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Trout Lake Watershed Study and Management Plan – Existing Conditions, Issues, Opportunities and Constraints

Prepared for: The Corporation of the City of North Bay
Job #: J210014

October 23, 2023

Final Report

October 23, 2023 HESL Job #: J210014

Beverley Hillier
City of North Bay
Manager, Planning and Building Services

Dear Ms. Hillier:

Re: Trout Lake Watershed Study and Management Plan – Existing Conditions, Issues, Opportunities and Constraints

J.L. Richards and Associates Limited (JLR) and Hutchinson Environmental Sciences Limited (HESL) were retained by the City of North Bay (City) to complete the Trout Lake Watershed Study and Management Plan. *Trout Lake Watershed Study and Management Plan – Background Report* (HESL 2021a) included a review of existing and relevant lake water quality information to determine the general health of the lake and how water quality may have changed over time. This report builds on the findings in the *Background Report* and was completed to examine waterfront Best Management Practices (BMPs) and development threshold calculations and considerations. A variety of management tools were employed, and multiple lines of evidence were used to inform the management of Trout Lake because of its importance as a drinking water source, and recreational amenity.

Historical and more recent data indicate that water quality in Trout Lake is excellent and nutrient concentrations are low. Waterfront BMPs, which are currently required to meet municipal planning policy, are effective means to mitigate impacts associated with shoreline development on adjacent waterbodies and monitoring of sewage treatment systems in the Trout Lake watershed have proven to be effective. Lakeshore Capacity Modelling results generally indicate that there is some additional development capacity on Trout Lake and inflowing streams but impacts from climate change and impacts on downstream waterbodies also need to be considered. We developed several recommendations to improve water quality and septic system monitoring and reporting requirements, and improve the connections between scientific information, lake management and planning policy development.

Sincerely,
Per. Hutchinson Environmental Sciences Ltd.

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Signatures

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Executive Summary

J.L. Richards and Associates Limited and Hutchinson Environmental Sciences Limited were retained by the City of North Bay to complete the Trout Lake Watershed Study and Management Plan (Trout Lake Study). The Trout Lake Study is being completed in partnership with the City of North Bay, Municipality of East Ferris, North Bay-Mattawa Conservation Authority and in consultation with a variety of residents and stakeholders. It is being completed to review lake water quality data to understand the health of the lake, determine the effectiveness of management actions to date, and adjust the management approach to reflect this new understanding and evolving best practices.

The *Trout Lake Watershed Study and Management Plan – Background Report* (Hutchinson Environmental Sciences Ltd., 2021a) included a review of existing and relevant lake water quality information to determine the general health of the lake and how water quality has changed over time. General limnology conditions were characterized based on data extracted from reports and provided by North Bay Mattawa Conservation Authority, but more intense statistical analyses and reporting focused on total phosphorus, mean volume weighted hypolimnetic dissolved oxygen, Secchi disk depth and phytoplankton assemblages, as those datasets are key indicators of water quality that are routinely linked to development impacts. Historical and more recent data indicate that water quality in Trout Lake is excellent and nutrient concentrations are low. Significant monitoring effort has been invested in the management of water quality of Trout Lake and there is no evidence of a marked impact of development on the lake.

Climate change has the potential to impact lakes through a variety of processes which could increase nutrient concentrations, decrease dissolved oxygen concentrations, and promote algal growth due to increases in water temperature, thermal stratification, and water column stability. Lake management should acknowledge potential stressors associated with climate change and develop management actions intended to minimize impacts moving forward. The uncertainty related to climate change impacts was considered during the development of conclusions and recommendations.

Waterfront Best Management Practices are commonly implemented to minimize impacts of development on adjacent water quality and ecological features. Research over the past 20 years has consistently shown that septic system phosphorus is largely immobilized in Precambrian Shield soils. A Site Plan Agreement established in ~2010 to allow development of new lots in the Eastview Developments at the east end of Trout Lake requires monitoring of the performance of septic systems and monitoring results indicated that phosphorus removal exceeded 93% in 28 of 44 samples and averaged 86%.

Shorelines link terrestrial and aquatic ecosystems, acting as a transition zone between land and water. They are biological hotspots and highly productive habitats that provide a myriad of ecological services, including maintenance of water quality, flood protection, and wildlife habitat (Hutchinson Environmental Sciences Ltd., 2021b). The City of North Bay currently requires a 15 m buffer and a 30 m shoreline setback for new dwellings to help to reduce any phosphorus loading to Trout Lake from shoreline development.

Stormwater management features include provisions to maximize infiltration and limit stormwater runoff. Specific options include proper re-contouring, discharging of roof leaders, use of soak away pits and other measures to promote infiltration such as grassed and vegetated swales, filter strips, roof leaders and French drains. The Site Plan Agreements for development on Trout Lake commonly include Erosion and Sediment

Control measures to mitigate short-term construction-related impacts and stormwater management techniques such as infiltration trenches and soak away pits to infiltrate roof runoff.

