Results of the 2017 Water Quality Survey of Eleven Lakes in Yarmouth and Digby Counties

Final Report

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Stantec

Prepared for:
Carleton River Watershed Area Water Quality Steering Committee

Prepared by:
Stantec Consulting Ltd.
102-40 Highfield Park Drive,
Dartmouth NS B3A 0A3

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Executive Summary

Through support from Nova Scotia Environment (NSE), a lake quality monitoring program has been carried out from 2008 to 2017 in a selection of lakes within the Carleton River, Meteghan River and Sissiboo River watersheds. The monitoring program was initially executed by Acadia University and in 2016 transitioned to a fully volunteer-based program. Monitoring began in response to a prevalence of potentially toxic algal blooms occurring in several lakes within the study area. Initial studies worked to provide a water quality review of a number of lakes within the studied watersheds, and identify potential nutrient sources to the affected waterbodies. Identified sources pointed to agricultural and aquaculture activities, but primarily to the prevalence of mink farming activities within or upstream of the affected lake watersheds. With the enactment of the Fur Industry Act in 2013 by the Nova Scotia Department of Agriculture, sampling focus has shifted to identifying if waste control measures outlined in the act have had an impact in reducing P impacts within the affected lakes and other associated waterbodies.

This report contains the results from the 2017 monitoring program as well as a review of historical trends within the lakes and watersheds through the review of previously collected data. The current monitoring year saw an increase in total precipitation over the previous year and, as a result, colour was up in most sampled lakes. Hourglass Lake and Lake Vaughan have shown increases in several parameter concentrations over the previous monitoring period, although trending of decreased nutrients continue to be observed through the downstream lakes in the Carleton River Watershed. Placides Lake inlet and outlet TP loads were some of the highest measured within the Carleton River Watershed and were a similar order of magnitude indicating minimal P removal within the lake water column. The contributing watershed to the Placides inlet contains a number of fur farms and other agricultural operations, potentially contributing to the high observed TP loads. Of note is the colour increase at Wentworth Lake; colour remains elevated, but decreasing in levels, in downstream lakes (Parr Lake, Ogden Lake and Lake Fanning). Colour has the potential to influence chlorophyll a concentrations in these lakes and make them susceptible to potential future algal issues should colour be reduced in the presence of sufficient TP.

Recommendations have been made to move towards better sourcing nutrient loading to specific lakes, through i) flow monitoring and loading calculations at lake inlets and outlets, and ii) the determination of the influence of benthic sediments in TP recharge to the water column.

The intent is to supplement the current monitoring program in identifying if loading rates are changing within lake systems, if specific inputs are contributing higher loadings to a system and if historical loadings have impacted benthic TP concentrations to the point where changes in land use may not be sufficient to lower TP concentrations within the system.

Future planning for land protection is also recommended, to better identify and mitigate further TP impacts to the lake systems from proposed developments in the primarily wooded watersheds.

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1.0 INTRODUCTION

Stantec Consulting Ltd. (Stantec) was retained by the Carleton River Watershed Area Water Quality Monitoring Steering Committee (CRWAWQM SC) through the Municipality of the District of Yarmouth (MODY) to complete the 2017 monitoring program of a series of lakes within the Carleton River, Sissiboo River and Meteghan River Watersheds, located in Yarmouth and Digby Counties, in southwestern Nova Scotia (Figures A.1 to A.3, Appendix A). The program was carried out under a Water Resources Program Grant through the Nova Scotia Federation of Agriculture. The annual monitoring event occurred on August 20 to 24, 2017 and was executed by Stantec staff and local volunteers. A separate storm flow monitoring event occurred on May 15, 2017, which is summarized as a letter report in the attached Appendix B.

2.0 BACKGROUND

In recent years, blue-green algal blooms have become a regular summer occurrence in several lakes in the Carleton, Meteghan and Sissiboo watersheds. In response, Nova Scotia Environment (NSE) has taken the lead in supporting a series of annual studies of select waterbodies within these watersheds, initially aimed at identifying the likely causes of the problem. Monitoring has been completed on an annual basis since 2008. The program was initially executed by Acadia University with increasing volunteer involvement beginning in 2013. In 2016, the monitoring program became entirely volunteer-based. Since the start of annual monitoring program, the suite of water quality parameters sampled and analysed for has been condensed to focus on key indicators and for quality control/quality assurance purposes. These studies have been helpful in indicating pre-conditions conducive to blooms in the various lakes, and have indicated vulnerabilities in a number of lakes.

In 2015, the CRWAWQM SC was developed to oversee and organize water quality monitoring within the Carleton, Meteghan and Sissiboo watersheds. The 2017 project objectives for work undertaken in conjunction with the CRWAWQM SC are as follows:

1. A data base that complements existing data bases by indicating trends and/or patterns in study parameters and more clearly defining environmental pressures on the study system;
2. A report that better equips managers, administrators, and politicians to educate the public and work with the public to manage public waters and catchment areas better;
3. Progress towards identifying best management plans for specific lakes and the watershed under study;
4. A case study that should have much wider applicability provincially and beyond, in terms of lessons for catchment area management; and,
5. Increased clarity in the identification of environmental stressors and the provision of recommendations regarding their mitigation.

3.0 APPROACH AND METHODS

3.1 PLANNING METHODS

To facilitate the organization and completion of lake monitoring by Stantec, a Project Plan (Stantec 2017) was drafted for submission and approval by the CRWAWQM SC, which includes the following information:

- Literature Review (Section 2.0) – review of phosphorus (P) loading sources to waterbodies, historical monitoring reports results and trends for various water quality parameters, including trophic status, chlorophyll a concentrations and lake colour;
- Project Plan (Section 3.0) – including a communication plan, a summary of consultation activities, and ground-truthing and training information for execution of the monitoring program;
- Monitoring Plan (Section 4.0) – including a summary of sample locations and scheduling, information on data collection and submission, and data management; and
- Project Schedule (Section 5.0)

3.2 MONITORING LOCATIONS

Monitoring and collection of water quality samples was conducted at eleven historically monitored lakes and select tributary streams. Within the Carleton River Watershed (Figures A.5 and A.7 to A.14, Appendix A), nine lakes were monitored:

- Hourglass Lake (5 sites)
- Placides Lake (3 sites)
- Porcupine Lake (3 sites)
- Wentworth Lake (6 sites)
- Parr Lake (5 sites)
- Ogden Lake (3 sites)
- Lake Fanning (5 sites)
- Sloans Lake (3 sites)
- Lake Vaughan (5 sites)

Within the Meteghan River Watershed, one lake was monitored (Figure A.6, Appendix A):

- Nowlans Lake (3 sites)

Within the Sissiboo River Watershed, one lake was monitored (Figure A.4, Appendix A):

- Provost Lake (2 sites)

Lakes within the Tusket River Watershed have been monitored within this program during past events; however, the select lakes were chosen for the 2017 monitoring event based on having comprehensive historical data sets. Water quality samples were collected at previously identified inlet, outlet and mid-lake sample sites. Inlet and outlet monitoring sites have been historically named as stream (ST) sites and represent well-defined inputs or outputs to a lake, as determined in previous watershed work through ground-truthing. Mid-lake (ML) sites represent the location of a previously identified deep-zone within each sampled lake, identified in previous watershed work through available lake bathymetry maps (Taylor 2009). A handheld GPS unit was used to navigate to the previously established monitoring sites.

Watershed map figures presenting watershed boundaries, general land use types and areas, and monitoring site locations for each individual lake are provided in Figures A.4 to A.14, Appendix A. Sample site IDs and coordinates are provided in Table C.1, Appendix C.

3.3 SITE MONITORING PROCEDURES

3.3.1 Stream Sites

The following is a summary of the monitoring procedures for in-field water quantity and quality measurements and water quality sample collection at the ST sites:

- Flow monitoring was completed at ST sites using a handheld acoustic doppler velocimeter (ADV) (SonTek Flowtracker). Velocity and depth measurements were taken at measured intervals along a stream cross-section to allow for flow calculation using the velocity area/ mid-section method.
- In-situ water quality measurements were taken at each site using a handheld water quality meter (YSI 650 MDS with a 6600-M Sonde), which recorded pH, dissolved oxygen (DO), specific conductance (SPC) and temperature.
- Single grab samples for laboratory analysis were taken by hand at each ST (inlet and outlet) location at an approximate water depth of 0.25 m below surface.

3.3.1.1 Flow Analysis

Three methods were used to calculate flows for this study, which were the mid-section method, watershed area ratio, and 2009 measured percent difference.

Mid-Section Method

The mid-section method, which is recommended and used by the Water Survey of Canada (Environment Canada 1999), is where water depth, velocity and width are measured at 15 to 20 panels (distance between measured points across stream width). Flow is calculated at each panel (half of the distance for each panel on either side of the flow measurement point) and then all the measurements are added together to get the watercourse flow rate.

Watershed Area Ratio

Flow is predicted for ungauged/unmeasured stations using the ratio of the ungauged station watershed area to the gauged/measured station watershed area multiplied by the measured flow rate (Archfield and Vogel 2010).

2009 Measured Percent Difference

The 2009 Carleton River annual monitoring event measured flows at the lake inlet and outlet stations at all 2017 study lakes, except Wentworth (Taylor 2010). The percentage difference between flows measured in 2009 were used to extrapolate 2017 flows from a monitoring station where flows were gauged in 2017 (i.e., PARL-INC) to a station where in 2017 flows were not monitored (e.g., VL-OL1). Additional details about the ST Sites where flow measurements were or were not measured in 2017 are presented in Section 5.1.4.

3.3.2 Mid-Lake Sites

The following is a summary of the monitoring procedures for in-field quality measurements and water quality sample collection at the ML sites:

- In-situ water quality measurements were taken at each site using a handheld water quality meter (YSI 650 MDS with a 6600-M Sonde), which recorded pH, DO, SPC and temperature.
- A standard 20 cm Secchi Disk was used to measure Secchi depth at each sample location, where lake depth allowed. The Secchi disk was lowered into the water column and when the white disk areas were no longer discernable, the associated depth would be recorded. The disk was then pulled up and when it became visible that depth was recorded. The calculated Secchi depth was the average of the two depths.
- Sample location depths were measured at each site using a depth-sounder (Garmin GPSMAP 531s).
- A Van-Dorn sampler was used to take composite and bottom grab samples for laboratory analysis at each ML site. Composite samples were a 50/50 composition of sample volumes taken at a depth of 0.25 m below surface and at a depth of 2x the Secchi depth at the site. Bottom samples were taken at a depth of 1 m above lake bottom at each ML site, where lake depth allowed.

3.4 WATER QUALITY LABORATORY SUBMISSION AND ANALYSIS

Water quality samples taken at each lake in appropriate laboratory supplied bottles were placed in a cooler with ice and shipped by ground courier/vehicle to the QEII Health Sciences Center (QEII) in Halifax, NS, for laboratory analysis. Single grab samples at SL sites and composite and bottom grab samples at ML sites were analyzed for the following suite of parameters:

- Chlorophyll a [1]
- Total Phosphorus (TP)
- Ortho-phosphorus (Ortho-P)
- Total Nitrogen (TN)
- Nitrate + Nitrite (NO2 + NO3)
- Total Ammonia (NH3 + NH4+)
- Colour
- pH
- Turbidity

[1]Chlorophyll a was not analyzed for bottom grab samples at ML sites. The QEII, for this study, subcontracted chlorophyll a analysis to ALS Laboratory, in Winnipeg, MB.

Duplicate samples were taken at the following locations during the 2017 monitoring period: NL-OL1B, WL-DS1 (bottom), LF-DS3 (bottom) and VL-DS2 (bottom). Discrepancies between duplicate and original samples are noted in Section 5.1.1, where applicable.

3.5 NOVA SCOTIA ENVIRONMENT SAMPLING PROGRAM AUGMENTATION

Historically, cyanobacteria and microcystin sampling and subsequent analysis have been conducted in a number of the study lakes at near-shore and shoreline sampling stations. Nova Scotia Environment (NSE) proposed during pre-planning discussions (November 18, 2016) and email correspondence potential available funding (i.e., in-kind contribution) for laboratory analysis of near-shore and shoreline water samples for cyanobacteria (blue-green algae) and microcystin. The additional samples were collected by volunteers and Stantec personnel concurrently with mid-lake sampling in previously identified lakes (e.g., historical algal blooms) from historical near-shore and shoreline stations. The holding times for microcystin and cyanobacteria prior to submission is 14 days and no specified holding time requirement, respectively. The cyanobacteria samples have a preservative added to the sample bottle, which allows for the non-specific holding time. Efforts were made to submit samples to the lab within these holding times to avoid jeopardizing sample integrity.

3.6 DATA MANAGEMENT

The 2017 monitoring program data was added to an existing modified version of the historical database, which consisted of an Excel spreadsheet file. The 2017 data entries were checked against laboratory certificates of analysis results. Field duplicate samples were collected, analysed for the full suite of water quality parameters for a given site, and subsequently used to confirm quality accuracy and control by completing Relative Percent Difference (RPD) calculations.

4.0 APPLICABLE GUIDELINES

Relevant Canadian guidelines applicable to fresh water surface water environments, which were used to assess the historical and 2017 monitoring water quality parameter results, consisted of the following:

Canadian Council of Ministers of the Environment (CCME) Guidelines for the Protection of Freshwater Aquatic Life (FAL) (2017) – guideline values presented under the CCME FAL framework are intended to protect aquatic life from exposure to a selection of chemical and physical water quality parameters. Guidelines are presented for both short-term and long-term exposure scenarios and can be concentration-based or follow a guidance framework based on baseline conditions. Monitored parameters covered under the CCME FAL guidelines include: TP, total ammonia, pH, DO and temperature.

