Fox Point Lake

2016 Water Quality Monitoring Report

Prepared for

Municipality of the District of Chester

Water Quality Monitoring Committee (Mill Cove)

By

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1.0 Introduction

1.1 Project Background

The Fox Point Lake Water Quality Monitoring Committee was appointed by the Municipality of the District of Chester in November 2014, in response to ongoing concerns about the water quality of Fox Point Lake (FPL) and the Aspotogan Ridge development project in Mill Cove. Aspotogan Ridge will be a 550-acre family lifestyle community, with the construction of over 500 residential units and an 18-hole golf course planned over the next several years. Residents of Fox Point Lake have documented several siltation run-off events in the lake during construction of the golf course, leading to concerns over the impacts of the development project on the health of Fox Point Lake and its drainage basin.

The Water Quality Monitoring Committee was tasked with developing a Water Quality Monitoring Program to document the baseline water quality conditions of Fox Point Lake and track any changes in the health of the lake over the course of the development project. In 2015, Bluenose Coastal Action Foundation was contracted to develop this monitoring program, provide training and assistance to a group of volunteers, and to analyze and report on the water quality results of the initial monitoring period. A description of the monitoring program, including the sampling methodology and field procedures, can be found in *Fox Point Lake Water Quality Monitoring Program* (2015), and the results of the first monitoring season can be found in *Fox Point Lake Water Quality Monitoring Report* (2015), 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 is the largest lake on the Aspotogan Peninsula. This 1.4 km^2 lake is shallow, long, and narrow, with 11 small islands and an average depth of 4.9 m (Beanlands, 1980). The lake receives drainage from its 8 km^2 catchment area through two inlet streams. The northern inlet flows through wetland habitat and drains the northern half of the catchment area, while the southern inlet flows directly through the golf course development site and drains the southern end of the catchment. A single outlet stream in the southeast corner of the lake flows directly into St. Margaret's Bay.

The FPL Water Quality Monitoring Program was designed to be carried out by residents of the lake on a volunteer basis, with the assistance of the Coastal Action Project Manager throughout the summer. In 2015, four sample sites were established around the lake, as well as a rainfall and water level monitoring station on a volunteer's shoreline property. Sample site locations were chosen to monitor water quality conditions in the lake, the outlet stream, and the north and south inlet streams before they enter the lake (see Fig. 1).

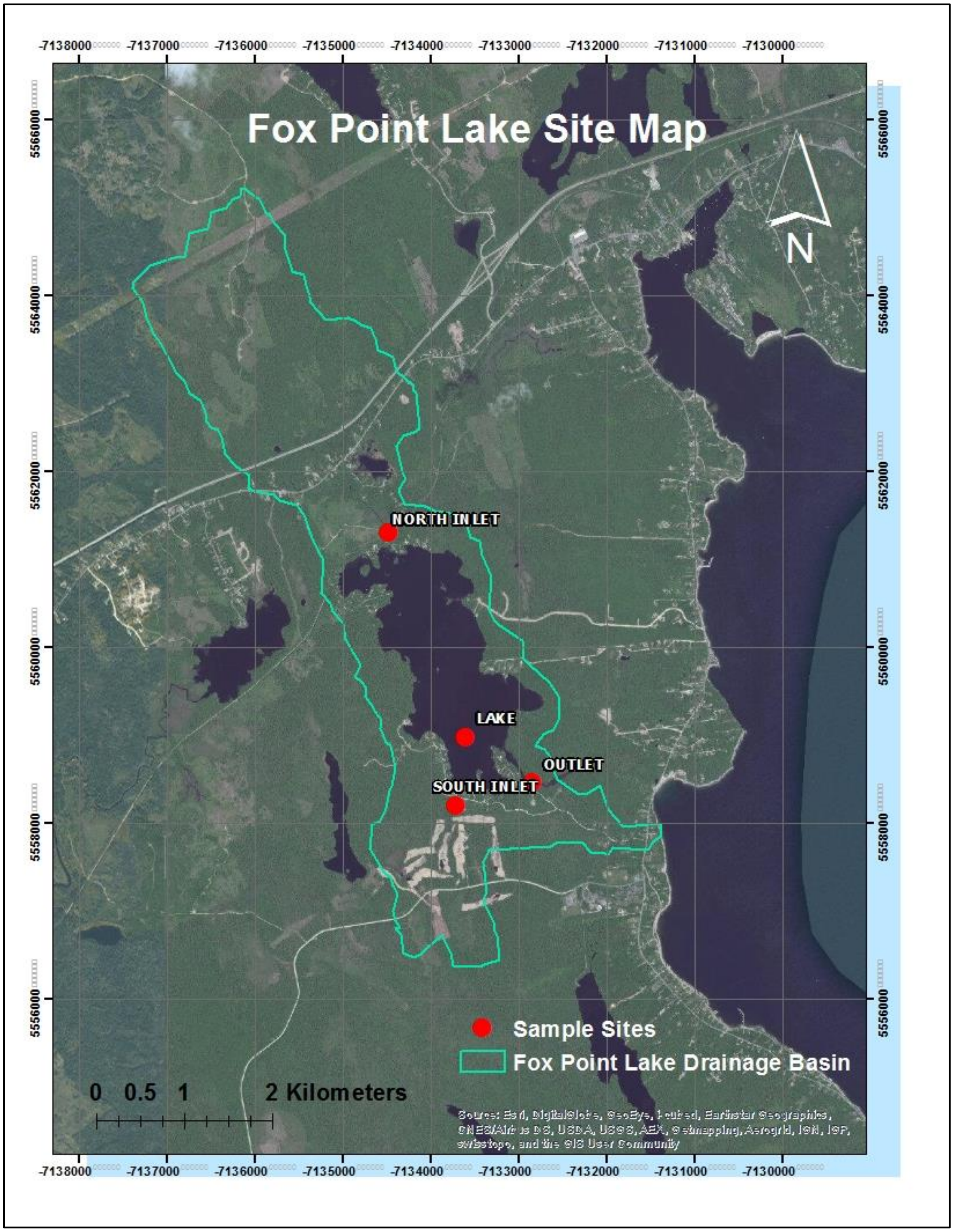

Figure 1 – Fox Point Lake drainage basin and locations of four water quality monitoring sites.

1.2 Review of 2015 Water Quality Report

The 2015 monitoring season provided valuable baseline data on the overall health of Fox Point Lake and its outlet and inlet streams. Following the initial monitoring period in 2015, it was determined that Fox Point Lake is healthy but at risk of cultural eutrophication if anthropogenic activities within its catchment area are not properly managed.

The trophic state was identified as oligotrophic approaching mesotrophic, meaning that the lake has low to moderate biological productivity. Thermal stratification occurred in the lake from June to October, leading to severe oxygen depletion in the bottom layer of the lake. Surface water temperatures in the lake exceeded 20°C in July and August, which causes stress for many aquatic organisms. These high surface water temperatures and low dissolved oxygen conditions in the bottom layer of the lake indicate that the outlet and inlet streams are likely providing important thermal refugia habitat for the fish populations of Fox Point Lake. The North Inlet sample site displayed very low dissolved oxygen concentrations during the warmest part of the summer. Nutrients (nitrogen and phosphorus) exceeded the recommended guidelines at the South Inlet sample site on several occasions, indicating that this stream is suffering from excessive nutrient loading. Fecal bacteria results fell well below Health Canada guidelines established to protect human health, except for one occasion when guidelines were exceeded at the North Inlet and South Inlet sample sites.

1.3 Changes to the 2016 Water Quality Monitoring Program

Two changes were made to the monitoring program in 2016, which involved the relocation of the North Inlet sample site, and the addition of a second dissolved oxygen/water temperature profile site in the lake.

The North Inlet sample site was moved approximately 100 m downstream from its original location in 2015 (see Fig. 2). The construction of a beaver dam immediately downstream of the original location caused a number of issues with accessing the site and collecting all the required data throughout the 2015 monitoring period.

Figure 2 – Relocation of the North Inlet sample site at FPL in 2016.

In 2015, depth profiles for dissolved oxygen and water temperature were conducted on a bi-weekly basis at the deepest point (19 m) in the lake (Lake sample site) to monitor thermal stratification throughout the water column and dissolved oxygen conditions in the bottom layer of the lake. These profiles revealed that Fox Point Lake was thermally stratified from June to October and dissolved oxygen became severely depleted in the bottom layer of the water column. In order to gain a better understanding of thermal stratification and oxygen depletion in the lake, a second profile site was established at the northern end of the lake in another deep spot (16 m) (see Fig. 3). The original Lake sample site will now be referred to as 'Lake Site 1' and the new depth profile site is called 'Lake Site 2'. YSI and depth profile data are collected from Lake Site 2; however, water samples for laboratory analysis are not collected from this site.

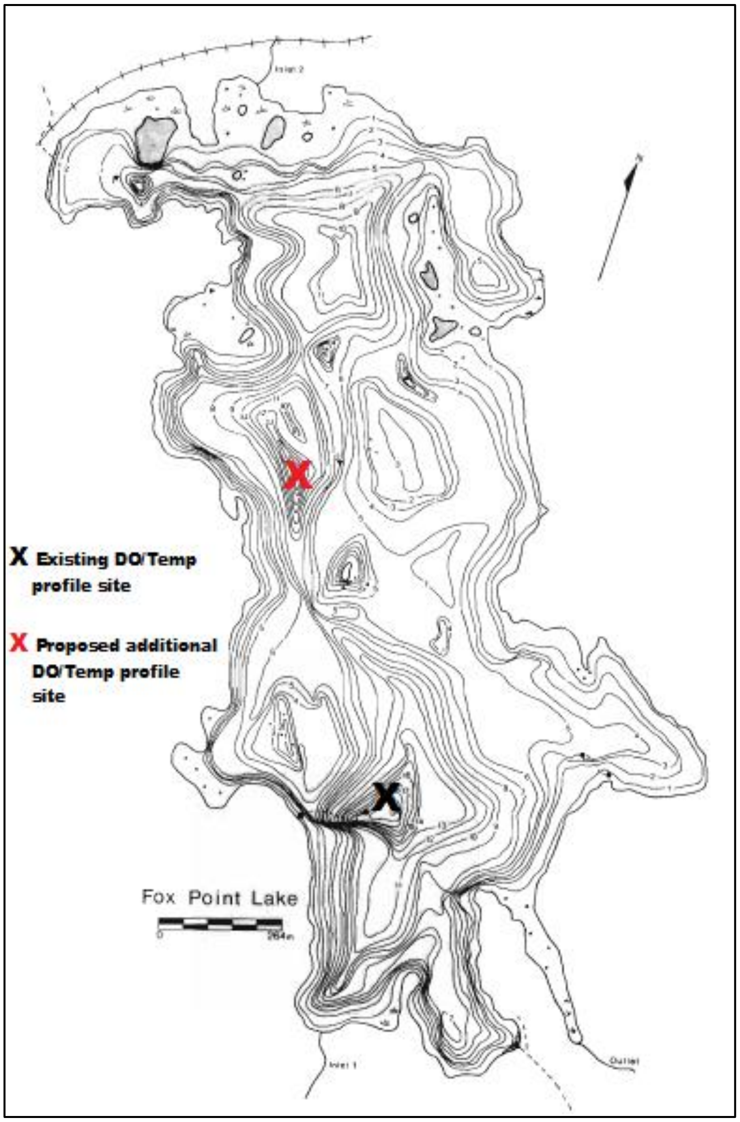

Figure 3 – Location of second dissolved oxygen/water temperature profile site in FPL.

