Item 7.1

Pollution Source Control Study for Lake Banook & Lake Micmac

Final Report

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Prepared for:

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Sign-off Sheet

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Executive Summary

The focus of this study is on sourcing and quantifying pollutant loadings of phosphorous (P) and *E.coli* to the studied lakes and recommending mitigation measures to counter the effects of these pollutants on recreational use of the lakes. Lake Micmac and Lake Banook are important recreational waterbodies located in Dartmouth, Nova Scotia. The watersheds contributing to both lakes are considered highly developed or urbanized (Figure 1). Land use within Lake Banook contributing watershed is primarily residential, with 78% of the land use attributed to high, medium and low-density residential areas and associated roadways. The Lake Micmac watershed land use is primarily commercial, with commercial developments and associated roadways covering 58% of the watershed.

Pollutant models were developed to assess P and *E.coli* loading from surrounding watershed land-uses on an annual and rain-event basis. Additionally, for P, a lake systems P model was used to estimate in-lake P concentrations using a method balancing P loading inputs and outputs. A field study was undertaken to capture water quality and flow data at select locations including near-shore, in-lake, watercourse and storm outfall inputs and lake outlets. The captured data was used as a comparison tool for pollutant models, as well as a measure of lake water quality.

Results from the in-lake P modeling showed predicted in-lake P concentrations which differed from measured data. Predicted P concentration for Lake Micmac was estimated to be 0.057 mg/L and predicted P concentration for Lake Banook was estimated to be 0.049 mg/L. Both predicted P concentrations are associated with a eutrophic status, meaning highly-productive in terms of vegetation growth. Measured in-lake P concentrations, however, did not correspond to modeled results. Lake Micmac was classified as oligotrophic, or low vegetative productivity, and Lake Banook as mesotrophic based on measured concentrations. It is possible that vegetation harvesting efforts in Lake Banook have contributed to a reduction in overall P concentration. The extension of the sampling program through the colder months has been recommended to extend lake concentrations capture results during the non-growth period.

Within Lake Micmac, 95% of the annual P loading comes from commercial developments and roadways. These land uses account for 84% of the P loading to Lake Banook (Figure 2). Commercial developments within Lake Micmac account for 73% of the annual bacteria loading, whereas residential developments account for the majority of bacteria loading to Lake Banook, at 76% (Figure 3). Rain-event models were completed for both lakes to provide both an estimate of typical pollutant removal requirements during a standard 25 mm design storm, as well as to allow for comparison of modeled vs. measured loading results. Rain-event model results were as expected when comparing to measured P loading data from the lake watersheds and select sub-watersheds; however, *E.coli* model results were higher than measured data. Variability in land use-based loading values for bacteria were noted in the literature, and likely contributed to poor comparison between modeled and measured loading for this parameter. It is recommended that assumptions regarding *E.coli* concentrations in the watershed be made using measured data.

An additional method of study was used to ascertain bacterial loading data from the lake watershed, which proved useful. Microbial Source Tracking (MST) was completed at select surface water locations within both lake systems. MST uses genetic marker detection to trace *E.coli* to a specific host-of origin. This study focused on human, canine, ruminant (deer) and avian genetic markers, with results showing high occurrence of each marker at specific lake locations. For example, high instances of avian genetic markers were found to be associated with high *E.coli* concentration events near a bridge separating the two lakes. Human genetic markers were detected at several locations discharging to the lake systems.

Recommendations have been made to mitigate pollutant loading and associated risk from the studied parameters through a varied combination of maintenance undertakings, infrastructure assessment, stormwater treatment implementation, land use changes, public consultation and continuation of existing mitigation activities in the form of submerged aquatic vegetation harvesting programs.

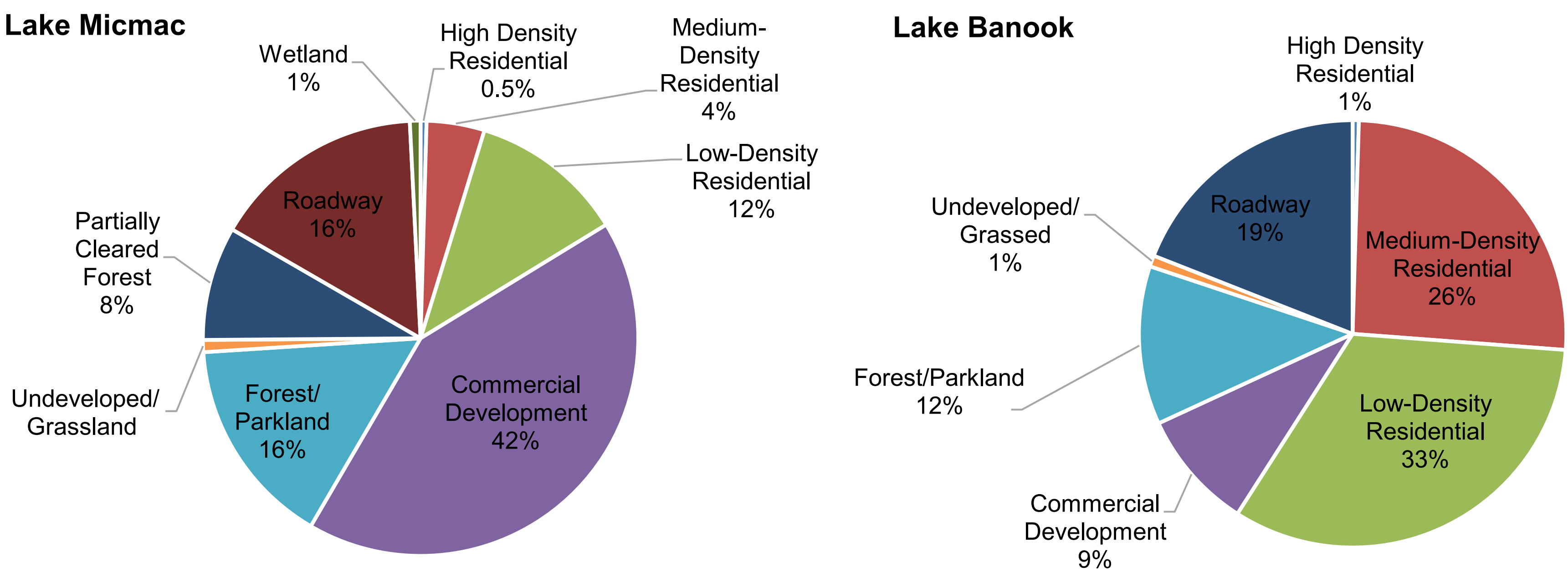


Figure 1 Land Use Breakdown of Lake Watersheds

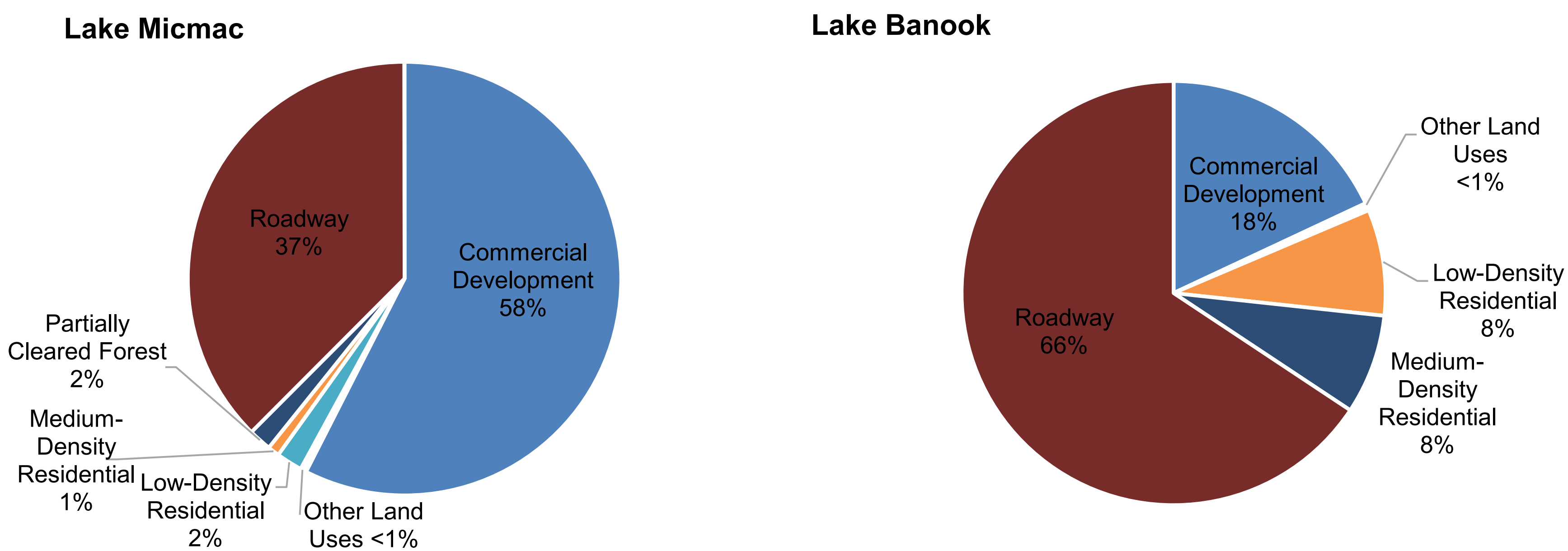
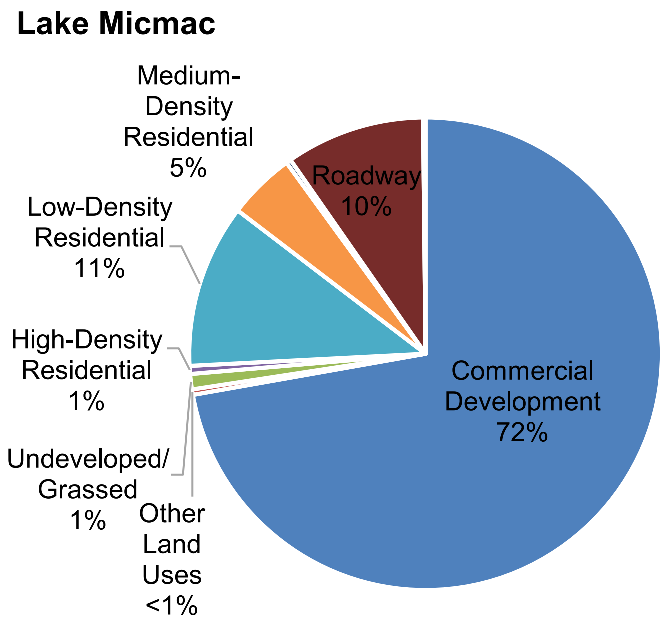


Figure 2 Phosphorous Loading Breakdown by Land Use



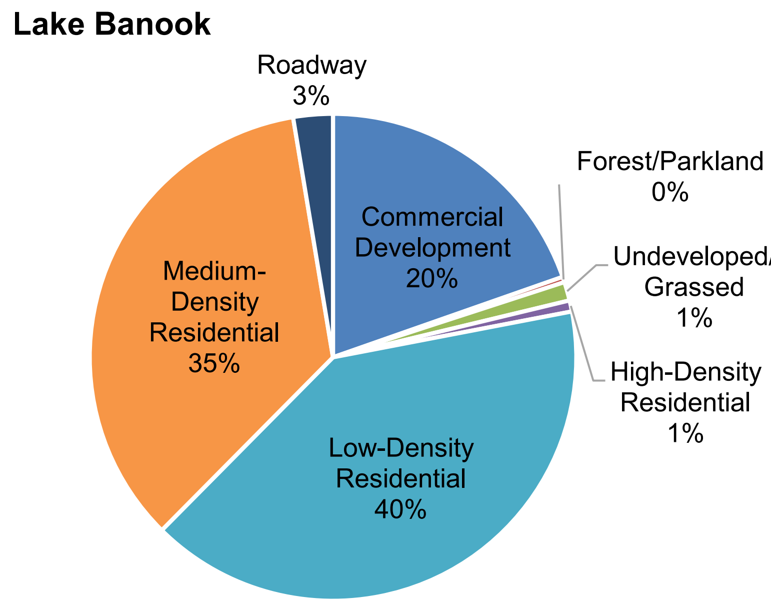


Figure 3 ***E.coli*** **Loading Breakdown by Land Use**

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1.0 BACKGROUND

1.1 STUDIED WATERSHEDS

Lake Micmac, Lake Banook, and their contributing watersheds form the focus of this report. The lakes are located within a highly urbanized watershed in the Halifax Regional Municipality (Halifax), in Dartmouth, Nova Scotia (NS) (Figure 4), with prominent commercial and residential land use in the surrounding areas (Figure 5).

The lakes represent the primary stormwater discharge point for the urbanized watershed, as the area is serviced by a storm sewer network with outfalls discharging to the lake systems. A wastewater collection system is used to collect and convey domestic wastewater to a centralized treatment plant, with no intended discharge of domestic wastewater to the lake systems. These lakes are of noted recreational value to Halifax, as the community frequents the waterbodies for swimming, rowing, paddling and fishing.

Over time, Halifax has noted two prominent issues affecting recreational use of these waterbodies, specifically:

i) The overgrowth of submerged aquatic vegetation (SAV); and

ii) The closure of recreational beaches due to observed high *E.coli* concentrations.

Phosphorous (P) is a common water quality parameter associated with the growth and proliferation of algae and SAV in freshwater bodies. It is typically considered a limiting nutrient in natural water systems, meaning it is not as readily available in comparison with other nutrients required for plant growth. In urbanized watersheds, however, the influence of human activities can cause an increase in P loading to waterbodies, contributing to an overabundance of vegetation and algae growth. In recent years, Halifax has undertaken SAV harvesting to combat the issue.

E.coli is a species of coliform bacteria of fecal origin, referred to as a fecal coliform bacteria. It is commonly used as a fecal indicator bacteria (FIB), denoting the potential presence fecal matter containing pathogens and an associated risk to human health. Although there are other species of bacteria within the fecal coliform family, *E.coli* and fecal coliform are considered analogous in this report for the purposes of modeling. The presence of *E.coli* in recreational waters may come from wild or domestic animals in proximity to a waterbody. In urbanized watersheds, stormwater runoff and domestic wastewater discharge represent additional sources of *E.coli*.

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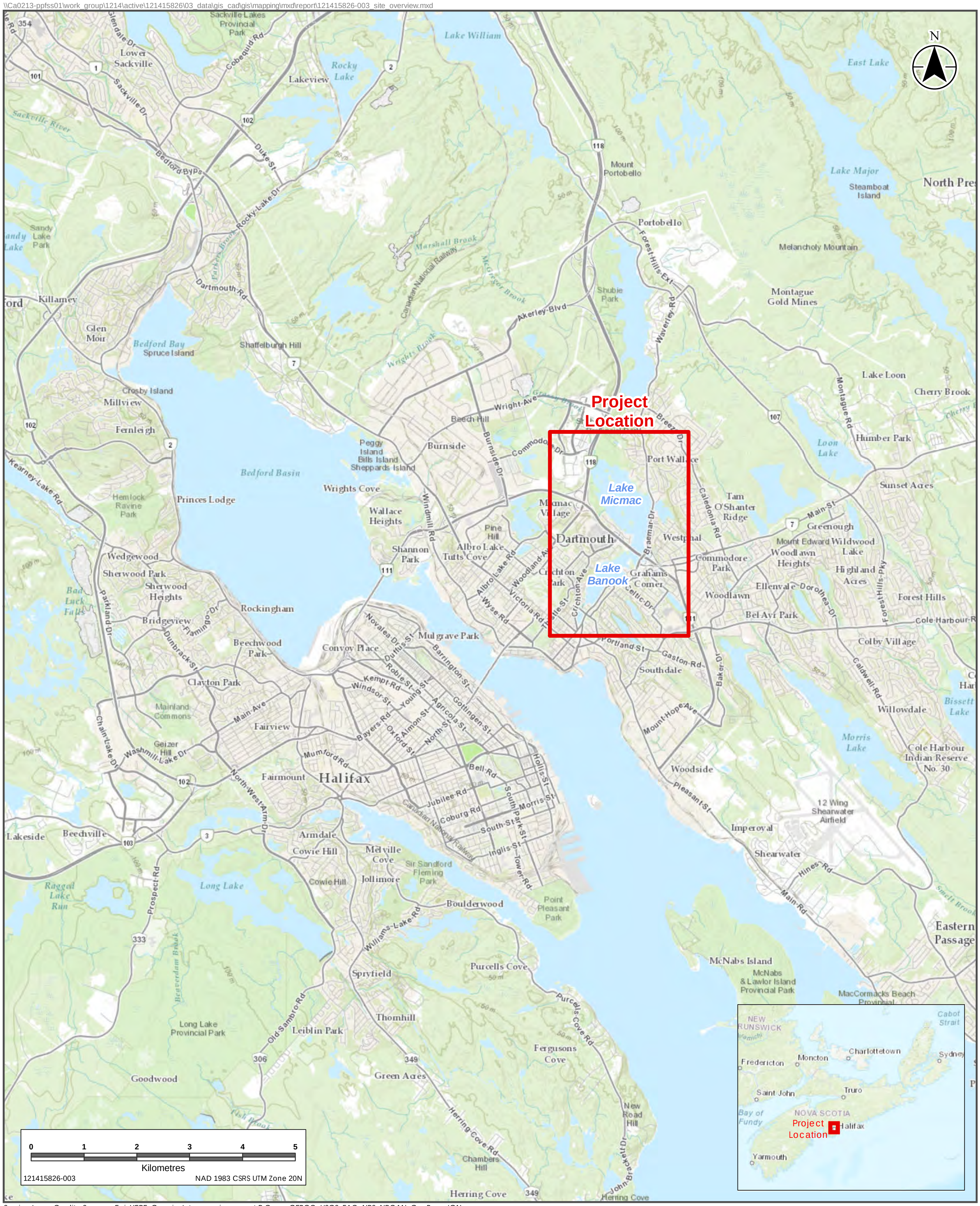

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Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Project Location

Stantec

Pollution Source Control Study for Lake Banook & Lake Micmac, Halifax Regional Municipality

Figure 4

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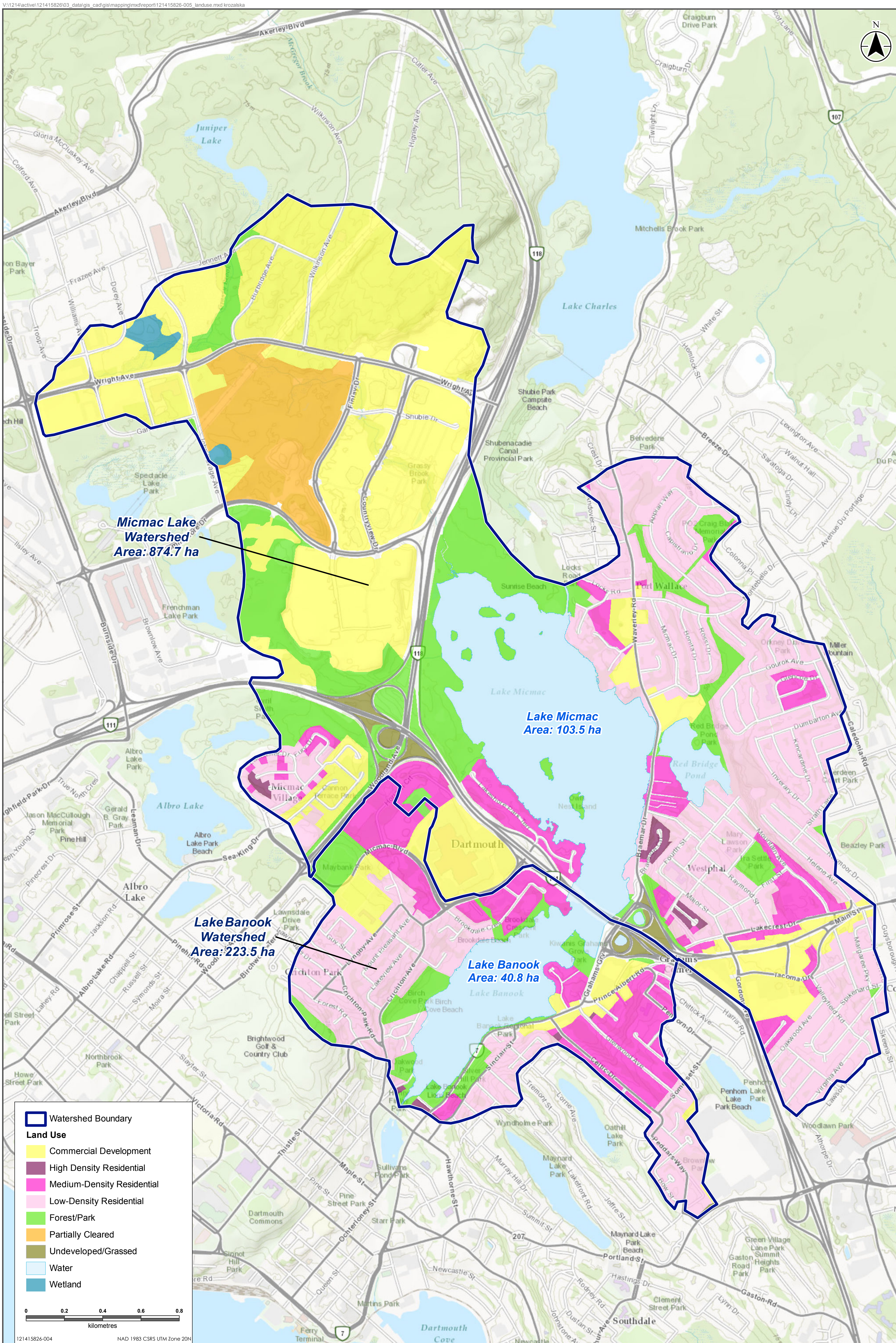

Sources: Landuse derived from HRM Zoning and Image Interpretation

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Land Use Breakdown for Lake Micmac and Lake Banook Watersheds

Stantec

Figure 5

1.2 REPORT OBJECTIVE

The objective of this report is to present the results of a watershed assessment focusing on the loading of two pollutants, *E.coli* and total P, into two recreational waterbodies within Halifax. The selection of these specific pollutants is based on the observation of adverse effects to the recreational use of the studied waterbodies from these pollutants. To complete the report objective, the following tasks were undertaken:

1. The review and summary of pertinent background information.
2. The development of pollutant loading models to estimate *E.coli* and P loads into the study lakes and identify potential land use-based sources.
3. The completion of a field monitoring program to assess pollutant concentration and loading into the study lakes during baseflows and storm events.
4. The development of recommendations to reduce pollutant loading and improve water quality based on results of the field monitoring program and pollutant load model.

Assessment of *E.coli* loading included high-level source identification through the analysis of select water samples for host-specific DNA markers (i.e., human, canine, avian). A summary of general water quality is also provided in order to identify any additional pollutants that may affect lake water quality.

1.3 SAMPLING PLAN DEVELOPMENT

1.3.1 Site Reconnaissance

Preliminary site reconnaissance field work was completed prior to the initiation of water quality sampling and flow monitoring program. This reconnaissance work was completed by Stantec on June 19, 2018 with the primary aim of confirming sampling locations, site access issues, and to identify locations of congregating wildlife or waterfowl. Based on the site reconnaissance, work location sample sites were divided into those that were to be sampled by a shore-based field team and those that required vessel access and would be sampled by a vessel-based field team. As outlined in the proposal, reconnaissance work was completed following a rainfall event to identify any additional inflows into the lake system and the presence/absence of stormwater outfalls discharging to the lakes. Many of the outfalls were noted to have no flow during the monitoring program except when sampling after heavy rainfall.

1.3.2 Background Information Review

Stantec reviewed GIS information provided by Halifax and Halifax Regional Water Commission to help identify outlet and inlet locations of the lake systems. This information was incorporated into field planning figures and mapping presented with this report. The provided information includes:

- Watershed boundaries
- Storm sewer outfall locations
- Wastewater pumping stations
- Storm sewer drainage area/infrastructure mapping

- Land use mapping, including roads and other transportation infrastructure (AECOM 2013)
- Available location information on stormwater management (SWM) infrastructure within the watersheds
- Existing water quality monitoring locations

Stantec also reviewed information collected during previous monitoring studies conducted on the lake system, as referenced throughout this report. Useful information gained from the aquatic vegetation reports previously completed by Stantec (Stantec 2012, 2014, 2015, 2016a, 2016b, 2017a, 2017b, 2018) included sampling site access locations and lake water depth profiles.

1.4 APPLICABLE GUIDELINES

There are two primary guidance documents used within Canada to assess the quality of fresh surface waters, as described below:

Canadian Council of Ministers of the Environment (CCME) Guidelines for the Protection of Freshwater Aquatic Life (FAL) – the CCME has a published set of guidelines used to assess risk to freshwater aquatic species for a selection of parameters within a freshwater source. Concentration-based guideline values are presented for both short-term and long-term exposure. Guidance frameworks are also provided for assessing nutrient status and baseline water quality conditions.

Health Canada Guidelines for Canadian Recreational Water Quality (CRWQ) – Health Canada provides a published set of concentration-based guidelines and guidance commentary for a selection of parameters used to assess risk to human health during recreational use of waters. Guidelines cover various exposure scenarios, including primary and secondary contact activities.

These guidance documents are used to assess water quality where applicable.

1.5 CLIMATE DATA

1.5.1 Precipitation

Graphs of daily precipitation for June - September 2018 are given in Figure 6. Daily precipitation data were taken from the Environment Canada Lake Major Climate Station (Climate ID: 8202896) located approximately 7 kilometres northeast of Lake Micmac. This station is the closest station to Lake Micmac with daily data for the sampling period. For the purpose of this study, a qualifying rainfall event is defined as having a minimum 3-hour duration and producing a minimum of 10 mm of rain, preceded by a dry period lasting a minimum of 48-hours. Sampling was to occur within 24-hours of a qualifying event. Sample events on August 14, 2018 and September 26, 2018 occurred during measured rainfall events with associated rainfall depths of 26 mm and 21 mm, respectively. The sample event on September 12, 2018 occurred within 24-hours of a recorded rainfall event of 21 mm, whereas events on June 27, 2018 and July 19, 2018 had minimal to no rainfall on the preceding day.

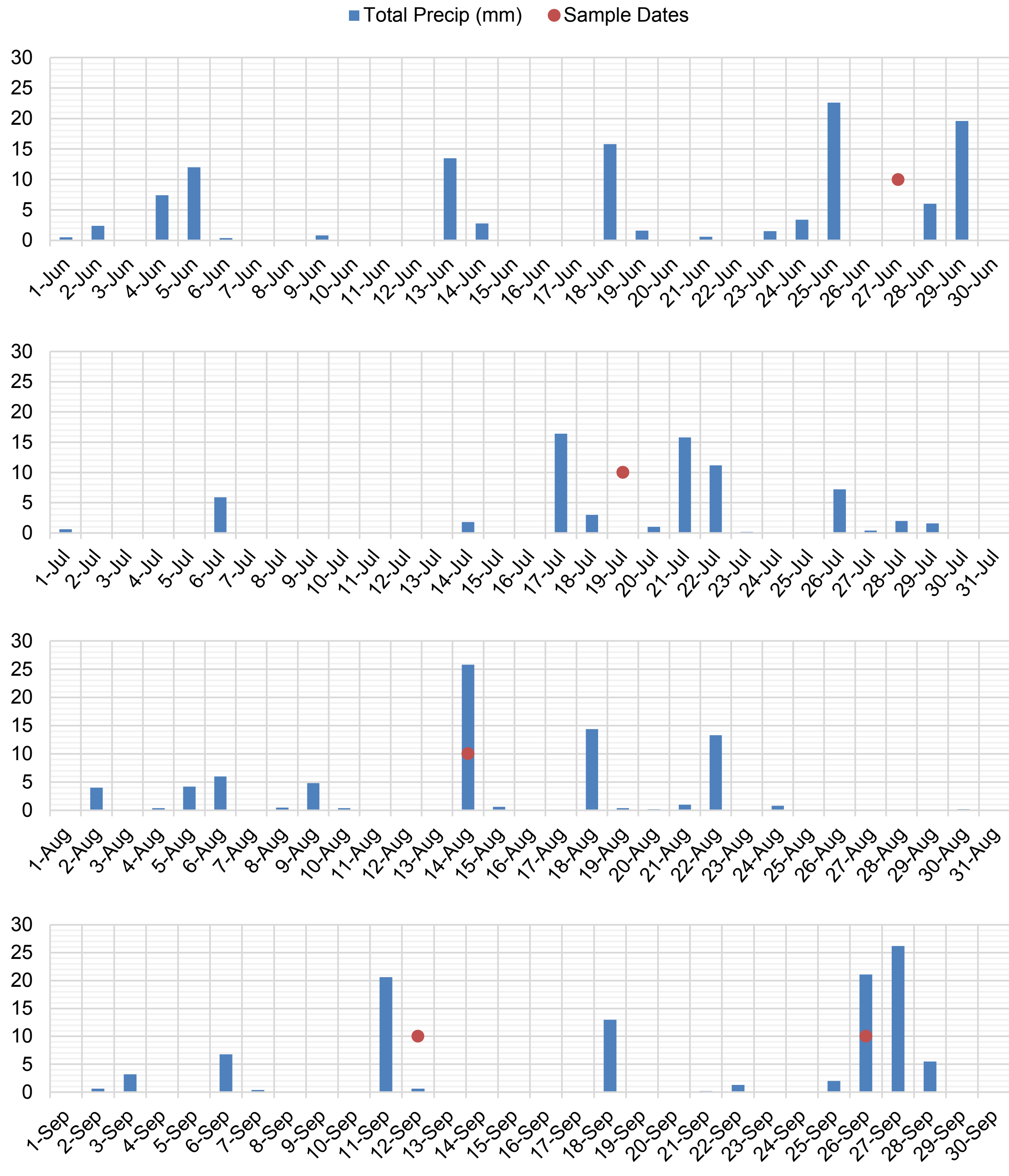

Figure 6 Daily Rainfall (mm), Lake Major Climate Station (ID: 8202896)

1.5.2 Climate Normals

Climate normal data were used for an estimate of the annual rainfall in the study area. The Environment Canada Shearwater Airport Climate Station (Climate ID: 8205090) data from 1981 to 2010 were used. This station is located approximately 7 km from Lake Micmac and is the closest climate station to the study area with climate normal data. For the thirty-year data period, the average annual precipitation is 1,261.2 mm per year.

2.0 METHODOLOGY

2.1 FIELD STUDIES

Field studies were conducted during the summer of 2018 to characterize water quality and quantity inflows and outflows in the lake system. Figure A-1 (Appendix A) shows the sampling and flow monitoring locations used in the program. Selected sample locations represent point source lake inputs, such as watercourses or stormwater discharge points, lake outlet points, and select in-lake sample locations. Location and selection rationale are given in Table 1, below.

Table 1 Sample Location and Selection Rationale

Sample ID	Location	Selection Rationale
Banook / Micmac	In-lake sample location at deep-lake location. Banook/Micmac 1 site is at the lake surface, Banook/Micmac 2 site is 1 m above lake bottom.	Selected to allow for surface and bottom concentration comparisons and vertical profiling of the lake water column.
Nearshore	In-lake sample location near the lake shore. Nearshore 1 is associated with Birch Cove Beach. Nearshore 2 is associated with Grahams Grove Park and On-Leash Dog Park. Nearshore 3 is associated with the Shubenacadie Wildlife Park and the Shubie Off-Leash Dog Park.	Selected based on proximity to a potential land-based pollutant source or sensitive area.
Watercourse	Natural watercourse discharging into the lake.	Selected to allow for sampling of surface water inputs into the lake.
Outfall	Urban surface water discharge into the lake. Functioning as major stormwater discharge point with baseflow from natural inputs.	Selected to allow for sampling of urban outfalls into the lake.
Headwall (HDW)	Stormwater culvert headwall discharging into the lake. Discharge expected during storm events only.	Selected to allow for sampling of minor stormwater outfalls into the lake.
Waterfowl	In-lake sample location at a bridge located at the Lake Micmac outlet as it flows into Lake Banook.	Selected as bridge acts as a roost for waterfowl which may be a source of pollution into the lake.

Five field sampling events were conducted, with two Stantec teams visiting each location in one day. One field team completed shore-based sampling, focusing on the northern portion of Lake Micmac and the eastern shore of Lake Banook. The second team completed vessel-based sampling, including the mid lake sampling locations and the western portion of both Lakes Micmac and Banook. Sampling events coincided with both dry and wet conditions. Sampling during wet conditions required quick response time as many stormwater outfalls showed a rapid response to rainfall.

A summary of field monitoring events is provided in Table 2.

Table 2 Field Monitoring Event Summary

Date	Field Activities Completed	Conditions
19-June-18	Site Reconnaissance	Dry
27-June and 28-June-18	Water Quality and Flow Monitoring	Dry
19-Jul-18	Water Quality and Flow Monitoring	Dry
27-Jul-18	Site Reconnaissance	Dry
14-Aug-18	Water Quality and Flow Monitoring	Rainfall Event
12-Sept-18	Water Quality and Flow Monitoring	1-day post Rainfall Event
26-Sept-18	Water Quality and Flow Monitoring	Rainfall Event

2.1.1 Surface Water Flow Monitoring

Surface water flow data was gathered to facilitate pollutant loading calculations and to assist in modelling. Flow monitoring was completed using several different methods, depending on the outlet type, flow quantity and site accessibility. The flow monitoring methods used during the field monitoring program are outlined in the table below. Outfall locations with no flow were noted during the monitoring program and help to identify locations that typically do not have base flow contributing to the lake systems. A summary of flow monitoring data by sample location is provided in Appendix B.

Table 3 Surface Water Flow Monitoring Methods Summary Table

Flow Monitoring Method	Situations Used	Method Summary
Volumetric Flow Method (Bucket Test)	Used to measure flow out of a perched culvert or outfall. Many of the headwall (HDW) locations used this method when there was flow present.	A bucket of a known volume collects flow from the outlet. The time it takes to fill the bucket is measured and flow is calculated by dividing the volume by time. Three measurements were taken at each location and the average flow time to fill the bucket was used.
Acoustic Doppler Velocimeter (ADV)	Used to measure flow in natural streams and larger outfalls. This method was used on watercourses and several outfalls: Watercourse 1, Watercourse 2, Watercourse 3, Watercourse 5 and Watercourse 6.	A SonTek FlowTracker was used to collect velocity and channel geometry information across a transect of the outfall location. Based on the collected data the FlowTracker provides a flow for the transect, calculated using the velocity-area method.
Current Meter	Used to measure flow in small outfalls and in culverts that could not be assessed using the bucket test method: Outfall 1, Outfall 7, Outfall 8, Watercourse 4.	A Pygmy Current Meter was used to collect velocity measurements. Manual measurements of the flow depth, and culvert diameter or channel width were also collected. Using this information, flow is calculated using either the continuity equation or Manning's equation.

2.1.2 Surface Water Quality Monitoring

Field staff conducted surface water sampling in accordance with Stantec's standard operating procedures (SOPs). Special care was taken at the sampling locations not to disturb sediments to avoid water column disturbance and contamination. Sampling was completed by shore-based and vessel-based teams consisting of a minimum of two employees for safety reasons. Samples were collected at lake inlet and outlet locations that had sufficient flow. Locations with no or low flow were noted. During wet weather sampling events, priority was given to locations that routinely reported no flow conditions.

2.1.2.1 In-Situ Monitoring

In-situ physical water quality parameters of temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), oxidation-reduction potential (ORP), and conductivity were measured using a YSI 556 multi meter. At the two in-lake deep-water locations, a vertical profile measurement was collected to outline the lake thermocline.

2.1.2.2 Surface Water Quality Grab Sampling

Grab samples were collected in laboratory supplied containers and preserved in insulated coolers provided by Maxxam Analytics (Maxxam). Samples were uniquely labeled, and control was maintained using chain of custody forms. Laboratory analytical services were also provided by Maxxam. Maxxam's Bedford Laboratory is accredited by the Standards Council of Canada (SCC) according to the International Standards Organization (ISO) Standard 17025:2005, RB-LAB (SCC-Accredited Laboratory No. 161). Deep water quality samples collected at in-lake sampling points were collected 1 m above the lake bottom using a Kemmerer sampler that allowed discrete water sample collection at depth.

Water quality samples for each location were analyzed for a suite of parameters which included some of or all of the following listed below:

- General Chemistry (RCAp) – a 30-parameter general chemistry analysis package that includes select minerals (calcium, potassium), nutrients (nitrate, nitrite, soluble reactive phosphorus); general water quality and nutrient concentration data;
- Total Kjeldahl Nitrogen (TKN) – TKN represents the summation of total ammonia and organic nitrogen (N) concentrations; TKN in combination with ammonia, nitrate and nitrite concentrations captured as part of the above general chemistry analysis can provide a better indication of nitrogen concentrations;
- Total Phosphorus (P) – represents the sum of the dissolved and particulate forms of phosphorus;
- Soluble reactive phosphorus (SRP) – also referred to as ortho-phosphate (PO4-P) represents the biologically available phosphorus fraction;
- Chlorophyll a (Chl a) – commonly used to indicate water column algal biomass within lake systems;
- Total suspended solids (TSS) – represents suspended solids within a water sample that cannot pass through typically a filter with a 1.5 µm pore size;
- Escherichia coli (*E. coli*) – a commonly used fecal indicator bacteria (FIB) in freshwater systems;
- Enterococci –can provide additional insight to potential bacteria sources if *E. coli* is not present and MST results indicate specific DNA markers are present;
- MST – Microbial Source Tracking used to analyze for ruminant, human, canine and avian DNA markers.

Water quality sampling parameters were different for the various sampling locations, based on upgradient activities, public land use near the site (i.e. beach), and flow conditions. A summary of the water quality sampling parameters and number of sampling events completed at each location is provided in Appendix B. This table shows the sampling parameters for each location; however, the number of sampling events varied by location for various reasons (no flow, weather-related access issues).

2.2 MICROBIAL SOURCE TRACKING

Microbial source tracking (MST) has become a useful alternate to the fecal indicator bacteria method for assessing fecal contamination in a source water as it can determine not only the presence-absence of fecal contamination, but also provides valuable information on the source of the fecal contamination (Ravaliya et al. 2014). A method for identifying specific sources through MST is to analyze samples for host-specific genetic markers using a library independent microbial source tracking (LI-MST) method. The LI-MST method is used to detect fecal-associated bacteria, chemicals or host genes from specific markers (McDonald et al. 2016). The markers used for this project are derived from human, canine, avian and ruminant sources and marker selection is supported by current research-based literature. To complete the LI-MST method, Bacteroidales-based genetic markers were selected for human and ruminant sources (Bonjoch et al. 2004; Savichtcheva et al. 2007; Walters et al. 2007; Lee et al. 2010). A genetic marker based on Heliobacter was used for avian sources (Ahmed et al. 2016), and a mitochondrial deoxyribonucleic acid (DNA) marker (Kortbaoui et al. 2009; Ballesté et al. 2010; Baker-Austin et al. 2010) was used for canine sources. Ruminant markers were assessed for select sites near Shubie Park and the Red Bridge Pond outflow only, based on Stantec's observations that deer (a ruminant species) are commonly present in these areas. Samples for LI-MST analysis were taken from surface water at select sample sites and transported to the Dalhousie University Centre for Water Resources Studies (CWRS) laboratory for analysis. As significant changes in MST analysis have occurred since the publishing of the USEPA 2005 MST guidance document (USEPA 2005), an updated method of analysis used by Dalhousie is provided in Appendix E, with details provided by Stea et al. (2015).

2.3 WATERSHED DELINEATION

Watershed delineation was completed in two steps to account for topography and the contributing storm sewer shed network. Provincially delineated watershed data (NS Department of Environment) were first used to define the large-scale watershed area contributing to both Lake Banook and Lake Micmac. Municipal LiDAR data (Halifax) were then used to delineate sub-watersheds contributing to each individual lake and identified outfall points of interest. Sub-watersheds contributing to a body of water within the primary lake watershed were considered separately for the purposes of modeling as these inputs would be captured as stream outlet points (*i.e.* Red Bridge Pond and Oathill Lake sub-watersheds). Storm-sewer network data provided by the Halifax Regional Water Commission were then integrated into the delineation and adjustments were made for any locations where catch basins and storm piping altered the delineated boundaries of the topographic sub-watersheds. Watercourse and waterbody GIS data was provided through the Nova Scotia Topographic Database.

Delineated watershed and sub-watershed maps are provided in Appendix A, Figure A-2.

2.4 WATER QUALITY MODELLING

2.4.1 Rainfall Event-Based Model

Rainfall event-based modeling is useful as it aids in design of stormwater treatment. A rainfall event-based pollutant load model uses literature-based pollutant concentration values derived for specific land uses to determine a stormwater pollutant load for a single precipitation event. Event mean concentration (EMC) data is derived from sampling runoff from specific land uses over the duration of a storm event. It is used for the purposes of modeling as it represents an average pollutant concentration generated over the duration of an event.

For the rainfall-event based model, the event-associated contaminant export load is calculated using the following formula:

$$P_{Event} = \sum R\,xA_{LU}xEMC_{LU}xRC_{LU}$$

Where:

P_{Event} = total pollutant load on an event basis, kg or CFU

R = rainfall depth associated with selected precipitation event, mm

A_{LU} = area associated with a specific land use, m^2

EMC_{LU} = pollutant event mean concentrations associated with a specific land use, mg/L or CFU/100 mL

RC_{LU} = rainfall runoff coefficient associated with a specific land use, unitless

To determine the volume of runoff discharging from each land use during the rain event, a hydrologic model was developed using PCSWMM (Computational Hydraulics Inc. of Guelph, Ontario, CA) to firstly estimate the runoff from the total watershed. A 25-mm 4-hr duration Chicago design storm was used to simulate the rain event and land use-based curve numbers (CN) were selected for use with the SCS method of rainfall runoff estimation (Table 4). Initial abstraction of 1.5 mm accounts for depression storage, interception and infiltration occurring before runoff begins and was estimated for pervious land use areas as per USDA 1986. When the total watershed runoff volume was determined, runoff for each land use was estimated using the formula provided above, with the runoff coefficients (RC) given in Table 4. The hydrologic model results were then used to validate the runoff volumes from the rain-event based model. A 25 mm 4-hr duration Chicago storm event was used as it represents a commonly used design storm for the sizing of stormwater treatment infrastructure.

Table 4 Summary of Land Use Runoff Parameters

Land Use	Curve Number[1]	Runoff Coefficient[1]
Commercial Development	92	0.89
Forest/Parkland	65	0.14
Undeveloped/Grassed	61	0.24

Table 4 Summary of Land Use Runoff Parameters

Land Use	Curve Number[1]	Runoff Coefficient[1]
High-Density Residential	85	0.39
Medium-Density Residential	72	0.35
Low-Density Residential	68	0.28
Partially Cleared Forest	66	0.28
Roadway	98	0.82
Water	99	0.99
Wetland	99	0.99

[1] McCuen 1998

2.4.1.1 Parameter Selection for Rain Event-Based Phosphorous Model

EMC P data were sourced for the land use distribution found within the studied watersheds. As there is limited availability of local data, EMC values were taken from commonly referenced literature sources, and are given in Table 5, below.

Table 5 Phosphorous Event Mean Concentrations for Select Land Use

Land Use	Phosphorous Event Mean Concentration (mg/L)
Commercial Development	0.30[1]
Forest/Parkland	0.15[2]
Undeveloped/Grassed	0.56[2]
High-Density Residential	0.22[2]
Medium-Density Residential	0.45[2]
Low-Density Residential	0.36[2]
Partially Cleared Forest	0.68[3]
Roadway	0.62[2]
Wetland	0.10[1]

[1] CH2M HILL 1993; [2] Pitt and MacLean 1986; [3] USEPA 2001

2.4.1.2 Parameter Selection for Precipitation Event-Based Fecal Coliform Loading Model

EMC FC data were sourced for the land use distribution found within the studied watersheds, as given in Table 6, below. Data is given in units of CFU/100 mL, which refers to the number of colony forming units (CFU) of bacteria per 100 mL of sample volume. FC EMC values were used as there is limited available data for land-used associated *E.coli* concentrations. These values are considered comparable to *E. coli* concentrations for the purpose of this study. Where available, data were taken from a study completed by

Theriault and Duchesne (2012) on FC loading in urban watersheds in Quebec. Commonly referenced literature sources were used for the remaining EMC values. Barnhart *et al.* (nd) found higher bacteria counts in runoff from residential areas and attributed loadings to wildlife rather than domestic animals. Variation in bacterial loadings from specific land uses was thought to be due to the transient nature of the wildlife sources. Differences in EMC values between forest/parkland and undeveloped/grassed areas may also be attributed to differences in runoff volumes from the specific land uses. A forested site would have significant wildlife use but minimal runoff volume comparison with a grassed site. As noted in the USEPA Preliminary Data Summary of Urban Stormwater Best Management Practices (1999), literature values for land use-based FC EMCs vary greatly between studies and show a strong trend of seasonal fluctuation.

Table 6 Fecal Coliform Event Mean Concentrations for Select Land Uses

Land Use	Fecal Coliform Event Mean Concentration (CFU/100 mL)
Commercial Development	4,500[1]
Field within Low-Density Residential	3,100[1]
Forest/Parkland	500[2]
Undeveloped/Grassed	10,365[3]
High-Density Residential	7,750[1]
Medium-Density Residential	7,750[1]
Low-Density Residential	7,750[1]
Roadway	1,400[2]

[1] Theriault and Duchesne 2012; [2] CH2M HILL1993; [3] Burnhart *et al.* nd

2.4.2 Annual Loading Model

Annual pollutant loading models use land use-based pollutant loading rates to determine the pollutant load derived from a watershed on an annual basis. As the annual rainfall amount is inherently integrated into the land use-based pollutant loading rates, the use of local data is most accurate. In the absence of local data, literature values are used.

For the annual loading model, the estimated annual pollutant load is calculated using the following formula:

$$Load_{Annual} = \sum LR_{LU} \ x \ A_{LU}$$

Where:

$Load_{Annual}$ = total pollutant load on an annual basis, kg/year or CFU/100mL·year^{-1}

LR_{LU} = areal pollutant loading rate associated with a specific land use, g/m^2·year^{-1} or CFU/100mL/ha·year^{-1}

A_{LU} = area associated with a specific land use, m^2

2.4.2.1 Parameter Selection for Annual Phosphorous Loading Model

Land use-based areal loading P data were sourced for the land use distribution found within the studied watersheds. Where possible, parameters were selected from the Nova Scotia-focused study completed by Brylinsky (2004). Selected parameters are given in Table 7, below.

Table 7 Area-based Phosphorous Loading Rates for Select Land Uses

Land Use	Phosphorous Loading Rate ($g/m^2 \cdot yr$)
Commercial Development	0.202[1]
Forest/Parkland	0.0024[2]
Undeveloped/Grassed	0.015[2]
High-Density Residential	0.035[1]
Medium-Density Residential	0.030[1]
Low-Density Residential	0.025[1]
Partially Cleared Forest	0.0625[3]
Roadway	0.35[3]
Wetland	0.0024[2]

[1]Waller and Hart 1986; [2] Reckhow *et al.* 1980; [3] MDEP 2000

2.4.2.2 Parameter Selection for Annual Fecal Coliform Loading Model

As there is limited areal-loading data available for land use-associated FC loading, EMC values were used to determine the annual loading of FC from the studied watersheds. Using the climate normal average annual precipitation value of 1,261.2 mm (Section 1.5.2), the event-based loading method was used to calculate the FC loading associated with the annual depth of rainfall. Results are given in Table 8, below. Due to limited available data, FC loading from wetland and partially cleared forest land uses were assumed to be similar to forest/park and use.

Table 8 Area-based Fecal Coliform Loading Rates for Select Land Uses

Land Use	Annual Loading Rate (CFU/ha/year)
Commercial Development	$4.99 \cdot 10^{11}$
Forest/Parkland	$6.94 \cdot 10^{9}$
Undeveloped/Grassed	$3.40 \cdot 10^{11}$
High-Density Residential	$3.62 \cdot 10^{11}$
Low-Density Residential	$2.83 \cdot 10^{11}$
Medium-Density Residential	$3.13 \cdot 10^{11}$
Partially Cleared Forest	$1.14 \cdot 10^{10}$
Roadway	$1.75 \cdot 10^{11}$
Wetland	$6.24 \cdot 10^{10}$

2.4.3 Lake System Model

The lake system model provides an estimate of the P balance within the studied lake system. It takes into account P lake inputs from atmospheric deposition, surface runoff and contributing waterbodies and provides an estimate of in-lake P concentration after accounting for P sedimentation and surface outflow. The estimated in-lake P concentration can then be compared to measured P concentration values.

The lake system model is taken from the widely accepted User's Manual for Prediction of Phosphorus Concentration in Nova Scotia Lakes (Brylinsky 2004). The model described by Brylinsky (2004) is a mass-balance approach, using the Vollenweider equation, as follows:

$$PV = \frac{M/V}{\left(\frac{Q}{V}\right) + \sigma}$$

Where:

PV = Total mass of phosphorus in lake (g)

P = Lake phosphorus concentration (g/m^3)

V = Lake volume (m^3)

t = time

M = Annual mass of phosphorus input to lake (g/year)

Q = Annual volume of water outflow from lake (m^3/year)

σ = Sedimentation coefficient (/year)

Brylinsky (2004) proposes a series of physical, hydraulic and water-quality-based parameters to determine the total mass of phosphorous in the studied lake. A full table of model parameters and results is given in Appendix D. To reference the calculation method for each model parameter, the User's Manual is included in Appendix E. A summary of select lake system model parameters are given in Table 9, below.

Table 9 Summary of Select Lake System Model Parameters

Parameter	Abbrev.	Value	Units	Source
Annual Unit Precipitation	Pr	1.26	m/yr	Estimated using climate normals data
Annual Unit Lake Evaporation	Ev	0.51	m/yr	Calculated using Thornthwaite method
Annual Unit Hydraulic Runoff - Developed	Ruv	1.10	m/yr	Brylinsky (2004)
Annual Unit Atmospheric P Deposition	Da	0.0173	g P m^2/yr	Brylinsky (2004)
Phosphorus Retention Coefficient	v	12.40	n/a	Brylinsky (2004)

As Lake Banook receives input from three adjacent water bodies, Lake Charles, Red Bridge Pond and Oathill Lake, a model was completed for these contributing waterbodies to account for P input from these sources. For Lake Charles, watershed land use and lake volume data was taken from the Shubenacadie Lakes Subwatershed Study, completed for Halifax by AECOM (2013). For Red Bridge Pond and Oathill Lake, the sub-watersheds were delineated as part of this study and land use and lake bathymetry mapping was used to complete the model for these water bodies.

3.0 MONITORING RESULTS

3.1 SURFACE WATER FLOW AND CONTAMINANT LOADING

Surface water flow measurements were taken during sampling events to allow for calculation of contaminant loading rates. A summary of flow data for select sample locations is given in Figure 7.

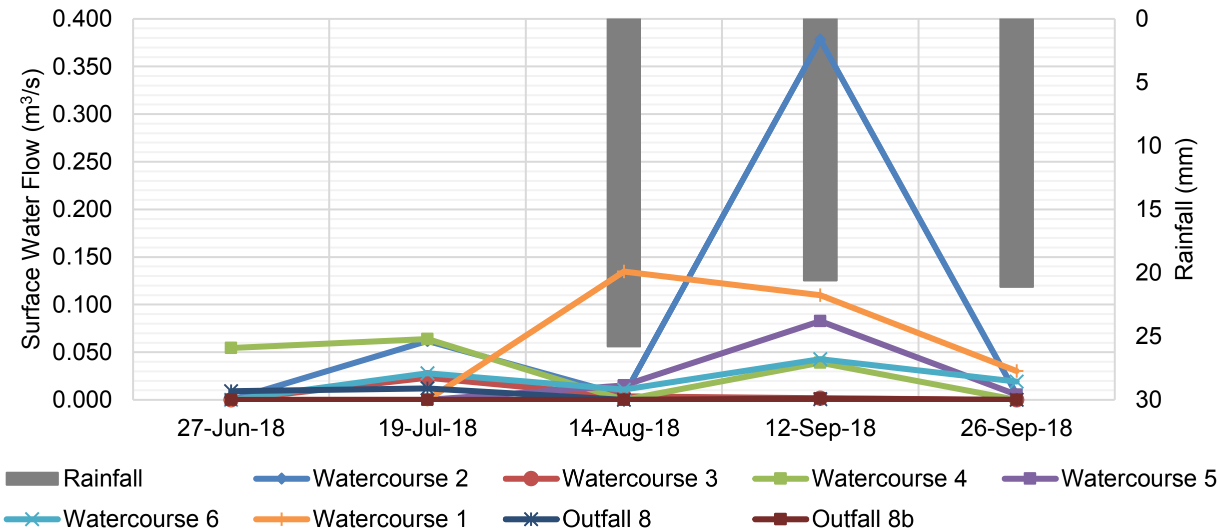

Figure 7 Measured Surface Water Flow by Sample Location

Sampling events in June and July occurred during baseflow conditions, which is defined as no reported rainfall in the watershed in the preceding 48 hours before sampling. Events in August and September occurred on days with reported rainfall on or within 24 hours of the day of sampling. At the time of sampling, elevated flow was observed on September 12, 2018 for most watercourses. Elevated flow was only observed in Watercourse 1 at the time of sampling on August 14, 2018. Elevated flow was not observed in the measured watercourses at the time of sampling on September 26, 2019.

Using surface water quality results from analyzed samples taken during flow measurement, daily loading rates for primary lake input sources were calculated for P and *E.coli* (Figures 8 and 9, respectively).

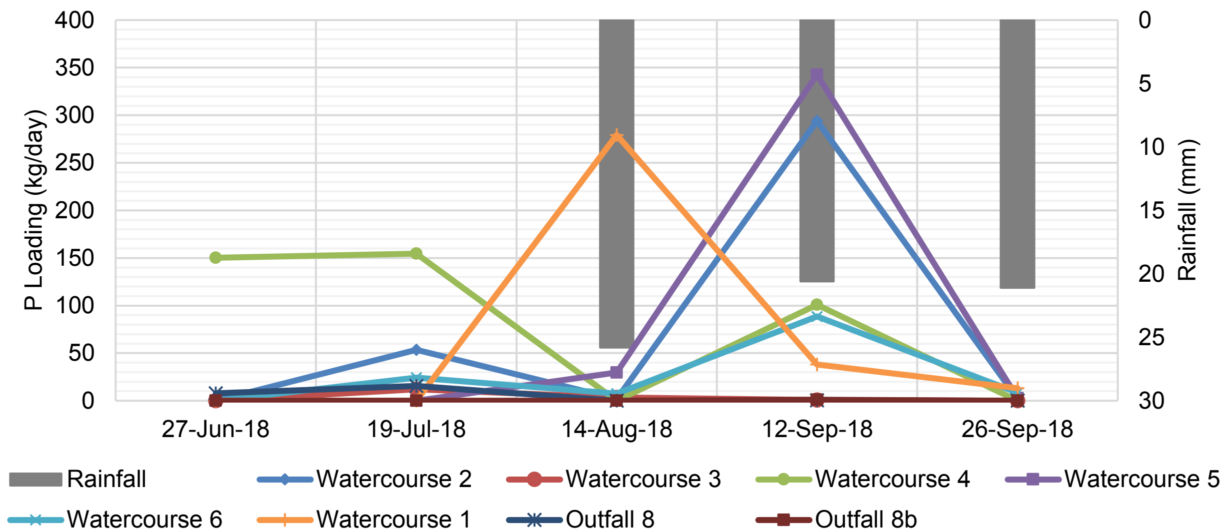

Figure 8 Measured P Loading by Sample Location

The highest P loading was calculated from Watercourse 2 and Watercourse 5 at 294 and 343 kg/day, respectively. Watercourse 1 had P loadings ranging from 13 to 280 kg/day. The highest measured P loading events coincided with the occurrence of the rain event on September 12, 2018. Watercourse 3 and Outfall 8 both have P loadings that appear to be increased during baseflow.

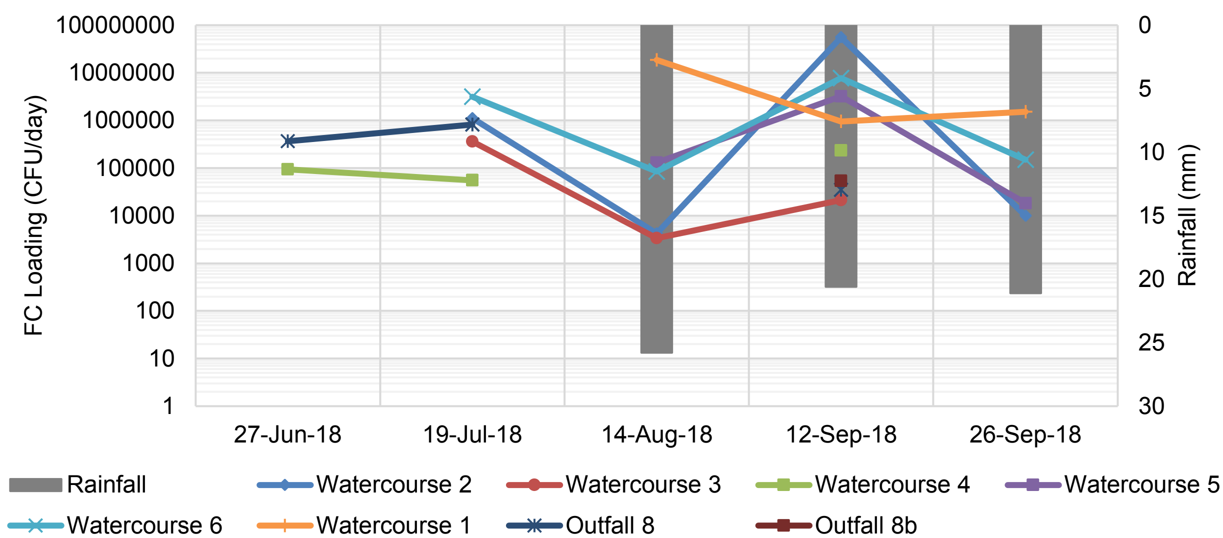

Figure 9 Measured *E.coli* Loading by Sample Location

E.coli loading was calculated to be highest from Watercourse 2 and Watercourse 1, at $5.5 \cdot 10^7$ and $1.9 \cdot 10^7$ CFU/100 mL, respectively. Similar to P loading trends, *E.coli* loading from Watercourse 3 and Outfall 8 appear to be increased during baseflow.

