Fox Point Lake

Water Quality Monitoring Report

Prepared for

Municipality of the District of Chester

Water Quality Monitoring Committee (Mill Cove)

By

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Summary

This report provides an analysis of results from the 2015 Fox Point Lake Monitoring Program. The Municipality of the District of Chester appointed a Water Quality Monitoring Committee, in 2014, in response to concerns about the impacts of the Aspotogan Ridge development project on the water quality of Fox Point Lake. The Fox Point Lake Water Quality Monitoring Program was developed to establish the baseline water quality conditions of Fox Point Lake and track any further impacts throughout the course of the development project. The initial monitoring season ran from May 26, 2015 to October 23, 2015 and was carried out by a small dedicated group of Fox Point Lake residents, with the assistance of the Coastal Action Project Manager.

The results of this initial monitoring season have provided insights into the biological productivity, trophic state, and dissolved oxygen conditions of the lake, as well as the water quality conditions within the outlet stream and the two inlet streams. Recommendations have been made for the continuation of this monitoring program in 2016.

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1. 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 Aspotogan Ridge development project in Mill Cove. Aspotogan Ridge is 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 entering 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 in order 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. 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.

The Fox Point Lake Water Quality Monitoring Program outlines the environmental conditions of the Fox Point Lake drainage basin, the potential environmental impacts of the Aspotogan Ridge development project, basic concepts of lake biology and water quality monitoring, and the detailed field procedures to be used by a group of volunteer citizens at Fox Point Lake.

1.2 Project Goals and Objectives

The Fox Point Lake Water Quality Monitoring Program clearly states a number of goals and objectives that will provide guidance and direction for the Committee and volunteers throughout the initial monitoring period and into subsequent monitoring years. Objectives may be added or modified to reflect any changes to the Aspotogan Ridge development project or the introduction of additional environmental impacts within the Fox Point Lake drainage basin.

The goals of the Program are as follows:

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.*

The objectives of the Program are as follows:

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.

1.3 Fox Point Lake 2015 Monitoring Program

The 2015 monitoring season at Fox Point Lake ran from May 26, 2015 to October 23, 2015 with a total of ten sampling days, four of which included the collection of water samples for laboratory analysis. Five residents of the Fox Point Lake area took part in the initial monitoring season. The volunteer group was provided with a Field Procedures and Sampling Methods document and took part in an online training program, two field training days on May 26th and June 14th, as well as a refresher training day on July 30th. Water quality monitoring was conducted at the four sampling sites identified in the Fox Point Lake Monitoring Program (see Fig. 1.0) as well as at the location of the rainfall and water level monitoring station (see Table 1.0).

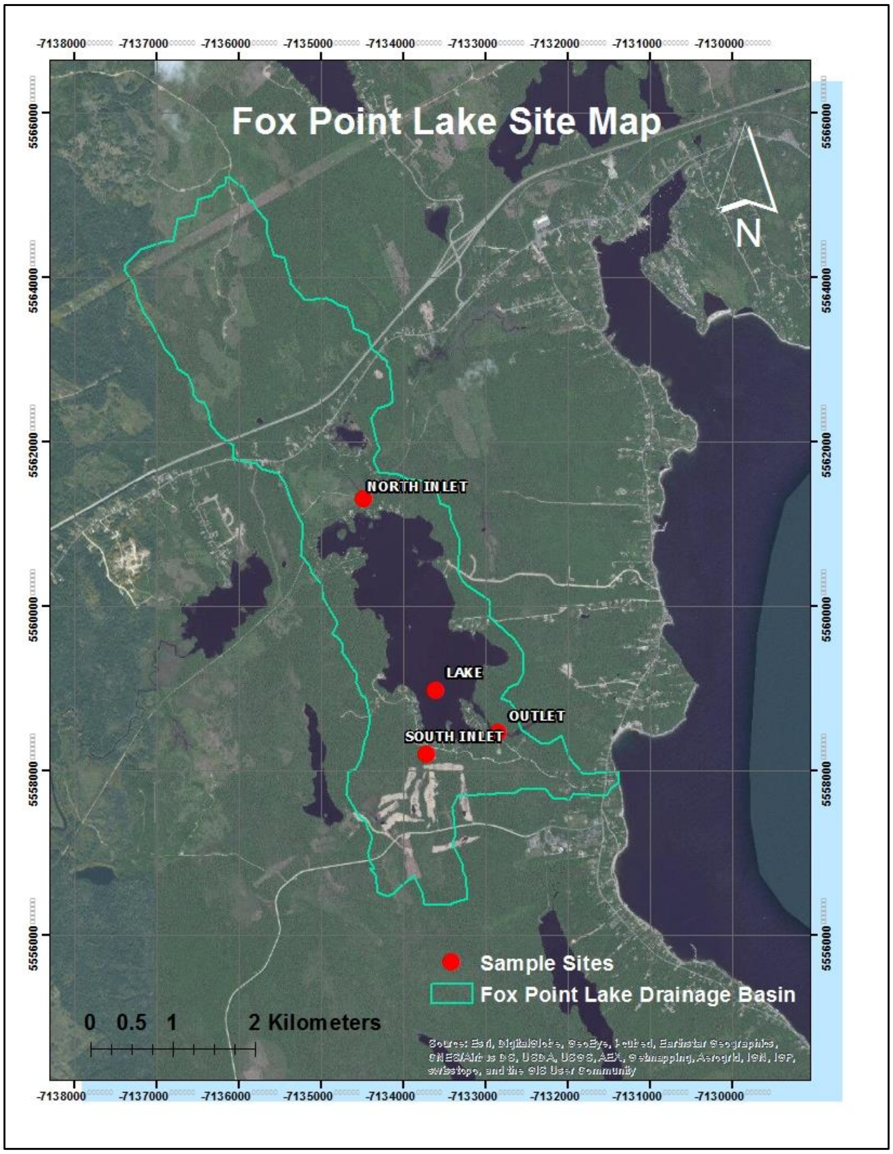

Figure 1.0 – Fox Point Lake drainage basin and sample sites

Table 1.0 – Coordinates of Fox Point Lake sample sites

Sample Site	**Sample Site Coordinates**
North Inlet	N 44°36’58.27” W 64°05’24.52”
South Inlet	N 44°35’47.00” W 64°04’60.00”
Lake	N 44°36’04.86” W 64°04.56.28”
Outlet	N 44°35’52.92” W 64°04.31.99”
Rainfall Gauge / Staff Gauge	N 44°35’56.62” W 64°05’02.11”

The rainfall gauge and water level staff gauge were installed on the property of one of the volunteers on June 19th. This individual lives at Fox Point Lake year-round and was able to collect daily recordings of rainfall and water level throughout the monitoring season. The staff gauge, installed on a dock footing, was positioned with the bottom of the gauge resting on the bottom of the lake. Once installed, the elevation of the gauge was established, in reference to nearby permanent objects, by a qualified surveyor. The surveyor is a resident of Fox Point Lake and provided his services at no charge. The staff gauge has been removed for the winter to avoid ice damage and will require re-installation, at the correct elevation, prior to the 2016 monitoring season. The local surveyor will likely be available to assist during this installation to ensure the gauge is set to the exact same elevation as the 2015 monitoring season to allow consistency and comparability of water level data from one year to the next.

As anticipated, there were some necessary adjustments to be made and additional training and guidance required throughout the first few weeks of the monitoring season. Gaps in data collection were identified after the volunteer group conducted two sampling days on their own, which meant that stream discharge rates could not be calculated for those sampling days. The refresher training day was provided in order to address these issues and ensure that all members of the volunteer group were clear on all sampling procedures.

The location of the North Inlet sample site posed a number of challenges throughout the monitoring season. The construction of a beaver dam and the depth of water at this site restricted access and made several sampling procedures difficult to perform. The water depth was often >1m and the channel was over 8 m wide, which meant that the velocity and water depth data had to be collected from a small boat. Beavers began constructing a dam directly under the Fox

Brook Bridge in June, which blocked the entire width of the stream by July and prevented the volunteers from accessing the sample site by boat. The dam was removed by local residents in August, however, water levels remained high.

On a day in early summer (date unknown), an unknown substance created a film with a strong odor over the water surface in the southwest cove of Fox Point Lake. A sample was collected in a plastic jar by a member of the volunteer group. Unfortunately, this sample could not be analyzed at a laboratory because it was not collected in a lab-certified sterilized jar and was not refrigerated. Following this event, a sample jar and cooler were requested from Maxxam Analytics and were kept at the volunteer's home. This allowed the volunteer group to be fully prepared to respond to an algal bloom by collecting a water sample before a bloom dissipates and delivering the sample to the laboratory within the required timeframe. This was an isolated event, which did not reoccur during the monitoring season, and therefore, this sampling jar was not used.

2. Monitoring Results

All of the data collected during the 2015 monitoring season was retrieved by the Coastal Action Project Manager and entered into a database. Hard copies of the field data sheets and laboratory results will be consolidated into a folder and given to the Water Quality Monitoring Committee, along with a digital copy of the 2015 monitoring season database.