Table 1 – Locations of monitoring sites at FPL in 2016.

Monitoring Site	Site Coordinates
North Inlet	N 44°36’55.14” W 64°05’24.21”
South Inlet	N 44°35’47.00” W 64°04’60.00”
Lake Site 1	N 44°36’04.86” W 64°04.56.28”
Outlet	N 44°35’52.92” W 64°04.31.99”
Lake Site 2	N 44°36’29.14” W 64°05’15.06”
Rainfall/Staff Gauges	N 44°35’56.62” W 64°05’02.11”

2.0 Water Quality Monitoring Results

The following section provides an analysis of the 2016 monitoring program results. Many of the water quality parameters will be compared to established guidelines that have been designated by the Canadian Council of Ministers of the Environment (CCME), Health Canada, or through other research bodies.

According to residents of FPL, no siltation run-off events were observed during the summer months of 2016 and the lake water was clearer than they have seen it over the past several years. The Aspotogan Ridge development project, currently one of the most significant sources of anthropogenic activities within the FPL catchment area, was not active during the 2016 monitoring period. Golf course operations and construction activities were put on hold and it is currently unknown when this development project will recommence.

2.1 Algae Bloom

On June 22, 2016, an algae bloom occurred in Fox Point Lake. Members of the FPL volunteer group collected a water sample to be analyzed at Maxxam Analytics laboratory for microcystin-LR, which is a toxin produced by cyanobacteria (blue-green algae). Analysis of the water sample indicated a level of microcystin-LR of 1.25 µg/L, confirming the presence of cyanobacterial toxins in the bloom. The drinking water guideline for cyanobacterial toxins – microcystin-LR is 1.5 µg/L (Health Canada, 2010). This guideline is meant to protect against exposure to other types of microcystins which may be present in a bloom. Microcystins can persist in aquatic environments after a visible bloom has dissipated (Federal-Provincial-Territorial Committee on Drinking Water, 2002).

Freshwater cyanobacteria can accumulate in surface waters, producing a ‘bloom’ or ‘scum’ layer on the surface of a waterbody. Cyanobacterial blooms can persist in water with adequate supplies of nitrogen and phosphorus, water temperatures between 15-30°C, and a pH between 6.0 - 9.0 and tend to recur within the same waterbody year after year. There is no simple method to distinguish between toxic and non-toxic blooms; therefore, every algal bloom should be treated as potentially dangerous. In general, 50-75% of the isolates from a bloom are capable of producing toxins and there is often more than one type of toxin present, although not all cyanobacterial blooms will produce toxins. Exposure to cyanobacterial toxins is most often through the consumption of drinking water, and minor exposure can occur through recreational activities and other domestic water uses. Although rare, illnesses can occur from recreational exposure through skin contact or inadvertent ingestion of water, and can include stomach cramps, vomiting, fever, headache, eye and skin irritation, and muscle pain and weakness (WHO, 2003; Federal-Provincial-Territorial Committee on Drinking Water, 2002).

The analysis of microcystin-LR in the water sample from FPL was sent to a laboratory in Alberta and results were not received by the Coastal Action Project Manager for several weeks. As a precaution, all algae blooms in FPL should be treated with caution as soon as they occur rather than wait for confirmation on the presence of cyanobacterial toxins. Domestic water use should be restricted and recreational use of the lake by humans and pets should be avoided until after the bloom has dissipated.

2.2 Trophic State

The trophic state of a lake describes its level of biological productivity and provides a valuable benchmark from which to monitor changes in the health of a lake and its drainage basin as a result of various anthropogenic activities. Oligotrophic lakes display low levels of productivity and relatively pristine conditions, mesotrophic lakes have moderate biological production, and eutrophic lakes exhibit high productivity and high densities of plant biomass. Eutrophication is the natural, long-term process of lakes progressing from lower trophic states to higher ones, while cultural eutrophication refers to the accelerated trend towards higher trophic states due to anthropogenic impacts within the drainage basin of a lake. Symptoms of cultural eutrophication include excessive nutrient loading, increased algal and rooted aquatic plant growth, and low dissolved oxygen conditions (Brown & Simpson, 1998; Brylinsky, 2004).

Determining the trophic state of a lake involves the analysis of key variables: total phosphorus, total nitrogen, chlorophyll *a*, and Secchi disk depth. In 2015, these water quality parameters were used to assess the trophic state of Fox Point Lake by calculating the Carlson Trophic State Index (TSI) scores (Carlson, 1977). The trophic state of Fox Point Lake in 2015 was determined to be oligotrophic and approaching mesotrophic. This analysis has been repeated using results from the 2016 monitoring season to identify any changes in trophic state.

Table 2 – Mean and range values for key parameters from Lake Site 1 from June to October, 2016.

	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Chlorophyll *a* (µg/L)	Secchi Disk Depth (m)
Mean	6.8	214	3.05	2.69
Range	5 - 8	187 - 266	1.25- 5.21	1.72 – 3.26

Table 3 – Means and ranges of variables 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.

A comparison of the results from Lake Site 1 (see Table 2) to a set of ranges and means established by Vollenweider & Kerekes (1982) (see Table 3) suggests that the trophic state of Fox Point Lake is predominantly oligotrophic and approaching mesotrophic. Additional analysis of trophic state, using the Carlson Trophic State Index (TSI), will provide a numerical score for each key parameter which can be directly compared to the scores calculated in 2015. The TSI ranges from 0 to 100 and can be calculated for each parameter individually using the following formulas:

Secchi disk:	TSI(SD) = 60 – 14.41 ln(SD)	**TSI(SD) = 45.7**
Chlorophyll *a*:	TSI(CHL) = 9.81 ln(CHL) + 30.6	**TSI(CHL) = 41.5**
Total phosphorus:	TSI(TP) = 14.42 ln(TP) + 4.15	**TSI(TP) = 31.8**
(ln = natural log)		

Figure 4 – TSI calculations for Fox Point Lake in 2016.

Table 4 – Comparison of Secchi disk, chlorophyll *a*, and total phosphorus TSI scores in 2015 and 2016 at Fox Point Lake.

	2015	2016
TSI (SD)	49	45.7
TSI (CHL)	34	41.5
TSI (TP)	37	31.8

Lakes with a TSI of less than 40 are oligotrophic, mesotrophic lakes have TSI values between 40 and 50, and lakes with a TSI value greater than 50 are classified as eutrophic. The TSI value for chlorophyll *a* is often given priority as it provides the most accurate prediction of algal biomass. TSI scores indicate, again, that Fox Point Lake has a trophic state of oligotrophic, approaching mesotrophic, meaning that the lake has low to moderate biological productivity.

The decrease in TSI scores for Secchi disk depth from 49 in 2015 to 45.7 in 2016 reflect improved water clarity. The average Secchi disk depth, in 2016, was 2.69 m at Lake Site 1 and 2.92 m at Lake Site 2, compared to an average Secchi disk depth of 2.09 at Lake Site 1 in 2015. Residents of the lake have reported that the water clarity is better than they have seen in years. The increase in TSI scores for chlorophyll *a* indicate an increase in algal biomass; however, Secchi disk depth is not only influenced by algal biomass, but can be effected by the presence of sediment, silt, and other materials in the water column (NSSA, 2014; EPA 2002).

This analysis of trophic state has not identified any significant changes in the biological productivity of the lake from 2015 to 2016. The trophic state of oligotrophic approaching mesotrophic remains the same as 2015, even with slight changes in TSI scores. Two years of monitoring data have produced a valuable baseline of trophic conditions in FPL from which to assess changes in future monitoring years.

2.3 Thermal Stratification

Thermal stratification of a lake involves the separation of the water column into layers of different densities based on changing water temperatures (see Fig. 5). This process begins with spring turnover, when the water temperature of a lake is consistent from top to bottom. Wind circulation draws dissolved oxygen from the surface to the bottom waters and pulls nutrients from the bottom to the surface. In late spring/early summer, the surface waters begin to warm and three layers begin to form throughout the water column. The epilimnion represents the warmer surface layer, where light can penetrate and wind action circulates the water, adding dissolved oxygen. The metalimnion, or thermocline, represents the middle layer where temperature changes rapidly with depth. The bottom layer, or hypolimnion, holds the coldest, densest water.

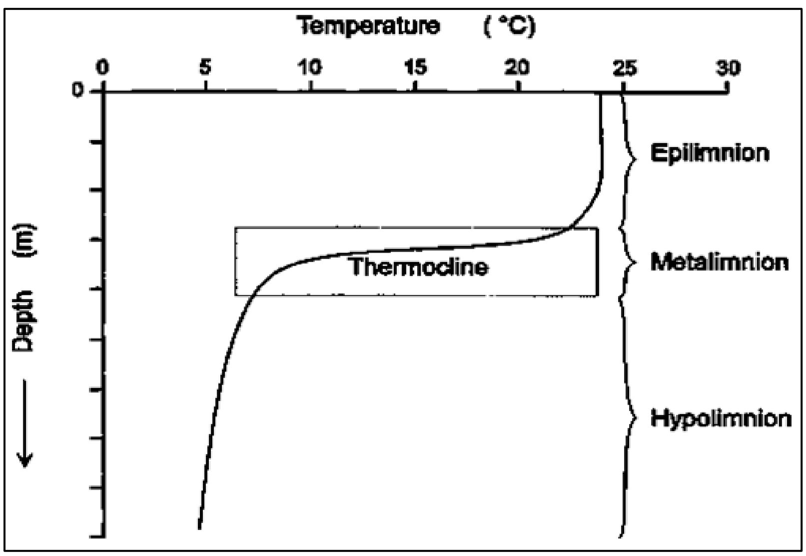

Figure 5 – Thermal stratification of a water column displaying three layers of varying densities (Chowdhury et al., 2014).