Ontario's Lakeshore Capacity Model was developed to determine development capacity on lakes through an assessment of total phosphorus loadings and lake response. The Lakeshore Capacity Model is a steady-state mass balance model that estimates hydrologic and phosphorus loading from natural (watershed runoff and atmospheric deposition) and human (septic systems and land disturbance) sources and links them together considering lake dynamics to predict total phosphorus concentrations in lakes. Measured total phosphorus data were compared with modelled total phosphorus results to determine the ability of the Lakeshore Capacity Model to accurately estimate total phosphorus concentrations in Trout Lake. The Province recommends that differences between measured and modelled results be less than 20% to confidently use the model to assess capacity. The modelled ice-free mean total phosphorus concentrations under existing conditions for Four Mile Bay and Trout Lake - Main Basin were 6.25 µg/L and 4.84 µg/L, respectively. Modelled total phosphorus concentrations are 11% and 5.9% higher than measured values of 5.64 µg/L and 4.57 µg/L, indicating good correspondence between measured and modelled values. The background total phosphorus concentrations predicted by the model were 5.18 µg/L (Four Mile Bay) and 3.76 µg/L (Trout Lake – Main Basin) which represent the TP concentration from natural watershed loading only. These correspond to background + 50% objectives of 7.77 µg/L (Four Mile Bay) and 5.64 µg/L (Trout Lake – Main Basin). Four Mile Bay and Trout Lake – Main Basin are both under capacity for development as the existing modelled total phosphorus concentrations are less than the Provincial Water Quality Objective of Background + 50% and the Municipal Water Quality Objective of 7 µg/L.

Three development scenarios were used to model future total phosphorus concentrations in Four Mile Bay and Trout Lake – Main Basin: 1) the build out of existing vacant lots of record, 2) the build out of existing vacant lots of record + the conversion of all seasonal residences to permanent, and 3) the build out of existing vacant lots of record + the conversion of all seasonal residences to permanent + build out of 20% of the remaining development capacity (i.e., 20 lots on Four Mile Bay or inflowing streams and 83 lots on Trout Lake – Main Basin or inflowing streams). The development scenarios increased modelled total phosphorus concentrations in Four Mile Bay from 6.25 µg/L to 6.44 µg/L (Scenario #1), 6.63 µg/L (Scenario #2), and 6.70 µg/L (Scenario #3), all of which are less than the Provincial Water Quality Objective of 7.77 µg/L and Municipal Water Quality Objective of 7 µg/L. The development scenarios increased modelled total phosphorus concentrations in Trout Lake – Main Basin from 4.57 µg/L to 5.03 µg/L (Scenario #1), 5.13 µg/L (Scenario #2), and 5.23 µg/L (Scenario #3), all of which are less than the Provincial Water Quality Objective of 5.64 µg/L and Municipal Water Quality Objective of 7 µg/L.

The Ontario Ministry of Natural Resources and Forestry is responsible for managing fish habitat and in that role supports the enforcement of development capacities on some lakes. Lake Trout (*Salvelinus namaycush*) are a sensitive fish species and have specific temperature and oxygen requirements including a criterion of 7 mg/L of dissolved oxygen, measured as the Mean Volume-Weighted Hypolimnetic Dissolved Oxygen at the end of summer. An empirical modelling approach has been developed where end of summer Mean Volume-Weighted Hypolimnetic Dissolved Oxygen can be predicted based on spring overturn phosphorus concentration and lake morphometry. The modelled existing spring overturn total phosphorus concentrations in Four Mile Bay (6.86 µg/L) and Trout Lake – Main Basin (5.45 µg/L) corresponded with predicted Mean Volume-Weighted Hypolimnetic Dissolved Oxygen concentrations of 8.93 mg/L and 11.0 mg/L, respectively. Future modelled spring overturn total phosphorus concentrations in Four Mile Bay of

7.05 µg/L (Scenario #1), 7.25 µg/L (Scenario #2) and 7.32 µg/L (Scenario #3) resulted in Mean Volume-Weighted Hypolimnetic Dissolved Oxygen concentrations of 8.86 mg/L, 8.78 mg/L and 8.76 mg/L, respectively, or declines of 0.07 mg/L to 0.17 mg/L from existing modelled concentrations. Future modelled spring overturn total phosphorus concentrations in Trout Lake (Main Basin) of 5.64 mg/L (Scenario #1), 5.74 mg/L (Scenario #2) and 5.84 mg/L (Scenario #3), resulted in Mean Volume-Weighted Hypolimnetic Dissolved Oxygen concentrations of 10.9 mg/L, or declines of 0.1 from existing modelled concentrations. Modelled changes in Lake Trout habitat associated with development scenarios are therefore minor.