Water quality parameters have been analyzed individually and compared to established guidelines that are designated for various forms of water usage, such as the protection of aquatic life, drinking water, or irrigation purposes. The Canadian Council of Ministers of the Environment (CCME) provides guidelines for many parameters in the Canadian Water Quality Guidelines (CCME, 2002). In addition, Health Canada provides guidelines based on drinking and recreational uses of water in Guidelines for Canadian Recreational Water Quality (Health Canada, 2012).

2.1 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, over time, 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 densities of plant biomass. Eutrophication is the natural, long-term process of lakes progressing from lower trophic states to higher ones over time, while cultural eutrophication refers to the accelerated trend towards higher trophic levels due to anthropogenic impacts within the drainage basin of a lake. Symptoms of cultural eutrophication include increased nutrient loading, increased algal and rooted aquatic plant growth, and low dissolved oxygen conditions (Brown & Simpson, 1998; Brylinski, 2004).

Determining the trophic state of a lake involves the analysis of key variables: total phosphorus, total nitrogen, chlorophyll *a*, and Secchi disk depth. The results obtained for these water quality parameters from the Lake sample site during the 2015 monitoring season (see Table 2.0) have been used to classify the current trophic state of Fox Point Lake.

Table 2.0 – Key parameter results for determining the trophic state of Fox Point Lake

	Total Phosphorus (µg/L)	**Total Nitrogen (µg/L)**	**Chlorophyll *a* (µg/L)**	**Secchi disk depth (m)**
Mean	9.8	233	1.36	2.09
Range	6-14	218-266	0.77-3.41	1.62-2.75

Table 3.0 – Parameter ranges associated with trophic state 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.

By comparing the results from Fox Point Lake to a set of parameter ranges and means (see Table 3.0) established by Vollenweider & Kerekes (1982), the trophic state of Fox Point Lake is predominantly oligotrophic. The ranges provided for total phosphorus, total nitrogen, and chlorophyll *a*, suggest that the lake is oligotrophic, while the results of Secchi disk depth indicate a eutrophic state. Given this discrepancy, the results from Fox Point Lake have been further analyzed, using the Carlson Trophic State Index (TSI), to assign a numerical score (Carlson, 1977). 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) = 49**
Chlorophyll *a*:	TSI(CHL) = 9.81 ln(CHL) + 30.6	**TSI(CHL) = 34**
Total Phosphorus:	TSI(TP) = 14.42 ln(TP) + 4.15	**TSI(TP) = 37**
(ln = natural log)		

Figure 2.0 – Trophic State Index calculations for Fox Point Lake in 2015

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. The results for Fox Point Lake using the TSI, again, indicate an oligotrophic state, suggesting that the lake has fairly low biological productivity (see Fig. 2.0). This classification, however, is based on the assumption that algal biomass should be considered the key parameter in defining the water quality of Fox Point Lake. Shallow lakes, such as Fox Point Lake, often suffer more from the overgrowth of rooted aquatic plants rather than algae, in which case the TSI for chlorophyll *a* may not be the most appropriate indicator (Brown & Simpson, 1998). In addition, the TSI value for Secchi disk depth (TSI = 49) suggests a nearly eutrophic state. Secchi disk depth is not only influenced by algal biomass, but can be effected by the presence of sediment, silt, and other dissolved materials in the water column (NSSA, 2014; EPA 2002). Given the fact that sedimentation issues have been documented on numerous occasions in Fox Point Lake, the TSI for Secchi disk depth should also be considered a key indicator of water quality in Fox Point Lake.

This analysis of trophic state has established an important baseline from which to monitor any changes in the water quality of Fox Point Lake over the next several years. While there are no absolutes in the classification of trophic state, the TSI values for total phosphorus, chlorophyll *a*, and Secchi disk depth provide a 'grade' which can be re-assessed each year and provide insight into potential causes of water quality degradation.

2.2 Thermal Stratification – Temperature / Dissolved Oxygen Depth Profiles

Thermal stratification of a lake involves the separation of the water column into layers of different densities based on changing water temperatures (see Fig. 3.0). This process begins with spring turnover, following ice melt, when the water temperature of a lake is consistent from top to bottom (see Fig. 4.0). Wind circulation draws dissolved oxygen to the bottom waters and pulls nutrients 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

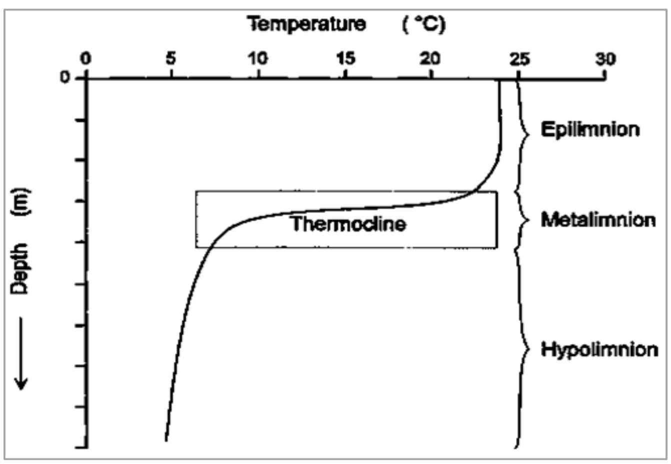

Figure 3.0 – Thermal stratification of the water column, showing the three layers of different density (Chowdhury et. al., 2014)

layer, where light is able to penetrate and wind action circulates the water. The metalimnion, or thermocline, represents the middle layer where temperature changes rapidly with depth. The bottom layer, or hypolimnion, holds the coldest, densest water.

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 as a result of dead organic matter sinking to the lake bottom and decomposing. Bacteria and other decomposers may use up the available oxygen as they consume this organic debris, leading to extremely low dissolved oxygen levels in the hypolimnion and a decreased ability to support aquatic life (Brylinski, 2004).

Low dissolved oxygen conditions have significant physiological and behavioural effects on aquatic organisms. The CCME Water Quality Guideline for the Protection of Aquatic Life for dissolved oxygen is ≥ 6.5 mg/L for cold 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.

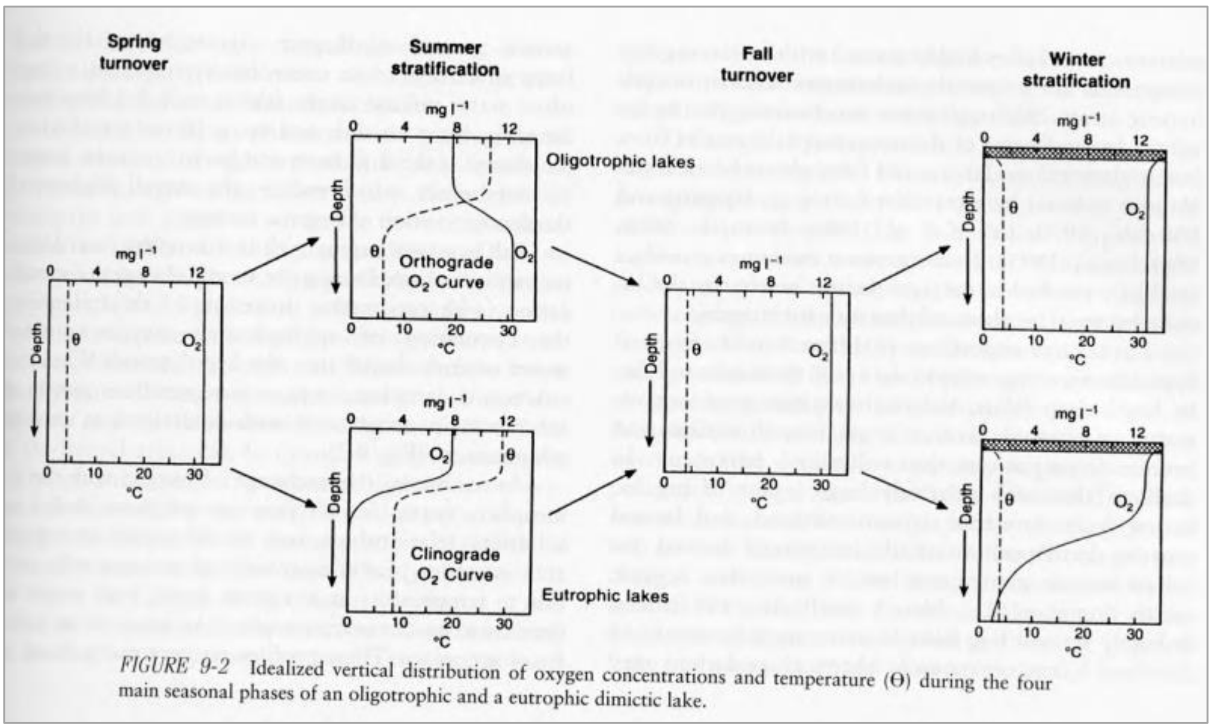

Figure 4.0 – Depth profile representation of thermal stratification in oligotrophic and eutrophic lakes (Wetzel, 2001)

In order to monitor thermal stratification and dissolved oxygen conditions in Fox Point Lake, depth profiles were conducted on a bi-weekly basis over the deepest point in the lake (Lake sample site). Both water temperature and dissolved oxygen data were collected at 1 m intervals from the water surface to the bottom of the lake. A graphical representation of this data is useful for identifying the depth of the thermocline, and understanding the dissolved oxygen conditions throughout the water column over the summer period. Depth profiles also provide useful insight into the trophic state of a lake (EPA, 2002).