By late summer, when stratification is at its strongest, there is little to no mixing between the layers, which means that the hypolimnion is no longer receiving dissolved oxygen from the surface. This finite supply of dissolved oxygen in the bottom layer can be depleted over the course of the summer because of organic material sinking to the lake bottom and being decomposed by bacteria. The available dissolved oxygen is consumed through microbial decomposition, leading to extremely low dissolved oxygen levels in the hypolimnion and a decreased ability to support aquatic life (Brylinsky, 2004).

Low dissolved oxygen conditions have significant physiological and behavioural effects on aquatic organisms. 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). Dissolved oxygen levels which fall below this guideline cause stress in aquatic organisms and may result in relocation, dormancy, or death.

Thermal stratification is broken in autumn as surface waters cool and the water temperature becomes uniform from top to bottom once again. Once the density layers have broken down, mixing of the water column replenishes dissolved oxygen in the bottom waters (see Fig. 6).

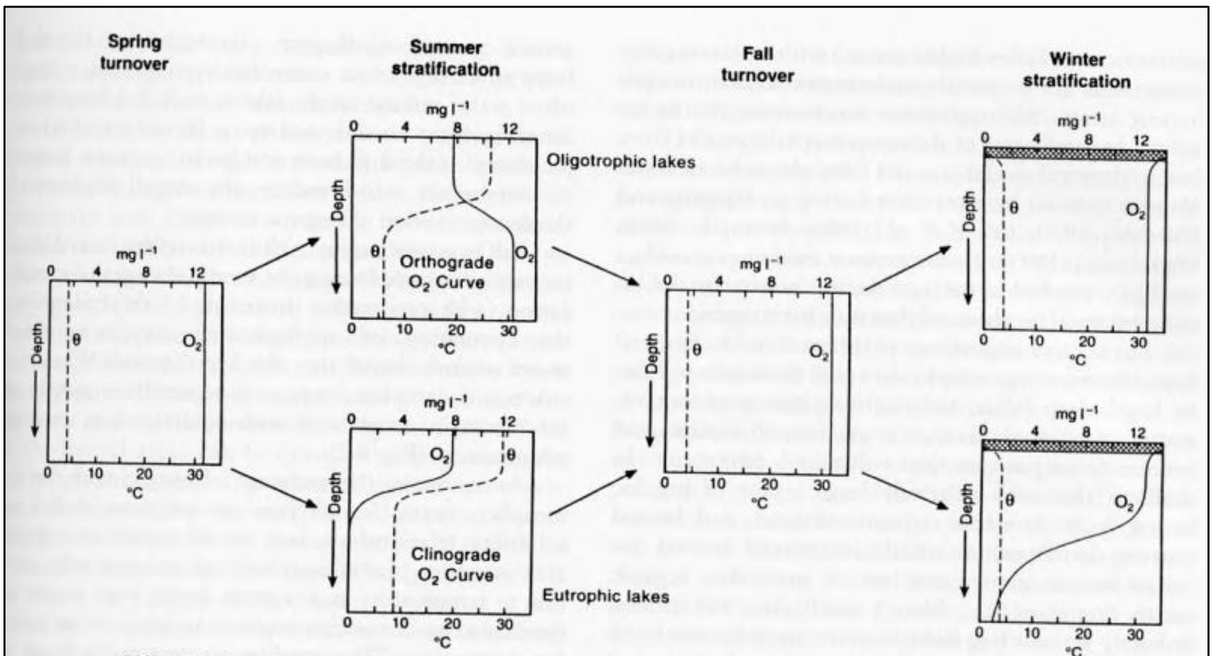

FIGURE 9-2 Idealized vertical distribution of oxygen concentrations and temperature (Θ) during the four main seasonal phases of an oligotrophic and a eutrophic dimictic lake.

Figure 6 – Thermal stratification in oligotrophic and eutrophic lakes represented by dissolved oxygen/water temperature depth profiles (Wetzel, 2001).

There are four types of dissolved oxygen profiles that can develop during thermal stratification, depending on the level of biological productivity (trophic state) of a lake (see Fig. 7). An orthograde profile is seen in oligotrophic lakes (low nutrient input, low productivity) when the dissolved oxygen concentration decreases in the epilimnion and increases in the hypolimnion. Clinograde profiles are observed in eutrophic and mesotrophic lakes (high nutrient input, high productivity) when the dissolved oxygen concentration decreases in the hypolimnion and increases in the epilimnion. Heterograde profiles develop when there are high or low concentrations of dissolved oxygen at unlikely depths throughout the water column. Negative heterograde profiles display low dissolved oxygen concentrations in the metalimnion (thermocline), usually caused by an accumulation of decomposing organisms caught at the density boundary. Positive heterograde profiles display high dissolved oxygen concentrations in the metalimnion, usually caused by a high concentration of photosynthesizers in that part of the water column (Mackie, 2004).

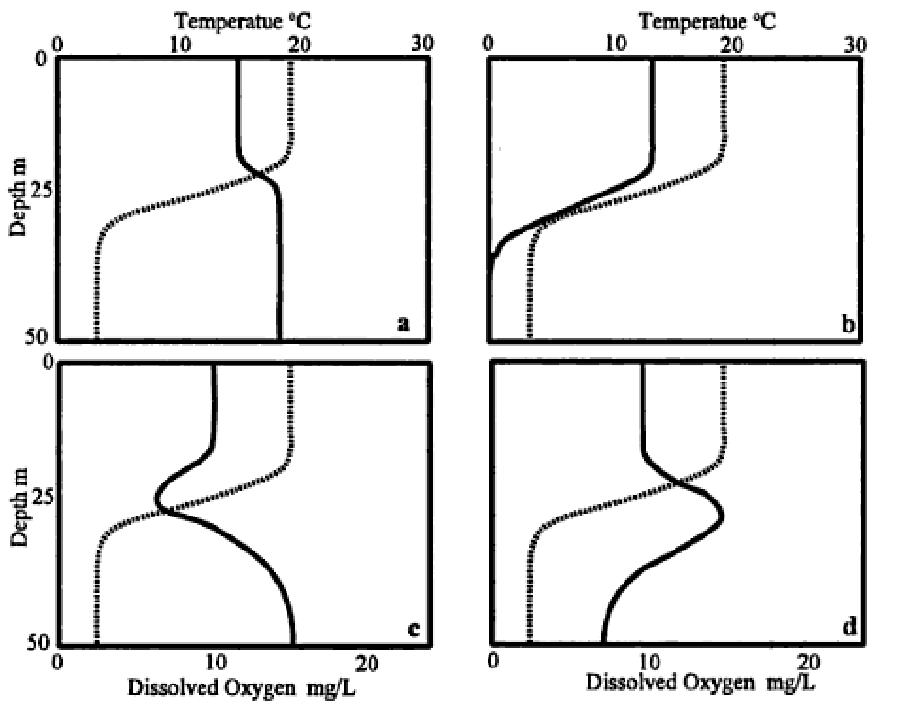

Figure 5.2. Common summer vertical oxygen profiles in lakes. (a) Orthograde. (b) Clinograde. (c) Negative heterograde. (d) Positive heterograde.

Figure 7 – Common dissolved oxygen profiles found in thermally stratified lakes (Mackie, 2004).

Depth profiles were conducted at both Lake Site 1 and Lake Site 2 from June to October, 2016 (see Fig. 8 and Fig. 9). At Lake Site 1, thermal stratification was established by June 15 with a thermocline depth of 8 m and dissolved oxygen concentrations above the CCME guideline throughout the water column. In July, the thermocline shifted upwards to approximately 4-6 m depth, which increased the proportion of the hypolimnion layer in the water column. Depth profiles on August 11 and August 23 displayed negative heterograde profiles, which means that decomposing organisms were caught in the density boundary of the thermocline (metalimnion) and consuming oxygen. By August 23, dissolved oxygen concentrations had fallen below the

CCME guideline. Depth profiles in September displayed clinograde profiles and dissolved oxygen concentrations had dropped as low as 2.74 mg/L. By October 27, thermal stratification had broken down at Lake Site 1 and water temperatures and dissolved oxygen concentrations were uniform throughout the water column.

At Lake Site 2, thermal stratification was established by June 15 with a thermocline depth of 8 m and dissolved oxygen conditions just above the CCME guideline. In July, the thermocline shifted upwards to a depth of 4-6 m, which increased the proportion of the hypolimnion layer. Depth profiles in July and August displayed clinograde profile curves, which indicates high productivity and microbial decomposition in the hypolimnion. On September 9, dissolved oxygen still displayed a clinograde profile, with concentrations dropping as low as 2.89 mg/L. Thermal stratification was broken by September 30, with uniform water temperatures throughout the water column and dissolved oxygen concentrations above the CCME guideline.

Thermal stratification was established at both Lake Site 1 and Lake Site 2 by June 15; however, this stratification began to break down earlier at Lake Site 2. Both sites displayed clinograde profiles and dissolved oxygen concentrations below 3 mg/L by late summer. Once established, thermal stratification in FPL does not appear to break down at any point through the summer, meaning that dissolved oxygen does not get replenished until fall turnover. Microbial decomposition consumes most of this finite supply of oxygen, causing severe depletion in the bottom waters of the lake.

If biological productivity increases in Fox Point Lake, oxygen conditions in the hypolimnion may become hypoxic (< 2 mg/L) or anoxic (< 1 mg/L) (USGS, 2014), which causes a shift in microbial decomposition from aerobic bacteria to anaerobic bacteria, which decompose organic material 20 times slower and release methane and hydrogen sulfide gases that are toxic to aquatic organisms. Anoxic conditions can also lead to the release of phosphorus and metals from bottom sediments through oxidation reduction reactions (Hayes et al., 1985). Bottom sediments of Fox Point Lake may be holding a significant amount of phosphorus, given the number of severe run-off siltation events that have occurred in recent years. If the bottom of the lake becomes anoxic, internal phosphorus loading could lead to algal blooms and increased aquatic plant growth in the lake (Brylinsky, 2004).