Stormwater discharge points (HDW) were also assessed to determine flow and point-source loading rates discharging to the lakes from stormwater infrastructure within the watersheds. Associated P and *E.coli* loading rates for sampled HDW locations are given in Tables 10 and 11 below. As shown in the tables, the majority of HDW locations had no flow during the assessment. The June and July events are omitted from the tables as no flow was observed at HDW locations during these events.

HDW locations which contribute the highest loading of P to the lake systems are HDW8714 within Lake Micmac and HDW8905 and HDW9311 within Lake Banook.

Table 10 Phosphorous Loading at HDW Locations

Sample Location	Flow (m^3/s)	P (mg/L)	P Load (kg/day)	Flow (m^3/s)	P (mg/L)	P Load (kg/day)	Flow (m^3/s)	P (mg/L)	P Load (kg/day)
	8/14/2018			9/12/2018			9/29/2018		
Lake Micmac									
HDW6453	No Flow	-	-	No Flow	-	-	No Flow	0.039	-
HDW7052	No Flow	-	-	No Flow	-	-	0.001	0.220	0.012
HDW7061	No Flow	-	-	0.001	0.035	0.002	0.002	0.140	0.022
HDW7395	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW8201	No Flow	-	-	ND	0.007	-	0.070	0.012	0.073
HDW8713	No Flow	-	-	ND	0.071	-	ND	0.240	-
HDW8714	No Flow	-	-	No Flow	-	-	2.414	0.130	27.113
HDW8210	ND	-	-	No Flow	-	-	0.001	0.053	0.002
Lake Banook									
HDW6534	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW6658	No Flow	-	-	No Flow	-	-	0.0002	0.180	0.003
HDW6660	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW6661	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW6662	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW8846	ND	0.500	-	No Flow	-	-	0.005	0.170	0.072
HDW8905	ND	0.310	-	No Flow	-	-	0.577	0.170	8.470
HDW8910	No Flow	-	-	No Flow	-	-	ND	0.091	-
HDW8989	ND	0.210	-	No Flow	-	-	Submerged	0.460	-
HDW8990	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW8991	ND	0.100	-	0.001	0.015	0.001	No Flow	-	-
HDW9085	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW9308	0.005	0.027	0.012	No Flow	-	-	0.002	0.009	0.001
HDW9311	0.120	0.660	6.857	No Flow	-	-	0.016	2.300	3.080
HDW9328	0.007	0.110	0.063	No Flow	-	-	0.005	0.240	0.104

ND= no data

Levels of *E. coli* in stormwater alone can range from 10^3 - 10^4 CFU/100mL, with higher levels indicating the possible presence of sewer cross-connections (Marsalek and Rochfort, 2004). While reported *E. coli* concentrations reach 2,500 – 5,300 CFU/100 mL at some sample sites, this may be attributed to overland sources. Completion of MST at these locations could aid in determining if there is a human-waste component. HDW locations identified to contribute the highest loading of FC to the lake systems are HDW8714 within Lake Micmac and HDW8905 and HDW9311 within Lake Banook. These locations were also flagged as contributing the highest loading of P to the lake systems. It is noted that although *E.coli* concentrations at HDW locations are routinely over the CCME CRWQ guideline value at the source, dilution is expected to occur within the lake.

Table 11 *E.coli* Loading at HDW Locations

Sample Location	Flow (m^3/s)	*E.coli* (CFU/100 mL)	FC Load (CFU/day)	Flow (m^3/s)	*E.coli* (CFU/100 mL)	FC Load (CFU/day)	Flow (m^3/s)	*E.coli* (CFU/100 mL)	FC Load (CFU/day)
	8/14/2018			9/12/2018			9/29/2018		
Lake Micmac									
HDW6453	No Flow	-	-	No Flow	-	-	No Flow	670	-
HDW7052	No Flow	-	-	No Flow	-	-	0.001	**2,500**	1.61E+04
HDW7061	No Flow	-	-	0.001	880	4.40E+03	0.002	3,000	5.47E+04
HDW7395	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW8201	No Flow	-	-	ND	40	-	0.070	50	3.50E+04
HDW8713	No Flow	-	-	ND	310	-	ND	880	-
HDW8714	No Flow	-	-	No Flow	-	-	2.414	150	3.62E+06
HDW8210	ND	-	-	No Flow	-	-	0.001	540	2.70E+03
Lake Banook									
HDW6534	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW6658	No Flow	-	-	No Flow	-	-	0.0002	**2,500**	4.80E+03
HDW6660	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW6661	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW6662	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW8846	ND	1,700	-	No Flow	-	-	0.005	740	3.63E+04
HDW8905	ND	1,100	-	No Flow	-	-	0.577	790	4.56E+06
HDW8910	No Flow	-	-	No Flow	-	-	ND	1,700	-
HDW8989	ND	550		No Flow	-	-	Submerged	670	-
HDW8990	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW8991	ND	**2,500**	-	0.001	920	4.60E+03	No Flow	-	-
HDW9085	No Flow	-	-	No Flow	-	-	No Flow	-	-
HDW9308	0.005	1,700	8.99E+04	No Flow	-	-	0.002	130	2.47E+03
HDW9311	0.120	**2,500**	3.01E+06	No Flow	-	-	0.016	5,200	8.06E+05
HDW9328	0.007	370	2.45E+04	No Flow	-	-	0.005	280	1.40E+04

ND= no data; **Bolded** values reported as >2,500 CFU/100 mL

3.2 SURFACE WATER QUALITY MONITORING

3.2.1 *In-Situ* Water Monitoring

In-situ water quality profiles were collected throughout the water column at both in-lake stations (Banook and Micmac) during each sampling event. *In-situ* water quality parameters included:

- Temperature (°C)
- Conductivity (mS/cm)
- pH
- Dissolved Oxygen (mg/L)
- Total Dissolved Solids (g/L)

3.2.1.1 Lake Micmac

Water quality profiles at the Micmac in-lake station were collected in an area of approximately 7 m in depth. Data was plotted against depth for temperature, pH, and dissolved oxygen. *In-situ* water quality profiles for the in-lake stations for Lake Micmac can be seen in Figures 10-12 below.

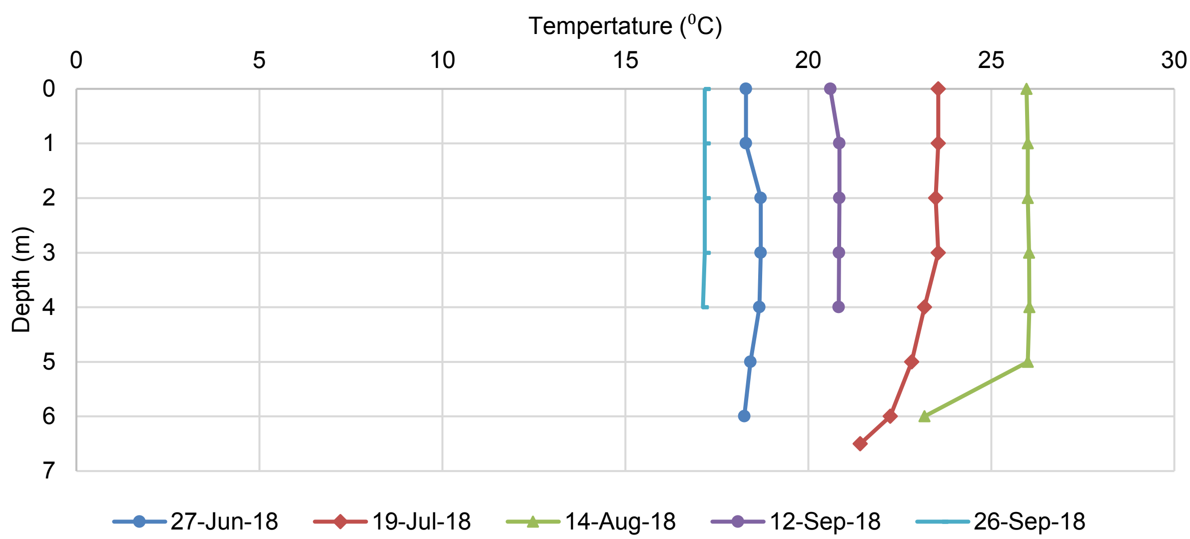

Figure 10 ***In-Situ*** **Temperature (°C) Profiles for the Lake Micmac In-Lake Station**

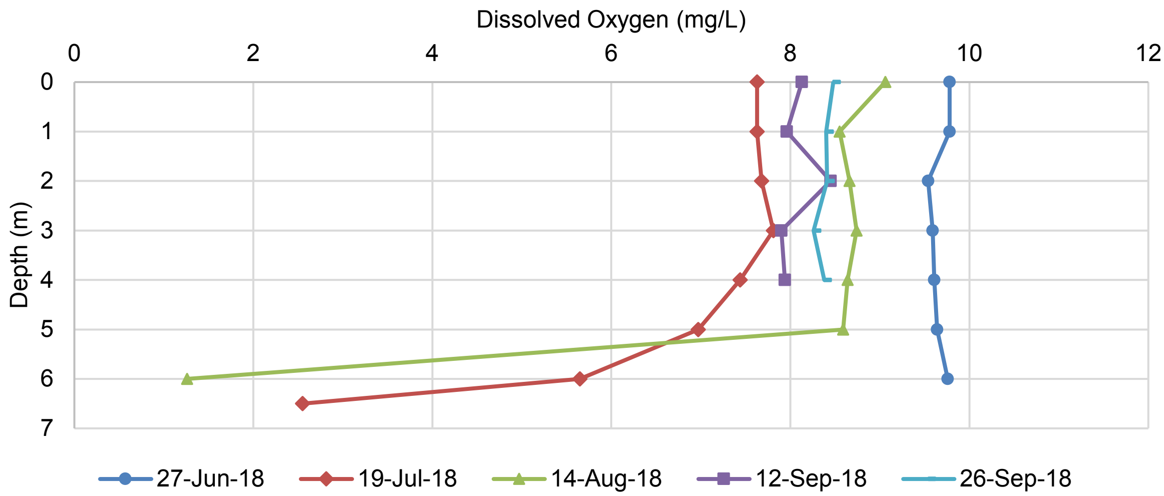

Figure 11 ***In-Situ*** **Dissolved Oxygen (mg/L) Profiles for the Lake Micmac In-Lake Station**

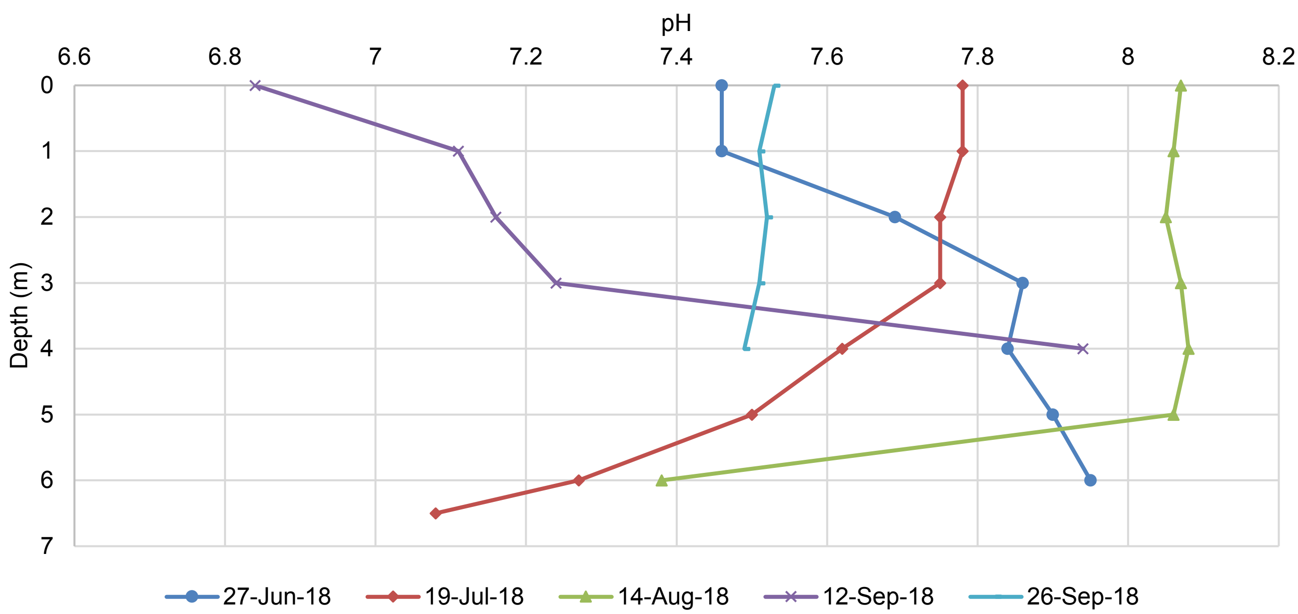

Figure 12 ***In-Situ*** **pH Profiles for the Lake Micmac In-Lake Station**

3.2.1.2 Lake Banook

In-situ data was plotted against depth in an identical manner as those for Lake Micmac. Both conductivity and total dissolved solids (TDS) remained relatively stable throughout the water column for each sampling event and thus were not visually plotted. Thermal stratification of Lake Banook was observed to begin within the first half of July with stratification being more pronounced by August (Figure 12). A similar pattern can be observed for dissolved oxygen. For the entire sampling period (June to September), the upper four meters of the lake were observed to be well oxygenated and greater than the CCME FAL recommended minimum DO of 6.5 mg/L. At the end of June, there is a significant drop in DO levels below the 8m water depth with DO dropping from 8.3 mg/L to 3.3 mg/L. By the middle of July, in water stratification is more pronounced with DO levels dropping from 7.0 to 2.9 mg/L in the 4 to 10 m water depth range. A similar pattern can be seen in August when the bottom layer reaches a total anoxic state with DO levels of <0.5 mg/L below the 7-meter water depth. *In-situ* water quality profiles for the in-lake stations can be seen in Figures 13-15 below.

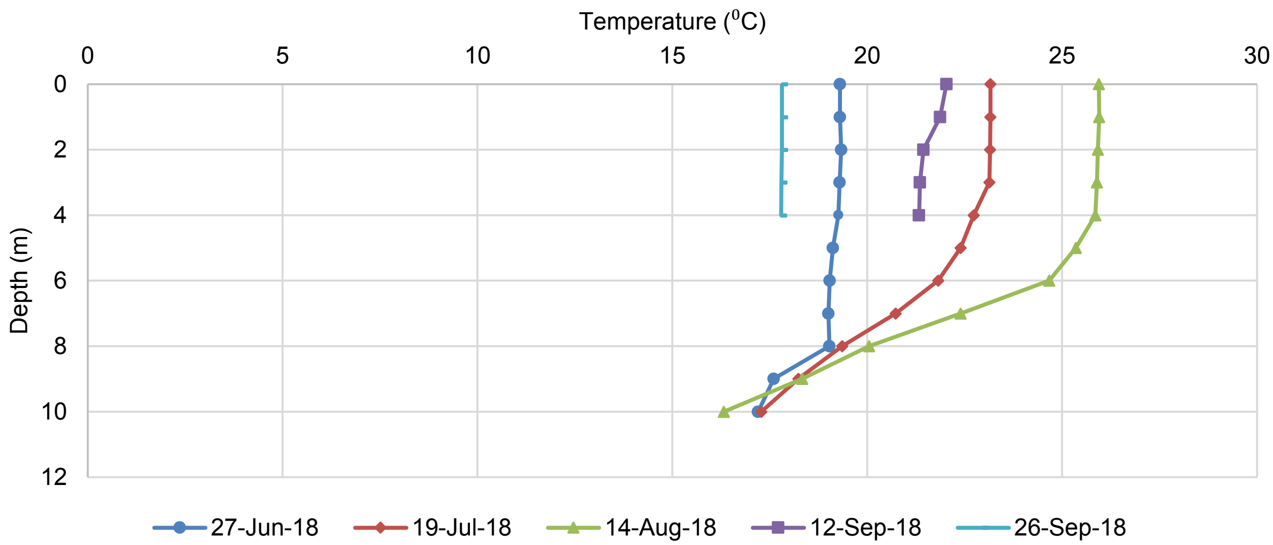

Figure 13 ***In-Situ*** **Temperature (°C) Profiles for the Lake Banook In-Lake Station**

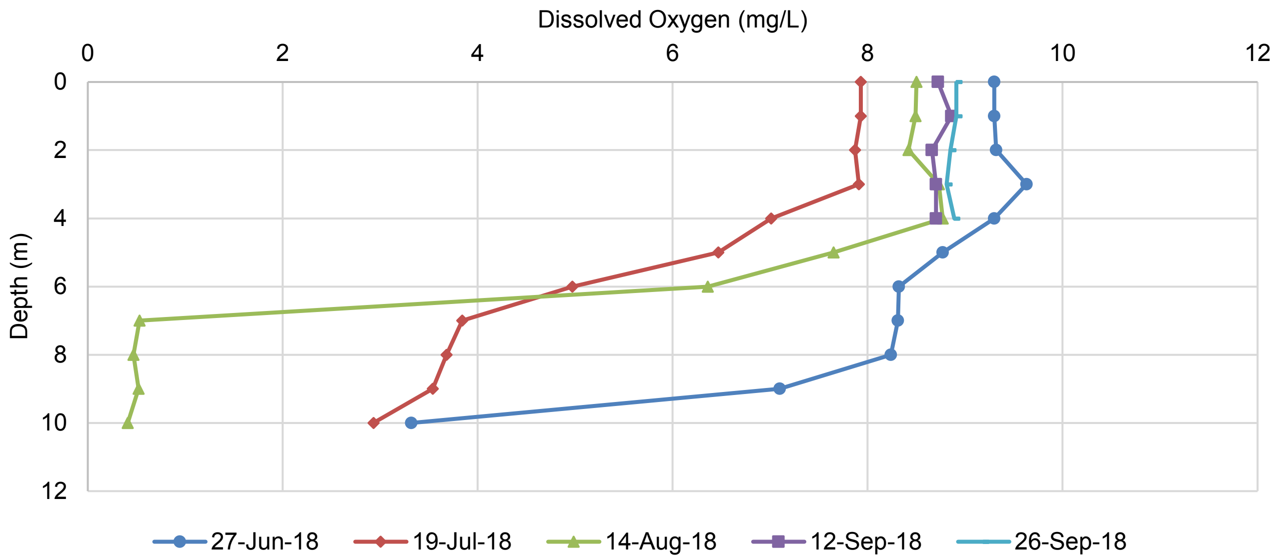

Figure 14 *In-Situ* **Dissolved Oxygen (mg/L) Profiles for the Lake Banook In-Lake Station**

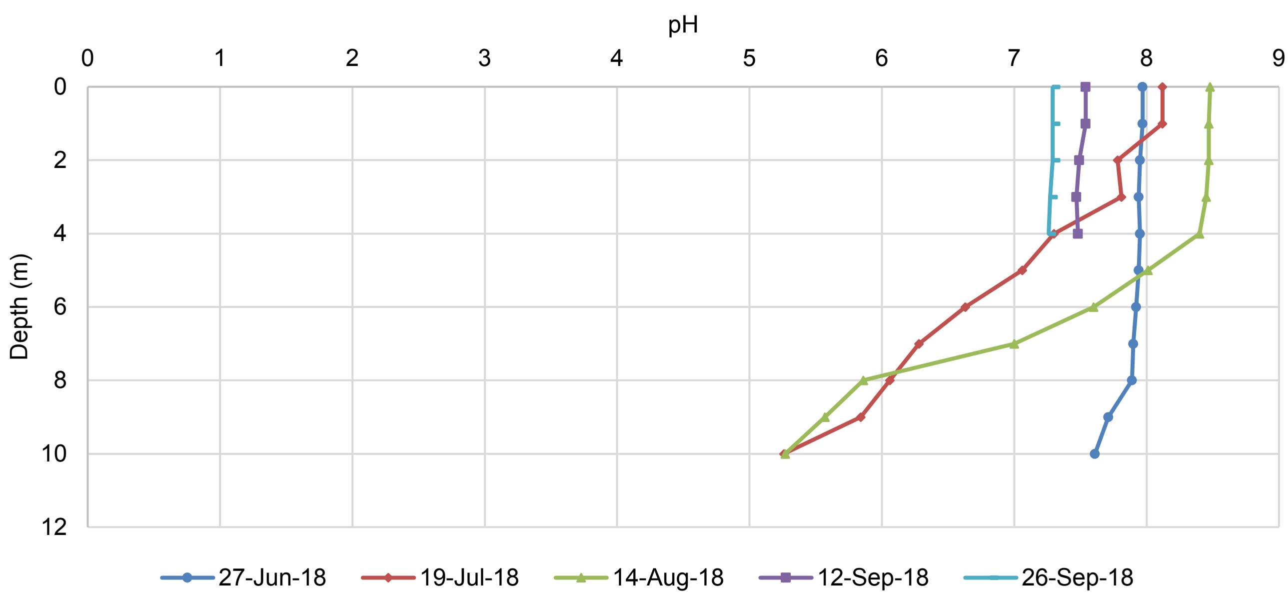

Figure 15 *In-Situ* **pH Profiles for the Lake Banook In-Lake Station**

3.2.2 Surface Water Quality

The following section provides a summary of the surface water quality as indicated by laboratory analysis of grab samples. Of the analyzed parameters, chloride and copper concentrations were found to be consistently above the CCME FAL guidelines within both lakes, with results described in further detail, below.

3.2.2.1 Lake Micmac

A selection of water quality plots is provided for Lake Micmac in Figures 16-18, below. Sample data are taken from the in-lake sample locations at Micmac 1 (taken from 0.25 m below the lake surface) and Micmac 2 (taken from 1 m above the lake bottom). A complete set of sample results is given in Appendix B, with Maxxam laboratory reports provided in Appendix C. It is noted that *E. coli* concentration analyzed in-lake were reported as non-detect (<10 CFU/100 mL) for lake bottom samples. Detections reported for surface samples were well below the CRWQ guideline value of 400 CFU/100 mL for a single-sample concentration. Average concentration of chlorophyll a (Micmac 1 only) was reported as 2.31 µg/L during the monitoring period, which is considered low. Average lake colour, at 5.22 TCU, is also considered low.

Phosphorous concentrations were higher at the lake bottom (Micmac 2) during the June and July sampling events. This trend was reversed in August, with the August and September sampling events having higher P concentrations at the lake surface (Micmac 1). This may be associated with lake stratification. It is noted that the difference between surface and bottom samples range from 0.001 to 0.006 mg/L for most sample events. Most analyzed P concentrations are within the oligotrophic range (0.004 to 0.010 mg/L).

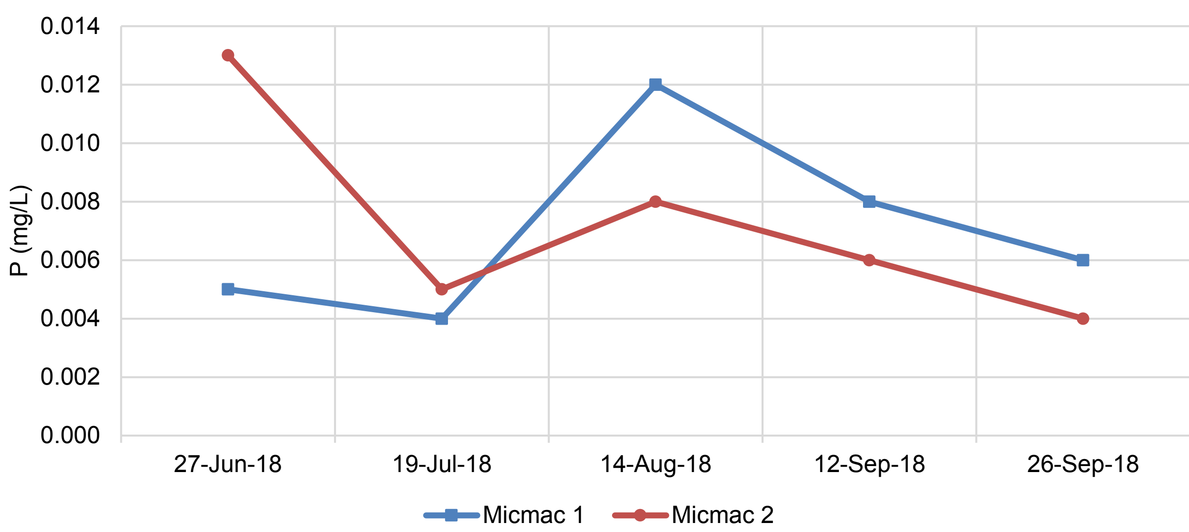

Figure 16 In-lake Phosphorous Concentrations, Lake Micmac

Chloride was analyzed for in-lake samples at Lake Micmac, with results shown in Figure 17. Sample results were consistent between surface and bottom samples, and all sampled events showed exceedances of the CCME FAL chronic exposure guideline value of 120 mg/L for chloride concentration. Chloride concentrations in freshwater lakes may be attributed to anthropogenic sources such as the use of fertilizer and road salt within an urban watershed (Dugan *et al.* 2017).

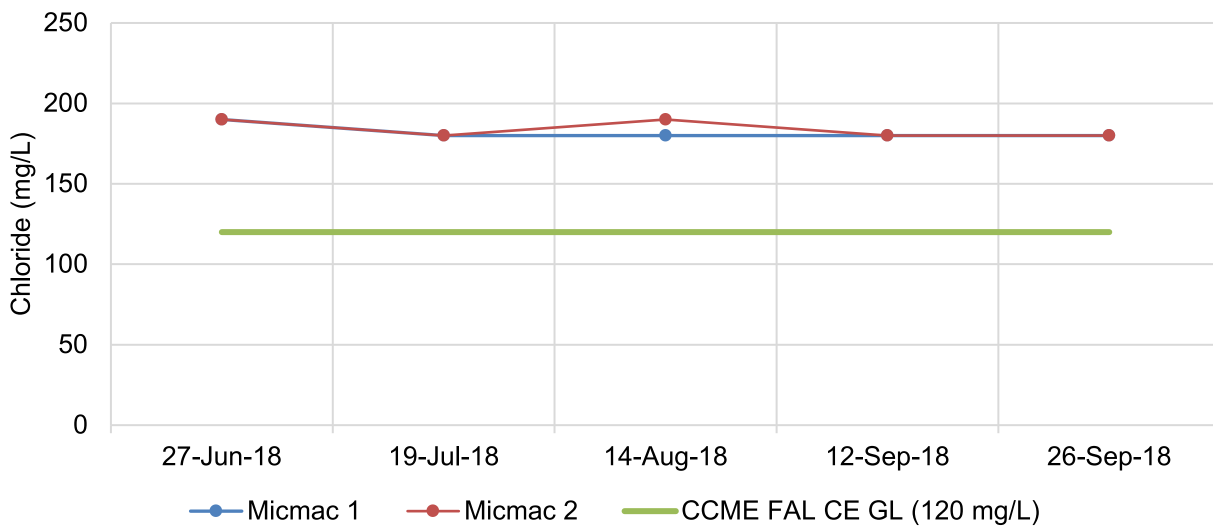

Figure 17 In-lake Chloride Concentrations, Lake Micmac

Copper concentrations in Lake Micmac for all lake bottom samples (Micmac 2) were also routinely above the CCME FAL guideline value, with analyzed samples having concentrations above 2 µg/L. It is noted that all surface samples (Micmac 1) were reported as below the guideline value. Results are shown in Figure 18. Copper is a contaminant typically found in stormwater, with the source deriving from vehicular wear, pesticides and fungicides as well as corrosion of building materials (Makepeace *et al.* 1995; Vaccari *et al.* 2006). The higher reported concentration of copper at the lake bottom indicates the metal is likely sediment-associated.

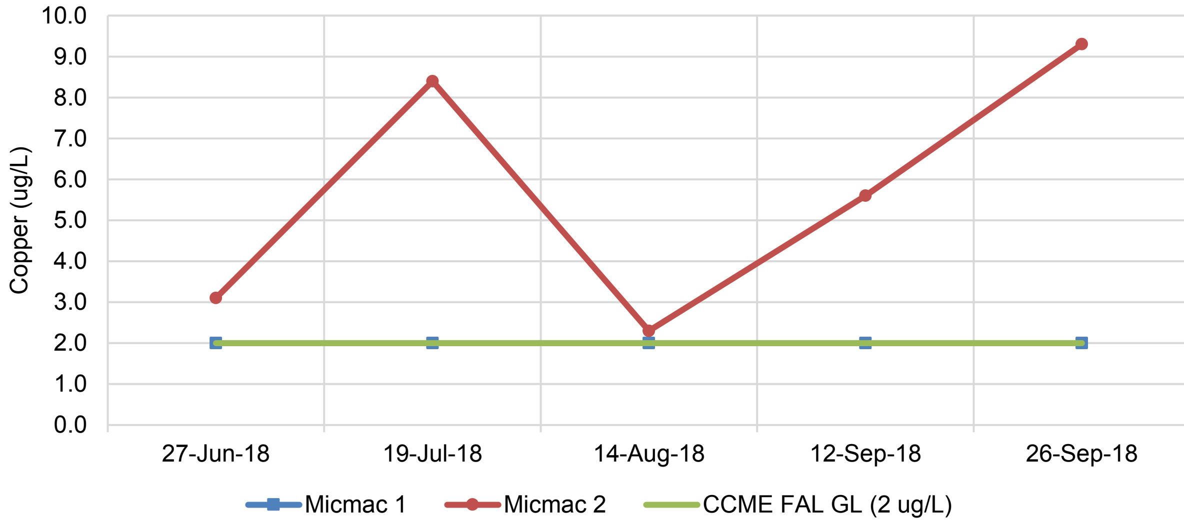

Figure 18 In-lake Copper Concentrations, Lake Micmac

3.2.2.2 Lake Banook

A selection of water quality plots is provided for Lake Banook in Figures 19-21, below. Sample data are taken from the in-lake sample locations at Banook 1 (taken from 0.25 m below the lake surface) and Banook 2 (taken from 1 m above the lake bottom). It is noted that *E. coli* concentration analyzed in-lake were reported as non-detect (<10 CFU/100 mL) for lake bottom samples. Detections reported for surface samples were well below the CRWQ guideline value of 400 CFU/100 mL for a single-sample concentration. Average concentration of chlorophyll a (Banook 1 only) was reported as 1.98 µg/L during the monitoring period, which is considered low. Average lake colour, at <5 TCU, is also considered low.

Historical sample results from Lake Banook for the years 2006 to 2011 are used for comparison purposes, where applicable. These data were referenced from the Analysis of Regional Centre Lakes Water Quality Data (2006 – 2011), completed by Stantec for Halifax in 2012.

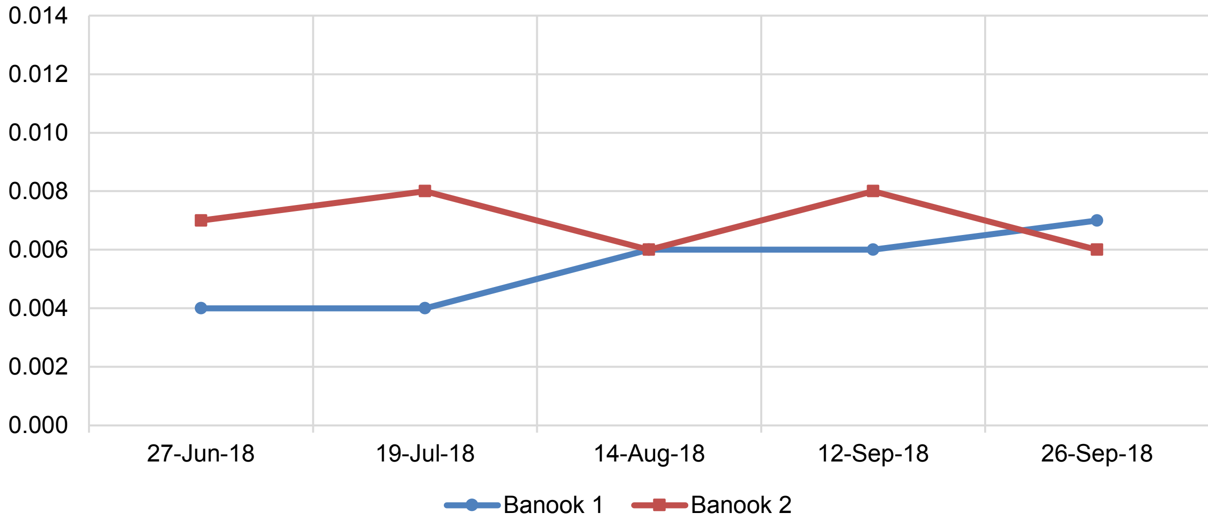

Figure 19 In-lake Phosphorous Concentrations, Lake Banook

Phosphorous concentrations appear similar between surface and bottom sample locations, with differences ranging from 0 to 0.004 mg/L. All analyzed P concentrations are within the oligotrophic range (0.004 to 0.010 mg/L). Mean P concentration reported by Stantec (2012) was 0.011 mg/L, or mesotrophic, with a value range reported as 0.002 to 0.044 mg/L over the period of analysis.

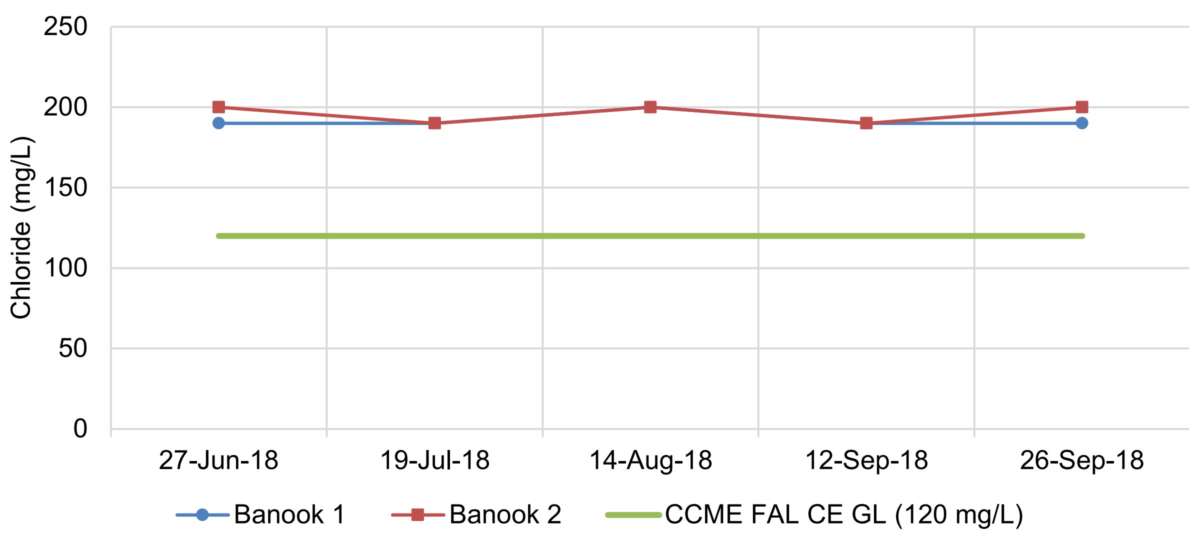

Figure 20 In-lake Chloride Concentrations, Lake Banook

Chloride concentrations in Lake Banook are shown in Figure 20. Sample results were consistent between surface and bottom samples, and all sampled events showed exceedances of the CCME FAL chronic exposure guideline value of 120 mg/L for chloride concentration. High chloride concentrations were also reported in the historical lake data set, with an average chloride concentration reported as 150 mg/L, with data covering a range from 65 to 210 mg/L (Stantec 2012).

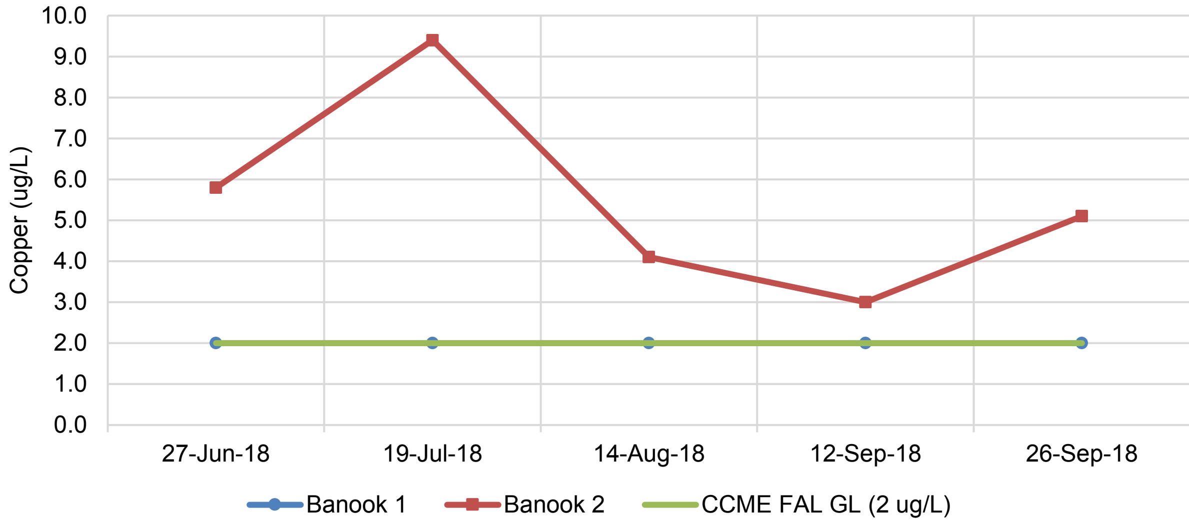

Figure 21 In-lake Copper Concentrations, Lake Banook

Similar to Lake Micmac results, copper concentrations in Lake Banook were also routinely above the CCME FAL guideline value, with analyzed samples having concentrations above 2 µg/L for all lake bottom samples (Banook 2). It is noted that all surface samples (Banook 1) were reported as below the guideline value. It is also assumed in this case that the metal is sediment-associated. Historical sample results from Lake Banook indicate copper concentrations at <2 µg/L for most sample events (Stantec 2012); however, from recent results, it is noted that copper detections are largely influenced by the depth of sampling.

3.3 FECAL SOURCE IDENTIFICATION

Results of LI-MST analysis are given in units of log gene copies/100 mL of sample, which represents the number of gene markers per 100 mL of sample for the selected genetic marker. Results of less than 1.1 log gene copies/100 mL are considered non-detect. Results greater than 1.1 log gene copies/100 mL represent an indication of the presence of fecal contamination, with source prevalence increasing with the number of gene copies detected. A summary of LI-MST results for analyzed sources is given in Table 12, below.

Table 12 Summary of *E. coli* Concentrations and Identified Fecal Markers by Sample Location

Waterbody	Sample Location	Geometric Mean Overall *E. coli* Concentrations (CFU/100 mL)	Overall Average Log Gene Copies/100 mL				Percent Occurrence of Overall Detections			
			Human	Avian	Canine	Ruminant	Human	Avian	Canine	Ruminant
In-Lake Sample Locations										
Lake Micmac	Micmac 1	14	<1.1	2.04	<1.1	-	0%	80%	0%	-
Lake Micmac	Nearshore 3	100	<1.1	2.08	3.33	-	0%	80%	100%	-
Lake Transition	Waterfowl 1	**516**	<1.1	1.99	<1.1	-	0%	80%	0%	-
Lake Banook	Banook 1	11	<1.1	1.78	<1.1	-	0%	80%	0%	-
Lake Banook	Banook 2	10	<1.1	2.06	<1.1	-	0%	100%	0%	-
Lake Banook	Nearshore 1	109	2.79	2.27	2.74	-	40%	100%	40%	-
Lake Banook	Nearshore 2	**396**	3.09	2.01	<1.1	-	20%	100%	0%	-
Outfall Sample Locations										
To Lake Micmac	Watercourse 2	59	5.53	2.70	3.45	4.73	20%	80%	60%	80%
To Lake Micmac	Watercourse 3	35	<1.1	1.97	2.33	-	0%	75%	25%	-
To Lake Micmac	Watercourse 4	24	<1.1	2.17	3.58	3.74	0%	100%	20%	20%
To Lake Micmac	Watercourse 5	165	<1.1	2.17	<1.1	4.35	0%	100%	0%	80%
To Lake Micmac	Watercourse 6	**386**	3.58	2.63	3.34	-	40%	100%	20%	-
To Lake Banook	Outfall 8	**762**	4.45	2.34	3.13	-	100%	100%	20%	-
Lake Banook Outlet	Watercourse 1	186	4.47	1.91	2.71	-	40%	80%	40%	-

Bold values indicate exceedances of the single-point CRWQ guideline value of 400 CFU/100 mL or geometric mean guideline value of 200 CFU/100 mL

Of the monitored sample locations, four locations had geometric mean *E. coli* concentrations above the associated CRWQ guideline value of 200 CFU/100 mL. Human markers were detected at the Outfall 8 sample location during all monitoring events, with an overall average of 4.45 log gene copies/100 mL and an associated geometric mean *E.coli* concentration of 438 CFU/100 mL at this location. Ruminant markers were detected during 80% of the sampling events at Watercourse 2 and Watercourse 5, with respective overall averages of 4.73 and 4.35 log gene copies/100 mL; however, the geometric mean *E. coli* concentrations at these locations are below the associated CRWQ guideline value at 58 and 165 CFU/100 mL, respectively. This appears due to increases in measured *E. coli* concentrations and associated increases in ruminant marker detection during the July 19, 2018 and September 12, 2018 sampling events. Avian markers showed a high percentage of detection at all sampling locations; however, the overall average log gene copies detected ranged from 1.78 to 2.70 log gene copies/100 mL. Human, canine and ruminant markers, when detected, were consistently higher than avian markers in number of gene copies detected. The frequency of avian detections is due in part to a higher-sensitivity of the avian marker used in analysis. Although detected less frequently, the number of markers detected for human, canine and ruminant sources suggest a higher prevalence of bacteria associated with these sources.

Table 13 shows a detailed summary of the high-bacteria events occurring over the sampling period and the associated genetic marker with the highest number of gene copies detected during the event. High-bacteria events are defined as events exceeding the CRWQ single-sample guideline value of 400 CFU/100 mL. Samples taken from the Waterfowl 1 and Outfall 8 sample locations have consistently exceeded guideline values, whereas most watercourse-associated sampling locations appear to fluctuate in bacterial concentrations. Guideline exceedances at the Waterfowl 1 location appear to be correlated with avian sources and guideline exceedances at Outfall 8 appear to be correlated with human sources. Guideline exceedances at Watercourse 5, when occurring, appear to be correlated with ruminant sources. The remaining sampling locations having high-bacteria events appear to fluctuate between a dominance of avian and canine sources, except for human markers identified in Watercourse 1 and the Nearshore 2 locations during the September 26, 2018 sampling event.

Table 13 *E. coli* Concentrations (CFU/100 mL) and Potential Contributing Sources

Waterbody	Sample Location	*E. coli* Concentrations (CFU/100 mL) and Potential Sources				
		28-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
In-Lake Sample Locations						
Lake Banook	Nearshore 1	-	-	-	-	-
		-	-	-	-	-
Lake Banook	Nearshore 2	-	500	-	2,500	540
		-	Avian	-	Avian	Human
Lake Micmac	Nearshore 3	-	-	-	-	-
		-	-	-	-	-

Table 13 *E. coli* Concentrations (CFU/100 mL) and Potential Contributing Sources

Waterbody	Sample Location	*E. coli* Concentrations (CFU/100 mL) and Potential Sources				
		28-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Outlet Sample Locations						
Lake Micmac Outlet	**Waterfowl 1**	-	530	690	640	490
		-	Avian	Avian	Avian	Indeterminate
Lake Banook Outlet	**Watercourse 1**	-	-	1,600	-	580
		-	-	Avian	-	Human
To Lake Micmac	**Watercourse 2**	-	-	-	1,700	-
		-	-	-	Ruminant/ Human	-
To Lake Micmac	**Watercourse 5**	-	-	-	450	-
		-	-	-	Ruminant	-
To Lake Micmac	**Watercourse 6**	-	1,300	-	2,100	-
		-	Canine	-	Avian	-
To Lake Banook	**Outfall 8**	470	790	550	660	1,900
		Human	Human	Human	Human	Human

Although prominently detected, non-human fecal sources may not pose as significant a risk to human health. Most viruses exhibit species-specificity, indicating a higher likelihood of infecting species from which the virus was sourced from (Dufour et al. 2012). From a human health perspective, it is recommended that remediation of locations identified to have human markers be priority. It is noted, however, that bacterial and parasitic pathogens, such as *Cryptosporidium*, may be transmitted from animal species to humans (Penakalapati *et al.* 2017). For this reason, sources of animal feces should be eliminated where possible and monitoring of *E.coli* concentrations at recreational beaches should continue.

4.0 MODELLING RESULTS

4.1 ANNUAL WATERSHED LOADING

Modelling was completed to predict land use-associated contaminant loadings from the Lake Micmac and Lake Banook watersheds. Models were completed for both P and FC using methods described in Section 2.5.2.

4.1.1 Phosphorous

The annual P loading from the Lake Micmac watershed is approximately 845 kg/year from the approximate 675 ha watershed (Table 14). This results in an annual watershed P loading of 0.125 g/m^2/year, analogous to area loading rates provided for commercial land use. An estimated 95% of the annual loading is generated from two land use types within the watershed; commercial developments and roadways. Residential areas account for approximately 13.7% of the land use within the watershed and contribute 2.9% of the annual P loading whereas forested/parkland areas account for 13.2% of the overall area and contribute 0.3% of the annual P loading.

Table 14 Predicted Annual P Loading to Lake Micmac

Lake Micmac Watershed Land Use	Area (ha)	Annual P Loading (kg/year)	Land Use Percentage	P Load Percentage
Commercial Development	240.6	486.1	35.6%	57.5%
Forest/Parkland	88.8	2.1	13.2%	0.3%
Undeveloped/Grassed	5.1	0.8	0.8%	0.1%
High-Density Residential	2.5	0.9	0.4%	0.1%
Low-Density Residential	65.7	16.4	9.7%	1.9%
Medium-Density Residential	24.6	7.4	3.6%	0.9%
Partially Cleared Forest	48.3	14.5	7.2%	1.7%
Roadway	90.6	317.0	13.4%	37.5%
Water	104.6	0.0	15.5%	0.0%
Wetland	4.5	0.1	0.7%	0.0%
Total	**675.4**	**845.2**	**100.0%**	**100.0%**

The annual P loading from the Lake Banook watershed is approximately 184 kg/year from the approximate 223 ha watershed (Table 15). This results in an annual watershed P loading of 0.082 g/m^2/year, analogous to area loading rates provided for partially cleared forested areas. An estimated 84% of this annual loading is generated from two land use types within the watershed; commercial developments and roadways. Roadways represent 65.7% of this total P load and 15.5% of the land use within the watershed area. Residential areas account for approximately 48% of the land use within the watershed and contribute 16% of the total P load.

Table 15 Predicted Annual P Loading to Lake Banook

Lake Banook Watershed Land Use	Area (ha)	Annual P Loading (kg/year)	Land Use Percentage	P Load Percentage
Commercial Development	16.5	33.2	7.4%	18.0%
Forest/Parkland	21.8	0.5	9.8%	0.3%
Undeveloped/Grassed	1.5	0.2	0.7%	0.1%
High-Density Residential	0.9	0.3	0.4%	0.2%
Low-Density Residential	59.7	14.9	26.7%	8.1%
Medium-Density Residential	46.7	14.0	20.9%	7.6%
Roadway	34.6	121.0	15.5%	65.7%
Water	41.9	0.0	18.7%	0.0%
Total	**223.5**	**184.2**	**100.0%**	**100.0%**

4.1.2 Fecal Coliform

The annual FC loading from the Lake Micmac watershed is approximately $1.659 \cdot 10^{13}$ CFU/year from the approximate 675.4 ha watershed (Table 16). An estimated 72.5% of this annual loading is generated from commercial land use types within the watershed, with commercial areas covering approximately 36% of the total watershed area. Residential areas account for approximately 13.7% of the land use within the watershed and contribute 16.4% of the annual FC loading whereas roadways account for 13.4% of the overall area and contribute 9.5% of the annual FC loading.

Table 16 Predicted Annual FC Loading to Lake Micmac

Lake Micmac Watershed Land Use	Area (ha)	Annual Loading (CFU/year)	Land Use Percentage	FC Load Percentage
Commercial Development	240.6	$1.202 \cdot 10^{14}$	35.6%	72.5%
Forest/Parkland	88.8	$6.162 \cdot 10^{11}$	13.2%	0.4%
Undeveloped/Grassed	5.1	$1.744 \cdot 10^{12}$	0.8%	1.1%
High-Density Residential	2.5	$9.150 \cdot 10^{11}$	0.4%	0.6%
Low-Density Residential	65.7	$1.862 \cdot 10^{13}$	9.7%	11.2%
Medium-Density Residential	24.6	$7.681 \cdot 10^{12}$	3.6%	4.6%
Partially Cleared Forest	48.3	$5.483 \cdot 10^{11}$	7.2%	0.3%
Roadway	90.6	$1.583 \cdot 10^{13}$	13.4%	9.5%
Water	104.6	-	15.5%	-
Wetland	4.5	$2.815 \cdot 10^{11}$	0.7%	0.2%
Total	**675.4**	**$1.659 \cdot 10^{14}$**	**100.0%**	**100.0%**

The annual FC loading from the Lake Banook watershed is approximately $4.183 \cdot 10^{13}$ CFU/year from the approximate 223 ha watershed (Table 17). An estimated 76% of this annual loading is generated from residential land use types within the watershed, with residential areas covering approximately 48% of the total watershed area. Remaining land use types in the watershed area (roadways, grassed and forested areas) do not contribute significant FC loading to the lake, contributing 4.2% of the annual FC load while covering 26% of the overall watershed area.

Table 17 Predicted Annual FC Loading to Lake Banook

Lake Banook Watershed Land Use	Area (ha)	Annual Loading (CFU/year)	Land Use Percentage	FC Load Percentage
Commercial Development	16.5	$8.216 \cdot 10^{12}$	7.4%	19.6%
Forest/Parkland	21.8	$1.512 \cdot 10^{11}$	9.8%	0.4%
Undeveloped/Grassed	1.5	$5.200 \cdot 10^{11}$	0.7%	1.2%
High-Density Residential	0.9	$3.084 \cdot 10^{11}$	0.4%	0.7%
Low-Density Residential	59.7	$1.692 \cdot 10^{13}$	26.7%	40.4%
Medium-Density Residential	46.7	$1.462 \cdot 10^{13}$	20.9%	34.9%
Roadway	34.6	$1.099 \cdot 10^{12}$	15.5%	2.6%
Water	41.9	-	18.7%	-
Total	**223.5**	**$4.183 \cdot 10^{13}$**	**100.0%**	**100.0%**

4.2 PRECIPITATION EVENT-BASED LOADING

4.2.1 Phosphorous

Precipitation event-based P loading was completed for a design storm event with a 25 mm precipitation depth occurring over the studied watershed, with results given in Tables 18, 19 and 20, below. Resultant P loading for the Lake Micmac, Lake Banook and Outfall 8 watersheds are predicted as 31 kg, 8 kg and 2 kg, respectively. These predicted loadings account for 3%, 2% and 4% of the overall annual loading for the respective watersheds. The measured loading rates for Outfall 8 (Section 3.1) ranged from 0.5 to 13 kg/day. The loading rate of 0.5 kg/day is associated with a rainfall event of 21 mm, whereas the higher loading event is associated with baseflow.

Table 18 Lake Micmac Predicted P Loading during 25 mm Rain Event

Lake Micmac Watershed Land Use	Area (ha)	P Loading (kg)	Land Use Percentage	P Load Percentage
Commercial Development	240.63	14.98	47.21%	48.13%
Forest/Parkland	88.83	0.27	1.68%	0.86%
Undeveloped/Grassed	5.13	0.13	0.22%	0.42%

Table 18 Lake Micmac Predicted P Loading during 25 mm Rain Event

Lake Micmac Watershed Land Use	Area (ha)	P Loading (kg)	Land Use Percentage	P Load Percentage
High-Density Residential	2.53	0.05	0.20%	0.15%
Medium-Density Residential	24.56	0.64	1.68%	2.06%
Low-Density Residential	65.70	1.63	3.42%	5.22%
Partially Cleared Forest	48.30	1.81	2.51%	5.83%
Roadway	90.57	11.51	17.55%	36.98%
Water	104.60	-	24.48%	-
Wetland	4.51	0.11	1.06%	0.36%
Total	**675.36**	**31.13**	**100.00%**	**100.00%**

Table 19 Lake Banook Predicted P Loading during 25 mm Rain Event

Lake Banook Watershed Land Use	Area (ha)	P Loading (kg)	Land Use Percentage	P Load Percentage
Commercial Development	16.45	1.02	12.14%	12.44%
Forest/Parkland	21.80	0.07	1.55%	0.79%
Undeveloped/Grassed	1.53	0.04	0.24%	0.47%
High-Density Residential	0.85	0.02	0.25%	0.19%
Medium-Density Residential	46.73	1.22	12.05%	14.81%
Low-Density Residential	59.68	1.48	11.68%	17.94%
Roadway	34.57	4.39	25.21%	53.36%
Water	41.86	-	36.86%	-
Total	**223.48**	**8.23**	**100.00%**	**100.00%**

Table 20 Outfall 8 (to Lake Banook) Predicted P Loading during 25mm Rain Event

Outfall 8 Sub-watershed Land Use	Area (ha)	P Loading (kg)	Land Use Percentage	P Load Percentage
Commercial Development	9.07	0.56	37.31%	27.70%
Forest/Parkland	6.20	0.02	2.46%	0.91%
Medium-Density Residential	17.75	0.46	25.51%	22.73%
Low-Density Residential	10.07	0.25	10.98%	12.23%
Roadway	5.84	0.74	23.74%	36.42%
Water	0.00	0.00	0.00%	0.00%
Total	**48.92**	**2.04**	**100.00%**	**100.00%**

4.2.2 Fecal Coliform

Precipitation event-based FC loading was completed for a design storm event with a 25mm precipitation depth occurring over the studied watershed, with results given in Tables 21, 22 and 23, below. Resultant FC loading for the Lake Micmac, Lake Banook and Outfall 8 watersheds are predicted as $2.99 \cdot 10^{12}$, $7.85 \cdot 10^{11}$ and $2.43 \cdot 10^{11}$ CFU, respectively. These predicted loadings account for 1.8% of the overall annual loading for the respective watersheds.

Table 21 Lake Micmac Predicted FC Loading during 25 mm Rain Event

Lake Micmac Watershed Land Use	Area (ha)	FC Loading (CFU)	Land Use Percentage	FC Load Percentage
Commercial Development	240.6	$2.25 \cdot 10^{12}$	35.6%	75.1%
Forest/Parkland	88.8	$8.88 \cdot 10^{9}$	13.2%	0.3%
Undeveloped/Grassed	5.1	$2.39 \cdot 10^{10}$	0.8%	0.8%
High-Density Residential	2.5	$1.62 \cdot 10^{10}$	0.4%	0.5%
Medium-Density Residential	24.6	$1.38 \cdot 10^{11}$	3.6%	4.6%
Low-Density Residential	65.7	$2.80 \cdot 10^{11}$	9.7%	9.4%
Partially Cleared Forest	48.3	$1.33 \cdot 10^{10}$	7.2%	0.4%
Roadway	90.6	$2.60 \cdot 10^{11}$	13.4%	8.7%
Water	104.6	-	15.5%	-
Wetland	4.5	$5.58 \cdot 10^{9}$	0.7%	0.2%
Total	**675.4**	**$2.99 \cdot 10^{12}$**	**100.0%**	**100.0%**

Table 22 Lake Banook Predicted FC Loading during 25 mm Rain Event

Lake Banook Watershed Land Use	Area (ha)	FC Loading (CFU)	Land Use Percentage	FC Load Percentage
Commercial Development	16.5	$1.54 \cdot 10^{11}$	7.4%	19.6%
Forest/Parkland	21.8	$2.18 \cdot 10^{9}$	9.8%	0.3%
Undeveloped/Grassed	1.5	$7.14 \cdot 10^{9}$	0.7%	0.9%
High-Density Residential	0.9	$5.45 \cdot 10^{9}$	0.4%	0.7%
Medium-Density Residential	46.7	$2.63 \cdot 10^{11}$	20.9%	33.8%
Low-Density Residential	59.7	$2.54 \cdot 10^{11}$	26.7%	32.4%
Roadway	34.6	$9.92 \cdot 10^{10}$	15.5%	12.7%
Water	41.9	0.00	18.7%	0.0%
Total	**223.5**	**$7.85 \cdot 10^{11}$**	**100.0%**	**100.0%**

Table 23 Outfall 8 (to Lake Banook) Sub-watershed Predicted FC Loading during 25 mm Rain Event

Outfall 8 Sub-watershed Land Use	Area (ha)	FC Loading (CFU)	Land Use Percentage	FC Load Percentage
Commercial Development	9.1	$8.47 \cdot 10^{10}$	18.5%	34.8%
Forest/Parkland	6.2	$6.20 \cdot 10^{8}$	12.7%	0.3%
Medium-Density Residential	17.7	$9.97 \cdot 10^{10}$	36.3%	41.0%
Low-Density Residential	10.1	$4.29 \cdot 10^{10}$	20.6%	17.6%
Roadway	5.8	$1.55 \cdot 10^{10}$	11.9%	6.4%
Water	0.0	0.00	0.0%	0.0%
Total	**48.9**	**$2.43 \cdot 10^{11}$**	**100.0%**	**100.0%**

4.3 LAKE SYSTEM PHOSPHOROUS LOADING

A lake system P loading model was completed for Lake Micmac and Lake Banook using a method developed by Brylinsky (2004), as described in Section 2.5.1. A summary of results is given in Table 24, below.