Figure 5.0 displays the four types of dissolved oxygen profiles that can develop during thermal stratification, depending on the level of biological productivity (trophic state) of a lake. 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).

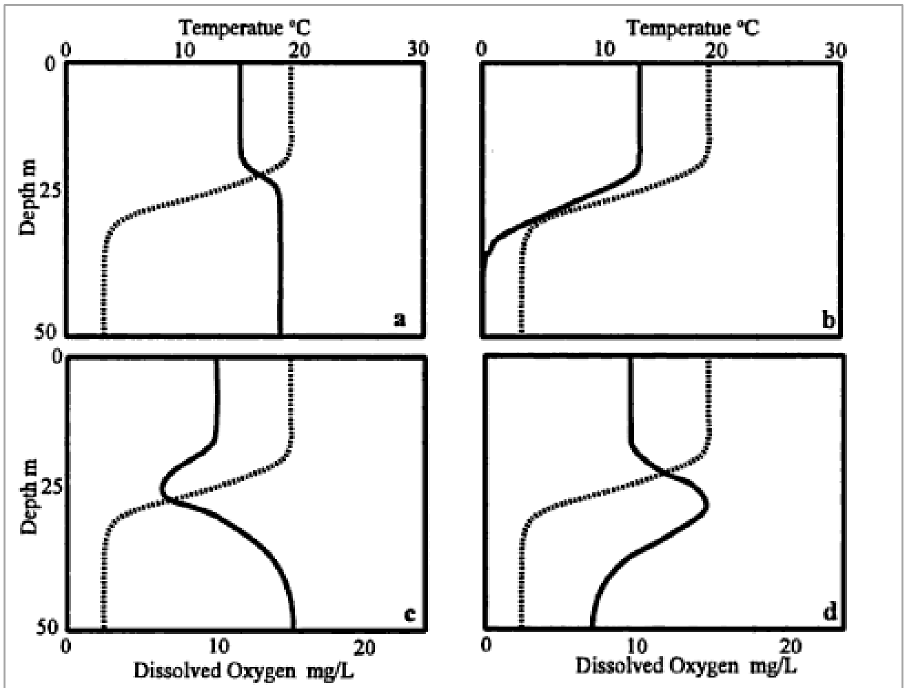

Figure 5.2. Common summer vertical oxygen profiles in lakes. (a) Orthograde. (b) Clinograde. (c) Negative heterograde. (d) Positive heterograde.

Figure 5.0 – Types of dissolved oxygen profiles found in lakes (Mackie, 2004)

A total of ten depth profiles were conducted in Fox Point Lake (see Fig. 6.0). On two occasions, May 26 and July 30, the profiles were done with a 10 m YSI water meter cable, rather than the 30 m cable which was normally used. The water temperature profile indicates that thermal stratification was established in the lake by early June, with an initial thermocline depth of 8-10 m. As surface water reaches peak temperatures in July and August, the depth of the thermocline shifts to 6-8 m, which increases the proportion of the low-oxygen hypolimnion layer in the water column. As surface temperatures begin to drop in October, the thermocline begins to sink to lower depths as the lake approaches fall turnover. Based on the results, the thermal stratification in Fox Point Lake did not break down at any point, which means that no additional dissolved oxygen would have reached the hypolimnion throughout the summer.

The dissolved oxygen profile displays fairly consistent, but gradually decreasing, concentrations of dissolved oxygen through the water column until mid-July. The dissolved oxygen begins to display negative heterograde profiles on July 30, Aug. 17, Aug. 30, and Sept. 14. These results indicate that decomposing organisms were caught at the density boundary between the metalimnion and hypolimnion and were consuming dissolved oxygen as they fed on organic material. During this time, dissolved oxygen levels were consistently below the CCME Guideline for Protection of Aquatic Life (≥ 6.5 mg/L) at depths > 4-6 m. On Oct. 5 and Oct. 23, the dissolved oxygen displays a clinograde profile, which indicates that Fox Point Lake is either mesotrophic or eutrophic.

The depth profiles conducted at Fox Point Lake in 2015 suggest a trophic state of mesotrophic or eutrophic. These results seem to contradict the Trophic State Index values calculated for chlorophyll *a*, total phosphorus, and Secchi disk depth. It is possible that the depth profiles provide a more accurate prediction of trophic state than the TSI values, given that water samples were collected only four times during the monitoring period, while depth profiles were conducted ten times.

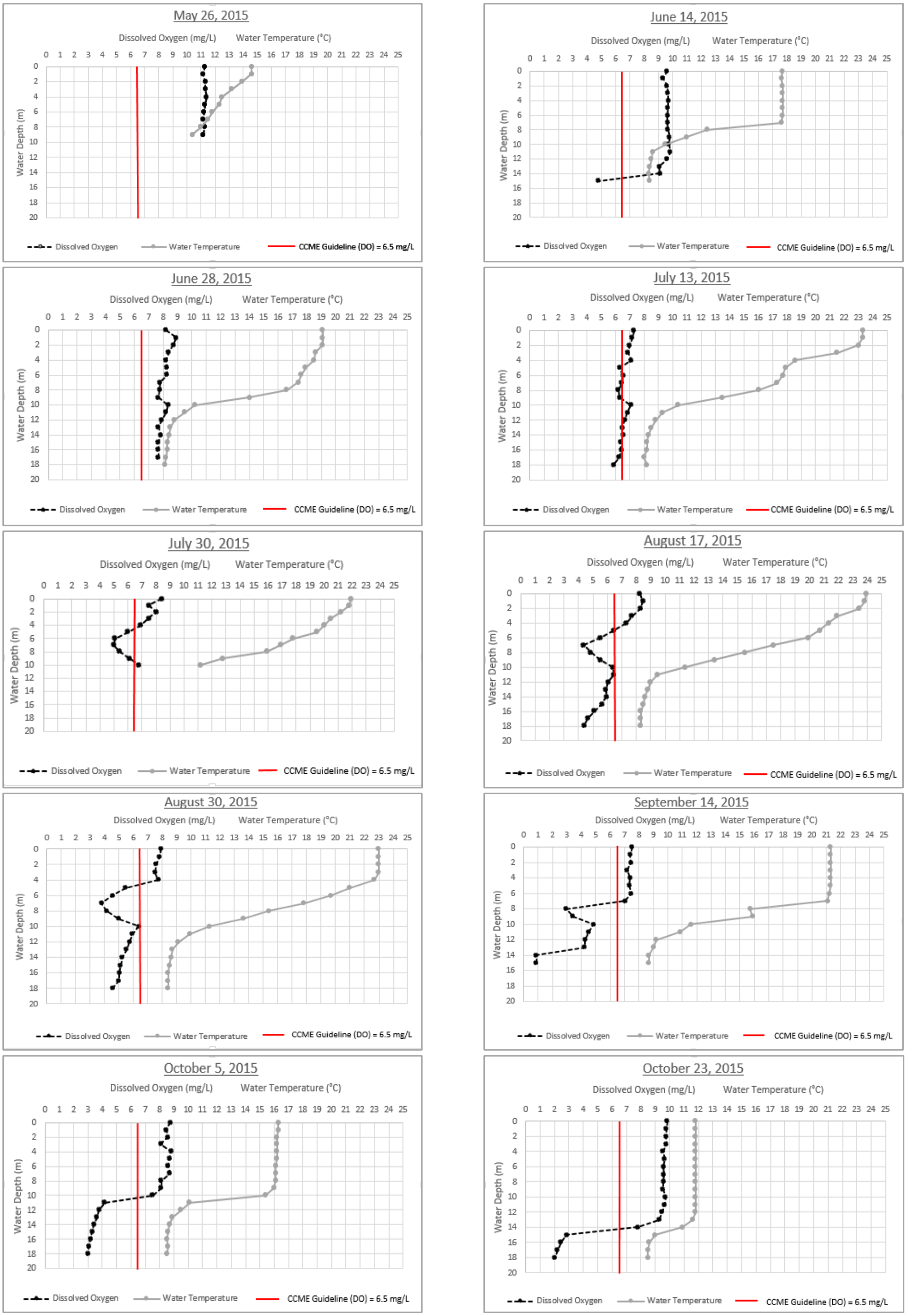

Figure 6.0 – Water temperature/dissolved oxygen depth profiles from Fox Point Lake in 2015

2.3 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. Water temperature effects many physical, chemical, and biological factors in an aquatic system. Dissolved oxygen is strongly influenced by temperature, as cold water is capable of holding more oxygen than warmer water. Aquatic organisms have varying levels of sensitivity to temperature as well as optimal temperature ranges, in order to maintain health and productivity. 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 when 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).