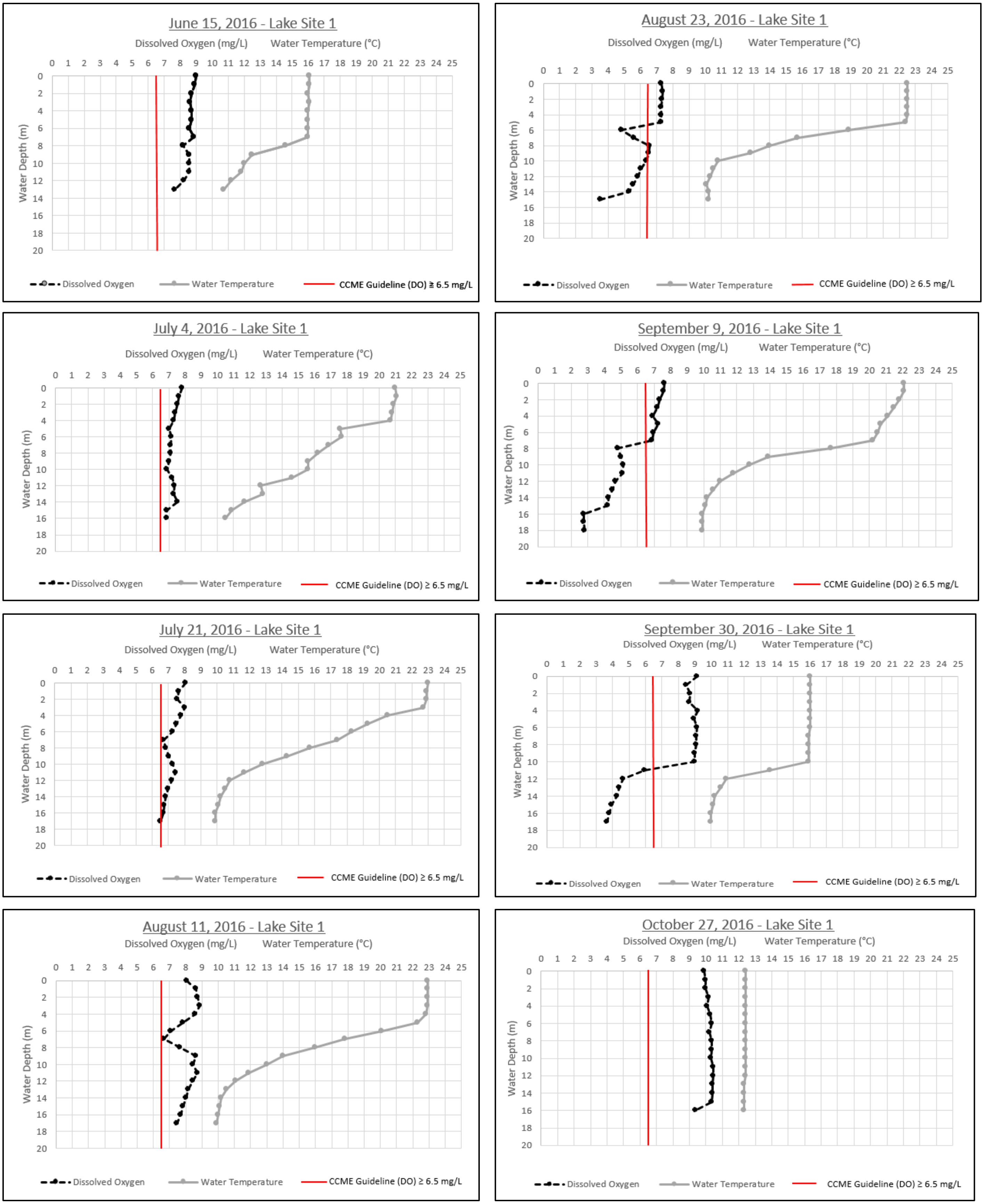

Figure 8 – Dissolved oxygen/water temperature depth profiles at Lake Site 1 in 2016.

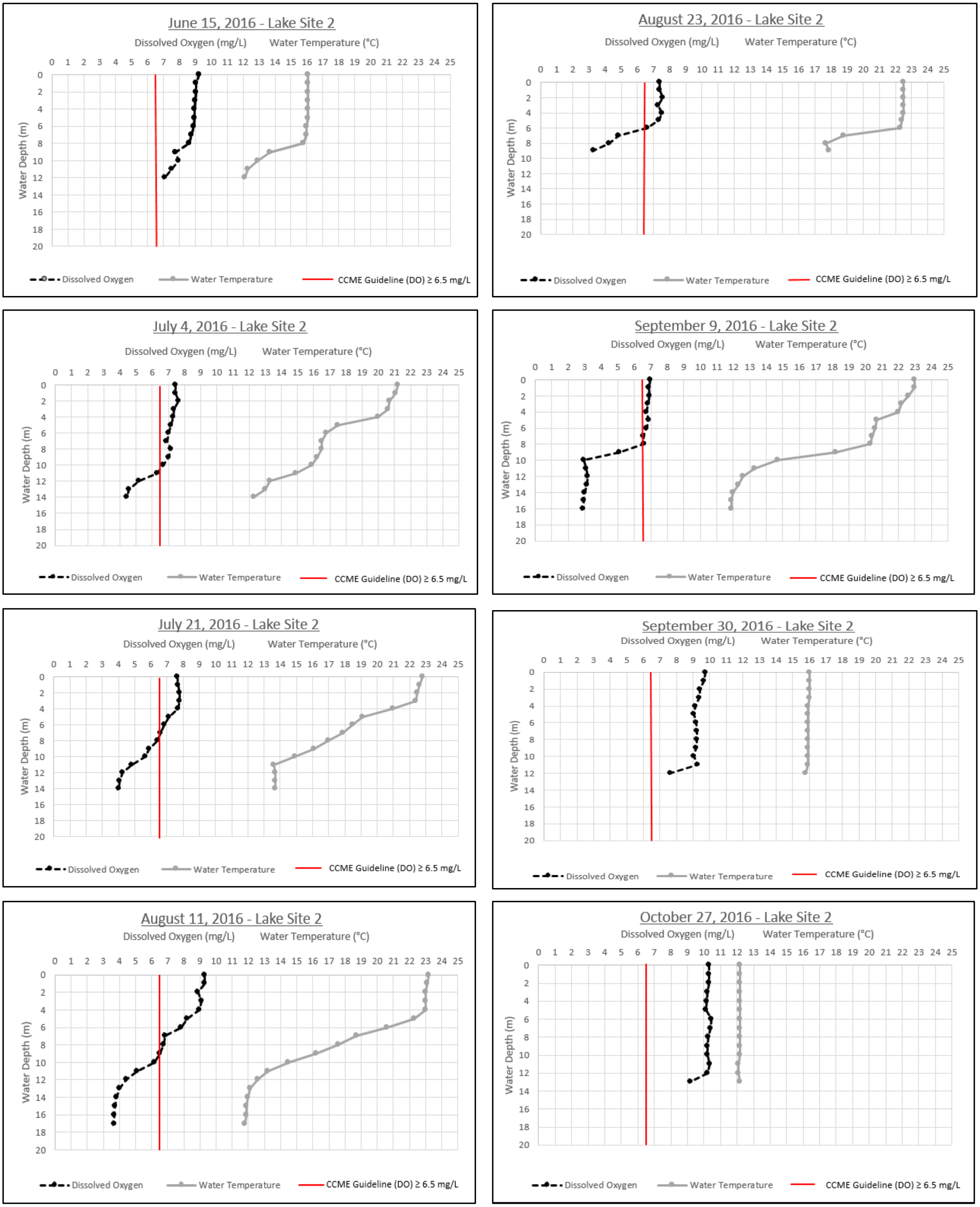

Figure 9 – Dissolved oxygen/water temperature depth profiles at Lake Site 2 in 2016.

2.4 Water Temperature

Water temperature is one of the most important indicators of water quality which plays a significant role in the health and productivity of aquatic ecosystems. Water temperature effects many physical, chemical, and biological factors in an aquatic system. Dissolved oxygen is strongly influenced by temperature, as cold water can hold more oxygen than warm water. Aquatic organisms have varying levels of sensitivity to temperature as well as optimal temperature ranges, and 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 at all 5 sample sites on a bi-weekly basis from June to October, 2016. Surface water temperatures were nearly identical at Lake Site 1 and Lake Site 2 (see Fig. 10), with both sites, as well as the Outlet site, exceeding 20°C from July to early September. The South Inlet site displayed the lowest water temperatures, as much of this stream flows through dense forest habitat which provides shade for the stream and maintains cooler water temperatures.

Maximum recorded water temperatures increased from 2015 at the North Inlet, South Inlet, and Outlet sites, while there was a decrease in the maximum temperature recorded at Lake Site 1 (see Table 5). Similar to what was observed in 2015, the inlet and outlet streams may be providing important thermal refugia habitat for cold-water fish populations, such as brook trout, as surface water temperatures exceed 20°C and dissolved oxygen levels decrease in the bottom layers of the lake.

Table 5 – Mean and maximum summer water temperatures from July to September, 2016 and 2015 maximum summer water temperatures.

	North Inlet	South Inlet	Lake Site 1	Outlet	Lake Site 2
Mean Summer Water Temperature (°C)	18.4	16.3	21.3	20.5	21.5
Maximum Summer Water Temperature (°C)	20.7	18.7	23	23.2	23.3
2015 Maximum Summer Water Temperature (°C)	18.7	17.7	23.9	22.9	N/A

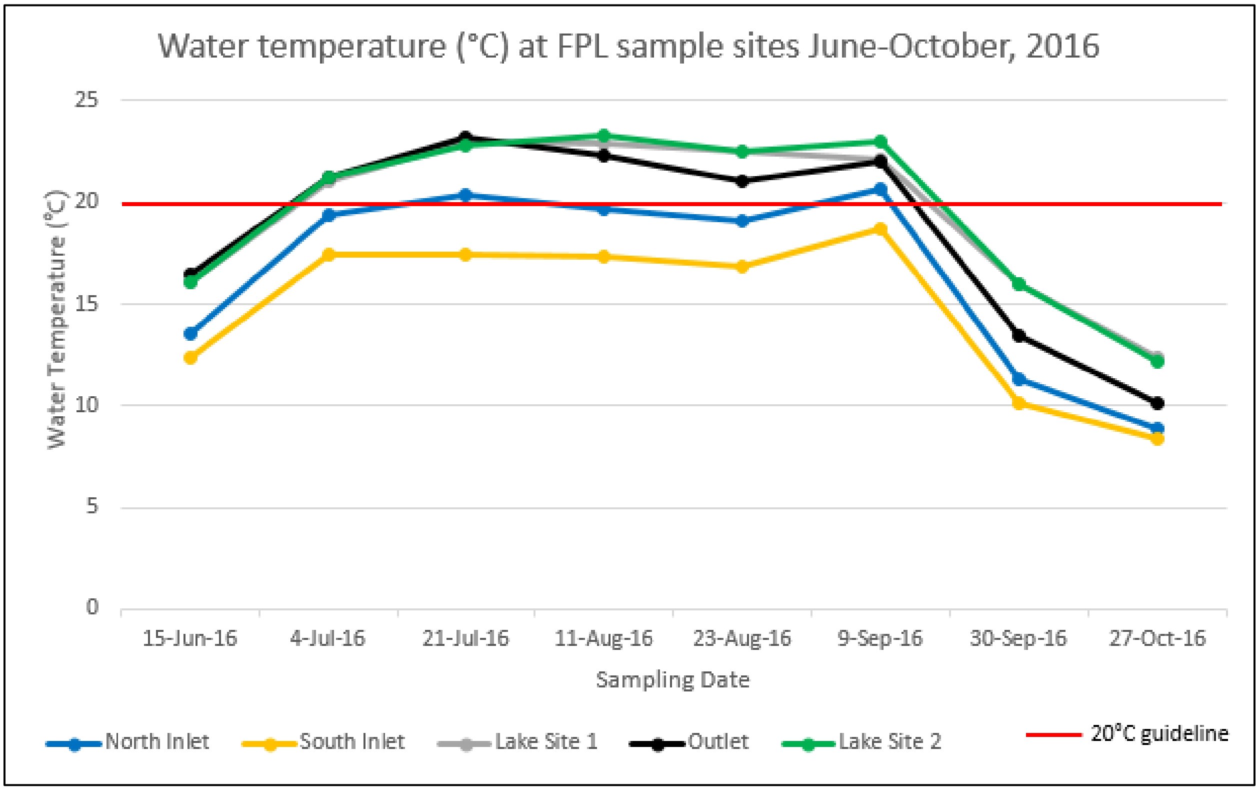

Figure 10 – Water temperatures at five FPL sample sites from June to October, 2016.