Nutrient loading associated with future development inputs on Trout Lake could theoretically cause increased total phosphorus concentrations and decreased Mean Volume-Weighted Hypolimnetic Dissolved Oxygen concentrations in downstream waterbodies, including Turtle Lake and Lake Talon. The Ministry of Environment, Conservation and Parks determined that Turtle Lake was at development capacity because Mean Volume-Weighted Hypolimnetic Dissolved Oxygen concentrations were <7 mg/L while Lake Talon is at capacity because total phosphorus concentrations were elevated, Mean Volume-Weighted Hypolimnetic Dissolved Oxygen concentrations were <7 mg/L in Basin 1 and the main basin is at capacity because Mean Volume-Weighted Hypolimnetic Dissolved Oxygen concentrations is close to 7 mg/L. A number of data limitations were however noted in the Ministry of Environment, Conservation and Parks assessment. The maximum increased downstream total phosphorus load associated with the future development scenarios is +22.6 kg/year. Additional Lakeshore Capacity and dissolved oxygen modelling should be completed to quantify the change in total phosphorus and Mean Volume Weighted Hypolimnetic Dissolved Oxygen in Turtle Lake and Lake Talon.

Recreational Carrying Capacity is generally assessed through changes to the amount of boaters on a lake as a result of a proposed waterfront development. Capacity is considered for safety purposes but boating traffic can also have negative impacts on water quality through the generation of wakes which erode soft shorelines. The Official Plan of Seguin Township, Ontario includes a provision for recreational capacity on lakes. It allows for 1 residential unit for every 1.6 ha of lake surface area beyond 30 m from shore. This approach reduces crowding of the lake, limits the number of boats and is easily implemented. Following this simple methodology, Four Mile Bay is over capacity while Trout lake – Main Basin is under capacity for further development. Recreational capacity was also assessed via lot frontage. The City of North Bay and East Ferris both require a minimum frontage of 60 m for waterfront lots on Trout Lake. The number of 60 m lots were calculated based on shoreline perimeter and following this simple methodology, Four Mile Bay is over capacity while Trout lake – Main Basin is under capacity for further development

Several streams and wetlands flow into both Four Mile Bay and Trout Lake - Main Basin, including Four Mile Creek which flows out of Four Mile Lake and empties into Four Mile Bay. Most of the remaining developable land is located adjacent to Four Mile Creek so those development impacts were considered. The phosphorus reduction efficiency of Four Mile Creek and other inflowing watercourses could not be quantified with available data as part of this study, but the watercourses appear to have many of the attributes that indicate high phosphorus reduction efficiencies. Nutrient retention processes in lands located between the septic field and the watercourses would reduce phosphorus loads associated with future development from impacting adjacent watercourses while additional attenuation of total phosphorus within watercourses would further reduce total phosphorus loads to downstream Four Mile Bay and Trout Lake.

The lines of evidence generally indicate that there is development capacity on Four Mile Bay and Trout Lake except for a) recreational capacity on Four Mile Bay, and b) measured total phosphorus and Mean Volume-Weighted Hypolimnetic Dissolved Oxygen on both waterbodies, which exceeded guidelines in select years. Public input indicated that recreational pressure such as boat traffic is actually more pronounced on Trout Lake than Four Mile Bay. Measured total phosphorus data exhibited considerable year to year variability which was in part the result of differences in laboratory procedures and Minimum Detection Limits, while Mean Volume-Weighted Hypolimnetic Dissolved Oxygen data were heavily interpolated which limited the utility of those findings.

Waterfront Best Management Practices are effective tools to limit development impacts (e.g. changes to total phosphorus and Mean Volume-Weighted Hypolimnetic Dissolved Oxygen concentrations) on Trout Lake and have been successfully implemented through Site Plan Agreements. Any future development adjacent to Four Mile Creek, other inflowing tributaries, Four Mile Bay or the main basin of Trout Lake should include comprehensive waterfront Best Management Practices such as those associated with sewage treatment systems, and those that are routinely implemented as part of Site Plan Agreements (i.e., shoreline buffers and ESC control). It is integral that Best Management Practices are encouraged through education and stewardship as well as enforced through appropriate regulation. Lastly, the uncertainty associated with climate change impacts on Trout Lake and downstream impacts needs to be acknowledged and monitored moving forward. Recommendations included in Section 10.0 should be implemented to improve monitoring and ensure that monitoring results are routinely used to assess the effectiveness of development policy and inform necessary revisions to the management of Trout Lake moving forward.

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Acronyms

BMP – Best Management Practices

ESC – Erosion and Sediment Control

DESC – Dorset Environmental Science Centre

HESL – Hutchinson Environmental Sciences Limited

JLR – J.L. Richards and Associates

LCM – Lakeshore Capacity Model

MDL – Minimum Detection Limit

MECP – Ministry of Environment, Conservation and Parks

MNRF – Ministry of Natural Resources and Forestry

MVWHDO – Mean Volume Weighted Hypolimnetic Dissolved Oxygen

MWQO – Municipal Water Quality Objective

NBMCA – North Bay Mattawa Conservation Authority

PWQO – Provincial Water Quality Objective

SER – Site Evaluation Report

TP – Total Phosphorus

1. Introduction

J.L. Richards and Associates Limited (JLR) and Hutchinson Environmental Sciences Limited (HESL) were retained by the City of North Bay (City) to complete the Trout Lake Watershed Study and Management Plan (Trout Lake Study). The Trout Lake Study is being completed in partnership with the City, Municipality of East Ferris, North Bay-Mattawa Conservation Authority (NBMCA), and in consultation with a variety of residents and stakeholders. It is being completed to review lake water quality data to understand the health of the lake, determine the effectiveness of management actions to date, and adjust the management approach of Trout Lake to reflect this new understanding and evolving best practices.