Table 24 Lake System P Model Results Summary, Lake Micmac and Lake Banook

	Lake Micmac	Lake Banook
Lake Characteristics		
Drainage Area (ha)	570.8	181.7
Lake Surface Area (ha)	103.5	40.8
Lake Volume (10^6 m^3)	3.49	1.65
Lake Flushing Rate (times/year)	5.82	13.65
Phosphorous Budget (g/yr)		
Upstream Inflow	1,032,357.0	1,067,582.0
Atmosphere	17,905.5	7,058.40
Land Runoff	845,237.0	184,332.0
Development	0	0
Sedimentation	-739,245.0	-226,615.0
Total Outflow	**1,156,255.0**	**1,032,357.0**

Phosphorous input sources are partitioned into four categories: input from upstream waterbodies, atmospheric deposition, overland runoff and development (largely septic system inputs). Phosphorous exits the lake system through either in-lake sedimentation or lake outflow. As the lake watersheds are serviced by a centralized wastewater collection system, development inputs from septic systems are not considered within the model. Within Lake Micmac, approximately 40% of P input remains in-lake through sedimentation and approximately 60% is discharged. Within Lake Banook, approximately 20% of P inputs remains in-lake and approximately 80% is discharged. As the flushing rate of Lake Banook is over twice the rate of Lake Micmac, this may contribute to the higher P discharge rate. When looking at drainage area runoff inputs versus lake volume, Lake Micmac accepts 0.242 g of P input per unit of volume, whereas Lake Banook accepts 0.111 g. There is an increase in predicted P loading from the Lake Micmac drainage area, at 1,480 g/ha, over the predicted loading of 1,014 g/ha from the Lake Banook Drainage area. This is consistent with expectations as the Lake Micmac drainage area is dominated by commercial land use whereas the Lake Banook drainage area is largely residential in nature.

Table 25 Model Validation of Predicted vs. Measured P Concentrations

Model Validation	Lake Micmac	Lake Banook
Predicted P – Lake system model (mg/L)	0.057	0.045
Measured P - 2018 monitoring (mg/L)	0.006	0.006
% Difference	843.0%	663.0%

As a result of the lake system nutrient loading modeling, in-lake P concentrations were predicated at 0.057 mg/L within Lake Micmac and 0.045 mg/L within Lake Banook. This represents a trophic status of eutrophic, or highly productive for vegetation growth, under the CCME FAL guidelines. There is a noted difference in model validation depending on the measured P data used in the validation. A comparionson of predicted verusus measured P concentrations is given in Table 25, above. The measured P concentration for the model validation is taken from the average P concentration for each lake (0.006 mg/L, oligotrophic or low productivity for vegetation growth) calculated with results from the 2018 in-lake monitoring, which occurred during the growing season between the months of June and September. Poor comparison is found between the model and sampled results when using this data set.

When comparing to measured P concentration for Lake Banook taken from a historical P data set (Stantec 2012), with the specific sample result of 0.044 mg/L (eutrophic) occurring in May of 2010, model comparison is good (4% difference). When assessing the historical P data set, in-lake concentrations range from 0.002 to 0.044 mg/L (ultra-oligotrophic to eutrophic), with an average concentration of 0.011 mg/L (mesotrophic), corresponding to an average percent difference of 316%. For complete model validation, it is suggested to incorporate sampling data taken during the non-growing season (typically November through May) to assess if there are increased P concentrations in the lakes after vegetation decay and lake turnover (if applicable) has occurred. It is noted that there is good correlation between the predicted annual overland runoff loading from the lake system model and the results from the annual watershed loading model.

5.0 ANALYSIS

5.1.1 Surface Water Flow and Contaminant Loading

The measurement of flow provides valuable interpretation to grab sample concentration data as it allows for the calculation of pollutant loading to a waterbody using measured data. High pollutant concentrations may represent acute risk to aquatic species or human health, but in the absence of significant associated flow, the pollutant load to a waterbody may minimal.

The highest P loading was calculated from Watercourse 2 and Watercourse 5 at 294 and 343 kg/day, respectively, with the highest measured P loading events coinciding with the occurrence of the rain event on September 12, 2018. *E.coli* loading was calculated to be highest from Watercourse 2 and Watercourse 1, at 5.5×10^7 and 1.9×10^7 CFU/100 mL, respectively. These loadings were associated with the September 12, 2018 and August 14, 2018 rain events.

Watercourse 3 and Outfall 8 both have P and *E.coli* loadings that appear to be increased during baseflow. This may be an indication of domestic wastewater discharge to these locations. Stormwater events would provide additional flow to dilute the wastewater, resulting in lower concentrations during storm events in comparison with baseflow.

Many HDW sites had no flow during the monitoring period. For sites with measurable flow, the sample locations with the highest loading of both P and *E.coli* were noted as HDW8714 within Lake Micmac and HDW8905 and HDW9311 within Lake Banook. Sample site HDW9311 had the single highest reported concentration of both P and *E.coli* of all sampled sites, at 2.3 mg/L and 5,200 CFU/100 mL, respectively. Sample site HDW8714 reported the highest loading of both parameters, at 27.1 kg/day P and 3.62×10^6 CFU/100 mL *E.coli*.

Although grab sample concentrations of P and *E.coli* were reported as higher at the HDW8714 sample location, calculated loadings are higher at the watercourse sample locations; therefore, the implementation of loading reduction strategies may be more effective at the watercourse sample locations.

5.1.2 Surface Water Quality Summary

5.1.2.1 In-Situ Monitoring

Thermal stratification and associated low DO values at lake bottom are important factors in P release from benthic sediments. For P release to occur, an anoxic zone must develop at the lake bottom. P is release into this anoxic zone and is distributed throughout the entire water column when seasonal temperature changes temporarily de-stratify the lake.

In-situ water quality profiles were collected throughout the water column at both in-lake stations (Banook and Micmac) during each sampling event. Thermal stratification in Lake Banook was found to begin within the first half of July, with a similar pattern being observed for DO. For the entire sampling period the upper four meters of Lake Banook was well oxygenated with DO levels found to be above the CCME FAL Guidelines. By mid-August a strong thermocline was observed to be present with DO levels dropping significantly under the four-meter mark. DO levels below the seven-meter mark were found to be anoxic in Lake Banook. A similar pattern was observed for pH, with the upper six meters meeting CCME FAL guidelines for pH concentrations. As the summer progressed and a thermocline developed, some pH values fell below these guidelines below water depths of six meters.

Thermal stratification in Lake Micmac was found to be less pronounced than Lake Banook. Lake Micmac is much shallower and appeared to be well mixed throughout the sampling period. Water quality data indicated that by mid-July, DO concentrations were below the CCME FAL guidelines for water depths below five meters. For all sampling events pH concentrations fell within the CCME FAL guideline range.

5.1.2.2 Surface Water Quality

Sampled surface water quality parameters met the referenced CCME FAL and Health Canada CRWQ guidelines in most instances, except for consistent exceedances of the CCME FAL guideline value for chloride (120 mg/L) and copper (2 µg/L) within both Lake Micmac and Lake Banook. Chloride exceedances appear consistent throughout the water column in both lakes, whereas copper exceedances were limited to the lake bottom sample locations (Banook 2 and Micmac 2). Both parameters are associated with anthropogenic sources and are considered common stormwater contaminants.

Bacteria concentrations (*E. coli)* were reported as non-detect or well below the single-sample CRWQ guideline of 400 CFU/100 mL at both in-lake deep-water sample locations; however, the Nearshore 2 location reported routine exceedances of the guideline value. The trophic status, based on in-lake P concentrations, is reported as oligotrophic to mesotrophic within Lake Micmac and oligotrophic in Lake Banook. These trophic statuses are associated with lower vegetative productivity and lower risk for algal blooms. Although thermal stratification and reduced DO was observed in deep-lake in-site profiles, lake bottom samples did not show an increase in P concentration over surface sample results.

Data from the current monitoring period (June to September 2018) were compared to historical data for Lake Banook for select parameters. Chloride exceedances were historically reported for this lake. Copper was not flagged as a contaminant of concern in the historical data set; however, data shows that depth of sampling is important in picking up exceedances of this parameter and surface sample data may not be indicative of bottom water quality.

5.1.3 Fecal Source Identification Summary

MST was conducted at a selection of watercourse and outfall locations within both lakes to identify potential sources of fecal contamination within the lake systems.

Human genetic markers were identified within the Lake Banook system at the following sampling locations: Nearshore 1 (in-lake), Nearshore 2 (in-lake), Outfall 8 (stormwater outfall), and Watercourse 1 (Lake Banook discharge point). High-bacteria events associated with a high number of human markers occurred at Nearshore 2, Watercourse 1 and Outfall 8. Human genetic markers were identified within the

Lake Micmac system at the following sampling locations: Watercourse 2 and Watercourse 6. High-bacteria events associated with a high number of human markers occurred at Watercourse 2. It is anticipated that the detection of human genetic markers is most likely associated with the unintentional discharge of domestic wastewater in areas where markers are detected. This is attributed to either leaking pipe networks, or unintentional cross-connections between wastewater and stormwater collection systems.

Ruminant genetic markers were identified within the Lake Micmac system at the following sampling locations: Watercourse 2, 4 and 5. High-bacteria events associated with a high number of ruminant markers occurred at Watercourse 2 and Watercourse 5. Watercourses 2 and 4 are discharge points within the Shubenacadie Wildlife Park and Watercourse 4 is the outfall of the Red Bridge Pond watershed. Deer have been observed in the wild at these locations.

Canine markers were also identified Nearshore 1, Nearshore 3, Watercourse 1, Watercourse 2, Watercourse 3, Watercourse 4, Watercourse 6 and Outfall 8. A high-bacteria event associated with a high number of canine markers occurred at Watercourse 6. Nearshore 1 and Nearshore 3 are beach locations and Nearshore 3 is also associated with an off-leash dog park.

Avian genetic markers were identified at all sampled locations at a high degree of occurrence. High-bacteria events associated with a high number of avian markers occurred at Waterfowl 1, Nearshore 1, Nearshore 2, Nearshore 3, Watercourse 1 and Watercourse 6. The bridge located at the Waterfowl 1 sample location is a common congregation point for waterfowl, as are the beach locations at Nearshore 1, 2 and 3.

With the exception of human markers, assumptions on why detections have occurred at watercourse locations are more difficult to make as canine, ruminant and avian detections may be a result of overland flow contributions or animal congregation within the watercourse. It is important to note, however, that high bacteria events have been reported associated with watercourses within the lake systems.

5.1.4 Modelling Results Summary

5.1.4.1 Phosphorous

Area and concentration-based P loadings within each watershed are largely generated by anthropogenic sources, namely commercial development and roadways. These two land uses contributed approximately 95% of the 845 kg/year loading to Lake Micmac and 84% of the 184 kg/year loading to Lake Banook. The influence of residential land use on P loadings would be greatly increased if the watersheds were not serviced by wastewater collection systems and centralized wastewater treatment.

During a design storm rainfall event of 25 mm, P loadings were calculated for Lake Banook, Lake Micmac, and a sub-watershed of Outfall 8, discharging to Lake Banook. Rain event-based loadings of 31 kg and 8 kg were calculated for Lake Micmac and Lake Banook, respectively. This would suggest that mitigation of rainfall-associated P loadings within each watershed could be achieved through the use of stormwater treatment designed to remove the loading associated with the modeled rain event.

A rain event-based loading of 2 kg was calculated for the Outfall 8 sub-watershed. When comparing the Outfall 8 model result to loading calculations from measured data during a captured 21 mm rain event, results are comparable at 0.5 kg measured and 2 kg modeled loading values. The measured loading rates for Outfall 8 during a baseflow sampling event increase to 13 kg/day. This indicates loading at this outfall may be more associated with domestic wastewater influence than overland runoff, as it decreases during rain events. Alternatively, measured loading rates for select watercourses captured during rain events suggest a significant increase in P loading from predicted values. Measured P loadings from Watercourse 1, 2 and 5 during a single rain event were analogous to estimated annual P loadings. These events were also associated with high bacteria events and genetic marker detections of human, ruminant and avian sources. This suggests that fecal-associated P may be present at these locations in concentrations that are higher than what is captured in the literature-based EMC values used in the model.

According to results of the lake systems P model, Lake Micmac retains approximately 740 kg of P on an annual basis and Lake Banook retains approximately 243 kg. Modeled in-lake P concentrations predict eutrophic status for both lakes; however, sample results show P concentrations within the lakes as oligotrophic during the sampled period. This is thought to be in part due to vegetation harvesting efforts that have been undertaken in Lake Banook over the past several years. It is also possible that the sampling program was carried out during the active growing season, where vegetation growth removes P from the water column. The extension of sampling into the colder months may capture changes in lake P concentration as vegetation die-off releases P into the environment.

5.1.4.2 Fecal Coliform

According to EMC-based model results, area and concentration-based FC loadings within Lake Banook are largely generated by residential developments (76%) and area and concentration-based FC loadings within Lake Micmac are largely generated by commercial developments (73%). It is noted, however, that model parameters used for FC have a high degree of variability. Results from rainfall-event modeling at Outfall 8 give a calculated loading of 2.43×10^{11} CFU/100 mL during a 25 mm design storm event. When compared to captured loading data for a similar rainfall within the watershed, at 3.51×10^{4} CFU/100 mL, the model results appear to overestimate FC loading from the sub-watershed. With more definitive bacteria source conclusions made as a result of MST sampling, it is recommended that future *E.coli* studies in the watershed be carried out using analytical methods as opposed to watershed modeling.

6.0 RECOMMENDATIONS TO MITIGATE LOADING

6.1 PHOSPHOROUS LOADING MITIGATION

6.1.1 Land Use-Based Mitigation

Commercial and road land uses contribute the highest percentage of P loading to both lake systems on an annual basis. As a result, the following suggested mitigation measured are designed to counter the effects of existing urban development by changing land-use loading rates derived from these developments.

1) The implementation of street maintenance programs to remove sediment-associated P from roadways prior to it being carried to the lake systems via stormwater runoff. Street sweeping and catch basin clean out are required routine maintenance for urban street systems to minimize sediment transport to downstream receptors.

2) The promotion of green space creation or reclamation within the highly urbanized watersheds. The loading rate for P changes significantly from commercial developments (0.2 gm/m^2 yr) to green space (0.015 gm/m^2 yr), meaning the promotion of green space can reduce P loadings to downstream receptors.

3) The implementation of both source-based and end-of-pipe P removal stormwater design best-management practices (BMPs). Infiltration-based or settling-based low-impact design (LID) techniques may be used to reduce sediment and sediment-associated P loadings from reaching discharge points within the lakes. Based on preliminary loading data captured within this study, P loading is greater from watercourse sample locations than stormwater headwall locations. Treatment should primarily focus on mitigating stormwater loading to watercourses within the watershed. This should be a requirement of new developments in the area. The installation of decentralized catch-basin-type treatment devices are a viable option in previously-developed areas. For design purposes, P loading derived from the precipitation-based model (25 mm, 4-hr duration Chicago storm) can be used as a benchmark for P loading removal requirements of selected stormwater management BMPs.

6.1.2 Vegetation Harvesting

Differences between modeled P loading and actual measured in-lake P concentrations suggest that the current lake P concentration and associated trophic status is better than expected for a highly urbanized watershed. The lake system model uses estimated P inputs and outputs to calculate an in-lake P concentration. The continuation of vegetation harvesting efforts in Lake Banook is recommended as this represents an additional P output from the lake system. If land-use based mitigation measures are successful in reducing P loading to the lake systems, the requirement for vegetation harvesting may be lessened over time.

6.1.3 On-going Monitoring

On-going monitoring provides a method to measure the success of implemented mitigation measures while keeping record of water quality within the lake system. The following monitoring activities are recommended to be carried out on an on-going basis within the lake systems:

1) The extension of in-lake P monitoring at deep lake locations through the vegetation die-off period. This is recommended to capture any increase in lake P concentrations and associated trophic status caused by a release of P from vegetation decay. If carried out after seasonal lake turnover, this data can also capture any increase in P concentration from the lake anoxic zone.

2) The continuation of profiling and surface and lake bottom sampling at deep-water lake locations. This will allow for the monitoring of P release from benthic sediments, through the identification of anoxic zones at lake bottom and surface and lake bottom concentration comparison.

3) The continuation of flow monitoring and grab sampling at select monitoring locations to track loading reductions as a result of mitigation measures. Suggested locations would be watercourse locations where stormwater treatment BMPs are being implemented, or headwall locations where roadway maintenance is being implemented.

6.2 *E.COLI* LOADING MITIGATION

6.2.1 Infrastructure-Based Mitigation

Fecal source identification is helpful in identifying changes to infrastructure that may aid in the reduction of *E.coli* loading to recreational water bodies. Of specific interest are various locations where human genetic markers have been identified in the lake systems, as well as a bridge structure at the outlet of Lake Micmac thought to be associated with the detection of avian markers. The following mitigation measures are recommended to reduce infrastructure-associated *E.coli* loading:

1) The identification of domestic wastewater sources contributing to human marker detection within the lake system. It is concluded that the likely source of human genetic markers within the lake systems is domestic wastewater, either from leaking pipework or stormwater network cross-connections. The completion of wastewater collection system inspections should be carried out to pinpoint the source. Based on the occurrence of high bacteria events in conjunction with human genetic marker detection, the focus should be on wastewater collection systems in the vicinity of Outfall 8 and Watercourses 2 and 6.

2) The installation of bird-deterrents on the bridge located at the Lake Micmac outlet (Waterfowl 1) is recommended. This bridge is a known congregation area for birds and sampling has shown recurring high bacteria events at this location associated with a strong presence of avian genetic markers.

6.2.2 Public Education

Public education efforts are expected to be most effective regarding *E.coli* loading to the lake systems as bacteria loading has a direct and potentially serious implication to human health, it affects the use of recreational water bodies, and public involvement with mitigation measures is expected to be more possible than with P loading sources. The following public education items are recommended as a result of study findings:

1) Increased public education on the need to pick-up droppings from domestic dogs. Canine markers were identified at numerous sample locations, with several hits near public beaches and an off-leash dog park. Increased awareness of the requirement to remove pet waste from public beaches, walkways, recreational and forested areas may aid in the reduction of canine marker detection.

2) Increased public education of the risk of swimming in areas where wildlife congregates. Ruminant and avian markers were detected at several locations with the lake systems, with some detections associated with high bacteria events. As these species are wild, control of these sources is difficult. Public risk awareness is needed to mitigate risk to human health from these sources.

3) Continuation of public education with respect to public beach closures. Regardless of the source of bacteria loadings, high bacteria events represent a risk to public health when they occur in areas used for recreational purposes.

6.2.3 On-going Monitoring

To further aid in the identification of infrastructure upgrade needs, further monitoring is recommended as follows:

1) The completion of MST sampling at HDW locations during storm events. During the assessment of HDW locations, *E. coli* was detected at all outfalls having flow at the time of sampling. While fecal bacteria is commonly present in stormwater from overland runoff and animal sources, the use of MST for fecal source identification at the sampled HDW sites could flag HDW locations that may be impacted by human waste. Sample location HDW9311 reported the highest measured concentration of *E.coli* during monitoring, whereas sample location HDW8714 reported the highest loading.

6.3 ADDITIONAL POLLUTANT MITIGATION

Through the analysis of general surface water quality, it was noted that copper and chloride concentrations within both lakes exceeded the CCME FAL guideline values. Both are common stormwater pollutants found in urbanized watersheds and may be mitigated through road-salt reduction strategies (chloride) and implementation of stormwater treatment BMPS (both chloride and copper). Continuation of monitoring for both parameters is recommended to assess changes in concentrations over time.

7.0 CONCLUSIONS

Lake Micmac and Lake Banook are valued recreational water bodies, used by the community for boating, swimming, fishing and as a means to interact and enjoy the natural environment. These lakes are situated within a highly urbanized watershed which presents challenges to their water quality and has a direct effect on the use of the lake system.

Increased P loading to these water bodies is a direct result of urbanization of the areas surrounding the lake and has the potential to increase vegetation growth within the lakes. Water sampling results show satisfactory P concentrations in-lake at the time of sampling. Current vegetation removal activities within Lake Banook may have contributed to lower P concentration within the lake system. Recommendations are made to further reduce P loading to the lakes to curb vegetation growth and maintain the recreational function of the lake system.

Potential impact on human health has also been identified by observing elevated concentrations of *E.coli* in the lakes. Elevated *E.coli* concentrations have been attributed to human, avian, canine and ruminant sources through the use of microbial source tracking. Recommendations have been made to mitigate human or human-controlled bacteria sources (human, canine and select avian sources) and to limit recreational use in areas where bacteria sources are outside of human control (avian and ruminant sources).

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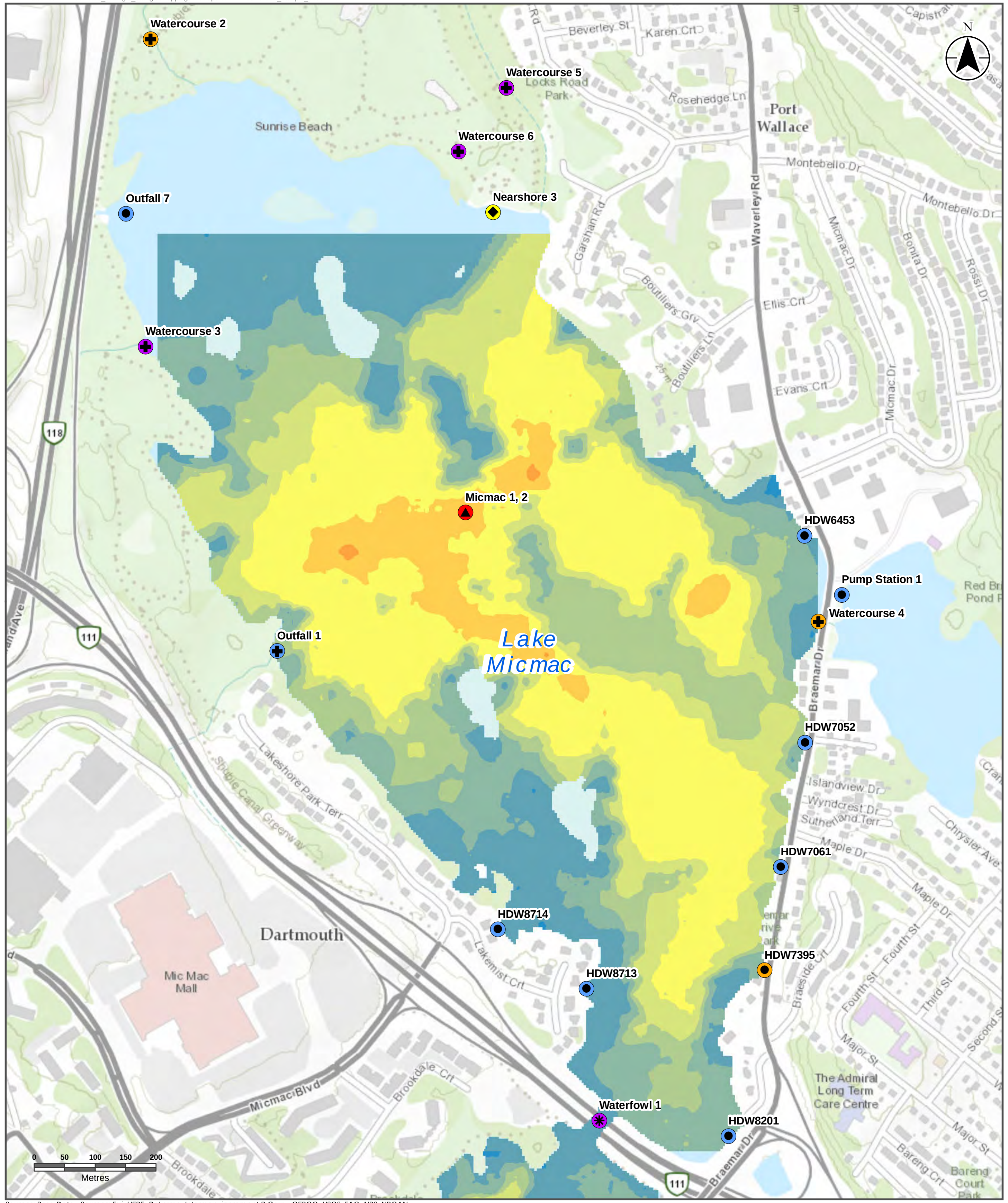
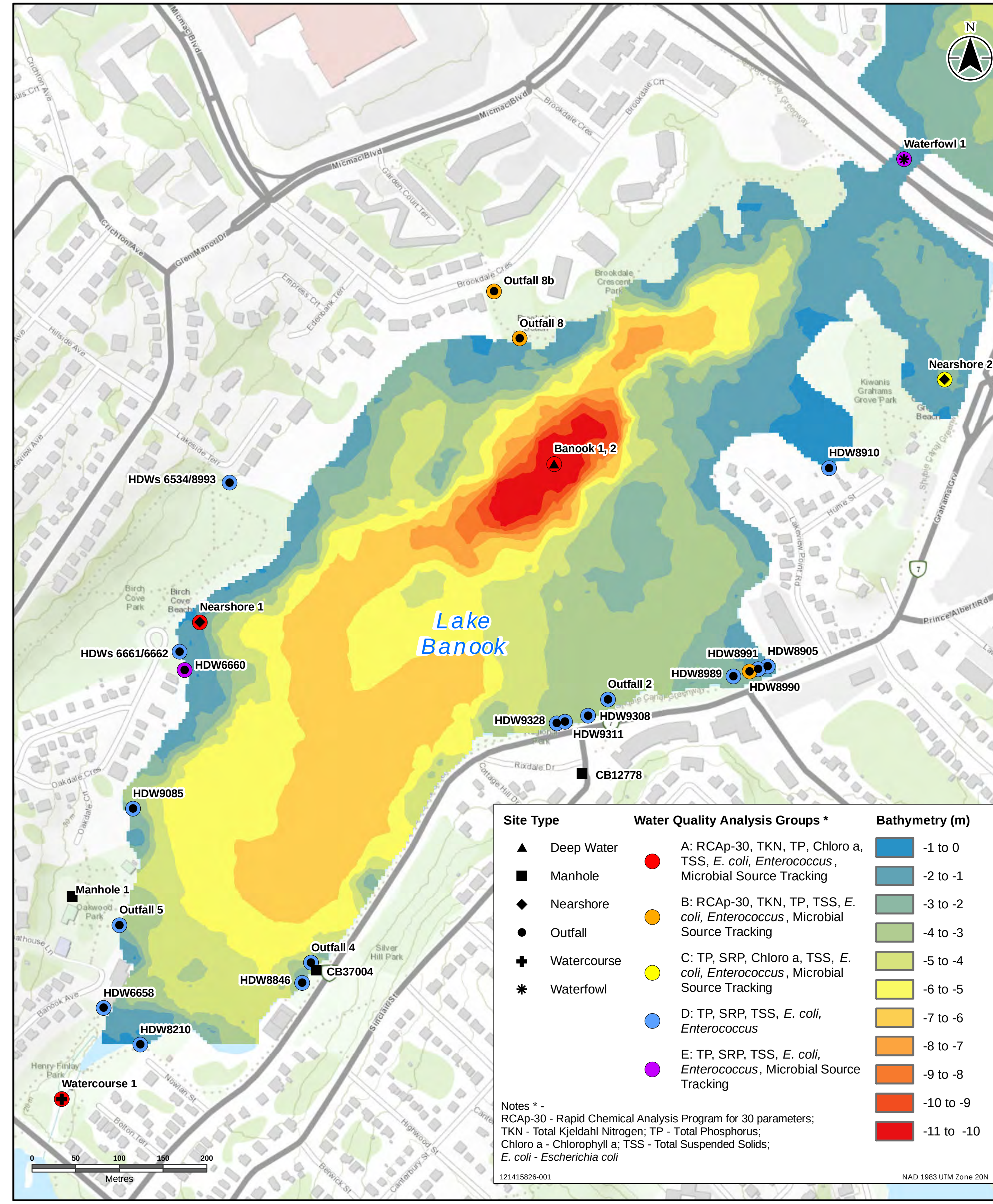
APPENDIX A

Maps



Identified Sampling and Monitoring Locations - Lake Micmac

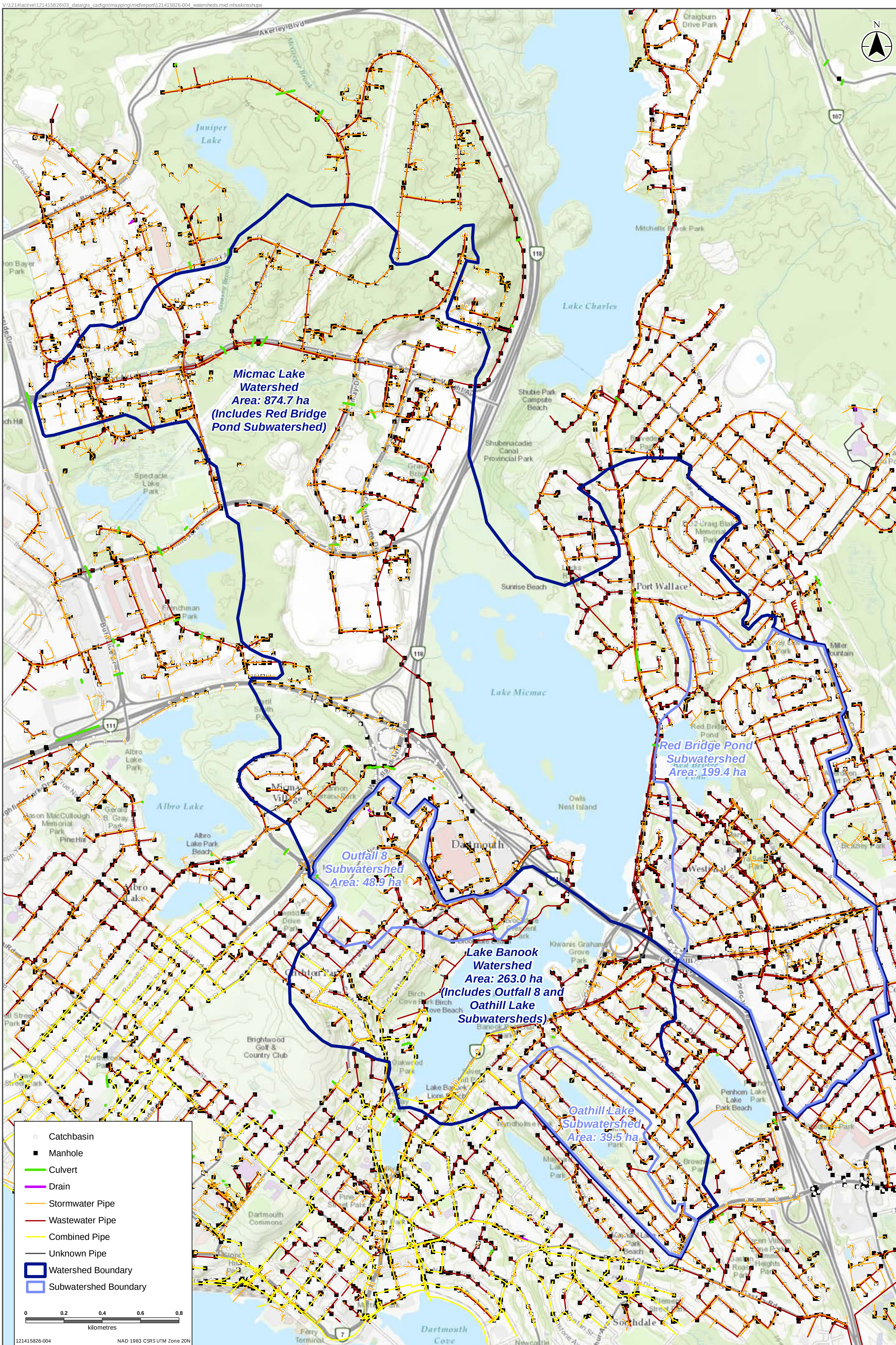


Identified Sampling and Monitoring Locations - Lake Banook

Stantec

Pollution Source Control Study for Lake Banook & Lake Micmac, Halifax Regional Municipality

Figure A-1



Sources: Infrastructure provided by Halifax Water

Service Layer Credits: Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Disclaimer: This map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Delineated Watersheds for Lake Micmac and Lake Banook

Figure A-2

APPENDIX B

Results Tables

B.1 – Water Quality Parameters by Sampling Location

Water Quality Parameters By Sampling Location

Sample ID	RCAp-30 (general chemistry and metals unfiltered) with low-level soluble reactive phosphorus	TKN	Total Phosphorous (low, Mississauga Lab, 4 µg/L)	Soluble Reactive Phosphorus (low level)	Chlorophyll *a*	TSS (low 1 mg/L)	*e. coli*	Enterococcus	MST	Number of Sampling Events
Lake Banook										
In-Lake Samples										
Banook 1	x	x	x	-	x	x	x	x	x	5
Banook 2	x	x	x	-	-	x	x	x	x	5
Near-Shore 1	x	x	x	-	x	x	x	x	x	5
Near-Shore 2	-	-	x	x	x	x	x	x	x	5
Lake Inflow Samples										
Watercourse 1	x	x	x	-	x	x	x	x	x	5
Outfall 2	-	-	x	x	-	x	x	x	-	1
Outfall 4	-	-	x	x	-	x	x	x	-	2
Outfall 5	-	-	x	x	-	x	x	x	-	0
Outfall 8	x	x	x	-	-	x	x	x	x	4
Outfall 8b	x	x	x	-	-	x	x	x	x	2
HDW6453	-	-	x	x	-	x	x	x	-	1
HDW6658	-	-	x	x	-	x	x	x	-	1
HDW6660	-	-	x	x	-	x	x	x	x	0
HDW6661/6662	-	-	x	x	-	x	x	x	-	0
HDW7052	-	-	x	x	-	x	x	x	-	1
HDW7061	-	-	x	x	-	x	x	x	-	2
HDW7395	x	x	x	-	-	x	x	x	x	0
HDW8201	-	-	x	x	-	x	x	x	-	2
HDW8210	-	-	x	x	-	x	x	x	-	1
HDW8713	-	-	x	x	-	x	x	x	-	2
HDW8714	-	-	x	x	-	x	x	x	-	1
HDW8846	-	-	x	x	-	x	x	x	-	2
HDW8905	-	-	x	x	-	x	x	x	-	2
Lake Micmac										
In-Lake Samples										
Micmac 1	x	x	x	-	x	x	x	x	x	5
Micmac 2	x	x	x	-	-	x	x	x	x	5
Waterfowl 1	-	-	x	x	-	x	x	x	x	5
Near-Shore 3	-	-	x	x	x	x	x	x	x	5
Lake Inflow Samples										
Watercourse 2	x	x	x	-	-	x	x	x	x	5
Watercourse 3	x	x	x	-	-	x	x	x	x	5
Watercourse 4	x	x	x	-	-	x	x	x	x	5
Watercourse 5	x	x	x	-	-	x	x	x	x	5
Watercourse 6	x	x	x	-	-	x	x	x	x	5
Outfall 1	-	-	x	x	-	x	x	x	-	5
Outfall 7	-	-	x	x	-	x	x	x	-	5
Pump Station 1	-	-	x	x	-	x	x	x	-	1
HDWs 6534/8993	-	-	x	x	-	x	x	x	-	0
HDW8910	-	-	x	x	-	x	x	x	-	1
HDW8989	-	-	x	x	-	x	x	x	-	2
HDW8990	x	x	x		-	x	x	x	x	0
HDW8991	-	-	x	x	-	x	x	x	-	2
HDW9085	-	-	x	x	-	x	x	x	-	0
HDW9308	-	-	x	x	-	x	x	x	-	2
HDW9311	-	-	x	x	-	x	x	x	-	2
HDW9328	-	-	x	x	-	x	x	x	-	2

B.2 – Surface Water Flow Monitoring

Location	Flow Data (m^3/s)				
	Date				
	27-Jun-18	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**
HDW6453	No Flow	No Flow	No Flow	No Flow	No Flow
HDW6534	No Flow	No Flow	No Flow	No Flow	No Flow
HDW6658	No Flow	No Flow	No Flow	No Flow	0.0002
HDW6660	No Flow	No Flow	No Flow	No Flow	No Flow
HDW6661	No Flow	No Flow	No Flow	No Flow	No Flow
HDW6662	No Flow	No Flow	No Flow	No Flow	No Flow
HDW7052	No Flow	ND	No Flow	No Flow	0.0006
HDW7061	No Flow	ND	No Flow	0.0005	0.0018
HDW7395	No Flow	No Flow	No Flow	No Flow	No Flow
HDW8201	No Flow	No Flow	No Flow	ND	0.07
HDW8210	No Flow	No Flow	ND	No Flow	0.0005
HDW8713	No Flow	No Flow	No Flow	ND	ND
HDW8714	No Flow	No Flow	No Flow	No Flow	2.4139
HDW8846	No Flow	No Flow	ND	No Flow	0.0049
HDW8905	No Flow	No Flow	ND	No Flow	0.5767
HDW8910	No Flow	No Flow	No Flow	No Flow	ND
HDW8989	No Flow	No Flow	ND	No Flow	Submerged
HDW8990	No Flow	No Flow	No Flow	No Flow	No Flow
HDW8991	ND	No Flow	ND	<0.0001	No Flow
HDW9085	No Flow	No Flow	No Flow	No Flow	No Flow
HDW9308	No Flow	No Flow	0.0053	No Flow	0.0019
HDW9311	No Flow	ND	0.1203	No Flow	0.0155
HDW9328	No Flow	ND	0.0066	No Flow	0.0050
Outfall 1	0.0056	0.0116	ND	0.0037	0.0002
Outfall 2	No Flow	No Flow	No Flow	No Flow	No Flow
Outfall 3	No Flow	No Flow	No Flow	No Flow	No Flow
Outfall 4	No Flow	No Flow	No Flow	No Flow	0.0016
Outfall 5	No Flow	No Flow	No Flow	No Flow	Not Measured
Outfall 7	ND	ND	<0.0001	0.0360	<0.0001
Outfall 8	0.0092	0.0120	ND	0.0006	Not Measured
Outfall 8b	N/A	N/A	ND	0.0015	Not Measured
Watercourse 1	ND	3.2173	0.1347	0.1099	0.0303
Watercourse 2	ND	0.0619	0.0049	0.3783	0.0058
Watercourse 3	ND	0.0232	0.0039	0.0018	0.22
Watercourse 4	0.0236	0.0375	Backwater	0.0474	Backwater
Watercourse 4	0.0375	0.0301	Backwater	0.0389	Backwater
Watercourse 4	0.0543	0.0639	Backwater	0.0389	Backwater
Watercourse 5	ND	0.002	0.0150	0.0827	0.0053
Watercourse 6	No Flow	0.0281	0.0109	0.0427	0.0193

Notes:
1) ND - No Data Captured
2) N/A - Not applicable as sample location was added later in program program as there was consistently no flow
3) No Flow - Dry conditions or zero flow was observed and recorded in field notes
Reverse water flow was observed at this location
4) Submerged - Outfall was submerged at time of
5) Not Measured - Safe flow measurement was not possible due to weather

B.3 – In-Situ Water Quality Monitoring

Field Parameters - Surface Water
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Parameter	Sample ID														
	Watercourse 1					Waterfowl 1					Nearshore 1				
Date Sampled:	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**
Temperature	ND	23.92	25.3	22.5	17.5	ND	22.96	25.52	20.68	17.08	ND	22.96	ND	23.83	18.02
Specific Conductance	ND	0.757	ND	0.673	0.743	ND	0.717	0.733	0.653	0.713	ND	0.753	ND	0.737	0.732
Conductivity	ND	741	692	ND	ND	ND	689	741	ND	ND	ND	724	ND	ND	ND
pH	ND	8.04	7.05	7.71	8.11	ND	7.71	8.17	7.39	7.1	ND	7.98	ND	7.88	7.39
Dissolved Oxygen Saturation	ND	114	8.1	106	73	ND	84.3	112.6	75	94	ND	93.7	ND	81.1	94.5
Dissolved Oxygen	ND	9.55	9.8	8.9	6.9	ND	7.21	9.05	6.73	9.04	ND	8.03	ND	6.81	8.9
Total Dissolved Solids	ND	0.492	ND	ND	ND	ND	0.456	0.477	0.462	0.546	ND	0.49	ND	0.489	0.549
Oxygen Reduction Potential	ND	70	ND	ND	ND	ND	160.6	68.9	ND	ND	ND	74.4	ND	Nd	Nd

Notes:
ND - No Data Captured

Field Parameters - Surface Water
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Parameter	SAMPLE ID														
	Nearshore 2					Outfall 2					Outfall 4				
Date Sampled:	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**19-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**19-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**
Temperature	18.38	24	25.54	22.16	16.8	ND	ND	ND	ND	18	ND	ND	23.4	ND	18.4
Specific Conductance	0.752	0.729	0.744	0.692	0.722	ND	ND	ND	ND	0.718	ND	ND	ND	ND	0.031
Conductivity	656	175	752	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.6	ND	ND
pH	7.7	8.1	8.17	7.52	7.5	ND	ND	ND	ND	7.58	ND	ND	7.21	ND	7.97
Dissolved Oxygen Saturation	ND	101.2	110.7	78.3	95.2	ND	ND	ND	ND	75	ND	ND	ND	ND	81
Dissolved Oxygen	9.22	8.5	9.01	6.79	9.17	ND	ND	ND	ND	7.1	ND	ND	7.3	ND	7.6
Total Dissolved Solids	0.488	ND	0.484	0.475	0.577	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Oxygen Reduction Potential	92	ND	67.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Surface Water
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Parameter	SAMPLE ID														
	Outfall 5					Outfall 8					Oufall 8b				
Date Sampled:	**19-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**
Temperature	ND	ND	ND	ND	ND	15.25	15.53	19.68	18.11	ND	ND	ND	17.09	17.12	ND
Specific Conductance	ND	ND	ND	ND	ND	1.713	2.117	2.444	1.864	ND	ND	ND	2.334	1.896	ND
Conductivity	ND	ND	ND	ND	ND	1392	1734	2195	ND	ND	ND	ND	1981	ND	ND
pH	ND	ND	ND	ND	ND	8.25	6.73	8.2	7.53	ND	ND	ND	8.01	7.13	ND
Dissolved Oxygen Saturation	ND	ND	ND	ND	ND	ND	93.3	114.9	102.5	ND	ND	ND	173.8	102.2	ND
Dissolved Oxygen	ND	ND	ND	ND	ND	11.1	9.24	10.36	9.64	ND	ND	ND	14.4	9.78	ND
Total Dissolved Solids	ND	ND	ND	ND	ND	1.112	1.376	1.589	1.395	ND	ND	ND	1.519	1.451	ND
Oxygen Reduction Potential	ND	ND	ND	ND	ND	192.6	202.5	86.5	ND	ND	ND	ND	55	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Surface Water
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Parameter	SAMPLE ID														
	HDW6660					HDW6661					HDW6662				
Date Sampled:	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**
Temperature	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Specific Conductance	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Conductivity	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
pH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Oxygen Saturation	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Oxygen	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total Dissolved Solids	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Oxygen Reduction Potential	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Surface Water
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Parameter	SAMPLE ID														
	HDW6658					HDW8210					HDW8846				
Date Sampled:	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**
Temperature	ND	ND	ND	ND	18.8	ND	ND	ND	ND	18.7	ND	ND	22.8	ND	18.1
Specific Conductance	ND	ND	ND	ND	0.002	ND	ND	ND	ND	0.058	ND	ND	ND	ND	0.0028
Conductivity	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	12.1	ND	ND
pH	ND	ND	ND	ND	7.62	ND	ND	ND	ND	7.75	ND	ND	6.88	ND	7.98
Dissolved Oxygen Saturation	ND	ND	ND	ND	82	ND	ND	ND	ND	79	ND	ND	ND	ND	84
Dissolved Oxygen	ND	ND	ND	ND	7.7	ND	ND	ND	ND	7.4	ND	ND	7.3	ND	8
Total Dissolved Solids	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Oxygen Reduction Potential	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Surface Water
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Parameter	SAMPLE ID														
	HDW8905					HDW8910					HDW8989				
Date Sampled:	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**27-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**
Temperature	ND	ND	27.2	ND	18.4	ND	ND	ND	ND	18.3	ND	ND	26	ND	18.1
Specific Conductance	ND	ND	ND	ND	0.002	ND	ND	ND	ND	0.03	ND	ND	ND	ND	0.146
Conductivity	ND	ND	64.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	15	ND	ND
pH	ND	ND	7	ND	7.84	ND	ND	ND	ND	6.2	ND	ND	7.22	ND	7.71
Dissolved Oxygen Saturation	ND	ND	97	ND	73	ND	ND	ND	ND	94.1	ND	ND	ND	ND	80
Dissolved Oxygen	ND	ND	7.7	ND	7	ND	ND	ND	ND	8.85	ND	ND	8.1	ND	7.9
Total Dissolved Solids	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.022	ND	ND	ND	ND	ND
Oxygen Reduction Potential	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Surface Water
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Parameter	SAMPLE ID														
	HDW8990					HDW8991					HDW/6534HDW8993				
Date Sampled:	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**
Temperature	ND	ND	ND	ND	ND	ND	ND	ND	22.15	ND	ND	ND	ND	ND	ND
Specific Conductance	ND	ND	ND	ND	ND	ND	ND	ND	0.683	ND	ND	ND	ND	ND	ND
Conductivity	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
pH	ND	ND	ND	ND	ND	ND	ND	ND	8.49	ND	ND	ND	ND	ND	ND
Dissolved Oxygen Saturation	ND	ND	ND	ND	ND	ND	ND	ND	94.8	ND	ND	ND	ND	ND	ND
Dissolved Oxygen	ND	ND	ND	ND	ND	ND	ND	ND	8.26	ND	ND	ND	ND	ND	ND
Total Dissolved Solids	ND	ND	ND	ND	ND	ND	ND	ND	0.469	ND	ND	ND	ND	ND	ND
Oxygen Reduction Potential	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Surface Water
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Parameter	SAMPLE ID														
	HDW9085					HDW9308					HDW9311				
Date Sampled:	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**27-Sep-18**	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**27-Sep-18**
Temperature	ND	ND	ND	ND	ND	NA	ND	22.5	NA	19	ND	ND	24.1	ND	18.3
Specific Conductance	ND	ND	ND	ND	ND	NA	ND	ND	NA	0.0122	ND	ND	ND	ND	0.0566
Conductivity	ND	ND	ND	ND	ND	NA	ND	5.3	NA	ND	ND	ND	2.9	ND	ND
pH	ND	ND	ND	ND	ND	NA	ND	6.6	NA	7.94	ND	ND	6.7	ND	7.62
Dissolved Oxygen Saturation	ND	ND	ND	ND	ND	NA	ND	ND	NA	78	ND	ND	ND	ND	91
Dissolved Oxygen	ND	ND	ND	ND	ND	NA	ND	9	NA	7.2	ND	ND	8.3	ND	8.6
Total Dissolved Solids	ND	ND	ND	ND	ND	NA	ND	ND	NA	ND	ND	ND	ND	ND	ND
Oxygen Reduction Potential	ND	ND	ND	ND	ND	NA	ND	ND	NA	ND	ND	ND	ND	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Surface Water
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Parameter	SAMPLE ID				
	HDW9328				
Date Sampled:	**27-Jun-18**	**19-Jul-18**	**14-Aug-18**	**12-Sep-18**	**26-Sep-18**
Temperature	ND	ND	24.8	ND	18.7
Specific Conductance	ND	ND	ND	ND	0.0255
Conductivity	ND	ND	19.8	ND	ND
pH	ND	ND	6.85	ND	7.78
Dissolved Oxygen Saturation	ND	ND	ND	ND	85
Dissolved Oxygen	ND	ND	8.7	ND	8
Total Dissolved Solids	ND	ND	ND	ND	ND
Oxygen Reduction Potential	ND	ND	ND	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Banook In-Lake
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Banook In-Lake	Temperature ºC					Specific Conductance mS/cm					Conductivity uS/cm					pH				
Depth (m)	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
0	19.3	23.16	25.94	22.03	17.81	0.755	0.754	0.758	0.701	0.746	673	727	772	ND	ND	7.97	8.12	8.48	7.54	7.29
1	19.3	23.16	25.95	21.87	17.81	0.755	0.754	0.758	0.702	0.746	673	727	771	ND	ND	7.97	8.12	8.47	7.54	7.29
2	19.33	23.15	25.92	21.44	17.81	0.755	0.754	0.758	0.695	0.746	673	727	771	ND	ND	7.95	7.78	8.47	7.49	7.29
3	19.29	23.13	25.89	21.35	17.8	0.755	0.754	0.758	0.695	0.746	673	727	771	ND	ND	7.94	7.81	8.45	7.47	7.27
4	19.26	22.73	25.85	21.33	17.79	0.755	0.756	0.757	0.694	0.746	672	722	770	ND	ND	7.95	7.3	8.4	7.48	7.26
5	19.12	22.39	25.35	ND	ND	0.754	0.757	0.754	ND	ND	669	720	758	ND	ND	7.94	7.06	8.01	ND	ND
6	19.04	21.82	24.67	ND	ND	0.754	0.756	0.755	ND	ND	666	708	785	ND	ND	7.92	6.63	7.6	ND	ND
7	19	20.73	22.39	ND	ND	0.754	0.755	0.761	ND	ND	668	694	723	ND	ND	7.9	6.28	7	ND	ND
8	19.03	19.36	20.05	ND	ND	0.754	0.752	0.76	ND	ND	669	671	687	ND	ND	7.89	6.06	5.86	ND	ND
9	17.6	18.23	18.33	ND	ND	0.753	0.753	0.759	ND	ND	685	655	663	ND	ND	7.71	5.84	5.57	ND	ND
10	17.2	17.28	16.32	ND	ND	0.753	0.756	0.776	ND	ND	630	644	647	ND	ND	7.61	5.26	5.27	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Banook In-Lake
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Banook In-Lake	Dissolved Oxygen Saturation %					Dissolved Oxygen mg/L					Total Dissolved Solids g/L					Oxygen Reduction Potential mV				
Depth (m)	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
0	ND	92.9	105	100.5	94	9.3	7.93	8.5	8.72	8.91	0.491	0.49	0.493	0.485	0.562	200	144.9	59.3	ND	ND
1	ND	92.9	104.59	101.3	94	9.3	7.93	8.49	8.86	8.91	0.491	0.49	0.493	0.485	0.562	200	144.9	60.7	ND	ND
2	ND	92.3	103.5	97.8	93.5	9.32	7.87	8.42	8.66	8.85	0.491	0.49	0.493	0.485	0.562	200	166.1	60.7	ND	ND
3	ND	92.7	107.6	98.5	93.1	9.63	7.91	8.73	8.7	8.81	0.491	0.49	0.493	0.485	0.562	209	166	61.3	ND	ND
4	ND	81.6	108.1	98.5	93.6	9.3	7.01	8.77	8.7	8.89	0.491	0.489	0.492	0.485	0.562	209	179.4	61.4	ND	ND
5	ND	74.7	93.3	ND	ND	8.77	6.47	7.65	ND	ND	0.49	0.492	0.489	ND	ND	208	183.4	66.8	ND	ND
6	ND	57.2	72.7	ND	ND	8.32	4.97	6.36	ND	ND	0.49	0.491	0.491	ND	ND	208	196	71.1	ND	ND
7	ND	43.3	6.2	ND	ND	8.31	3.84	0.53	ND	ND	0.49	0.491	0.495	ND	ND	207	206.2	87.2	ND	ND
8	ND	40.2	5.1	ND	ND	8.24	3.68	0.47	ND	ND	0.49	0.489	0.494	ND	ND	207	216.8	141.5	ND	ND
9	ND	37.7	5.6	ND	ND	7.1	3.54	0.52	ND	ND	0.489	0.49	0.494	ND	ND	208	228	154.9	ND	ND
10	ND	30.5	4.2	ND	ND	3.32	2.93	0.41	ND	ND	0.49	0.491	0.505	ND	ND	211	263.7	174.4	ND	ND

Notes:
ND - No Data Captured

Field Parameters - Micmac In-Lake
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Micmac In-Lake	Temperature ºC					Specific Conductance mS/cm					Conductivity uS/cm					pH				
Depth (m)	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
0	18.3	23.55	25.96	20.6	17.17	0.718	0.708	0.714	0.646	0.648	632		721	ND	ND	7.46	7.78	8.07	6.84	7.53
1	18.3	23.55	26	20.85	17.17	0.718	0.708	0.716	0.648	0.645	632	689	730	ND	ND	7.46	7.78	8.06	7.11	7.51
2	18.7	23.48	26	20.85	17.17	0.716	0.711	0.717	0.648	0.688	632	690	731	ND	ND	7.69	7.75	8.05	7.16	7.52
3	18.7	23.55	26.03	20.84	17.17	0.716	0.713	0.717	0.648	0.692	631	692	731	ND	ND	7.86	7.75	8.07	7.24	7.51
4	18.66	23.17	26.04	20.83	17.12	0.716	0.716	0.717	0.648	0.691	627	690	731	ND	ND	7.84	7.62	8.08	7.94	7.49
5	18.42	22.82	26	ND	ND	0.716	0.715	0.717	ND	ND	626	685	731	ND	ND	7.9	7.5	8.06	ND	ND
6	18.25	22.24	23.17	ND	ND	0.716	0.722	0.725	ND	ND	622	684	700	ND	ND	7.95	7.27	7.38	ND	ND
6.5	ND	21.42	ND	ND	ND	ND	0.733	ND	ND	ND	ND	682	ND	ND	ND	ND	7.08	ND	ND	ND

Field Parameters - Micmac In-Lake
Halifax Regional Municipality
Pollution Source Control Study for
Lake Banook & Lake Micmac
Stantec Consulting Ltd.
Project No. 121415826

Micmac In-Lake	Dissolved Oxygen Saturation %					Dissolved Oxygen mg/L					Total Dissolved Solids g/L					Oxygen Reduction Potential mV				
Depth (m)	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
0	ND	90.1	112	91.3	88.2	9.78	7.63	9.06	8.13	8.48	0.466	0.46	0.465	0.457	0.519	133	137.2	ND	ND	ND
1	ND	90.1	105.9	89	87.4	9.78	7.63	8.55	7.96	8.4	0.466	0.46	0.465	0.457	0.493	133	137.2	ND	ND	ND
2	ND	90.7	107.8	90	87.5	9.54	7.68	8.66	8.45	8.41	0.466	0.462	0.466	0.497	0.527	147	142.1	ND	ND	ND
3	ND	89.9	108	88.4	86.4	9.59	7.81	8.74	7.9	8.26	0.465	0.464	0.466	0.457	0.529	147.8	144.6	ND	ND	ND
4	ND	87.4	106.9	89	86.8	9.61	7.44	8.64	7.94	8.38	0.465	0.464	0.466	0.458	0.529	147	148	ND	ND	ND
5	ND	80.7	106	ND	ND	9.64	6.97	8.59	ND	ND	0.465	0.465	0.467	ND	ND	145	149.7	ND	ND	ND
6	ND	64.9	12.2	ND	ND	9.76	5.65	1.26	ND	ND	0.465	0.469	0.47	ND	ND	144	154.3	ND	ND	ND
6.5	ND	28.7	ND	ND	ND	ND	2.55	ND	ND	ND	ND	0.476	ND	ND	ND	ND	71.3	ND	ND	ND

B.4 – Surface Water Grab Samples

Table B.1 Surface Water Analytical Data - BANOOK 1

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	6.41	6.54	6.54	6.63	-	-	6.49	6.54	6.63	6.41	6.62
Bicarbonate (as CaCO3)	mg/L	31	35	34.8	39	-	-	31	34	35	35	39
Total Dissolved Solids	mg/L	370	380	378	380	-	-	380	370	380	380	380
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	6.18	6.28	6.31	6.46	-	-	6.39	6.18	6.28	6.46	6.24
Hardness (as CaCO3)	mg/L	64	65	65.2	67	-	-	64	64	66	67	65
Ion Balance (% Difference)	%	0.39	2.71	1.93	2.95	-	-	0.780	2.83	2.71	0.390	2.95
Langelier Index (@ 20C)	-	-1.01	-0.838	-0.83	-0.698	-	-	-1.01	-0.838	-0.698	-0.876	-0.730
Langelier Index (@ 4C)	-	-1.26	-1.09	-1.08	-0.946	-	-	-1.26	-1.09	-0.946	-1.13	-0.979
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	0.13	13	-	0.13	<0.050	<0.050	<0.050	<0.050
Saturation pH (@ 20C)	-	8.5	8.54	8.55	8.59	-	-	8.59	8.57	8.54	8.54	8.50
Saturation pH (@ 4C)	-	8.75	8.79	8.8	8.84	-	-	8.84	8.82	8.79	8.79	8.75
Inorganics												
Alkalinity (as CaCO3)	mg/L	32	35	35.4	40	-	-	32	34	36	35	40
Chloride	mg/L	190	190	192	200	120	-	**190**	**190**	**200**	**190**	**190**
Colour	TCU	<5	<5	<5	6.6	-	-	6.6	<5.0	<5.0	<5.0	<5.0
Nitrate + Nitrite (as N)	mg/L	<0.05	<0.05	<0.05	0.13	-	-	0.13	<0.050	<0.050	<0.050	<0.050
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	<0.010	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	<0.05	<0.05	<0.05	20	-	<0.050	<0.050	<0.050	<0.050	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	<0.1	0.1	0.1	0.18	-	-	0.18	0.12	0.10	<0.10	<0.10
TOC	mg/L	2.5	2.6	2.6	2.7	-	-	2.6	2.7	2.7	2.5	2.5
Ortho Phosphate (as P)	mg/L	<0.001	0.0024	0.00288	<0.01	-	-	<0.010	<0.001	<0.010	0.0024	0.0015
Low Level Orthophosphate	mg/L	0.0019	<0.003	<0.003	<0.003	-	-	0.0019	-	<0.0030	-	-
pH	pH	7.58	7.73	7.72	7.84	6.5 to 9.0	5.0 to 9.0	7.58	7.73	7.84	7.67	7.77
Reactive Silica (as SiO2)	mg/L	0.53	1.9	1.89	3	-	-	0.53	1.1	1.9	3.0	2.9
Sulphate	mg/L	17	18	18.6	21	-	-	21	20	18	17	17
Turbidity	NTU	0.59	0.72	0.754	1.1	-	50	0.72	0.63	1.1	0.73	0.59
Conductivity	µS/cm	740	760	764	790	-	-	760	790	770	760	740
Phosphorus	mg/L	<0.004	0.006	0.005	0.007	-	-	0.004	<0.004	0.006	0.006	0.007
TSS	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Metals												
Calcium	µg/L	22000	22000	22400	23000	-	-	22000	22000	23000	23000	22000
Copper	µg/L	<2	<2	<2	<2	2	-	<2.0	<2.0	<2.0	<2.0	<2.0
Iron	µg/L	<50	<50	<50	<50	300	-	<50	<50	<50	<50	<50
Magnesium	µg/L	2100	2300	2320	2500	-	-	2100	2300	2400	2500	2300
Manganese	µg/L	43	59	58.6	82	-	-	82	43	59	50	59
Potassium	µg/L	1600	1600	1640	1700	-	-	1600	1600	1600	1700	1700
Sodium	µg/L	110000	110000	114000	120000	-	-	120000	110000	110000	120000	110000
Zinc	µg/L	<5	<5	<5	<5	30	-	<5.0	<5.0	<5.0	<5.0	<5.0
Microbiological												
Escherichia coli	CFU/100mL	10	10	10	20	-	400	10	20	<10	<10	10
Enterococci	CFU/100mL	5	7.5	7.5	10	-	70	5.0	10	-	-	-
Chlorophyll a												
Chl a - Acidification	µg/L	0.92	1.48	1.98	3.64	-	-	2.84	1.48	3.64	0.92	1.02
Chl a - Welschmeyer	µg/L	1.45	2.69	2.69	3.93	-	-	3.93	1.45	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1
Average Avian Marker	Log copies/100 mL water	<1.1	1.7	1.54	2.34	-	-	1.81	1.7	1.28	2.34	<1.1
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1