2.5 Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important indicators of water quality and aquatic ecosystem health. Sources of DO in water include wind and wave action, photosynthesis by aquatic vegetation, rainfall, and cascading water. The amount of DO available to aquatic life in a lake is influenced by several factors including thermal stratification, algal and aquatic plant density, water temperature, and the oxygen content of inlet streams (EPA, 2002). The CCME

Water Quality 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).

Dissolved oxygen shows an inverse relationship with water temperature, with DO concentrations decreasing at all sites during the warmest part of the monitoring period, because oxygen becomes less soluble in water as temperature increases (CCME, 1999). Both Lake Site 1 and Lake Site 2 display surface DO concentrations above the CCME guideline for the entire monitoring period, due to wind and wave action and photosynthesis in the photic zone. The North Inlet and South Inlet sample sites display DO conditions below the CCME guideline from July to September. Both streams have very slow moving water, which limits the rate of oxygen transfer from the atmosphere into surface waters. DO concentrations at the Outlet sample site fell below the CCME guideline on three occasions; however, the cascading riffle habitat upstream of this site normally maintains suitable DO conditions (see Fig. 11).

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

	North Inlet	South Inlet	Lake Site 1	Outlet	Lake Site 2
Mean Summer Dissolved Oxygen (mg/L) (2015 results)	3.36 (2.25)	5.63 (6.31)	8.02 (7.88)	6.97 (7.05)	8.09 (N/A)
Minimum Summer Dissolved Oxygen (mg/L) (2015 results)	2.31 (1.38)	3.92 (5.86)	7.43 (7.33)	5.61 (5.75)	6.98 (N/A)

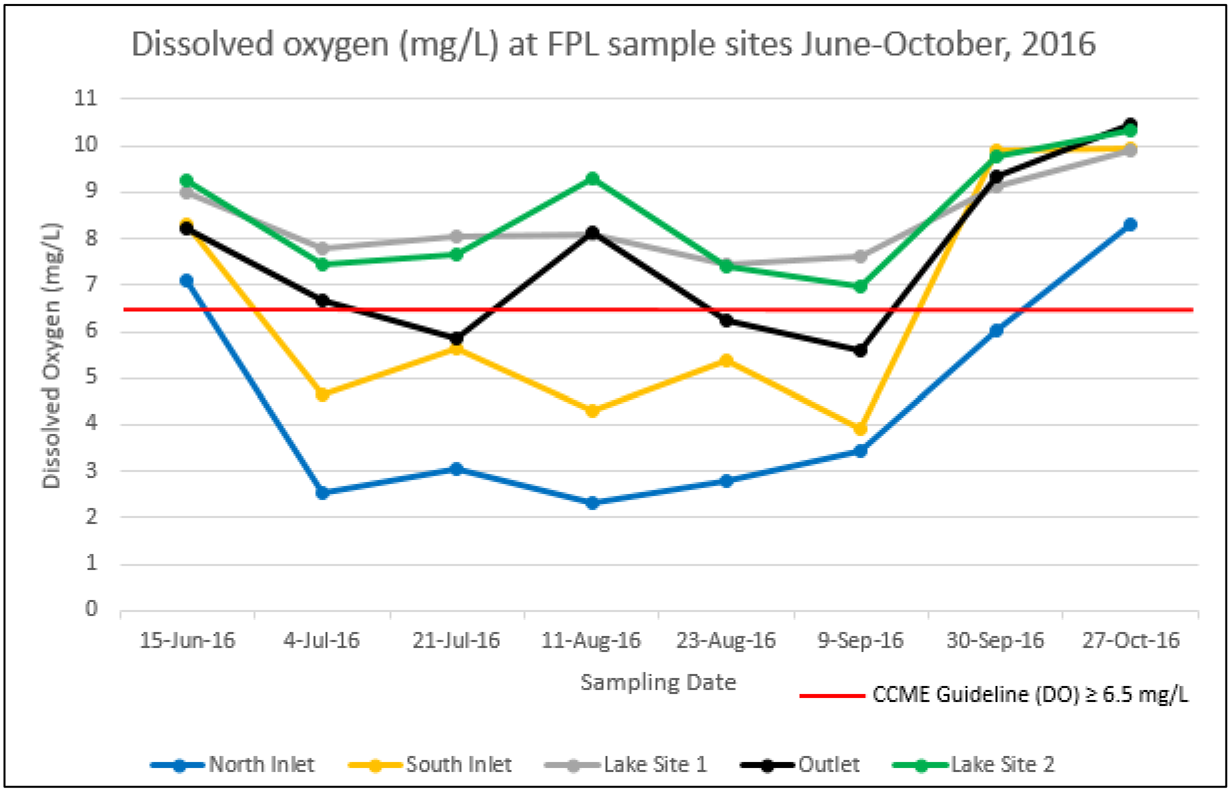

Figure 11 – Dissolved oxygen at five FPL sample sites from June to October, 2016.

2.6 pH

pH is the measurement of the hydrogen-ion concentration in water, and is expressed on a logarithmic scale from 0 to 14. A pH of 0 is the most acidic, a pH of 7 is neutral, and a pH of 14 is the most basic. The CCME Guideline for the Protection of Aquatic Life is within the pH range of 6.5 – 9.0, while the drinking water guideline is 6.5 - 8.5, and the recreational water quality guideline is 5.0 - 9.0 (CCME, 2002). Natural variation in pH occurs as a result of the composition of soils and bedrock, drainage from coniferous forests, and the amount of aquatic vegetation and organic material present. Anthropogenic influences on pH include wastewater discharge, increased atmospheric carbon dioxide, and acid precipitation (B.C. MoE, 1998).

Fish and other aquatic organisms experience negative physiological impacts in acidic water with pH < 5.0. Salmon can withstand a pH as low as 5.0, while trout are slightly hardier and can withstand a pH as low as 4.7. The impact of low pH depends on the proportions of organic and inorganic acids in the water. Organic acids, which leach out of soils and wetlands and give water a tea color, are less harmful to aquatic life than inorganic acids (sulphuric and nitric acids) from acid precipitation (NSSA, 2014).

Acidification of water bodies is a significant issue in Nova Scotia, with the province having lost the greatest percentage of fish habitat, due to acid precipitation, in all of North America. Nova Scotia lies directly downwind of the high emission polluting areas of central Canada and the Midwestern United States. Southwestern Nova Scotia suffers significantly from 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).

All the pH readings fell below the CCME Guideline for the Protection of Aquatic Life at the North Inlet, South Inlet, Outlet, and Lake Site 2, while Lake Site 1 had only two recorded pH values above the guideline (see Fig. 12). The North Inlet site is the most acidic, and both this site and the South Inlet site displayed pH < 5.0 on October 27, 2016. The average and minimum pH values recorded in 2016 have all increased from 2015 (see Table 7).

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

	North Inlet	South Inlet	Lake Site 1	Outlet	Lake Site 2
Mean pH (2015 results)	5.17 (4.56)	5.64 (5.08)	6.39 (6.11)	5.74 (5.45)	6.06 (N/A)
Minimum pH (2015 results)	4.36 (3.88)	4.85 (4.10)	6.08 (5.66)	5.59 (5.04)	5.86 (N/A)

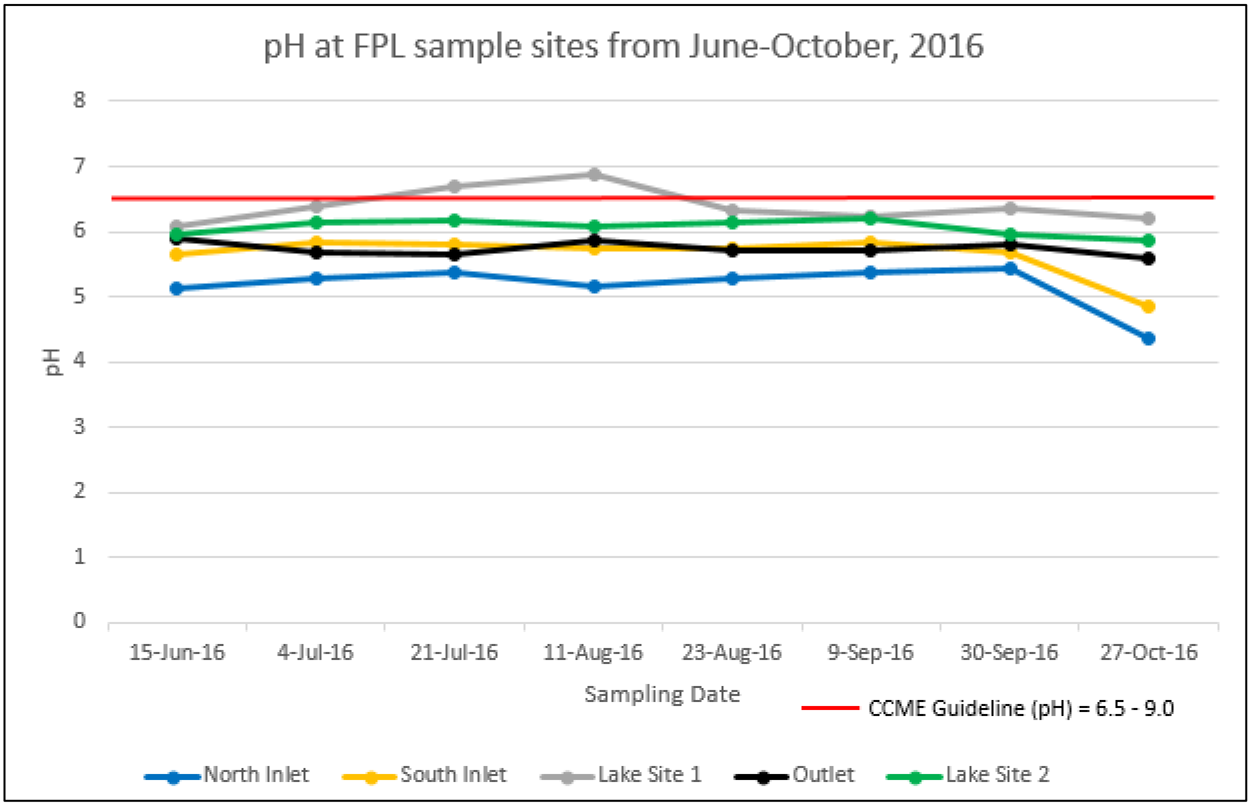

Figure 12 – pH at five FPL sample sites from June to October, 2016.