Health Canada Guidelines for Canadian Recreational Water Quality (CRWQ) (2012) - guideline values presented under Health Canada's recreational water quality framework pertain to the safety of surface waters for recreational use by humans. Specific concentration values are given for cyanobacteria, cyanobacterial toxins (microcystins), pH and turbidity. Otherwise, a list of considerations as to the applicability of the use of the water body for recreational purposes is provided and is primarily based on visibility within the water column and water temperature. Monitored parameters covered under the Health Canada CRWQ guidelines include: microcystins, cyanobacteria cell counts, turbidity, pH and Secchi depth.

5.0 RESULTS AND DISCUSSION

5.1 2017 MONITORING RESULTS

The following section outlines the results of the 2017 lake monitoring within the Meteghan River, Carleton River and Sissiboo River watersheds. Limitations of the 2017 data set are outlined as follows:

- Nowlans Lake did not permit for a safe launching of the boat based on low water levels and exposed mud flats along the shoreline and as such samples at the ML site NL-DS1 were not collected during the August 24, 2017 monitoring event. Data collected at NL-DS1, on August 29, 2017 by the Nova Scotia Department of Agriculture and Forestry (NSDAF) was used for interpretation purposes. The deep collection point had two water quality samples collected at the surface (1 - immediately below the surface, and 2 – at two times Secchi depth).
- No locations in the immediate vicinity of NL-IN1 were identified as being of sufficient water depth to submerge the YSI in-field water quality probes, and therefore measurements were not obtained.
- Flow data was not obtained at some of the ST locations during the 2017 monitoring period, for the following reasons:
    - Watercourse depth exceeded safe depths and water velocities for Stantec staff and volunteers to conduct the flow measurements based on Stantec's Standard Operating Procedures (SOP) for working in and near water, as well as the Ontario Ministry of Natural Resources and Forestry (MNRF) River & Systems: Flooding Hazard Limit (2002) 2x2 loss of life rule regarding safe wading depths and water velocities (discussed further in Section 5.1.4).
    - Data download was only possible for one monitored site, an ST location on Parr Lake (PARL-INC). This was due to a malfunction with the SonTek Flowtracker download process.
    - No flow was observed at the ST site HL-IN2, and as such, no water quality samples or in—field water quality measurements were collected.

- Laboratory analyzed and field measured pH results differed, with field pH results consistently lower for the majority of sampled sites. This is potentially due to temperature changes from the field to laboratory environments. Field pH was used for the purposes of data comparison.
- Acidified and non-acidified chlorophyll a samples were collected and submitted for analysis at ALS through a sub-contract with QEII. The acidified chlorophyll a were 1000x greater in value than the non-acidified results. The non-acidified chlorophyll a results were closer in

value to past monitoring event results. Consultation with the ALS lab indicated these results were correct and they identified no errors. Due to the high level of value discrepancy between the two methods, the acidified chlorophyll a results were discarded from results assessment.

- Data for ML composite samples are missing for Parr Lake and Ogden Lake. Samples were taken at these locations during the 2017 monitoring period for both Parr Lake and Ogden Lake; however, due to issues with lab requisition submission, these samples were not analyzed by the QEII laboratory.

Data tables of the 2017 analytical and field results, as well as the historical database, are provided in Appendix D. Data graphs of the monitoring results for each lake are also provided for select parameters in Appendix E.

5.1.1 Lake Site General Water Quality

Trophic status is used to describe lake water quality in the following sections. This is in reference to TP concentrations and associated vegetative productivity, with trophic conditions defined as follows: ultra-oligotrophic (< 0.004 mg/L TP), oligotrophic (0.004-0.01 mg/L TP), mesotrophic (0.01-0.02 mg/L TP), meso-eutrophic (0.02-0.035 mg/L TP), eutrophic (0.035-0.1 mg/L TP) and hyper-eutrophic (>0.1 mg/L TP). Ultra-oligotrophic lakes are considered to have low TP concentrations and low vegetative productivity, whereas eutrophic and hyper-eutrophic lakes have high TP concentrations and high vegetative productivity. As a result, eutrophic and hyper-eutrophic water bodies are more susceptible to algal blooms.

5.1.1.1 Provost Lake

Provost Lake (Figure A.4, Appendix A) is located at the headwaters of the Sissiboo River Watershed. There are no distinct lake inlets. The lake outlet drains into the Sissiboo River to the northeast (Brylinsky 2011). The predominant land use in the watershed area is forest with some development and silviculture.

Two locations were monitored on Provost Lake on August 22, 2017. One sample was taken at PROL-OL1, an outlet ST location, and two samples (composite and bottom) were taken at PROL-DS1, an ML location. In-situ field measurements were also recorded at each sample location. The bottom depth at PROL-DS1 was recorded at 4.5 m, with an estimated Secchi depth of 2.2 m. With the exception of pH and DO, field and laboratory water quality results did not exceed applicable CCME FAL and CRWQ guideline values. Ranging from 5.63 to 6.16, values of pH were lower than the CCME FAL desired pH range of 6.5 to 9.0 at the monitoring sites. DO concentration was lower than the CCME FAL recommended minimum DO concentration of 6.5 mg/L at the PROL-DS1 bottom site. Colour was higher at PROL-OL1 (133.0 TCU) than the ML composite and bottom monitoring sites (34.3 and 36.1 TCU, respectively). Temperature and DO profiles at PROL-DS1 (Figure 1) show relatively consistent values through the mid-lake water column indicating a non-stratified lake environment.

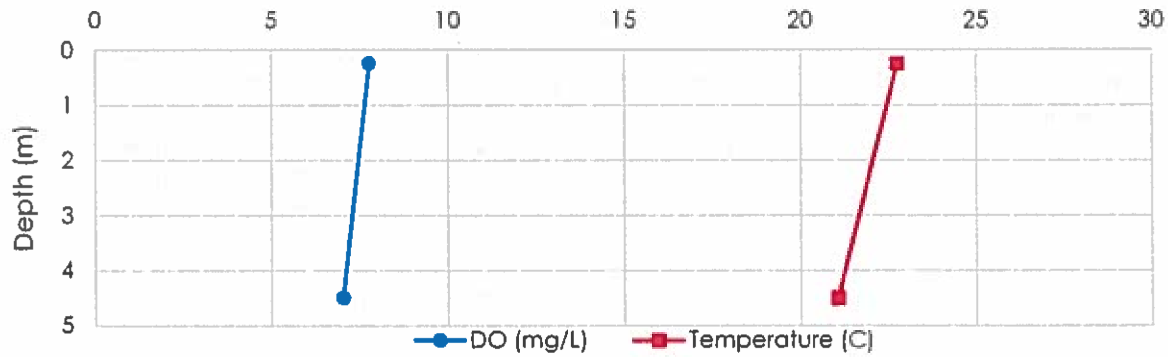

Figure 1 DO and Temperature Profile for Provost Lake, Mid-Lake

5.1.1.2 Nowlans Lake

Nowlans Lake (Figure A.3, Appendix A) is located in the upper-eastern region of the Meteghan River Watershed. There is a single, small inlet located on the eastern side of the Lake. The lake outlet drains westward to Prime Lake (Brylinsky 2011). Land use within the lake watershed is predominantly forested with mink farm operations and residential development along the eastern watershed boundary.

Two locations were monitored within Nowlans Lake on August 24, 2017 and one location was monitored on August 29, 2017. One sample was taken at NL-IN1 and one at NL-OL1, inlet and outlet ST locations on August 24, 2017. Historical ML site NL-DS1 was not accessed by Stantec during the August 24, 2017 monitoring event due to boat access issues (Section 5.1); however, data provided from a NSDAF sample event at NL-DS1 on August 29, 2017 is used in lieu of Stantec-collected data at this location. With the exception of DO, grab samples and field measurements did not exceed applicable CCME FAL and CRWQ guideline values. In comparison with other monitored lakes, cyanobacterial cell counts were the highest at Nowlans Lake at 20,300 cells/mL. TP concentrations were classified as hyper-eutrophic (3.33 mg/L) at the inlet, NL-IN1, and eutrophic (0.571 mg/L) at the outlet, NL-OL1 and ML sample site, NL-DS1 (0.62 mg/L). The NL-IN1 TP sample result of 3.33 mg/L represents the highest TP concentration measured at a lake site during the monitoring period. The subwatershed contributing to this inlet is bounded by Hilltown Cross Road to the south and Route 340 to the west and land use in the subwatershed consists of a large mink farming operation surrounded by several residences, with the remaining areas forested. DO concentration was lower than the CCME FAL recommended minimum DO concentration of 6.5 mg/L at NL-OL1 and at NS-DS1 bottom sites. Field measurements were not taken at NL-IN1 due to insufficient water depth (Section 5.1). The chlorophyll a concentration was higher at NL-DS1 (average of 48.25 µg/L) than both NL-OL1 (16.70 µg/L) and NL-IN1 (1.36 µg/L). Temperature and DO profiles at NL-DS1 (Figure 2) show values through the water column that are indicative of thermal stratification.

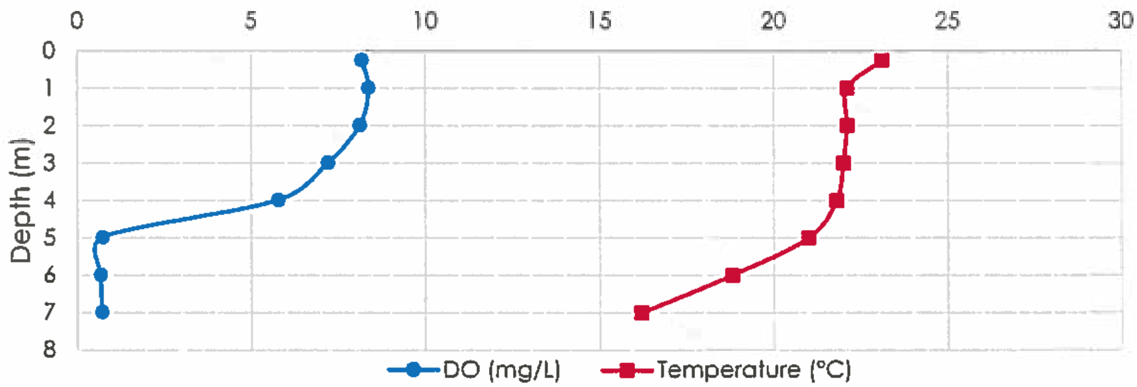

Figure 2 DO and Temperature Profile for Nowlans Lake, Mid-Lake

5.1.1.3 Hourglass Lake

Hourglass Lake (Figure A.3, Appendix A) is located at the headwaters of the Carleton River Watershed. There is a single, poorly-defined inlet with intermittent flow. The outlet is located to the south and ultimately drains into Placides Lake (Brylinsky 2011). Land use in the lake watershed area is primarily forested; however, there are agricultural (mink farming and other) and aquaculture operations within the watershed. An aquaculture operation on the northwestern lake side discharges into the lake at two locations.

Four locations were monitored on Hourglass Lake on August 24, 2017. Single water quality samples were taken at three ST locations; two representing inlets to the lake from a nearby aquaculture facility (HL-AQIN1 and HL-AQIN2), one at the outlet of the lake (HL-OL1). Two samples (composite and bottom) were taken at HL-DS1, an ML location. In-situ field measurements were also recorded at each sample location. The lake inlet (HL-IN1) was observed as being stagnant water with no flow (Section 5.1) and no samples were taken. The bottom depth at HL-DS1 was recorded at 6.5 m, with an estimated Secchi depth of 1 m. Secchi depth at the HL-DS1 location did not meet the 1.2 m guideline value for lake clarity given by the Health Canada CRWQ guidelines.

TP concentrations were classified as hyper-eutrophic at both aquaculture inlet locations (0.125 mg/L at HL-AQIN1 and 0.134 mg/L at HL-AQIN2) and at the HL-DS1 bottom site (0.651 mg/L). The TP concentration at the HL-DS1 composite site was classified as eutrophic, at 0.073 mg/L. Chlorophyll a concentrations were notably higher at this lake than other monitored lakes, with concentrations at the aquaculture discharge points of 66.00 µg/L (AQ-IN1) and 61.80 µg/L (AQ-IN2). Values were slightly lower at the lake outlet, at 49.80 µg/L (HL-OL1). Values of pH were lower than the CCME FAL desired pH range of 6.5 to 9.0 at HL-AQIN1, HL-AQIN2 and HL-DS1 bottom sites. DO concentrations were lower than the CCME FAL recommended minimum DO concentration of 6.5 mg/L at the HL-DS1 bottom and mid-depth sites. Colour was higher at the HL-DS1 bottom site (205.0 TCU) than other sites, which ranged from 59.6 TCU at HL-OL1 to 123.0 TCU at HL-AQIN1. Temperature and DO profiles at HL-DS1 (Figure 3) show changes in temperature and DO through the water column that are indicative of thermal stratification.

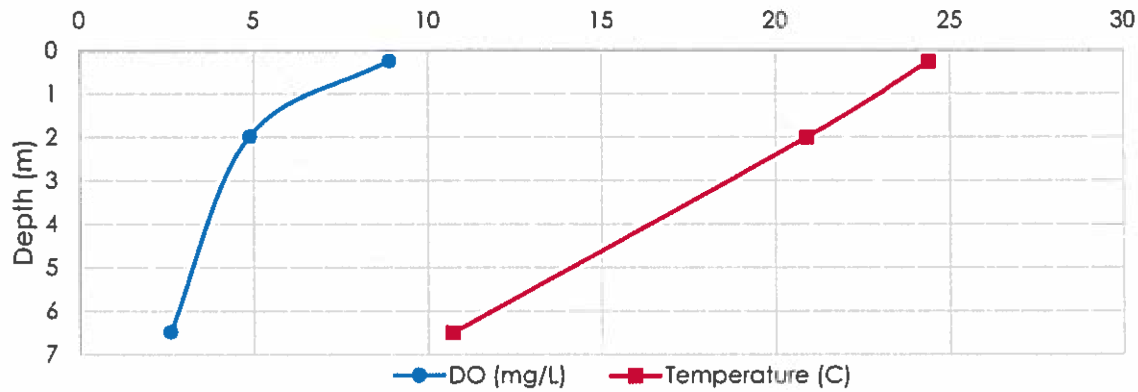

Figure 3 DO and Temperature Profiles for Hourglass Lake, Mid-Lake

5.1.1.4 Placides Lake

Placides Lake (Figure A.4, Appendix A) is located in the Carleton River Watershed, downstream of Hourglass Lake on the main branch of the Carleton River. The lake has a single inlet and outlet, and flow moves from northeast to southwest (Brylinsky 2011). Land uses in the watershed area are predominantly forest with some silviculture activities, but the watershed upstream of the inlet contains Hourglass Lake, mink farming and other agricultural activities.