The project was completed using a three-phase process as described in Table 1. This Issues, Opportunities and Constraints Report is the second deliverable of the project and includes:

- A summary of existing and relevant lake water quality information to determine the general health of the lake and whether water quality has changed over time (Section 2.0);
- A brief synopsis on potential impacts of climate change on lakes (Section 3.0);
- A review of the scientific understanding associated with waterfront Best Management Practices (BMPs), including a summary of septic system monitoring results from the Trout Lake watershed (Section 4.0);
- A Lakeshore Capacity Assessment to determine development thresholds based on utilization of the Lakeshore Capacity Model (Section 5.0);
- A discussion on potential changes to Turtle Lake and Lake Talon which are located downstream of Trout Lake (Section 6.0)
- A review of recreational capacity (Section 7.0);
- A discussion on development and phosphorus attenuation associated with inflowing streams (Section 8.0);
- Conclusions (Section 9.0); and
- Recommendations (Section 10.0).

The findings from this report informed the Trout Lake Watershed Study and Management Plan - Existing Conditions, Opportunities and Constraints Report (JLR 2022) which includes a review of municipal best practices, observations on the existing land use planning framework and management approach. The scientific (HESL) and planning (JLR) Background Reports and Existing Conditions, Opportunities and Constraints reports, and consultations undertaken during the Directions and Planning Phases, all informed the Trout Lake Watershed Study and Management Plan – Directions Report (JLR 2023).

Table 1. Project Phases and a Summary of the Related Scope and Deliverables from each Phase.

Phase	Scope	Deliverables	Status
Understanding	Review existing and relevant lake water quality and land use planning information	Background Reports	Completed
	Complete Lakeshore Capacity Modelling	Updated Lakeshore Capacity Model	Completed
	Review municipal best practices and synthesize information from the Background Report and Lakeshore Capacity Model	Issues, Opportunities and Constraints Report	Completed
Directions	Consultations with residents and stakeholders to receive feedback	Directions Report	Completed
Planning	Consultation with public and stakeholders on Directions Report	Final Report	Completed

2. Existing Conditions

The *Trout Lake Watershed Study and Management Plan – Background Report* (HESL 2021a), provided in Appendix A, includes a review of relevant lake water quality information to assess the general health of the lake and how water quality may have changed over time. In summary, a wide variety of background reports and datasets were reviewed to characterize water quality conditions in Trout Lake and compare water quality conditions spatially and temporally. Eight core sampling stations have been consistently sampled across multiple monitoring programs and special studies (Figure 1). General limnological conditions were characterized based on data extracted from reports and provided by NBMCA, but more intense statistical analyses and reporting focused on total phosphorus (TP), Mean Volume-Weighted Hypolimnetic Dissolved Oxygen (MVWHDO), Secchi disk depth and phytoplankton assemblages as those datasets were sufficiently robust and are key indicators of water quality that are routinely linked to development impacts.

Long-term data indicate that water quality in Trout Lake is excellent and nutrient concentrations are low (HESL 2021a). Significant monitoring effort has been invested in the management of water quality of Trout Lake and there is no evidence of a marked impact of development on the lake.

Waterfront development can have a variety of impacts and is often assessed in terms of recreational water quality, as defined by total phosphorus and its relationship to algal growth, and dissolved oxygen, so those results are discussed in more detail in the following paragraphs to inform conclusions.

2.1 Total Phosphorus Trends

Long-term TP data collected from 2000 to 2019 has not shown any significant change in concentrations at the eight long-term monitoring locations on the lake, suggesting that increased phosphorus loading from recent (i.e., 20 years) development has not occurred or has not been captured by the current monitoring program (HESL 2021a). Historical data analyses from 1977 to 1986 (Conestoga Rovers and Associates 1988), and from 1975 to 2002 (Gartner Lee Limited 2002) also did not record trends in TP concentrations over time. When average annual TP concentrations were calculated for all sites (both the Main Basin and Four Mile Bay), a subtle long-term decline was noted but the change was not statistically significant and was subject to high year-to-year variability.

2.2 Total Phosphorus Concentrations

Ice-free average total phosphorus concentrations exceeded the Municipal Water Quality Objective (MWQO) of 7 μg/L at individual sites and in specific years when all sites are combined from both Four Mile Bay and the Main Basin of Trout Lake (Figure 2). Total phosphorus concentrations were highly variable year-to-year, but TP concentrations were consistently higher in Four Mile Bay than the main basin, where annual MWQO exceedances occurred in 2008 (8.32 μg/L), 2009 (7.69 μg/L) and 2011 (8.98 μg/L). Average annual TP concentrations in the main basin of Trout Lake exhibited no exceedances of the MWQO. No historical exceedances of the Provincial Water Quality Objective (PWQO) for TP (10 μg/L) occurred at any of the 8 long-term monitoring stations suggesting a high level of protection against aesthetic deterioration across Trout Lake and Four Mile Bay.