2.7 Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the amount of dissolved materials in the water column, such as calcium, magnesium, chloride, sodium, sulphate, nitrate, and bicarbonate. Dissolved solids can come from natural sources in the environment as well as from sewage effluent, urban and agricultural run-off, industrial wastewater, and road salts. High TDS will influence the taste, color, and clarity of water, thus restricting its use as drinking water or for irrigation (B.C. MoE, 1998; NSSA, 2014). There are no guidelines for the protection of aquatic life in terms of dissolved solids; however, Health Canada has established a drinking water guideline of ≤ 500 mg/L (Health Canada, 1991). The average TDS for pristine lakes in Nova Scotia is 20 mg/L (Hinch & Underwood, 1985).

Fox Point Lake displayed an average TDS of 29.7 mg/L (at both Lake Site 1 and Lake Site 2) in 2016, compared to an average of 27.5 mg/L in 2015, which falls above the average for pristine N.S. lakes but well below the Health Canada drinking water guideline. Lake Site 1, Lake Site 2, and the Outlet site all displayed very similar TDS levels (see Fig. 13) ranging between 28.6-31.2 mg/L. The North Inlet site displayed the highest TDS concentrations in both 2015 and 2016.

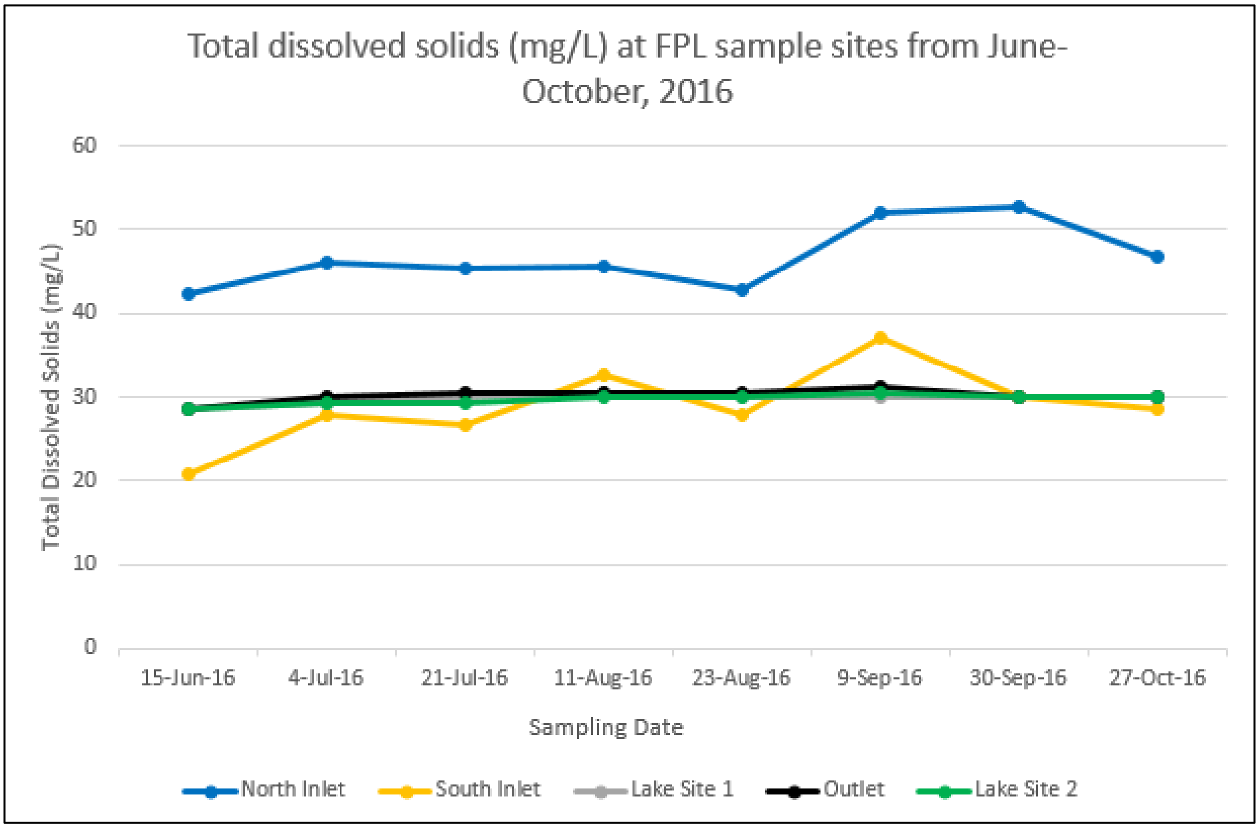

Figure 13 – Total dissolved solids at five FPL sample sites from June to October, 2016.

2.8 Total Suspended Solids

Total suspended solids (TSS) is a measure of the solids suspended in a water column which do not pass through a 45 µm glass fibre filter, such as silt, clay, plankton, microscopic organisms, and fine organic and inorganic particles. TSS is one of the most visible indicators of water quality, as it provides a measure of sedimentation and water clarity. Sources of suspended solids include natural geological erosion, agriculture, forestry, construction, and wastewater discharge. High TSS can cause an increase in surface water temperatures as particles in the water column absorb solar radiation, and a decrease in dissolved oxygen as suspended particles decrease light penetration and rates of photosynthesis. 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 also dependent on background (baseline) levels of suspended solids. When background levels are ≤ 100 mg/L, the maximum allowable increase is 10 mg/L above the background level. When background levels are > 100 mg/L, the maximum allowable increase is 10% of background levels (CCME, 2002).

Table 8 – Total suspended solids (mg/L) results at four FPL sample sites from June to October, 2016.

	North Inlet	South Inlet	Lake Site 1	Outlet
15-June-2016	ND (RDL = 1.0)	1.8	1.4	1.4
21-July-2016	1.2	5.5	ND (RDL = 1.0)	1.4
23-August-2016	ND (RDL = 1.0)	1	1.2	1.2
30-September-2016	2.0	1.8	ND (RDL = 1.0)	2.4
27-October-2016	2.0	1.2	1.2	ND (RDL = 1.0)
ND = Not Detected RDL = Reportable Detection Limit				

TSS results from Lake Site 1 fall below the average background concentration of TSS in Nova Scotia's lakes (3.0 mg/L), as they did in 2015, indicating that suspended solids are not a significant problem in Fox Point Lake and are likely not contributing to increased surface water temperatures or decreased dissolved oxygen conditions (see Table 8). Residents of FPL have stated that the water was clearer during the summer of 2016 than it has been for several years. The highest concentration of TSS was 5.5 mg/L, which occurred at the South Inlet site on July 21, 2016.

2.9 Total Phosphorus

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

Lakes which are not significantly impacted by anthropogenic activities usually display total phosphorus levels < 0.01 mg/L (B.C. MoE, 1998). CCME has not established a guideline for total phosphorus because it is not a 'toxic substance', rather it has secondary effects such as eutrophication and oxygen depletion (CCME, 2004). Provincial guidelines have been established in some parts of Canada, but not in Nova Scotia. Guidelines established by Ontario's Ministry of Environment and Climate Change (MOECC) are widely cited and include separate guidelines for lake and stream habitats. The total phosphorus guideline in lakes is ≤ 0.02 mg/L, and for rivers and streams the guideline is ≤ 0.03 mg/L (MOECC, 1979).

Table 9 – Mean and maximum total phosphorus results from June to October, 2016 with 2015 results for comparison.

	North Inlet	South Inlet	Lake Site 1	Outlet
Mean Total Phosphorus (mg/L) (2015 results)	0.018 (0.020)	0.149 (0.164)	0.007 (0.010)	0.012 (0.008)
Maximum Total Phosphorus (mg/L) (2015 results)	0.031 (0.030)	0.320 (0.240)	0.008 (0.014)	0.027 (0.008)

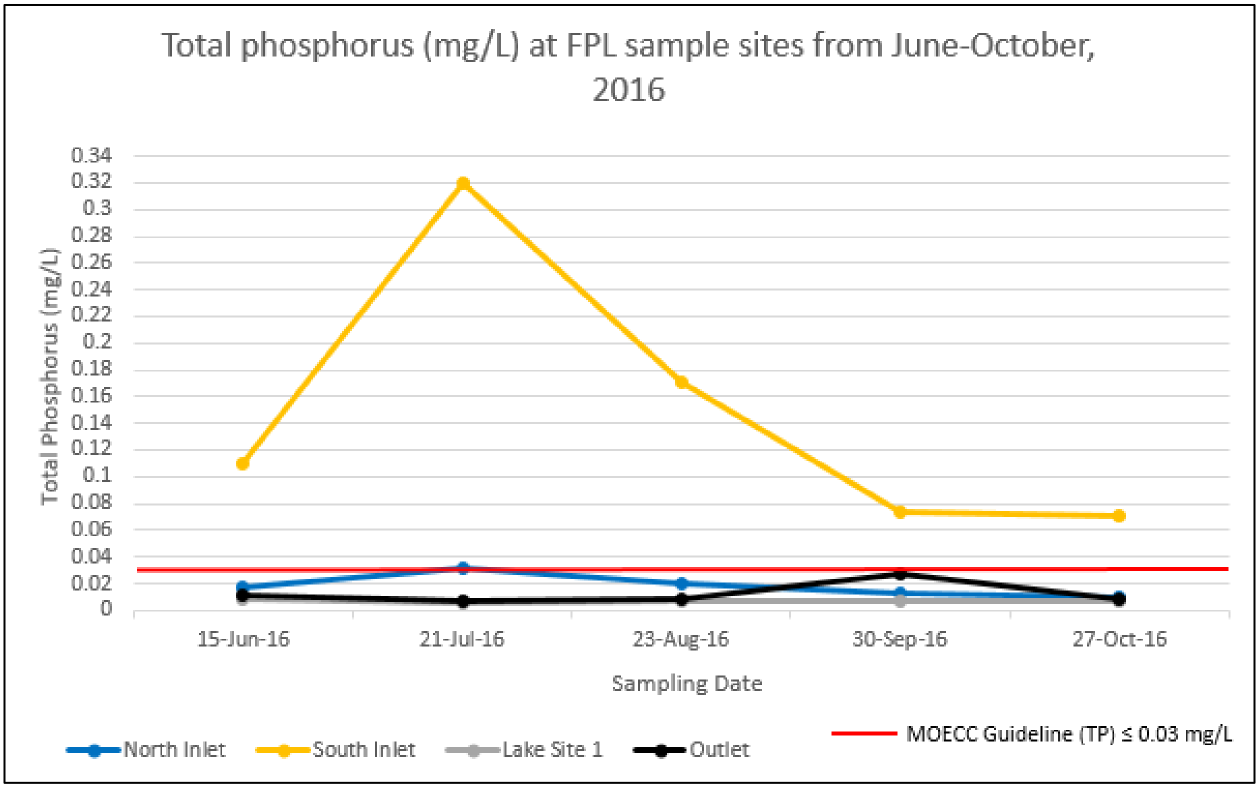

Figure 14 – Total phosphorus at four FPL sample sites from June to October, 2016.