Three locations were monitored on Placides Lake on August 22, 2017. Single samples were taken at two ST locations, PLAL-IN1 at the lake inlet and PLAL-OL1 at the lake outlet, and two samples (composite and bottom) were taken at PLAL-DS1, an ML location. In-situ field measurements were also recorded at each sample location. The bottom depth at PLAL-DS1 was recorded as 3.5 m, with an estimated Secchi depth of 0.625 m. Secchi depth at the PLAL-DS1 location did not meet the 1.2 m guideline value for lake clarity given by the Health Canada CRWQ guidelines. TP concentrations were classified as hyper-eutrophic at the sampled locations, at 0.661 mg/L (composite) and 0.618 mg/L (bottom)...Values of pH were lower than the CCME FAL pH range of 6.5 to 9.0 at the sampled locations. DO concentrations were lower than the CCME FAL minimum recommended DO concentration of 6.5 mg/L at the PARL-DS1 bottom and mid-depth sites. Temperature and DO profiles at PARL-DS1 (Figure 4) show changes in temperature and DO through the water column that may be indicative of thermal stratification.

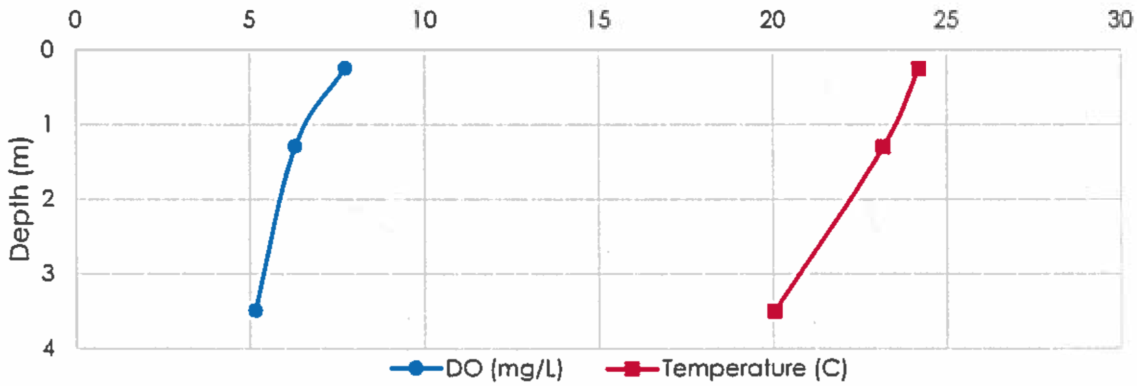

Figure 4 DO and Temperature Profiles for Placides Lake, Mid-Lake

5.1.1.5 Porcupine Lake

Porcupine Lake (Figure A.5, Appendix A) is located within the Carleton River Watershed, and is a tributary lake off the main branch of the Carleton River. The lake has a single inlet on the eastern boundary and ultimately discharges to Wentworth Lake through an outlet on the western boundary (Brylinsky 2011). Land use in the lake watershed area is varied, with mink farming operations and development in the far eastern watershed area. The immediate area around the lake is forested.

Three locations were monitored on Porcupine Lake on August 22, 2017. Single samples were taken at two ST locations, PORL-IN1 at the lake inlet and PORL-OL1 at the lake outlet, and two samples (composite and bottom) were taken at PORL-DS1, an ML location. In-situ field measurements were also recorded at each sample location. The bottom depth at PORL-DS1 was recorded as 12 m, with an estimated Secchi depth of 3.375 m. Secchi depth at the PORL-DS1 location met the 1.2 m guideline value for lake clarity given by the Health Canada CRWQ guidelines. TP concentrations were classified as hyper-eutrophic at the lake inlet (0.197 mg/L at PORL-IN1, and eutrophic at the PORL-DS1 bottom site (0.065 mg/L). Colour was higher at the lake inlet (212.0 TCU) than other sampled sites within the lake. Colour at the ML (composite and bottom) and outlet locations were similar, at 44.7-52.0 TCU and 45.9 TCU. Values of pH were lower than the CCME FAL pH range of 6.5 to 9.0 at the sampled locations. DO concentrations were lower than the CCME FAL minimum recommended DO concentration of 6.5 mg/L at the inlet and PORL-DS1 bottom and mid-depth sites. Temperature and DO profiles at PORL-DS1 (Figure 5) show changes in temperature and DO through the water column that is indicative of thermal stratification.

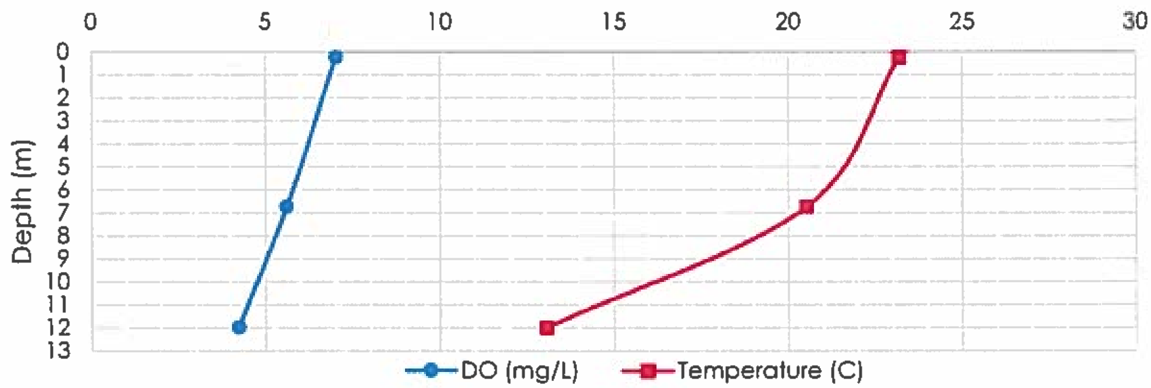

Figure 5 DO and Temperature Profiles for Porcupine Lake, Mid-Lake

5.1.1.6 Wentworth Lake

Wentworth Lake (Figure A.6, Appendix A) is located in the Carleton River Watershed, along the main branch of the Carleton River. The lake has multiple inlets and a single outlet that drains to Parr Lake. Land use in the lake watershed area is primarily forested with silviculture in the northeastern section.

Six locations were monitored on Wentworth Lake on August 21, 2017, which included five ST locations (four inlets and one outlet), and one ML location. Single samples were taken at ST locations WL-IN1, WL-IN2, WL-IN3, WL-IN4 and WL-OL1, and two samples (composite and bottom) were taken at ML location WL-DS1. In-situ field measurements were also recorded at each sample location. The bottom depth at WL-DS1 was recorded as 4.5 m, with an estimated Secchi depth of 0.675 m. Secchi depth at the WL-DS1 location did not meet the 1.2 m guideline value for lake clarity given by the Health Canada CRWQ guidelines. TP concentrations were classified as hyper-eutrophic at a lake inlet (WL-IN1; 0.219 mg/L), outlet (WL-OL1; 0.131 mg/L) and WL-DS1 bottom site (0.134 mg/L), and eutrophic at a second lake inlet (WL-IN2; 0.026 mg/L) and the WL-DS1 composite site (0.084 mg/L). Colour was notably higher at this lake than other monitored lakes. Colour was high at the inlet sites, at values ranging from 192.0 TCH at WL-IN1 to 516.0 TCU at WL-IN2. Colour at the ML and lake outlet site were lower, ranging from 156.0 to 164.0 TCU. Values of pH were lower than the CCME FAL pH range at the sampled locations, and below the Health Canada CRWQ guidelines at the inlet and WL-DS1 bottom sites. DO concentrations were lower than the CCME FAL DO range at the inlet locations. Temperature and DO profiles at WL-DS1 (Figure 6) show relatively consistent values through the water column, indicating a non-stratified lake environment.

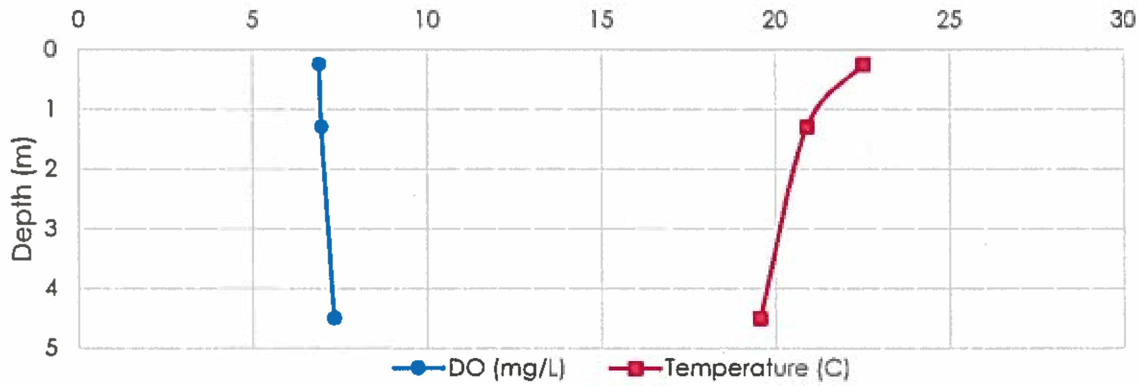

Figure 6 **DO and Temperature Profiles for Wentworth Lake, Mid-Lake**

5.1.1.7 Parr Lake

Parr Lake (Figure A.7, Appendix A) is located in the Carleton River Watershed, downstream of Wentworth Lake. The lake has three defined inlets and a single outlet to the south, which drains to Ogden Lake. Land use in the lake watershed area is a mix of forested, developed and silviculture operations.

Five locations were monitored on Parr Lake on August 20, 2017, which included four ST locations (three inlets and one outlet), and one ML location. Single samples were taken at ST locations PARL-INA, PARL-INB, PARL-INC and PARL-OL1, and one sample (bottom) was taken at ML location PARL-DS1. In-situ field measurements were also recorded at each sample location. The bottom depth at PARL-DS1 was recorded as 5.8 m, with an estimated Secchi depth of 0.875 m. Secchi depth at the PARL-DS1 location did not meet the 1.2 m guideline value for lake clarity given by the Health Canada CRWQ guidelines. TP concentrations were classified as eutrophic at the lake inlet (0.040 mg/L at PARL-INA), outlet (0.060 mg/L at PARL-OL1) and PARL-DS1 bottom site (0.063 mg/L). Colour was similar in value at the inlet sites, at values of 213.0 TCU (PARL-INA), 216.0 TCU (PARL-INB), and 296.0 TCU (PARL-INC). Colour values were lower at the PARL-DS1 bottom site and outlet, at 124.0 and 113.0 TCU, respectively. Values of pH were lower than the CCME FAL pH range of 6.5 to 9.0 at the sampled locations, and below the Health Canada CRWQ guideline range of 5.0 to 9.0 at the inlet and outlet sites. DO concentrations were lower than the CCME FAL recommended minimum DO concentration of 6.5 mg/L at the PARL-INA inlet location and the PARL-DS1 ML location. Temperature and DO profiles at PARL-DS1 (Figure 7) show relatively consistent values through the water column, indicating a non-stratified lake environment.

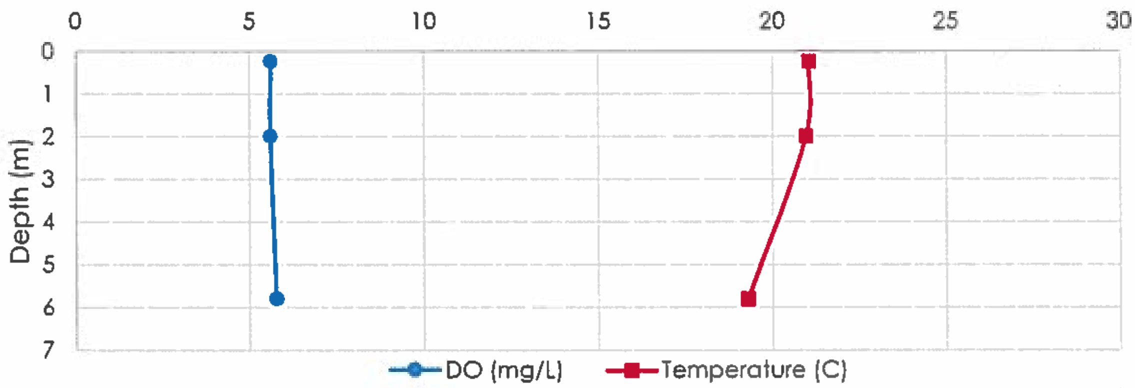

Figure 7 DO and Temperature Profiles for Parr Lake, Mid-Lake

5.1.1.8 Ogden Lake

Ogden Lake (Figure A.8, Appendix A) is located immediately south of Parr Lake in the southern area of the Carleton River Watershed. The lake has a single inlet and single outlet, which drains to the northwest, ultimately reaching Lake Fanning. Land use in the lake watershed area is a mix of forested and residential, with some silviculture.

