration of 460 mg/kg on October 31, 2017. A median total phosphorus concentration of 360 mg/kg was reported by McDaniel et al. (2009) for 105 streams in agricultural-dominated watersheds across Illinois, while McDowell and Sharpley (2001) reported an average total phosphorus concentration of 281 mg/kg in sediment from four agricultural streams in Pennsylvania. In comparison to streams in agricultural watersheds, which are likely to receive external nutrient loading, the total phosphorus in the sediment at the South Inlet sample site suggests that this stream does receive an external source of nutrient loading, much of which is being retained within the bottom sediments. The total phosphorus concentration at this site does not exceed Ontario's Ministry of the Environment guideline for lowest effect level of 600 mg/kg, which indicates that the phosphorus load in the sediment at this location is not having a detrimental effect on the aquatic environment (Ontario MOE, 2008).

The Southwest Cove sample site revealed a total phosphorus concentration of 850 mg/kg in the bottom sediments. Lake sediments normally contain much higher concentrations of phosphorus than the overlying waters (CCME, 2004), and this internal load can contribute to eutrophication and algal blooms when stratification and hypolimnial anoxic conditions facilitate the release of phosphorus from sediment (Hickey & Gibbs, 2009). The total phosphorus concentration at this location falls within the range of lowest effect level to severe effect level (600-2,000 mg/kg) according to Ontario's Ministry of the Environment Sediment Quality Guidelines, closer to the lowest effect level guideline, which suggests the sediment is clean to marginally polluted in terms of phosphorus loading (Ontario MOE, 2008).

5. Recommendations

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

- The Fox Point Lake Water Quality Monitoring Program should continue in 2018 and beyond, as construction at the Aspotogan Ridge development project is slated to continue into future years and this program was developed to track changes in the health of Fox Point Lake throughout the development of this site.
- Consider amending the frequency of the sampling program (i.e. reducing sampling to monthly rather than bi-weekly) to reduce volunteer time and commitments to the program.
- Continue to collect sediment samples from the South Inlet sample site and the southwest cove of Fox Point Lake once per year for the analysis of phosphorus and orthophosphate.
- Water samples should be collected at the Lake sample site from below the hypolimnion layer during thermal stratification for the analysis of total nitrogen and total phosphorus to determine if dissolved oxygen depletion in the bottom waters of the lake are resulting in the release of nutrients from lake sediments.
- Field replicates and blank samples should be added to the Quality Assurance/Quality Control plan to ensure the validity of field sampling procedures.
- Residents of Fox Point Lake should continue to be supplied with laboratory-certified bottles and sampling procedures for the collection of water samples during an algae bloom.

References

Abu-Hmeidan, H.Y., Williams, G.P. & Miller, A.W. 2018. Characterizing Total Phosphorus In Current and Geologic Utah Lake Sediments: Implications for Water Quality Management Issues. *Hydrology* 5, 8; doi: 10,3390/hydrology 5010008.

Anderson, L.E., Krkosek, W.H., Stoddart, A.K., Trueman, B.F. & Gagnon, G.A. 2017. Lake Recovery Through Reduced Sulphate Deposition: A New Paradigm for Drinking Water Treatment. *Environ. Sci. Technol.* 51, 1414-1422.

Beanlands, D.I. 1980. Surveys of Ten Lakes in Guysborough, Halifax, Hants, and Lunenburg Counties, Nova Scotia, 1978. Freshwater and Anadromous Division Resource Branch. Canadian Data Report of Fisheries and Aquatic Sciences No. 192.

British Columbia Ministry of Environment (B.C. MoE). 1998. Guidelines for Interpreting Water Quality Data. Version 1.0. Resources Inventory Committee.

Brown, T. & Simpson, J. 1998. Managing Phosphorus Impacts to Urban Lakes: Determining the Trophic State of Your Lake. *Urban Lake Management*. 771-778 pp.

Brylinksy, M. 2004. User's Manual for Prediction of Phosphorus Concentration in Nova Scotia Lakes: A Tool for Decision Making Version 1.0. Acadia Centre for Estuarine Research, Acadia University. 82 p.

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian water quality guidelines for the protection of aquatic life: Dissolved oxygen (Freshwater). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 2002. Canadian water quality guidelines for the protection of aquatic life: Total particulate matter. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment. 2004. Canadian water quality guidelines for the protection of aquatic life: Phosphorus: Canadian Guidance Framework for the Management of Freshwater Systems. In: Canadian environmental quality guidelines, 2004, Canadian Council of Ministers of the Environment, Winnipeg.

Carlson, R.E. 1977. A Trophic State Index for Lakes. *Limnol Oceanography* 22: 361-369.

Chowdhury, M.S.A., Hasan, K. & Alam, K. 2014. The Use of an Aeration System to Prevent Thermal Stratification of Water Bodies: Pond, Lake and Water Supply Reservior. *Applied Ecology and Environmental Sciences*. 2(1), 1-7.