Table B.2 Surface Water Analytical Data - BANOOK 2

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	6.6	6.63	6.72	6.99	-	-	6.61	6.60	6.99	6.63	6.77
Bicarbonate (as CaCO3)	mg/L	31	39	39.2	46	-	-	31	35	46	45	39
Total Dissolved Solids	mg/L	380	380	384	390	-	-	380	380	390	390	380
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	6.07	6.31	6.28	6.53	-	-	6.33	6.16	6.31	6.53	6.07
Hardness (as CaCO3)	mg/L	63	65	65.8	70	-	-	63	65	68	70	63
Ion Balance (% Difference)	%	0.76	3.45	3.39	5.45	-	-	2.16	3.45	5.11	0.760	5.45
Langelier Index (@ 20C)	-	-1.1	-1.05	-1.01	-0.877	-	-	-1.06	-1.10	-0.943	-1.05	-0.877
Langelier Index (@ 4C)	-	-1.35	-1.3	-1.26	-1.13	-	-	-1.31	-1.35	-1.19	-1.30	-1.13
Nitrate (as N)	mg/L	<0.05	<0.05	0.0604	0.16	13	-	0.16	0.067	<0.050	<0.050	<0.050
Saturation pH (@ 20C)	-	8.41	8.51	8.5	8.61	-	-	8.61	8.55	8.41	8.41	8.51
Saturation pH (@ 4C)	-	8.65	8.76	8.74	8.85	-	-	8.85	8.80	8.66	8.65	8.76
Inorganics												
Alkalinity (as CaCO3)	mg/L	31	39	39.4	46	-	-	31	35	46	46	39
Chloride	mg/L	190	200	196	200	120	-	**200**	**190**	**200**	**190**	**200**
Colour	TCU	<5	5.1	<5	6.6	-	-	<5.0	<5.0	5.1	6.6	5.6
Nitrate + Nitrite (as N)	mg/L	<0.05	<0.05	0.071	0.16	-	-	0.16	0.12	<0.050	<0.050	<0.050
Nitrite	mg/L	<0.01	<0.01	0.0202	0.05	0.06	-	<0.010	0.050	0.036	<0.010	<0.010
Ammonia	mg/L	<0.05	0.14	0.119	0.23	20	-	0.051	0.14	0.15	0.23	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	0.11	0.23	0.21	0.27	-	-	0.25	0.23	0.19	0.27	0.11
TOC	mg/L	2.3	2.5	2.44	2.6	-	-	2.5	2.3	2.3	2.6	2.5
Ortho Phosphate (as P)	mg/L	0.0013	<0.01	<0.01	<0.01	-	-	<0.010	0.002	<0.010	0.0052	0.0013
Low Level Orthophosphate	mg/L	0.0024	0.0028	0.0028	0.0032	-	-	0.0024	-	0.0032	-	-
pH	pH	7.35	7.47	7.49	7.64	6.5 to 9.0	5.0 to 9.0	7.55	7.44	7.47	7.35	7.64
Reactive Silica (as SiO2)	mg/L	0.71	2.7	2.26	3.1	-	-	0.71	1.9	2.7	3.1	2.9
Sulphate	mg/L	17	18	18.8	21	-	-	21	20	18	18	17
Turbidity	NTU	0.6	1.1	1.47	2.6	-	50	0.66	2.6	2.4	1.1	0.60
Conductivity	µS/cm	740	780	774	790	-	-	780	780	790	780	740
Phosphorus	mg/L	0.006	0.007	0.007	0.008	-	-	0.007	0.008	0.006	0.008	0.006
TSS	mg/L	<1	<1	<1	1.9	-	-	<1.0	1.9	<1.1	1.4	<1.0
Metals												
Calcium	µg/L	22000	22000	22800	24000	-	-	22000	22000	24000	24000	22000
Copper	µg/L	3	5.1	5.48	9.4	2	-	**5.8**	**9.4**	**4.1**	**3.0**	**5.1**
Iron	µg/L	<50	<50	<50	140	300	-	<50	140	<50	<50	<50
Magnesium	µg/L	2000	2300	2260	2400	-	-	2000	2300	2300	2400	2300
Manganese	µg/L	46	450	2050	6800	-	-	46	450	2900	6800	65
Potassium	µg/L	1600	1700	1700	1900	-	-	1600	1700	1700	1900	1600
Sodium	µg/L	110000	110000	114000	120000	-	-	120000	110000	110000	120000	110000
Zinc	µg/L	<5	<5	5.22	11	30	-	<5.0	11	<5.0	7.6	<5.0
Microbiological												
Escherichia coli	CFU/100mL	<10	<10	<10	10	-	400	<10	<10	<10	10	<10
Enterococci	CFU/100mL	2	<10	<10	<10	-	70	2.0	<10	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	-	-	-
Average Avian Marker	Log copies/100 mL water	1.84	2.06	2.06	2.28	-	-	2.28	1.84	-	-	-
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	-	-	-

Table B.19 Surface Water Analytical Data - BANOOK 3

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results
		Minimum	Median	Mean	Maximum			
							Date Sampled:	14-Aug-18
Parameter								
Calculated Parameters								
Anion Sum	meq/L	6.7	6.7	6.7	6.7	-	-	6.70
Bicarbonate (as CaCO3)	mg/L	38	38	38	38	-	-	38
Total Dissolved Solids	mg/L	380	380	380	380	-	-	380
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0
Cation Sum	meq/L	6.34	6.34	6.34	6.34	-	-	6.34
Hardness (as CaCO3)	mg/L	66	66	66	66	-	-	66
Ion Balance (% Difference)	%	2.76	2.76	2.76	2.76	-	-	2.76
Langelier Index (@ 20C)	-	-1.16	-1.16	-1.16	-1.16	-	-	-1.16
Langelier Index (@ 4C)	-	-1.41	-1.41	-1.41	-1.41	-	-	-1.41
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	13	-	<0.050
Saturation pH (@ 20C)	-	8.51	8.51	8.51	8.51	-	-	8.51
Saturation pH (@ 4C)	-	8.76	8.76	8.76	8.76	-	-	8.76
Inorganics								
Alkalinity (as CaCO3)	mg/L	38	38	38	38	-	-	38
Chloride	mg/L	200	200	200	200	120	-	**200**
Colour	TCU	6.4	6.4	6.4	6.4	-	-	6.4
Nitrate + Nitrite (as N)	mg/L	0.14	0.14	0.14	0.14	-	-	0.14
Nitrite	mg/L	0.11	0.11	0.11	0.11	0.06	-	**0.11**
Ammonia	mg/L	<0.05	<0.05	<0.05	<0.05	20	-	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	0.16	0.16	0.16	0.16	-	-	0.16
TOC	mg/L	2.5	2.5	2.5	2.5	-	-	2.5
Ortho Phosphate (as P)	mg/L	<0.01	<0.01	<0.01	<0.01	-	-	<0.010
Low Level Orthophosphate	mg/L	0.0091	0.0091	0.0091	0.0091	-	-	0.0091
pH	pH	7.36	7.36	7.36	7.36	6.5 to 9.0	5.0 to 9.0	7.36
Reactive Silica (as SiO2)	mg/L	2.9	2.9	2.9	2.9	-	-	2.9
Sulphate	mg/L	17	17	17	17	-	-	17
Turbidity	NTU	3	3	3	3	-	50	3.0
Conductivity	µS/cm	760	760	760	760	-	-	760
Phosphorus	mg/L	<0.004	<0.004	<0.004	<0.004	-	-	<0.004
TSS	mg/L	<1	<1	<1	<1	-	-	<1.0
Metals								
Calcium	µg/L	23000	23000	23000	23000	-	-	23000
Copper	µg/L	6.2	6.2	6.2	6.2	2	-	**6.2**
Iron	µg/L	<50	<50	<50	<50	300	-	<50
Magnesium	µg/L	2400	2400	2400	2400	-	-	2400
Manganese	µg/L	290	290	290	290	-	-	290
Potassium	µg/L	1700	1700	1700	1700	-	-	1700
Sodium	µg/L	110000	110000	110000	110000	-	-	110000
Zinc	µg/L	<5	<5	<5	<5	30	-	<5.0
Microbiological								
Escherichia coli	CFU/100mL	<10	<10	<10	<10	-	400	<10
Chlorophyll a								
Chl a - Acidification	µg/L	2.16	2.16	2.16	2.16	-	-	2.16

Table B.3 Surface Water Analytical Data - MICMAC 1

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	6.07	6.23	6.2	6.33	-	-	6.29	6.07	6.23	6.08	6.33
Bicarbonate (as CaCO3)	mg/L	32	36	35.8	40	-	-	32	34	36	37	40
Total Dissolved Solids	mg/L	350	360	356	360	-	-	360	350	360	350	360
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	5.82	6.03	5.98	6.04	-	-	6.04	5.82	6.04	6.03	5.98
Hardness (as CaCO3)	mg/L	62	65	64.2	66	-	-	63	62	66	65	65
Ion Balance (% Difference)	%	0.41	2.03	1.79	2.84	-	-	2.03	2.10	1.55	0.410	2.84
Langelier Index (@ 20C)	-	-1.1	-0.846	-0.843	-0.652	-	-	-0.966	-1.10	-0.846	-0.652	-0.652
Langelier Index (@ 4C)	-	-1.35	-1.1	-1.09	-0.901	-	-	-1.21	-1.35	-1.10	-0.901	-0.901
Nitrate (as N)	mg/L	<0.05	<0.05	0.0538	0.13	13	-	0.13	0.064	<0.050	<0.050	<0.050
Saturation pH (@ 20C)	-	8.49	8.52	8.54	8.59	-	-	8.59	8.58	8.52	8.52	8.49
Saturation pH (@ 4C)	-	8.74	8.77	8.79	8.84	-	-	8.84	8.82	8.77	8.77	8.74
Inorganics												
Alkalinity (as CaCO3)	mg/L	32	36	35.8	40	-	-	32	34	36	37	40
Chloride	mg/L	180	180	182	190	120	-	**190**	**180**	**180**	**180**	**180**
Colour	TCU	<5	5.8	5.22	6.3	-	-	<5.0	5.8	6.3	5.4	6.1
Nitrate + Nitrite (as N)	mg/L	<0.05	<0.05	0.0538	0.13	-	-	0.13	0.064	<0.050	<0.050	<0.050
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	<0.010	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	<0.05	<0.05	0.053	20	-	0.053	0.052	<0.050	<0.050	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	0.1	0.16	1.48	6.8	-	-	6.8	0.17	0.16	0.10	0.15
TOC	mg/L	2.9	3	2.96	3	-	-	3.0	2.9	3.0	3.0	2.9
Ortho Phosphate (as P)	mg/L	<0.001	0.0026	0.00296	<0.01	-	-	<0.010	<0.001	<0.010	0.0026	0.0017
Low Level Orthophosphate	mg/L	0.0021	0.00275	0.00275	0.0034	-	-	0.0021	-	0.0034	-	-
pH	pH	7.47	7.68	7.7	7.87	6.5 to 9.0	5.0 to 9.0	7.63	7.47	7.68	7.87	7.84
Reactive Silica (as SiO2)	mg/L	0.56	1.8	1.87	3	-	-	0.56	1.1	1.8	3.0	2.9
Sulphate	mg/L	16	16	17.2	20	-	-	20	18	16	16	16
Turbidity	NTU	0.32	1.1	1.04	1.6	-	50	0.32	1.1	1.6	1.1	1.1
Conductivity	µS/cm	700	720	718	730	-	-	720	720	720	730	700
Phosphorus	mg/L	<0.004	0.006	0.0066	0.012	-	-	0.005	<0.004	0.012	0.008	0.006
TSS	mg/L	1	1.4	1.3	2	-	-	<1.0	1.4	1.6	2.0	1.0
Metals												
Calcium	µg/L	21000	22000	22000	23000	-	-	22000	21000	23000	22000	22000
Copper	µg/L	<2	<2	<2	<2	2	-	<2.0	<2.0	<2.0	<2.0	<2.0
Iron	µg/L	<50	<50	<50	<50	300	-	<50	<50	<50	<50	<50
Magnesium	µg/L	2100	2400	2320	2400	-	-	2100	2300	2400	2400	2400
Manganese	µg/L	52	96	99.6	150	-	-	150	120	96	80	52
Potassium	µg/L	1600	1700	1700	1800	-	-	1600	1700	1800	1700	1700
Sodium	µg/L	100000	110000	108000	110000	-	-	110000	100000	110000	110000	110000
Zinc	µg/L	<5	<5	<5	<5	30	-	<5.0	<5.0	<5.0	<5.0	<5.0
Microbiological												
Escherichia coli	CFU/100mL	10	10	16	50	-	400	<10	50	<10	10	10
Enterococci	CFU/100mL	13	24	24	35	-	70	13	35	-	-	-
Chlorophyll a												
Chl a - Acidification	µg/L	1.62	1.91	2.31	3.92	-	-	1.62	2.28	3.92	1.91	1.8
Chl a - Welschmeyer	µg/L	1.86	2.05	2.05	2.24	-	-	1.86	2.24	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1
Average Avian Marker	Log copies/100 mL water	<1.1	1.72	1.74	2.76	-	-	2.4	1.27	1.72	2.76	<1.1
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1

Table B.4 Surface Water Analytical Data - MICMAC 2

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	6.1	6.35	6.29	6.49	-	-	6.39	6.10	6.49	6.10	6.35
Bicarbonate (as CaCO3)	mg/L	31	37	37	41	-	-	31	35	41	37	41
Total Dissolved Solids	mg/L	350	360	358	370	-	-	360	350	370	350	360
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	5.86	6.01	5.97	6.05	-	-	6.05	5.86	6.04	6.01	5.90
Hardness (as CaCO3)	mg/L	62	65	64.4	67	-	-	62	62	67	66	65
Ion Balance (% Difference)	%	0.74	2.73	2.55	3.67	-	-	2.73	2.01	3.59	0.740	3.67
Langelier Index (@ 20C)	-	-1.05	-0.958	-0.928	-0.728	-	-	-0.988	-1.05	-0.918	-0.958	-0.728
Langelier Index (@ 4C)	-	-1.3	-1.21	-1.18	-0.977	-	-	-1.24	-1.30	-1.17	-1.21	-0.977
Nitrate (as N)	mg/L	<0.05	<0.05	0.051	0.12	13	-	0.12	0.060	<0.050	<0.050	<0.050
Saturation pH (@ 20C)	-	8.46	8.52	8.53	8.62	-	-	8.62	8.56	8.46	8.52	8.48
Saturation pH (@ 4C)	-	8.71	8.77	8.78	8.86	-	-	8.86	8.81	8.71	8.77	8.73
Inorganics												
Alkalinity (as CaCO3)	mg/L	31	37	37.2	42	-	-	31	35	42	37	41
Chloride	mg/L	180	180	184	190	120	-	**190**	**180**	**190**	**180**	**180**
Colour	TCU	<5	5.5	5.42	7.6	-	-	5.1	7.6	5.5	6.4	<5.0
Nitrate + Nitrite (as N)	mg/L	<0.05	<0.05	0.051	0.12	-	-	0.12	0.060	<0.050	<0.050	<0.050
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	<0.010	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	0.06	0.126	0.45	20	-	0.072	0.060	0.45	<0.050	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	0.1	0.17	0.236	0.56	-	-	0.17	0.20	0.56	0.10	0.15
TOC	mg/L	2.8	3	2.98	3.2	-	-	3.0	2.8	2.9	3.2	3.0
Ortho Phosphate (as P)	mg/L	<0.001	0.0025	0.0029	<0.01	-	-	<0.010	<0.001	<0.010	0.0025	0.0015
Low Level Orthophosphate	mg/L	0.0019	<0.003	<0.003	<0.003	-	-	0.0019	-	<0.0030	-	-
pH	pH	7.51	7.56	7.6	7.76	6.5 to 9.0	5.0 to 9.0	7.63	7.51	7.55	7.56	7.76
Reactive Silica (as SiO2)	mg/L	0.57	2.8	2.17	3	-	-	0.57	1.6	3.0	2.9	2.8
Sulphate	mg/L	16	16	17.4	20	-	-	20	19	16	16	16
Turbidity	NTU	0.57	0.77	1.88	5	-	50	0.57	0.76	5.0	2.3	0.77
Conductivity	µS/cm	700	730	724	740	-	-	730	740	730	720	700
Phosphorus	mg/L	<0.004	0.006	0.0068	0.013	-	-	0.013	0.005	0.008	0.006	<0.004
TSS	mg/L	<1	1.4	2.49	8.4	-	-	<1.0	1.4	8.4	1.6	<1.1
Metals												
Calcium	µg/L	21000	22000	22000	23000	-	-	22000	21000	23000	22000	22000
Copper	µg/L	2.3	5.6	5.74	9.3	2	-	**3.1**	**8.4**	**2.3**	**5.6**	**9.3**
Iron	µg/L	<50	<50	<50	110	300	-	50	110	<50	<50	<50
Magnesium	µg/L	2100	2400	2320	2400	-	-	2100	2300	2400	2400	2400
Manganese	µg/L	52	160	795	3500	-	-	160	180	3500	82	52
Potassium	µg/L	1600	1700	1720	1800	-	-	1600	1800	1800	1700	1700
Sodium	µg/L	100000	110000	106000	110000	-	-	110000	100000	110000	110000	100000
Zinc	µg/L	<5	<5	9.6	38	30	-	<5.0	**38**	<5.0	<5.0	<5.0
Microbiological												
Escherichia coli	CFU/100mL	<10	<10	<10	<10	-	400	<10	<10	<10	<10	<10
Enterococci	CFU/100mL	14	22	22	30	-	70	30	14	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	-	<1.1	-	-	<1.1
Average Avian Marker	Log copies/100 mL water	<1.1	1.14	1.14	1.72	-	-	-	1.72	-	-	<1.1
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	-	<1.1	-	-	<1.1

Table B.5 Surface Water Analytical Data - NEAR-SHORE 1

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	6.43	6.52	6.54	6.64	-	-	6.62	6.52	6.64	6.43	6.49
Bicarbonate (as CaCO3)	mg/L	30	36	34.4	36	-	-	30	34	36	36	36
Total Dissolved Solids	mg/L	370	370	374	380	-	-	380	370	380	370	370
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	6.01	6.28	6.22	6.41	-	-	6.34	6.01	6.28	6.41	6.08
Hardness (as CaCO3)	mg/L	62	65	64.4	66	-	-	65	62	66	66	63
Ion Balance (% Difference)	%	0.16	2.79	2.49	4.07	-	-	2.16	4.07	2.79	0.160	3.26
Langelier Index (@ 20C)	-	-1.03	-0.917	-0.907	-0.798	-	-	-0.965	-0.917	-1.03	-0.798	-0.826
Langelier Index (@ 4C)	-	-1.28	-1.17	-1.16	-1.05	-	-	-1.21	-1.17	-1.28	-1.05	-1.08
Nitrate (as N)	mg/L	<0.05	<0.05	0.059	0.15	13	-	0.15	0.070	<0.050	<0.050	<0.050
Saturation pH (@ 20C)	-	8.53	8.55	8.56	8.61	-	-	8.61	8.58	8.54	8.53	8.55
Saturation pH (@ 4C)	-	8.78	8.8	8.81	8.86	-	-	8.86	8.83	8.79	8.78	8.80
Inorganics												
Alkalinity (as CaCO3)	mg/L	30	36	34.6	36	-	-	30	35	36	36	36
Chloride	mg/L	190	190	194	200	120	-	**200**	**190**	**200**	**190**	**190**
Colour	TCU	5.2	5.4	5.62	6.4	-	-	5.2	5.4	6.4	5.3	5.8
Nitrate + Nitrite (as N)	mg/L	<0.05	<0.05	0.059	0.15	-	-	0.15	0.070	<0.050	<0.050	<0.050
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	<0.010	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	<0.05	<0.05	0.15	20	-	<0.050	0.15	<0.050	<0.050	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	0.1	0.13	0.148	0.3	-	-	0.30	0.13	<0.10	0.10	0.16
TOC	mg/L	2.4	2.7	2.64	2.9	-	-	2.7	2.5	2.9	2.7	2.4
Ortho Phosphate (as P)	mg/L	<0.001	0.0039	0.00298	<0.01	-	-	<0.010	<0.001	<0.010	0.0039	<0.0010
Low Level Orthophosphate	mg/L	0.0019	<0.003	<0.003	<0.003	-	-	0.0019	-	<0.0030	-	-
pH	pH	7.51	7.66	7.65	7.73	6.5 to 9.0	5.0 to 9.0	7.65	7.66	7.51	7.73	7.72
Reactive Silica (as SiO2)	mg/L	0.55	1.9	1.81	2.9	-	-	0.55	1.1	1.9	2.9	2.6
Sulphate	mg/L	17	18	18.4	21	-	-	21	19	18	17	17
Turbidity	NTU	0.35	1.7	1.53	2	-	50	1.6	0.35	1.7	2.0	2.0
Conductivity	µS/cm	720	760	754	770	-	-	770	770	750	760	720
Phosphorus	mg/L	0.005	0.011	0.01	0.014	-	-	0.014	0.005	0.007	0.011	0.013
TSS	mg/L	<1	1.9	12.1	53	-	-	3.4	<1.0	1.6	53	1.9
Metals												
Calcium	µg/L	21000	23000	22400	23000	-	-	23000	21000	23000	23000	22000
Copper	µg/L	<2	<2	<2	<2	2	-	<2.0	<2.0	<2.0	<2.0	<2.0
Iron	µg/L	<50	<50	89	270	300	-	100	<50	<50	270	<50
Magnesium	µg/L	2100	2300	2280	2400	-	-	2100	2200	2400	2400	2300
Manganese	µg/L	36	56	89.6	180	-	-	120	36	56	180	56
Potassium	µg/L	1500	1600	1640	1800	-	-	1600	1500	1700	1800	1600
Sodium	µg/L	110000	110000	112000	120000	-	-	110000	110000	110000	120000	110000
Zinc	µg/L	<5	<5	<5	<5	30	-	<5.0	<5.0	<5.0	<5.0	<5.0
Microbiological												
Escherichia coli	CFU/100mL	30	90	150	340	-	400	210	80	30	90	340
Enterococci	CFU/100mL	200	200	226	>250	-	70	>250	200	-	-	-
Chlorophyll a												
Chl a - Acidification	µg/L	1.2	2.1	2.43	4.17	-	-	4.17	1.6	3.08	2.1	1.2
Chl a - Welschmeyer	µg/L	1.61	3.93	3.93	6.25	-	-	6.25	1.61	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	1.45	3.38	-	-	<1.1	<1.1	<1.1	3.38	2.2
Average Avian Marker	Log copies/100 mL water	1.69	1.94	2.27	3.19	-	-	1.69	1.8	1.94	2.74	3.19
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	1.42	3.05	-	-	<1.1	3.05	<1.1	2.42	<1.1

Table B.6 Surface Water Analytical Data - NEAR-SHORE 2

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Inorganics												
Ortho Phosphate (as P)	mg/L	<0.001	<0.001	<0.001	<0.001	-	-	-	<0.001	-	-	-
Low Level Orthophosphate	mg/L	0.0017	<0.003	<0.003	<0.003	-	-	0.0017	-	<0.0030	-	-
Phosphorus	mg/L	0.004	0.007	0.0084	0.017	-	-	0.007	0.008	0.004	0.017	0.006
TSS	mg/L	1	2	2.22	5.2	-	-	2.0	<1.0	2.4	5.2	1.0
Microbiological												
Escherichia coli	CFU/100mL	80	340	760	>2500	-	400	180	500	80	>2500	540
Enterococci	CFU/100mL	73	73	162	>250	-	70	>250	73	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	3.09	-	-	<1.1	<1.1	<1.1	<1.1	3.09
Average Avian Marker	Log copies/100 mL water	1.55	1.72	2.02	3.25	-	-	1.89	1.72	1.67	3.25	1.55
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1

Table B.7 Surface Water Analytical Data - NEAR-SHORE 3

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Inorganics												
Ortho Phosphate (as P)	mg/L	<0.001	<0.001	<0.001	<0.001	-	-	-	<0.001	-	-	-
Low Level Orthophosphate	mg/L	0.0021	<0.003	<0.003	<0.003	-	-	0.0021	-	<0.0030	-	-
Phosphorus	mg/L	<0.004	0.0045	0.0075	0.019	-	-	0.005	-	0.019	0.004	<0.004
TSS	mg/L	1	2	2.04	3.2	-	-	1.4	3.2	2.6	2.0	1.0
Microbiological												
Escherichia coli	CFU/100mL	<10	200	157	280	-	400	200	80	280	220	<10
Enterococci	CFU/100mL	28	129	129	230	-	70	28	230	-	-	-
Chlorophyll a												
Chl a - Acidification	µg/L	1.49	1.53	2.01	3.87	-	-	1.49	1.65	3.87	1.53	1.52
Chl a - Welschmeyer	µg/L	1.8	1.88	1.88	1.95	-	-	1.95	1.8	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1
Average Avian Marker	Log copies/100 mL water	<1.1	1.91	1.77	2.63	-	-	1.91	1.82	1.94	2.63	<1.1
Average Dog Marker	Log copies/100 mL water	2.23	3.25	3.33	4.92	-	-	2.5	4.92	3.77	2.23	3.25

Table B.8 Surface Water Analytical Data - OUTFALL 1

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Inorganics												
Ortho Phosphate (as P)	mg/L	0.002	0.002	0.002	0.002	-	-	-	0.002	-	-	-
Low Level Orthophosphate	mg/L	0.0036	0.0037	0.0037	0.0038	-	-	0.0038	-	0.0036	-	-
Phosphorus	mg/L	0.006	0.008	0.0104	0.023	-	-	0.006	0.007	0.023	0.008	0.008
TSS	mg/L	<1	2.2	5.74	20	-	-	2.2	<1.0	20	2.0	4.0
Microbiological												
Escherichia coli	CFU/100mL	30	120	176	350	-	400	110	350	30	270	120
Enterococci	CFU/100mL	77	149	149	220	-	70	<u>77</u>	<u>220</u>	-	-	-

Table B.9 Surface Water Analytical Data - OUTFALL 7

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Inorganics												
Ortho Phosphate (as P)	mg/L	0.0033	0.00465	0.00465	0.006	-	-	-	0.006	-	0.0033	-
Low Level Orthophosphate	mg/L	0.0043	0.00465	0.00465	0.005	-	-	0.005	-	0.0043	-	-
Phosphorus	mg/L	0.007	0.007	0.0096	0.018	-	-	0.007	0.009	0.007	0.007	0.018
TSS	mg/L	1	1	2.87	9.7	-	-	<1.0	2.6	9.7	1.0	<1.1
Microbiological												
Escherichia coli	CFU/100mL	10	150	524	2200	-	400	60	150	10	200	2200
Genetic Markers												
Average Human Marker	Log copies/100 mL water	2.47	2.47	2.47	2.47	-	-	-	2.47	-	-	-
Average Avian Marker	Log copies/100 mL water	2.65	2.65	2.65	2.65	-	-	-	2.65	-	-	-
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	-	<1.1	-	-	-

Table B.10 Surface Water Analytical Data - OUTFALL 8

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	14.8	19.3	19	22.6	-	-	14.8	18.9	22.6	19.7	-
Bicarbonate (as CaCO3)	mg/L	94	115	116	140	-	-	94	110	140	120	-
Total Dissolved Solids	mg/L	870	1100	1090	1300	-	-	870	1100	1300	1100	-
Carbonate (as CaCO3)	mg/L	<1	<1	<1	1.5	-	-	<1.0	<1.0	1.5	<1.0	-
Cation Sum	meq/L	15.1	18.6	18.6	22.1	-	-	15.1	18.0	22.1	19.1	-
Hardness (as CaCO3)	mg/L	150	170	175	210	-	-	150	160	210	180	-
Ion Balance (% Difference)	%	1.2	1.41	1.61	2.42	-	-	1.20	2.42	1.25	1.57	-
Langelier Index (@ 20C)	-	0.05	0.066	0.17	0.499	-	-	0.0500	0.0820	0.499	0.0500	-
Langelier Index (@ 4C)	-	-0.196	-0.179	-0.0747	0.255	-	-	-0.196	-0.163	0.255	-0.195	-
Nitrate (as N)	mg/L	0.63	0.755	0.773	0.95	13	-	0.65	0.86	0.95	0.63	-
Saturation pH (@ 20C)	-	7.58	7.73	7.72	7.83	-	-	7.83	7.77	7.58	7.68	-
Saturation pH (@ 4C)	-	7.83	7.97	7.96	8.08	-	-	8.08	8.01	7.83	7.93	-
Inorganics												
Alkalinity (as CaCO3)	mg/L	95	115	116	140	-	-	95	110	140	120	-
Chloride	mg/L	420	560	548	650	120	-	**420**	**550**	**650**	**570**	-
Colour	TCU	6.5	7.7	8.23	11	-	-	11	7.5	7.9	6.5	-
Nitrate + Nitrite (as N)	mg/L	0.63	0.755	0.773	0.95	-	-	0.65	0.86	0.95	0.63	-
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	<0.010	<0.010	<0.010	<0.010	-
Ammonia	mg/L	<0.05	<0.05	<0.05	<0.05	20	-	<0.050	<0.050	<0.050	<0.050	-
Kjeldahl Nitrogen (TKN)	mg/L	<0.1	<0.1	0.138	0.4	-	-	0.40	<0.10	<0.10	<0.10	-
TOC	mg/L	2.7	2.95	2.98	3.3	-	-	2.7	3.3	3.0	2.9	-
Ortho Phosphate (as P)	mg/L	0.008	<0.01	<0.01	0.015	-	-	<0.010	0.008	<0.010	0.015	-
Low Level Orthophosphate	mg/L	0.0055	0.0063	0.0063	0.0071	-	-	0.0055	-	0.0071	-	-
pH	pH	7.73	7.87	7.89	8.08	6.5 to 9.0	5.0 to 9.0	7.88	7.85	8.08	7.73	-
Reactive Silica (as SiO2)	mg/L	5.2	5.85	5.83	6.4	-	-	5.7	5.2	6.4	6.0	-
Sulphate	mg/L	50	57	57.3	65	-	-	50	55	65	59	-
Turbidity	NTU	0.26	0.45	1.79	6	-	50	6.0	0.26	0.54	0.36	-
Conductivity	µS/cm	1700	2150	2130	2500	-	-	1700	2100	2500	2200	-
Phosphorus	mg/L	0.01	0.0105	0.0115	0.015	-	-	0.010	0.015	0.011	0.010	-
TSS	mg/L	<1	1.7	3.48	10	-	-	1.0	10	2.4	<1.0	-
Metals												
Calcium	µg/L	53000	62500	63000	74000	-	-	53000	59000	74000	66000	-
Copper	µg/L	<2	<2	<2	2.1	2	-	<2.0	**2.1**	<2.0	<2.0	-
Iron	µg/L	<50	<50	<50	85	300	-	<50	85	<50	<50	-
Magnesium	µg/L	3900	4300	4430	5200	-	-	3900	4100	5200	4500	-
Manganese	µg/L	24	37	38.5	56	-	-	32	42	56	24	-
Potassium	µg/L	3500	3750	3980	4900	-	-	3500	3600	4900	3900	-
Sodium	µg/L	280000	345000	345000	410000	-	-	280000	340000	410000	350000	-
Zinc	µg/L	<5	<5	<5	7.8	30	-	6.2	7.8	<5.0	<5.0	-
Microbiological												
Escherichia coli	CFU/100mL	470	605	618	790	-	400	470	790	550	660	-
Enterococci	CFU/100mL	120	515	515	910	-	70	120	910	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	3.23	4.28	4.45	6.12	-	-	4.56	4.28	4.05	3.23	6.12
Average Avian Marker	Log copies/100 mL water	1.91	2.45	2.34	2.63	-	-	2.45	2.53	1.91	2.63	2.19
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	3.13	-	-	<1.1	<1.1	<1.1	<1.1	3.13

Table B.20 Surface Water Analytical Data - OUTFALL 8B

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results		
		Minimum	Median	Mean	Maximum					
							Date Sampled:	14-Aug-18	12-Sep-18	26-Sep-18
Parameter										
Calculated Parameters										
Anion Sum	meq/L	20.6	21.4	21.4	22.1	-	-	22.1	20.6	-
Bicarbonate (as CaCO3)	mg/L	120	125	125	130	-	-	130	120	-
Total Dissolved Solids	mg/L	1200	1250	1250	1300	-	-	1300	1200	-
Carbonate (as CaCO3)	mg/L	<1	<1	<1	1.1	-	-	1.1	<1.0	-
Cation Sum	meq/L	19.7	20.8	20.8	21.8	-	-	21.8	19.7	-
Hardness (as CaCO3)	mg/L	190	195	195	200	-	-	200	190	-
Ion Balance (% Difference)	%	0.73	1.56	1.56	2.38	-	-	0.730	2.38	-
Langelier Index (@ 20C)	-	0.134	0.24	0.24	0.346	-	-	0.346	0.134	-
Langelier Index (@ 4C)	-	-0.112	-0.0055	-0.0055	0.101	-	-	0.101	-0.112	-
Nitrate (as N)	mg/L	0.7	0.775	0.775	0.85	13	-	0.85	0.70	-
Saturation pH (@ 20C)	-	7.61	7.64	7.64	7.66	-	-	7.61	7.66	-
Saturation pH (@ 4C)	-	7.86	7.88	7.88	7.9	-	-	7.86	7.90	-
Inorganics										
Alkalinity (as CaCO3)	mg/L	120	125	125	130	-	-	130	120	
Chloride	mg/L	600	625	625	650	120	-	**650**	**600**	-
Colour	TCU	7.2	7.4	7.4	7.6	-	-	7.2	7.6	-
Nitrate + Nitrite (as N)	mg/L	0.7	0.785	0.785	0.87	-	-	0.87	0.70	-
Nitrite	mg/L	<0.01	0.016	0.016	0.027	0.06	-	0.027	<0.010	-
Ammonia	mg/L	<0.06	0.1	0.1	0.17	20	-	0.17	<0.060	-
Kjeldahl Nitrogen (TKN)	mg/L	<0.1	<0.1	<0.1	0.1	-	-	0.10	<0.10	-
TOC	mg/L	2.8	2.85	2.85	2.9	-	-	2.9	2.8	-
Ortho Phosphate (as P)	mg/L	0.01	<0.01	<0.01	0.01	-	-	<0.010	0.010	-
Low Level Orthophosphate	mg/L	0.0048	0.0048	0.0048	0.0048	-	-	0.0048	-	-
pH	pH	7.79	7.88	7.88	7.96	6.5 to 9.0	5.0 to 9.0	7.96	7.79	
Reactive Silica (as SiO2)	mg/L	6.1	6.45	6.45	6.8	-	-	6.8	6.1	-
Sulphate	mg/L	59	59.5	59.5	60	-	-	60	59	-
Turbidity	NTU	0.48	0.515	0.515	0.55	-	50	0.48	0.55	-
Conductivity	µS/cm	2300	2350	2350	2400	-	-	2400	2300	-
Phosphorus	mg/L	0.004	0.006	0.006	0.008	-	-	0.004	0.008	-
TSS	mg/L	<1	<1	<1	<1.1	-	-	<1.0	<1.1	-
Metals										
Calcium	µg/L	69000	70500	70500	72000	-	-	72000	69000	-
Copper	µg/L	<2	<2	<2	<2	2	-	<2.0	<2.0	-
Iron	µg/L	100	110	110	120	300	-	120	100	-
Magnesium	µg/L	4500	4900	4900	5300	-	-	5300	4500	-
Manganese	µg/L	200	255	255	310	-	-	310	200	-
Potassium	µg/L	3800	4300	4300	4800	-	-	4800	3800	-
Sodium	µg/L	360000	385000	385000	410000	-	-	410000	360000	-
Zinc	µg/L	<5	<5	<5	7.3	30	-	<5.0	7.3	-
Microbiological										
Escherichia coli	CFU/100mL	420	435	435	450	-	400	<u>450</u>	<u>420</u>	-
Genetic Markers										
Average Human Marker	Log copies/100 mL water	3.7	3.75	4.52	6.12	-	-	3.75	3.7	6.12
Average Avian Marker	Log copies/100 mL water	1.72	2.15	2.18	2.67	-	-	1.72	2.67	2.15
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	1.28	2.75	-	-	<1.1	<1.1	2.75

Table B.11 Surface Water Analytical Data - PUMP STATION 1

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results
		Minimum	Median	Mean	Maximum			
							Date Sampled:	27-Jun-18
Parameter								
Inorganics								
Low Level Orthophosphate	mg/L	0.0022	0.0022	0.0022	0.0022	-	-	0.0022
Phosphorus	mg/L	0.029	0.029	0.029	0.029	-	-	0.029
TSS	mg/L	1.8	1.8	1.8	1.8	-	-	1.8
Microbiological								
Escherichia coli	CFU/100mL	30	30	30	30	-	400	30

Table B.12 Surface Water Analytical Data - WATERCOURSE 1

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	6.1	6.52	6.44	6.69	-	-	6.54	6.52	6.10	6.37	6.69
Bicarbonate (as CaCO3)	mg/L	32	34	35	39	-	-	32	34	34	36	39
Total Dissolved Solids	mg/L	350	370	370	380	-	-	380	370	350	370	380
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	5.66	6.33	6.22	6.51	-	-	6.51	6.28	5.66	6.34	6.33
Hardness (as CaCO3)	mg/L	60	66	64.6	67	-	-	67	64	60	66	66
Ion Balance (% Difference)	%	0.23	1.87	1.77	3.74	-	-	0.230	1.87	3.74	0.240	2.76
Langelier Index (@ 20C)	-	-1.21	-0.968	-0.923	-0.722	-	-	-0.972	-1.21	-0.968	-0.722	-0.744
Langelier Index (@ 4C)	-	-1.46	-1.22	-1.17	-0.97	-	-	-1.22	-1.46	-1.22	-0.970	-0.993
Nitrate (as N)	mg/L	<0.05	<0.05	0.0558	0.13	13	-	0.13	0.074	<0.050	<0.050	<0.050
Saturation pH (@ 20C)	-	8.49	8.57	8.56	8.6	-	-	8.58	8.57	8.60	8.54	8.49
Saturation pH (@ 4C)	-	8.74	8.82	8.81	8.85	-	-	8.83	8.82	8.85	8.79	8.74
Inorganics												
Alkalinity (as CaCO3)	mg/L	32	34	35.2	40	-	-	32	34	34	36	40
Chloride	mg/L	180	190	190	200	120	-	**190**	**190**	**180**	**190**	**200**
Colour	TCU	<5	5.4	5.1	6.8	-	-	5.7	5.1	6.8	<5.0	5.4
Nitrate + Nitrite (as N)	mg/L	<0.05	<0.05	0.0558	0.13	-	-	0.13	0.074	<0.050	<0.050	<0.050
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	<0.010	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	<0.05	<0.05	<0.05	20	-	<0.050	<0.050	<0.050	<0.050	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	<0.1	0.14	0.204	0.57	-	-	0.57	0.15	0.11	<0.10	0.14
TOC	mg/L	2.5	2.6	2.7	3.1	-	-	2.6	2.7	3.1	2.6	2.5
Ortho Phosphate (as P)	mg/L	<0.001	0.0033	0.0031	<0.01	-	-	<0.010	<0.001	<0.010	0.0033	0.0017
Low Level Orthophosphate	mg/L	0.002	0.00275	0.00275	0.0035	-	-	0.002	-	0.0035	-	-
pH	pH	7.36	7.63	7.63	7.82	6.5 to 9.0	5.0 to 9.0	7.60	7.36	7.63	7.82	7.75
Reactive Silica (as SiO2)	mg/L	0.57	1.9	1.87	3	-	-	0.57	1.1	1.9	3.0	2.8
Sulphate	mg/L	16	17	18	21	-	-	21	19	16	17	17
Turbidity	NTU	0.62	1.1	1.82	5.5	-	50	1.1	0.62	5.5	1.1	0.78
Conductivity	µS/cm	700	760	752	800	-	-	760	800	700	770	730
Phosphorus	mg/L	0.004	0.005	0.0086	0.024	-	-	0.005	0.005	0.024	0.004	0.005
TSS	mg/L	<1	1.2	1.92	5.2	-	-	2.2	1.2	5.2	<1.0	<1.0
Metals												
Calcium	µg/L	20000	22000	21800	23000	-	-	23000	22000	20000	22000	22000
Copper	µg/L	<2	<2	<2	<2	2	-	<2.0	<2.0	<2.0	<2.0	<2.0
Iron	µg/L	<50	<50	64.8	190	300	-	<50	59	190	<50	<50
Magnesium	µg/L	2200	2300	2300	2400	-	-	2200	2300	2200	2400	2400
Manganese	µg/L	56	91	107	210	-	-	91	100	210	56	76
Potassium	µg/L	1600	1600	1640	1700	-	-	1700	1600	1600	1700	1600
Sodium	µg/L	100000	110000	110000	120000	-	-	120000	110000	100000	110000	110000
Zinc	µg/L	<5	<5	<5	<5	30	-	<5.0	<5.0	<5.0	<5.0	<5.0
Microbiological												
Escherichia coli	CFU/100mL	<10	100	473	1600	-	400	<10	80	1600	100	580
Enterococci	CFU/100mL	19	42.5	42.5	66	-	70	19	66	-	-	-
Chlorophyll a												
Chl a - Acidification	µg/L	0.85	1.51	1.96	3.23	-	-	3.18	1.51	3.23	1.03	0.85
Chl a - Welschmeyer	µg/L	1.58	3.12	3.12	4.65	-	-	4.65	1.58	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	2.12	6.33	-	-	<1.1	<1.1	<1.1	2.61	6.33
Average Avian Marker	Log copies/100 mL water	<1.1	1.54	1.64	2.42	-	-	1.43	1.54	2.24	2.42	<1.1
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	1.41	2.89	-	-	<1.1	2.52	<1.1	<1.1	2.89

Table B.13 Surface Water Analytical Data - WATERCOURSE 2

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	4.58	8.66	8.71	12.7	-	-	8.66	5.80	12.7	4.58	11.8
Bicarbonate (as CaCO3)	mg/L	31	62	67.8	100	-	-	62	48	98	31	100
Total Dissolved Solids	mg/L	270	500	500	720	-	-	500	330	720	270	680
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	4.51	8.33	8.45	12	-	-	8.33	5.52	12.0	4.51	11.9
Hardness (as CaCO3)	mg/L	61	130	137	210	-	-	130	83	200	61	210
Ion Balance (% Difference)	%	0.63	1.94	1.79	3.12	-	-	1.94	2.47	3.12	0.770	0.630
Langelier Index (@ 20C)	-	-1.1	-0.367	-0.317	0.257	-	-	-0.367	-0.552	0.179	-1.10	0.257
Langelier Index (@ 4C)	-	-1.35	-0.615	-0.565	0.01	-	-	-0.615	-0.801	-0.0680	-1.35	0.0100
Nitrate (as N)	mg/L	0.14	0.76	0.624	0.92	13	-	0.76	0.42	0.88	0.14	0.92
Saturation pH (@ 20C)	-	7.63	8.04	8.05	8.62	-	-	8.04	8.30	7.68	8.62	7.63
Saturation pH (@ 4C)	-	7.88	8.29	8.3	8.87	-	-	8.29	8.55	7.93	8.87	7.88
Inorganics												
Alkalinity (as CaCO3)	mg/L	31	63	68.2	100	-	-	63	48	99	31	100
Chloride	mg/L	130	240	238	350	120	-	**240**	**160**	**350**	**130**	**310**
Colour	TCU	6.4	9	9.96	15	-	-	9.0	15	7.4	12	6.4
Nitrate + Nitrite (as N)	mg/L	0.14	0.76	0.624	0.92	-	-	0.76	0.42	0.88	0.14	0.92
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	<0.010	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	<0.05	<0.05	<0.05	20	-	<0.050	<0.050	<0.050	<0.050	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	<0.1	0.11	<0.1	0.15	-	-	0.15	0.11	<0.10	<0.10	0.11
TOC	mg/L	2.5	3	3.22	4	-	-	3.0	4.0	2.9	3.7	2.5
Ortho Phosphate (as P)	mg/L	<0.001	<0.001	0.0023	<0.01	-	-	<0.010	<0.001	<0.010	<0.0010	<0.0010
Low Level Orthophosphate	mg/L	0.003	0.00305	0.00305	0.0031	-	-	0.0031	-	0.003	-	-
pH	pH	7.52	7.75	7.74	7.89	6.5 to 9.0	5.0 to 9.0	7.67	7.75	7.86	7.52	7.89
Reactive Silica (as SiO2)	mg/L	5.1	5.2	5.56	6.6	-	-	5.1	5.1	6.6	5.8	5.2
Sulphate	mg/L	13	27	27.4	41	-	-	27	18	38	13	41
Turbidity	NTU	0.17	1.3	1.13	1.7	-	50	0.17	1.7	1.2	1.3	1.3
Conductivity	µS/cm	530	960	976	1400	-	-	960	690	1400	530	1300
Phosphorus	mg/L	<0.004	<0.004	0.005	0.01	-	-	<0.004	0.010	<0.004	0.009	<0.004
TSS	mg/L	<1	2.2	2.4	5.4	-	-	<1.0	5.4	<1.0	3.4	2.2
Metals												
Calcium	µg/L	20000	43000	46000	71000	-	-	43000	28000	68000	20000	71000
Copper	µg/L	<2	<2	<2	<2	2	-	<2.0	<2.0	<2.0	<2.0	<2.0
Iron	µg/L	84	97	117	200	300	-	84	93	97	200	110
Magnesium	µg/L	2600	4600	5320	8300	-	-	4600	3300	7800	2600	8300
Manganese	µg/L	46	97	99.2	160	-	-	97	46	160	83	110
Potassium	µg/L	1300	2300	2300	3100	-	-	2300	1700	3100	1300	3100
Sodium	µg/L	75000	130000	129000	180000	-	-	130000	88000	180000	75000	170000
Zinc	µg/L	<5	<5	<5	<5	30	-	<5.0	<5.0	<5.0	<5.0	<5.0
Microbiological												
Escherichia coli	CFU/100mL	10	20	390	1700	-	400	10	210	10	1700	20
Enterococci	CFU/100mL	20	200	200	380	-	70	20	380	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	1.55	5.53	-	-	<1.1	<1.1	<1.1	<1.1	5.53
Average Avian Marker	Log copies/100 mL water	<1.1	2.3	2.27	3.58	-	-	2.04	2.87	2.3	3.58	<1.1
Average Dog Marker	Log copies/100 mL water	<1.1	2.68	2.29	4.34	-	-	<1.1	3.33	<1.1	2.68	4.34
Average Ruminant Marker	Log copies/100 mL water	<1.1	4.91	3.89	6.93	-	-	1.59	4.91	5.47	6.93	<1.1

Table B.14 Surface Water Analytical Data - WATERCOURSE 3

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	7.53	8.36	8.91	10.5	-	-	7.87	7.53	10.3	8.36	10.5
Bicarbonate (as CaCO3)	mg/L	47	73	67	85	-	-	47	54	76	73	85
Total Dissolved Solids	mg/L	440	480	514	590	-	-	470	440	590	480	590
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	7.73	8.47	8.88	9.98	-	-	8.47	7.73	9.96	8.26	9.98
Hardness (as CaCO3)	mg/L	91	120	115	140	-	-	92	91	130	120	140
Ion Balance (% Difference)	%	0.6	1.53	1.92	3.67	-	-	3.67	1.31	1.53	0.600	2.49
Langelier Index (@ 20C)	-	-0.678	-0.201	-0.279	0.082	-	-	-0.678	-0.512	-0.0870	-0.201	0.0820
Langelier Index (@ 4C)	-	-0.926	-0.449	-0.527	-0.166	-	-	-0.926	-0.760	-0.334	-0.449	-0.166
Nitrate (as N)	mg/L	0.16	0.18	0.214	0.33	13	-	0.18	0.33	0.16	0.22	0.18
Saturation pH (@ 20C)	-	7.86	8	8.06	8.28	-	-	8.28	8.22	7.94	8.00	7.86
Saturation pH (@ 4C)	-	8.11	8.25	8.31	8.53	-	-	8.53	8.47	8.18	8.25	8.11
Inorganics												
Alkalinity (as CaCO3)	mg/L	47	73	67.2	85	-	-	47	54	77	73	85
Chloride	mg/L	210	230	250	290	120	-	**230**	**210**	**290**	**230**	**290**
Colour	TCU	10	13	15	21	-	-	18	21	13	13	10
Nitrate + Nitrite (as N)	mg/L	0.16	0.18	0.214	0.33	-	-	0.18	0.33	0.16	0.22	0.18
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	<0.010	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	<0.05	<0.05	<0.05	20	-	<0.050	<0.050	<0.050	<0.050	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	<0.1	0.14	0.132	0.21	-	-	0.21	0.12	0.14	<0.10	0.14
TOC	mg/L	3.5	3.7	3.88	4.4	-	-	4.3	4.4	3.7	3.5	3.5
Ortho Phosphate (as P)	mg/L	<0.001	0.005	0.0048	0.013	-	-	<0.010	<0.001	<0.010	0.013	<0.0010
Low Level Orthophosphate	mg/L	0.003	0.00305	0.00305	0.0031	-	-	0.003	-	0.0031	-	-
pH	pH	7.6	7.8	7.78	7.94	6.5 to 9.0	5.0 to 9.0	7.60	7.71	7.85	7.80	7.94
Reactive Silica (as SiO2)	mg/L	2.8	4.4	4	4.7	-	-	2.8	3.4	4.4	4.7	4.7
Sulphate	mg/L	21	21	22.2	26	-	-	21	22	21	21	26
Turbidity	NTU	0.48	1.3	1.54	3.3	-	50	3.3	1.5	0.48	1.1	1.3
Conductivity	µS/cm	960	1000	1070	1200	-	-	1000	960	1200	970	1200
Phosphorus	mg/L	<0.004	0.006	0.0066	0.01	-	-	0.010	0.006	0.010	0.005	<0.004
TSS	mg/L	<1	1.4	1.94	4.8	-	-	1.8	1.2	4.8	1.4	<1.0
Metals												
Calcium	µg/L	32000	40000	40200	50000	-	-	32000	32000	47000	40000	50000
Copper	µg/L	<2	<2	<2	<2	2	-	<2.0	<2.0	<2.0	<2.0	<2.0
Iron	µg/L	200	220	234	290	300	-	200	200	260	290	220
Magnesium	µg/L	2800	3800	3680	4500	-	-	2800	2900	4400	3800	4500
Manganese	µg/L	150	180	206	270	-	-	150	170	180	270	260
Potassium	µg/L	2000	2400	2340	2600	-	-	2100	2000	2600	2400	2600
Sodium	µg/L	130000	150000	150000	170000	-	-	150000	130000	170000	140000	160000
Zinc	µg/L	<5	<5	<5	<5	30	-	<5.0	<5.0	<5.0	<5.0	<5.0
Microbiological												
Escherichia coli	CFU/100mL	<10	20	71	180	-	400	10	180	<10	140	20
Enterococci	CFU/100mL	31	141	141	250	-	70	31	250	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	-	<1.1
Average Avian Marker	Log copies/100 mL water	<1.1	1.86	1.61	2.19	-	-	2.19	2.04	1.67	-	<1.1
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	2.33	-	-	<1.1	<1.1	<1.1	-	2.33

Table B.15 Surface Water Analytical Data - WATERCOURSE 4

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	4.51	5.02	4.9	5.11	-	-	5.02	5.10	5.11	4.51	4.76
Bicarbonate (as CaCO3)	mg/L	37	42	42.6	47	-	-	37	42	47	45	42
Total Dissolved Solids	mg/L	260	280	276	290	-	-	280	280	290	260	270
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	<1.0	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	4.31	4.63	4.56	4.76	-	-	4.66	4.63	4.76	4.44	4.31
Hardness (as CaCO3)	mg/L	47	49	49.8	54	-	-	48	47	54	51	49
Ion Balance (% Difference)	%	0.78	3.72	3.57	4.96	-	-	3.72	4.83	3.55	0.780	4.96
Langelier Index (@ 20C)	-	-1.34	-1.07	-1.11	-0.925	-	-	-1.34	-1.23	-0.972	-1.07	-0.925
Langelier Index (@ 4C)	-	-1.59	-1.32	-1.36	-1.17	-	-	-1.59	-1.48	-1.22	-1.32	-1.17
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	0.097	13	-	0.097	<0.050	<0.050	<0.050	<0.050
Saturation pH (@ 20C)	-	8.49	8.56	8.55	8.62	-	-	8.62	8.59	8.49	8.51	8.56
Saturation pH (@ 4C)	-	8.73	8.81	8.8	8.87	-	-	8.87	8.84	8.73	8.76	8.81
Inorganics												
Alkalinity (as CaCO3)	mg/L	38	42	42.8	47	-	-	38	42	47	45	42
Chloride	mg/L	120	140	134	140	120	-	**140**	**140**	**140**	120	**130**
Colour	TCU	17	26	24.2	31	-	-	19	26	28	31	17
Nitrate + Nitrite (as N)	mg/L	<0.05	<0.05	<0.05	0.12	-	-	0.12	<0.050	<0.050	<0.050	<0.050
Nitrite	mg/L	<0.01	<0.01	<0.01	0.022	0.06	-	0.022	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	0.061	0.152	0.54	20	-	0.54	0.11	<0.050	0.061	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	0.23	0.31	0.402	0.84	-	-	0.84	0.35	0.31	0.28	0.23
TOC	mg/L	4.7	5.2	5.18	5.7	-	-	5.0	5.2	5.7	5.3	4.7
Ortho Phosphate (as P)	mg/L	0.0011	<0.01	<0.01	0.011	-	-	<0.010	0.004	<0.010	0.011	0.0011
Low Level Orthophosphate	mg/L	0.0023	<0.003	<0.003	<0.003	-	-	0.0023	-	<0.0030	-	-
pH	pH	7.28	7.44	7.45	7.64	6.5 to 9.0	5.0 to 9.0	7.28	7.36	7.51	7.44	7.64
Reactive Silica (as SiO2)	mg/L	0.83	2.2	2.05	3.6	-	-	0.83	1.0	2.2	2.6	3.6
Sulphate	mg/L	6.3	8.5	8.84	13	-	-	13	10	6.3	6.4	8.5
Turbidity	NTU	0.98	1.9	1.82	2.8	-	50	1.9	1.5	1.9	2.8	0.98
Conductivity	µS/cm	520	560	554	590	-	-	580	590	560	520	520
Phosphorus	mg/L	0.018	0.03	0.0286	0.035	-	-	0.032	0.028	0.035	0.030	0.018
TSS	mg/L	1.7	1.8	2.06	3	-	-	1.8	1.8	2.0	3.0	1.7
Metals												
Calcium	µg/L	16000	17000	17000	18000	-	-	17000	16000	18000	17000	17000
Copper	µg/L	<2	<2	<2	<2	2	-	<2.0	<2.0	<2.0	<2.0	<2.0
Iron	µg/L	570	720	788	1200	300	-	**720**	**690**	**760**	**1200**	**570**
Magnesium	µg/L	1700	1800	1800	2000	-	-	1700	1800	2000	1800	1700
Manganese	µg/L	77	120	126	220	-	-	120	220	83	130	77
Potassium	µg/L	560	760	874	1500	-	-	1500	930	620	560	760
Sodium	µg/L	75000	83000	80400	84000	-	-	83000	83000	84000	77000	75000
Zinc	µg/L	<5	<5	<5	<5	30	-	<5.0	<5.0	<5.0	<5.0	<5.0
Microbiological												
Escherichia coli	CFU/100mL	<10	20	29	70	-	400	20	<10	20	70	30
Enterococci	CFU/100mL	33	36	36	39	-	70	39	33	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1
Average Avian Marker	Log copies/100 mL water	1.43	2.24	2.17	2.97	-	-	2.27	2.24	1.43	2.97	1.93
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	1.16	3.58	-	-	<1.1	<1.1	<1.1	<1.1	3.58
Average Ruminant Marker	Log copies/100 mL water	<1.1	<1.1	1.72	6.38	-	-	<1.1	<1.1	<1.1	6.38	<1.1