Table 4.0 – Mean and maximum water temperatures for the Fox Point Lake sample sites

	North Inlet	South Inlet	Lake	Outlet
Mean Water Temperature (°C)	14.5	14.4	18.9	17.7
Maximum Water Temperature (°C)	18.7	17.7	23.9	22.9

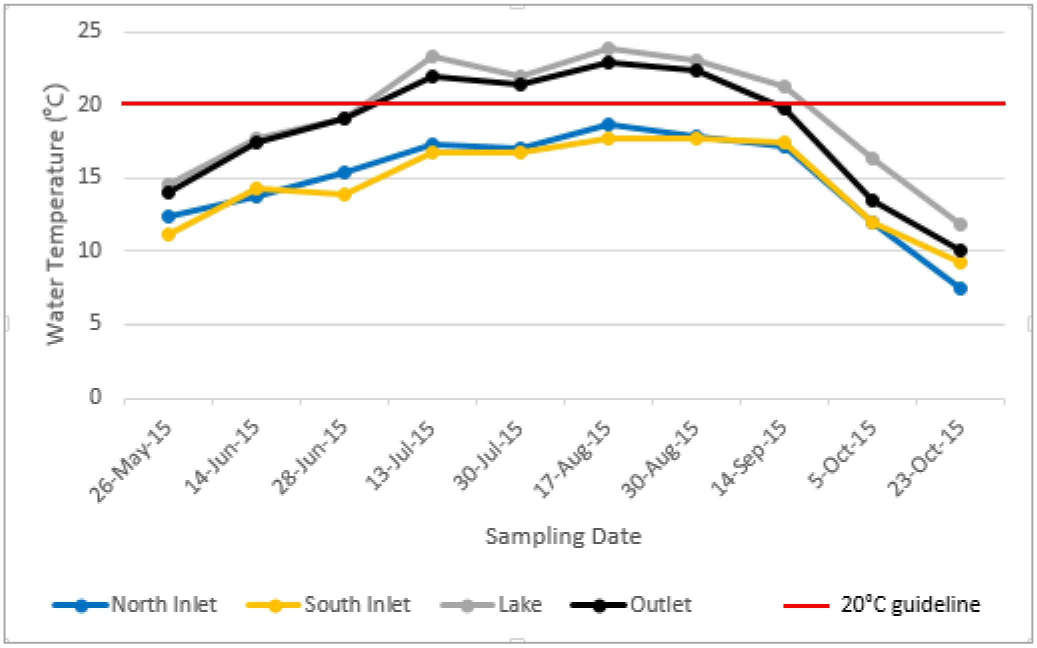

Figure 7.0 – Water temperature data for the Fox Point Lake sample sites in 2015

Figure 7.0 displays the water temperature data collected at the four Fox Point Lake sample sites throughout the 2015 monitoring season. All four sites show a similar warming and cooling trend from spring, through summer, and into the fall season. The Lake and Outlet sample sites exceeded the 20°C threshold consistently throughout the months of July and August, while the North Inlet and South Inlet sample sites did not exceed 20°C at any point during the monitoring season (see Table 4.0). These results indicate that fish may have experienced physiological stress, during July and August, in certain parts of the outlet stream and in the surface waters (epilimnion) of the lake, causing them to seek out cooler habitats such as deep-water pools within the outlet stream, deeper water in the lake (hypolimnion), or the cooler waters of both the north and south inlet streams. These results highlight the fact that the north and south inlet streams provide important thermal refugia habitat for fish during times of high water temperature in the lake. Maintaining the health of these streams is critical for the fish populations of Fox Point Lake, particularly the ecosystem functions which regulate in-stream water temperature such as riparian vegetation, groundwater discharge, and natural channelization. Impacts of development such as the removal of riparian vegetation, re-direction of groundwater sources, sedimentation, or over-widening of a watercourse would degrade stream health and lead to higher in-stream temperatures (DFO, 2006).

2.4 Dissolved Oxygen

Dissolved oxygen is one of the most important indicators of water quality and aquatic ecosystem health. Sources of dissolved oxygen in water include wind and wave action, photosynthesis by aquatic vegetation, rainfall, and cascading water. The amount of dissolved oxygen 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).

Dissolved oxygen is measured and reported in two ways, as a concentration in mg/L and as percent saturation (% SAT). Percent saturation describes the amount of dissolved oxygen in water relative to the maximum amount of oxygen that could be dissolved in that amount of water. When water can no longer dissolve any additional oxygen, it has reached its saturation point (100% SAT), however, water can become supersaturated (> 100% SAT) in very turbulent conditions or during periods of high photosynthetic rates (see Fig. 8.0). 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).

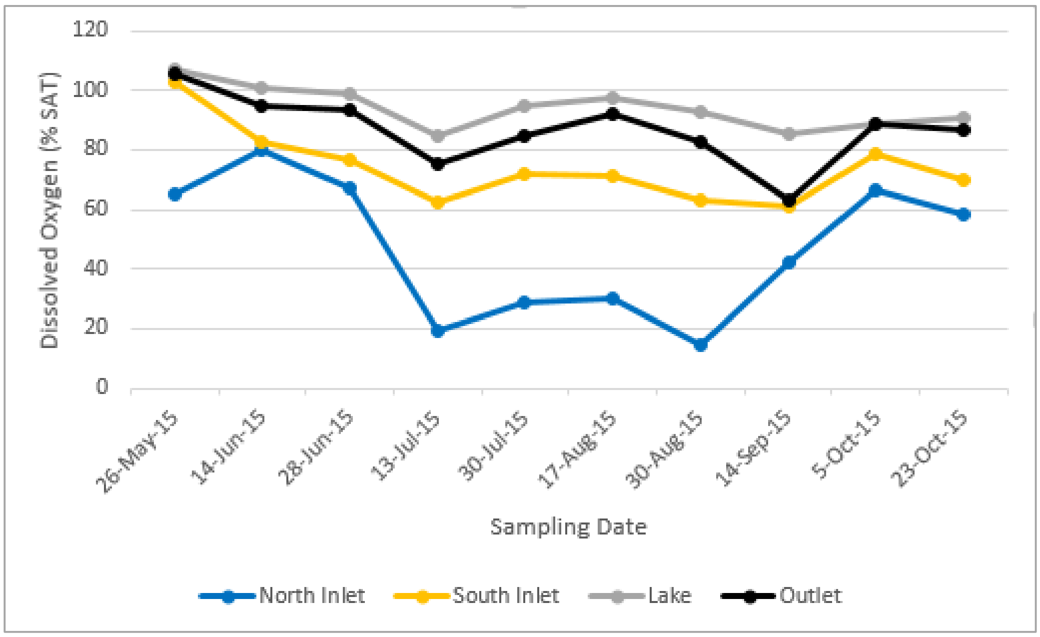

Figure 8.0– Dissolved oxygen (% SAT) data for the Fox Point Lake sample sites in 2015

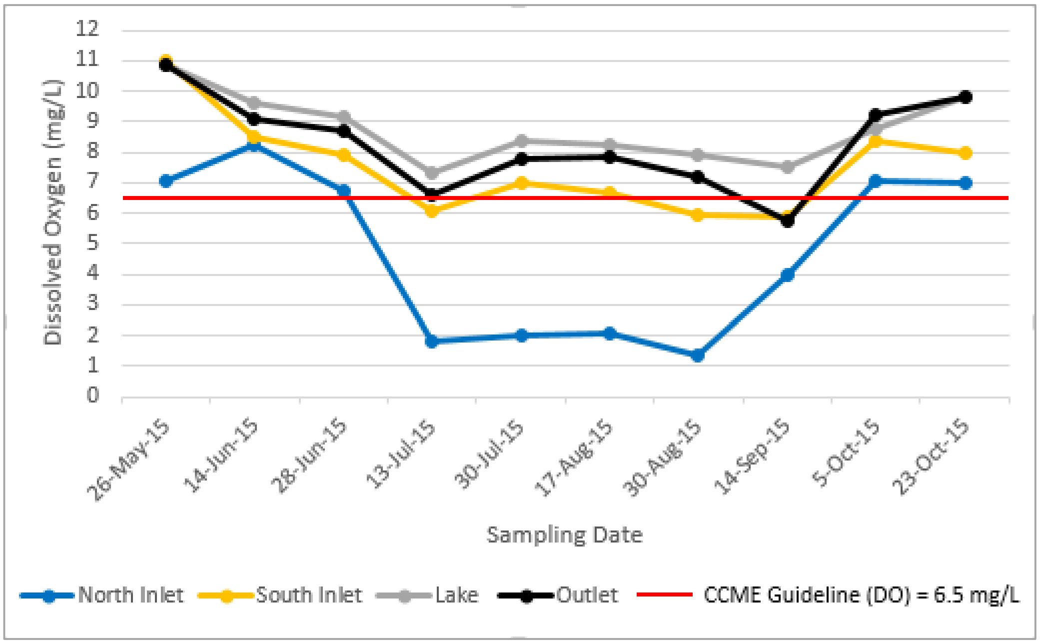

Figure 9.0 – Dissolved oxygen (mg/L) data for the Fox Point Lake sample sites in 2015

As seen in Figure 9.0, the dissolved oxygen levels at all four sample sites show a similar trend of decreasing during the warmest period of the monitoring season (July-Aug) due to the fact that oxygen becomes less soluble in water as temperature increases (CCME, 1999; Mackie, 2004). The surface waters at the Lake sample site remained well above the guideline, likely due to wind and wave action, rainfall, and photosynthesis. The Outlet sample site also displayed healthy dissolved oxygen conditions, mostly due to the turbulent, cascading flow of water directly upstream of the sample site. Dissolved oxygen levels at the South Inlet sample site were close to or below the guideline during the warmest part of the monitoring period, which may be a result of the slow water velocity in this stream or the elevated levels of nutrients leading to excessive algal growth and decreased dissolved oxygen.