Three locations were monitored on Ogden Lake on August 20, 2017, which included two ST locations (one inlet and one outlet), and one ML location. Single samples were taken at ST locations OL-IN1 and OL-OL1, and one sample (bottom) was taken at ML location OL-DS1. In-situ field measurements were also recorded at each sample location. The bottom depth at OL-DS1 was recorded as 19 m, with an estimated Secchi depth of 2 m. Secchi depth at the OL-DS1 location met the 1.2 m guideline value for lake clarity given by the Health Canada CRWQ guidelines. TP concentrations were classified as eutrophic at the lake inlet (OL-IN1). Colour was similar in value at the inlet site, at 119.0 TCU (OL-IN1), and lower at the OL-DS1 bottom site and outlet, at 83.4 and 81.6 TCU, respectively. Values of pH were lower than the CCME FAL pH range of 6.5 to 9.0 at the sampled locations, and below the Health Canada CRWQ pH range of 5.0 to 9.0 at the inlet and mid-depth ML site. DO concentrations were lower than the CCME FAL minimum recommended DO concentration of 6.5 mg/L at the OL-IN1, OL-DS1 and OL-OL1 locations. Temperature and DO profiles at OL-DS1 (Figure 8) show changes in temperature and DO through the water column that is indicative of thermal stratification. A bottom DO concentration of 0.67 mg/L indicates low oxygen conditions at the ML bottom location. The low bottom DO concentration creates a reducing environment that would potentially convert biologically unavailable precipitated P compounds in the sediment to biologically available dissolved forms of P.

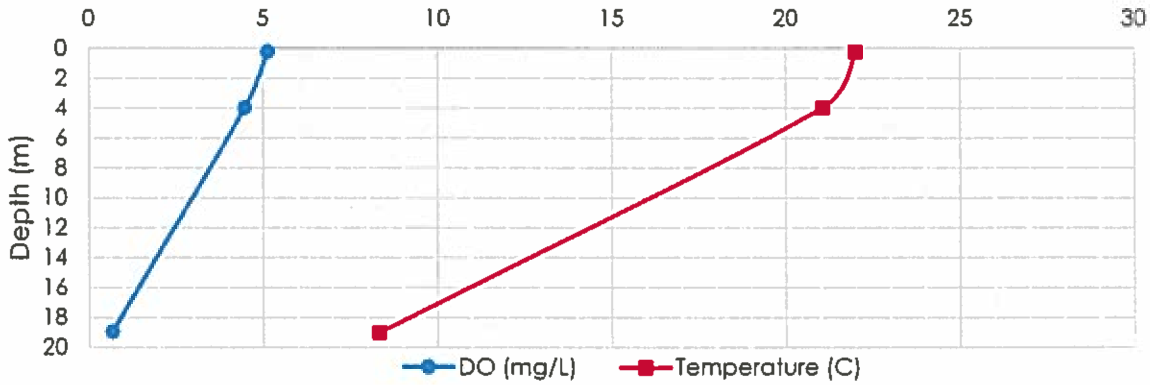

Figure 8 DO and Temperature Profiles for Ogden Lake, Mid-Lake

5.1.1.9 Lake Fanning

Lake Fanning (Figure A.9, Appendix A) is located in the southern area of the Carleton River Watershed to the south of Ogden Lake. The lake has three defined inlets and a single outlet, draining through Raynards Lake. Land use in the lake watershed area is mixed forested and developed, with some silviculture.

Five locations were monitored on Lake Fanning on August 23, 2017, which included four ST locations (three inlets and one outlet), and one ML location. Single samples were taken at ST locations LF-IN1, LF-IN2, and LF-IN3 and LF-OL1, and two samples (composite and bottom) were taken at ML location LF-DS3. In-situ field measurements were also recorded at each sample location. The bottom depth at LF-DS3 was recorded as 10 m, with an estimated Secchi depth of 1.5 m. Secchi depth at the LF-DS3 location met the 1.2 m guideline value for lake clarity given by the Health Canada CRWQ guidelines. TP concentrations were classified as meso-eutrophic, mesotrophic and oligotrophic at the lake inlets (0.030 mg/L at LF-IN1, 0.011 mg/L at LF-IN2 and 0.004 mg/L at LF-IN3) and meso-eutrophic at the outlet (0.022 mg/L at LF-OL1). A laboratory duplicate sample was taken at the LF-DS3 bottom site and TP concentrations differed at this location from 0.010 to 0.067 mg/L. Colour was lower at LF-IN3 (33.5 TCU) than other monitoring sites, which ranged from 76.8 TCU (LF-OL1) to 105.0 TCU (LF-IN1). Values of pH were lower than the CCME FAL pH range of 6.5 to 9.0 at the sampled locations, with the exception of the lake outlet. DO concentrations were lower than the CCME FAL minimum recommended DO concentration of 6.5 mg/L at the LF-OL1 and LF-DS3 ML location. Temperature and DO profiles at LF-DS3 (Figure 9) show changes in temperature and DO through the water column that is indicative of thermal stratification. A bottom DO concentration of 1.93 mg/L indicates low oxygen conditions at the ML bottom location.

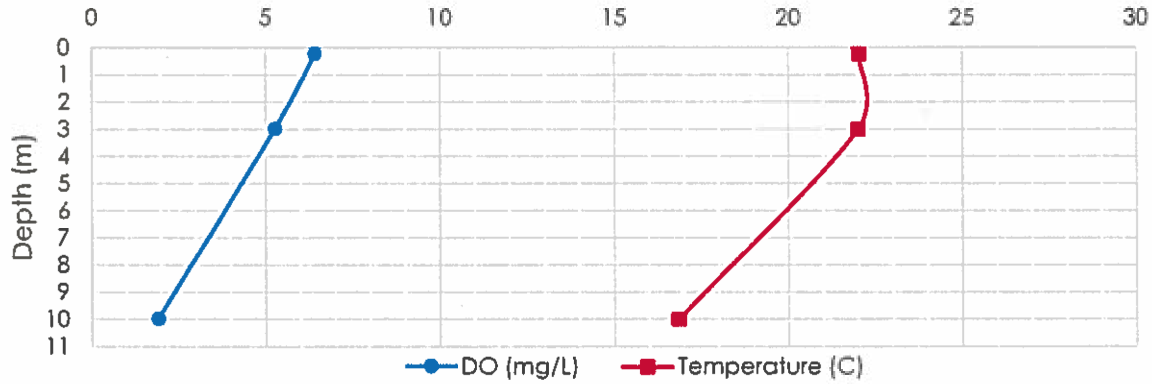

Figure 9 DO and Temperature Profiles for Lake Fanning, Mid-Lake

5.1.1.10 Sloans Lake

Sloans Lake (Figure A.10, Appendix A) is a tributary lake, located off the main branch of the Carleton River, in the southern area of the river watershed. There are no defined inlets to the lake, and the single outlet drains to Raynards Lake, south of Lake Fanning. Land use in the lake wastershed area is primarily forested, with residential developments along the northern boundary and some silviculture along the southern boundary. A mink farm has been constructed in the southwest drainage area (technical committee, personal communication) since the monitoring program began in 2009.

Three locations were monitored on Sloans Lake on August 21, 2017, which included one ST location (lake outlet), and two ML locations. Single samples were taken at the ST location, SL-OL1, and two samples (composite and bottom) were taken at each ML location, SL-DS1 and SL-DS2. In-situ field measurements were also recorded at each sample location. The bottom depth at SL-DS1 was recorded as 21 m, with an estimated Secchi depth of 4.35 m, and the bottom depth at SL-DS2 was recorded as 15.5 m, with an estimated Secchi depth of 4.75 m. Secchi depth at the both ML locations met the 1.2 m guideline value for lake clarity given by the Health Canada CRWQ guidelines. With the exception of pH and DO, grab samples and field measurements met the applicable guideline values. TP concentrations were classified as oligotrophic or ultra-oligotrophic at the sampled locations. Colour was low at the sampled locations, ranging from 11.4 TCU to 16.9 TCU. Values of pH were lower than the CCME FAL pH range of 6.5 to 9.0 at the sampled locations, and pH values mid-depth at the SL-DS2 location were lower than the desired pH range of 5.0 to 9.0 for the Health Canada CRWQ guidelines. DO concentrations were lower than the CCME FAL minimum recommended DO concentration of 6.5 mg/L at the sampled locations, except for the lake outlet (SL-OL1). Temperature and DO profiles at SL-DS1 and SL-DS2 (Figure 10) show changes in temperature and DO through the water column that is indicative of thermal stratification. The DO profile at SL-DS2 indicates similar DO concentrations through the water column.

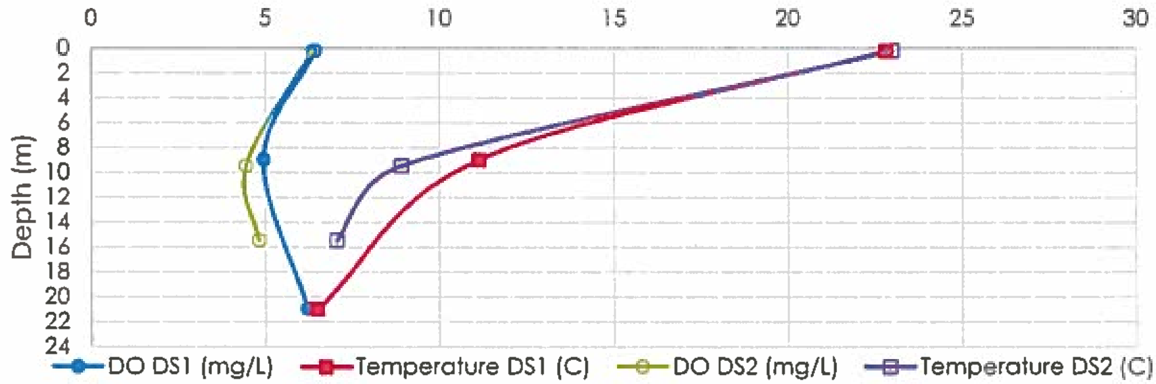

Figure 10 DO and Temperature Profiles for Sloans Lake, Mid-Lake at Two Locations

5.1.1.11 Lake Vaughan

Lake Vaughan (Figure A.11, Appendix A) is located within the southwestern area of the Carleton River Watershed, on the boundary of the Tusket River Watershed. The lake has two inlets, one receiving flow from Raynards Lake in the Carleton River Watershed, and one receiving flow from Gavels Lake, in the Tusket River Watershed (Brylinsky 2011). The single outlet drains to the Tusket River. Land uses in the lake watershed area consist of forest, residential, agricultural and silviculture operations. There is a mink farm located along the southern lake watershed boundary.

Five locations were sampled on Lake Vaughan on August 24, 2017, which included three ST location (two inlets and one outlet), and two ML locations. Single samples were taken the ST locations, VL-IN1, VL-IN2 and VL-OL1, and two samples (composite and bottom) were taken at each ML location, VL-DS1 and VL-DS2. In-situ field measurements were also recorded at each sample location. The bottom depth at VL-DS1 was recorded as 17.6 m, with an estimated Secchi depth of 1.625 m, and the bottom depth at VL-DS2 was recorded as 8 m, with an estimated Secchi depth of 0.875 m. Secchi depth at the VL-DS2 ML location did not meet the 1.2 m guideline value for lake clarity given by the Health Canada CRWQ guidelines. TP concentrations were classified as mesotrophic (ranging from 0.011 mg/L to 0.015 mg/L) at the sampled locations, except for a hyper-eutrophic classification at the ML bottom site VL-DS2 (at 0.136 mg/L). Colour varies between monitoring sites, with lower values at VL-IN1 (47.9 TCU) and the VL-DS1 composite site (51.2 TCU) and higher values at the VL-DS2 sites (193.0 and 178.0 TCU) and the lake outlet 141.0 TCU. Values of pH were lower than the CCME FAL desired pH range at the sampled locations, and pH values were lower than the desired pH range for the Health Canada CRWQ guidelines at the sampled locations with the exception of VL-DS1. DO concentrations were lower than the CCME FAL desired DO range at ST location VL-IN2 and the mid-depth and bottom sites at ML location VL-DS1. Temperature and DO profiles at VL-DS1 and VL-DS2 (Figure 11) show a well-mixed water column at VL-DS2 and changes in temperature and DO through the water column that is indicative of thermal stratification at VL-DS1. A bottom DO concentration of 1.83 mg/L at VL-DS1 indicates low DO conditions at that ML bottom location.

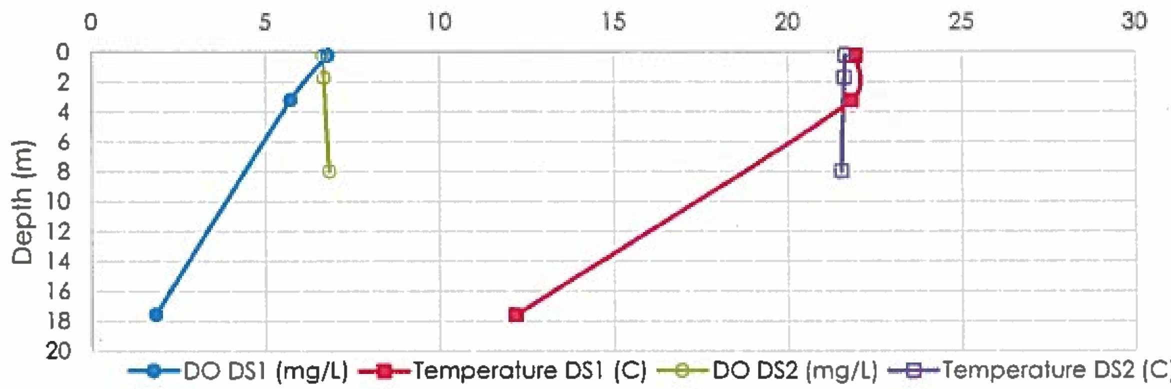

Figure 11 DO and Temperature Profiles for Lake Vaughan, Mid-Lake at Two Locations

5.1.2 Trophic Status Assessment

As discussed in Brylinsky (2011, 2013), Brylinsky and Sollows (2014), there are limitations when applying standard P-based trophic status frameworks to lakes with high colour. Colour can limit light penetration through the water column, potentially suppressing algal blooms that would typically occur in the presence of high-P concentration waters. The suppression of algal blooms can lead to a false suppression in chlorophyll a concentrations in these waters. Additionally, high-colour waters can have lower Secchi disk depths which, in low-coloured waters, are typically attributed to low lake water clarity caused by vegetation or algal growth. The Organization for Economic Co-Operation and Development (OECD) has developed a framework for trophic status assessment using TP as a primary indicator parameter and chlorophyll a and Secchi depth as secondary indicator parameters (OECD 1982). A modification to the OECD trophic status was proposed by Brylinsky and Sollows (2011), to include lake colour in lieu of Secchi depth (Table 1). Dystrophic refers to the degree of colour within a surface water body, with oligo-dystrophic corresponding to low colour values and eu-dystrophic corresponding to high colour values. The trophic status determined by TP and chlorophyll a concentrations refers to the vegetative productivity of a surface water body, with ultra-oligotrophic corresponding to low vegetative productivity and hyper-eutrophic corresponding to high vegetative productivity.