Table B.16 Surface Water Analytical Data - WATERCOURSE 5

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	2.61	2.78	2.8	3.05	-	-	-	2.61	2.88	2.68	3.05
Bicarbonate (as CaCO3)	mg/L	29	30	31	35	-	-	-	29	30	30	35
Total Dissolved Solids	mg/L	150	160	160	170	-	-	-	150	160	160	170
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	-	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	2.42	2.68	2.62	2.71	-	-	-	2.42	2.66	2.69	2.71
Hardness (as CaCO3)	mg/L	40	43.5	43.3	46	-	-	-	40	43	46	44
Ion Balance (% Difference)	%	0.19	3.88	3.46	5.9	-	-	-	3.78	3.97	0.190	5.90
Langelier Index (@ 20C)	-	-1.28	-1.21	-1.17	-0.987	-	-	-	-1.28	-1.23	-1.20	-0.987
Langelier Index (@ 4C)	-	-1.53	-1.46	-1.43	-1.24	-	-	-	-1.53	-1.48	-1.45	-1.24
Nitrate (as N)	mg/L	<0.05	0.089	0.101	0.2	13	-	-	0.20	0.10	0.078	<0.050
Saturation pH (@ 20C)	-	8.67	8.73	8.73	8.77	-	-	-	8.77	8.74	8.72	8.67
Saturation pH (@ 4C)	-	8.92	8.98	8.98	9.02	-	-	-	9.02	8.99	8.97	8.92
Inorganics												
Alkalinity (as CaCO3)	mg/L	30	30	31.3	35	-	-	-	30	30	30	35
Chloride	mg/L	63	68.5	68.8	75	120	-	-	63	72	65	75
Colour	TCU	6.9	9.9	9.68	12	-	-	-	12	11	8.8	6.9
Nitrate + Nitrite (as N)	mg/L	<0.05	0.089	0.101	0.2	-	-	-	0.20	0.10	0.078	<0.050
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	-	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	<0.05	<0.05	<0.05	20	-	-	<0.050	<0.050	<0.050	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	<0.1	0.12	0.115	0.17	-	-	-	0.17	0.13	<0.10	0.11
TOC	mg/L	2.4	3.7	3.7	5	-	-	-	3.7	3.7	5.0	2.4
Ortho Phosphate (as P)	mg/L	0.001	<0.01	<0.01	<0.01	-	-	-	0.002	<0.010	0.0074	0.0010
Low Level Orthophosphate	mg/L	0.0035	0.0039	0.0039	0.0043	-	-	0.0035	-	0.0043	-	-
pH	pH	7.49	7.52	7.55	7.68	6.5 to 9.0	5.0 to 9.0	-	7.49	7.51	7.52	7.68
Reactive Silica (as SiO2)	mg/L	1.9	2.1	2.22	2.8	-	-	-	2.0	1.9	2.2	2.8
Sulphate	mg/L	11	11	11	11	-	-	-	11	11	11	11
Turbidity	NTU	0.76	1.6	2.14	4.6	-	50	-	1.1	0.76	4.6	2.1
Conductivity	µS/cm	300	310	310	320	-	-	-	300	320	310	310
Phosphorus	mg/L	0.006	0.01	0.0194	0.048	-	-	0.010	0.010	0.023	0.048	0.006
TSS	mg/L	1	4.6	24	98	-	-	1.0	4.6	15	98	1.6
Metals												
Calcium	µg/L	13000	14500	14300	15000	-	-	-	13000	14000	15000	15000
Copper	µg/L	<2	<2	2.25	6	2	-	-	<2.0	<2.0	**6.0**	<2.0
Iron	µg/L	180	200	520	1500	300	-	-	190	210	**1500**	180
Magnesium	µg/L	1600	1850	1850	2100	-	-	-	1600	1800	2100	1900
Manganese	µg/L	100	235	258	460	-	-	-	120	100	350	460
Potassium	µg/L	1400	1550	1550	1700	-	-	-	1400	1600	1700	1500
Sodium	µg/L	36000	39500	39000	41000	-	-	-	36000	40000	39000	41000
Zinc	µg/L	<5	<5	8.13	25	30	-	-	<5.0	<5.0	25	<5.0
Microbiological												
Escherichia coli	CFU/100mL	40	190	228	450	-	400	190	360	100	<u>450</u>	40
Enterococci	CFU/100mL	160	165	165	170	-	70	<u>170</u>	<u>160</u>	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1
Average Avian Marker	Log copies/100 mL water	1.74	1.95	2.17	2.65	-	-	2.65	1.74	1.94	2.57	1.95
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1
Average Ruminant Marker	Log copies/100 mL water	<1.1	4.58	3.6	5.9	-	-	1.72	4.58	5.24	5.9	<1.1

Table B.17 Surface Water Analytical Data - WATERCOURSE 6

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Calculated Parameters												
Anion Sum	meq/L	2.67	2.82	2.84	3.04	-	-	-	2.67	2.95	2.69	3.04
Bicarbonate (as CaCO3)	mg/L	31	33.5	33.3	35	-	-	-	31	35	33	34
Total Dissolved Solids	mg/L	150	160	160	170	-	-	-	150	160	160	170
Carbonate (as CaCO3)	mg/L	<1	<1	<1	<1	-	-	-	<1.0	<1.0	<1.0	<1.0
Cation Sum	meq/L	2.54	2.62	2.64	2.76	-	-	-	2.54	2.60	2.64	2.76
Hardness (as CaCO3)	mg/L	42	43	43.5	46	-	-	-	42	43	43	46
Ion Balance (% Difference)	%	0.94	3.67	3.64	6.31	-	-	-	2.50	6.31	0.940	4.83
Langelier Index (@ 20C)	-	-1.47	-1.37	-1.33	-1.14	-	-	-	-1.47	-1.29	-1.44	-1.14
Langelier Index (@ 4C)	-	-1.72	-1.62	-1.58	-1.39	-	-	-	-1.72	-1.54	-1.69	-1.39
Nitrate (as N)	mg/L	<0.05	<0.05	0.0592	0.13	13	-	-	0.13	<0.050	<0.050	0.057
Saturation pH (@ 20C)	-	8.66	8.68	8.69	8.74	-	-	-	8.74	8.67	8.70	8.66
Saturation pH (@ 4C)	-	8.91	8.93	8.94	8.99	-	-	-	8.99	8.92	8.95	8.91
Inorganics												
Alkalinity (as CaCO3)	mg/L	31	33.5	33.5	36	-	-	-	31	36	33	34
Chloride	mg/L	65	68.5	69.3	75	120	-	-	65	72	65	75
Colour	TCU	7.8	10.2	10	12	-	-	-	12	11	9.3	7.8
Nitrate + Nitrite (as N)	mg/L	<0.05	<0.05	0.0592	0.13	-	-	-	0.13	<0.050	<0.050	0.057
Nitrite	mg/L	<0.01	<0.01	<0.01	<0.01	0.06	-	-	<0.010	<0.010	<0.010	<0.010
Ammonia	mg/L	<0.05	<0.05	<0.05	<0.05	20	-	-	<0.050	<0.050	<0.050	<0.050
Kjeldahl Nitrogen (TKN)	mg/L	<0.1	0.1	0.103	0.16	-	-	-	<0.10	0.16	<0.10	0.15
TOC	mg/L	3	3.1	3.18	3.5	-	-	-	3.5	3.1	3.0	3.1
Ortho Phosphate (as P)	mg/L	0.0013	0.0057	0.00668	0.014	-	-	-	0.004	0.014	0.0074	0.0013
Low Level Orthophosphate	mg/L	0.0047	0.005	0.005	0.0053	-	-	0.0047	-	0.0053	-	-
pH	pH	7.26	7.32	7.36	7.52	6.5 to 9.0	5.0 to 9.0	-	7.27	7.38	7.26	7.52
Reactive Silica (as SiO2)	mg/L	2.1	2.55	2.55	3	-	-	-	2.2	2.9	3.0	2.1
Sulphate	mg/L	9.5	9.85	10.6	13	-	-	-	10	9.7	9.5	13
Turbidity	NTU	0.55	0.72	0.823	1.3	-	50	-	0.88	0.56	1.3	0.55
Conductivity	µS/cm	310	315	315	320	-	-	-	310	320	310	320
Phosphorus	mg/L	0.005	0.008	0.0106	0.024	-	-	0.006	0.010	0.008	0.024	0.005
TSS	mg/L	<1	1.4	3.28	12	-	-	<1.0	12	1.4	2.0	<1.0
Metals												
Calcium	µg/L	14000	14000	14300	15000	-	-	-	14000	14000	14000	15000
Copper	µg/L	<2	<2	<2	<2	2	-	-	<2.0	<2.0	<2.0	<2.0
Iron	µg/L	97	215	332	800	300	-	-	150	280	**800**	97
Magnesium	µg/L	1700	1800	1800	1900	-	-	-	1700	1800	1800	1900
Manganese	µg/L	88	350	472	1100	-	-	-	130	570	1100	88
Potassium	µg/L	1400	1550	1550	1700	-	-	-	1500	1400	1700	1600
Sodium	µg/L	38000	39000	39300	41000	-	-	-	38000	39000	39000	41000
Zinc	µg/L	<5	<5	<5	<5	30	-	-	<5.0	<5.0	<5.0	<5.0
Microbiological												
Escherichia coli	CFU/100mL	90	695	895	2100	-	400	-	1300	90	2100	90
Enterococci	CFU/100mL	190	190	190	190	-	70	-	190	-	-	-
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	1.76	4.81	-	-	<1.1	2.35	<1.1	<1.1	4.81
Average Avian Marker	Log copies/100 mL water	1.27	2.85	2.63	3.26	-	-	2.68	2.85	3.1	3.26	1.27
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	1.11	3.34	-	-	<1.1	3.34	<1.1	<1.1	<1.1

Table B.18 Surface Water Analytical Data - WATERFOWL 1

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results				
		Minimum	Median	Mean	Maximum							
							Date Sampled:	27-Jun-18	19-Jul-18	14-Aug-18	12-Sep-18	26-Sep-18
Parameter												
Inorganics												
Ortho Phosphate (as P)	mg/L	0.001	0.001	0.001	0.001	-	-	-	0.001	-	-	-
Low Level Orthophosphate	mg/L	<0.001	0.0021	0.0021	0.0037	-	-	<0.0010	-	0.0037	-	-
Phosphorus	mg/L	0.006	0.006	0.0072	0.01	-	-	0.006	0.006	0.006	0.010	0.008
TSS	mg/L	1	1	1.08	2.2	-	-	<1.0	<1.0	2.2	1.2	1.0
Microbiological												
Escherichia coli	CFU/100mL	320	530	534	690	-	400	320	530	690	640	490
Genetic Markers												
Average Human Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1
Average Avian Marker	Log copies/100 mL water	<1.1	1.61	1.7	2.71	-	-	2.26	1.37	1.61	2.71	<1.1
Average Dog Marker	Log copies/100 mL water	<1.1	<1.1	<1.1	<1.1	-	-	<1.1	<1.1	<1.1	<1.1	<1.1

Table B.21 Surface Water Analytical Data - HDW8846

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	14-Aug-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.019	0.019	0.019	0.019	-	-	-	0.019
Low Level Orthophosphate	mg/L	0.018	0.018	0.018	0.018	-	-	0.018	-
Phosphorus	mg/L	0.17	0.335	0.335	0.5	-	-	0.5	0.17
TSS	mg/L	140	335	335	530	-	-	530	140
Microbiological									
Escherichia coli	CFU/100mL	740	1220	1220	1700	-	400	1700	740

Table B.22 Surface Water Analytical Data - HDW8905

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	14-Aug-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	<0.001	<0.001	<0.001	<0.001	-	-	-	<0.0010
Low Level Orthophosphate	mg/L	0.0057	0.0057	0.0057	0.0057	-	-	0.0057	-
Phosphorus	mg/L	0.17	0.24	0.24	0.31	-	-	0.31	0.17
TSS	mg/L	180	235	235	290	-	-	290	180
Microbiological									
Escherichia coli	CFU/100mL	790	945	945	1100	-	400	1100	790

Table B.23 Surface Water Analytical Data - HDW8989

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	14-Aug-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.017	0.017	0.017	0.017	-	-	-	0.017
Low Level Orthophosphate	mg/L	0.016	0.016	0.016	0.016	-	-	0.016	-
Phosphorus	mg/L	0.21	0.335	0.335	0.46	-	-	0.21	0.46
TSS	mg/L	170	205	205	240	-	-	170	240
Microbiological									
Escherichia coli	CFU/100mL	550	610	610	670	-	400	550	670

Table B.24 Surface Water Analytical Data - HDW8991

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	14-Aug-18	12-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.0034	0.0034	0.0034	0.0034	-	-	-	0.0034
Low Level Orthophosphate	mg/L	0.0043	0.0043	0.0043	0.0043	-	-	0.0043	-
Phosphorus	mg/L	0.015	0.0575	0.0575	0.1	-	-	0.10	0.015
TSS	mg/L	8.2	22.6	22.6	37	-	-	37	8.2
Microbiological									
Escherichia coli	CFU/100mL	920	920	1710	>2500	-	400	>2500	920
Genetic Markers									
Average Human Marker	Log copies/100 mL water	2.45	2.45	2.45	2.45	-	-	-	2.45
Average Avian Marker	Log copies/100 mL water	2.71	2.71	2.71	2.71	-	-	-	2.71
Average Dog Marker	Log copies/100 mL water	<1.1	#VALUE!	<1.1	<1.1	-	-	-	<1.1

Table B.25 Surface Water Analytical Data - HDW9308

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	14-Aug-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.0026	0.0026	0.0026	0.0026	-	-	-	0.0026
Low Level Orthophosphate	mg/L	0.0099	0.0099	0.0099	0.0099	-	-	0.0099	-
Phosphorus	mg/L	0.009	0.018	0.018	0.027	-	-	0.027	0.009
TSS	mg/L	3.2	3.5	3.5	3.8	-	-	3.8	3.2
Microbiological									
Escherichia coli	CFU/100mL	130	915	915	1700	-	400	1700	130

Table B.26 Surface Water Analytical Data - HDW9311

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	14-Aug-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.0077	0.0077	0.0077	0.0077	-	-	-	0.0077
Low Level Orthophosphate	mg/L	0.029	0.029	0.029	0.029	-	-	0.029	-
Phosphorus	mg/L	0.66	1.48	1.48	2.3	-	-	0.66	2.3
TSS	mg/L	960	2780	2780	4600	-	-	960	4600
Microbiological									
Escherichia coli	CFU/100mL	>2500	5200	>2500	5200	-	400	>2500	5200

Table B.27 Surface Water Analytical Data - HDW9328

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	14-Aug-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.0089	0.0089	0.0089	0.0089	-	-	-	0.0089
Low Level Orthophosphate	mg/L	0.029	0.029	0.029	0.029	-	-	0.029	-
Phosphorus	mg/L	0.11	0.175	0.175	0.24	-	-	0.11	0.24
TSS	mg/L	120	190	190	260	-	-	120	260
Microbiological									
Escherichia coli	CFU/100mL	280	325	325	370	-	400	370	280

Table B.28 Surface Water Analytical Data - HDW6453

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results
		Minimum	Median	Mean	Maximum			
							Date Sampled:	26-Sep-18
Parameter								
Inorganics								
Ortho Phosphate (as P)	mg/L	0.0011	0.0011	0.0011	0.0011	-	-	0.0011
Phosphorus	mg/L	0.039	0.039	0.039	0.039	-	-	0.039
TSS	mg/L	18	18	18	18	-	-	18
Microbiological								
Escherichia coli	CFU/100mL	670	670	670	670	-	400	670

Table B.29 Surface Water Analytical Data - HDW6658

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results
		Minimum	Median	Mean	Maximum			
							Date Sampled:	26-Sep-18
Parameter								
Inorganics								
Ortho Phosphate (as P)	mg/L	0.12	0.12	0.12	0.12	-	-	0.12
Phosphorus	mg/L	0.18	0.18	0.18	0.18	-	-	0.18
TSS	mg/L	8.7	8.7	8.7	8.7	-	-	8.7
Microbiological								
Escherichia coli	CFU/100mL	>2500	#VALUE!	>2500	>2500	-	400	>2500

Table B.30 Surface Water Analytical Data - HDW7052

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results
		Minimum	Median	Mean	Maximum			
							Date Sampled:	26-Sep-18
Parameter								
Inorganics								
Ortho Phosphate (as P)	mg/L	0.097	0.097	0.097	0.097	-	-	0.097
Phosphorus	mg/L	0.22	0.22	0.22	0.22	-	-	0.22
TSS	mg/L	33	33	33	33	-	-	33
Microbiological								
Escherichia coli	CFU/100mL	>2500	#VALUE!	>2500	>2500	-	400	>2500

Table B.31 Surface Water Analytical Data - HDW7061

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	12-Sep-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.03	0.03	0.03	0.03	-	-	0.030	-
Phosphorus	mg/L	0.035	0.0875	0.0875	0.14	-	-	0.035	0.14
TSS	mg/L	1.6	31.8	31.8	62	-	-	1.6	62
Microbiological									
Escherichia coli	CFU/100mL	880	1940	1940	3000	-	400	880	3000

Table B.32 Surface Water Analytical Data - HDW8201

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	12-Sep-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.014	0.014	0.014	0.014	-	-	0.014	-
Phosphorus	mg/L	0.007	0.0095	0.0095	0.012	-	-	0.007	0.012
TSS	mg/L	1.8	1.9	1.9	2	-	-	1.8	2.0
Microbiological									
Escherichia coli	CFU/100mL	40	45	45	50	-	400	40	50

Table B.33 Surface Water Analytical Data - HDW8210

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results
		Minimum	Median	Mean	Maximum			
							Date Sampled:	26-Sep-18
Parameter								
Inorganics								
Ortho Phosphate (as P)	mg/L	0.022	0.022	0.022	0.022	-	-	0.022
Phosphorus	mg/L	0.053	0.053	0.053	0.053	-	-	0.053
TSS	mg/L	9.3	9.3	9.3	9.3	-	-	9.3
Microbiological								
Escherichia coli	CFU/100mL	540	540	540	540	-	400	540

Table B.34 Surface Water Analytical Data - HDW8214

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results
		Minimum	Median	Mean	Maximum			
							Date Sampled:	26-Sep-18
Parameter								
Inorganics								
Ortho Phosphate (as P)	mg/L	0.0033	0.0033	0.0033	0.0033	-	-	0.0033
Phosphorus	mg/L	0.13	0.13	0.13	0.13	-	-	0.13
TSS	mg/L	49	49	49	49	-	-	49
Microbiological								
Escherichia coli	CFU/100mL	150	150	150	150	-	400	150

Table B.35 Surface Water Analytical Data - HDW8713

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	12-Sep-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.0014	0.0014	0.0014	0.0014	-	-	0.0014	-
Phosphorus	mg/L	0.071	0.155	0.156	0.24	-	-	0.071	0.24
TSS	mg/L	24	52	52	80	-	-	24	80
Microbiological									
Escherichia coli	CFU/100mL	310	595	595	880	-	400	310	880

Table B.36 Surface Water Analytical Data - HDW8910

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results
		Minimum	Median	Mean	Maximum			
							Date Sampled:	26-Sep-18
Parameter								
Inorganics								
Ortho Phosphate (as P)	mg/L	0.056	0.056	0.056	0.056	-	-	0.056
Phosphorus	mg/L	0.091	0.091	0.091	0.091	-	-	0.091
TSS	mg/L	7.2	7.2	7.2	7.2	-	-	7.2
Microbiological								
Escherichia coli	CFU/100mL	1700	1700	1700	1700	-	400	1700

Table B.37 Surface Water Analytical Data - OUTFALL 2

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results
		Minimum	Median	Mean	Maximum			
							Date Sampled:	26-Sep-18
Parameter								
Inorganics								
Ortho Phosphate (as P)	mg/L	0.0026	0.0026	0.0026	0.0026	-	-	0.0026
Phosphorus	mg/L	0.011	0.011	0.011	0.011	-	-	0.011
TSS	mg/L	8.2	8.2	8.2	8.2	-	-	8.2
Microbiological								
Escherichia coli	CFU/100mL	10	10	10	10	-	400	10

Table B.38 Surface Water Analytical Data - OUTFALL 4

Parameter	Units	Statistics				CCME FAL	GCRWQ	Results	
		Minimum	Median	Mean	Maximum				
							Date Sampled:	14-Aug-18	26-Sep-18
Parameter									
Inorganics									
Ortho Phosphate (as P)	mg/L	0.013	0.013	0.013	0.013	-	-	-	0.013
Low Level Orthophosphate	mg/L	0.016	0.016	0.016	0.016	-	-	0.016	-
Phosphorus	mg/L	0.053	0.0635	0.0635	0.074	-	-	0.074	0.053
TSS	mg/L	17	22.5	22.5	28	-	-	17	28
Microbiological									
Escherichia coli	CFU/100mL	410	855	855	1300	-	400	1300	410

B.5 – Microbial Source Tracking

Sample Date: June 27 2018

	Human marker result		Avian (bird) marker result		Dog marker result		Ruminant marker result (updated)	
Sample name	Log copies/100 mL water	Average (Log copies/100 mL)	Log copies/100 mL water	Average (Log copies/100 mL)	Log copies/100 mL water	Average (Log copies/100 mL)	Log copies/100 mL water	Average (Log copies/100 mL)
Banook 1	<1.1	<1.1	1.71	1.81	<1.1	<1.1	-	-
Banook 1	<1.1		1.91		<1.1		-	
Banook2	<1.1	<1.1	2.25	2.28	<1.1	<1.1	-	-
Banook2	<1.1		2.32		<1.1		-	
Micmac 1	<1.1	<1.1	2.49	2.40	<1.1	<1.1	-	-
Micmac1	<1.1		2.31		<1.1		-	
Waterfowl1	<1.1	<1.1	2.19	2.26	<1.1	<1.1	-	-
Waterfowl1	<1.1		2.34		<1.1		-	
Outfall8	4.62	4.56	2.45	2.45	<1.1	<1.1	-	-
Outfall8	4.51		2.45		<1.1		-	
Nearshore 2	<1.1	<1.1	1.89	1.89	<1.1	<1.1	-	-
Nearshore 2	<1.1		1.88		<1.1		-	
Nearshore 3	<1.1	<1.1	2.08	1.91	2.51	2.50	-	-
Nearshore 3	<1.1		1.74		2.48		-	
Nearwater 11	<1.1	<1.1	1.97	1.69	<1.1	<1.1	-	-
Nearwater 11	<1.1		1.40		<1.1		-	
Watercourse1	<1.1	<1.1	1.65	1.43	<1.1	<1.1	-	-
Watercourse1	<1.1		1.21		<1.1		-	
Watercourse2	<1.1	<1.1	2.06	2.04	<1.1	<1.1	1.59	1.59
Watercourse2	<1.1		2.03		<1.1		1.59	
Watercourse3	<1.1	<1.1	2.12	2.19	<1.1	<1.1	-	-
Watercourse3	<1.1		2.27		<1.1		-	
Watercourse4	<1.1	<1.1	2.41	2.27	<1.1	<1.1	<1.1	<1.1
Watercourse4	<1.1		2.14		<1.1		<1.1	
Watercourse5	<1.1	<1.1	2.61	2.65	<1.1	<1.1	1.72	1.67
Watercourse5	<1.1		2.68		<1.1		1.62	
Watercourse6	<1.1	<1.1	2.57	2.68	<1.1	<1.1	-	-
Watercourse6	<1.1		2.79		<1.1		-	

Sample Date: July 19 2018

	Human marker result		Avian (bird) marker result		Dog marker result		Ruminant marker result (updated)	
Sample name	Log copies/100 mL water	Average (Log copies/100 mL)	Log copies/100 mL water	Average (Log copies/100 mL)	Log copies/100 mL water	Average (Log copies/100 mL)	Log copies/100 mL water	Average (Log copies/100 mL)
Banook1	<1.1	<1.1	1.80	1.70	<1.1	<1.1	-	-
Banook1	<1.1		1.61		<1.1		-	
Banook2	<1.1	<1.1	1.78	1.84	<1.1	<1.1	-	-
Banook2	<1.1		1.89		<1.1		-	
Waterfowl1	<1.1	<1.1	1.16	1.37	<1.1	<1.1	-	-
Waterfowl1	<1.1		1.58		<1.1		-	
Duplicate1	<1.1	<1.1	0.92	0.99	<1.1	<1.1	-	-
Duplicate1	<1.1		1.07		<1.1		-	
Duplicate2	<1.1	<1.1	2.19	2.15	<1.1	<1.1	-	-
Duplicate2	<1.1		2.11		<1.1		-	
Watercourse1	<1.1	<1.1	1.61	1.54	2.42	2.52	-	-
Watercourse1	<1.1		1.48		2.62		-	
Watercourse2	<1.1	<1.1	2.91	2.87	3.31	3.33	4.82	4.91
Watercourse2	<1.1		2.83		3.35		5.01	
Watercourse3	<1.1	<1.1	1.88	2.04	<1.1	<1.1	-	-
Watercourse3	<1.1		2.20		<1.1		-	
Watercourse4	<1.1	<1.1	2.23	2.24	<1.1	<1.1	<1.1	<1.1
Watercourse4	<1.1		2.25		<1.1		<1.1	
Watercourse5	<1.1	<1.1	1.45	1.74	<1.1	<1.1	4.58	4.58
Watercourse5	<1.1		2.04		<1.1		4.58	
Watercourse6	2.35	2.35	2.89	2.85	3.10	3.34	-	-
Watercourse6	2.35		2.80		3.59		-	
MicMac1	<1.1	<1.1	1.16	1.27	<1.1	<1.1	-	-
MicMac1	<1.1		1.39		<1.1		-	
MicMac2	<1.1	<1.1	1.66	1.72	<1.1	<1.1	-	-
MicMac2	<1.1		1.78		<1.1		-	
Nearshore1	<1.1	<1.1	1.95	1.80	3.09	3.05	-	-
Nearshore1	<1.1		1.66		3.02		-	
Nearshore2	<1.1	<1.1	1.84	1.72	<1.1	<1.1	-	-
Nearshore2	<1.1		1.59		<1.1		-	
Nearshore3	<1.1	<1.1	1.92	1.82	4.41	4.92	-	-
Nearshore3	<1.1		1.73		5.43		-	
Outfall7	2.47	2.47	2.66	2.65	<1.1	<1.1	-	-
Outfall7	2.47		2.63		<1.1		-	
Outfall8	4.28	4.28	2.16	2.53	<1.1	<1.1	-	-
Outfall8	4.28		2.91		<1.1		-	

Sample Date: August 14 2018

	Human marker result		Avian (bird) marker result		Dog marker result		Ruminant marker result	
Sample name	Log copies/100 mL water	Average (Log copies/100 mL)	Log copies/100 mL water	Average (Log copies/100 mL)	Log copies/100 mL water	Average (Log copies/100 mL)	Log copies/100 mL water	Average (Log copies/100 mL)
Banook 1	<1.1	<1.1	1.22	1.28	<1.1	<1.1	-	-
Banook 1	<1.1		1.33		<1.1		-	
Micmac 1	<1.1	<1.1	1.83	1.72	<1.1	<1.1	-	-
Micmac1	<1.1		1.62		<1.1		-	
Watercourse1	<1.1	<1.1	2.27	2.24	<1.1	<1.1	-	-
Watercourse1	<1.1		2.22		<1.1		-	
Watercourse2	<1.1	<1.1	2.28	2.30	<1.1	<1.1	5.22	5.47
Watercourse2	<1.1		2.32		<1.1		5.72	
Watercourse3	<1.1	<1.1	1.63	1.67	<1.1	<1.1	-	-
Watercourse3	<1.1		1.71		<1.1		-	
Watercourse4	<1.1	<1.1	1.25	1.43	<1.1	<1.1	<1.1	<1.1
Watercourse4	<1.1		1.61		<1.1		<1.1	
Watercourse5	<1.1	<1.1	1.95	1.94	<1.1	<1.1	5.20	5.24
Watercourse5	<1.1		1.93		<1.1		5.29	
Watercourse6	<1.1	<1.1	3.11	3.10	<1.1	<1.1	-	-
Watercourse6	<1.1		3.10		<1.1		-	
Nearshore1	<1.1	<1.1	2.04	1.94	<1.1	<1.1	-	-
Nearshore1	<1.1		1.84		<1.1		-	
Nearshore2	<1.1	<1.1	1.78	1.67	<1.1	<1.1	-	-
Nearshore2	<1.1		1.56		<1.1		-	
Nearshore3	<1.1	<1.1	2.00	1.94	3.68	3.77	-	-
Nearshore3	<1.1		1.88		3.86		-	
Waterfowl1	<1.1	<1.1	1.72	1.61	<1.1	<1.1	-	-
Waterfowl1	<1.1		1.51		<1.1		-	
Outfall8	4.01	4.05	1.96	1.91	<1.1	<1.1	-	-
Outfall8	4.10		1.85		<1.1		-	
Outfall8b	3.72	3.75	1.80	1.72	<1.1	<1.1	-	-
Outfall8b	3.79		1.64		<1.1		-	

Sample Date: September 12 2018

	Human marker result		Avian (bird) marker result		Dog marker result		Ruminant marker result	
Sample name	**Log copies/100 mL water**	**Average (Log copies/100 mL)**	**Log copies/100 mL water**	**Average (Log copies/100 mL)**	**Log copies/100 mL water**	**Average (Log copies/100 mL)**	**Log copies/100 mL water**	**Average (Log copies/100 mL)**
Waterfowl1	<1.1	<1.1	2.71	2.71	<1.1	<1.1	-	-
Waterfowl1	<1.1		2.71		<1.1		-	
Banook1	<1.1	<1.1	2.34	2.34	<1.1	<1.1	-	-
Banook1	<1.1		2.34		<1.1		-	
Nearshore 3	<1.1	<1.1	2.70	2.63	2.23	2.23	-	-
Nearshore 3	<1.1		2.56		2.23		-	
Watercourse 4	<1.1	<1.1	2.92	2.97	<1.1	<1.1	6.38	6.38
Watercourse 4	<1.1		3.02		<1.1		6.38	
Watercourse 5	<1.1	<1.1	2.56	2.57	<1.1	<1.1	6.78	5.90
Watercourse 5	<1.1		2.59		<1.1		5.02	
Watercourse 1	2.62	2.61	2.38	2.42	<1.1	<1.1	-	-
Watercourse 1	2.59		2.45		<1.1		-	
Watercourse 6	<1.1	<1.1	3.25	3.26	<1.1	<1.1	-	-
Watercourse 6	<1.1		3.28		<1.1		-	
Watercourse 2	<1.1	<1.1	3.62	3.58	2.68	2.68	6.82	6.93
Watercourse 2	<1.1		3.55		2.68		7.04	
Nearshore 2	<1.1	<1.1	3.28	3.25	<1.1	<1.1	-	-
Nearshore 2	<1.1		3.22		<1.1		-	
Micmac 1	<1.1	<1.1	2.80	2.76	<1.1	<1.1	-	-
Micmac 1	<1.1		2.72		<1.1		-	
Outfall 8b	4.63	3.70	2.64	2.67	<1.1	<1.1	-	-
Outfall 8b	2.77		2.70		<1.1		-	
Outfall 8	3.48	3.23	2.61	2.63	<1.1	<1.1	-	-
Outfall 8	2.97		2.65		<1.1		-	
HDW 8991	2.69	2.45	2.72	2.71	<1.1	<1.1	-	-
HDW 8991	2.22		2.70		<1.1		-	
Nearshore 1	2.96	3.38	2.67	2.74	2.42	2.42	-	-
Nearshore 1	3.80		2.80		2.42		-	

Sample Date: September 26 2018

	Human marker result		Avian (bird) marker result		Dog marker result		Ruminant marker result	
Sample name	**Log copies/100 mL water**	**Average (Log copies/100 mL)**	**Log copies/100 mL water**	**Average (Log copies/100 mL)**	**Log copies/100 mL water**	**Average (Log copies/100 mL)**	**Log copies/100 mL water**	**Average (Log copies/100 mL)**
Watercourse 5	<1.1	<1.1	1.98	1.95	<1.1	<1.1	<1.1	<1.1
Watercourse 5	<1.1		1.92		<1.1		<1.1	
Micmac 2	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	-	-
Micmac 2	<1.1		<1.1		<1.1		-	
Lake Banook 1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	-	-
Lake Banook 1	<1.1		<1.1		<1.1		-	
Watercourse 3	<1.1	<1.1	<1.1	<1.1	2.42	2.33	-	-
Watercourse 3	<1.1		<1.1		2.23		-	
Nearshore 3	<1.1	<1.1	<1.1	<1.1	3.61	3.25	-	-
Nearshore 3	<1.1		<1.1		2.90		-	
Nearshore 1	2.2	2.2	3.18	3.19	<1.1	<1.1	-	-
Nearshore 1	2.2		3.20		<1.1		-	
Watercourse 4	<1.1	<1.1	1.92	1.93	4.61	3.58	<1.1	<1.1
Watercourse 4	<1.1		1.94		2.54		<1.1	
Micmac 1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	-	-
Micmac 1	<1.1		<1.1		<1.1		-	
Nearshore 1 DUP	2.13	2.13	2.85	2.86	<1.1	<1.1	-	-
Nearshore 1 DUP	2.13		2.87		<1.1		-	
Nearshore 2	3.09	3.09	1.63	1.55	<1.1	<1.1	-	-
Nearshore 2	3.09		1.47		<1.1		-	
Waterfowl 1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	-	-
Waterfowl 1	<1.1		<1.1		<1.1		-	
Watercourse 6	4.81	4.81	1.21	1.27	<1.1	<1.1	-	-
Watercourse 6	4.81		1.32		<1.1		-	
Watercourse 2	5.53	5.53	<1.1	<1.1	4.37	4.34	<1.1	<1.1
Watercourse 2	5.53		<1.1		4.31		<1.1	
Watercourse 1	6.33	6.33	<1.1	<1.1	2.74	2.89	-	-
Watercourse 1	6.33		<1.1		3.04		-	
Outfall 8	6.12	6.12	2.29	2.19	3.16	3.13	-	-
Outfall 8	6.12		2.10		3.11		-	
Outfall 8b	6.12	6.12	2.21	2.15	2.77	2.75	-	-
Outfall 8b	6.12		2.08		2.73		-	

APPENDIX D

Modelling Outputs

D.1 – Rain-Event Based Model

Precipitation Event-based Model - Phosphorous - Lake Banook Watershed

Lake Banook Watershed Land Use	Area (m^2)	Area (ha)	CN	RC	Dstor (mm)	Runoff Volume (m3)	P EMC (mg/L)	P Loading (kg)	Land Use Percentage	P Load Percentage
Commercial	164,510.00	16.45	92	0.89	1.5	3,413.58	0.3	1.024	12.14%	12.44%
Forest/Park	217,959.22	21.80	65	0.14	1.5	435.92	0.15	0.065	1.55%	0.79%
Grass	15,298.06	1.53	61	0.24	1.5	68.84	0.56	0.039	0.24%	0.47%
High Density Residential	8,526.35	0.85	85	0.39	1.5	70.34	0.22	0.015	0.25%	0.19%
Medium-Density Residential	467,344.85	46.73	72	0.35	1.5	3,388.25	0.36	1.220	12.05%	14.81%
Low-Density Residential	596,821.72	59.68	68	0.28	1.5	3,282.52	0.45	1.477	11.68%	17.94%
Road	345,733.00	34.57	98	0.82	0	7,087.53	0.62	4.394	25.21%	53.36%
Water	418,644.79	41.86	99	0.99	0	10,361.46	-	-	36.86%	-
Total	2,234,838.00	223.48	-	-	-	28,108.44	-	8.235	100.00%	100.00%

Weighted CN= **80.78**

Percent Impervious= **52.32%**

25mm Chicago Storm Runoff Vol= **28824** m^3

Direct Lake Rainfall= **10466.12** m^3

Overland Runoff= **18357.88** m^3

% Diff.= **-2.55%**

Precipitation Event-based Model - Phosphorous - Lake Micmac Watershed

Lake Micmac Watershed Land Use	Area (m^2)	Area (ha)	CN	RC	Dstor (mm)	Runoff Volume (m3)	P EMC (mg/L)	P Loading (kg)	Land Use Percentage	P Load Percentage
Commercial	2,406,303.63	240.63	92	0.89	1.5	49,930.80	0.3	14.979	47.21%	48.13%
Forest/Park	888,304.00	88.83	65	0.14	1.5	1,776.61	0.15	0.266	1.68%	0.86%
Grass	51,314.55	5.13	61	0.24	1.5	230.92	0.56	0.129	0.22%	0.42%
High Density Residential	25,300.22	2.53	85	0.39	1.5	208.73	0.22	0.046	0.20%	0.15%
Medium-Density Residential	245,579.69	24.56	72	0.35	1.5	1,780.45	0.36	0.641	1.68%	2.06%
Low-Density Residential	656,957.27	65.70	68	0.28	1.5	3,613.26	0.45	1.626	3.42%	5.22%
Partial cut forest	483,028.42	48.30	66	0.28	1.5	2,656.66	0.683	1.814	2.51%	5.83%
Road	905,675.17	90.57	98	0.82	0	18,566.34	0.62	11.511	17.55%	36.98%
Water	1,046,036.06	104.60	99	0.99	0	25,889.39	-	-	24.48%	-
Wetland	45,096.47	4.51	99	0.99	0	1,116.14	0.1	0.112	1.06%	0.36%
Total	**6,753,595.50**	**675.36**	**-**	**-**	**-**	**105,769.30**	**-**	**31.125**	**100.00%**	**100.00%**

Weighted CN= **85.108285**

Percent Impervious= **62.46%**

25mm Chicago Storm Runoff Vol= **104423** m^3

Direct Lake Rainfall= **26150.902** m^3

Overland Runoff= **78272.098** m^3

% Diff.= **1.27%**

Precipitation Event-based Model - Phosphorous - Outfall 8 Sub-watershed

Outfall 8 Watershed Land Use	Area (m^2)	Area (ha)	CN	RC	Dstor (mm)	Runoff Volume (m3)	P EMC (mg/L)	P Loading (kg)	Land Use Percentage	P Load Percentage
Commercial	90,703.06	9.07	92	0.89	1.5	1,882.09	0.3	0.565	37.31%	27.70%
Forest/Park	61,954.60	6.20	65	0.14	1.5	123.91	0.15	0.019	2.46%	0.91%
Medium-Density Residential	177,492.19	17.75	72	0.35	1.5	1,286.82	0.36	0.463	25.51%	22.73%
Low-Density Residential	100,687.46	10.07	68	0.28	1.5	553.78	0.45	0.249	10.98%	12.23%
Road	58,406.54	5.84	98	0.82	0	1,197.33	0.62	0.742	23.74%	36.42%
Water	0.00	0.00	99	0.99	0	0.00	0	0.000	0.00%	0.00%
Total	**489,243.85**	**48.92**	**-**	**-**	**-**	**5,043.93**	**-**	**2.038**	**100.00%**	**100.00%**

Weighted CN= **77.102157**

Percent Impervious= **42.70%**

25mm Chicago Storm Runoff Vol= **5074** **m^3**

Direct Lake Rainfall= **0**

Overland Runoff= **5074**

% Diff.= **-0.60%**

Precipitation Event-based Model - Fecal Coliform - Lake Banook Watershed

Lake Banook Watershed Land Use	Area (m^2)	Area (ha)	CN	RC	Dstor (mm)	Runoff Volume (m3)	FC EMC (CFU/100 mL)	FC Loading (CFU)	Land Use Percentage	FC Load Percentage
Commercial	164,510.00	16.45	92	0.89	1.5	3,413.58	4500	1.54E+11	7.36%	19.58%
Forest/Park	217,959.22	21.80	65	0.14	1.5	435.92	500	2.18E+09	9.75%	0.28%
Grass	15,298.06	1.53	61	0.24	1.5	68.84	10365	7.14E+09	0.68%	0.91%
High Density Residential	8,526.35	0.85	85	0.39	1.5	70.34	7750	5.45E+09	0.38%	0.69%
Medium-Density Residential	467,344.85	46.73	72	0.35	1.5	3,388.25	7750	2.63E+11	20.91%	33.47%
Low-Density Residential	596,821.72	59.68	68	0.28	1.5	3,282.52	7750	2.54E+11	26.71%	32.42%
Road	345,733.00	34.57	98	0.82	0	7,087.53	1400	9.92E+10	15.47%	12.65%
Water	418,644.79	41.86	99	0.99	0	10,361.46	0	0.00E+00	18.73%	0.00%
Total	2,234,838.00	223.48	-	-	-	28,108.44	-	7.85E+11	100.00%	100.00%

Weighted CN= **80.78**

Percent Impervious= **52.32%** | **Direct Lake Rainfall=** **10466.12** m^3 | **% Diff.=** **-2.55%**

25mm Chicago Storm Runoff Vol= **28824** m^3 | **Overland Runoff=** **18357.88** m^3

Precipitation Event-based Model - Fecal Coliform - Lake Micmac Watershed

Lake Micmac Watershed Land Use	Area (m^2)	Area (ha)	CN	RC	Dstor (mm)	Runoff Volume (m3)	FC EMC (CFU/100 mL)	FC Loading (CFU)	Land Use Percentage	FC Load Percentage
Commercial	2,406,303.63	240.63	92	0.89	1.5	49,930.80	4500	2.25E+12	35.63%	75.08%
Forest/Park	888,304.00	88.83	65	0.14	1.5	1,776.61	500	8.88E+09	13.15%	0.30%
Grass	51,314.55	5.13	61	0.24	1.5	230.92	10365	2.39E+10	0.76%	0.80%
High Density Residential	25,300.22	2.53	85	0.39	1.5	208.73	7750	1.62E+10	0.37%	0.54%
Medium-Density Residential	245,579.69	24.56	72	0.35	1.5	1,780.45	7750	1.38E+11	3.64%	4.61%
Low-Density Residential	656,957.27	65.70	68	0.28	1.5	3,613.26	7750	2.80E+11	9.73%	9.36%
Partial cut forest	483,028.42	48.30	66	0.28	1.5	2,656.66	500	1.33E+10	7.15%	0.44%
Road	905,675.17	90.57	98	0.82	0	18,566.34	1400	2.60E+11	13.41%	8.69%
Water	1,046,036.06	104.60	99	0.99	0	25,889.39	-	-	15.49%	-
Wetland	45,096.47	4.51	99	0.99	0	1,116.14	500	5.58E+09	0.67%	0.19%
	6,753,595.50	675.36	-	-	-	105,769.30		2.99E+12	100.00%	100.00%

Weighted CN= **85.11**

Percent Impervious= **62.46%** | **Direct Lake Rainfall=** **26150.90** m^3 | **% Diff.=** **1.27%**

25mm Chicago Storm Runoff Vol= **104423** m^3 | **Overland Runoff=** **78272.10** m^3

Precipitation Event-based Model - Fecal Coliform - Outfall 8 Sub-watershed

Outfall 8 Sub-watershed Land Use	Area (m^2)	Area (ha)	CN	RC	Dstor (mm)	Runoff Volume (m3)	FC EMC (CFU/100 mL)	FC Loading (CFU)	Land Use Percentage	FC Load Percentage
Commercial	90,703.06	9.07	92	0.89	1.5	1,882.09	4500	8.47E+10	18.54%	34.61%
Forest/Park	61,954.60	6.20	65	0.14	1.5	123.91	500	6.20E+08	12.66%	0.25%
Medium-Density Residential	177,492.19	17.75	72	0.35	1.5	1,286.82	7750	9.97E+10	36.28%	40.75%
Low-Density Residential	100,687.46	10.07	68	0.28	1.5	553.78	7750	4.29E+10	20.58%	17.54%
Road	58,406.54	5.84	98	0.82	0	1,197.33	1400	1.68E+10	11.94%	6.85%
Water	83,242.70	0.00	99	0.99	0	2,060.26	0	0.00E+00	0.00%	0.00%
	572,486.54	48.92	-	-	-	7,104.19	-	2.45E+11	100.00%	100.00%

Weighted CN= **80.29**

Percent Impervious= **51.03%** | **Direct Lake Rainfall=** **2081.07** | **% Diff.=** **28.58%**

25mm Chicago Storm Runoff Vol= **5074** m^3 | **Overland Runoff=** **2992.93**

D.2 – Annual Loading Model

Annual Loading Model - Phosphorous - Lake Banook Watershed

Lake Banook Watershed Land Use	Area (m)	Area (ha)	P Loading Rate (gm/m^2 yr)	Annual P Loading (kg/year)	Land Use Percentage	P Load Percentage
Commercial	164510.00	16.5	0.202	33.23	7.36%	18.04%
Field within low density residential	57.81	0.01	0.015	0.0009	0.00%	0.00%
Forest/Park	217959.22	21.8	0.0024	0.52	9.75%	0.28%
Grass	15298.06	1.5	0.015	0.23	0.68%	0.12%
High Density Residential	8526.35	0.9	0.035	0.30	0.38%	0.16%
Low-Density Residential	596821.72	59.7	0.025	14.92	26.70%	8.10%
Medium-Density Residential	467344.85	46.7	0.03	14.02	20.91%	7.61%
Road	345733.00	34.6	0.35	121.01	15.47%	65.68%
Water	418644.79	41.86	0	0.00	18.73%	0.00%
Total	**2234895.81**	**223.5**	-	**184.23**	**100.00%**	**100.00%**
			Anthropogenic Sources	**183.48**	**99.6%**	

Annual Loading Model - Phosphorous - Lake Banook Watershed

Lake Micmac Watershed Land Use	Area (m)	Area (ha)	P Loading Rate (gm/m^2 yr)	Annual P Loading (kg/year)	Land Use Percentage	P Load Percentage
Commercial	2406303.63	240.6	0.202	486.07	35.63%	57.51%
Forest/Park	888304.00	88.83	0.0024	2.1319	13.15%	0.25%
Grass	51314.55	5.1	0.015	0.77	0.76%	0.09%
High Density Residential	25300.22	2.5	0.035	0.89	0.37%	0.10%
Low-Density Residential	656957.27	65.7	0.025	16.42	9.73%	1.94%
Medium-Density Residential	245579.69	24.6	0.03	7.37	3.64%	0.87%
Partial cut forest	483028.42	48.3	0.03	14.49	7.15%	1.71%
Road	905675.17	90.6	0.35	316.99	13.41%	37.50%
Water	1046036.06	104.60	0	0.00	15.49%	0.00%
Wetland	45096.47	4.51	0.0024	0.11	0.67%	0.01%
Total	**6753595.50**	**675.4**	-	**845.24**	**100.00%**	**100.00%**
			Anthropogenic Sources	**827.74**	**97.9%**	

Annual Loading Model - Phosphorous - Lake Banook Watershed

Outfall 8 Subwatershed Land Use	Area (m)	Area (ha)	P Loading Rate (gm/m2 yr)	Annual P Loading (kg/year)	Land Use Percentage	P Load Percentage
Commercial	90703.06	9.1	0.202	18.32	18.54%	39.09%
Forest/Park	61954.60	6.20	0.0024	0.1487	12.66%	0.32%
Low-Density Residential	100687.46	10.1	0.035	3.52	20.58%	7.52%
Medium-Density Residential	177492.19	17.7	0.025	4.44	36.28%	9.47%
Road	58406.54	5.8	0.35	20.44	11.94%	43.61%
Total	**489243.85**	**48.9**	-	**46.87**	**100.00%**	**100.00%**
			Anthropogenic Sources	**46.73**	**99.7%**	

Annual Loading Model - Fecal Coliform - Lake Banook Watershed

Land Use Breakdown Banook Drainage Area	Area (m^2)	Area (ha)	RC	Runoff (m^3)	Land Use Percentage	Annual Loading (CFU/year)	Annual Area Loading (CFU/ha/year)	FC Load Percentage
Commercial	164510.00	16.45	0.88	182582.41	7.36%	8.22E+12	4.99E+11	19.64%
Forest/Park	217959.22	21.80	0.11	30237.92	9.75%	1.51E+11	6.94E+09	0.36%
Grass	15298.06	1.53	0.26	5016.42	0.68%	5.20E+11	3.40E+11	1.24%
High Density Residential	8526.35	0.85	0.37	3978.77	0.38%	3.08E+11	3.62E+11	0.74%
Low-Density Residential	596821.72	59.68	0.29	218286.35	26.71%	1.69E+13	2.83E+11	40.44%
Medium-Density Residential	467344.85	46.73	0.32	188612.90	20.91%	1.46E+13	3.13E+11	34.95%
Road	345733.00	34.57	0.18	78486.92	15.47%	1.10E+12	3.18E+10	2.63%
Water	418644.79	41.86	0.99	522714.86	18.73%	-	-	-
Total	**2234838.00**	**223.48**	**-**	**1229916.56**	**100.00%**	**4.18E+13**	**-**	**100.00%**

Annual Loading Model - Fecal Coliform - Lake Micmac Watershed

Land Use Breakdown MicMac Drainage Area	Area (m^2)	Area (ha)	RC	Runoff (m^3)	Land Use Percentage	Annual Loading (CFU/year)	Annual Area Loading (CFU/ha/year)	FC Load Percentage
Commercial	2406303.63	240.63	0.88	2670650.53	35.63%	1.20E+14	4.99E+11	72.22%
Forest/Park	888304.00	88.83	0.11	123236.19	13.15%	6.16E+11	6.94E+09	0.37%
Grass	51314.55	5.13	0.26	16826.66	0.76%	1.74E+12	3.40E+11	1.05%
High Density Residential	25300.22	2.53	0.37	11806.20	0.37%	9.15E+11	3.62E+11	0.55%
Low-Density Residential	656957.27	65.70	0.29	240280.81	9.73%	1.86E+13	2.83E+11	11.19%
Medium-Density Residential	245579.69	24.56	0.32	99112.03	3.64%	7.68E+12	3.13E+11	4.62%
Partial cut forest	483028.42	48.30	0.18	109655.18	7.15%	5.48E+11	1.14E+10	-
Road	905675.17	90.57	0.99	1130815.15	13.41%	1.58E+13	1.75E+11	9.51%
Water	1046036.06	104.60	-	-	15.49%	-	-	-
Wetland	45096.47	4.51	0.99	56306.91	0.67%	2.82E+11	6.24E+10	0.17%
Total	**6753595.50**	**675.36**	**-**	**4458689.66**	**100.00%**	**1.66E+14**	**-**	**99.67%**

Annual Loading Model - Fecal Coliform - Outfall 8 Sub-watershed

Land Use Breakdown Outfall 8 Drainage Area	Area (m^2)	Area (ha)	RC	Runoff (m^3)	Land Use Percentage	Annual Loading (CFU/year)	Annual Area Loading (CFU/ha/year)	FC Load Percentage
Commercial	90703.06	9.07	0.88	100667.33	18.54%	4.53E+12	4.99E+11	32.36%
Forest/Park	61954.60	6.20	0.11	8595.09	12.66%	4.30E+10	6.94E+09	0.31%
Low-Density Residential	100687.46	10.07	0.29	36826.24	20.58%	2.85E+12	2.83E+11	20.39%
Medium-Density Residential	177492.19	17.75	0.32	71633.01	36.28%	5.55E+12	3.13E+11	39.66%
Road	58406.54	5.84	0.99	72925.70	11.94%	1.02E+12	1.75E+11	7.29%
Water	0.98	0.00			0.00%	-	-	-
Total	**489244.82**	**48.92**	**-**	**290647.36**	**100.00%**	**1.40E+13**	2.86E+11	**100.00%**

D.3 – Lake System P Model

Lake Banook

Input Parameters	Symbol	Value	Units
Morphology			
Drainage Basin Area (Excl. of Lake Area)	Ad	181.7	ha
Area Land Use Category 1 (Commercial)	Ad1	16.5	ha
Area Land Use Category 2 (Forest/Park)	Ad2	21.8	ha
Area Land Use Category 3 (Grass)	Ad3	1.5	ha
Area Land Use Category 4 (HDR)	Ad4	0.9	ha
Area Land Use Category 5 (LDR)	Ad5	59.7	ha
Area Land Use Category 6 (MDR)	Ad6	46.7	ha
Area Land Use Category 7 (Road)	Ad7	34.6	ha
Area Land Use Category 8	Ad8	0.0	ha
Area Land Use Category 9	Ad9	0.0	ha
Area Land Use Category 10	Ad10	0.0	ha
Lake Surface Area	Ao	40.8	ha
Lake Volume	V	1.6522	10^6 m^3
Hydrology			
Upstream Hydraulic Inputs	Qi	20,317,872.08	m^3 yr^{-1}
Annual Unit Precipitation	Pr	1.261	m yr^{-1}
Annual Unit Lake Evaporation	Ev	0.513	m yr^{-1}
Point Source Hydraulic Input	Qps	0.000	m^3 yr^{-1}
Annual Unit Hydraulic Runoff - Developed	Ruv	1.100	m yr^{-1}
Annual Unit Hydraulic Runoff - Non-Developed	Ruu	1.020	m yr^{-1}
P Loading			
Upstream P Input	Pi	1,067,582.00	gm P yr^{-1}
Annual Unit Atmospheric P Deposition	Da	0.017	gm P m^{-2} yr^{-1}
Land Use Category 1 P Export Coefficient	E1	0.202	gm P m^{-2} yr^{-1}
Land Use Category 2 P Export Coefficient	E2	0.002	gm P m^{-2} yr^{-1}
Land Use Category 3 P Export Coefficient	E3	0.015	gm P m^{-2} yr^{-1}
Land Use Category 4 P Export Coefficient	E4	0.035	gm P m^{-2} yr^{-1}
Land Use Category 5 P Export Coefficient	E5	0.025	gm P m^{-2} yr^{-1}
Land Use Category 6 P Export Coefficient	E6	0.030	gm P m^{-2} yr^{-1}
Land Use Category 7 P Export Coefficient	E7	0.350	gm P m^{-2} yr^{-1}
Land Use Category 8 P Export Coefficient	E8	0.000	gm P m^{-2} yr^{-1}
Land Use Category 9 P Export Coefficient	E9	0.000	gm P m^{-2} yr^{-1}
Land Use Category 10 P Export Coefficient	E10	0.000	gm P m^{-2} yr^{-1}
Number of Dwellings	N_d	0	#
Average number of Persons per Dwelling	N_u	2.90	n/a
Average Fraction of Year Dwellings Occupied	N_{pc}	1	yr^{-1}
Phosphorus Load per Capita per Year	Sl	800	gm P cap^{-1} yr^{-1}
Septic System Retention Coefficient	Rsp	0.5	n/a
Point Source Input 1	PS1	0	
Point Source Input 2	PS2	0	
Point Source Input 3	PS3	0	
Point Source Input 4	PS4	0	
Point Source Input 5	PS5	0	
Phosphorus Retention Coefficient	v	12.4	n/a
Model Outputs			
Total Precipitation Hydraulic Input	Ppt_i	514,569.60	m^3 yr^{-1}
Total Evaporation Hydraulic Loss	Eo	209,100.00	m^3 yr^{-1}
Total Hydraulic Surface Run Off	Ql	1,930,200.20	m^3 yr^{-1}
Total Hydraulic Input	Qt	22,762,641.88	m^3 yr^{-1}
Areal Hydraulic Load	q_s	55.28	m yr^{-1}
Total Hydraulic Outflow	Qo	22,553,541.88	m^3 yr^{-1}
Upstream P Input	Ju	1,067,582.00	gm yr^{-1}
Total Atmospheric P Input	Jd	7,058.40	gm yr^{-1}
Total Overland Run Off P Input	Je	184,332.00	gm yr^{-1}
Total Development P Input	Jd	0.00	gm yr^{-1}
Total P Input	Jt	1,258,972.00	gm yr^{-1}
Lake P Retention Factor	Rp	0.18	n/a
Lake Phosphorus Retention	Ps	226,615.00	gm yr^{-1}
Predicted Lake Phosphorus Concentration	[P]	**0.046**	mg L^{-1}
Lake Phosphorus Outflow	Jo	1,032,357.00	gm yr^{-1}
Lake Mean Depth	z	4.00	m
Lake Turnover Time	TT	0.07	yr
Lake Flushing Rate	FR	13.65	times yr^{-1}
Lake Response Time	RT	0.04	yr

Budgets

Hydraulic Budget (m^{-3})

		% Total
Upstream Inflow	20317872.1	89.26
Precipitation	514569.6	2.26
Surface Run Off	1930200.2	8.48
Evaporation	-209100	0.92
Point Sources	0.000	
Total Outflow	22553541.9	99.08
Total Check		100.00

Phosphorus Budget (gm yr^{-1})

		% Total
Upstream Inflow	1067582	84.8
Atmosphere	7058	0.56
Land Run Off	184332	14.64
Development	0	0.00
Sedimentation	-226615	18.00
Total Outflow	1032357	82.00
Total Check		100.00

Model Validation

Predicted P (mg L^{-1})	0.0458
Measured P (mg L^{-1})	0.0060
% Difference	**663%**