Water samples collected in Trout Lake by the NBMCA have been analyzed at a variety of laboratories including PSC Analytical (2003 - 2004), Maxxam Analytics (2005, 2008 - 2012), Near North (2006) and Dorset Environmental Science Centre (2013 - current; Harrison, J., personal communication, March 29, 2018; Mills, A., personal communication, February 9, 2022). TP concentrations were temporally variable (HESL 2021a) until 2013 when water quality analysis at the Dorset Environmental Science Centre (DESC) began. Exceedances of the MWQO in Four Mile Bay occurred in three out of the four years that samples were analyzed at Maxxam Analytics, and the fourth year (2010) contained the lowest TP concentrations on record (Four Mile Bay = 2.64 μg/L; Trout Lake – Main Basin = 1.65 μg/L) – findings that severely limit the impact of these findings (i.e., exceedances of MWQO) on our conclusions due to a lack of confidence in the data (HESL 2021a).

Minimum Detection Limits (MDLs) are the minimum measured concentration of a given parameter that can be distinguished with 99% confidence from method blank results, and they vary substantially between laboratories and parameters. In terms of study objectives, MDLs must be sufficient to test a given hypothesis and characterize the level of change of interest, which in this case requires a low MDL given the low TP concentrations in Trout Lake. The DESC, where samples have been analyzed since 2013, has an MDL of 1 µg/L +/- 0.5 which is lower than what other commercial laboratories can match (i.e., 3 µg/L), including Maxxam Analytics. Since sampling methodology has remained consistent for the duration of the sampling program, temporal and year-to-year variability in TP results may be driven by differences in laboratory procedures and different MDLs rather than rapidly changing TP concentrations in Trout Lake.

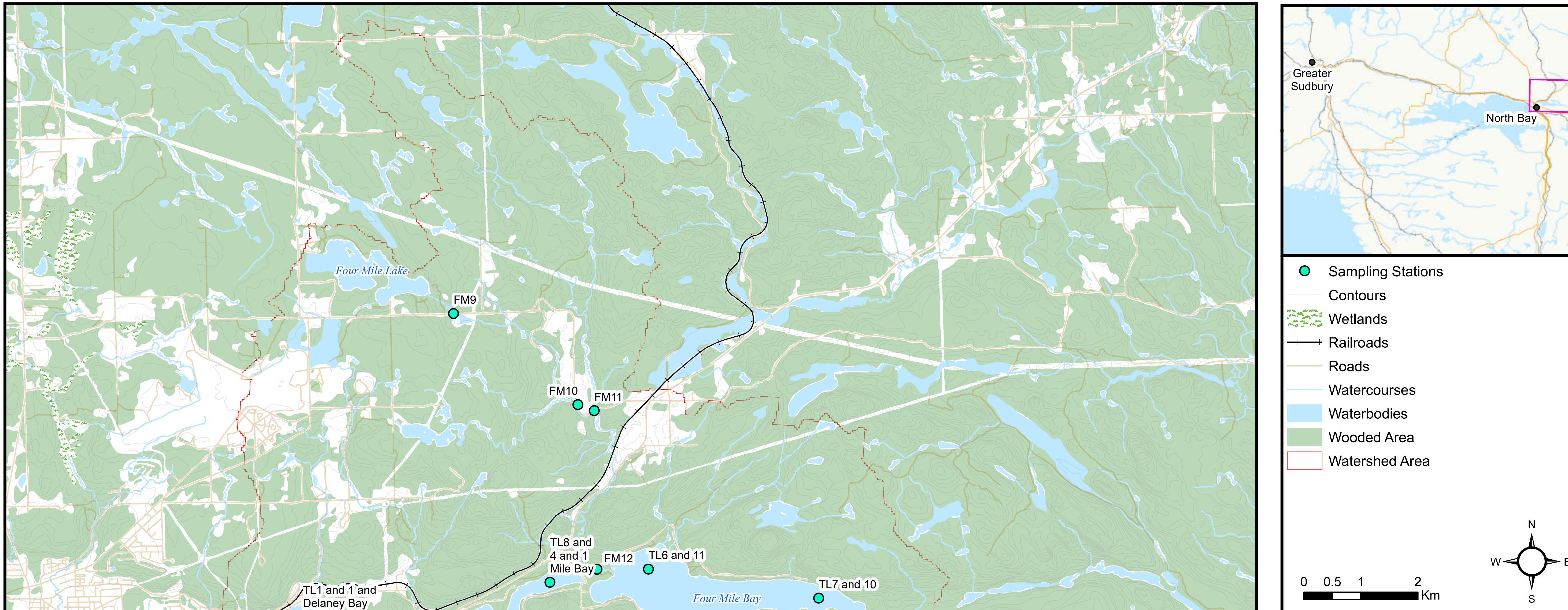

Figure 1:
Sampling Stations

Project Lead: Brent Parsons
Prepared by: Kris Hadley
Data Source: HESL,ESRI Imagery
Coordinate System: NAD 1983 UTM Zone 17N