Table 1 Criteria for OECD Trophic Status with Colour Modification (OECD 1982; Brylinsky and Sollows 2011)

Total Phosphorus		Chlorophyll a		Colour	
mg/L	Trophic Status	µg/L	Trophic Status	TCU	Dystrophic Status
< 0.004	Ultra-oligotrophic	<1.0	Ultra-oligotrophic	-	-
0.004-0.01	Oligotrophic	≥1.0 - <2.5	Oligo-trophic	< 50	Oligo-dystrophic

Table 1 Criteria for OECD Trophic Status with Colour Modification (OECD 1982; Brylinsky and Sollows 2011)

Total Phosphorus		Chlorophyll a		Colour	
mg/L	Trophic Status	µg/L	Trophic Status	TCU	Dystrophic Status
0.01-0.02	Mesotrophic	≥2.5 - <8.0	Meso-trophic	≥50 - <100	Meso-dystrophic
0.02-0.035	Meso-eutrophic	≥8.0 - <25.0	Eutrophic	≥100	Eu-dystrophic
0.035-0.1	Eutrophic	≥25.0	Hyper-eutrophic	-	-
>0.1	Hyper-eutrophic	-	-	-	-

The modified trophic status is applied to the analytical data for composite ML locations for the 2017 monitoring period, with results shown in Table 2, below. Both Sloans Lake and Provost Lake are categorized low productivity and low colour lakes. Wentworth lake is categorized as a high colour and high productivity lake, with respect to TP concentrations. Algae growth in this lake appears to be suppressed by high colour, resulting in a meso-trophic status for chlorophyll a. Colour appears to be suppressing algae growth concentrations at the VL-DS2 ML sample location in Lake Vaughan, as chlorophyll a is categorized as oligo-trophic despite higher TP concentrations. Nowlans Lake, Hourglass Lake and Placides Lake are categorized as high productivity with respect to both TP and chlorophyll a concentrations. Colour is present in these lakes, but was not observed at sufficient high enough values to suppress algae growth. If colour becomes reduced in Wentworth Lake and the VL-DS2 ML site in Lake Vaughan, vegetative productivity could potentially increase at these locations. ML composite sample results were not available for Ogden Lake or Parr Lake (Section 5.1).

Table 2 Modified Trophic Status for ML Surface Composite Sample Monitoring Sites

Lake	Station ID	Total Phosphorus	Chlorophyll a	Colour
Provost	PROL-DS1	Oligotrophic	Meso-trophic	Oligo-dystrophic
Hourglass	HL-DSI-CS	Eutrophic	Hyper-eutrophic	Meso-dystrophic
Nowlans	NL-DS1	Hyper-eutrophic	Hyper-eutrophic	Oligo-dystrophic
Placides	PLAL-DS1	Hyper-eutrophic	Eutrophic	Meso-dystrophic
Porcupine	PORL-DS1	Mesotrophic	Oligo-trophic	Oligo-dystrophic
Wentworth	WL-DS1	Eutrophic	Meso-trophic	Eu-dystrophic
Fanning	LF-DS3-CS	Meso-eutrophic	Meso-trophic	Meso-dystrophic
Sloans	SL-DS1	Oligotrophic	Oligo-trophic	Oligo-dystrophic
Sloans	SL-DS2	Ultra-oligotrophic	Oligo-trophic	Oligo-dystrophic
Vaughan	VL-DS1X-CS	Mesotrophic	Eutrophic	Meso-dystrophic
Vaughan	VL-DS2-CS	Mesotrophic	Oligo-trophic	Eu-dystrophic

5.1.3 Nutrient Ratio Assessment

5.1.3.1 Limiting Nutrients

In a variety of natural systems, TP is typically considered a 'limiting nutrient'; that is, the availability of TP in the natural environment is reduced in comparison to other required nutrients and vegetation growth can be limited by the lack of available TP for growth. In systems influenced by anthropogenic TP sources, TP is no longer considered a limiting nutrient and vegetation or algal growth can increase. In general, a mass ratio of TN:TP concentrations below 17:1 is an indicator of nitrogen limitation, whereas a mass ratio of TN:TP concentrations above 17:1 is an indicator of P limitation. This is based off of the Redfield Ratio theory (Redfield 1934), which assumes the ideal nutrient ratio between TN and TP and is employed in Brylinsky (2011). The calculated TN:TP mass ratios for composite ML sample sites for the 2017 monitoring period are shown in Table 3.

Table 3 TN:TP Mass Ratios for ML Monitoring Sites

Lake	Station ID	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	TN:TP Mass Ratio
Provost	PROL-DS1	0.29	0.008	36
Hourglass	HL-DSI-CS	0.41	0.073	6
Nowlans	NL-DS1	1.25	0.620	2
Placides	PLAL-DS1	0.46	0.618	1
Porcupine	PORL-DS1	0.29	0.017	17
Wentworth	WL-DS1	0.46	0.084	5
Fanning	LF-DS3-CS	0.33	0.022	15
Sloans	SL-DS1	0.15	0.004	38
Sloans	SL-DS2	0.15	0.003	50
Vaughan	VL-DS1X-CS	0.28	0.015	19
Vaughan	VL-DS2-CS	0.38	0.012	32

Four lakes have a TN:TP mass ratio of less than 17:1: Hourglass Lake, Nowlans Lake, Placides Lake and Wentworth Lake. These lakes are considered nitrogen-limited, meaning P is readily available for aquatic vegetative growth. Lake Fanning and Porcupine Lake have ratios close to the threshold, indicating they may be limited by both TN and TP. Provost Lake, Sloans Lake and Lake Vaughan are considered P-limited, with TN:TP ratios of greater than 17:1. These ratios are generally supported by the trophic status indicators presented in Section 5.1.3.1, with the exception of Lake Vaughan.

5.1.3.2 Phosphorus Ratios

Ortho-phosphate (ortho-P) is an inorganic form of P that is readily available in the dissolved form for vegetation uptake and use. In P-limited environments, ortho-P uptake is rapid and measurement of ortho-P may be difficult (CCME 2004). The ratio of ortho-P to TP in a lake system may be indicative of the degree of P limitation within the system. Ratios of ortho-P:TP for composite ML sites for the 2017 monitoring period are shown in Table 4, below.

Table 4 Ortho-P:TP Ratios for ML Monitoring Sites

Lake	Station ID	Total Phosphorus (mg/L)	Ortho-phosphorus (mg/L)	Ortho-P:TP Ratio
Provost	PROL-DS1	0.008	0.004	0.50
Hourglass	HL-DSI-CS	0.073	0.028	0.38
Nowlans	NL-DS1	**0.620**	0.465	**0.75**
Placides	PLAL-DS1	**0.618**	0.506	**0.82**
Porcupine	PORL-DS1	**0.017**	0.013	**0.76**
Wentworth	WL-DS1	**0.084**	0.082	**0.98**
Fanning	LF-DS3-CS	**0.022**	0.010	**0.45**
Sloans	SL-DS1	0.004	0.004	1.00
Sloans	SL-DS2	0.003	0.003	1.00
Vaughan	VL-DS1X-CS	**0.015**	0.010	**0.67**
Vaughan	VL-DS2-CS	0.012	0.006	0.50

Previous assessments (Sollows 2016) applied an arbitrary threshold of a ratio of greater than 0.50 or higher at a TP concentration of 0.02 mg/L or higher to assess risk for algal blooms in the monitored lakes. Using this criteria, Nowlans Lake, Placides Lake, Porcupine Lake, Wentworth Lake, Fanning Lake and Vaughan Lake are flagged as having excess inorganic P. These lakes also have the highest TP concentrations in the data set.

5.1.4 Flow Monitoring and Phosphorus Loading Rates

Flow monitoring was scheduled to be conducted at ST (inlet/outlet) locations during the 2017 monitoring period; however, site conditions prevented the collection of this data at the majority of sites (Section 5.1).

Data in this section is presented for PARL-INC, an ST inlet location on Parr Lake (Table 5). At the time of sampling, flow at this location was measured as 0.091 m^3/s, through a stream cross-section measuring 4.62 m of total width. Using this flow rate and select laboratory data associated with this site at the time of flow measurement, estimated loading rates for select parameters are shown in Table 5, below.

Table 5 Select Parameter Loading Rates for PARL-INC (August 20, 2017)

Parameter	Total Phosphorus (mg/L)
Concentration	0.02
Loading Rate (kg/day)	0.157

As previously discussed, a number of the lake inlet/outlet monitoring stations were not safe for staff and volunteers to access to measure flow (Section 5.1). Additionally, there were technical issues (data download) with the flow results recorded at a number of monitored sites. To inform future work in the lake watersheds, a table summary of whether flow monitoring can be conducted at each ST site has been complied in a 'go/no-go' format and is given in Table F.1, Appendix F.

Flows for the 2017 monitoring event were estimated at the ST stations using the watershed area-ratio and 2009 measured percent difference methods (Table D.6, Appendix D and Figure 12). The flows were extrapolated from the measured flow at PAR-INC. The area-ratio method for lower Carleton River Watershed Lakes for the larger drainage area lakes (>20,000 ha) typically predicted the highest flow rates of the two flow prediction methods, particularly for Vaughan at VL-IN2 and VL-OL1 (Figure 12). The 2009 percent difference calculated flows were closer in order of magnitude consistently at all stations when compared to 2009, 2010 and 2011 measured flow rates. The 2009, 2010 and 2011 measured flows based on interpretation of the results were calculated based on a single velocity, single depth and single width measurement with an assumed channel dimension of rectangular, based on depth and width. The actual channel shape at these locations may be triangular or trapezoidal, particularly for the smaller headwater inlet channels.

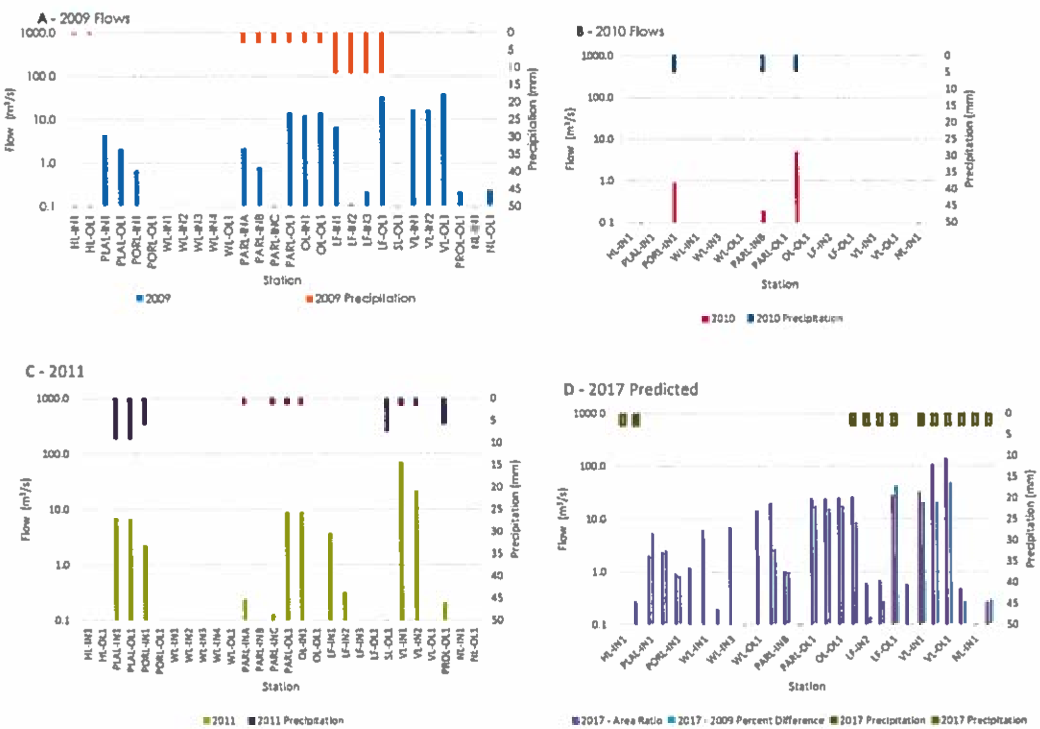

Figure 12 **2009, 2010 and 2011 Measured Flows and 2017 Measured/Predicted Flows at Stream Stations.**

Figure 13 presents the observed and predicted TP loads for 2009, 2010, 2011 and 2017. The 2017 area-ratio predicted TP loads were typically higher than the 2009 percentage difference flow TP loads, except for Placides inlet (PLAL-IN1) and outlet (PLAL-OL1), and Lake Fanning outlet (LF-OL1). Placides inlets and outlets had the highest predicted TP loads for the 2009 percent difference method in the study and were also high for the area-ratio method. The Placides Lake inlet and outlet TP loads are similar in order of magnitude indicating the immediate lakeshore drainage area as not a significant contributor to the P load, and minimal P removal within the lake water column. Parr Lake results observed a substantial difference in predicted TP loads between the inlets and outlet where substantially higher TP loads are observed at the outlet. This potentially indicates that the Parr Lake P loading to the lake is coming from immediate lakeshore drainage area and/or lake bottom sediments and contributing to the increased lake outlet TP load. The Ogden inlet TP load was observed to be higher than the Ogden outlet load, indicating P is potentially being deposited into the lake sediments through settling of particulate P and/or incorporated into the aquatic vegetation within the lake. The area-ratio method predicted the highest TP load at the Vaughan Lake outlet (VL-OL1).