Lake Micmac

Input Parameters	Symbol	Value	Units
Morphology			
Drainage Basin Area (Excl. of Lake Area)	Ad	570.8	ha
Area Land Use Category 1 (Commercial)	Ad1	240.6	ha
Area Land Use Category 2 (Forest/Park)	Ad2	88.8	ha
Area Land Use Category 3 (Grassed)	Ad3	5.1	ha
Area Land Use Category 4 (HDR)	Ad4	2.5	ha
Area Land Use Category 5 (LDR)	Ad5	65.7	ha
Area Land Use Category 6 (MDR)	Ad6	24.6	ha
Area Land Use Category 7 (Partially-Cleared)	Ad7	48.3	ha
Area Land Use Category 8 (Road)	Ad8	90.6	ha
Area Land Use Category 9 (Wetland)	Ad9	4.5	ha
Area Land Use Category 10	Ad10	0.0	ha
Lake Surface Area	Ao	103.5	ha
Lake Volume	V	3.4890	10^6 m^3
Hydrology			
Upstream Hydraulic Inputs	Qi	14593923	m^3 yr^{-1}
Annual Unit Precipitation	Pr	1.261	m yr^{-1}
Annual Unit Lake Evaporation	Ev	0.513	m yr^{-1}
Point Source Hydraulic Input	Qps	0.000	m^3 yr^{-1}
Annual Unit Hydraulic Runoff - Developed	Ruv	1.100	m yr^{-1}
Annual Unit Hydraulic Runoff - Non-Developed	Ruu	1.020	m yr^{-1}
P Loading			
Upstream P Input	Pi	1,032,357.00	gm P yr^{-1}
Annual Unit Atmospheric P Deposition	Da	0.0173	gm P m^{-2} yr^{-1}
Land Use Category 1 P Export Coefficient	E1	0.2020	gm P m^{-2} yr^{-1}
Land Use Category 2 P Export Coefficient	E2	0.0024	gm P m^{-2} yr^{-1}
Land Use Category 3 P Export Coefficient	E3	0.0150	gm P m^{-2} yr^{-1}
Land Use Category 4 P Export Coefficient	E4	0.0350	gm P m^{-2} yr^{-1}
Land Use Category 5 P Export Coefficient	E5	0.0250	gm P m^{-2} yr^{-1}
Land Use Category 6 P Export Coefficient	E6	0.0300	gm P m^{-2} yr^{-1}
Land Use Category 7 P Export Coefficient	E7	0.0300	gm P m^{-2} yr^{-1}
Land Use Category 8 P Export Coefficient	E8	0.3500	gm P m^{-2} yr^{-1}
Land Use Category 9 P Export Coefficient	E9	0.0024	gm P m^{-2} yr^{-1}
Land Use Category 10 P Export Coefficient	E10	0.0000	gm P m^{-2} yr^{-1}
Number of Dwellings	N_d	0	#
Average number of Persons per Dwelling	N_u	2.90	n/a
Average Fraction of Year Dwellings Occupied	N_{pc}	1	yr^{-1}
Phosphorus Load per Capita per Year	Sl	800	gm P cap^{-1} yr^{-1}
Septic System Retention Coefficient	Rsp	0.5	n/a
Point Source Input 1	PS1	0	
Point Source Input 2	PS2	0	
Point Source Input 3	PS3	0	
Point Source Input 4	PS4	0	
Point Source Input 5	PS5	0	
Phosphorus Retention Coefficient	v	12.4	n/a
Model Outputs			
Total Precipitation Hydraulic Input	Ppt_i	1,305,135.00	m^3 yr^{-1}
Total Evaporation Hydraulic Loss	Eo	530,437.50	m^3 yr^{-1}
Total Hydraulic Surface Run Off	Ql	4,949,251.58	m^3 yr^{-1}
Total Hydraulic Input	Qt	20,848,309.58	m^3 yr^{-1}
Areal Hydraulic Load	q_s	19.63	m yr^{-1}
Total Hydraulic Outflow	Qo	20,317,872.08	m^3 yr^{-1}
Upstream P Input	Ju	1,032,357.00	gm yr^{-1}
Total Atmospheric P Input	Jd	17,905.50	gm yr^{-1}
Total Overland Run Off P Input	Je	845,237.00	gm yr^{-1}
Total Development P Input	Jd	0.00	gm yr^{-1}
Total P Input	Jt	1,895,500.00	gm yr^{-1}
Lake P Retention Factor	Rp	0.39	n/a
Lake Phosphorus Retention	Ps	739,245.00	gm yr^{-1}
Predicted Lake Phosphorus Concentration	[P]	**0.057**	mg L^{-1}
Lake Phosphorus Outflow	Jo	1,156,255.00	gm yr^{-1}
Lake Mean Depth	z	3.40	m
Lake Turnover Time	TT	0.17	yr
Lake Flushing Rate	FR	5.82	times yr^{-1}
Lake Response Time	RT	0.08	yr

Budgets		
Hydraulic Budget (m^{-3})		
		% Total
Upstream Inflow	14593923	70
Precipitation	1305135	6.26
Surface Run Off	4949251.58	23.74
Evaporation	-530437.5	2.54
Point Sources	0.000	
Total Outflow	20317872.1	97.46
Total Check		100.00
Phosphorus Budget (gm yr^{-1})		
		% Total
Upstream Inflow	1032357	54.46
Atmosphere	17906	0.94
Land Run Off	845237	44.59
Development	0	0.00
Sedimentation	-739245	39.00
Total Outflow	1156255	61.00
Total Check		99.99
Model Validation		
Predicted P (mg L^{-1})		0.0569
Measured P (mg L^{-1})		0.0060
% Difference		**848%**

Lake Charles

Input Parameters	Symbol	Value	Units
Morphology			
Drainage Basin Area (Excl. of Lake Area)	Ad	1443.7	ha
Area Land Use Category 1 (Commercial)	Ad1	835.0	ha
Area Land Use Category 2 (Forest)	Ad2	2.3	ha
Area Land Use Category 3 (Grassed)	Ad3	198.8	ha
Area Land Use Category 4 (HDR)	Ad4	11.2	ha
Area Land Use Category 5 (Institutional)	Ad5	25.0	ha
Area Land Use Category 6 (MDR)	Ad6	179.3	ha
Area Land Use Category 7 (Road)	Ad7	52.9	ha
Area Land Use Category 8 (Wetland)	Ad8	139.2	ha
Area Land Use Category 9 (Quarry)	Ad9		ha
Area Land Use Category 10	Ad10		ha
Lake Surface Area	Ao	141.4	ha
Lake Volume	V	11.2000	$10^6\ m^3$
Hydrology			
Upstream Hydraulic Inputs	Qi	0	$m^3\ yr^{-1}$
Annual Unit Precipitation	Pr	1.261	$m\ yr^{-1}$
Annual Unit Lake Evaporation	Ev	0.513	$m\ yr^{-1}$
Point Source Hydraulic Input	Qps	0.000	$m^3\ yr^{-1}$
Annual Unit Hydraulic Runoff - Developed	Ruv	1.100	$m\ yr^{-1}$
Annual Unit Hydraulic Runoff - Non-Developed	Ruu	1.020	$m\ yr^{-1}$
P Loading			
Upstream P Input	Pi	0	$gm\ P\ yr^{-1}$
Annual Unit Atmospheric P Deposition	Da	0.0173	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 1 P Export Coefficient	E1	0.2020	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 2 P Export Coefficient	E2	0.0024	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 3 P Export Coefficient	E3	0.0150	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 4 P Export Coefficient	E4	0.0350	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 5 P Export Coefficient	E5	0.0420	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 6 P Export Coefficient	E6	0.0300	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 7 P Export Coefficient	E7	0.3500	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 8 P Export Coefficient	E8	0.0080	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 9 P Export Coefficient	E9	0.0024	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 10 P Export Coefficient	E10		$gm\ P\ m^{-2}\ yr^{-1}$
Number of Dwellings	N_d	0	#
Average number of Persons per Dwelling	N_u	2.90	n/a
Average Fraction of Year Dwellings Occupied	N_{pc}	1	yr^{-1}
Phosphorus Load per Capita per Year	Sl	800	$gm\ P\ cap^{-1}\ yr^{-1}$
Septic System Retention Coefficient	Rsp	0.5	n/a
Point Source Input 1	PS1	0	
Point Source Input 2	PS2	0	
Point Source Input 3	PS3	0	
Point Source Input 4	PS4	0	
Point Source Input 5	PS5	0	
Phosphorus Retention Coefficient	v	12.4	n/a
Model Outputs			
Total Precipitation Hydraulic Input	Ppt_i	1783054	$m^3\ yr^{-1}$
Total Evaporation Hydraulic Loss	Eo	724675	$m^3\ yr^{-1}$
Total Hydraulic Surface Run Off	Ql	13535544	$m^3\ yr^{-1}$
Total Hydraulic Input	Qt	15318598	$m^3\ yr^{-1}$
Areal Hydraulic Load	q_s	10.32	$m\ yr^{-1}$
Total Hydraulic Outflow	Qo	14593923	$m^3\ yr^{-1}$
Upstream P Input	Ju	0	$gm\ yr^{-1}$
Total Atmospheric P Input	Jd	24462	$gm\ yr^{-1}$
Total Overland Run Off P Input	Je	1980965	$gm\ yr^{-1}$
Total Development P Input	Jd	0	$gm\ yr^{-1}$
Total P Input	Jt	2005427	$gm\ yr^{-1}$
Lake P Retention Factor	Rp	0.55	n/a
Lake Phosphorus Retention	Ps	1102985	$gm\ yr^{-1}$
Predicted Lake Phosphorus Concentration	[P]	**0.0618**	$mg\ L^{-1}$
Lake Phosphorus Outflow	Jo	902442	$gm\ yr^{-1}$
Lake Mean Depth	z	7.9	m
Lake Turnover Time	TT	0.77	yr
Lake Flushing Rate	FR	1.3	times yr^{-1}
Lake Response Time	RT	0.27	yr

Budgets

Hydraulic Budget (m^{-3})

		% Total
Upstream Inflow	0	0
Precipitation	1783054	11.64
Surface Run Off	13535544	88.36
Evaporation	-724675	4.73
Point Sources	0.000	
Total Outflow	14593923	95.27
Total Check		100.00

Phosphorus Budget ($gm\ yr^{-1}$)

		% Total
Upstream Inflow	0	0
Atmosphere	24462	1.22
Land Run Off	1980965	98.78
Development	0	0.00
Sedimentation	-1102985	55.00
Total Outflow	902442	45.00
Total Check		100.00

Model Validation

Pedicted P ($mg\ L^{-1}$)	0.0618
Measured P ($mg\ L^{-1}$)	-
% Difference	-

Red Bridge Pond

Input Parameters	Symbol	Value	Units
Morphology			
Drainage Basin Area (Excl. of Lake Area)	Ad	191.1	ha
Area Land Use Category 1 (Commercial)	Ad1	21.5	ha
Area Land Use Category 2 (Forest)	Ad2	8.8	ha
Area Land Use Category 3 (HDF)	Ad3	1.0	ha
Area Land Use Category 4 (LDR)	Ad4	98.8	ha
Area Land Use Category 5 (MDR)	Ad5	19.2	ha
Area Land Use Category 6 (Road)	Ad6	41.7	ha
Area Land Use Category 7	Ad7		ha
Area Land Use Category 8	Ad8		ha
Area Land Use Category 9	Ad9		ha
Area Land Use Category 10	Ad10		ha
Lake Surface Area	Ao	7.8	ha
Lake Volume	V	0.0300	$10^6\ m^3$
Hydrology			
Upstream Hydraulic Inputs	Qi	0	$m^3\ yr^{-1}$
Annual Unit Precipitation	Pr	1.261	$m\ yr^{-1}$
Annual Unit Lake Evaporation	Ev	0.513	$m\ yr^{-1}$
Point Source Hydraulic Input	Qps	0.000	$m^3\ yr^{-1}$
Annual Unit Hydraulic Runoff - Developed	Ruv	1.100	$m\ yr^{-1}$
Annual Unit Hydraulic Runoff - Non-Developed	Ruu	1.020	$m\ yr^{-1}$
P Loading			
Upstream P Input	Pi	0	$gm\ P\ yr^{-1}$
Annual Unit Atmospheric P Deposition	Da	0.0173	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 1 P Export Coefficient	E1	0.2020	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 2 P Export Coefficient	E2	0.0024	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 3 P Export Coefficient	E3	0.0350	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 4 P Export Coefficient	E4	0.0250	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 5 P Export Coefficient	E5	0.0300	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 6 P Export Coefficient	E6	0.3500	$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 7 P Export Coefficient	E7		$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 8 P Export Coefficient	E8		$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 9 P Export Coefficient	E9		$gm\ P\ m^{-2}\ yr^{-1}$
Land Use Category 10 P Export Coefficient	E10		$gm\ P\ m^{-2}\ yr^{-1}$
Number of Dwellings	N_d	0	#
Average number of Persons per Dwelling	N_u	2.90	n/a
Average Fraction of Year Dwellings Occupied	N_{pc}	1	yr^{-1}
Phosphorus Load per Capita per Year	Sl	800	$gm\ P\ cap^{-1}\ yr^{-1}$
Septic System Retention Coefficient	Rsp	0.5	n/a
Point Source Input 1	PS1	0	
Point Source Input 2	PS2	0	
Point Source Input 3	PS3	0	
Point Source Input 4	PS4	0	
Point Source Input 5	PS5	0	
Phosphorus Retention Coefficient	v	12.4	n/a
Model Outputs			
Total Precipitation Hydraulic Input	Ppt_i	98610.2	$m^3\ yr^{-1}$
Total Evaporation Hydraulic Loss	Eo	40077.5	$m^3\ yr^{-1}$
Total Hydraulic Surface Run Off	Ql	2043979.581	$m^3\ yr^{-1}$
Total Hydraulic Input	Qt	2142590	$m^3\ yr^{-1}$
Areal Hydraulic Load	q_s	26.89	$m\ yr^{-1}$
Total Hydraulic Outflow	Qo	2102512.281	$m^3\ yr^{-1}$
Upstream P Input	Ju	0	$gm\ yr^{-1}$
Total Atmospheric P Input	Jd	1353	$gm\ yr^{-1}$
Total Overland Run Off P Input	Je	220496	$gm\ yr^{-1}$
Total Development P Input	Jd	0	$gm\ yr^{-1}$
Total P Input	Jt	221849	$gm\ yr^{-1}$
Lake P Retention Factor	Rp	0.32	n/a
Lake Phosphorus Retention	Ps	70992	$gm\ yr^{-1}$
Predicted Lake Phosphorus Concentration	[P]	**0.0718**	$mg\ L^{-1}$
Lake Phosphorus Outflow	Jo	150857	$gm\ yr^{-1}$
Lake Mean Depth	z	0.4	m
Lake Turnover Time	TT	0.01	yr
Lake Flushing Rate	FR	70.08	$times\ yr^{-1}$
Lake Response Time	RT	0.01	yr

Budgets

Hydraulic Budget (m^{-3})		% Total
Upstream Inflow	0	0
Precipitation	98610.2	4.6
Surface Run Off	2043979.58	95.4
Evaporation	-40077.5	1.87
Point Sources	0.000	
Total Outflow	2102512.28	98.13
Total Check		100.00

Phosphorus Budget ($gm\ yr^{-1}$)		% Total
Upstream Inflow	0	0
Atmosphere	1353	0.61
Land Run Off	220496	99.39
Development	0	0.00
Sedimentation	-70992	32.00
Total Outflow	150857	68.00
Total Check		100.00

Model Validation		
Pedicted P ($mg\ L^{-1}$)		0.0718
Measured P ($mg\ L^{-1}$)		-
% Difference		-

Oathill Lake

Input Parameters	Symbol	Value	Units
Morphology			
Drainage Basin Area (Excl. of Lake Area)	Ad	35.1	ha
Area Land Use Category 1 (Commercial)	Ad1	0.0	ha
Area Land Use Category 2 (Forest)	Ad2	4.8	ha
Area Land Use Category 3 (HDF)	Ad3	0.8	ha
Area Land Use Category 4 (LDR)	Ad4	21.0	ha
Area Land Use Category 5 (MDR)	Ad5	0.9	ha
Area Land Use Category 6 (Road)	Ad6	7.6	ha
Area Land Use Category 7	Ad7		ha
Area Land Use Category 8	Ad8		ha
Area Land Use Category 9	Ad9		ha
Area Land Use Category 10	Ad10		ha
Lake Surface Area	Ao	4.4	ha
Lake Volume	V	0.2050	10^6 m^3
Hydrology			
Upstream Hydraulic Inputs	Qi	0	m^3 yr^{-1}
Annual Unit Precipitation	Pr	1.261	m yr^{-1}
Annual Unit Lake Evaporation	Ev	0.513	m yr^{-1}
Point Source Hydraulic Input	Qps	0.000	m^3 yr^{-1}
Annual Unit Hydraulic Runoff - Developed	Ruv	1.100	m yr^{-1}
Annual Unit Hydraulic Runoff - Non-Developed	Ruu	1.020	m yr^{-1}
P Loading			
Upstream P Input	Pi	0	gm P yr^{-1}
Annual Unit Atmospheric P Deposition	Da	0.0173	gm P m^{-2} yr^{-1}
Land Use Category 1 P Export Coefficient	E1	0.2020	gm P m^{-2} yr^{-1}
Land Use Category 2 P Export Coefficient	E2	0.0024	gm P m^{-2} yr^{-1}
Land Use Category 3 P Export Coefficient	E3	0.0350	gm P m^{-2} yr^{-1}
Land Use Category 4 P Export Coefficient	E4	0.0250	gm P m^{-2} yr^{-1}
Land Use Category 5 P Export Coefficient	E5	0.0300	gm P m^{-2} yr^{-1}
Land Use Category 6 P Export Coefficient	E6	0.3500	gm P m^{-2} yr^{-1}
Land Use Category 7 P Export Coefficient	E7		gm P m^{-2} yr^{-1}
Land Use Category 8 P Export Coefficient	E8		gm P m^{-2} yr^{-1}
Land Use Category 9 P Export Coefficient	E9		gm P m^{-2} yr^{-1}
Land Use Category 10 P Export Coefficient	E10		gm P m^{-2} yr^{-1}
Number of Dwellings	N_d	0	#
Average number of Persons per Dwelling	N_u	2.90	n/a
Average Fraction of Year Dwellings Occupied	N_{pc}	1	yr^{-1}
Phosphorus Load per Capita per Year	Sl	800	gm P cap^{-1} yr^{-1}
Septic System Retention Coefficient	Rsp	0.5	n/a
Point Source Input 1	PS1	0	
Point Source Input 2	PS2	0	
Point Source Input 3	PS3	0	
Point Source Input 4	PS4	0	
Point Source Input 5	PS5	0	
Phosphorus Retention Coefficient	v	12.4	n/a
Model Outputs			
Total Precipitation Hydraulic Input	Ppt_i	55484	m^3 yr^{-1}
Total Evaporation Hydraulic Loss	Eo	22550	m^3 yr^{-1}
Total Hydraulic Surface Run Off	Ql	375680.1	m^3 yr^{-1}
Total Hydraulic Input	Qt	431164	m^3 yr^{-1}
Areal Hydraulic Load	q_s	9.29	m yr^{-1}
Total Hydraulic Outflow	Qo	408614.1	m^3 yr^{-1}
Upstream P Input	Ju	0	gm yr^{-1}
Total Atmospheric P Input	Jd	761	gm yr^{-1}
Total Overland Run Off P Input	Je	32456	gm yr^{-1}
Total Development P Input	Jd	0	gm yr^{-1}
Total P Input	Jt	33217	gm yr^{-1}
Lake P Retention Factor	Rp	0.57	n/a
Lake Phosphorus Retention	Ps	18934	gm yr^{-1}
Predicted Lake Phosphorus Concentration	[P]	**0.035**	mg L^{-1}
Lake Phosphorus Outflow	Jo	14283	gm yr^{-1}
Lake Mean Depth	z	4.7	m
Lake Turnover Time	TT	0.5	yr
Lake Flushing Rate	FR	1.99	times yr^{-1}
Lake Response Time	RT	0.17	yr

Budgets

Hydraulic Budget (m^{-3})

		% Total
Upstream Inflow	0	0
Precipitation	55484	12.87
Surface Run Off	375680.1	87.13
Evaporation	-22550	5.23
Point Sources	0.000	
Total Outflow	408614.1	94.77
Total Check		100.00

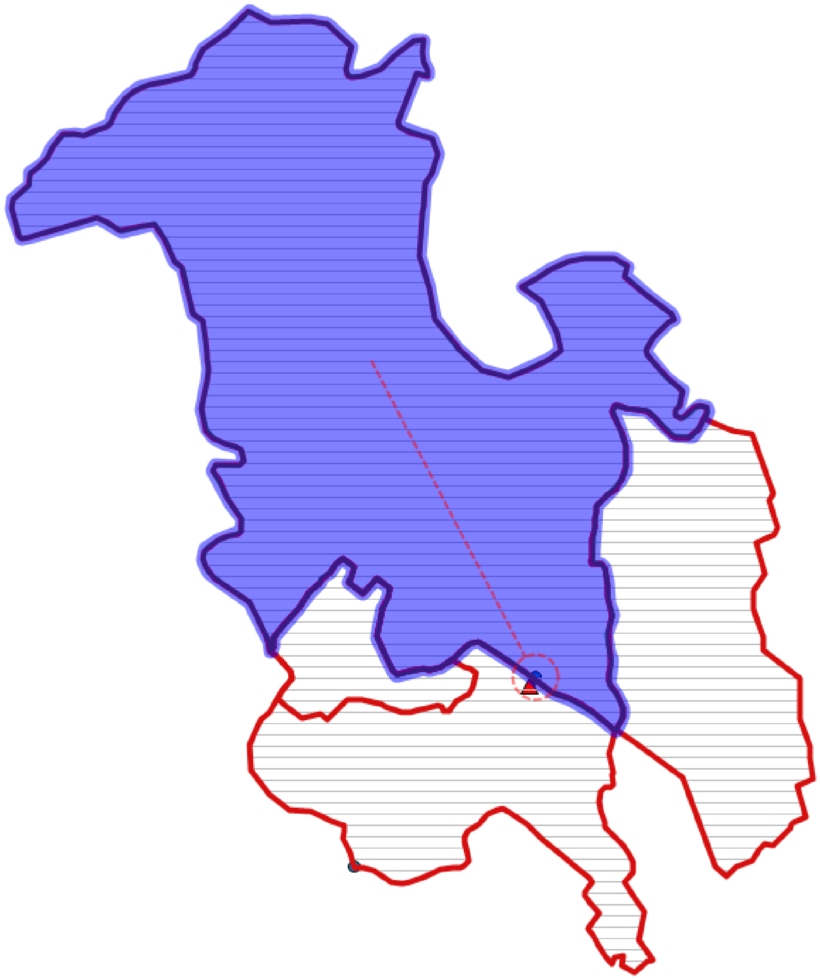
Phosphorus Budget (gm yr^{-1})

		% Total
Upstream Inflow	0	0
Atmosphere	761	2.29
Land Run Off	32456	97.71
Development	0	0.00
Sedimentation	-18934	57.00
Total Outflow	14283	43.00
Total Check		100.00

Model Validation

Pedicted P (mg L^{-1})	0.0350
Measured P (mg L^{-1})	-
% Difference	-

D.4 – PCSWMM Reports



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  --------------------------------------------------------------


  WARNING 04: minimum elevation drop used for Conduit C1


  *************

  Element Count

  *************

  Number of rain gages ...... 1

  Number of subcatchments ... 1

  Number of nodes ........... 3

  Number of links ........... 1

  Number of pollutants ...... 0

  Number of land uses ....... 0



  ****************

  Raingage Summary

  ****************

                                                    Data       Recording

  Name                Data Source                   Type       Interval

  ----------------------------------------------------------------------

  Chicago_25mm        Chicago_25mm                  INTENSITY    5 min.



  ********************

  Subcatchment Summary

  ********************

  Name                       Area     Width   %Imperv    %Slope Rain Gage
Outlet

  ----------------------------------------------------------------------------------
-----------------------

  S1                       675.36   5000.00     62.46    1.0000 Chicago_25mm
MM
```

```
************
Node Summary
************
                                        Invert      Max.    Ponded    External
Name                 Type                Elev.     Depth      Area    Inflow
-------------------------------------------------------------------------------
BanO                 JUNCTION             0.00      0.00       0.0
MM                   JUNCTION             0.00      3.00       0.0
OF1                  OUTFALL              0.00      3.00       0.0


************
Link Summary
************
Name             From Node        To Node          Type            Length    %Slope Roughness
---------------------------------------------------------------------------------------------
C1               MM               OF1              CONDUIT           56.0    0.0005    0.0100


*********************
Cross Section Summary
*********************
                                        Full     Full     Hyd.     Max.   No. of     Full
Conduit          Shape                 Depth     Area     Rad.    Width  Barrels     Flow
---------------------------------------------------------------------------------------
C1               RECT_OPEN              3.00    30.00     1.88    10.00        1    10.64


*********************************************************
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```
NOTE: The summary statistics displayed in this report are
based on results found at every computational time step,
not just on results from each reporting time step.
*********************************************************

****************
Analysis Options
****************
Flow Units ............... CMS
Process Models:
  Rainfall/Runoff ........ YES
  RDII ................... NO
  Snowmelt ............... NO
  Groundwater ............ NO
  Flow Routing ........... YES
  Ponding Allowed ........ NO
  Water Quality .......... NO
Infiltration Method ...... CURVE_NUMBER
Flow Routing Method ...... DYNWAVE
Starting Date ............ 01/01/2019 00:00:00
Ending Date .............. 01/01/2019 23:59:59
Antecedent Dry Days ...... 0.0
Report Time Step ......... 00:01:00
Wet Time Step ............ 00:05:00
Dry Time Step ............ 00:05:00
Routing Time Step ........ 5.00 sec
Variable Time Step ....... YES
Maximum Trials ........... 8
Number of Threads ........ 1
Head Tolerance ........... 0.001500 m


**************************        Volume         Depth
Runoff Quantity Continuity     hectare-m            mm
```

```
*************************    ---------       -------
Total Precipitation ......      16.884        25.000
Evaporation Loss .........       0.000         0.000
Infiltration Loss ........       5.655         8.373
Surface Runoff ...........      10.443        15.462
Final Storage ............       0.814         1.205
Continuity Error (%) .....      -0.159


*************************        Volume        Volume
Flow Routing Continuity       hectare-m      10^6 ltr
*************************     ---------     ---------
Dry Weather Inflow .......       0.000         0.000
Wet Weather Inflow .......      10.443       104.427
Groundwater Inflow .......       0.000         0.000
RDII Inflow ..............       0.000         0.000
External Inflow ..........       0.000         0.000
External Outflow .........      10.442       104.424
Flooding Loss ............       0.000         0.000
Evaporation Loss .........       0.000         0.000
Exfiltration Loss ........       0.000         0.000
Initial Stored Volume ....       0.000         0.000
Final Stored Volume ......       0.000         0.005
Continuity Error (%) .....      -0.002


***************************
Time-Step Critical Elements
***************************
None


********************************
Highest Flow Instability Indexes
```

```
  ********************************
  All links are stable.


  *************************
  Routing Time Step Summary
  *************************
  Minimum Time Step           :     2.50 sec
  Average Time Step           :     5.00 sec
  Maximum Time Step           :     5.00 sec
  Percent in Steady State     :     0.00
  Average Iterations per Step :     2.00
  Percent Not Converging      :     0.00



  ***************************
  Subcatchment Runoff Summary
  ***************************

  ------------------------------------------------------------------------------------
--------------------
                            Total      Total      Total      Total      Total
Total     Peak  Runoff
                           Precip      Runon       Evap      Infil     Runoff
Runoff   Runoff   Coeff
  Subcatchment                 mm         mm         mm         mm         mm    10^6
ltr      CMS
  ------------------------------------------------------------------------------------
--------------------
  S1                        25.00       0.00       0.00       8.37      15.46
104.43    27.58   0.618


  ******************
  Node Depth Summary
  ******************


  ---------------------------------------------------------------------------------
                                 Average  Maximum  Maximum  Time of Max    Reported
```

Node	Type	Depth Meters	Depth Meters	HGL Meters	Occurrence days hr:min	Max Depth Meters
BanO	JUNCTION	0.00	0.00	0.00	0 00:00	0.00
MM	JUNCTION	0.10	0.99	0.99	0 01:40	0.99
OF1	OUTFALL	0.07	0.92	0.92	0 01:40	0.92

****

Node Inflow Summary

****

Node	Type	Maximum Lateral Inflow CMS	Maximum Total Inflow CMS	Time of Max Occurrence days hr:min	Lateral Inflow Volume 10^6 ltr	Total Inflow Volume 10^6 ltr	Flow Balance Error Percent
BanO	JUNCTION	0.000	0.000	0 00:00	0	0	0.000 ltr
MMO	JUNCTION	27.583	27.583	0 01:40	104	104	0.003
OF1	OUTFALL	0.000	27.627	0 01:40	0	104	0.000

****

Node Surcharge Summary

****

Surcharging occurs when water rises above the top of the highest conduit.

Node	Type	Hours Surcharged	Max. Height Above Crown Meters	Min. Depth Below Rim Meters
BanO	JUNCTION	24.00	0.000	0.000

****

Node Flooding Summary

****

No nodes were flooded.

****

Outfall Loading Summary

****

Outfall Node	Flow Freq Pcnt	Avg Flow CMS	Max Flow CMS	Total Volume 10^6 ltr
OF1	99.70	1.212	27.627	104.423
System	99.70	1.212	27.627	104.423

****

Link Flow Summary

****

Maximum Time of Max Maximum Max/ Max/

Link	Type	|Flow| CMS	Occurrence days hr:min	|Veloc| m/sec	Full Flow	Full Depth
C1	CONDUIT	27.627	0 01:40	2.91	2.60	0.32

****

Flow Classification Summary

****

Conduit	Adjusted /Actual Length	Dry	Up Dry	Down Dry	Sub Crit	Sup Crit	Up Crit	Down Crit	Norm Ltd	Inlet Ctrl
		---------- Fraction of Time in Flow Class ----------								
C1	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

****

Conduit Surcharge Summary

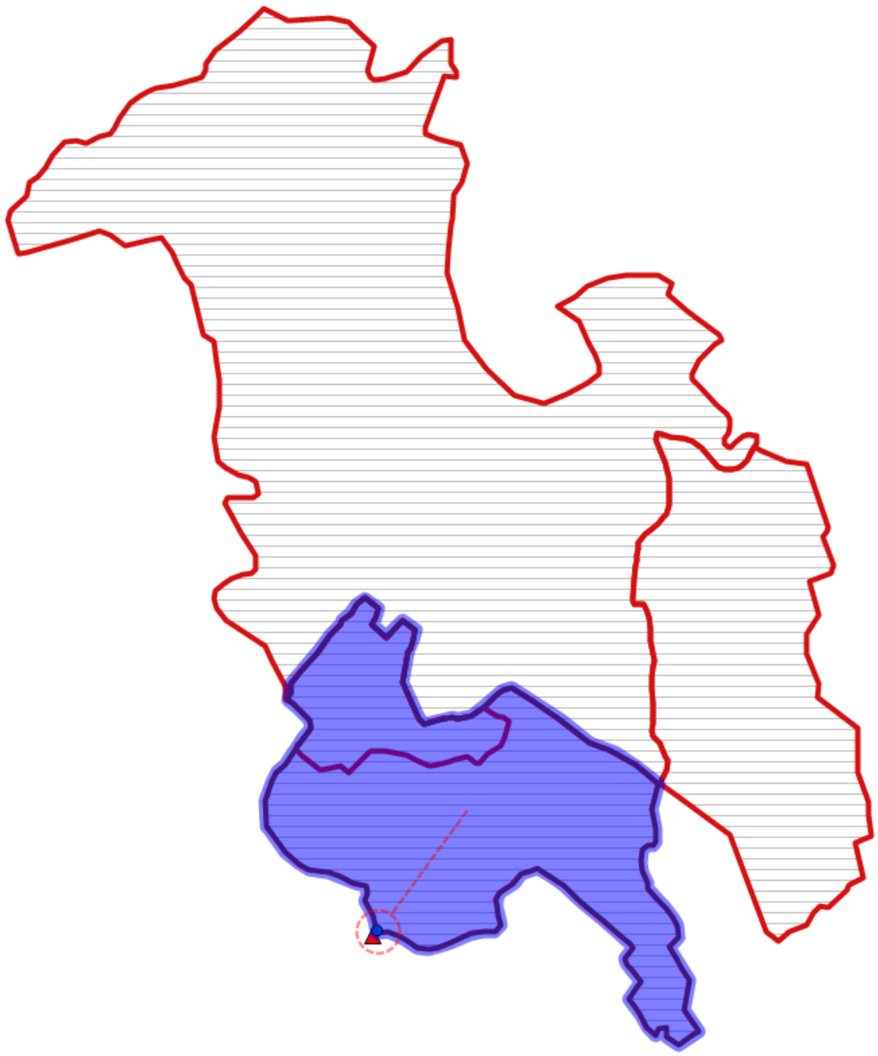
****

Conduit	Hours Full: Both Ends	Hours Full: Upstream	Hours Full: Dnstream	Hours Above Full Normal Flow	Hours Capacity Limited
C1	0.01	0.01	0.01	0.81	0.01

Analysis begun on: Fri Nov 02 15:20:18 2018

Analysis ended on: Fri Nov 02 15:20:19 2018

Total elapsed time: 00:00:01



```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.1 (Build 5.1.012)
  --------------------------------------------------------------

  WARNING 04: minimum elevation drop used for Conduit C1

  *************
  Element Count
  *************
  Number of rain gages ...... 1
  Number of subcatchments ... 1
  Number of nodes ........... 2
  Number of links ........... 1
  Number of pollutants ...... 0
  Number of land uses ....... 0


  ****************
  Raingage Summary
  ****************
                                                              Data       Recording
  Name                 Data Source                            Type       Interval
  ------------------------------------------------------------------------
  Chicago_25mm         Chicago_25mm                           INTENSITY    5 min.


  ********************
  Subcatchment Summary
  ********************
  Name                       Area     Width   %Imperv    %Slope Rain Gage
Outlet
  -----------------------------------------------------------------------------------
-----------------------
  Banook                   223.78   5000.00     52.32    1.0000 Chicago_25mm
BanO


  ************
  Node Summary
  ************
                                                   Invert      Max.    Ponded    External
  Name                 Type                         Elev.     Depth      Area    Inflow
  -------------------------------------------------------------------------------
  BanO                 JUNCTION                      0.00      3.00       0.0
  OF1                  OUTFALL                       0.00      3.00       0.0


  ************
  Link Summary
  ************
  Name             From Node        To Node          Type            Length    %Slope
Roughness
  -----------------------------------------------------------------------------------
---------
  C1               BanO             OF1              CONDUIT           31.5    0.0010
0.0100


  *********************
  Cross Section Summary
  *********************
                                        Full     Full     Hyd.     Max.   No. of
Full
```

```
  Conduit          Shape                Depth     Area     Rad.    Width  Barrels
Flow
  ---------------------------------------------------------------------------------
---
  C1               TRAPEZOIDAL           3.00    33.00     1.79    17.00        1
15.14


  *********************************************************
  NOTE: The summary statistics displayed in this report are
  based on results found at every computational time step,
  not just on results from each reporting time step.
  *********************************************************

  ****************
  Analysis Options
  ****************
  Flow Units ............... CMS
  Process Models:
    Rainfall/Runoff ........ YES
    RDII ................... NO
    Snowmelt ............... NO
    Groundwater ............ NO
    Flow Routing ........... YES
    Ponding Allowed ........ NO
    Water Quality .......... NO
  Infiltration Method ...... CURVE_NUMBER
  Flow Routing Method ...... DYNWAVE
  Starting Date ............ 01/01/2019 00:00:00
  Ending Date .............. 01/01/2019 23:59:59
  Antecedent Dry Days ...... 0.0
  Report Time Step ......... 00:01:00
  Wet Time Step ............ 00:05:00
  Dry Time Step ............ 00:05:00
  Routing Time Step ........ 5.00 sec
  Variable Time Step ....... YES
  Maximum Trials ........... 8
  Number of Threads ........ 1
  Head Tolerance ........... 0.001500 m


  **************************        Volume         Depth
  Runoff Quantity Continuity     hectare-m            mm
  **************************     ---------       -------
  Total Precipitation ......         5.594        25.000
  Evaporation Loss .........         0.000         0.000
  Infiltration Loss ........         2.465        11.015
  Surface Runoff ...........         2.882        12.880
  Final Storage ............         0.264         1.180
  Continuity Error (%) .....        -0.300