The North Inlet sample site is immediately downstream of a wetland and over the month of June, a large beaver dam was constructed 5 m downstream of the sample site. The low dissolved oxygen conditions at the North Inlet sample site (see Fig. 9.0) can be explained by its location. Wetlands have high levels of organic materials and decomposition, as well as slow moving water, which contributes to the low dissolved oxygen conditions. In addition, the beaver dam had formed a full blockage across the stream in July (removed in August). Beaver impoundments accumulate organic matter and lead to higher decomposition rates and decreased dissolved oxygen (Gibbs, 2014; B.C. MoE, 1998).

2.5 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 inverse logarithmic scale means that each pH unit represents a tenfold change in acidity or alkalinity of water. A pH of 4 is ten times more acidic than a pH of 5. 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 forms of aquatic life 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 severity of these impacts depend 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 midwest U.S. Southwestern Nova Scotia, in particular, suffers the most 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).

Table 5.0 – Mean and minimum pH for the Fox Point Lake sample sites

	North Inlet	**South Inlet**	**Lake**	**Outlet**
Mean pH	4.56	5.08	6.11	5.45
Minimum pH	3.88	4.1	5.66	5.04

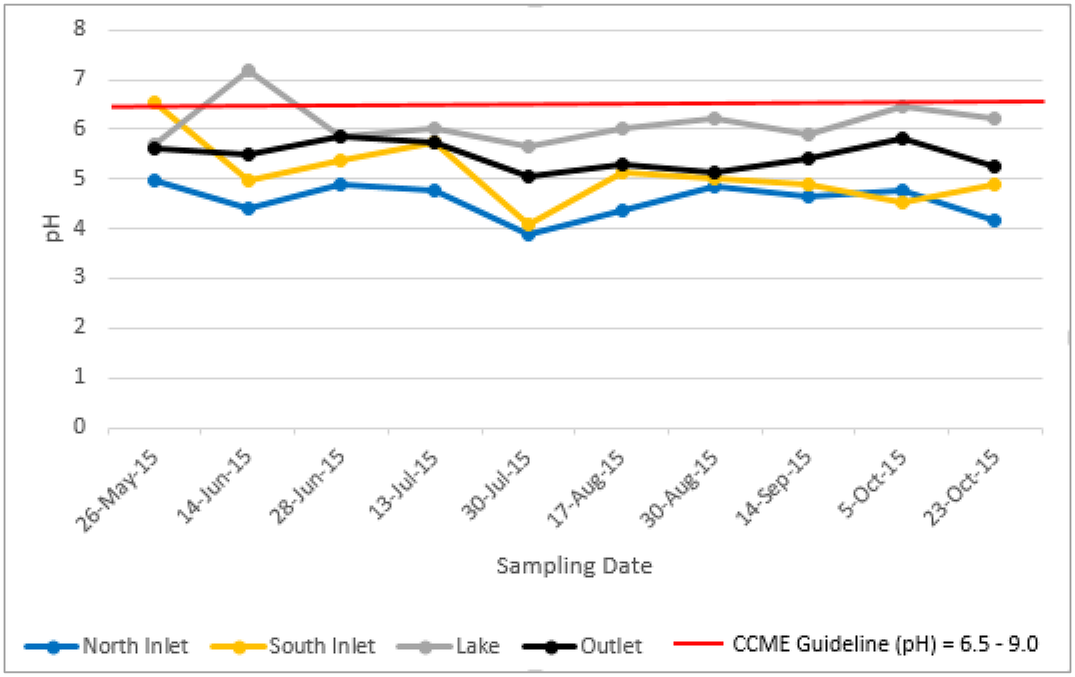

Figure 10.0 – pH data for the Fox Point Lake sample sites in 2015

The pH conditions at Fox Point Lake are similar to those found in many lakes and streams in southwestern Nova Scotia. All four sample sites displayed pH values below the CCME Guideline range of 6.5 - 9.0 for the entire monitoring period (see Fig. 10) except for the Lake and South Inlet sample sites, which each had one pH reading above 6.5. Both the South Inlet and North Inlet sample sites displayed pH readings <5.0. These acidic conditions may cause stress for fish populations, however, further research would be required to determine the proportion of organic and inorganic acids in these ecosystems, and thus the severity of the impacts on fish.

2.6 Total Dissolved Solids

Total dissolved solids is a measure of the amount of dissolved materials in the water column, such as calcium, magnesium, chloride, sodium, sulphate, nitrate, and bicarbonate. These 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 levels of dissolved solids will influence water taste, color, and clarity, 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 total dissolved solids for pristine lakes in Nova Scotia is 20 mg/L (Hinch & Underwood, 1985).

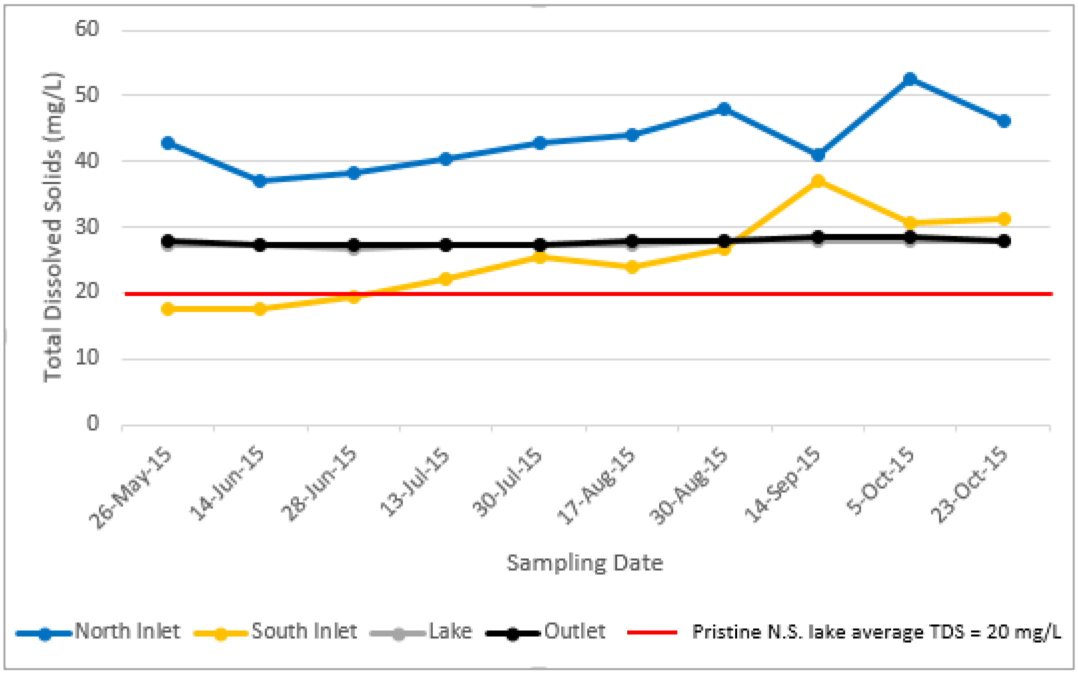

Figure 11.0 – Total dissolved solids data for the Fox Point Lake sample sites in 2015

Fox Point Lake displayed an average total dissolved solids of 27.5 mg/L, which falls above the historical average for pristine lakes in Nova Scotia (20 mg/L) but well below the Health Canada drinking water guideline of 500 mg/L.