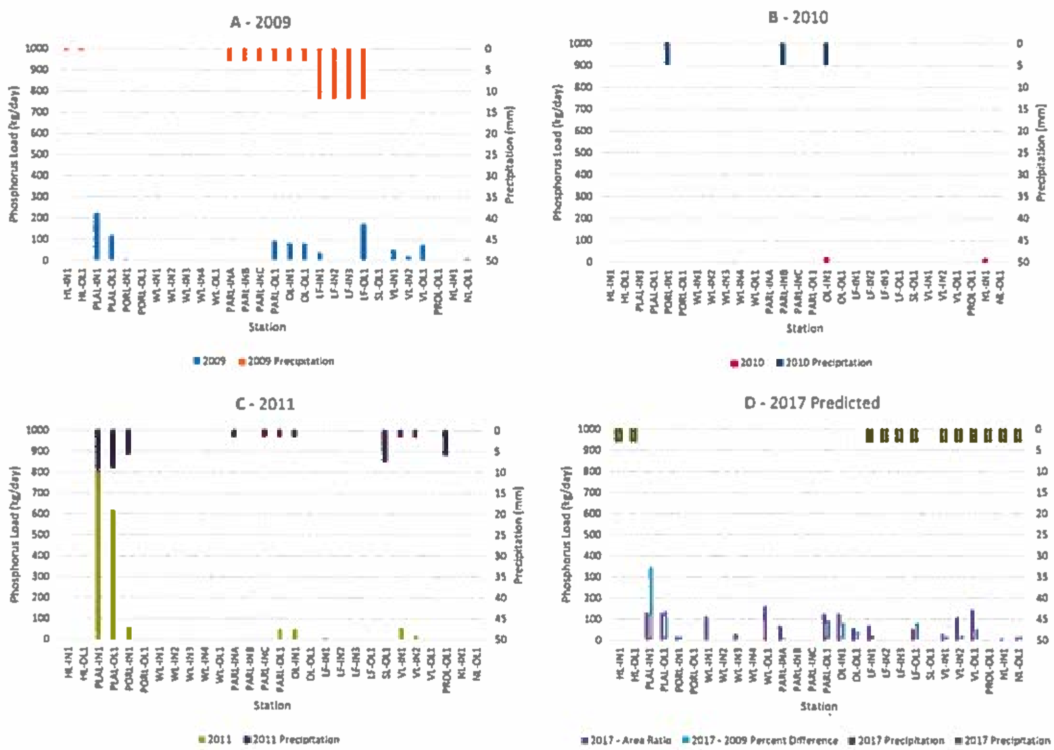

Figure 13 2009, 2010, 2011 and 2017 Total Phosphorus Loads at Stream Stations.

As a comprehensive nutrient/contaminant loading study requires flow monitoring to estimate event or annual loads at each ST location for a given lake, lakes where data collection may not be possible at one or more ST locations are considered a 'no-go' for future flow monitoring. Based on ground-truthing during the August 2017 monitoring event, inlet/outlet flow monitoring and contaminant load estimation is considered possible at the following lakes using the mid-section method with chest waders:

- Hourglass Lake
- Placides Lake
- Porcupine Lake
- Lake Fanning
- Provost Lake
- Nowlans Lake
- Sloans Lake

Flow monitoring by wading in with chest waders is not recommended at the following lakes, based on the depth of watercourse at either the inlet or outlet ST stations preventing safe access for personnel:

- Wentworth Lake
- Parr Lake
- Ogden lake
- Lake Vaughan

For these lakes, alternative flow methods may be required to safely estimate flows. One potential method is to string a rope across the channel that is anchored to wooden or metal stakes driven into the ground. The boat would be tethered to this rope across the watercourse and flow measurements would be done using a velocimeter that can be attached to a pole of sufficient length to measure flow at 20, 50 and 80% of the water depth at 15-20 locations across the watercourse width. Another alternative method is to use an acoustic doppler current profiler; however, the local availability and associated purchase or rental costs may make this a prohibitive method for consistent use in an ongoing monitoring program. Stantec recommends developing a procedure using a tethered boat and a velocimeter attached to a sufficiently long rod to measure stream velocity at appropriate depths.

5.2 HISTORICAL DATA AND TRENDING

5.2.1 Climate Normals

Climate data was taken from the Environment and Climate Change Canada meteorological station at the Yarmouth Airport (Climate ID: 8206495) (Environment and Climate Change Canada 2017). Climate data for the sampling/open water seasons (May 1 – September 30) of the current and previous monitoring year is presented in Figures 14 and 15, below.

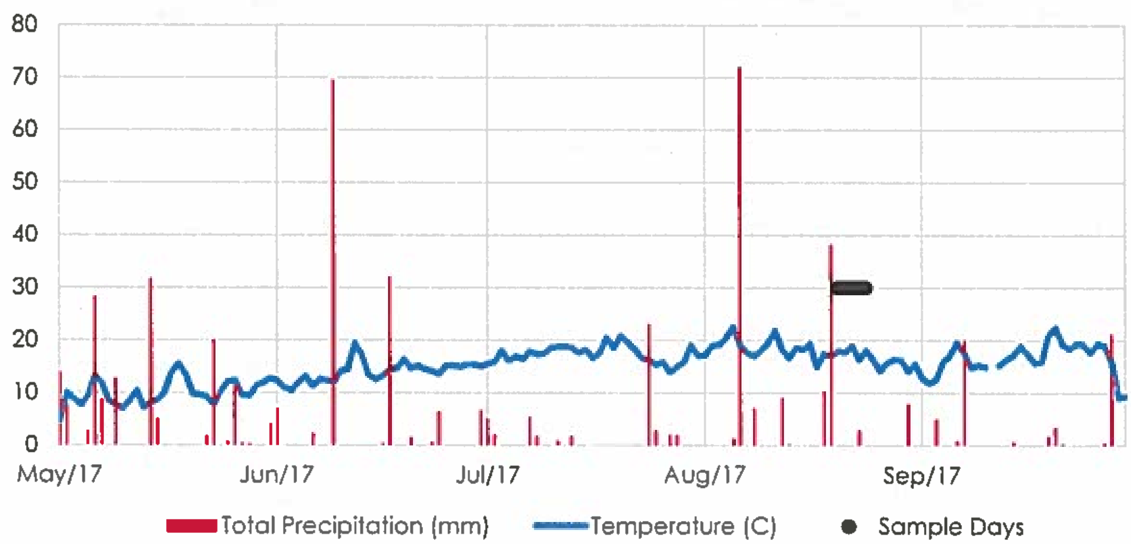

Figure 14 Temperature and Precipitation Normals for 2017 Sampling Season

During the 2017 sampling season a total of 533.2 mm of precipitation was recorded, with peak rainfall amounts of 72.2 mm during a single event in August. A rainfall event of 38.4 mm was recorded on August 19, 2017, immediately preceding the August 2017 monitoring period, and rainfall in an amount of <5 mm was recorded during monitoring, on August 23, 2017.

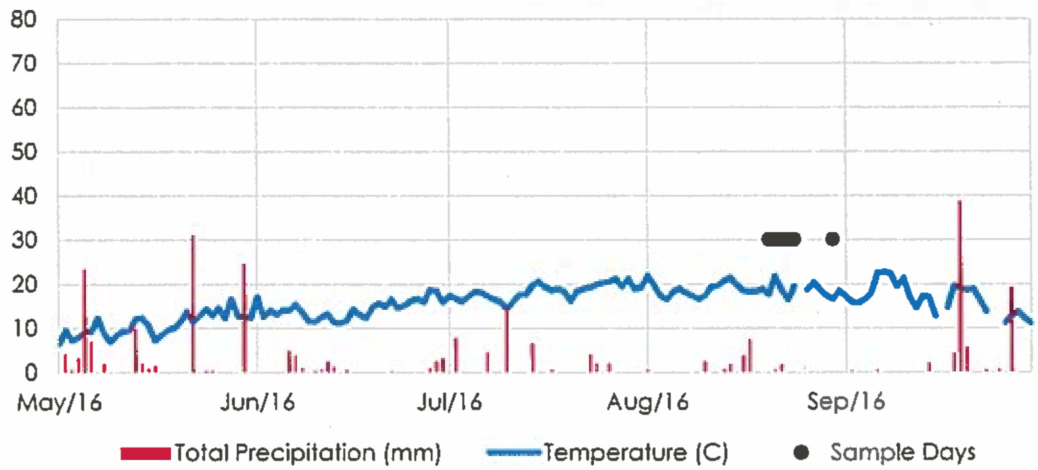

Figure 15 Temperature and Precipitation Normals for 2016 Sampling Season

During the 2016 growing period, a total of 270.8 mm of precipitation was recorded, with peak rainfall amounts of 38.6 mm during a single event in September. Several small rainfall events (<5 mm) were recorded in August, immediately preceding and during the August 2016 monitoring period.

Based on climate normals provided for Yarmouth Airport meteorological station (1981 to 2010) (Table 6), rainfall amounts during the sampling of 2017 were higher than average. Rainfall amounts during the sampling season of 2016 was significantly below average precipitation normals for the area.

Table 6 Climate Normals for the Yarmouth Airport (1981 to 2010)

Month	Average Precipitation (mm)	Average Temperature (°C)
May	100.9	9.7
June	94.8	13.8
July	88.4	16.8
August	84.3	17
September	94.9	14.1
Total Precipitation	463.3	-

Rainfall data taken from a select number of weather stations local to the Yarmouth area is shown in Table 7.

Table 7 AGRG Rainfall Data for Select Stations in Yarmouth, NS

Station	Year	Sampling Season Total Precipitation (mm)	Peak August Rainfall (mm)
YA3	2016	195.6	22
	2017	225.8	33.2
YA4	2016	317.8	29.2
	2017	443.2	93.6
WE5	2016	358.4	23
	2017	439.8	42.6

The Applied Geomatics Research Group (AGRG) Weather Network (2017) has a network of weather stations (~75) in the southwestern area of Nova Scotia. Rainfall data taken from three stations (YA3, YA4 and WE5) show similar trends to the Environment Canada climate data in that rainfall amounts in 2017 are higher than 2016; however, peak daily rainfall in August are higher using the AGRG data. Total rainfall amounts differ depending on the location in the watershed, and trend upward as you move inland from the station closest to Yarmouth (YA3). Rainfall data graphs taken from AGRG (2017) are shown in Appendix G.

5.2.2 Historical Watershed Select Water Quality Parameter Trends

Historical monitoring results of select parameters from each sampled lake between 2009 and 2017 (with no sample event in 2012) are presented in the following sections. Results are given for select ML sample locations and represent an average between composite and bottom samples. While these composited results provide an estimate of average conditions within the lake environment there is potential bias based on lake shape and volume associated with sample depths. Results from Parr Lake and Ogden Lake for the 2017 monitoring period reflect bottom samples only (Section 5.1).

5.2.2.1 Total Phosphorus

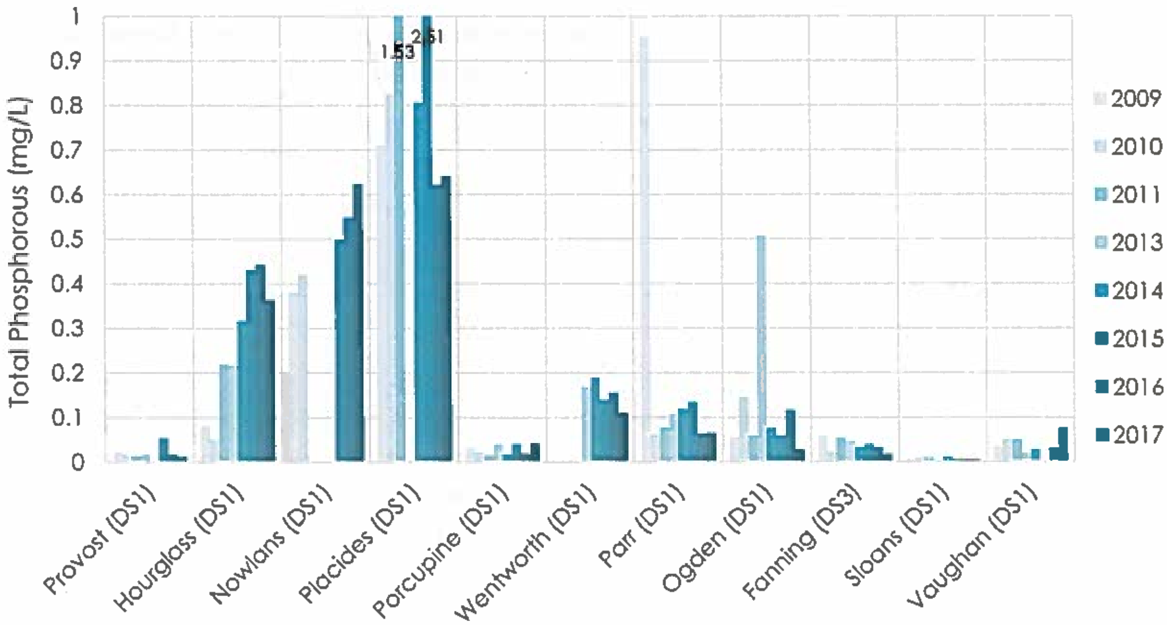

Figure 16 Historical Average Mid-Lake Composite and Bottom TP Concentrations by Lake (2009 – 2017)

Increases in TP concentration over the previous 2016 monitoring period were found in Nowlans Lake (0.55 mg/L to 0.62 mg/L), Placides Lake (0.62 mg/L to 0.64 mg/L), Porcupine Lake (0.017 mg/L to 0.041 mg/L) and Lake Vaughan (0.031 mg/L to 0.076 mg/L) (Figure 16). The increases in Placides Lake and Porcupine Lake are considered within the range of historical concentration fluctuations in these lakes. The 2017 TP concentrations in Nowlans Lake and Lake Vaughan represent the highest TP concentration measured in these lakes over the historical monitoring period, replacing the previous peak values of 0.049 mg/L as measured in Lake Vaughan in 2011, and 0.55 mg/L, as measured in Nowlans Lake in 2016. Trends appear to show TP levels increasing over time in Hourglass Lake and Nowlans Lake. As per historical trends, Placides Lake has the highest TP concentrations in the watershed, and Sloans Lake has the lowest. Overall TP concentrations shift from increasing TP concentrations through the three Carleton River watershed headwater lakes (Hourglass Lake, Placides Lake and Porcupine Lake) and Nowlans Lake in the Meteghan River Watershed, to decreasing concentrations within the tailwater lakes from Wentworth Lake to Lake Vaughan. A notable decrease in ML TP concentrations occurs between Placides Lake and Wentworth Lake.