  **************************        Volume        Volume
  Flow Routing Continuity        hectare-m      10^6 ltr
  **************************     ---------     ---------
  Dry Weather Inflow .......         0.000         0.000
  Wet Weather Inflow .......         2.882        28.823
  Groundwater Inflow .......         0.000         0.000
  RDII Inflow ..............         0.000         0.000
  External Inflow ..........         0.000         0.000
  External Outflow .........         2.882        28.824
  Flooding Loss ............         0.000         0.000
```

Evaporation Loss	0.000	0.000
Exfiltration Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.000	0.000
Continuity Error (%)	-0.004	

****
Time-Step Critical Elements
****
None

****
Highest Flow Instability Indexes
****
All links are stable.

****
Routing Time Step Summary
****

Minimum Time Step	:	0.83 sec
Average Time Step	:	5.00 sec
Maximum Time Step	:	5.00 sec
Percent in Steady State	:	0.00
Average Iterations per Step	:	2.00
Percent Not Converging	:	0.00

****
Subcatchment Runoff Summary
****

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
Banook	25.00	0.00	0.00	11.01	12.88	28.82	14.55	0.515

****
Node Depth Summary
****

Node	Type	Average Depth Meters	Maximum Depth Meters	Maximum HGL Meters	Time of Max Occurrence days hr:min	Reported Max Depth Meters
BanO	JUNCTION	0.05	0.90	0.90	0 01:35	0.89
OF1	OUTFALL	0.04	0.85	0.85	0 01:35	0.83

****
Node Inflow Summary

****

Node	Type	Maximum Lateral Inflow CMS	Maximum Total Inflow CMS	Time of Max Occurrence days hr:min	Lateral Inflow Volume 10^6 ltr	Total Inflow Volume 10^6 ltr	Flow Balance Error Percent
BanO	JUNCTION	14.548	14.548	0 01:35	28.8	28.8	-0.002
OF1	OUTFALL	0.000	14.663	0 01:35	0	28.8	0.000

****
Node Surcharge Summary
****

No nodes were surcharged.

****
Node Flooding Summary
****

No nodes were flooded.

****
Outfall Loading Summary
****

Outfall Node	Flow Freq Pcnt	Avg Flow CMS	Max Flow CMS	Total Volume 10^6 ltr
OF1	99.82	0.338	14.663	28.824
System	99.82	0.338	14.663	28.824

****
Link Flow Summary
****

Link	Type	Maximum |Flow| CMS	Time of Max Occurrence days hr:min	Maximum |Veloc| m/sec	Max/ Full Flow	Max/ Full Depth
C1	CONDUIT	14.663	0 01:35	2.53	0.97	0.29

****
Flow Classification Summary
****

Conduit	Adjusted /Actual Length	Dry	Up Dry	Down Dry	Sub Crit	Sup Crit	Up Crit	Down Crit	Norm Ltd	Inlet Ctrl
		---------- Fraction of Time in Flow Class ----------								
C1	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

****
Conduit Surcharge Summary
****

No conduits were surcharged.

Analysis begun on: Thu Nov 01 21:46:53 2018
Analysis ended on: Thu Nov 01 21:46:55 2018
Total elapsed time: 00:00:02

APPENDIX E

Supporting Documentation

E.1 – Microbial Source Tracking Laboratory Methodology

Dalhousie University Centre for Water Resources Studies

Detection of Host Specific Microbial Source Tracking (MST) Markers by Quantitative Polymerase Chain Reaction (qPCR) Methods

Samples were collected in sterilized 1 L Nalgene collection bottles (Thermo Fisher Scientific, Waltham, MA, USA). Samples were kept on ice packs during transport to the laboratory at Dalhousie University in Halifax, NS, and stored in a refrigerator at 4°C until analysis. All samples were processed within 24 hours from receiving the samples.

Water sample volumes of 500 mL were filtered through sterile filters (0.45 µM pore size, 47 mm diameter, Millipore, Inc., Bedford, MA, USA) using a vacuum filtration system with sterile sample cups (Millipore, Inc., Bedford, MA, USA). The filters were aseptically placed into the DNA extraction tubes provided by a Mo Bio Power Soil DNA extraction kit (VWR International, Ville Mont-Royal, QC, Canada) and manufacturers instructions were followed for extraction of genomic DNA. The genomic DNA was stored at -20°C until analysis. The concentration and purity of genomic DNA were measured by ultraviolet absorbance spectrophotometry at 260/280 nm and 260/230 nm (Implen NanoPhotometer™, Implen, München, Germany).

Detection of host specific genetic markers was performed using quantitative polymerase chain reaction (qPCR) methods. More specifically, the Taqman qPCR methods were developed to analyse human-, ruminant-, and canine-specific markers (Haugland *et al.* 2010; Reischer *et al*. 2006; Caldwell and Levine 2009; Tambalo *et al.* 2012). The human-specific *Bacteroidales* genetic marker (*HF183*) was assessed and quantified to determine the sources of human fecal contamination (Haugland *et al.* 2010). Ruminant *Bacteroidales* genetic marker (*BacR*) was quantified to investigate the ruminant-associated contamination (Reischer *et al.* 2006). The canine-specific marker, referred as dogmt, from dog mitochondrial DNA was targeted to assess the canine-associated contamination (Caldwell and Levine 2009; Tambalo *et al.* 2012). The Sybr Green qPCR assay was used to detect the avian-specific marker (*GFD*) t (Green *et al.* 2012).

References

Caldwell, J.M., Levine, J.F. (2009). Domestic wastewater influent profiling using mitochondrial real-time PCR for source tracking animal contamination. *Journal of Microbiological Methods, 77,* 17-22.

Green, H.C., Dick, L.K., Samadpour, M., Field, K.G. (2012). Genetic markers for rapid PCR-based identification of gull, Canada goose, duck, and chicken fecal contamination in water. *Applied and Environmental Microbiology, 78*(2), 503-510.

Haugland, R.A., Varma, M., Sivaganesan, M., Kelty, C., Preed, L., Shanks, O.C. (2010). Evaluation of genetic markers from the 16S rRNA gene V2 region for use in quantitative detection of selected *Bacteroidales* species and human fecal waste by qPCR. *Systematic and Applied Microbiology, 33,* 348-357.

Reischer, G.H., Kasper, D.C., Steinborn, R., Mach, R.L., Farnleitner, A.H., (2006) Quantitative PCR method for sensitive detection of ruminant fecal pollution in freshwater and evaluation of this method in alpine karstic regions. *Applied and Environmental Microbiology*, *72*, 5610-5614.

Tambalo, D.D., Boa, T., Liljebjelke K., Yost, C.K. (2012). Evaluation of two quantitative PCR assays using *Bacteroidales* and mitochondrial DNA for tracking dog fecal contamination in waterbodies. *Journal of Microbiological Methods, 91*, 459-467.

E.2 – User's Manual for Prediction of Phosphorus Concentration In Nova Scotia Lakes: A Tool for Decision Making

User's Manual for Prediction of Phosphorus Concentration In Nova Scotia Lakes: A Tool for Decision Making

Version 1.0

Prepared For

The Nova Scotia Water Quality Objectives and Model Development Steering Committee

Nova Scotia Department of Environment and Labour

By

M. Brylinsky
Acadia Centre for Estuarine Research
Acadia University
Wolfville, Nova Scotia
B4P 2R6

January 2004

NOVA SCOTIA
Environment and Labour

ACADIA ESTUARINE CENTRE FOR RESEARCH

SUMMARY

Increasing demands on our freshwater resources to provide clean water for industrial, domestic, agricultural and recreational purposes, together with increasing development of watersheds, has raised concerns about the kind and amount of development that can be tolerated in watersheds containing these resources. Of major concern are watershed activities that result in increased inputs of phosphorus to lakes, the nutrient most important in controlling lake productivity and, when present in high concentrations, the major cause of lake eutrophication. As a result, considerable effort has been extended by various agencies to develop methods that can be used to determine the extent to which a watershed can be altered before the aquatic ecosystems it contains begin to exhibit impaired water quality.

This manual documents a simple modeling procedure that has been widely used to predict the amount of phosphorus present in the water column of a lake based on its morphological, hydrological and drainage basin characteristics. This model has proven to be a useful tool in decision making and assessments of the effect of various alterations within a watershed with respect to how they may influence lake phosphorus concentrations. The intended users of the manual include federal and provincial resource management agencies, provincial regulatory officers, municipal planners, consulting agencies and non-governmental organizations and individuals.

Table of Contents

User's Manual for Prediction of Phosphorus Concentration In Nova Scotia Lakes: A Tool for Decision Making

Version 1.0

1. Introduction

Increasing pressure on our freshwater resources to provide clean water for industrial, domestic, agricultural and recreational purposes has raised concerns about the kind and amount of development that can be tolerated in watersheds containing these resources. In many areas of the world, freshwater systems have been severely degraded as a result of poor watershed management and lack of land use planning. Although Nova Scotia contains many relatively pristine watersheds, concern about threats to the quality of our freshwater resources from increased development, and the land use changes that accompany development, has been raised in the past (Waller 1971), and many believe that it is now time to develop procedures for determining the kind and level of development that can be endured within Nova Scotia watersheds before water quality becomes impaired.

Over the last three decades, considerable effort has been extended by many agencies to develop a simple procedure that can be used to determine the extent to which a watershed can be altered before the aquatic ecosystems it contains begin to exhibit impaired water quality as a result of excessive nutrient enrichment. In North America, many provinces and states are in the process of developing nutrient criteria designed to protect freshwater systems from nutrient overenrichment.

Of major concern is human activity that results in alterations of the tropic status of lakes. The term ***trophic*** literally means 'nourish', and when applied to a water body it refers to its level of biological productivity. Three commonly used terms to define the trophic status of a water body are ***oligotrophic*** (little nourishment), ***mesotrophic*** (moderate nourishment) and ***eutrophic*** (much nourishment). Oligotrophic systems are characterized by relatively pristine conditions and low levels of production. Eutrophic systems are characterized by a high biomass of plants, especially algae, and in many instances, low levels of dissolved oxygen which can result in the build up of toxic products such as methane, hydrogen sulphide and ammonia. Eutrophic conditions can lead to fish kills and species shifts of both plants and animals. A fourth trophic term, ***dystrophic***, literally means abnormal nourishment, and is used to describe systems that do not fall into the above categories. Dystrophic water bodies are characterized by colored water, mostly as a result of receiving run off containing dissolved humic compounds that originate from peatlands or leachates produced from the breakdown of coniferous vegetation within a watershed.

Because lakes lie in depressions within the land, they are natural traps for particulate materials containing nutrients that enter via their inflows. As a result, all lakes gradually accumulate nutrients and at some point will become eutrophic. This ***natural eutrophication*** is a slow process, on the order of tens of centuries in most cases, but it is often accelerated by the activities of humans, a process referred to as ***cultural eutrophication***, through land use alterations within a lake's drainage basin, or by the direct discharge of sewage, or other effluents containing nutrients, into a lake.

Although freshwater algae require a number of nutrients in order to grow, the two that are most commonly present in limiting amounts are phosphorus and nitrogen. Of these, phosphorus is the nutrient that most often limits the growth of aquatic plants in freshwater systems and, when present in high concentrations, is most often responsible for lake eutrophication. A general rule of thumb used by limnologists is that phosphorus is considered the limiting nutrient when the ratio of total nitrogen to total phosphorus concentration (by weight) is greater than about 7. Although there is considerable variation, on a global scale the concentration of phosphorus that results in oligotrophic, mesotrophic, and eutrophic conditions is about <10, 10-35 and > 35 $\mu g\ L^{-1}$, respectively.

Considerable effort has been devoted to developing quantitative empirical relationships between the concentration of phosphorus in a lake and water quality parameters that provide an indication of the trophic status of a lake. The two most commonly used parameters for this purpose are chlorophyll *a* concentration, an index of the amount of algae contained within the water column of the lake, and Secchi Disk depth, a measure of the lake's water clarity. Table 1 contains an example of one set of guidelines commonly employed to determine the trophic status of a lake.

Table 1. Total phosphorus, chlorophyll *a* and Secchi Disk depth boundary values for determining a lake's trophic state (Vollenweider and Kerekes 1982).

Trophic Category	TP ($\mu g\ L^{-1}$)	Mean Chlorophyll ($mg\ m^{-3}$)	Max Chlorophyll ($mg\ m^{-3}$)	Mean Secchi Depth (m)	Min Secchi Depth (m)
Ultra-oligotrophic	<4	<1	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8	>6	>3
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hyper-eutrophic	>100	>25	>75	<1.5	<0.7

Explanation of terms:
TP - mean annual in lake total phosphorus concentration;
Mean Chlorophyll - mean annual chlorophyll *a* concentration in surface waters;
Max Chlorophyll - peak annual chlorophyll *a* concentration in surface waters;
Mean Secchi Depth – mean annual Secchi Disk depth;
Min Secchi Depth – minimum annual Secchi Disk depth.

The purpose of this manual is to document a procedure that can be used to predict the amount of phosphorus that a lake will contain based on its morphological, hydrological and drainage basin characteristics. This information can then, in turn, be used to assess its susceptibility to eutrophication as a result of modifications of any of these characteristics, and particularly with respect to inputs of phosphorus resulting from human activities. The intended users of the manual include federal and provincial resource management agencies, provincial regulatory officers, municipal planners, consulting agencies and non-governmental organizations and individuals.

The general approach presented here has previously been applied within Nova Scotia for lakes associated with the Gaspereau River watershed (Horner Associates Ltd. 1995), Shubenacadie River watershed (Hart et al. 1978), Nine Mile River watershed (Dillon Consulting Ltd. 2003), a Cape Breton highlands lake (Kerekes 1983) and numerous lakes in the Halifax area (Soil and Water Conservation Society of Metro Halifax 1992; 1993).

Scott et al. (2003) carried out a study comparing these models and concluded that all of the models were essentially the same in terms of their general formulations and assumptions.

2. Some Basic Limnological Concepts

Anyone who attempts to use the model presented in this manual to predict the phosphorus concentration of a lake, or to determine the permissible loading of phosphorus to a lake, should have at least a general knowledge of the factors that cause eutrophication, as well as of the processes that determine the degree to which a particular lake is subject to becoming eutrophic. Of particular importance is an understanding of how phosphorus cycles within a lake, and the way in which lake stratification and the mixing processes occurring within the water column of a lake influence this cycle. It is also important to know something of the relationship between light availability and lake stratification in terms of how this also influences lake productivity. The discussion below provides a general description of these factors.

2.1. Lake Stratification

Lake stratification refers to the condition in which the water column of a lake becomes separated into layers of different densities as a result of differences in temperature. In temperate climates, this stratification is typically most strongly developed during the late summer and consists of three water layers (Figure 2.1).

The upper surface portion of the water column, the epilimnion, is the warmest layer, and the lower bottom layer, the hypolimnion, is the coldest. Between the two is the metalimnion, a layer of water in which a strong temperature gradient, called the thermocline, exists.

In Nova Scotia, the depth of the thermocline during the summer is generally about six metres, unless the lake is colored in which case the thermocline forms at about three metres. Aside from color, the strength and depth of the thermocline, as well as the temperature difference between the epilimnion and hypolimnion, depends on a number of factors, of which exposure to winds is one of the most important.

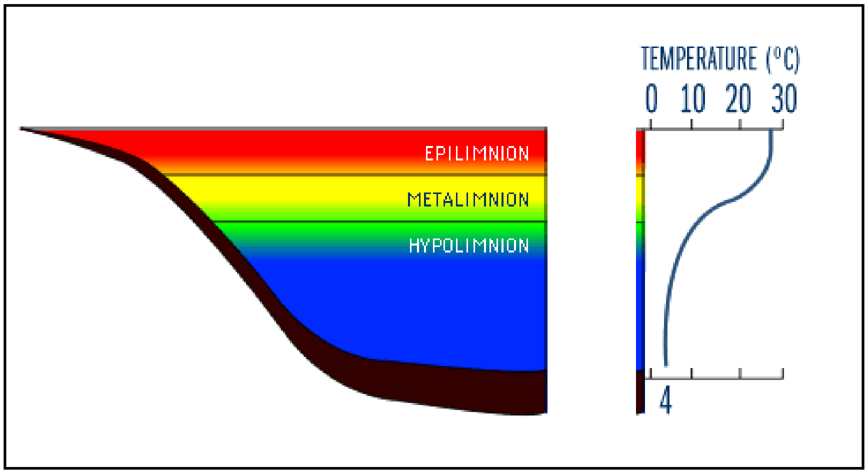


Figure 2.1. Cross section through a stratified lake showing the three water layers and a temperature-depth profile.

Lake stratification typically begins during spring when daylength increases and the lake begins to warm. It ends in the fall when daylength begins to decrease and the surface water cools causing it to sink to the bottom of the lake. At this time the lake undergoes the 'fall overturn' and the bottom waters rise to the surface having been displaced by the sinking surface waters. This process results in bottom waters becoming re-oxygenated in those instances when the lake has experienced a decrease in oxygen during the period of summer stratification.

Temperate zone lakes may also undergo stratification during winter if covered by ice, and this may also result in depletion of oxygen in the bottom waters. Figure 2.2 illustrates the seasonal variation in thermal structure of a lake that undergoes stratification. One of the most significant consequences of stratification is that it limits the degree to which oxygen is mixed from the surface of the lake to the hypolimnion. As a result, if the lake has a high level of algal production, the dead organic matter that eventually results settles to the bottom of the lake where it is metabolized by organisms that consume whatever oxygen was present when the lake first stratified, and the bottom waters may become anoxic.

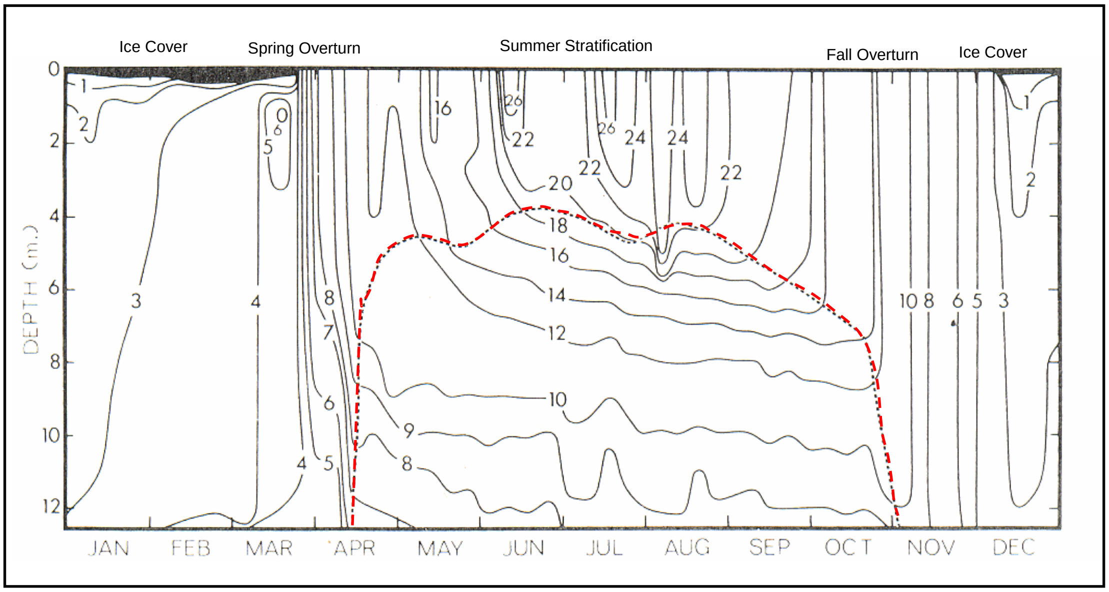


Figure 2.2. A temperature isopleth illustrating the seasonal development of stratification in a lake. The dashed line represents the position of the thermocline. (Modified from Wetzel (1983))

2.2. The Aquatic Phosphorus Cycle

The cycling of phosphorus in aquatic ecosystems is complex and involves physical, chemical and biological transformations (Figure 2.3). The major source of natural phosphorus is through weathering and erosion of rocks where phosphorus exists in a relatively insoluble, oxidized form complexed with metals such as aluminium, iron and magnesium. The resistance of these compounds to dissolution is one of the reasons why phosphorus is so often limiting in aquatic ecosystems.

Once phosphorus enters a water body it has numerous fates. If it exists as an insoluble precipitate, it may settle to the bottom where it becomes buried within the sediments with little chance of being returned to the water column. This is typically the case in an unproductive, well oxygenated lake. If, however, the lake is a productive one, and it contains an anoxic zone, either at the sediment surface or within the bottom water layer, the precipitate may be chemically transformed to a reduced state which is soluble and biologically available. In this case, the phosphorus may become resuspended into the water column where it is available for uptake by plants. This chemical transformation of insoluble phosphorus to a soluble form under anoxic conditions is one of the reasons why a lake that has accumulated phosphorus in its sediments over a long period of time, and that has an anoxic hypolimnion, may take considerable time, often on the order of decades, to respond to a reduction in phosphorus loading.

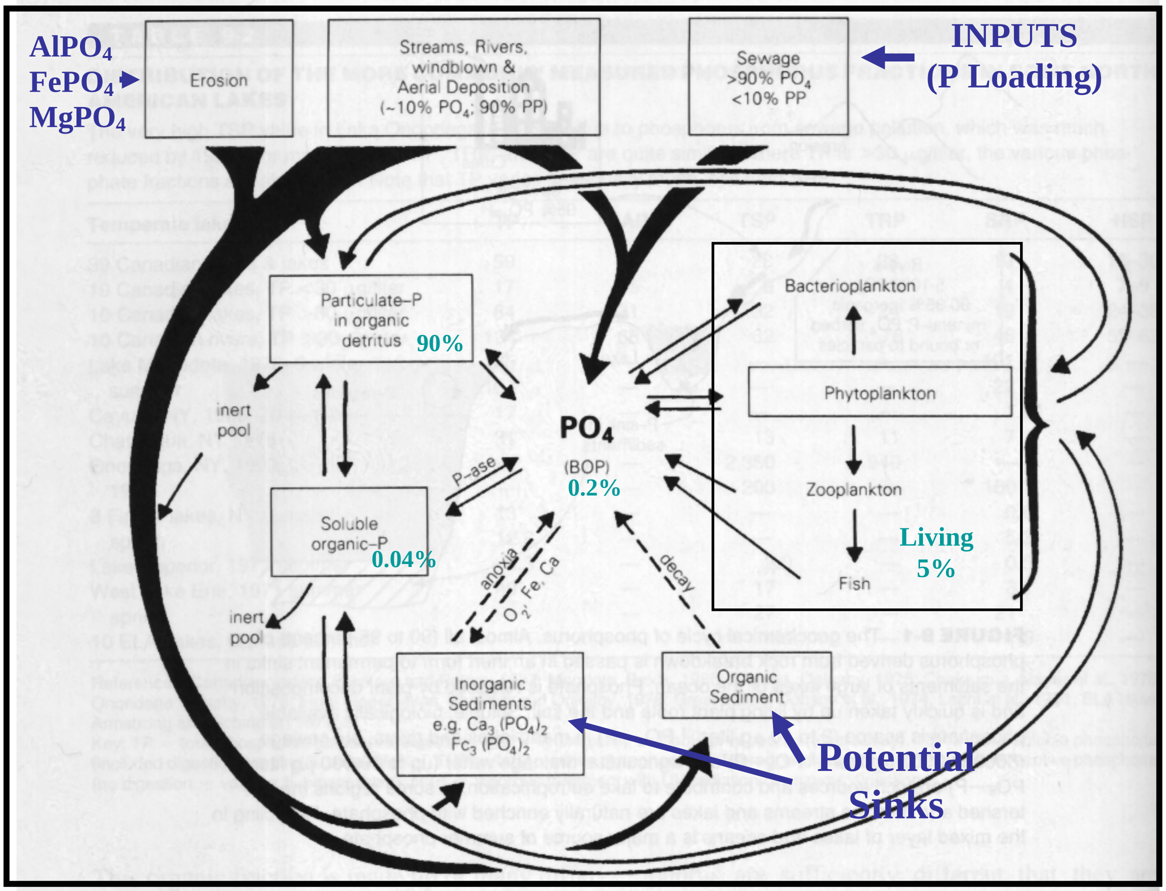


Figure 2.3. The cycle of phosphorus in a lake (percentages represent the relative amounts of phosphorus typically found in each form within the water column of a lake). Modified from Horne and Goldman (1994).

Plants can only assimilate phosphorous in the dissolved inorganic form. This form is referred to as orthophosphate and, because of the rapidity with which plants take it up, it is usually present in very low amounts. Orthophosphate that has been taken up by plants becomes incorporated into the food web as living particulate phosphorus. This pool of phosphorus is much larger than that present as orthophosphate. As organisms die and decay, the phosphorus they contain can be transformed into forms that can be recycled if they remain in the soluble form. By far the largest quantity of phosphorus present in aquatic systems is that contained in the non-living organic particulate form. This is commonly referred to as detrital phosphorus, and consists of dead aquatic organisms as well as terrestrial plants and animals that have been washed into the system. As this pool of organic matter is metabolized by bacteria and other detritus feeding organisms, phosphorus is released and may once again become available to plants to complete the cycle.

2.3. Factors Controlling Algal Growth

The two major factors that control algal growth in aquatic ecosystems are the availability of light and the availability of nutrients, both of which are strongly influenced by the amount of mixing of the water column. In stratified systems, the depth to which algae are mixed is determined by the thermocline depth. If the thermocline depth is shallow, the algae will spend most of the time within the upper portion of the water column where there is usually sufficient light for photosynthesis and, if nutrients are plentiful, will grow rapidly. If, however, the system is unstratified and relatively deep, the algae will be mixed throughout the water column and may spend a significant portion of the time in that part of the water column where light levels are too low to support photosynthesis. In this case, algal growth will be limited, even though nutrients levels may be quite high. Because of the dependency of algal growth on both light and nutrients, stratified systems are more susceptible to becoming eutrophic than are unstratified systems, unless the lake is relatively shallow and sufficient light is available throughout the water column.

3. Model Overview

Figure 3.1 is a hierarchical diagram showing the relationships between the major factors that determine the concentration of phosphorus in a lake. Climate, watershed characteristics and lake morphology are the main determinants, and information on all of these factors is required to construct the model. Climate and watershed characteristics are the main determinants of the amount of water and phosphorus that enters the lake, and the morphological characteristics of the lake determine how much phosphorus remains within the water column of the lake.

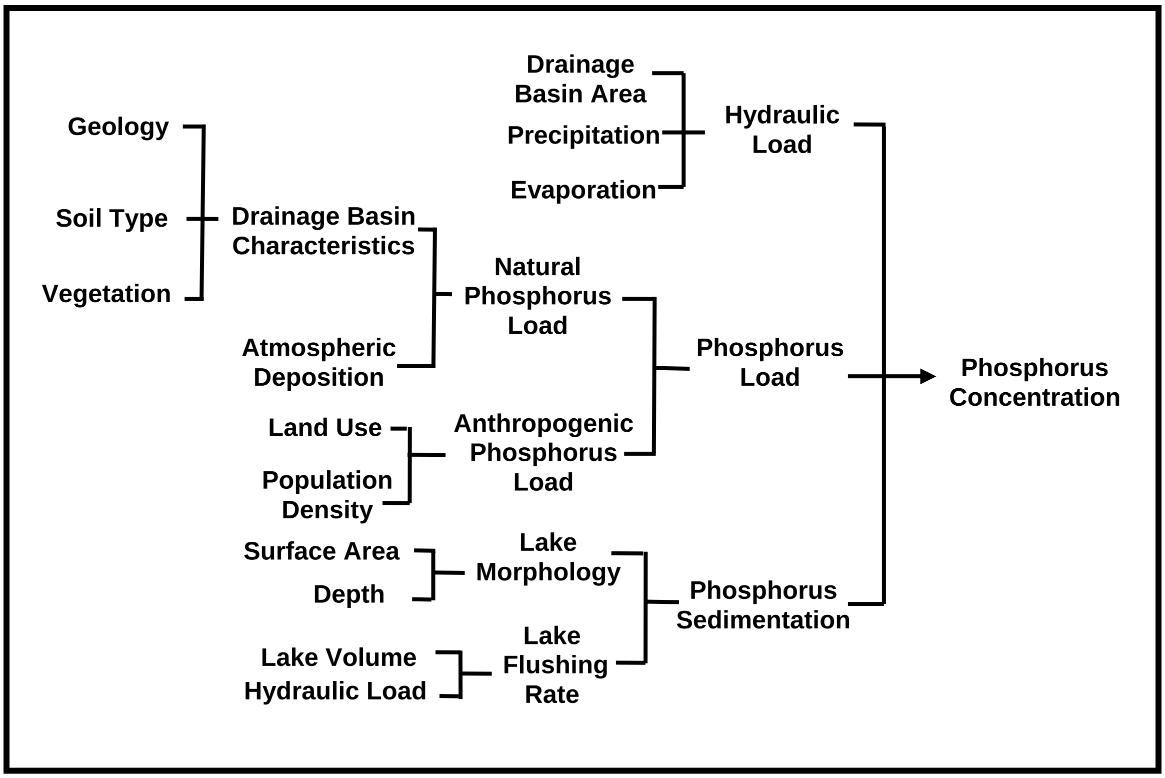


Figure 3.1. Hierarchical diagram illustrating the major factors controlling lake phosphorus concentration.

The spatial extent of the watershed required for the model depends on the relationship of the lake being modeled to other lakes. If the lake is a headwater lake, then only its watershed needs to be included in the model. If, however, the lake receives inputs from lakes located upstream, the watersheds of those lakes will also have to be included in the model.

The mathematical formulation of the model is best described as a black box, mass balance, steady-state model. The term black box implies that the model does not attempt to include any of the processes involved in determining the amount of phosphorus entering the lake, nor any of the biological or chemical processes that phosphorus goes through once it enters the lake. The term mass balance indicates that the model is essentially a budget of the amount of phosphorus entering and leaving the lake, and the term steady-state means that, on an annual time scale, the amount of phosphorus entering the lake is equal to the sum of that which sediments to the bottom and that which leaves the lake via its outflow. The model is essentially an accounting system that sums the hydraulic inputs, phosphorus inputs and amount of phosphorus lost to the sediments to estimate the phosphorus concentration of the lake. Figure 3.2 illustrates this further.

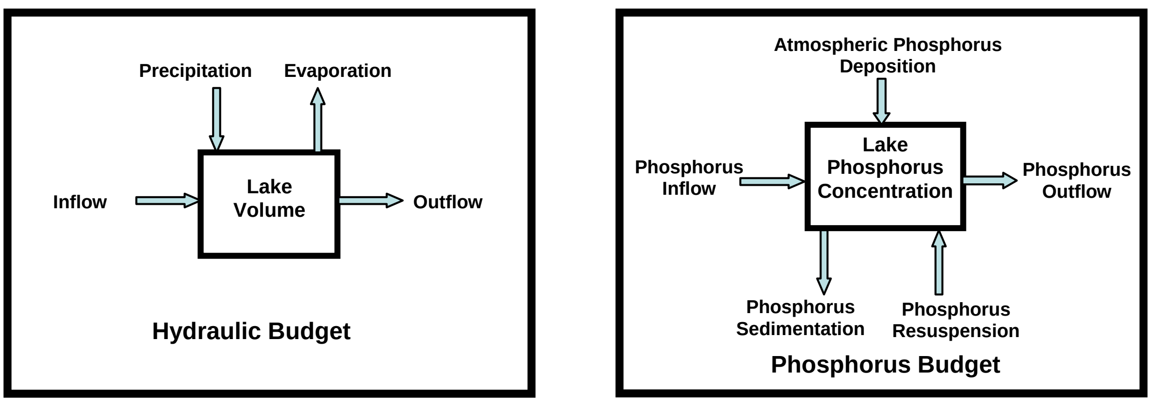


Figure 3.2. Inputs and outputs of the hydraulic and phosphorus budgets.

4. Model Formulation

The general equation used to determine the concentration of phosphorus in the lake once the hydraulic and phosphorous inputs are known is based on formulations originally proposed by Bifi (1963) and Piontelli and Tonolli (1964), and further developed by Vollenweider (1968; 1975).

The Vollenweider model assumes that the change in the amount of phosphorus in the lake over time is equal to the amount of phosphorus entering the lake minus the amount of phosphorus lost to the sediments and the outflow:

$$(\Delta PV / \Delta t) = M - (PV \times Q / V) - (\sigma \times P) \quad \text{where,}$$

PV = Total mass of phosphorus in lake (gm)
P = Lake phosphorus concentration (gm m^{-3})
V = Lake volume (m^3)
t = time
M = Annual mass of phosphorus input to lake (gm yr^{-1})
Q = Annual volume of water outflow from lake (m^{-3} yr^{-1})
σ = Sedimentation coefficient (yr^{-1})

The steady state solution (i.e., setting $\Delta PV / \Delta t = 0$) to this equation is:

$$PV = \frac{M / V}{(Q / V) + \sigma}$$

The major assumptions of the model are:

- Phosphorus entering the lake is mixed throughout the lake,
- The concentration of phosphorus in the outflow is equal to the concentration in the lake,
- The loss of phosphorus by settling to sediments is proportional to its concentration in the lake,
- Seasonal fluctuations in hydraulic and phosphorus loading can be neglected.

A major difficulty encountered in using Vollenweider's model is that it requires knowing the net sedimentation rate of phosphorus once it enters the lake. This has proven to be a difficult parameter to measure, largely because of the problems involved in separating phosphorus settling from phosphorus resuspension under experimental conditions. Based on an analysis of data from 21 temperate zone European and North American lakes, Vollenweider (1976) estimated σ, the phosphorus sedimentation rate, to be equal to approximately 10 divided by the mean depth of the lake. This formulation, however, requires that the mean depth of the lake be known which, in turn, requires a bathymetric survey of the lake. A number of studies (Larsen and Mercier 1976; Canfield and Bachmann 1980) have shown that lake phosphorus retention is highly correlated with the areal hydraulic load. One of the most commonly used formulations for phosphorus retention was developed by Kirchner and Dillon (1975) based on an analysis of Ontario lakes. In this formulation, the proportion of phosphorus lost to the sediments (Rp) is estimated as follows:

$$\mathrm{Rp} = \mathrm{v} / (\mathrm{v} + q_s) \quad \text{where,}$$

v = apparent settling velocity
q_s = areal hydraulic load

In a later study (Dillon et al. 1994), they suggested the use of different values of v depending on whether the lake contained an oxic or anoxic hypolimnion, 12.4 for the former and 7.2 for the latter.

Incorporation of this equation into the Vollenweider steady state equation results in the following equation for lake phosphorus concentration (note that this formulation does not require that the mean depth or volume of the lake be known):

$$\mathrm{P} = \frac{\mathrm{M} \times (1 - \mathrm{Rp})}{\mathrm{Q}}$$

Kalff (2002) provides an excellent discussion of the derivation of this, and other variations, of the Vollenweider formulation.

The general model formulations presented above have been widely used and applied successfully to numerous lakes (Sas 1989). Dillon and Rigler (1975) were the first to incorporate these formulations into what is commonly referred to as an export coefficient model where the phosphorus loadings are estimated using phosphorus export coefficients for the various land use characteristics of a lake's drainage basin.

There are, however, certain types of lakes for which these formulations do not appear to work well (Kalff 2002). These include: colored lakes having high concentrations of humic substances; lakes that have a low nitrogen to phosphorous ratio and are more likely to be limited by nitrogen rather than phosphorus; lakes that have high turbidity and are more likely to be limited by light than nutrients; and lakes that are very shallow and have short residence times (i.e. high flushing rates).

It should be noted that the time scale for models based on these formulations is one year which means that the models can not be used to determine average lake phosphorus concentrations for time periods shorter than this.

There are also numerous other assumptions and limitations associated with this model. In some cases, modifications can be made to the model to deal with these. Some of these limitations, and possible solutions for dealing with them, are discussed in the Supplementary Technical Report contained in Appendix VI.

5. Model Format

The model is formatted as an Excel® workbook and has been designed so that all of the data for a single lake is contained in a separate worksheet. Appendix I contains a sample of the format. If the lake being modeled is a headwater lake, only one worksheet is required. If the lake receives inputs from lakes located upstream, those lakes will also have to be modeled, each as a separate worksheet.*

* An exception to this would be if the upstream hydraulic and phosphorus loadings were already known.

6. Modeling Procedure

Figure 3.4 illustrates the basic steps involved in constructing and applying the model.

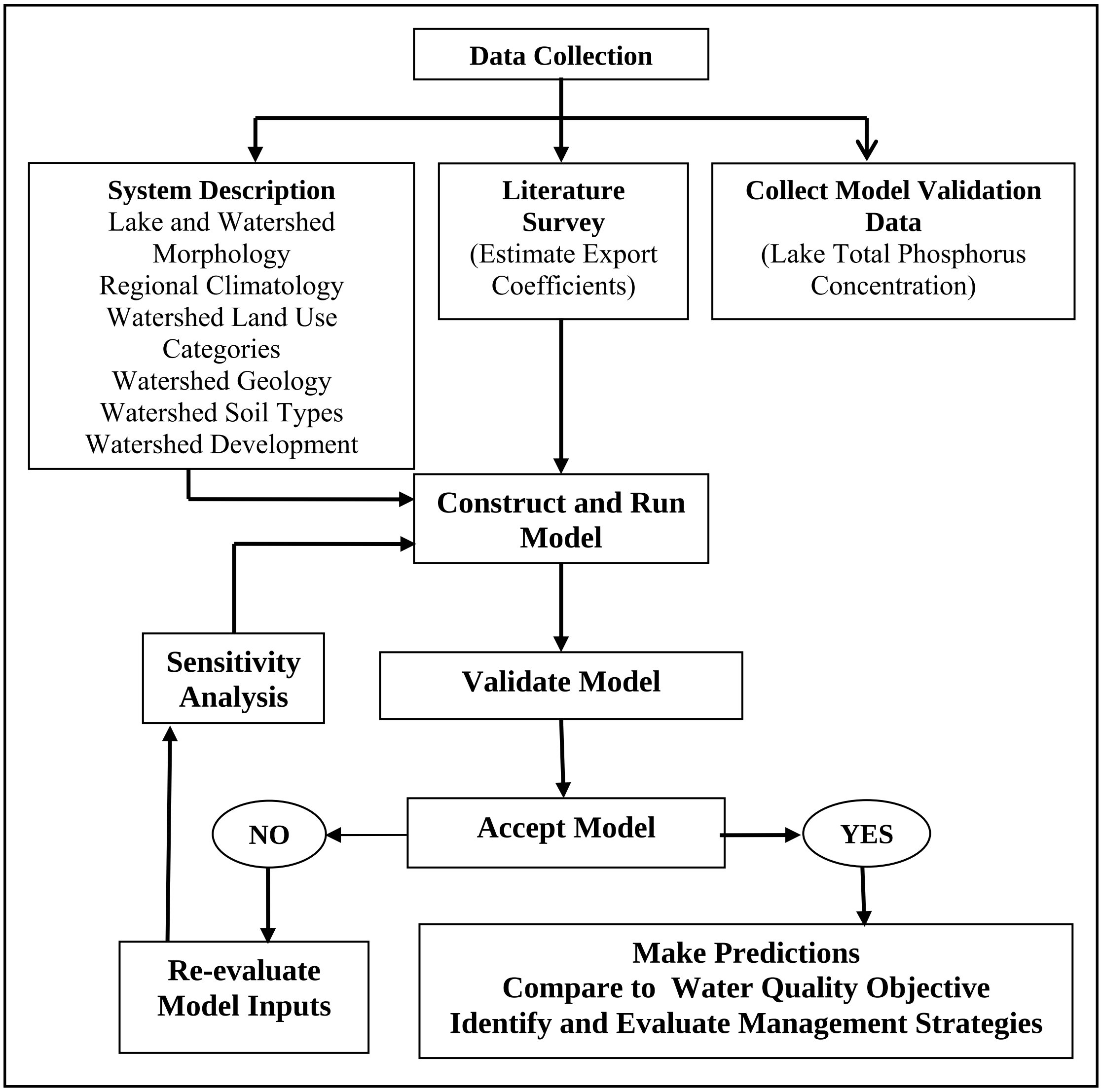


Figure 4.3. Model development and application procedure.

Data assimilated from existing literature and other sources is compiled and used to provide the necessary inputs for the model. The model is validated by comparing its prediction of the lake's total phosphorus concentration with field measurements (see Section 9). If the model prediction and field data agree, the model is considered to be validated and can then be used to determine how changes in the model's input parameters will affect the lake's total phosphorus concentration. If the model prediction and field data do not agree, it will be necessary to review and re-evaluate the data used to estimate the model inputs. In the latter case, it may prove useful to carry out a sensitivity analysis of each model input (see Section 11).

7. Model Construction

7.1. Model Inputs

The information required to construct the model falls into three general categories: (1) drainage basin and lake morphology characteristics; (2) hydraulic inputs; and (3) phosphorous inputs. The specific parameters associated with each of these categories is summarized in Table 7.1

A number of model inputs require estimation of surface areas. Examples include the surface area of the lake, the surface area of the lake's drainage basin and the surface areas of soil, geology and land use types within the drainage basin. In the past, surface areas have typically been measured using a planimeter. There are, however, other ways to estimate surface areas. One of the best and often most precise are those that use Geographic Information System (GIS) databases containing digital elevations and land use characteristics. These are often available through Municipal and Provincial planning agencies. If a GIS database is not available, it will be necessary to obtain maps containing the necessary information and to estimate areas using planimetry.*

There are also a number of image analysis programs that can be used to estimate surface areas. They require a digital image of the area to be estimated, which may be available from the same agencies that have GIS databases, or which can be obtained by digital scanning of an aerial photographs or maps. One potential disadvantage is that the scale of the image may be too small to obtain accurate results if the watershed or lake is large.

* Wetzel and Likens (1991) is an excellent source of information on planimetric procedures.

Appendix II contains a listing of agencies that can be contacted to obtain maps and other data required to estimate model parameters.

Table 7.1. Model inputs.

Morphological Parameters	Symbol	Units
Drainage Basin Area (exclusive of lake)	Ad	m^2
Surface Area of Each Land Use Category	Adi	m^2
Lake Surface Area	Ao	m^2
Lake Volume	V	m^3
Hydraulic Input Parameters		
Upstream Hydraulic Inputs	Qi	$m^3\ yr^{-1}$
Annual Unit Precipitation	Pr	$m\ yr^{-1}$
Annual Unit Lake Evaporation	Ev	$m\ yr^{-1}$
Annual Unit Hydraulic Run Off	Ru	$m\ yr^{-1}$
Phosphorus Input Parameters		
Upstream Phosphorus Input	Ji	$gm\ yr^{-1}$
Annual Unit Atmospheric Phosphorus Deposition	D	$gm\ m^{-2}\ yr^{-1}$
Annual Unit Phosphorus Export from Land*	Ei	$gm\ m^{-2}\ yr^{-1}$
Number of Dwellings	Nd	#
Average Number of Persons per Dwelling	Nu	#
Average Fraction of Year Dwellings Occupied	Npc	yr^{-1}
Phosphorus Input per Capita Year	Si	$gm\ capita^{-1}\ yr^{-1}$
Septic System Retention Coefficient	Rsp	-
Point Source Phosphorus Inputs	PSi	$gm\ yr^{-1}$
Lake Phosphorus Retention Coefficient	v	-

*A separate estimate is required for each combination of geology, soil type and land use present in the drainage basin.

7.1.1. Morphology

7.1.1.1. Drainage Basin Area (Ad)

Estimation of the drainage basin area requires using a topographic map (typically at scales of 1:10,000 or 1:50,000) to define the watershed boundary. The watershed boundary is the area between the highest points of land and the outlet of the lake. This area is outlined on the topographic map and then, by planimetry or some other available method, the area of the drainage basin is estimated. Use of the largest scale map available that includes the entire drainage basin will provide the most accurate estimates. The surface area of the lake should not be included as part of the drainage basin area.

7.1.1.2. Surface Area of Each Land Use Category (Adi)

If the drainage basin of the lake contains more than one type of land use and/or varies in geology and soil type, it will be necessary to estimate the surface area of each combination of land use and soil type since these are likely to differ in their phosphorus export coefficients.

7.1.1.3. Lake Surface Area (Ao)

The surface area of the lake is determined by planimetry using either aerial photographs, topographic maps or GIS databases. In some cases this, and other lake morphological characteristics, can be obtained from the Nova Scotia Department of Agriculture and Fisheries Lake Survey database. The Province has surveyed almost 2000 lakes in Nova Scotia and this information is readily available.

If the lake contains islands, the surface area of the islands should not be included as part of the lake's surface area, but should be included as part of the lake's drainage basin.

7.1.1.4. Lake Volume (V)

Although the volume of the lake is not, in most cases, required to predict the lake's phosphorus concentration, it is required for calculation of the lake's mean depth, residence time, turnover rate and response time (see Section 7.2.3).

Determining the volume of the lake requires having a bathymetric map that shows the area of the lake at each depth. This information is then used to construct a hypsographic curve, which represents the change in surface area with depth. The area under the curve is then integrated by planimetry to determine the volume of the lake. Alternatively, the volume of the lake can be determined using the formula for either a truncated pyramid or truncated cone (see Appendix V for an example).

7.1.2. Hydrology

7.1.2.1. Upstream Hydraulic Inputs (Qi)

If the lake being modeled is not a headwater lake, it will be necessary to determine the hydraulic input from any upstream lakes that flow into the lake. Unless this is known from field measurements of stream and river inflows into the lake, it will be necessary to estimate the hydraulic input using the same procedures as for the lake being modeled.

7.1.2.2. Annual Unit Precipitation (Pr)

An estimate of the total annual precipitation, expressed on a square metre basis, is required to account for the precipitation input that falls directly onto the lake. This information can be obtained from the Canadian Climate Normals (see Appendix II). Long-term averages (e.g., 20 year means) from the nearest weather station should be used.

7.1.2.3. Annual Unit Lake Evaporation (Ev)

Evaporation from the surface of the lake is required to estimate the lake outflow. This parameter is the evaporation rate per square metre per year. This information can be also be obtained from the Canadian Climate Normals. As is the case for precipitation, long-term averages should be used.

7.1.2.4. Annual Unit Hydraulic Run Off (Ru)

The average annual unit water run off is the amount of water, expressed as m yr^{-1}, (this is the same as m^3 m^{-2} yr^{-1}) that runs off the drainage basin and flows into the lake. It represents net run off and is the difference between precipitation and evapotranspiration. It should not include groundwater inputs to the lake.

Ideally, this should be estimated from direct measurements made at weirs located at the inputs or outputs of the lake. This information, however, is seldom available and is costly to obtain. In most cases, it will be necessary to estimate this parameter from other studies. An isorunoff map for Nova Scotia is contained in Appendix III and can be used to obtain a rough estimate when more precise data is unavailable.

7.1.3. Phosphorus Inputs

The most critical data input for the model is the phosphorus loading to the lake. This includes both point source loadings, such as the effluent of sewage treatment plants and storm sewers, and non-point inputs such as atmospheric deposition and surface run off from forested and agricultural lands. Although direct measurement of phosphorus loading to the lake would provide the most accurate data, this is often impractical to do because of the effort and cost involved. In addition, if the model is to be used to predict how the lake's phosphorus concentration would change as a result of changes in land use, it is essential that land use characteristics, and the amount of phosphorus run off associated with each land use, be incorporated into the model.

7.1.3.1. Upstream Phosphorus Input (Ju)

If the lake being modeled is not a headwater lake, phosphorus inputs from streams and rivers draining the watersheds and lakes located upstream must also be estimated (from either field measurements or model estimates) in order to determine the total phosphorus input to the lake.

7.1.3.2. Annual Unit Atmospheric Phosphorus Deposition (Da)

Atmospheric deposition includes dry deposition of particulate phosphorus transported by wind to the lake, and wet deposition of phosphorus dissolved in the precipitation falling directly onto the lake. Estimates of the dryfall portion are often 70 to 90 % of the total deposition (Likens and Loucks 1978). Sources of phosphorus transported to a lake by atmospheric deposition can originate outside of the lake's watershed. Atmospheric deposition tends to be highest in areas surrounding agricultural lands as a result of wind erosion of fertilized soils, and within urban areas as a result of the fly ash produced by burning of fossil fuels.

There have been very few measurements of atmospheric phosphorus deposition for Nova Scotia. Studies by Hart (1977), Hart et al. (1978) and Thirumurthi and Hart (1985) carried out in the Halifax area and the headwater region of the Shubenacadie River watershed suggest that a value of 0.025 gm m^{-2} yr-^{1} is a reasonable estimate for Nova Scotia. Lowe (2002) estimated a value of 0.014 gm m^{-2} yr^{-1} for the Wolfville area. The lower value may be related to differences in the relative degree of urban development. Measurements made by Underwood (1984) for various areas in Nova Scotia suggest an average value of about 0.017 gm m^{-2} yr-^{1}.

7.1.3.3. Annual Unit Phosphorus Export from Land (Ei)

The export of phosphorus from the land is expressed as an export coefficient which is the amount of phosphorus carried into the lake by surface water run off, expressed as gm per square metre per year. The value of export coefficients vary depending on geology, soil type and land use and require analyzing the drainage basin of the lake to determine what combination of these characteristics it possesses. Phosphorus export coefficients are often the most difficult model parameter to estimate because of the diversity of climate, geology, soil type and land use activity that can occur in a watershed.

The first step is to partition the drainage basin according to its various combinations of geology, soil type, and land use and determine the area of each partition. Maps depicting geology, soil type and forest type cover are readily available from various Provincial agencies. Land use characteristics are often available from Municipal databases and in many cases are available in GIS formats. Recent aerial photography is also a useful resource for delineating land use characteristics. It is always a good idea to ground truth the results of any land use interpretations, especially if the maps or photos being used are not recent (i.e., more than 3-5 years old).

Once appropriate maps and photos have been acquired, it is necessary to determine the surface area of each land use category, along with the underlying soil type and geology. The general land use categories most often considered in the development of phosphorus loading models are forest lands, cultivated and uncultivated agricultural land, wetlands and developed urban and residential lands. While there is considerable variation in the amount of phosphorus exported from a given land use category, partly as a result of differences in climate, soil type and geology, some general patterns have emerged (Reckhow et al. 1980). These are summarized below

Climate:

- Warm climates with high rainfall have higher export coefficients than those with colder, dryer climates

- The amount, intensity and duration of precipitation have a large influence on phosphorus export coefficients

Geology and Soil Types

- Sandy soils overlying granitic igneous formations tend to have high nutrient export

- Loamy soils contain more nutrients and are more subject to erosion than sandy and gravely soils and tend to have higher export coefficients

- Clay soils are highly erosive, have poor water infiltration and a high capacity to adsorb phosphorus which results in high export

- Organic soils have high nutrient contents, poor infiltration capacity, limited phosphorus retention capacity and high export

Forestry

- Relative to other land uses, phosphorus export from forests is generally low, on the order of 0.001 to 0.015 gm m^{-2} yr^{-1}
- Forested watersheds with sandy soils overlying granitic igneous formations export about one-half the phosphorus than do forested watersheds with loamy soils overlying sedimentary formations
- Deforested watersheds have high export of phosphorus
- Young (<5 years old) forests have relatively high phosphorus export

Cultivated Lands

- Phosphorus export from cultivated lands tends to be very high and variable
- Heavily fertilized or manured lands, particularly if over-fertilized, have high phosphorus export, but this is reduced considerably if the fertilizer or manure is worked into the soil shortly after application
- Pasture and grazing land, if overgrazed or fertilized, export high amounts of nutrients
- Feedlots, especially if uncovered and exposed to precipitation, have high phosphorus export

Urbanization

- Urban run off tends to export high amounts of phosphorus and, since it is often channelled into storm drains, may contain discharges originating from more than one watershed

Because export coefficients vary depending on a multitude of factors, unless they have been measured in the watershed being modeled, the choice of the most appropriate export coefficient to use remains somewhat subjective. It is very important to attempt to match climate, geology, soil and vegetation type as closely as possible when estimates are based on studies that have been carried out in other areas,

Land Use Export Coefficients Measured in Nova Scotia

There have been a few studies carried out in Nova Scotia to determine phosphorous export coefficients from various combinations of geology, soil type and land use. Scott et al. (2000) carried out the most extensive study. The results are listed in Table 7.2.

Table 7.2. Phosphorus export coefficients measured by Scott et al. (2000) for various Nova Scotia watersheds.

Watershed Location	Geology[1]	Soil Type[2]	Land Use (%)							Phosphorus Export (gm m^{-2} yr^{-1})
			Forest	Clear Cut	Wetland	Agriculture	Barren	Urban	Other[3]	
Halifax	I	C	83.5	0.0	4.6	0.0	4.1	7.1	0.7	0.0166
Halifax	I	C	88.2	0.0	9.9	0.0	0.0	0.0	1.9	0.0137
Halifax	I	C	45.0	0.0	0.0	0.0	0.0	0.0	55.0	0.0024
Petit Etang	I	C	63.7	0.0	26.5	0.0	8.6	0.0	1.2	0.0107
Petit Etang	I	C	81.5	0.0	18.3	0.0	0.0	0.0	0.2	0.0041
Prospect	I	M-C	76.4	19.5	0.9	1.6	0.0	0.6	1.0	0.0083
Gillisdale	I	M	97.1	0.6	0.0	2.1	0.0	0.0	0.2	0.0130
Wentworth	I	M	86.1	7.9	0.5	2.5	0.0	0.8	2.3	0.0056
Wentworth	I	M	87.9	8.8	0.9	0.0	0.0	0.1	2.2	0.0041
Wentworth	I	M	85.2	11.1	0.4	0.0	0.0	0.4	2.9	0.0042
Wentworth	S	M	85.6	5.6	1.5	5.4	0.0	0.0	1.9	0.0087
Wentworth	S	M	93.1	1.8	4.8	0.0	0.0	0.0	0.3	0.0072
Wentworth	S	M	85.9	5.0	1.0	4.5	0.0	0.6	3.0	0.0108
Mount Thom	S	M	88.8	5.0	0.8	2.8	0.0	0.3	2.4	0.0058
Mount Thom	S	M	86.7	6.2	0.7	2.8	0.0	0.3	3.2	0.0061
Mount Thom	S	M	79.9	8.9	0.2	6.1	0.0	3.4	1.5	0.0143
Union Centre	S	M	81.1	5.5	0.5	7.4	0.0	0.7	1.9	0.0073
Union Centre	S	M	83.7	4.4	0.5	4.3	0.0	0.6	2.1	0.0058
Union Centre	S	M	83.3	2.4	0.6	3.2	0.0	0.4	2.3	0.0054
Union Centre	S	M	86.6	4.7	1.0	5.1	0.0	0.5	2.2	0.0058
Mount Thom	S	M	82.9	6.4	9.5	0.7	0.0	0.0	0.5	0.0116
Mount Thom	S	M	82.4	6.5	9.0	1.5	0.1	0.0	0.6	0.0104
Mount Thom	S	M	83.2	5.5	7.1	3.2	0.2	0.0	0.8	0.0126
Mount Thom	S	M	82.5	10.9	4.4	0.0	0.3	0.0	1.8	0.0061
Mount Thom	S	M	77.9	16.1	0.2	5.2	0.0	0.3	0.3	0.0195
Streets Ridge	S	F	80.0	12.1	1.5	3.5	0.0	0.1	2.9	0.0071

[1]I - Igneous; S - Sedimentary
[2]F - Fine (>15% clay); M – Medium (5 to 15% clay); C - Coarse (<5% clay)
[3]Mainly roads and open water

In a summary of their results, Scott et al. (2000) suggest the following general export values:

- Igneous Forested Watersheds – 0.0069 gm m^{-2} yr^{-1}
- Igneous Forested Watersheds with >15% cleared/wetland – 0.0083 gm m^{-2} yr^{-1}
- Sedimentary Forested Watersheds – 0.0088 gm m^{-2} yr^{-1}
- Sedimentary Forested Watersheds with >5% cleared/wetland – 0.0115 gm m^{-2} yr^{-1}

Lowe (2002) carried out a similar study for a number of stream catchments located in the Gaspereau River watershed. The estimated phosphorus export coefficients (Table 7.3) are considerably higher than those reported by Scott et al. (2000). The difference may be related to the highly colored waters typical of the lower reaches of the Gaspereau watershed where the study was carried out.

Table 7.3. Phosphorus export coefficients measured by Lowe (2002) for watersheds located in the Gaspereau River system, Kings County, Nova Scotia.

Geology	Soil Type	Land Use (%)				Phosphorus Export (gm m^{-2} yr^{-1})
		Forest	Clearcut	Wetland	Agriculture	
Igneous	Coarse	99	0	1	0	0.0327
Igneous	Coarse	85	15	0	0	0.0634
Igneous	Medium Coarse	80	14	0	6	0.0304
Sedimentary	Medium Fine	79	3	0	18	0.0354
Sedimentary	Medium Fine	80	4	0	16	0.0408
Sedimentary	Medium Fine	89	4	3	4	0.0213
Sedimentary	Fine/Coarse	98	1	0	1	0.0191
Sedimentary	Medium Fine	74	4	0	22	0.0311
Sedimentary	Medium Fine	72	8	0	20	0.0321
Igneous	Fine/Coarse	69	6	2	23	0.0624

Some phosphorus export coefficient estimates are also available for Maine which has similar climate, geological and soil characteristics to Nova Scotia. The following export coefficients were established by the Maine Department of Environmental Protection (2000) based on an extensive survey of values reported in the literature:

- Managed Forests (ca. 15 % clearcut/10% selective cut) - 0.050-0.075 gm m^{-2} yr^{-1}
- Unmanaged Forest – 0.0035-0.0050 gm m^{-2} yr^{-1}
- Agriculture (Rotation Crops) – 0.150-0.350 gm m^{-2} yr^{-1}
- Agriculture (Using Soil Conservation Practices) – 0.010-0.030 gm m^{-2} yr^{-1}
- Residential Lots – 0.025-0.035 gm m^{-2} yr^{-1}
- Logging Roads – 0.35 gm m^{-2} yr^{-1}
- Public Highways – 0.35 gm m^{-2} yr^{-1}
- Camp/Private Roads – 0.35 gm m^{-2} yr^{-1}

Reckhow et al. (1980) carried out and an extensive literature survey of export coefficients and compiled the summary listed in Table 7.4.

Table 7.4. Summary of land use phosphorus export coefficients (gm m^{-2} yr^{-1}) compiled by Reckhow et al. (1980).

Land Use	Range	Median	Mean
Forest	0.0019 - 0.0083	0.0021	0.0024
Row Crops	0.0026 - 0.1860	0.0224	0.0446
Non-row Crops	0.0010 – 0.0290	0.0076	0.0108
Grazing/Pasture Land	0.0014 - 0.0490	0.0081	0.0150

Run off coefficients for land uses other than those listed above will have to be estimated from literature containing coefficients measured in other regions of North America. (See Appendix IV for literature references of compiled export coefficients.) It should be noted that the utmost care should used in deciding if an estimate is really applicable to the situation that exists in the watershed being modeled. Export coefficients are among the most sensitive parameters determining the level of phosphorous concentration predicted by the model.

Urban Run Off

Urban areas typically have a high run off of phosphorus. Sources include run off from pavement (roads, parking lots and driveways) and lawns and leaf fall.

Reckhow et al. (1980) list a wide variety of export coefficients for urban areas, ranging from 0.0019 to 0.0623 gm m^{-2} yr^{-1}. The lowest values were for areas of low density housing and the highest for high density housing areas.

Waller and Hart (1986) estimated surface run off from urban areas in Ontario to be about 0.11 gm m^{-2} yr^{-1}. They also presented the following estimates for impervious urban areas in Halifax:

Residential/Vegetation/Low Traffic	0.186 gm m^{-2} yr^{-1}
Commercial/No Vegetation/High Traffic	0.202 gm m^{-2} yr^{-1}
Commercial/Vegetation/Moderately High Traffic	0.398 gm m^{-2} yr^{-1}
Institutional/No Vegetation/Low Traffic	0.042 gm m^{-2} yr^{-1}

7.1.3.4. Development Inputs (Nd, Nu, Npc, Si, Rsp)

Development input is the amount of phosphorus supplied to the lake from the human population present in the watershed. It is based on a determination of the number of capita-years in the watershed, the amount of phosphorus produced per capita and the proportion of the phosphorus produced that enters the lake. It also includes point source inputs of phosphorus. Although some of this information may be available from local planning offices, it will most likely have to be gathered from surveys. The information required to estimate the number of capita-years is as follows:

- **Nd -** the number of dwelling units within 300 m of the shoreline of the lake and any tributaries that enter into the lake
- **Nu -** the average number of people occupying the dwellings
- **Npc -** the average fraction of the year each dwelling is occupied

The amount of phosphorus produced per capita (**Si**) depends on the nature of the activities of the population residing in the watershed, and whether the residences are simple recreational cottages or full time residences. Factors such as the use of fertilizer for gardening and lawn maintenance, use of phosphate based detergents and prevalence of garbage grinders are some of the factors that should be considered. Estimates of the amount of phosphorus inputs to septic systems range from as low as 300 to as high as 1800 gm P $capita^{-1}$ $year^{-1}$ (Uttormark 19 74; Reckhow et al.1980), the higher values being for areas where phosphate detergents are used. A commonly used estimate in many models is 800 gm P $capita^{-1}$ yr^{-1} (Dillon et al. 1986).

The final parameter required to estimate phosphorus input from residential development is a measure of the adsorption capacity (**Rsp**) of the soils in which the septic systems are located. This depends on factors such as the age of the septic system, the frequency of maintenance, the physical and chemical characteristics of the soil surrounding the system, and the degree to which the system interacts with the water table. Hart et al. (1978) estimated that septic systems on Halifax and Wolfville soils retained about 50% of the phosphorus input to septic systems. In instances where the model is being used to make conservative predictions of the potential long-term consequences of residential development, the septic system retention coefficient is often assumed to equal zero (see e.g., Horner Associates Ltd. 1995).

7.1.3.5. Point Source Inputs (PSi)

The previous discussion of phosphorus loading has dealt with non-point sources of phosphorus. There are a number of potential point sources of phosphorus that also need to be considered. Examples include inputs from sewage treatment plants, livestock feedlots and aquaculture operations.

Sewage Treatment Plants

Sewage treatment plants (STP) are often the most important point source inputs to water bodies receiving influents from domestic wastes that discharge either into a lake itself or a tributary leading into a lake. Although the quality of STP effluents is required to be monitored, the amount of phosphorus contained in STP effluents is not always included in the water quality parameters monitored. In this case, it becomes necessary to estimate the phosphorus loading based on the number of persons the plant services. Table 7.5 provides estimates of the effluent phosphorus load for Ontario STPs having various levels of treatment.

Table 7.5. Total phosphorus load in the final effluent for various levels of wastewater treatment (from Chambers et al. (2001) based on data contained in OMEE (1993)).

Treatment Type	P Removal	Number of Samples	Effluent Load (gm P capita^{-1} yr^{-1})
Primary	No	9	624.2
	Yes	19	273.5
	Average	**28**	**386.9**
Secondary	No	46	376.0
	Yes	137	153.3
	Average	**183**	**211.7**
Lagoons	No	45	284.7
	Yes	76	73.0
	Average	**121**	**153.3**
Tertiary	No	2	372.3
	Yes	33	54.8
	Average	**35**	**73.0**

Livestock Feedlots

Animal feedlots are also usually treated as point sources of phosphorus export. Measured export coefficients are very high, on the order of 30 gm m^{-2} yr^{-1} for intensive operations (Rast and Lee 1977).

Aquaculture Operations

Inland aquaculture operations are also potential point sources of phosphorus. Within Nova Scotia, salmonid aquaculture is most common. The amount of phosphorus exported depends mainly on the type and amount of food used. For salmonids, current operations use high nutrient dense feeds which contain about 1% phosphorus by weight, of which approximately one-third is assimilated by the fish and two-thirds is exported in the effluent (personal communication; J. Blanchard, Nova Scotia Department of Agriculture and Fisheries). It is therefore possible to estimate the total amount of phosphorus exported based on the amount of food used.

7.1.3.6. Lake Phosphorus Retention Coefficient (v)

The amount of phosphorus retained within the lake as a result of phosphorus settling to the sediments requires an estimate of the phosphorus retention coefficient (see Section 4 for the coefficients developed by Dillon et al (1986).

7.2. Model Outputs

The outputs of the model are listed in Table 7.6.

Table 7.6. Model outputs.

Parameter	Symbol	Units
Total Precipitation Hydraulic Input	Ppt_i	m^3 yr^{-1}
Total Evaporation Hydraulic Loss	E_o	m^3 yr^{-1}
Total Hydraulic Surface Run Off	Q_l	m^3 yr^{-1}
Total Hydraulic Input	Q_t	m^3 yr^{-1}
Areal Hydraulic Load	*qs*	m yr^{-1}
Total Hydraulic Outflow	Q_o	m^3 yr^{-1}
Atmospheric Phosphorus Input	Jd	gm yr^{-1}
Surface Run Off Phosphorus Input	Je	gm yr^{-1}
Development Phosphorus Input	Jr	gm yr^{-1}
Total Phosphorus Input	Jt	gm yr^{-1}
Lake Phosphorus Retention Factor	Rp	-
Lake Phosphorus Retention	P_s	gm yr^{-1}
Lake Phosphorus Concentration	[P]	mg L^{-1}
Total Phosphorus Outflow	Jo	gm yr^{-1}
Lake Mean Depth	z	m
Lake Flushing Rate	FR	times yr^{-1}
Lake Turnover Time	TT	yr
Lake Response Time	RT(1/2)	yr

7.2.1. Hydrology

7.2.1.1. Total Precipitation Hydraulic Input (Ppt_i)

The total amount of precipitation input to the lake is calculated as follows:

$$Ppt_i = Ao \times Pr \quad \text{where,}$$

Ao = Lake Surface Area
Pr = Annual Unit Precipitation

7.2.1.2. Total Evaporation Hydraulic Loss (Eo)

The total loss of water due to evaporation from the lake is calculated as follows:

$$Eo = Ao \times Ev$$ where,

Ao = Lake Surface Area
Ev = Annual Unit Lake Evaporation

7.2.1.3. Total Hydraulic Surface Run Off (Ql)

The total amount of water entering the lake from land run off is calculated as follows:

$$Q_l = Ad \times Ru$$ where,

Ad = Drainage Basin Area
Ru = Annual Unit Water Run Off

7.2.1.4. Total Hydraulic Input (Qt)

The Total Hydraulic Input to the lake is calculated as the sum of all water inputs to the lake:

$$Qt = P_{pti} + Q_l + Qi$$ where,

P_{pti} = Total Precipitation Input
Q_l = Total Hydraulic Surface Run Off
Qi = Upstream Hydraulic Input

7.2.1.5. Areal Hydraulic Load (q_s)

The Areal Hydraulic Load to the lake is the amount of water entering the lake relative to the surface area of the lake. It is calculated as the ratio of the total annual water input minas evaporation and the lake surface area:

$$qs = (Qt - Eo / A_o)$$ where,

Q_t = Total Hydraulic Input
E_o = Evaporation Hydraulic Loss
A_o = Lake Surface Area

7.2.1.6. Total Hydraulic Outflow (Q_o)

The Total Annual Hydraulic Outflow is calculated as the Total Hydraulic Input minus Evaporation for the lake surface:

$$Q_o = Q_t - E_o$$ where,

Q_t = Total Hydraulic Input
E_o = Evaporation Loss

7.2.2. Phosphorus

7.2.2.1. Atmospheric Phosphorus Input (Jd)

The Atmospheric Phosphorus Input is calculated as the product of the Annual Unit Atmospheric Deposition and the Lake Surface Area:

$$Jd = D \times A_o$$ where,

D = Annual Unit Atmospheric Deposition
A_o = Lake Surface Area