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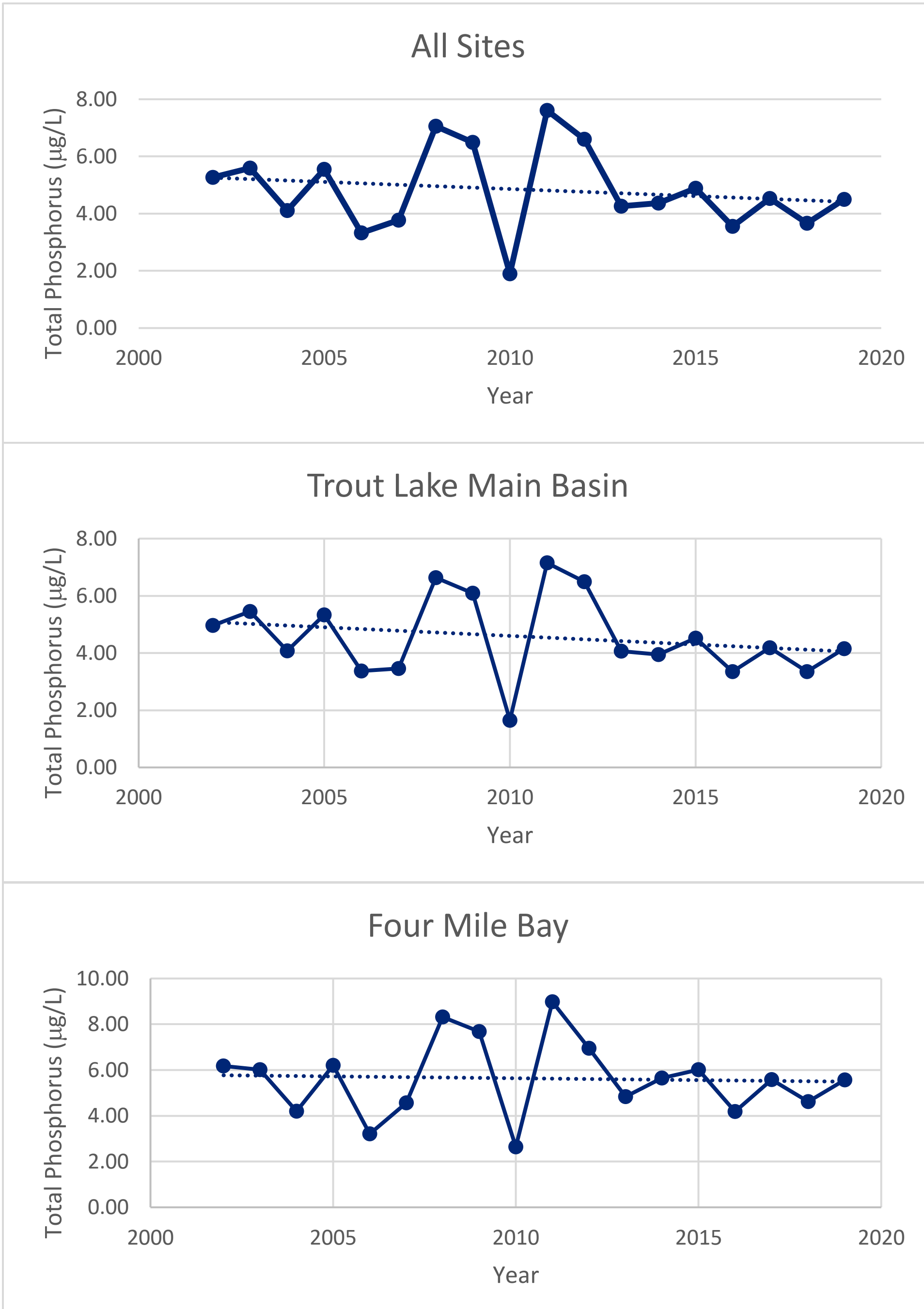
Figure 2. Annual Average Ice-Free TP for Combined Sites at All Monitoring Locations, within Trout Lake – Main Basin and Four Mile Bay.



Note: trendlines were added to showcase declining patterns in total phosphorus concentrations but data are highly irregular.

2.3 Mean Volume-Weighted Hypolimnetic Dissolved Oxygen Concentrations

Ontario has adopted a MVWHDO concentration of 7 mg/L (measured between August 15th and September 15th) as a criterion to protect Lake Trout (*Salvelinus namaycush*) habitat. The Municipal regulations for Trout Lake add a layer of conservatism to the Provincial objective, setting an objective for MVWHDO at 8 mg/L. MVWHDO concentrations were different between Four Mile Bay and the Main Basin so results from each area of the lake were compared to provincial and municipal objectives independently. Based on data available from nine years of monitoring (i.e., 1987, 1989, 1994, 2001, 2002, 2006, 2014, 2015 and 2018) in the main basin of Trout Lake, a single value in 1994 fell below the municipal objective while no concentrations below the Provincial objective were recorded. Multiple MVWHDO concentrations below the municipal objective (8 mg/L) in Four Mile Bay have been recorded (1993, 1994, 2015, 2018), and one concentration (1994) was also lower than the Provincial objective of 7 mg/L. Note however that the data which MECP used to complete these calculations for all years besides 2018 were heavily interpolated and therefore results should be interpreted with caution (see HESL (2021a) for more detail). A consistent sampling approach, data analysis and interpretation are required to better assess MVWHDO against Provincial and Municipal objectives as discussed in Section 10 – Recommendation 4.