Total phosphorus concentrations at Lake Site 1 remained below the MOECC guideline for lakes (≤ 0.02 mg/L) for the entire monitoring period. The Outlet sample site did not exceed the MOECC guideline for stream habitats (≤0.03 mg/L) and the North Inlet site narrowly exceeded this guideline by 0.001 mg/L on one occasion. The South Inlet site exceeded the stream guideline throughout the entire monitoring period, reaching a maximum total phosphorus concentration of 0.32 mg/L on July 21, 2016 (see Fig. 14).

Total phosphorus results in 2016 are similar to those in 2015, with the South Inlet sample site exceeding guidelines for the entire monitoring period. The average total phosphorus concentration at the South Inlet sample site has decreased from 0.164 mg/L in 2015 to 0.149 mg/L in 2016 (see Table 9).

2.10 Total Nitrogen

Total nitrogen is a measure of all forms of organic and inorganic nitrogen. Nitrogen is an essential nutrient in plant growth, and is usually the limiting factor for the growth of algae and aquatic plants in marine systems. Anthropogenic sources of nitrogen include sewage effluent, urban and agricultural run-off, and industrial effluent (B.C. MoE, 1998). Similar to total phosphorus, the CCME has not established a guideline for total nitrogen because it is not considered a 'toxic substance' and its negative effects on the environment occur through secondary effects (eutrophication and oxygen depletion) (CCME, 2004). Guidelines have been established through extensive research on the fate of nutrients in freshwater systems. Dodds & 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.

Table 10 - Mean and maximum total nitrogen results from June to October, 2016 with 2015 results for comparison.

	North Inlet	South Inlet	Lake Site 1	Outlet
Mean Total Nitrogen (mg/L) (2015 results)	0.481 (0.530)	0.612 (1.22)	0.214 (0.234)	0.236 (0.365)
Maximum Total Nitrogen (mg/L) (2015 results)	0.584 (0.624)	0.763 (2.01)	0.266 (0.266)	0.298 (0.696)

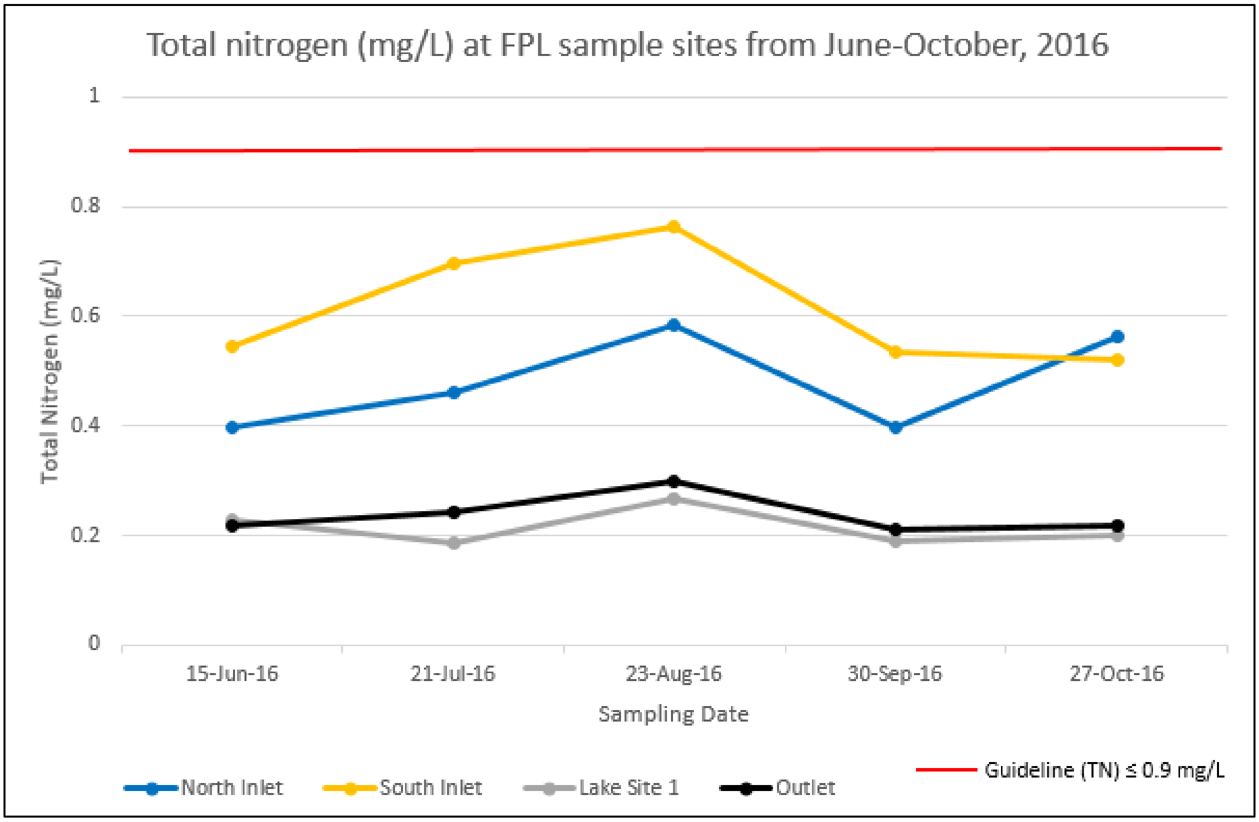

Figure 15 – Total nitrogen at four FPL sample sites from June to October, 2016.

In 2015, the South Inlet was the only sample site to exceed the guideline for total nitrogen (see Fig. 15). In 2016, there were no exceedances of the guideline and the average total nitrogen concentrations decreased at all four sample sites. The South Inlet site displayed an average concentration of 0.612 mg/L and a maximum concentration of 0.763 mg/L in 2016, compared to an average of 1.221 mg/L and maximum of 2.01 mg/L in 2015 (see Table 10).

2.11 Fecal Coliform

Fecal coliform bacteria are found in the waste of warm-blooded animals and are used as an indicator of fecal contamination in the environment. There are hundreds of types of disease-causing bacteria, viruses, parasites and other harmful microorganisms, making it impractical to test for all of them. Non-pathogenic fecal bacteria species, which are easier and more affordable to test for, are used as 'indicators' of the possible presence of more harmful disease-causing organisms. E. coli (*Escherichia coli*) is the most appropriate indicator of fecal contamination in freshwater environments. Most fecal coliform bacteria are comprised of E.

coli and will be used as a proxy measurement for E. coli, to be compared to the Health Canada guidelines for E. coli.

Health Canada has developed several comprehensive guidelines for the protection of human health. Separate guidelines have been developed to protect human health during various forms of water recreation:

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)

Sources of fecal contamination include stormwater run-off, malfunctioning septic systems, livestock, wildlife, domestic animals, and agricultural run-off. The abundance and persistence of fecal bacteria in freshwater systems can be influenced by several factors, which means that bacteria sampling results can be highly variable. Exposure to water which is contaminated with fecal bacteria poses a significant risk to public health and can cause illnesses such as gastroenteritis, hepatitis, and respiratory infections (B.C. MoE, 1998; Health Canada, 2012).

The Health Canada guideline for primary contact is ≤ 400 cfu/100 mL, and the secondary contact guideline is ≤ 1000 cfu/100 mL. The results for all four FPL sample sites fell well below both the primary and secondary contact guidelines (see Table 11).

Table 11 – Fecal coliform (cfu/100 mL) results at four FPL sample sites from June to October, 2016.

	North Inlet	South Inlet	Lake Site 1	Outlet
15-June-2016	20	10	ND (RDL = 10)	10
21-July-2016	60	70	ND (RDL = 10)	10
23-August-2016	20	30	10	10
30-September-2016	20	50	ND (RDL = 10)	10
27-October-2016	ND (RDL = 10)	ND (RDL = 10)	ND (RDL = 10)	ND (RDL = 10)
ND = Not Detected RDL = Reportable Detection Limit				

2.12 Rainfall and Water Level

Rainfall amount and the water level of Fox Point Lake were monitored daily from June 22 to October 21, 2016 using a rainfall gauge and a staff gauge. This provides valuable baseline data to gain insight into the natural variability of this lake and its catchment, as well as identify any significant changes which may be attributable to anthropogenic activities such as land level alterations, watercourse and wetland alterations, irrigation water usage, or vegetation removal (Fisheries and Oceans Canada, 2006).

The total rainfall amount from June 22 to October 21, 2016 equalled 163 mm, compared to a total rainfall amount of 318 mm over the same time period in 2015. The water level of the lake fluctuated between 0.63 m – 0.78 m in 2016, similar to 2015 levels which fluctuated between 0.61 m – 0.80 m (see Fig. 16).