2.7 Total Suspended Solids

Total suspended solids 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. This water quality parameter acts as an indicator of sedimentation and water clarity. Sources of suspended solids include natural geological erosion, agriculture, forestry, construction, and wastewater discharge. 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 6.0 – Total suspended solids (mg/L) results for the Fox Point Lake sample sites

	North Inlet	South Inlet	Lake	Outlet
26-May-2015	<2.0	2.8	<1.0	1.0
30-Jul-2015	1.0	2.0	<1.0	<1.0
14-Sep-2015	<1.0	<2.0	1.2	1.2
23-Oct-2015	1.0	2.0	<1.0	<1.0

Many of the water samples collected from the Fox Point Lake sample sites had levels of suspended solids that were too low to be detectable (see Table 6.0). These results are recorded as being less than the 'Readily Detectable Limit' (ie: <2.0 mg/L). The highest levels of total suspended solids were observed at the South Inlet sample site. Sedimentation problems have been documented in the south inlet stream, presumably a result of golf course and road development upstream, however, without knowing the baseline levels of suspended solids in this area, it is hard to determine if these levels of suspended solids are a direct result of sedimentation impacts.

2.8 Total Phosphorus

Total phosphorus is a measure of both inorganic and organic forms of phosphorus. Phosphorus is an essential nutrient for plant growth, which 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. Guidelines established by Ontario's Ministry of Environment and Climate Change 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 (OMOE, 1979).

Table 7.0 – Mean and maximum total phosphorus (mg/L) for the Fox Point Lake sample sites

	North Inlet	**South Inlet**	**Lake**	**Outlet**
Mean Total Phosphorus (mg/L)	0.019	0.154	0.010	0.008
Maximum Total Phosphorus (mg/L)	0.030	0.240	0.014	0.008

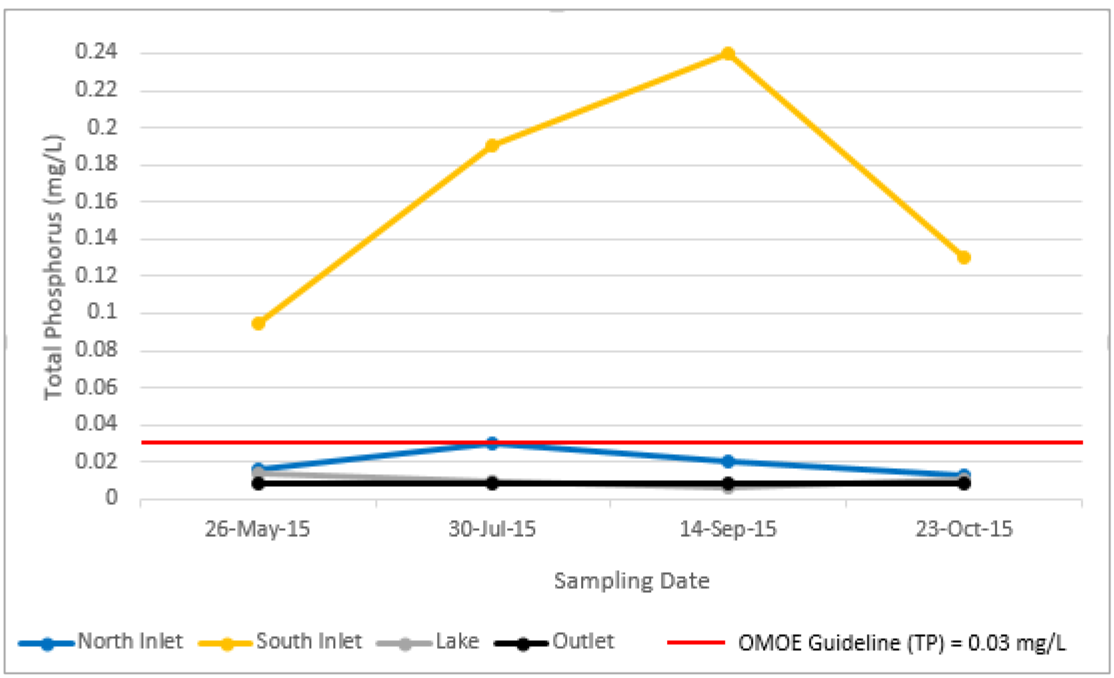

Figure 12.0 – Total phosphorus data for the Fox Point Lake sample sites in 2015

The mean total phosphorus level recorded in Fox Point Lake in 2015 was 0.01 mg/L, suggesting that the lake is not significantly impacted by anthropogenic activities. Both the North Inlet and

Outlet sample sites displayed total phosphorus levels below the guideline for streams (0.03 mg/L). Total phosphorus levels observed at the South Inlet sample site were consistently higher than the other sample sites, falling well above the stream guideline of 0.03 mg/L. The mean total phosphorus at this site was 0.154 mg/L and the maximum value recorded was 0.240 mg/L. These results suggest that there may be anthropogenic activities within the drainage area of the south inlet stream which are releasing phosphorus into the environment. The South Inlet sample site was positioned upstream of any drainage from residential development around Fox Point Lake, and downstream of all development at Aspotogan Ridge, which means that any environmental impacts observed at this site are likely attributable to upstream development activities.

2.9 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) (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 $\leq$ 0.9 mg/L for freshwater environments in which excessive nutrient loading and eutrophication are likely to occur.

Table 8.0 – Mean and maximum total nitrogen (mg/L) for the Fox Point Lake sample sites

	North Inlet	**South Inlet**	**Lake**	**Outlet**
Mean Total Nitrogen (mg/L)	0.53	1.12	0.23	0.33
Maximum Total Nitrogen (mg/L)	0.62	2.01	0.27	0.70

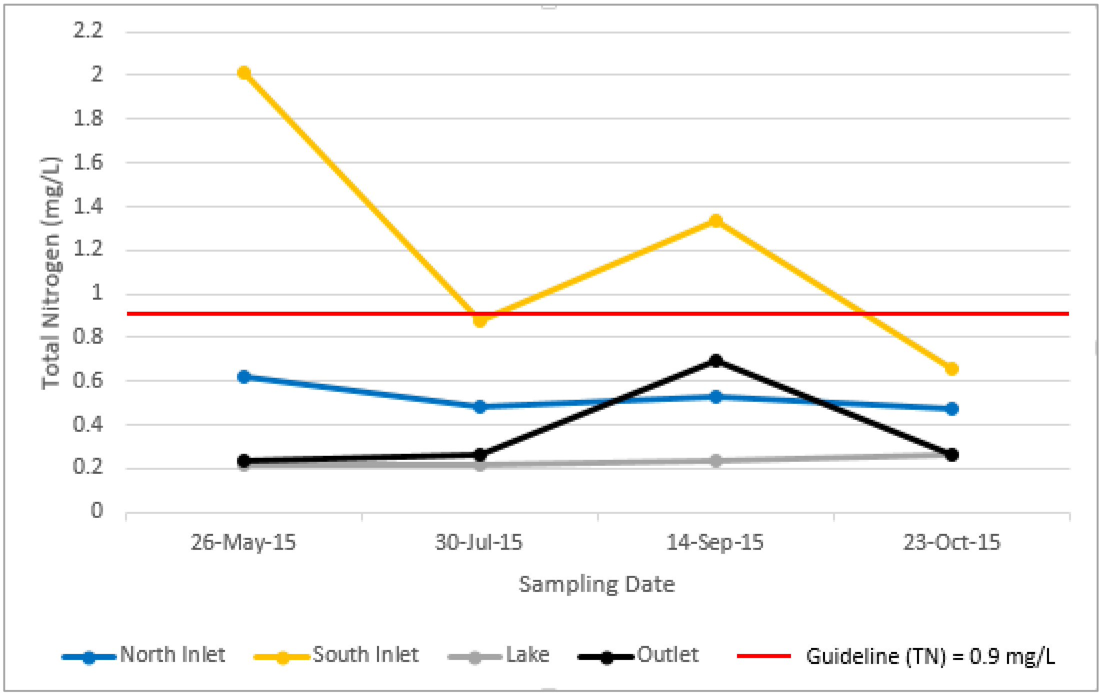

Figure 13.0 – Total nitrogen data for the Fox Point Lake sample sites in 2015

The results for total nitrogen are similar to those for phosphorus, with the South Inlet sample site being the only location to display elevated nutrient levels. The South Inlet sample site displayed a mean total nitrogen value of 1.12 mg/L and a maximum value of 2.01 mg/L. These results, along with those for total phosphorus, suggest that the south inlet stream may be suffering from excessive nutrient loading from anthropogenic activities.

2.10 Fecal Coliform

Fecal coliform bacteria are found in the wastes 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. The majority of fecal coliform bacteria is comprised of E. coli and will be used as a proxy measurement of E. coli and be compared to the Health Canada guidelines for E. coli.

Health Canada has developed several comprehensive guidelines for the protection of human health in Guidelines for Recreational Water Quality (2012). 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)

Table 9.0 – Health Canada guidelines for E. coli during recreational water contact

Parameter / Contact Level	Guideline for Water Recreation
E. coli Primary Contact	≤ 400 CFU/100 mL
E. coli Secondary Contact	≤ 1000 CFU/100 mL

* CFU = colony forming units

Sources of fecal contamination in a watershed include 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 a number of 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).