Dodds, W.K. & Welch, E.B. 2000. Establishing nutrient criteria in streams. J. N. Am. Benthol. Soc. 19(1): 186-196.

Environmental Protection Agency (EPA). 2002. Volunteer Lake Monitoring: A Methods Manual. United States Environmental Protection Agency. 65 p.

Federal-Provincial-Territorial Committee on Drinking Water. 2002. Cyanobacterial Toxins – Microcystin-LR. Guidelines for Canadian Drinking Water Quality: Supporting Documentation.

Fisheries and Oceans Canada (DFO). 2006. Ecological Restoration of Degraded Aquatic Habitats: A Watershed Approach. Fisheries and Oceans Canada, Science Branch, Gulf Region. 180 p.

Hayes, F.R., Reid, B.L., & Cameron, M.L. 1985. Lake Water and sediment. Limnology and Oceanography 3: 308-317.

Health Canada. 1991. Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Total Dissolved Solids (TDS). Government of Canada.

Health Canada. 2010. Guidelines for Canadian Drinking Water Quality – Summary Table.

Health Canada. 2012. Guidelines for Canadian Recreational Water Quality, Third Edition. Water, Air, and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No H129-15/2012E).

Hickey, C.W. & Gibbs, M.M. 2009. Lake sediment phosphorus release management – Decision Support and risk assessment framework. *New Zealand Journal of Marine and Freshwater Research*, 43:3, 819-856.

Hinch, P.R. & Underwood, J.K. 1985. A study of aquatic conditions in Lake Echo during 1984. N.S. Dept. Env. Lib. L192.1 85/00 C2. 38 p.

Howell, J. 2010. The distribution of phosphorus in sediment and water downstream from a Sewage treatment works. *Bioscience Horizons* Vol. 3 No. 2, June 2010.

Mackie, G. 2004. Applied Aquatic Ecosystem Concepts. 2d ed. Dubuque, Iowa. Kendall/Hunt Publishing Company.

MacMillan, J.L., Caissie, D., LeBlanc, J.E. & Crandlemere, T.J. 2005. Characterization of summer water temperatures for 312 selected sites in Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 2582: 43p.

McDaniel, M.D., David, M.B. & Royer, T.V. 2009. Relationships between Benthic Sediments and Water Column Phosphorus in Illinois Streams. *J. Environ. Qual.* 38: 607-617.

McDowell, R.W. & Sharpley, A.N. 2001. A Comparison of Fluvial Sediment Phosphorus (P) Chemistry in Relation to Location and Potential to Influence Stream P Concentrations. *Aquatic Geochemistry*. 7: 255-265.

Meals, D.A. & Dressing, S.A. 2008. Surface water flow measurement for water quality monitoring projects, Tech Notes 3, March 2008. Developed for U.S. Environmental Protection Agency by TetraTech Inc., Fairfax, VA. 16 p.

Nova Scotia Environment. 2014. Environmental Quality Standards for Contaminated Sites, Rationale and Guidance Document. Version 1.0, April 2014. 57 p.

Nova Scotia Salmon Association (NSSA) NSLC Adopt-a-Stream Program. 2014. Walking the River: A Citizen's Guide to Interpreting Water Quality Data. 43 p.

Nova Scotia Salmon Association (NSSA) NSLC Adopt-a-Stream Program. 2015. Acid Rain. [http://www.nssalmon.ca/issues/acid-rain].

Ontario Ministry of the Environment. 1979. Rationale for the establishment of Ontario's Provincial Water Quality Objectives. Queen's Printer for Ontario. 236 p.

Ontario Ministry of the Environment. 2008. Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario. Queens Printer for Ontario.

Reddy, K.R., Kadlec, R.H., Flaig, E. & Gale, P.M. 1999. Phosphorus Retention in Streams and Wetlands: A Review, Critical Reviews in Environmental Science and Technology, 29:1, 83-146, DOI: 10.1080/10643389991259182.

Underwood, J.K. & Josselyn, D.M. 1979. The extent of road salt and nutrient stressing of Williams Lake, Halifax, Nova Scotia. N.S. Dept. Env. Lib. # W724 79/08. 88p.

U.S. Geological Survey. 2014. Hypoxia in the Gulf of Mexico. [toxics.usgs.gov/hypoxia/]

Vollenweider, R.A. & Kerekes, J.J. (eds). 1982. Eutrophication of Waters: Monitoring, Assessment and Control. Organization for Economic Co-operation and Development, Paris. 156 p.

Wetzel, G. 2001. Limnology: Lake and River Ecosystems. 3d ed. San Diego, CA: Academic Press.

World Health Organization. 2003. Cyanobacterial toxins: Microcystin-LR in Drinking Water. Guidelines for drinking-water quality, 2nd ed. World Health Organization, Geneva, 1998.