A strong correlation between MVWHDO concentrations and sampling date was apparent in the current dataset with elevated concentrations being associated with earlier sampling dates (e.g., 2001, 2002 and 2006) within the August 15 - September 15 timing window. Maintaining consistent sampling timing will be vital for long-term comparison of MVWHDO concentrations to Municipal and Provincial guidelines and when comparing concentrations between years.

3. Climate Change

Recent climate change represents one of the most serious anthropogenic threats to lake ecosystems in Canada. As meteorological and hydrological conditions are altered by climate change, so too are physical, chemical and biological properties of lakes. Climate change has the potential to impact lakes through increased flooding, pollutant transport, erosion and droughts, while increased air and water temperature will impact the length of the growing season, lake stratification, oxygen regimes and life cycles of aquatic biota (Kundzewicz et al. 2007). Climate change could increase nutrient concentrations, decrease dissolved oxygen concentrations, and promote algal growth due to increases in water temperature, thermal stratification, and water column stability (O'Neil et al. 2012; Orihel et al. 2017). For example, the duration of thermal stratification in the water column will increase which could cause oxygen depletion in bottom waters and increased internal loading of nutrients. The interactive effects of climate change are difficult to discern from existing monitoring data and are difficult to predict but Paterson et. al (2017) noted that the frequency, extent and reporting of harmful algal blooms have increased over the past few decades in Canada. Harmful algal blooms are being reported in oligotrophic lakes on the Precambrian Shield in Ontario like Trout Lake, and reports are occurring later in the season which aligns with warmer fall temperatures (Winter et al. 2011). Similar patterns in harmful algal blooms have been observed elsewhere in Northeastern USA and Canada (Carey et al. 2012), suggesting that the increased blooms observed in low-nutrient Ontario lakes are being driven by factors beyond local and regional scale impacts.

Lake management should address potential stressors associated with climate change and develop management actions intended to minimize impacts, and not solely focus on the management of direct anthropogenic impacts such as septic systems from development. The uncertainty related to climate change impacts was considered during the development of conclusions (Section 10) and recommendations (Section 11).

3.1 Other Uncertainties

Lake management and the determination of an appropriate level of waterfront development is complicated by a number of additional factors beyond climate change. The Lakeshore Capacity Model has traditionally been used to determine development capacity in Ontario based on the assumption that a considerable phosphorus load from septic systems is transported to the adjacent waterbody. Scientific peer-reviewed studies have largely proven that most of the septic-related phosphorus is actually retained in septic systems and in native soils, especially on the PreCambrian Shield, as is further discussed in Section 4.1. However, septic systems are not the sole stressor that waterfront development imparts on a waterbody, nor is phosphorus the only water quality parameter of concern. The problem is that there is no quantitative model which calculates development capacity based on the combination of stressors that waterfront development causes (e.g., sedimentation and increased total suspended solids caused by boat usage or chloride inputs from winter road maintenance). This study therefore included in depth examination of water quality data, discussions with stakeholders and the evaluation of multiple lines of evidence to try and develop a holistic understanding of the water quality status of Trout Lake, determine an appropriate level of development that can be sustained and most importantly, and develop a series of recommendations that should be implemented to improve the health of Trout Lake.

4. Waterfront Best Management Practices

Waterfront Best Management Practices (BMPs) are commonly implemented to minimize impacts of development on adjacent water quality and ecological features. A review of municipal best practices implemented by other municipalities was completed in JLR (2022). The scientific underpinning of three common waterfront development BMPs is described in the following paragraphs to provide an understanding of how the mechanisms of each help to reduce development-related impacts.

4.1 Sewage Treatment Systems

Research over the past 20 years has consistently shown that septic system phosphorus is immobilized in Precambrian Shield soils. Mechanistic evidence (Stumm and Morgan 1970; Jenkins et al. 1971; Isenbeck-Schroter et al. 1993) and direct observations made in septic systems (Willman et al. 1981; Zanini et al., 1998; Robertson et al. 1998; Robertson 2003) all show strong adsorption of phosphate on charged soil surfaces and mineralization of phosphate with iron (Fe) and aluminum (Al) in soil. The mineralization reactions, in particular, appear to be favoured in acidic and mineral rich groundwater in Precambrian Shield settings (Robertson et al. 1998; Robertson 2003), such as those found in the Trout Lake watershed, typically resulting in over 90% of septic phosphorus being immobilized. The mineralization reactions appear to be permanent (Isenbeck-Schroter et al. 1993) and many studies conclude that most septic phosphorus is stable within 0.5m – 1m of the tile drains in a septic field (Robertson et al. 1998; Robertson 2003; Robertson 2012).