Table 10.0 – Fecal coliform (CFU/100 mL) results for the Fox Point Lake sample sites

	North Inlet	South Inlet	Lake	Outlet
26-May-2015	< 10,000	< 100	< 10	< 10
30-Jul-2015	100	< 100	< 10	10
14-Sep-2015	690	1500	< 10	10
23-Oct-2015	40	140	60	10

Several of the fecal coliform results received from the laboratory were recorded as 'Not Detected' (see Table 10.0). These results are reported as being less than the 'Readily Detectable Limit' (ie: < 100 CFU/100 mL). The Readily Detectable Limit (RDL) can be different from one sample to another depending on the condition of the individual samples and whether or not sample dilution was required. Reporting a result as < 100 CFU/100 mL means that the true fecal coliform level in that sample could have been anywhere between 0 and 100 CFU/100 mL, but the laboratory can only state with confidence that the sample is less than the RDL of 100 CFU/100 mL.

On May 26th, the fecal coliform sample from the North Inlet sample site had a high RDL of 10,000 CFU/100 mL. According to the laboratory technician at Maxxam Analytics, this particular sample had a lot of organic debris and sediments in it, requiring a number of dilutions in order to accurately analyze fecal coliform, and resulting in the high RDL value. This means that it is not possible to know what the true level of fecal coliform bacteria was in this sample, only that it fell somewhere between 0 and 10,000 CFU/100 mL.

Two exceedances of the Health Canada guideline for primary contact (≤ 400 CFU/100 mL) were observed during the 2015 monitoring season. These exceedances occurred on the same sampling date, September 14th 2015, in the north and south inlet streams. The North Inlet sample site result was 690 CFU/100 mL, and the South Inlet sample site result was 1500 CFU/100 mL. Both the Lake and Outlet sample sites had very low fecal coliform levels, suggesting that the bacterial contamination was effectively diluted once it entered the lake. These high fecal coliform levels may be a result of increased overland run-off due to rainfall. On September 11th, three days before the sampling date, there were 25.4 mm of rainfall recorded by the rainfall gauge, as well as an additional 8.1 mm of rain on the sampling date of September 14th. The Nova Scotia Environment Inspector involved with the Aspotogan Ridge development project was notified of these sampling results, and a site visit by the inspector did not reveal any obvious sources of fecal contamination in the south inlet stream or near the development site.

By the next sampling date, October 23rd, the fecal coliform levels had dropped to well below the Health Canada guideline for primary contact. An additional water sample was collected from the southwest cove in Fox Point Lake, on this date, to ensure that bacteria contamination was not entering the lake through the south inlet stream. The results from this sample were well below the guideline as well (40 CFU/100 mL).

2.11 Rainfall and Lake Water Level

Rainfall amounts and lake water level were recorded on a daily basis at Fox Point Lake throughout the monitoring season. Establishing a baseline of the hydrologic conditions within the Fox Point Lake drainage basin is necessary in order to identify any significant impacts caused by the development project. Watercourse and wetland alterations, land level alterations, pond construction, vegetation removal, and irrigation water usage have the potential to alter the drainage patterns of the Fox Point Lake catchment area.

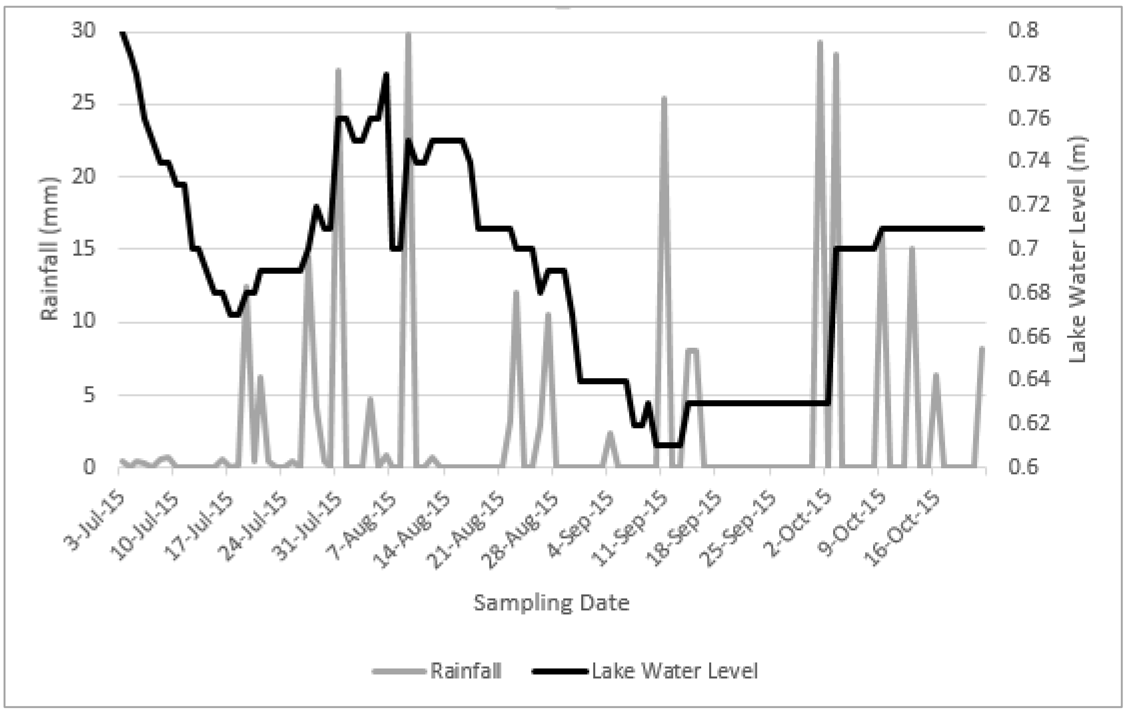

Figure 14.0 – Rainfall and lake water level data from Fox Point Lake in 2015

Figure 14.0 displays both the rainfall and water level data together. This data is not represented at a comparable scale, with rainfall data graphed in millimeters, and water level data graphed in meters. It is useful, however, to visualize how rainfall influences the lake water level by graphing these two datasets together. The water level in Fox Point Lake fluctuates up and down in response to periods of little rainfall (early July) or periods of persistent rainfall (late July to August). The water level rose quickly following two significant rainfall events in early October.

A total of 368.3 mm of rainfall was recorded at Fox Point Lake from June 19th to October 22nd. The maximum rainfall amount in a single day was 29.8 mm on August 9th. The water level of

Fox Point Lake fluctuated between a depth of 0.61 m and 0.80 m over the monitoring season. With no historical baseline data available, no inferences can be made about the water level conditions of the lake. This data will act as a baseline for comparison in future years as monitoring and development continue. Residents of Fox Point Lake did not observe any noticeable changes in the fluctuation of water levels in 2015 compared to previous years.

2.12 Stream Discharge

The discharge rate of a stream is a product of its velocity times the depth and width of the water flowing in that stream (cross-sectional area). Development activities which effect the hydrologic conditions of the drainage basin may result in changes in stream discharge rates (Meals & Dressing, 2008).

Table 11.0 – Mean and range stream discharge data for the Fox Point Lake sample sites

	North Inlet	**South Inlet**	**Outlet**
Mean Stream Discharge (m^3/s)	0.378	0.033	0.152
Range of Stream Discharge (m^3/s)	0.202 – 0.701	0.021 – 0.058	0.052 – 0.749

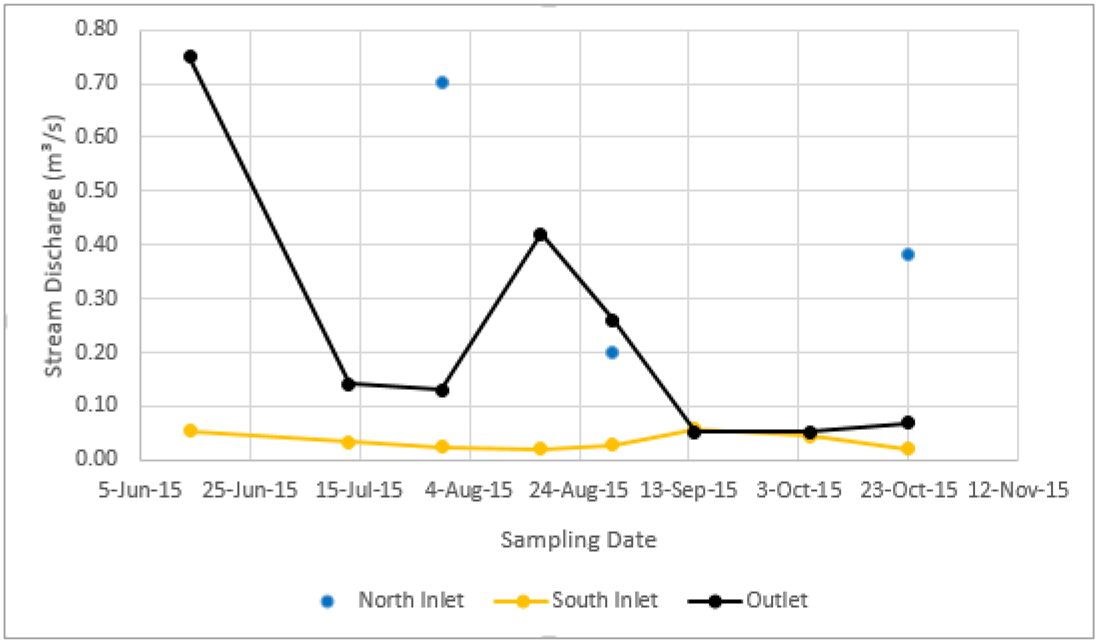

Figure 15.0 – Stream discharge data for the Fox Point Lake sample sites in 2015

The construction of a beaver dam near the North Inlet sample site created problems for accessing the site and collecting stream discharge data. Only three discharge rates were calculated for the North Inlet sample site over the monitoring season. The South Inlet sample site displayed a consistently low discharge rate with very little variation. The Outlet sample site displayed a great deal of variability in discharge rates. The construction of a small beaver dam roughly 20 m upstream from this sample site may have contributed to the decrease in discharge rate during the months of September and October.