7.2.2.2. Total Surface Run Off Phosphorus Input (Je)

The Total Surface Run Off Phosphorus Input is the sum of all the phosphorus export from each land use class:

$$Je = Ad_i \times Ei$$ where,

Ad_i = Area of land use i
Ei = Annual unit phosphorous export from land use i

7.2.2.3. Development Phosphorus Input (Jr)

The Development Phosphorus Input is the sum of phosphorus inputs from all point sources and dwellings within the lake's drainage basin:

$$Jr = \Sigma PS_i + (N_d \times N_u \times N_{pc} \times S_i \times (1 - Rsp)) \quad \text{where,}$$

PS_i = Total phosphorus input from Point Source i
N_d = Number of dwellings in the drainage basin
N_u = Average number of persons occupying each dwelling
N_{pc} = Average fraction of the year dwelling are occupied
S_i = Phosphorus load per capita year
Rsp = Septic system retention coefficient

7.2.2.4. Total Phosphorus Input (Jt)

The Total Phosphorus Input is the sum of all phosphorus inputs to the lake. These include upstream phosphorus input, atmospheric phosphorus deposition, phosphorus surface run off, and phosphorus inputs due to development:

$$Jt = Ji + Jd + Je + Jr \quad \text{where,}$$

Ji = Upstream Phosphorus Input
Jd = Atmospheric Phosphorus Input
Je = Surface Run Off Phosphorus Input
Jr = Development Phosphorus Input

7.2.2.5. Lake Phosphorus Retention Factor (Rp)

The Lake Phosphorus Retention Factor is the fraction of phosphorus entering the lake that is lost by settling to the sediments:

$$Rp = v / (v + q_s) \quad \text{where,}$$

v = Phosphorus Retention Coefficient[1]
q_s = Areal Hydraulic Load

[1] 12.4 for lakes with an oxic hypolimnion and 7.2 for lakes with an anoxic hypolimnion

7.2.2.6. Lake Phosphorus Retention (Ps)

The amount of phosphorus that is retained in the lake as a result of being lost to the sediments is calculated from the Total Phosphorus Input and the Phosphorus Retention Factor:

$$Ps = Jt \times Rp \quad \text{where,}$$

Jt = Total Phosphorus Input
Rp = Phosphorus Retention Factor

7.2.2.7. Lake Phosphorus Concentration ([P])

The Lake Phosphorus Concentration is calculated as the Total Phosphorus Input minus the amount lost to sedimentation divided by the Total Hydraulic Outflow:

$$[P] = (Jt - Ps) \,/\, Q_o) \quad \text{where,}$$

Jt = Total Phosphorus Input
Ps = Phosphorus Retention
Q_o = Total Hydraulic Outflow

7.2.2.8. Lake Phosphorus Outflow (Jo)

The amount of phosphorus that flows out of the lake is the difference between the total phosphorus input and the amount of phosphorus retained by the lake as a result of settling to the sediments:

$$Jo = Jt - Ps \quad \text{where,}$$

Jt = Total Phosphorus Input
Ps = Lake Phosphorus Retention

7.2.3. Lake Characterization Parameters

The following parameters essentially characterize the lake's hydraulic characteristics and can be important in determining the choice of formulations to use for calculation of phosphorus retention. They all require that the volume of the lake be known.

7.2.3.1. Mean Depth (z)

The Mean Depth of the lake is calculated as the ratio of the surface area and volume of the lake:

$$z = Ao / V \quad \text{where,}$$

Ao = Lake Surface Area
V = Lake Volume

7.2.3.2. Flushing Rate (FR)

The Flushing Rate is the number of times a volume of water equal to the volume of the lake flows through the lake per year. It is calculated as:

$$FR = Q_o / V \quad \text{where,}$$

Q_o = Total Hydraulic Outflow
V = Lake Volume

7.2.3.3. Turnover Time (TT)

The Turnover (or residence) Time of a lake is the average amount of time that water remains in the lake. It is the reciprocal of the lake's flushing rate and is calculated as follows:

$$TT = V / Qo \quad \text{where,}$$

V = Lake Volume
Q_o = Total Hydraulic Outflow

The longer the residence time, the greater the amount of phosphorus that will be subject to sedimentation and lost to the sediments.

7.2.3.4. Response Time (RT(1/2))

The Response Time of a lake is a measure of the time it would take for the lake to respond to a change in its phosphorus loading. Response time is a function of the lake's flushing rate and is independent of either the lake's phosphorus load or content. Because the rate at which a substance is accumulated or removed from a lake is a logarithmetic function, response time is usually expressed as the time it would take to increase or reduce the concentration of a substance by one-half and can be estimated by the following equation (Dillon and Rigler 1975):

$$RT(1/2) = 0.69 / (FR + 10/z) \quad \text{where,}$$

FR = Flushing Rate of the lake
z = Mean Depth of the lake

It should be noted that this formulation does not consider the case where a significant portion of the phosphorus within the water column of the lake is a result of internal loading (i.e., the resuspension of phosphorus that has been accumulated within the sediments of the lake).

8. Entering Data

Entering the data into the Excel spreadsheets is quite straight forward for most of the input parameters. The only potential difficulty that may be encountered is in the case where more than one upstream input enters the lake. In this instance, it will be necessary to develop a customized formula for the Excel cells to sum all of the upstream water and phosphorus inputs. It is also important to zero out any inputs listed on the spreadsheet that may not be applicable for the lake being modeled.

9. Model Validation

Validation of the model is necessary before it can be used with confidence for prediction and as a basis for making policy decisions. Model validation simply involves comparing the model's prediction with data collected in the field. As a general rule, the model can be considered valid if the model prediction and field measurements of phosphorus concentration do not differ by more than about 20%, a value that is considered to reflect the confidence limits of most field and laboratory measurements[2]. It is important to realize that the model is likely to have been constructed using parameter estimates that are averages of many years, and that the validation data should also be representative of an average year. Mean annual lake phosphorus concentrations can vary considerably from year to year and it is necessary to collect the validation data over a number of years to determine a reasonable average. Although the number of years required is debatable, most believe that it should be somewhere between five and ten years. Hutchinson (2002) provides a number of suggestions for the design of monitoring programs in instances when limited resources are available. He suggests that, *at minimum*, the following data should be collected:

- An annual spring overturn measurement of total phosphorus,
- Biweekly measurements of Secchi Disk depth during the summer,
- An annual determination of a dissolved oxygen profile at the end of the summer and prior to fall turnover.

It would also be wise to collect water samples for determination of chlorophyll *a* concentrations on at least a bimonthly basis.

9.1 Protocol for Collection of Validation Data

The Nova Scotia Department of Environment and Labour (1999) has produced a manual that provides details of the protocols for collecting water samples for validation data.

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[2] This criteria, however, may be difficult to meet for lakes having phosphorus concentrations near to the limit of analytical detection.

Although the manual was specifically developed for a volunteer water quality monitoring program carried out in Kings County of the Annapolis Valley, the protocols described are generic and applicable to any water quality monitoring program. This manual should be consulted in designing the validation data sampling program.

The manual assumes that the analysis of field samples will be done at an accredited laboratory having the capability of processing samples for water quality, and especially for carrying out total phosphorus analyses at a detection limit of 0.001 mg L^{-1}.

10. Model Re-evaluation

If the model does not predict well when compared to the validation data, it must be re-evaluated. Re-evaluation involves assessing each input parameter in terms of its accuracy. It may also require that the processes incorporated into the model be re-evaluated. For example, if the lake is stratified it may be necessary to alter the way in which sedimentation rate is modeled.

11. Sensitivity Analysis

Carrying out a sensitivity analysis can be quite insightful in terms of understanding which factors exert the most influence in determining the level of phosphorus predicted by the model. It is also useful in determining where the greatest effort should be placed in refining the model if it does not meet the validation criteria. As an example, a sensitivity analysis of the Gaspereau River watershed model indicated that the prediction of phosphorus concentration was most sensitive to the phosphorus land run off coefficients and the lake phosphorus retention coefficient.

The general procedure for carrying out a sensitivity analysis is to alter the value of each model input parameter by a constant percentage while holding all other parameters constant, and then determining the percent change in the model's predictions. A factor of ten percent is typically used and, because there is some non-linearity in the model, it is always a good idea to both increase and decrease the input. In some cases, such as inputs related to precipitation, it may be instructive to alter the input parameter by a factor that corresponds to how much the parameter is known to vary on an annual basis.

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14. Glossary

Algae - A general term applied to aquatic photosynthetic organisms.

Anaerobic – life without oxygen

Anoxic - having no oxygen

Catchment Area - See watershed.

Chlorophyll *a* - The major photosynthetic pigment present in algae and other plants. Measurement of its concentration in a water body is used as an indication of algal biomass.

Drainage Basin - The land area from which water runs off to drain into a stream, river, lake or estuary.

Epilimnion – The upper, warmer surface layer of a stratified lake.

Export coefficient - A measure of the amount of a substance exported from a system, usually expressed as mass area^{-1} time^{-1}.

Export Coefficient Model - A model for calculating nutrient loads to an aquatic ecosystem based on knowledge of land use and other drainage basin characteristics.

Eutrophic - A measure of a lake's trophic status. Literally means 'well nourished' and applied to aquatic ecosystems exhibiting a high level of productivity (see Table 1).

Flushing Rate - The number of times a volume of water equal to the volume of the lake flows out of the lake. It is calculated as the ratio of the volume of water leaving the lake to the volume of the lake, usually on an annual basis.

Hypolimnion - The lower, colder water later of a stratified lake.

Hypoxia – having low (generally < 2-3 mg L^{-1}) dissolved oxygen

Internal Nutrient Loading - The release of nutrients from sediments into the water column.

Mesotrophic – A measure of a lake's trophic status. Literally means moderately nourished and applied to lakes exhibiting a moderate level of productivity (see Table 1).

Metalimnion – The middle layer of a stratified lake containing an area of rapid temperature change (the thermocline).

Non-point Pollution Source – A nutrient, or other pollutant, source that originates from a diffuse area of the watershed as opposed to a clearly identified single source.

Oligotrophic - A measure of a lake's trophic status. Literally means 'poorly nourished' and applied to lakes exhibiting a low level of productivity (see Table 1).

Oxic - having oxygen

Point Source Pollutant - A pollutant that originates from a single, easily identified location such as a sewage treatment plant.

Residence Time - See Turnover Time

Response Time - The time it would take for the lake to respond to a change in its loading of a substance. Because this is a logarithmetic function, response time is usually expressed as the time for half the change to take place.

Secchi Disk - A circular disk, typically 20 cm in diameter and divided into white and black quadrants, used to measure the transparency of a water body.

Thermocline – The area of a stratified lake in which a strong gradient in temperature exists. It is often further defined as the area of the lake having a change in temperature of at least 1 ºC per metre of depth.

Trophic State - An indication of the relative productivity of an ecosystem. For freshwater systems it is typically evaluated in terms of the chlorophyll *a* concentration (a measure of algal biomass), and the Secchi Disk depth (a measure of water transparency).

Turnover Time - The average amount of time that water remains in a lake. It is calculated as the ratio of the volume of the lake to the volume of water leaving the lake, usually on an annual basis.

Watershed - See Drainage Basin.

Zooplankton - Animals, usually microscopic, that live suspended within the water column.

15. APPENDICES

Appendix I. Sample Excel Worksheet

Lake Name						
Input Parameters	**Symbol**	**Value**	**Units**	**Budgets**		
Morphology				**Hydraulic Budget (m^3)**		
Drainage Basin Area (Excl. of Lake Area)	Ad		ha			
Area Land Use Category 1	Ad1		ha			**% Total**
Area Land Use Category 2	Ad2		ha	Upstream Inflow		
Area Land Use Category 3	Ad3		ha	Precipitation		
Area Land Use Category 4	Ad4		ha	Surface Run Off		
Area Land Use Category 5	Ad5		ha	Evaporation		
Area Land Use Category 6	Ad6		ha	Total Outflow		
Area Land Use Category 7	Ad7		ha			
Area Land Use Category 8	Ad8		ha	**Phosphorus Budget (gm)**		
Area Land Use Category 9	Ad9		ha			
Area Land Use Category 10	Ad10		ha			**% Total**
Lake Surface Area	Ao		ha	Upstream Inflow		
Lake Volume	V		10^6 m^3	Atmosphere		
Hydrology Inputs				Surface Run Off		
Upstream Hydraulic Inputs	Qi		m^3 yr^{-1}	Development		
Annual Unit Precipitation	Pr		m yr^{-1}	Sedimentation		
Annual Unit Lake Evaporation	Ev		m yr^{-1}	Total Outflow		
Annual Unit Hydraulic Run Off	Ru		m yr^{-1}	**Model Validation**		
Phosphorus Inputs						
Upstream P Input	Ju		gm P yr^{-1}	Predicted P (mg m^{-3})		
Annual Unit Atmospheric Phosphorus Deposition	Da		gm P m^{-2} yr^{-1}	Measured P (mg m^{-3})		
Land Use Category 1 P Export Coefficient	E1		gm P m^{-2} yr^{-1}	% Difference		
Land Use Category 2 P Export Coefficient	E2		gm P m^{-2} yr^{-1}			
Land Use Category 3 P Export Coefficient	E3		gm P m^{-2} yr^{-1}			
Land Use Category 4 P Export Coefficient	E4		gm P m^{-2} yr^{-1}			
Land Use Category 5 P Export Coefficient	E5		gm P m^{-2} yr^{-1}			
Land Use Category 6 P Export Coefficient	E6		gm P m^{-2} yr^{-1}			
Land Use Category 7 P Export Coefficient	E7		gm P m^{-2} yr^{-1}			
Land Use Category 8 P Export Coefficient	E8		gm P m^{-2} yr^{-1}			
Land Use Category 9 P Export Coefficient	E9		gm P m^{-2} yr^{-1}			
Land Use Category 10 P Export Coefficient	E10		gm P m^{-2} yr^{-1}			
Number of Dwellings	Nd		#			
Average Number of Persons per Dwelling	Nu		#			
Average Fraction of Year Dwellings Occupied	Npc		yr^{-1}			
Phosphorus Load per Capita per Year	Si		gm $capita^{-1}$ yr^{-1}			
Septic System Retention Coefficient	Rsp		n/a			
Point Source Input 1	PS1		gm yr^{-1}			
Point Source Input 2	PS2		gm yr^{-1}			
Point Source Input 3	PS3		gm yr^{-1}			
Point Source Input 4	PS4		gm yr^{-1}			
Point Source Input 5	PS5		gm yr^{-1}			
Lake Phosphorus Retention Coefficient	v		n/a			
Model Outputs						
Total Precipitation Hydraulic Input	Ppti		m^3 yr^{--1}			
Total Evaporation Hydraulic Loss	Eo		m^3 yr^{--1}			
Total Hydraulic Surface Run Off	Ql		m^3 yr^{--1}			
Total Hydraulic Input	Qt		m^3 yr^{--1}			

Areal Hydraulic Input	q_s		m yr^{--1}			
Total Hydraulic Outflow	Qo		m^3 yr^{--1}			
Total Atmospheric P Input	Jd		gm yr^{-1}			
Total Surface Run Off P Input	Je		gm yr^{-1}			
Total Development P Input	Jr		gm yr^{-1}			
Total P Input	Jt		gm yr^{-1}			
Lake P Retention Factor	Rp		-			
Lake P Retention	Ps		gm yr^{-1}			
Predicted Lake P Concentration	[P]		mg L^{-1}			
Lake P Outflow	Jo		gm yr^{-1}			
Lake Mean Depth	z		m			
Lake Flushing Rate	FR		times yr^{-1}			
Lake Turnover Time	TT		yr			
Lake Response Time	RT(1/2)		yr			

Appendix II. Data Sources

Lake Morphology:

Information Officer
Nova Scotia Department of Agriculture and Fisheries
P.O. Box 700
Pictou, N.S.
B0K 1H0
Tel: (902) 485-5056
(http://www.gov.ns.ca/nsaf/sportfishing/lakesurvey/)

Drainage Basin Topographic Maps:

Nova Scotia Geomatics Centre
160 Willow Street
Amherst, N.S.
B4H 3W5
Tel: 902-667-721
Fax: 902-667-6299
(http://www.gov.ns.ca/snsmr/land/)

Service Nova Scotia and Municipal Relations
5151 Terminal Road
P.O. Box 2205
Halifax, N.S
B3J 3C4
Tel: 902-424-2735
Fax: 902-424-5747
email: lic_hfx@gov.ns.ca

Climate/Meteorology:

Environment Canada - Canadian Climate Normals
(http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html)

Geology:

Nova Scotia Department of Natural Resources
Mineral Resources Branch
1701 Hollis Street
Founders Square, 3rd. Floor
Halifax, N. S.
B3J 3M8
Tel: 902 424-2035
Fax: 902 424-7735
(http://www.gov.ns.ca/natr/meb/pubs/pubshome.htm)

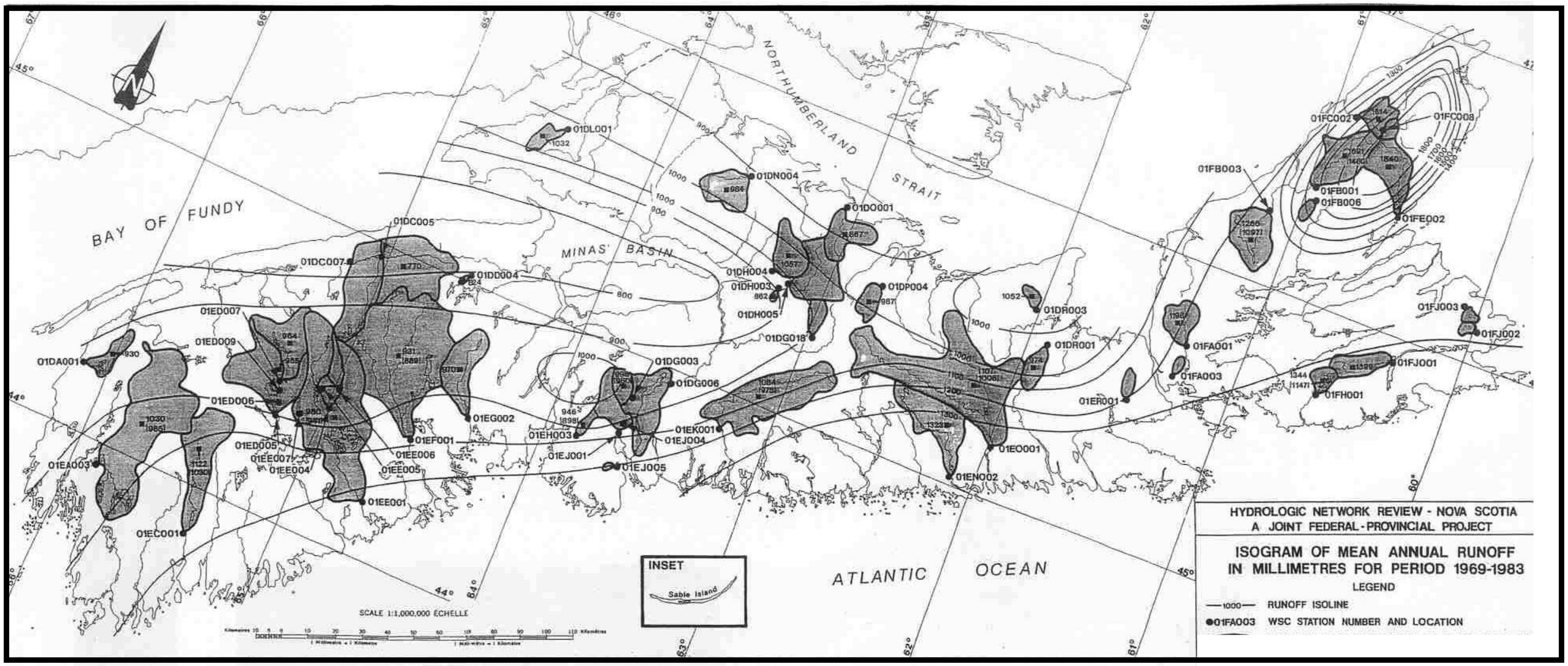
Soil Characteristics:

Nova Scotia Department of Agriculture and Marketing Soils Survey Reports
Agriculture and Agri-Food Canada. 1999. Canadian Soil Information Systems. National Soil Database. (http://sis.agr.gc.ca/cansis/)

Land Use and Population Statistics:

Local Municipal Planning Offices

Appendix III. Isorunoff Map for Estimating Surface Run Off



Modified from Brimley et al. (1985).

Appendix IV – Literature References for Estimating Export Coefficients

Dillon, P.J. and W.B. Kirchner. 1974. The effects of geology and land use on the export of phosphorus from watersheds. Water Research. 9:135-148.

Lowe, J.S. 2001. Revision of the Kings County lake capacity model: validation and implications. Report prepared for the Municipality of Kings. 21p.

Rast, W. and G.F. Lee. 1977. Summary analysis of North American (U.S. Portion) OECD Eutrophication Project: Nutrient loading-lake response relationship and trophic status indices. Report No. EPA-600/3-78-008. Ecological Research Series. United States Environmental Protection Agency, Corvallis, Oregon.

Reckhow, K.H., M.N. Beaulac and J.T. Simpson. 1980. Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients. Report No. EPA-440/5-80-011. Office of Water Regulations, Criteria and Standards Division, United States Environmental Protection Agency, Washington, D.C.

Reckhow, K.H. and S.C. Chapra. 1983. Engineering approaches for lake management, Volume I: Data analysis and empirical modeling. Butterworth, Boston.

Scott, R.S., W.C. Hart and G. Patterson. 2000. Phosphorus export from stream catchments in Nova Scotia. Internal Report No. 93-3, DalTech, Dalhousie University, Halifax, Nova Scotia. 102 p.

Uttomark, P.D., J.D. Chapin and K.M. Green. 1974. Estimating nutrient loading of lakes from non-point sources. Report No. 660/13-74-020, Ecological Research Series, United States Environmental Protection Agency, Corvallis, Oregon.

Appendix V
Example of Model Application

This appendix contains an example of the application of the model to Lake George, a headwater lake located in the Gaspereau River watershed in Kings County, Nova Scotia. Development of each model input is explained according to the order in which they are presented in the manual and listed in the Excel worksheet.

V.1 Determination of Drainage Basin Area

The area of the drainage basin is determined by outlining the drainage basin on a topographic map (Figure V.1) and determining its area using planimetry (the actual size of the map used for this was at a scale of 1:5,000). The drainage basin surface area was determined to be 747.8 ha.

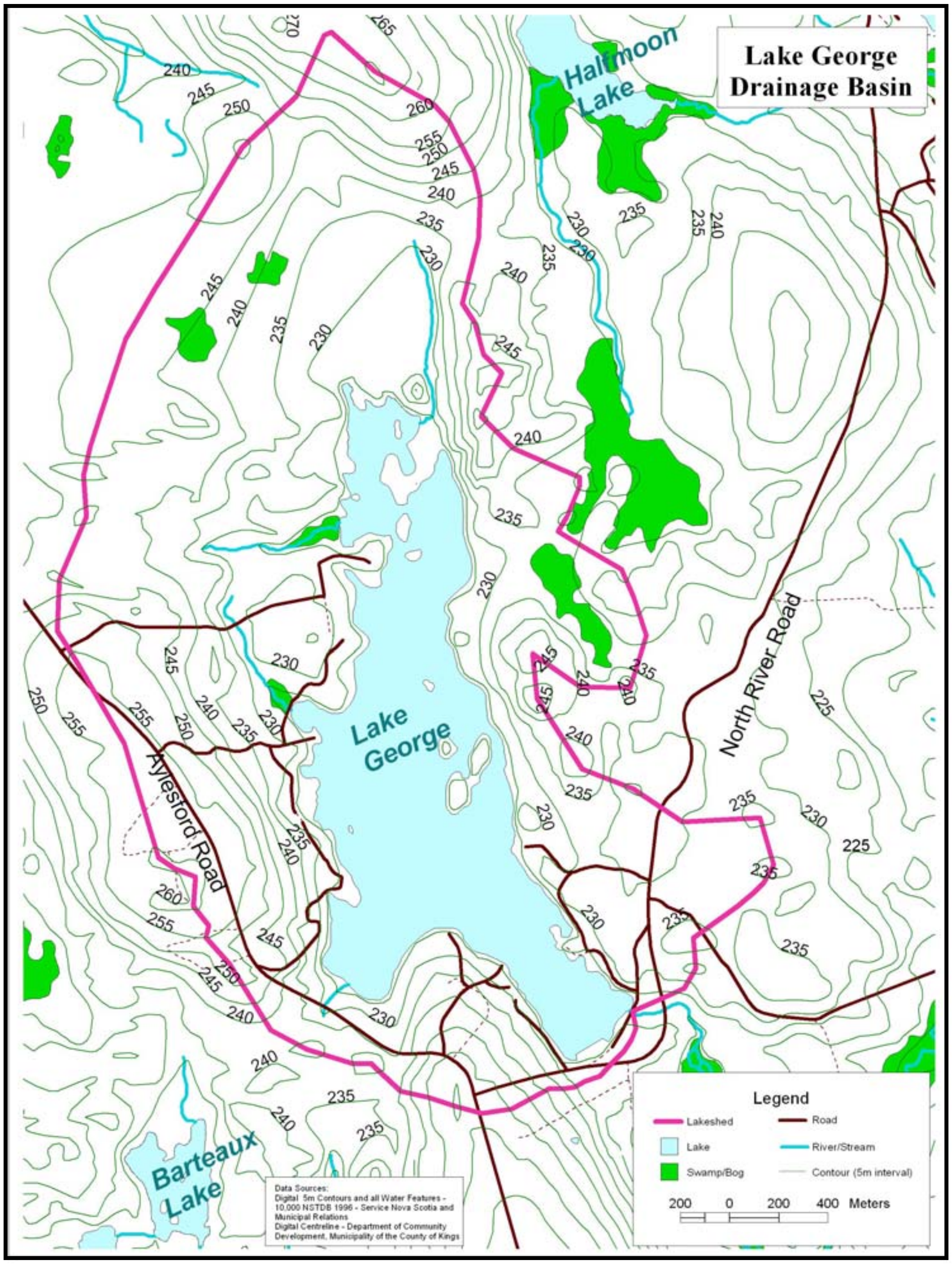


Figure V.1. Map of Lake George showing its drainage basin.

V.2. Determination of the Area of Each Land Use Category

The area of each land use is determined by subdividing the drainage basin into land use categories. For Lake George, in addition to the forestland, four other land use categories were identified (Figure V.2).

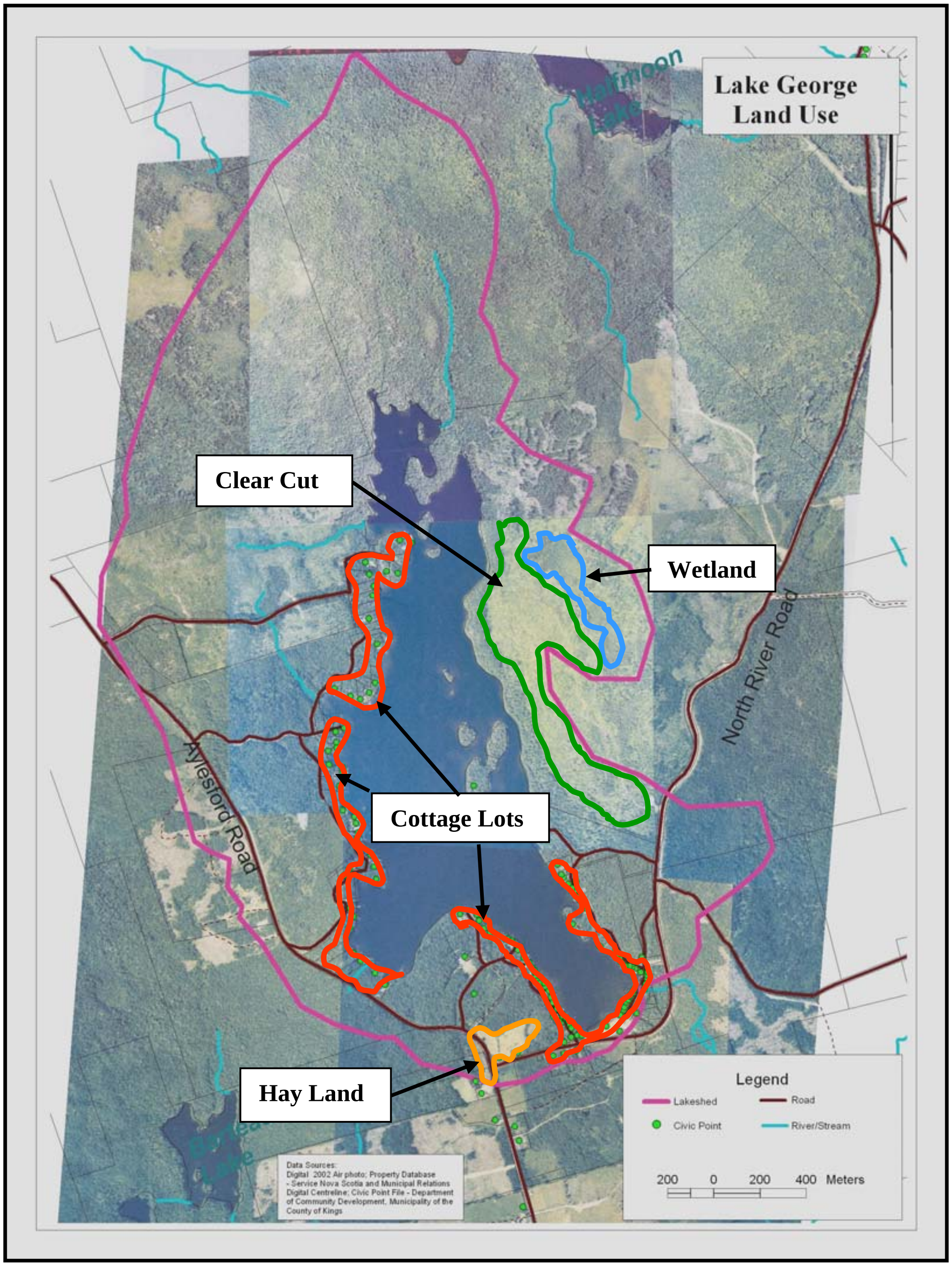


Figure V.2. Air photo of Lake George drainage basin showing land use categories.

V.3. Determination of Hydrological Inputs/Outputs

The hydrological inputs/outputs include upstream inputs, run off from the land, precipitation onto the lake, and evaporation from the lake.

Since Lake George is a headwater lake, it receives no water inputs from upstream lakes so this value (**Qi**) is set to zero. If it were to receive upstream inputs, this value would be set equal to the Total Hydrologic Outflow of the upstream lake (**Qo**).

The hydraulic input from land run off is determined as the product of the Annual Unit Hydraulic Run Off and the Area of the Drainage Basin. The Hydraulic Unit Run Off (**Ru**) is estimated at 0.80 metres yr^{-1} from the isorunoff map contained in Appendix III.

The Annual Unit Precipitation (**Pr**) onto the lake is estimated as 1.21 metres yr^{-1} from weather records for Kentville, Nova Scotia obtained from the Canadian Climate Normals (see Appendix II for source). The Canadian Climate Normals is also used to estimate Annual Unit Lake Evaporation (**Eu**) of 0.18 metres yr^{-1}.

The following is a partial listing of the database obtained from the Canadian Climate Normals website.

Canadian Climate Normals 1971-2000

Created 2002-06-21; Modified 2003-07-24; Reviewed 2003-07-24.

URL: http://climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html

The Green Lane, Environment Canada's World Wide Web Site

NOTE!! *Data used in the calculation of these Normals may be subject to further quality assurance checks. This may result in minor changes to some values presented here.*

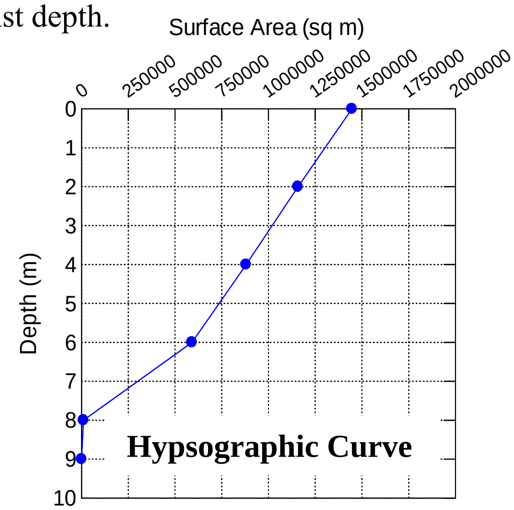
KENTVILLE CDA NOVA SCOTIA Latitude: 45º 4' N; Longitude 64º 28' W; Elevation 48.80 m.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Rainfall (mm)	60.2	45.0	63.9	70.5	92.7	81.4	87.6	85.5	87.3	93.3	103.7	77.0	948.0
Snowfall (cm)	70.9	59.2	45.9	17.3	3.7	0.0	0.0	0.0	0.0	1.9	11.9	55.0	265.9
Precipitation (mm)	126.7	101.5	110.6	90.2	97.4	81.4	87.6	85.5	87.3	95.5	117.4	129.9	1210.9
Lake Evaporation (mm)					3.1	3.6	3.9	3.4	2.5	1.5			18.0

V.4. Determination of Lake Surface Area and Volume

The surface area of the lake (**Ao**), as well as the surface areas at selected depth contours, is determined from a bathymetric map (Figure V.3) using planimetric or image analysis procedures. The results for Lake George are shown in the table below. (It should be noted that if the lake contains islands, as does Lake George, the area of the islands must be subtracted.) This information is used to construct a hypsographic curve in which the area of each depth contour is plotted against depth.

Surface Area at Each Two Metre Depth Contour	
Depth (m)	**Surface Area (m^2)**
0	1,447,015
2	1,157,891
4	880,354
6	590,589
8	10,259
9	0



The volume of the lake (**V**)is equal to the area under the hypsographic curve. This can be determined by counting the number of squares under the curve (each square is equal to 250,000 m^3) or by using the following formula, which assumes each layer of the lake is shaped like a truncated pyramid:

$$\text{Volume} = h \times (A_U + A_L)/2 \quad \text{where,}$$

h = depth between contours
A_U = Surface area of upper contour
A_L = Surface area of lower contour

For Lake George, the volumes are as follows:

Volume 0 - 2 m = 2 × (1447015 + 1157891)/2 = 2,604,906
Volume 2 - 4 m = 2 × (157891 + 880354)/2 = 2,038,245
Volume 4 - 6 m = 2 × (880354 + 590589)/2 = 1,470,943
Volume 6 - 8 m = 2 × (590589 + 10259)/2 = 600,848
Volume 8 - 9 m = 1 × (10259 + 0)/2 = 5130
Total Volume = 6,720,072 m^3

Another method for calculating the volume of a lake is to use the formula for a truncated cone, which assumes each layer of the lake is shaped like a truncated cone (symbols are the same as for the truncated pyramid formula):

$$\text{Volume} = (h/3) \times \left(A_U + A_L + \sqrt{(A_U \times A_L)}\right)$$

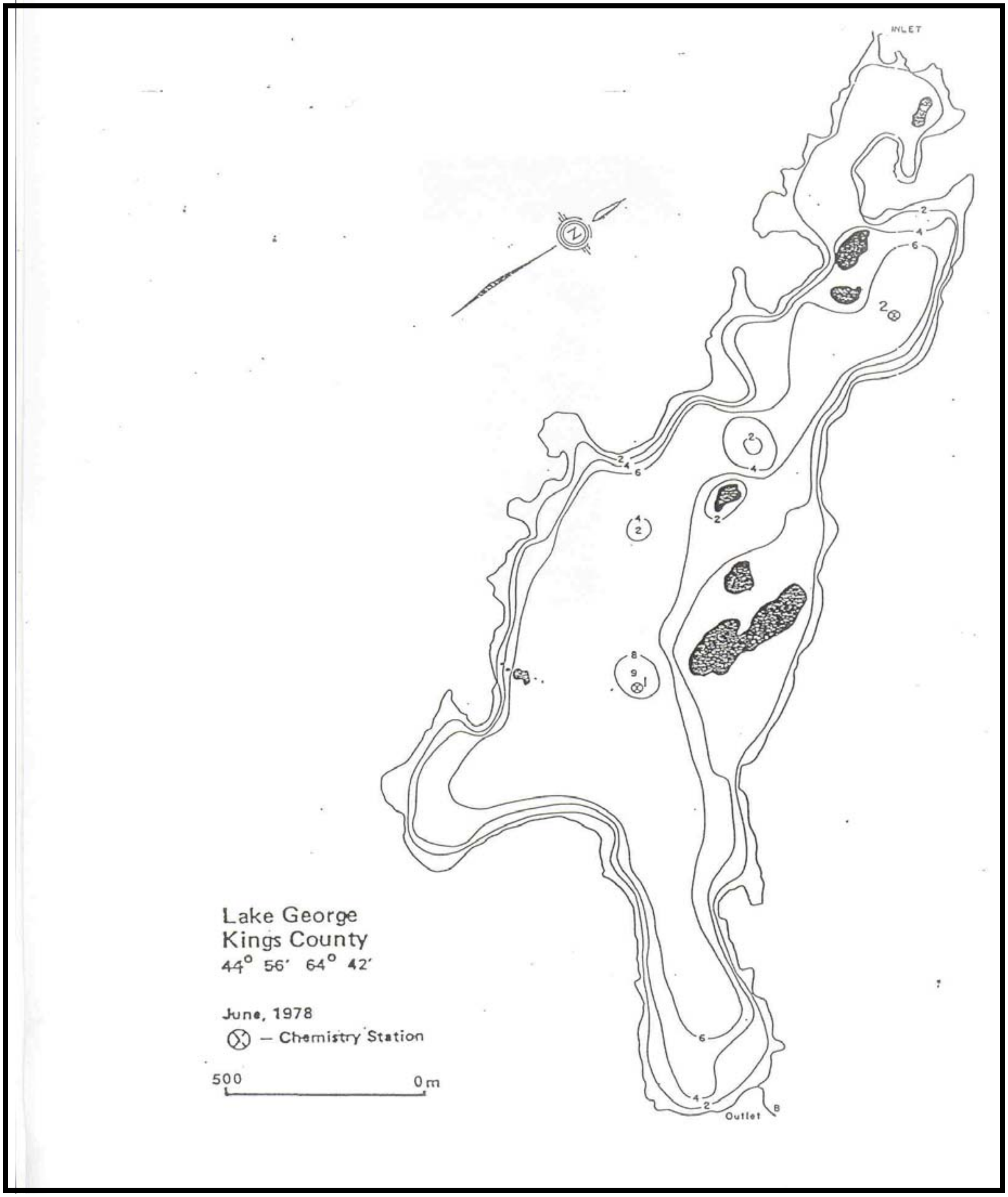


Figure V.3. Bathymetric map of Lake George obtained from the Nova Scotia Department of Agriculture and Fisheries.

V.5. Estimate of Atmospheric Phosphorus Deposition Coefficient

Atmospheric phosphorus unit deposition (**Da**) was assumed to be 0.020 mg gm m^{-2} yr^{-1}, the average of the values reported for Nova Scotia (see Section 7.1.3.2).

V.6. Estimates of Phosphorus Surface Run Off Coefficients

Estimates of phosphorus surface run off coefficients were made based on the geology, soil types and land use characteristics of the drainage basin. Information on bedrock geology was obtained from Donohoe and Grantham (1989)[3] and Finck et al. (1994)[4] and soil characteristics were obtained from Cann et al. (1965)[5]

The bedrock geology is primarily intrusive granite coved by a shallow layer of glacial drift. The major soil type in the drainage basin belongs to the Gibraltar series which consists of coarse till. There is little evidence that either geology or soil type vary significantly within the drainage basin of Lake George.

Land use categories include forest (640.4 ha), clear cut forest land (52.3 ha), wetland (8.3 ha), agriculture (mainly hay land – 3.2 ha), and cottage lots (43.6 ha). The area of each was estimated using an image analysis program..

The following phosphorus export coefficients were estimated from the export coefficients tabulated in Section 7.1.3.3 of the User's Manual.

- Igneous Forested - 0.0069 gm m^{-2} yr^{-1} (from Scott et al. (2000) summary)
- Managed Forest -0.0625 gm m^{-2} yr^{-1} (from Maine Department of Environmental Protection (2000) summary)
- Wetlands – 0.0000 gm m^{-2} yr^{-1} (see discussion in Section 2.1.4 of Supplementary Technical Report)
- Agriculture (mainly hay land) – 0.0081 gm m^{-2} yr^{-1} (mean value for grazing/pasture from Reckhow et al. (1980) in Table 7.4)
- Cottage Lots – 0.0300 gm m^{-2} yr^{-1} (from Maine Department of Environmental Protection (2000) summary)

[3] Donohoe, H.V. and R.G. Grantham. 1989. Geological highway map of Nova Scotia. Department of Mines and Energy.

[4] Finck, P.W., R.M. Graves, F.J. Bonner and H.B. Bent. 1994. Glacial and till clast geology of Gaspereau Lake, Nova Scotia – South Mountain Batholith Project. Map 94-14. Nova Scotia Department of Natural Resources.

[5] Cann, D.B., J.L. MacDougall and J.D. Hilchey. 1965. Soil survey of Kings County, Nova Scotia. Canadian Department of Agriculture and Nova Scotia Department of Agriculture and Marketing.

V.7. Determination of Development Input

Development input of phosphorus is determined according to the following equation:

$$P_d = \Sigma\, PSi + (Nd \times Nu \times Npc \times Si \times (1 - Rsp)) \quad \text{where,}$$

PSi = Total phosphorus input from Point Source i
Nd = Number of dwellings in the drainage basin
Nu = Average number of persons occupying each dwelling
Npc = Average fraction of the year dwelling are occupied
Si = Phosphorus load per capita year
Rsp = Septic system retention coefficient

Development on Lake George is due to residential use, most of which is summer cottages. The number of cottages and permanent residences located within 300 metres of the shoreline of the lake was determined from statistics compiled by the Municipality of Kings County. Information on the frequency of occupancy and number of persons using each residence was obtained through a mail-out survey.

The number of dwellings (**Nd**) was determined to be 110. Of these, 104 are seasonal and 6 are permanent. Results of the survey indicated that the average number of persons occupying each dwelling was 2.73 for the seasonal dwellings and 3.20 for the permanent dwellings. The average fraction of the year each dwelling was occupied was 0.19 for the seasonal dwellings and 0.82 for the permanent dwellings. Based on this information, the average number of occupants (**Nu**) and the average fraction of the year occupied for seasonal and permanent dwellings (**Npc**) combined were calculated to be 2.73 and 0.22.

The phosphorus load per capita (**Si**) was considered to be 800 gm P yr^{-1}, and the septic system retention coefficient (**Rsp)** was assumed to be 0.5.

There are no point source inputs to Lake George, so **PSi** is set to zero on the worksheet.

V. 8. Determination of Phosphorus Retention Coefficient

The Phosphorus Retention Coefficient (**v**) is an empirically derived constant (see Section 7.2.2.5). Since there is some evidence, based on monitoring of surface and bottom water temperatures, that Lake George experiences stratification, and possibly anoxic conditions, the value of v is chosen to be 7.2 according to the relationships developed by Kichner and Dillon (1975).

V.9. Model Prediction of Phosphorus Concentration

The following table is an illustration of the Excel spreadsheet containing all of the data entries for Lake George. The model prediction of phosphorus concentration is 0.0082 mg L^{-1}. The phosphorus budget indicates that 19.88 % of the total phosphorus input is due to atmospheric deposition, 61.97 % is due to surface run off, and 18.15 % is due to development[6]. Of the total phosphorus outputs, 58.00 % is lost to the sediments and 42.00 % is lost via the outflow.

Lake George (Initial Model)

Input Parameters	Symbol	Value	Units
Morphology			
Drainage Basin Area (Excl. of Lake Area)	Ad	747.8	ha
Area Land Use Category 1 (Forest)	Ad1	640.4	ha
Area Land Use Category 2 (Clear Cut)	Ad2	52.3	ha
Area Land Use Category 3 (Wetland)	Ad3	8.3	ha
Area Land Use Category 4 (Hay Land)	Ad4	3.2	ha
Area Land Use Category 5 (Cottage Lots)	Ad5	43.6	ha
Area Land Use Category 6	Ad6	0.0	ha
Area Land Use Category 7	Ad7	0.0	ha
Area Land Use Category 8	Ad8	0.0	ha
Area Land Use Category 9	Ad9	0.0	ha
Area Land Use Category 10	Ad10	0.0	ha
Lake Surface Area	Ao	144.7	ha
Lake Volume	V	6.72	10^6 m^3
Hydrology			
Upstream Hydraulic Inputs	Qi	0	m^3 yr^{-1}
Annual Unit Precipitation	Pr	1.21	m yr^{-1}
Annual Unit Lake Evaporation	Ev	0.18	m yr^{-1}
Annual Unit Hydraulic Run Off	Ru	0.80	m yr^{-1}
Phosphorus Inputs			
Upstream P Input	Ju	0	gm P yr^{-1}
Annual Unit Atmospheric P Deposition	Da	0.0200	gm P m^{-2} yr^{-1}
Land Use Category 1 P Export Coefficient	E1	0.0069	gm P m^{-2} yr^{-1}
Land Use Category 2 P Export Coefficient	E2	0.0625	gm P m^{-2} yr^{-1}
Land Use Category 3 P Export Coefficient	E3	0.0000	gm P m^{-2} yr^{-1}
Land Use Category 4 P Export Coefficient	E4	0.0081	gm P m^{-2} yr^{-1}
Land Use Category 5 P Export Coefficient	E5	0.0300	gm P m^{-2} yr^{-1}
Land Use Category 6 P Export Coefficient	E6	0.0000	gm P m^{-2} yr^{-1}
Land Use Category 7 P Export Coefficient	E7	0.0000	gm P m^{-2} yr^{-1}
Land Use Category 8 P Export Coefficient	E8	0.0000	gm P m^{-2} yr^{-1}
Land Use Category 9 P Export Coefficient	E9	0.0000	gm P m^{-2} yr^{-1}
Land Use Category 10 P Export Coefficient	E10	0.0000	gm P m^{-2} yr^{-1}
Number of Dwellings	Nd	110	#
Average number of Persons per Dwelling	Nu	2.73	#
Average Fraction of Yr Dwellings Occupied	Npc	0.22	yr^{-1}

Budgets		
Hydraulic Budget (m^{-3})		
		% Total
Upstream Inflow	0	0
Precipitation	1750991	22.64
Surface Run Off	6066090	77.36
Evaporation	-260478	3.37
Total Outflow	7556603	96.63
Total Check		100.00
Phosphorus Budget (gm yr^{-1})		
		% Total
Upstream Inflow	0	0
Atmosphere	28942	19.88
Surface Run Off	90214	61.97
Development	26426	18.15
Sedimentation	-84438	58.00
Total Outflow	61144	42.00
Total Check		100.00
Model Validation		
Predicted P (mg L^{-1})		0.0082
Measured P (mg L^{-1})		0.0105
% Difference		-21.9

[6] This includes only the input from septic systems. It could also, and probably should, include the increase in run off of phosphorus from dwelling lots above that which would occur if the lots were left as forest land.

Phosphorus Load per Capita per Year	Si	800	gm P cap^{-1} yr^{-1}			
Septic System Retention Coefficient	S_r	0.5	n/a			
Point Source Input 1	PS_1	0	gm yr^{-1}			
Point Source Input 2	PS_2	0	gm yr^{-1}			
Point Source Input 3	PS_3	0	gm yr^{-1}			
Point Source Input 4	PS_4	0	gm yr^{-1}			
Point Source Input 5	PS_5	0	gm yr^{-1}			
Phosphorus Retention Coefficient	v	7.2	n/a			
Model Outputs						
Total Precipitation Hydraulic Input	Ppt_i	1750991	m^3 yr^{-1}			
Total Evaporation Hydraulic Loss	E_o	260478	m^3 yr^{-1}			
Total Hydraulic Surface Run Off	Q_l	5982400	m^3 yr^{-1}			
Total Hydraulic Input	Q_t	773391	m^3 yr^{-1}			
Areal Hydraulic Load	q_s	5.16	m yr^{-1}			
Total Hydraulic Outflow	Q_o	7472913	m^3 yr^{-1}			
Upstream P Input	Jd	0	gm yr^{-1}			
Total Atmospheric P Input	Jd	28942	gm yr^{-1}			
Total Surface Run Off P Input	Je	90214	gm yr^{-1}			
Total Development P Input	Jr	26426	gm yr^{-1}			
Total P Input	Jt	145582	gm yr^{-1}			
Lake P Retention Factor	Rp	0.58	n/a			
Lake Phosphorus Retention	Ps	84438	gm yr^{-1}			
Lake Phosphorus Concentration	[P]	**0.0082**	mg L^{-1}			
Lake Phosphorus Outflow	Jo	81144	gm yr^{-1}			
Lake Mean Depth	z	4.6	m			
Lake Flushing Rate	FR	1.11	times yr^{-1}			
Lake Turnover Time	TT	0.90	yr			
Lake Response Time	RT(1/2)	0.21	yr			

V.10. Model Validation

Model validation involves comparing the model's predicted phosphorus concentration with phosphorus concentrations obtained from field measurements. Figure V.4 shows the seasonal and yearly variation in phosphorus concentration for Lake George based on measurements made as part of a volunteer based water quality monitoring program coordinated by the Municipality of Kings County. The mean value of all of the measurements is 0.0105 mg L^{-1}.

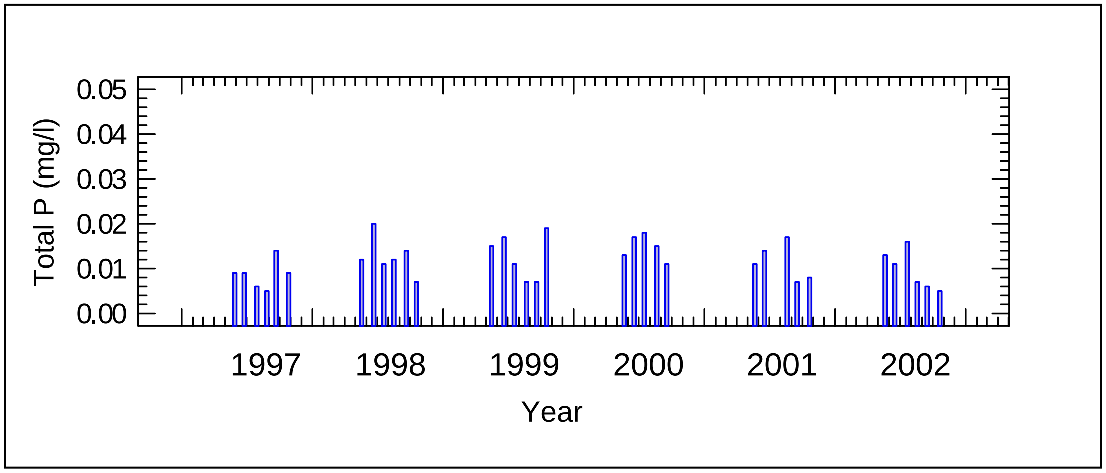


Figure V.4. Phosphorous concentration validation data for Lake George.

The model under predicts the lake's phosphorus concentration by 21.9 %, which is above the 20% difference generally considered acceptable for model validation (see Section 9 of the User's Manual). As a result, it was decided that the model should be re-evaluated.

V.11. Model Re-evaluation

In re-evaluation of the model, it was discovered that Lake George has a summer camp located on its north shore. The camp accommodates 34 persons per day for a period of 14 days, which is equivalent to 476 user days per year or 1.30 capita per year. Assuming a septic input of 800 gm P per capita per year and a septic retention coefficient of 0.5, this would result in an input of 520 gm P per year. The area of land used for the camp should also be considered, and it was assumed that it occupied an area of five ha and had a phosphorus export coefficient of 0.0300 gm m^{-2} yr^{-1} (equal to that of the cottage lots).

Further re-evaluation indicated that Lake George also contains a public beach. Data on the per capita use of the public beach is not available, but if it is conservatively assumed that phosphorus inputs from this source are equal to about four times that of the summer camp, this addition results in a difference of 20.0%, which is on the borderline of the of the 20% guideline.

Other factors that could also be re-evaluated include inputs from roadways along the lake’s shoreline and the assumption that there is no phosphorus export from the wetland present in the drainage basin.

The validated model is illustrated below (the input values that were changed or added in the re-evaluation process are in bold print).

Lake George (Validated Model)

Input Parameters	Symbol	Value	Units	Budgets		
Morphology				**Hydraulic Budget (m^{-3})**		
Drainage Basin Area (Excl. of Lake Area)	Ad	747.8	ha			
Area Land Use Category 1 (Forest)	Ad1	**635.4**	ha			**% Total**
Area Land Use Category 2 (Clear Cut)	Ad2	52.3	ha	Upstream Inflow	0	0
Area Land Use Category 3 (Wetland)	Ad3	8.3	ha	Precipitation	1750991	22.64
Area Land Use Category 4 (Hay Land)	Ad4	3.2	ha	Land Run Off	5982400	77.36
Area Land Use Category 5 (Cottage Lots)	Ad5	43.6	ha	Evaporation	-260478	3.37
Area Land Use Category 6 **(Campground)**	Ad6	**5.0**	ha	Total Outflow	7472913	96.63
Area Land Use Category 7	Ad7	0.0	ha	Total Check		100.00
Area Land Use Category 8	Ad8	0.0	ha			
Area Land Use Category 9	Ad9	0.0	ha	**Phosphorus Budget (gm yr^{-1})**		
Area Land Use Category 10	Ad10	0.0	ha			
Lake Surface Area	Ao	144.7	ha			**% Total**
Lake Volume	V	6.72	10^6 m^3	Upstream Inflow	0	0
Hydrology				Atmosphere	28942	19.38
Upstream Hydraulic Inputs	Qi	0	m^3 yr^{-1}	Surface Run Off	91369	61.18
Annual Unit Precipitation	Pu	1.21	m yr^{-1}	Development	29026	19.44
Annual Unit Lake Evaporation	Eu	0.18	m yr^{-1}	Sedimentation	-86615	58.00
Annual Unit Hydraulic Run Off	Ru	0.80	m yr^{-1}	Total Outflow	62722	42.00
Phosphorus Inputs				Total Check		100.00
Upstream P Input	Ju	0	gm P yr^{-1}			
Annual Unit Atmospheric P Deposition	Da	0.0200	gm P m^{-2} yr^{-1}			

Land Use Category 1 P Export Coefficient	E1	0.0069	gm P m^{-2} yr^{-1}
Land Use Category 2 P Export Coefficient	E2	0.0625	gm P m^{-2} yr^{-1}
Land Use Category 3 P Export Coefficient	E3	0.0000	gm P m^{-2} yr^{-1}
Land Use Category 4 P Export Coefficient	E4	0.0081	gm P m^{-2} yr^{-1}
Land Use Category 5 P Export Coefficient	E5	0.0300	gm P m^{-2} yr^{-1}
Land Use Category 6 P Export Coefficient	E6	**0.0300**	gm P m^{-2} yr^{-1}
Land Use Category 7 P Export Coefficient	E7	0.0000	gm P m^{-2} yr^{-1}
Land Use Category 8 P Export Coefficient	E8	0.0000	gm P m^{-2} yr^{-1}
Land Use Category 9 P Export Coefficient	E9	0.0000	gm P m^{-2} yr^{-1}
Land Use Category 10 P Export Coefficient	E_{10}	0.0000	gm P m^{-2} yr^{-1}
Number of Dwellings	Nd	110	#
Average number of Persons per Dwelling	Nu	2.73	n/a
Average Fraction of Yr Dwellings Occupied	Npc	0.22	yr^{-1}
Phosphorus Load per Capita per Year	Si	800	gm P cap^{-1} yr^{-1}
Septic System Retention Coefficient	Rsp	0.5	n/a
P Input from camp	PS1	**520**	gm yr
P input from public beach	PS2	**2080**	gm yr
Point Source Input 3	PS3	0	gm yr
Point Source Input 4	PS4	0	gm yr
Point Source Input 5	PS5	0	gm yr
Phosphorus Retention Coefficient	v	7.2	n/a
Model Outputs			
Total Precipitation Hydraulic Input	Ppt_i	1750991	m^{3} yr^{-1}
Total Evaporation Hydraulic Loss	Eo	260478	m^{3} yr^{-1}
Total Hydraulic Surface Run Off	Ql	5982400	m^{3} yr^{-1}
Total Hydraulic Input	Qt	7733391	m^{3} yr^{-1}
Areal Hydraulic Load	q_s	5.16	m yr^{-1}
Total Hydraulic Outflow	Qo	7472913	m^{3} yr^{-1}
Total Atmospheric P Input	Jd	28942	gm yr^{-1}
Total Surface Run Off P Input	Je	91369	gm yr^{-1}
Total Development P Input	Jr	29026	gm yr^{-1}
Total P Input	Jt	149337	gm yr^{-1}
Lake P Retention Factor	Rp	0.58	n/a
Lake Phosphorus Retention	Ps	62722	gm yr^{-1}
Lake Phosphorus Concentration	[P]	**0.0083**	mg L^{-1}
Lake Phosphorus Outflow	Jo	86615	gm yr^{-1}
Lake Mean Depth	z	4.6	m
Lake Flushing Rate	FR	1.11	times yr^{-1}
Lake Turnover Time	TT	0.9	yr
Lake Response Time	RT(1/2)	0.21	yr

Model Validation		
Measured P (mg L^{-1})		0.0105
Predicted P (mg L^{-1})		0.0084
% Difference		-20.0

V.12. Examples of Model Application

Having verified the model it can now be used to assess the impact of a particular activity with respect to how it will influence the lake's phosphorus concentration. Three examples are presented. (You may want to make these changes on the Excel spreadsheet to verify the results for yourself.)

1. What would be the effect of doubling the amount of clear cut forest?

To evaluate this land use change, it is necessary to adjust the areas of the natural forest and clear cut forest in the spreadsheet. Increasing the area of the clear cut from 52.3 to 104.6 ha and decreasing the area of the natural forest from 635.4 to 583.1 ha results in a change in phosphorus concentration from 0.0084 to 0.0100 mg L^{-1}, an increase of 19.3 %.

2. What would be the effect of doubling the number of dwellings?

Doubling the number of cottages to 220, as well as the area of the cottage lots from 43.6 to 87.2 ha (which also requires decreasing the area of forestland by 43.6 ha), results in changing the phosphorus concentration from 0.0084 to 0.0106 mg L^{-1}, an increase of 26.2 %.

3. What was the lake's phosphorus concentration prior to human activity in the watershed?

This question can be answered by eliminating all of the land uses from the model that result from human activity. This includes agriculture, cottage development, camp, and public beach inputs and setting the area of the forestland to that of the drainage basin minus the wetland area. The results is a lake phosphorus concentration of 0.0045 mg L^{-1}, a value that could be used as reference point for what the lake's phosphorus concentration was prior to human activity in the watershed.

APPENDIX VI
Supplementary Technical Report
Assumptions and Limitations of the Model

VI.1. Introduction

Over the last several decades, the use of mathematical models for predictive purposes has become well established in many areas of ecology. This is especially true in aquatic ecology, and particularly with regard to their use for the prediction of water quality. A large number of water quality models, varying greatly in sophistication and level of complexity currently exist (see e.g., Jorgenson 1995; Chapra 1997).

The major advantage to the use of mathematical models for predictive purposes is that they represent simplifications of natural systems that are difficult or impossible to duplicate experimentally, and provide a means whereby 'experiments' can be performed by altering components of the model and observing the resulting changes. They also provide an important means of evaluating how well we understand a system by comparing model predictions to what occurs in nature. If the model replicates what occurs in nature, we can have some confidence in believing that it contains all the important elements that control a particular process. If, however, the model behaves differently from what we observe in nature, this is an indication that the model lacks important qualitative elements, or is not correct in its quantitative formulations. If the model does appear to work well in terms of its predictive ability, we then have a tool that we can use to make management decisions.

The phosphorus run off coefficient modeling approach is one of the simplest approaches available to evaluate potential changes in phosphorus concentration resulting from changes in land use activities. This simplification has both its advantages and disadvantages. Its main advantage is that it is relatively easy to apply, does not require a great deal of costly field work for estimation of parameters and, most importantly, it provides for a relatively standardized procedure for making the 'best guess' when a decision has to made based on the potential impact of a particular development scenario being proposed for a watershed.

Because the model is simple, its main disadvantage is that it has a number of inherent simplifications and assumptions, and these must be fully appreciated and understood in order to avoid application of the model to situations in which it has not been shown to work successfully. The major purpose of this supplementary document is to discuss these limitations and assumptions, to the extent they have been discussed and recorded in the literature, so that users of the manual will be able to determine the degree to which the model is applicable to the systems they propose to model. A secondary objective of this document is to present some approaches that have been suggested, and in some cases applied, to overcome some of these assumptions and limitations and should prove particularly useful as a reference in those cases when it proves difficult to validate a model. There is also a discussion of the potential for use of the model as an aid to the development of a Phosphorus Water Quality Objective.

VI.2. Model Assumptions

VI.2.1. Phosphorus Transport

VI.2.1.1 Drainage Basin Size and Juxtaposition of Land Use Types

A major assumption of the model is that the amount of phosphorus transported by surface run off to the lake is independent of the distance over which transport occurs (Shuman et al. 1975). This means, for example, that an agricultural land use located in an area of the drainage basin far removed from the lake, or tributaries that enter the lake, will transport as much phosphorus to the lake as an agricultural area located in close proximity to the shoreline of the lake.

Related to this is the influence of drainage basin size on phosphorus transport. The model assumes that the transport of phosphorus is a linear function of drainage basin area. Prairie and Kalff (1986) have evaluated this assumption using literature data tabulated on phosphorus export from 210 drainage basins having a diversity of land uses that included forested and agricultural lands. The latter included pasture, row crops, non-row crops and mixed agriculture. Their results indicated that drainage basin size does not appear to have an affect on phosphorus export for forested, mixed agricultural and non-row crops, but does for pastures and row crops.

They suggest that the differences in observed export may be related to the form of phosphorus that is exported from the different land use areas, and that particulate phosphorus is, for a number of reasons, more likely to be retained within the drainage basin than dissolved phosphorus. In their study, the range and mean percent of particulate phosphorus exported from agricultural land was 44-98 and 84.5 percent, respectively. For forest lands, less than 50 percent of the phosphorus exported was in the particulate form.

The authors provided the following equations to estimate the relationship between phosphorus export and drainage basin area for pasture and row crop agricultural land uses:

Pasture $\quad \log \text{TP export} = 1.562 + 0.589 \times \log \text{Drainage Basin Area}$

Row Crops $\quad \log \text{TP export} = 1.880 + 0.589 \times \log \text{Drainage Basin Area}$

They suggest these equations be utilized by determining a 'standardization factor' based on drainage basin area. Thus, if an estimate of the amount of phosphorus exported for a particular land use is to be estimated based on export coefficients obtained from a study carried out in another area, the export should be corrected to account for any difference in drainage basin size. They provide the following example:

> "...if the TP export of two row crop catchments (5 and 15 km^2) are to be validly compared, the export of the larger basin must be pro-rated by a factor of 1.6

> (the expected TP export from 5 km^2 divided by the expected TP export from 15 km^2) so as to correct for the spatial scale effect observed from this agricultural practice. … The [standardization] factor is simply the ratio of the expected TP exports [predicted from the above equations] for the two catchments."

VI.2.1.2 Phosphorus Retention in Stream and Rivers

The model makes no allowance for the assimilation of phosphorus within upstream rivers or streams entering a lake, or for tributaries contained within a lake's drainage basin. This is a potentially serious limitation if the model is used to determine the permissible level of development within the watershed of a lake that has effluents entering lakes located downstream. If a downstream lake exceeds a phosphorus objective, no upstream development would be allowed.

The retention of phosphorus in streams and rivers can result from settling of particulate phosphorus, sorption of dissolved phosphorus to stream sediments, chemical precipitation of phosphorus, and uptake of phosphorus by benthic algae and macrophytes (Wagner et al. 1996). Behrendt and Opitz (2000) carried out a number of studies in which it was found that as much as 20 to 40 % of the phosphorus load was retained within streams before reaching the receiving water body.

VI.2.1.3. Proximity of Dwellings to Lake

When assessing the impacts of development, most phosphorus loading models have only considered dwellings located within 300 m of the lake's shoreline or a tributary entering the lake, and that phosphorus export to the lake is not influenced by the distance of the dwelling from the lake. The 300 m distance is arbitrary and has never been substantiated.

Hutchinson (2002) has proposed that this be modified to at least include a factor that takes into consideration the distance of the dwelling from the shoreline of the tributary. He proposes that the 300 m limit be maintained, but because all soils have some ability to retain phosphorus, the amount of phosphorus export to the lake or tributary be reduced as follows:

- Development between 100 and 200 m be reduced by one third
- Development between 200 and 300 m be reduced by two thirds
- Development beyond 300 m considered to have no input

VI.2.1.4. Wetlands

There are conflicting reports of the amount of phosphorus contributed by wetlands. At one extreme, some report that wetlands act neither as sources or sinks of phosphorus and that, on an annual basis, do not have a net export of phosphorus (Uttomark et al. 1974; Lee et al. 1980). Scott et al. (2002) on the other hand, suggest that wetlands export high amounts of organic rich phosphates. Rast and Lee (1980), however, suggest that much of the phosphorus exported from wetlands may not be in a form available to algae. The results of other studies indicate that wetlands have variable export or retention of phosphorus depending on their flushing rates and the sorptive capacity of the soils contained in the wetland, which decreases with time as wetlands age (Faulkner and Richardson 1989). Knight et al. (1987) advocate that retention is minimal if the residence time of water in the wetland is less than 10 to 15 days. Soil sorptive capacity is much more variable and requires empirical data to estimate.

Dillon and Molot (1997) made estimates of phosphorus loadings for wetlands located in south-central Ontario and presented the following relationship:

$$P_W = A_d \times (3.05 + (0.54 \times \%\ \text{wetland}) \quad \text{where,}$$

P_W = Wetland Phosphorus Load (kg yr^{-1})
A_d = Drainage Basin Area (km^2)
% Wetland = Percentage Wetland in the Drainage Basin

VI.2.1.5. Groundwater Inputs

The model does not address either the loss of phosphorus to groundwater, or the potential for phosphorus input by way of groundwater flows into a lake. It is often assumed that groundwater is relatively depleted of phosphorus because of the immobility of phosphorus in soils. Although this may be true generally, a recent review of phosphorus loss in agricultural drainage (Sims et al. 1998) indicates that considerable phosphorus can leach into groundwater systems under conditions of deep sandy soils and soils with high phosphorus concentrations resulting from over-fertilization or excessive use of organic fertilizers. There is also the possibility of groundwater transport to surface run off in agricultural fields that are tile drained. This should be considered in model applications where a significant proportion of the lake's drainage basin contains agricultural land use, especially if the crops grown receive high levels of fertilization.

VI.2.2. Lake Morphology

Aside from the surface area and, indirectly, volume of the lake, the model does not take into account differences in lake morphology or the position of water inputs to the lake.

A lake having a complex shoreline with bays and arms may have considerable spatial variation in such things as residence times, which in turn could result in considerable variation in phosphorus retention. Long, narrow water bodies, of the type commonly associated with river impoundments for example, may have a horizontal gradient in hydrological characteristics resulting in a greater amount of phosphorus retention in the upper portion where influents enter.

Some lakes also contain more than one basin and these may behave differently from each other. In this case, it may become necessary to treat each basin as a separate lake, especially if there are major differences in the number and characteristics of any tributaries that may enter each basin.

VI.3 Model Limitations

The model does not appear to work well for lakes that are very shallow. Shallow lakes are often characterized by high flushing rates and a limited ability to retain phosphorus. Any phosphorus that does settle appears to be easily resuspended as a result of the lake's water column being mixed to depths at or near the sediment surface (Welch and Cooke 1995). As a result, the model tends to overestimate the retention of phosphorus in shallow lakes (Hutchinson 2002). The presence of macrophytes, which are often well developed in shallow lakes, is also thought to influence the cycling of phosphorus since they can act as pumps bringing nutrients that have been deposited into the sediments back up into the water column.

Colored lakes are those lakes characterized by high levels of naturally occurring organic acids. The organic acids are largely in the form of humic and fulvic acids that arise from run off originating in wetlands and forested landscapes dominated by coniferous vegetation. Application of nutrient loading models to colored lakes has not been very successful as model predictions of phosphorus concentration are generally much lower than measured lake phosphorus concentrations (Kerekes 1981). In addition, the relationship between phosphorus concentration, phytoplankton production, phytoplankton biomass, chlorophyll *a* concentration and Secchi Disk depth appears to be different for colored lakes (Jackson and Hecky 1980; Chow-Fraser and Duthie 1987; Nurnberg 1996).

At present, it does not appear that phosphorus loading models, as they are presently developed, can be as easily applied to reservoirs as they can to natural lakes (Kerekes 1982; Kennedy 1998). The major reasons for this are as follows:

- The depth and volume of reservoirs typically undergo changes over a relatively short term depending on the need for the water they contain. As a result, the flushing rate and, in turn, the sedimentation rate of phosphorus, varies greatly over the same time period

- Reservoirs used for power generation have their outflows located at the bottom which depletes the hypolimnion and the phosphorus that has settled into it
- Reservoirs are often constructed in drowned river valleys and tend to be morphologically more like rivers than lakes
- The watersheds of reservoirs are generally much larger than those of lakes and tend to have more surface run off relative to the volume of the reservoir
- Because of their larger watersheds, reservoirs tend to have higher sediment loads and a greater proportion of their phosphorus input in particulate form.

Kennedy (1998) makes the following recommendations for anyone attempting to develop phosphorus loading models for reservoirs:

- Because reservoirs tend to have short hydraulic residence times, it may be necessary to formulate nutrient and water balances on a seasonal, as opposed to annual, basis
- If the sediment load is high, the phosphorus sedimentation factor should be adjusted
- Because of the river-like morphology of reservoirs, and the tendency for phosphorus to settle near inlets, it may be necessary to model reservoirs as a series of longitudinal segments. (Kerekes (1982) provides an example of how this approach can be applied.)

VI.4. Application of Model to Establishing Phosphorus Water Quality Objectives

The trophic response of a lake to inputs of phosphorus depends on many factors and it is unlikely that a single phosphorus water quality objective can be established that would be applicable to all Nova Scotia lakes. This makes it necessary to either develop objectives on an individual lake basis, or develop objectives for lakes that behave similarly in terms of their trophic response to phosphorus. The former is unlikely to be practical because of the effort and cost that would be involved. The latter approach requires the development of some sort of lake classification system based on how a lake responds to additions of phosphorus. This approach, often referred to as the 'ecoregional' or 'reference condition' approach, is currently being taken by many federal and state agencies in the United States (USEPA 2000) and has been suggested as a potential approach for setting phosphorus objectives in Canada. (Environment Canada 2003).

Determining exactly which factors should be considered in classifying lakes for this purpose is still a subject of debate. In general, they are those factors that determine the degree to which a lake will respond to an increase in phosphorus concentration, and particularly those factors that determine the biomass of algae under conditions when nutrients are not limiting. These include those factors that determine the potential level of algal production, especially the relationship of lake mixing depth to euphotic zone depth (both of which are closely related to the lake's morphology), and those factors that determine the loss of algal biomass. The later include grazing by zooplankton and flushing from the lake.

The establishment of phosphorus water quality objectives also requires a somewhat subjective assessment of how much of a change in water quality is considered acceptable. The two most commonly used characteristics used to assess water quality with respect to trophic status are water clarity and, in a stratified lake, the degree to which dissolved oxygen levels become depleted in the hypolimnion. If these two criteria are to be used in determining the amount of acceptable change in the water quality of a lake, then quantitative relationships between these factors and the biomass of algae, and between phosphorus concentration and algal biomass, must be developed. The latter will differ depending on the particular characteristics of the lake and is further argument of the need for a lake classification system.

In establishing phosphorus objectives, it is also important to consider the range in levels of phosphorus that are characteristic of natural lakes not impacted by human activities. This also requires that an extensive database be developed, using both existing information and by acquiring new information for those lake types that have not been well studied. This approach also requires that data be available on phosphorus concentration for lakes not impacted by human activity. Hutchinson (2002) presents a means whereby a phosphorus water quality objective can be set for a lake that has already been subjected to development. The approach involves using a validated phosphorus model based on export coefficients, and simply removing the development contribution of phosphorus to determine the pre-development lake phosphorus concentration. He stresses, however, that the model must be well developed and validated, if the results are to be of any significance.

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