Additionally, at the aquaculture facility inlet in Hourglass Lake (HL-AQIN1) and watercourse outlet (AQOL1) measured the highest TP concentration (0.125 mg/L and 0.134 mg/L, respectively) in comparison to previous years (Table D.4, Appendix D). Active discharge was observed from the inlet pipe and watercourse outlet during the August 2017 sample event.

The Placides Lake inlet and outlet TP loads were estimated to be some of the highest within the Carleton River Watershed, particularly for 2011 (Figure 13). The inlet to Placides has an estimated 2,111 ha watershed area, which includes a number of fur farms and other agricultural operations, potentially contributing to the high observed and predicted TP loads. Other lake inlet and outlet predicted TP results for 2017 using the 2009 percent difference prediction method were comparable to previous years. The Vaughan Lake inlet station (VL-IN1) for the upstream Carleton River Watershed predicted a decreased TP load in comparison to 2009 and 2011 predicted TP loads. The Lake Fanning outlet TP loads (LF-OL1) were estimated for 2009 and 2017 (2009 percent difference method) to be higher than all of the inlet loads combined, indicating potential internal TP loading from the lake sediments or the immediate lakeshore drainage area.

5.2.2.2 Total Nitrogen

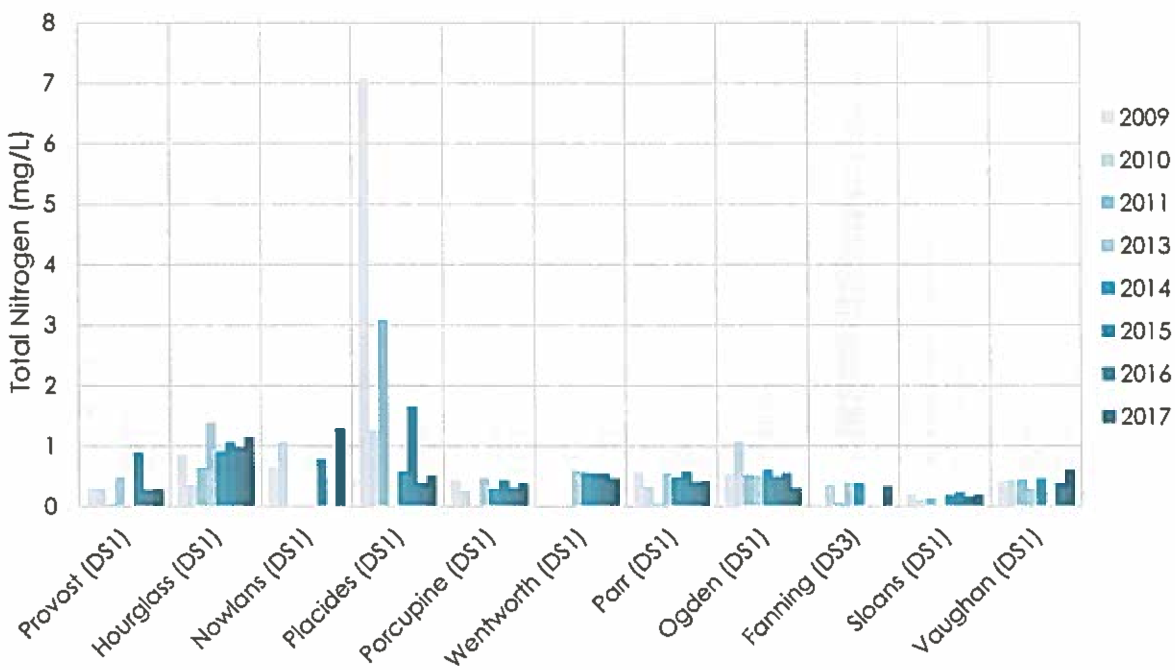

Figure 17 Historical Average Mid-Lake Composite and Bottom TN Concentrations by Lake (2009 – 2017)

Increases in TN concentrations over the previous 2016 monitoring period were observed in Nowlans Lake (0.77 mg/L in 2015 to 1.28 mg/L), Provost Lake (0.27 mg/L to 0.28 mg/L), Hourglass Lake (0.97 mg/L to 1.14 mg/L), Placides Lake (0.38 mg/L to 0.5 mg/L), Porcupine Lake (0.29 mg/L to 0.38 mg/L), Sloans Lake (0.15 mg/L to 0.18 mg/L) and Lake Vaughan (0.37 mg/L to 0.595 mg/L) (Figure 17). With the exception of Nowlans Lake, Hourglass Lake, Placides Lake and Lake Vaughan, the increases in TN concentration are considered within the range of historical concentration fluctuations in these lakes. The 2017 TN concentrations in Nowlans Lake and Lake Vaughan represent the highest TN concentrations measured in these lakes over the historical monitoring period, replacing the previous peak value of 1.06 mg/L observed in Nowlans Lake in

2010 and 0.455 mg/L observed in Lake Vaughan in 2014. Nowlans Lake and Sloans Lake have the highest and lowest TN concentrations, respectively, within the monitoring program. High TN concentrations are also observed in Hourglass Lake. Aquaculture operations are a potential source of nitrogen to surface water bodies, which may account for some of the higher TN concentrations found in Hourglass Lake (CCME 2007; Merceron et al. 2002). Placides Lake has historically had the highest reported TN concentrations within the watershed but TN concentrations appear to be trending downward in this lake. Nowlans Lake, Hourglass Lake and Lake Vaughan TN concentrations are observed to be increasing. Although there are fluctuations in TN concentrations within each lake between monitoring years, overall trends appear to be relatively stable in the remaining lakes.

5.2.2.3 Chlorophyll a

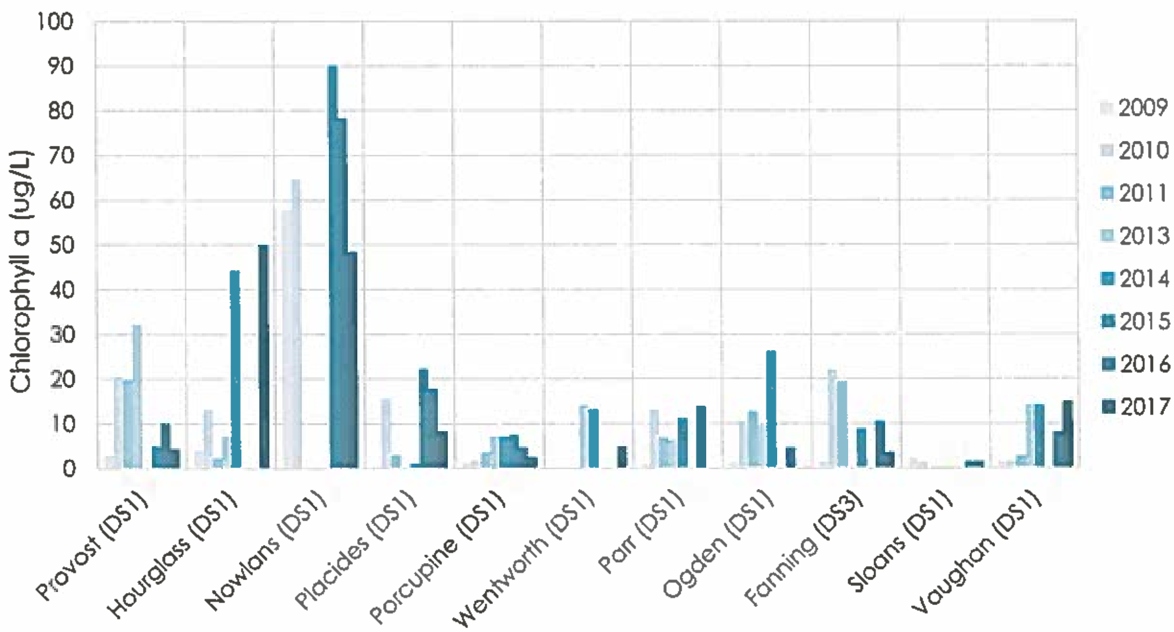

Figure 18 **Historical Average Mid-Lake Composite and Bottom Chlorophyll a Concentrations by Lake (2009 – 2017)**

As presented in Figure 18, increases in chlorophyll a concentrations over the previous monitoring period were found in Hourglass Lake (7 μg/L to 44 μg/L), Parr Lake (11 μg/L to 13.7 μg/L) and Lake Vaughan (7.87 μg/L to 14.7 μg/L). With the exception of Hourglass Lake, the increases in chlorophyll a concentration are considered within the range of historical concentration fluctuations in these lakes. The 2017 chlorophyll a concentration in Hourglass Lake represents the highest chlorophyll a concentration measured in the lake over the historical monitoring period, replacing the previous peak value of 44 μg/L as measured in 2014. While chlorophyll a concentrations in Hourglass Lake appear to represent trending patterns that align with increasing TP concentration trends, other monitored lakes do not, including those downstream of Hourglass. The headwater Sloans Lake remains the lake with the lowest concentrations. Although Placides Lake has higher concentrations of TP and TN than both Hourglass Lake and Nowlans Lake, it is markedly lower in chlorophyll a concentrations, potentially due to high colour as discussed in the section below. As chlorophyll a concentrations are directly affected by the quantity of algae present in the water during sampling, results may be skewed if a sampling event occurs during an algal bloom. Additionally, fluctuations in colour may also affect vegetation growth in a lake from year to year, resulting in changes in chlorophyll a concentrations.

5.2.2.4 Colour

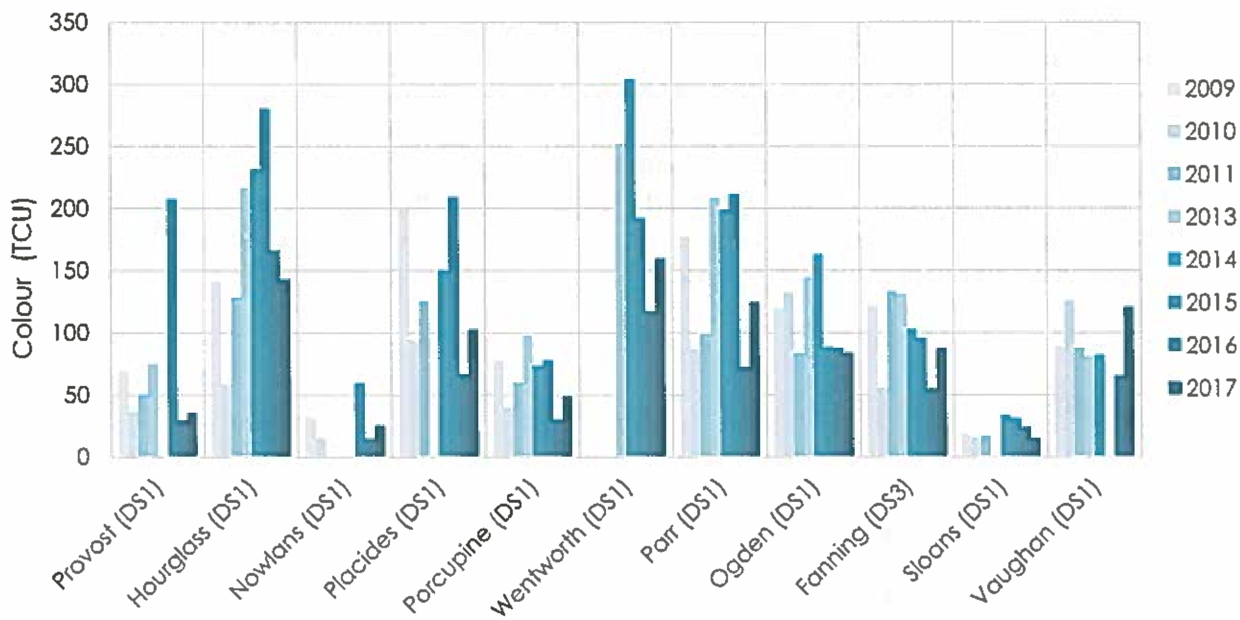

Figure 19 Historical Average Mid-Lake Composite and Bottom Colour Values by Lake (2009 – 2017)

Historical monitoring results of colour from each sampled lake are shown in Figure 19, above.