Similar to the lake water level data, this stream discharge data will act as a baseline for comparison to future monitoring efforts as the Aspotogan Ridge development project progresses.

3. Discussion

Fox Point Lake is at risk of suffering from cultural eutrophication if human activities and development projects within its drainage basin are not properly managed. Currently, development activities cover most of the lake's southern catchment area, which drains toward the lake and into the south inlet stream. Understanding the current trophic state of the lake is necessary in order to recognize any further degradation of water quality as development activities proceed. A trophic state analysis has suggested that Fox Point Lake is likely oligotrophic and approaching mesotrophic. Using the results for total phosphorus, total nitrogen, and chlorophyll *a*, the lake would be considered oligotrophic, however, the results for Secchi disk depth and the temperature/dissolved oxygen depth profiles suggest that the lake is mesotrophic and close to being eutrophic. An additional monitoring season, with more frequent monitoring of nutrients and chlorophyll *a*, will provide a clearer picture in regards to the trophic state of the lake.

Water temperature results have highlighted the importance of the north and south inlet streams as thermal refugia for fish as temperatures reach stressful levels in the outlet stream and surface waters of the lake during July and August. Depth profiles conducted in the lake reveal that dissolved oxygen conditions in the hypolimnion fall below the CCME Guideline for Protection of Aquatic Life, which means that fish are not able to escape high surface water temperatures by moving to the bottom waters. Maintaining the health and water quality of the north and south inlet streams is important for fish populations of Fox Point Lake.

The monitoring results for the South Inlet sample site suggest that this stream may be suffering from anthropogenic impacts. Elevated total suspended solids and nutrient levels indicate that the stream may be receiving run-off from areas impacted by human activity. Excessive sedimentation and algal growth have been observed in this stream throughout the monitoring period. This stream is most likely not providing high quality habitat for aquatic organisms and habitat conditions will continue to degrade if this stream is exposed to further anthropogenic impacts.

Overall, Fox Point Lake does not appear to be suffering significantly from the effects of cultural eutrophication and development activities within its drainage basin, however, there are signs of water quality and habitat degradation in the south inlet stream which may be attributable to development activities throughout the southern part of the drainage basin. Additional monitoring is required to identify a baseline and determine if the elevated nutrients and suspended sediments are increasing due to development activities. Temperature/dissolved oxygen depth profiles have revealed that biological productivity in the lake is high enough to cause oxygen depletion near the bottom of the lake as a result of decomposition. If productivity increases, as a result of cultural eutrophication, the dissolved oxygen conditions in the hypolimnion will continue to decline and may become anoxic.

4. Recommendations

The initial 2015 monitoring season was a success overall. The following list of recommendations is meant to provide guidance for the 2016 monitoring season and address any issues encountered during the first monitoring season.

- It is recommended that the Water Quality Monitoring Committee organizes the equipment loan through the Community Based Environmental Monitoring Network (CBEMN) as soon as possible prior to the 2016 monitoring season. Equipment from the CBEMN is in high demand throughout the summer, especially the 30 m YSI cable which is required for depth profiles.
- Field training is recommended prior to the 2016 monitoring season. Refresher training should be provided for existing volunteers as well as full training for any new volunteers that may become involved in 2016.
- Pesticide sampling should be added to the monitoring program in 2016. The Nova Scotia Environment Inspector involved with Aspotogan Ridge has indicated that no pesticides were used at the development site in 2015, however, they may be included in golf course management practices once the course is operational.
- A sample bottle and cooler should be ordered from Maxxam Analytics at the start of the 2016 monitoring season and kept at Fox Point Lake in order for the volunteers to immediately collect a water sample in the case of an algal bloom.
- The North Inlet sample site should be relocated for the 2016 monitoring season due to access issues and interference by a beaver colony. The sample site should be moved closer to the lake in an area that allows for easier access.
- Additional temperature/dissolved oxygen depth profiles could be conducted in other deep parts of Fox Point Lake to better understand thermal stratification and dissolved oxygen conditions within the lake.

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Appendix A

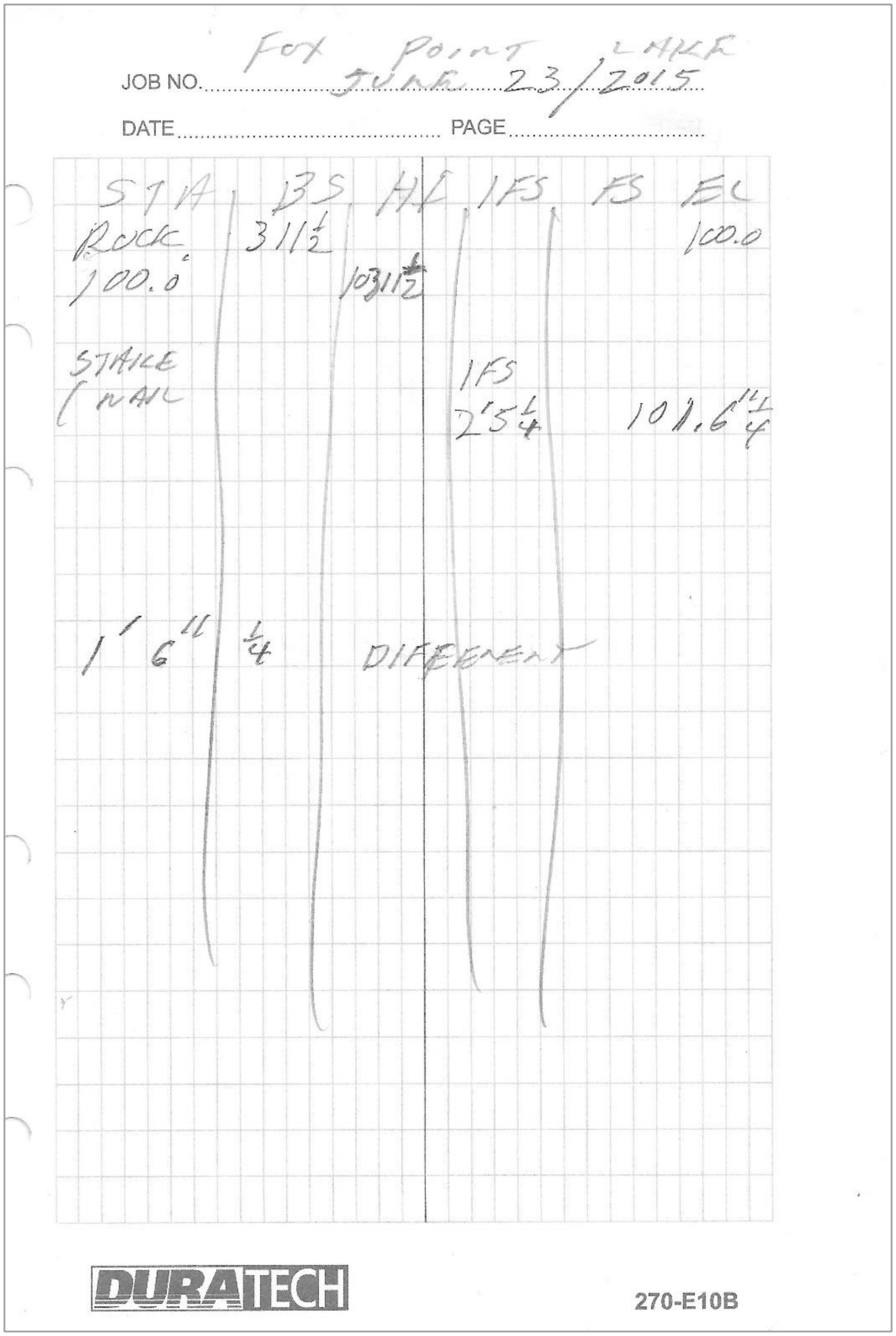

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Figure A1 – Elevation survey results for installation of water level staff gauge at Fox Point Lake