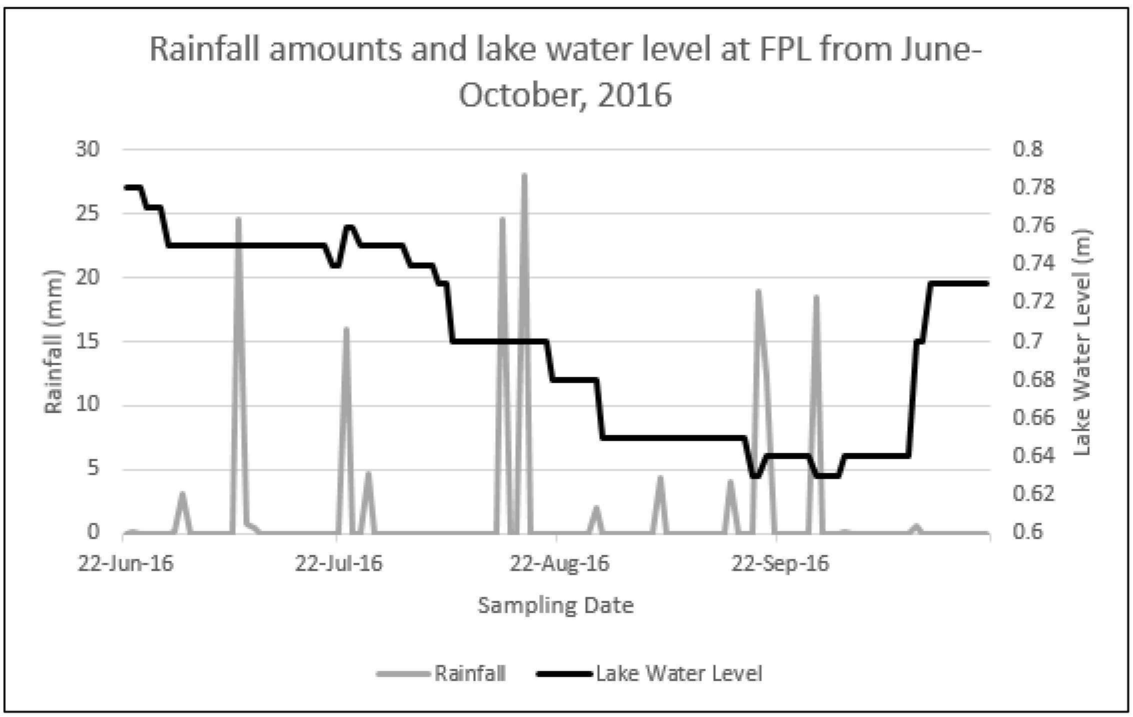

Figure 16 – Rainfall and water level results at FPL from June 22, 2016 to October 21, 2016.

2.13 Stream Discharge

Water velocity was monitored at the North Inlet, South Inlet, and Outlet sample sites on a bi-weekly basis, along with water depths and stream widths, to determine stream discharge rates. The discharge rate of a stream is a product of its velocity times the depth and width (crosssectional area) of the water flowing in that stream. Anthropogenic activities which effect the hydrologic conditions in a catchment area may result in changes in stream discharge rates (Meals & Dressing, 2008).

The average discharge rates in 2016 are lower than the average rates in 2015 for all three stream sites. This may be a reflection of the different rainfall amounts recorded during the 2015 and 2016 monitoring periods (2015 = 318 mm; 2016 = 163 mm). The South Inlet stream displays the lowest discharge rate and the least variability (see Fig. 17).

Table 12 – Mean and range of stream discharge rates in FPL outlet and inlet streams from June to October, 2016.

	North Inlet	South Inlet	Outlet
Mean Stream Discharge (m^3/s) (2015 results)	0.213 (0.428)	0.027 (0.036)	0.178 (0.235)
Range of Stream Discharge (m^3/s) (2015 results)	0.161 – 0.271 (0.202 – 0.701)	0.012 – 0.035 (0.021 – 0.058)	0.032 – 0.540 (0.052 – 0.749)

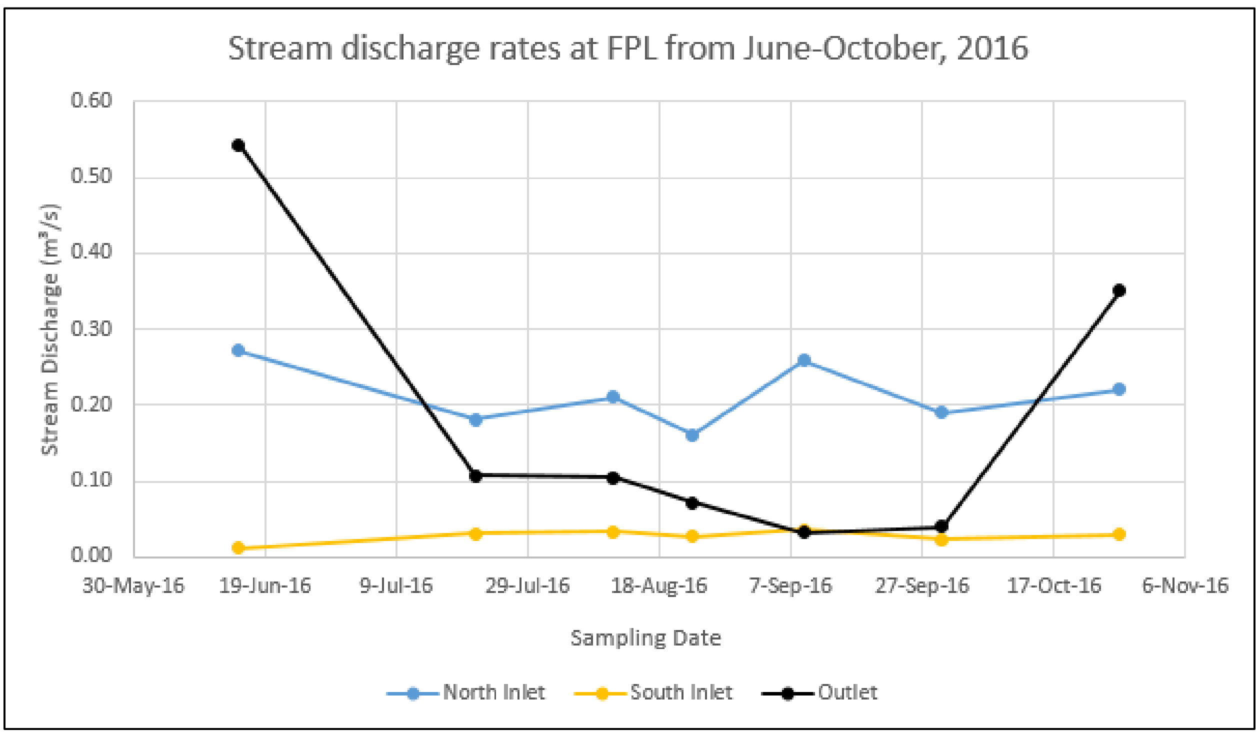

Figure 17 – Stream discharge rates in the outlet and inlet streams at FPL from June to October, 2016.

3.0 Discussion

Fox Point Lake did not experience any siltation run-off events during the 2016 monitoring season, and residents of the lake have stated that the water clarity was better than they have seen in several years. Total suspended solids results have increased slightly from 2015 results in the lake; however, they continue to fall below the average TSS concentration in Nova Scotia lakes, and Secchi disk depths (another measure of water clarity) have improved since 2015.

An algal bloom occurred in the lake on June 22, 2016. Water sample analysis confirmed the presence of the cyanobacterial toxin microcystin-LR. The concentration of this toxin did not exceed drinking water guidelines. Cyanobacterial blooms tend to recur in the same waterbody year after year, and it is likely that an algal bloom occurred during the summer of 2015, as reported by FPL residents (samples were not taken to confirm the presence of toxins) (WHO, 2003).

Surface water temperatures in the lake and the outlet stream exceeded 20°C from July to early September, which causes stress for fish and other aquatic organisms. Water temperatures in the North and South Inlet streams remained cooler throughout the summer, indicating that these streams may be providing important thermal refugia for fish populations in the lake. While surface water temperatures were high at the Outlet sample site, this stream does have deep, cold-water pools as well as better dissolved oxygen conditions compared to the North and South Inlet sample sites; therefore, the Outlet stream is likely providing important summer habitat for fish as well. It is important to maintain the health of these inlet and outlet streams so they can continue to support aquatic life and to prevent excessive nutrient loading and sedimentation from entering the lake from these streams.

Similar to 2015 results, exceedances of nutrient (phosphorus and nitrogen) guidelines were only observed at the South Inlet sample site. This site exceeded the guideline for total phosphorus throughout the entire monitoring period, although the average concentration did decrease slightly from 2015. Total nitrogen concentrations have also decreased in the South Inlet, with two guideline exceedances occurring at this site in 2015 and no exceedances in 2016. With few natural sources in the environment, it is likely that the excessive phosphorus loading in this stream is due to anthropogenic activities (B.C. MoE, 1998). The poor water quality in this stream warrants further investigation.

An analysis of trophic state has confirmed the results from 2015, indicating that Fox Point Lake is oligotrophic and approaching mesotrophic, which means it has low to moderate biological productivity. Increased biological productivity could shift the trophic state to mesotrophic; highlighting the importance of managing anthropogenic activities within the drainage basin to prevent cultural eutrophication.

Thermal stratification was monitored at two locations in the lake in 2016. The lake was thermally stratified from June to October and both monitoring sites displayed severe dissolved oxygen depletion in the bottom layer of the lake (hypolimnion), with oxygen concentrations dropping to < 3 mg/L. If biological productivity increases in Fox Point Lake, oxygen conditions in the hypolimnion may become hypoxic (< 2 mg/L) or anoxic (< 1 mg/L) (USGS, 2014), which causes a shift in microbial decomposition from aerobic bacteria to anaerobic bacteria, which decompose organic material 20 times slower and release gases that are toxic to aquatic organisms. Anoxic conditions can also lead to the release of phosphorus and metals from bottom sediments through oxidation reduction reactions (Hayes et al., 1985). Bottom sediments of Fox Point Lake may be holding a significant amount of phosphorus, given the number of run-off siltation events in recent years. If the bottom of the lake becomes anoxic, internal phosphorus loading could lead to algal blooms and increased aquatic plant growth in the lake (Brylinsky, 2004).

4.0 Recommendations

The monitoring program at Fox Point Lake should continue. If biological productivity increases in the lake, due to excessive external or internal nutrient loading, the lake is at risk of increased algal blooms, anoxic conditions, and a decrease in its ability to support aquatic life. The South Inlet stream has exhibited poor water quality, it is a source of excessive nutrient loading for the lake, and it is likely suffering from anthropogenic impacts.

- Increase monitoring efforts in the South Inlet stream. A detailed stream assessment should be conducted along the entire length of this stream to identify sources of habitat degradation, pollution, and nutrient inputs. Pending the results of a stream health assessment, a second sampling site may be recommended further upstream towards the headwaters of this stream.
- Residents of FPL should continue to visually monitor the lake for algal blooms. Information on algal blooms, including how to identify a bloom and what precautions to take during a bloom, should be distributed to all residents of the lake.

- Members of the volunteer group should continue to be equipped with sampling materials to collect water samples in the event of an algal bloom. Follow-up sampling should occur after a bloom has dissipated to confirm that cyanobacterial toxins are gone before normal activity resumes in the lake.
- All current sampling sites should remain as part of the monitoring program. Monitoring and sampling frequencies should not be changed, with grab samples being collected for laboratory analysis at a minimum of 5-6 times throughout the monitoring period.

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