Increases in colour over the previous 2016 monitoring period were found in Nowlans Lake (14.7 TCU to 25 TCU), Provost Lake (29 TCU to 35.2 TCU), Placides Lake (66.2 TCU to 102.3 TCU), Porcupine Lake (29.7 TCU to 48.35 TCU), Wentworth Lake (117 TCU to 159.5 TCU), Parr Lake (71.95 TCU to 124 TCU), Lake Fanning (54.5 TCU to 87 TCU) and Lake Vaughan (64.95 TCU to 120.1 TCU). This represents a deviation from historical downward trends in Wentworth Lake, Lake Fanning and Lake Vaughan and may be attributed to the marked increase in total precipitation during the 2017 sampling season from 2016, and importantly, immediately preceding the sampling events in August 2017. There is a distinct increase in colour within the watershed beginning at Wentworth Lake, with colour decreasing from this point through downstream lakes. Nowlans Lake and Sloans Lake had the lowest colour measurements within the watershed, with Hourglass

Lake and Wentworth Lake having the highest. In certain cases, colour may be inversely proportional to the concentration of chlorophyll a in a lake system due to suppression of light penetration through the water column. The inverse colour to chlorophyll a relationship is potentially observed in Hourglass Lake, Placides Lake and Wentworth Lake, where TP concentrations are not limiting yet chlorophyll a concentrations are similar to lakes that are not limited by TP (Figures 14 and 16).

5.2.2.5 Cyanobacteria and Microcystins

Historical cyanobacteria cell counts from each sampled lake are shown in Figure 20. Cell counts have fluctuated in lakes over the historical monitoring period; however, counts in Nowlans Lake have been consistently higher than all other monitored lakes. Nowlans Lake is the only lake to have exceeded the Health Canada GCRWQ value of 100,000 cells/mL, which occurred during monitoring in October 2009 and again in August 2015. Provost Lake, Placides Lake, Wentworth Lake, Parr Lake and Sloans Lake have historically had concentrations below 5,000 cells/mL. Nowlans Lake, Ogden Lake and Lake Fanning are the only lakes to have exceeded 20,000 cells/mL over the historical monitoring period. Nowlans Lake is the only monitored lake to have observed detections of microcystins over the course of historical monitoring, with detections occurring in August 2011 (11.82 µg/L), August 2015 (0.37 µg/L) and August 2016 (0.27 µg/L).

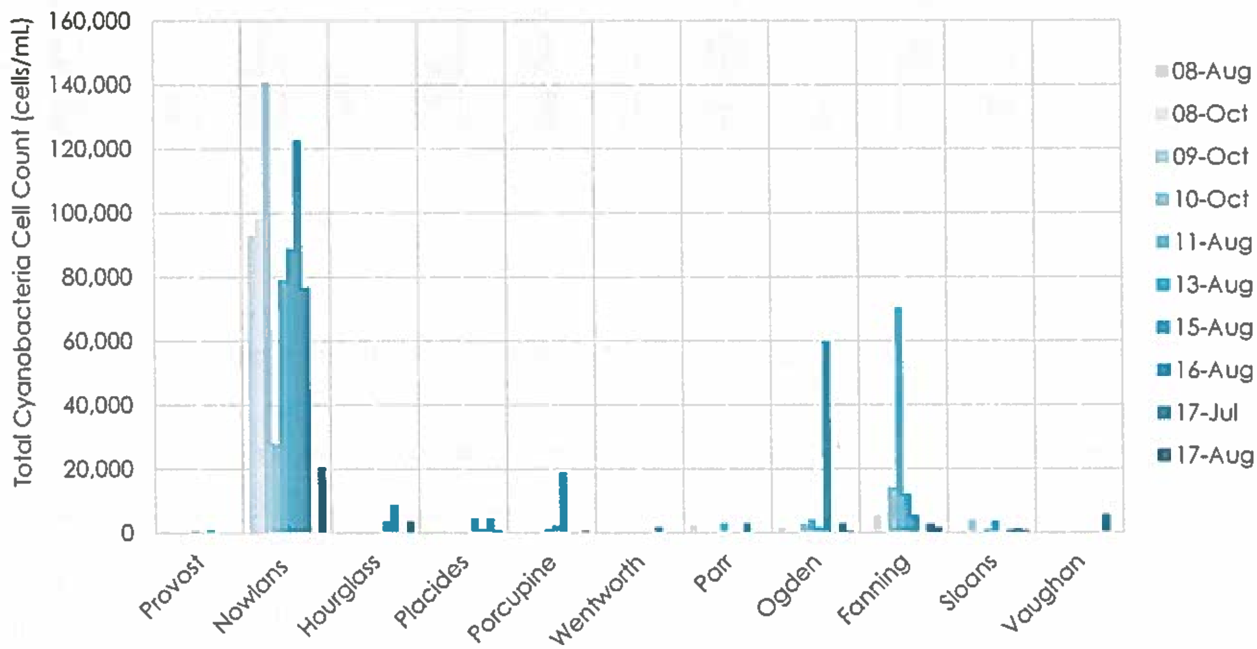

Figure 20 Historical Cyanobacteria Cell Counts by Lake (2008 - 2017)

6.0 SUMMARY AND RECOMMENDATIONS

Summary points derived from the review of annual and historical data are as follows:

- At 3.3 mg/L, the inlet TP concentration at NL-IN1 on Nowlans Lake was significantly higher than other monitored lakes. There is a large mink farming operation and several residences in the small subwatershed draining to the inlet location, which may be sources of the elevated TP concentrations.
- Hourglass Lake and Placides Lake each have consistently high TP concentrations within lake waters (ML monitoring sites). Residences, aquaculture operations and mink farming within the Hourglass Lake watershed are likely contributors to the current TP conditions within this lake.
- Placides Lake has the highest TP concentrations and TP inlet and outlet loads of all sampled lakes. The Placides Lake watershed includes upstream lakes (Hourglass), a number of mink farm and other agricultural operations, and residences upstream of the Placides Lake inlet. The inlet and outlet TP loads are similar in order of magnitude indicating the immediate lakeshore drainage area is not a significant contributor to the P load. There is potential that TP sources in this lake are derived from upstream sources (Hourglass Lake) as land use in the lakeshore watershed area does not have an identifiable source of TP loading to the lake (i.e. domestic wastewater sources, aquaculture operations, agricultural or mink farming operations).
- Parr Lake for the 2017 monitoring event indicated lower inlet TP loads then the outlet TP load. This potentially indicates TP loading from the lakeshore drainage area and/or lake sediments. Additional sampling events (during surface runoff events and more baseflow monitoring), including sediment samples for P analysis, may assist with identifying P load dynamics in this lake system. Additionally, P analysis of Ogden lake bottom sediments would be potentially worth monitoring due to the observed reduction in predicted TP loads between the inlet and outlet observed in 2017.
- Hourglass Lake and Lake Vaughan consistently showed increases in parameter concentrations (TP, TN, chlorophyll a) over the previous monitoring period (2016). Trophic indicator parameters tend to decrease in concentration/value as one moves downstream through the Carleton River watershed system, except the outlet lake, Lake Vaughan. Land use in the area surrounding Lake Vaughan may be a contributing factor to increases at this lake (i.e. agricultural activities and mink farming).
- Colour values increase sharply (48.35 to 159.5 TCU) within the Carleton River Watershed at Wentworth Lake. These colour values are elevated, yet decreasing, through the subsequent three downstream lakes (Parr Lake, Ogden Lake and Lake Fanning).

- Values of pH tend to decrease from headwater to tailwater lakes within the Carleton River Watershed. Lower values of pH are not necessarily attributed to high colour lakes (i.e. humic acid addition from vegetation sources) and may be potentially caused by local geomorphology (Trudell and White 2013).

Recommendations for future work are as follows:

- The implementation of a dedicated flow monitoring program at inlet/outlet ST locations within select lakes. The trending of loading rates over time is thought to be a valuable asset to the identification of persistent nutrient sources within the monitored watersheds.
- Estimating TP loads from individual land uses is difficult and requires monitoring of flows and TP concentrations prior to discharge into a lake environment. This requires channelized flows to be identified as potential sample sites. Future monitoring programs should potentially ground truth small drainage areas to identify areas where channelized flow from overland runoff occurs and what size precipitation event triggers measurable flows. This will help develop a better monitoring program to quantify land use loads from individual land uses, particularly when assessing the P loading impacts from implemented mitigation measures.
- The determination of the effect of benthic sediments in the contribution to TP concentrations in the water column of select lakes. This can be accomplished through i) the development of nutrient balance models for several select lakes (Nowlans, Hourglass and Placides) using established ST loading rates and land use inputs to determine lake source/sink of nutrients in conjunction with a baseflow and storm event monitoring program (6+ sample events) or ii) the carrying out of a sampling program using sediment cores within the select lakes. Additionally, differences between inlet and outlet TP loads in Parr and Ogden would be worth investigating. This could be achieved by assessing the impacts of sediments via a sediment sampling program and by increased inlet/outlet storm event and baseflow water quality monitoring.
- The use of development planning tools to account for and mitigate TP loading from future development within each watershed. Land use in many lake watersheds is primarily forested and changes in land use can potentially affect TP loading rates to adjacent lakes.

6.1 OBJECTIVES

The following were the objectives of the 2017 monitoring project objectives and how each was achieved:

1. *A data base that complements existing data bases by indicating trends and/or patterns in study parameters and more clearly defining environmental pressures on the study system.*

A data base was created of historic monitoring data and the 2017 monitoring program water quality results and associated graphs, that has been provided under separate cover to the CRWAWQM SC.

2. *A report that better equips managers, administrators, and politicians to educate the public and work with the public to manage public waters and catchment areas better.*

This monitoring report along with the Project Plan (Stantec 2017) provides information on potential land use nutrient loading sources within the CRW and historic water quality trends. The report also provides recommendations for BMPs and additional research studies to address nutrient loading.

3. *Progress towards identifying best management plans for specific lakes and the watershed under study.*

This task was achieved through the production of land use mapping for each immediate lakeshore drainage area to better identify potential nutrient load sources. A theoretical P load table was developed for the CRW (see Project Plan [Stantec 2017]) to identify potential theoretical contributions to P loading within the watershed. Assessment of P loads and water quality trends within the study lakes has identified potential BMPs for implementation to address nutrient loads and areas requiring additional research to better characterize P loading.

4. *A case study that should have much wider applicability provincially and beyond, in terms of lessons for catchment area management.*

This monitoring report in conjunction with the previous monitoring reports for the CRW provide a record of water quality trends and observations from 2009 to 2017, represents a long-term lake water quality case study. The observed changes in nutrient loads into and out of individual lakes and their upstream watersheds, and changes in land uses (e.g., fur farm management regulations) have produced mixed results. These mixed results indicate the need for long-term monitoring to determine changes in nutrient load sources (e.g., lake sediments) with time with changes in land uses.

5. *Increased clarity in the identification of environmental stressors and the provision of recommendations regarding their mitigation,*

This monitoring report provides additional information on potential nutrient sources within lake drainage areas and/or lake sediments based on observed trends and inlet/outlet loads. Recommendations are provided for additional research to better identify these specific contributors, particularly lake sediments and the implementation of BMPs to reduce nutrient loadings.

7.0 CLOSURE

This report documents work that was performed in accordance with generally accepted professional standards at the time and location in which the services were provided. No other representations, warranties or guarantees are made concerning the accuracy or completeness of the data or conclusions contained within this report, including no assurance that this work has uncovered all potential liabilities associated with the identified property.

This report provides an evaluation of selected environmental conditions associated with the identified portion of the assessed lakes and associated tributaries that were assessed at the time the work was conducted and is based on information obtained by and/or provided to Stantec at that time. There are no assurances regarding the accuracy and completeness of this information. All information received from the client or third parties in the preparation of this report has been assumed by Stantec to be correct. Stantec assumes no responsibility for any deficiency or inaccuracy in information received from others.

The opinions in this report can only be relied upon as they relate to the condition of the sample sites within the assessed lakes and associated tributaries that were assessed at the time the work was conducted. Stantec cannot comment on other areas of the estuary or associated tributaries that were not assessed.

Conclusions made within this report consist of Stantec's professional opinion as of the time of the writing of this report, and are based solely on the scope of work described in the report, the limited data available and the results of the work. They are not a certification of the property's environmental condition. This report should not be construed as legal advice.

This report has been prepared for the exclusive use of the client identified herein and any use by any third party is prohibited. Stantec assumes no responsibility for losses, damages, liabilities or claims, howsoever arising, from third party use of this report.

The conclusions are based on the site conditions encountered by Stantec at the time the work was performed at the specific sampling locations, and conditions may vary among sampling locations. Factors such as areas of potential concern identified in previous studies, site conditions and cost may have constrained the sampling locations used in this assessment. In addition, analysis has been carried out for only a limited number of chemical parameters, and it should not be inferred that other chemical species are not present. Due to the nature of the investigation and the limited data available, Stantec does not warrant against undiscovered environmental liabilities nor that sampling results are indicative of the condition of the entire site. As the purpose of this report is to identify site conditions which may pose an environmental risk; the identification of non-environmental risks to structures or people on the site is beyond the scope of this assessment.

This document entitled Results of the 2017 Water Quality Survey of Eleven Lakes in Yarmouth and Digby Counties was prepared by Stantec Consulting Ltd. ("Stantec") for the account of the

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Yours truly,

STANTEC CONSULTING LTD.

Janeen McGuigan, M.A.Sc., E.I.T.
Ph: (902) 566-2866
Janeen.mcguigan@stantec.com
Janeen.mcguigan@stantec.com

Andrew Sinclair, Ph.D., P.Eng.
Environmental Engineer
Ph: (902) 468-7777
Andrew.sinclair@stantec.com

Maylia Parker, P.Geo.
Senior Associate, Environmental Remediation
Ph: (902) 468-7777
Maylia.parker@stantec.com

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