Robertson et al. (2019) summarized phosphorus concentrations in groundwater plumes from 24 septic systems throughout Ontario in the Precambrian Shield Basement (Muskoka, Parry Sound, Lake of the Woods and Southwest of Sudbury) that were monitored over a 30-year period. Phosphorus removal averaged 97% at the non-calcareous sites and 69% at the calcareous sites within drainfields and proximal plumes within 10 m of the drainfields, regardless of site age or loading rate.

Trophic status modelling also supports the mechanistic and geochemical evidence. Dillon et al. (1994) reported that only 28% of the potential loading of phosphorus from septic systems around Harp Lake, Muskoka, could be accounted for in the measured phosphorus budget of the lake. The authors attributed the variance between measured and modelled estimates of phosphorus to retention of septic phosphorus in tills that were found in the catchment (Mollard et al. 1980, Gartner Lee Ltd. 2005).

A septic retention coefficient for the Lakeshore Capacity Assessment was selected in Section 5.3.1 based on scientific literature as discussed above, monitoring of septic systems as discussed in the following section (Section 4.1.1), and an examination of soil and geology mapping in the Trout Lake watershed.

4.1.1 Mitigation Measures Implemented in the Trout Lake Watershed

The City of North Bay maintains strict controls on new development to reduce any phosphorus loading to Trout Lake from shoreline development. Site Evaluation Reports are completed to inform development of Site Plan Agreements that are designed to minimize potential impacts on Trout Lake. A Site Plan Agreement was established in ~2010 to allow for development of new lots in the Eastview Estates Development at the east end of Trout Lake. The Site Plan Agreements require monitoring of the performance of septic systems in the Eastview Development properties to ensure that they meet an objective of 93% phosphorus removal. Phosphorus abatement is determined by comparing measurements of TP measured in a) the raw effluent in the septic tank, and b) a piezometer installed in the septic tile field downgradient. Three samples are taken each year for a period of five years. The City provided data for seven properties that were monitored between 2012 and 2021. Information on the sampling program is provided in Table 2 and results are presented in Table 3.

Five properties on the North Shore were monitored from 2012 – 2016 with the goal of collecting 3 samples each year for a total of 15 samples. The required monitoring schedule was not always met, for a variety of reasons.

- Site 2589 was sampled three times/year from 2012-2015 but not in 2016. One anomalous value of 40[1] mg/L of TP in the raw effluent was measured and excluded from the analysis due to suspected contamination,
- Site 2601 was sampled three times/year from 2012-2015 but not in 2016. One anomalous value of 120[1] mg/L of TP in the raw effluent was measured but excluded from the analysis. Treated effluent results were only reported for 7 of the 12 events sampled,

[1] Robertson et al (2019) reported soluble reactive phosphorus concentrations of 0.1 – 25 mg/L (average = 8.2 +/- 4.9 mg/L) from 123 samples taken at 23 Ontario sites.

- Although raw effluent at Site 2625 was sampled 15 times from 2012-2016, the piezometer for sampling treated effluent was reported as dry on each event and so no samples were taken,
- Site 2637 was sampled 11 times from 2012-2015 but not in 2016. Treated effluent results were only reported for 9 of the 11 events sampled,
- Raw effluent was sampled at Site 2685 in 14 occasions from 2012-2016 but the results reported "No Monitoring Port" and so no samples of treated effluent were taken.

North Shore property 2661 was sampled on six occasions in 2019 - 2020 and both raw and treated effluent samples were taken. One sample taken in May 2021 produced anomalous results and was scheduled for resampling, but no other 2021 results were available at the time of reporting.

Four Mile Road property 1000 was sampled 10 times between 2018 and May of 2021 and all results were provided for raw and treated effluent. No other results were available at the time of reporting.

Table 2. Sampling Program for Eastview Development Properties.

	No. Raw Effluent Samples	No. Treated Effluent Samples	Comment
Site	n = 15	n = 15	
North Shore 2012- 2016			
2589	12	12	Raw Value of 40 mg/L excluded
2601	12	7	Raw Value of 120 mg/L excluded
2625	15	0	"Port is Dry"
2637	11	9	
2685	14	0	"No Monitoring Port"
North Shore 2019- 2020			
2661	6	6	May 2021 "Resample Required"
Four Mile Road 2018 - 2021	n = 10	n = 10	1 sample only in 2021
1000	10	10	

All septic systems achieved the required 93% reduction in TP in some samples but, on average, only two of the seven (i.e., 2637 and 2661) met the requirement with average reductions of 95% (Table 3). Removal exceeded 93% in 28 of 44 samples and averaged 86%. In at least three samples the results were suspect but could not be justifiably excluded for our analysis. The results provided for the three suspect samples did not indicate the locations of the treated effluent sampling piezometers and so they may not have been located at the edge of the mantle on the downgradient side of the tile field where treatment would be maximized. Recommendations related to septic system monitoring are provided in Section 10.2.

Table 3. Phosphorus Treatment in 7 Eastview Septic Systems.

	No. Treated Effluent Samples	Raw Effluent	Treated Effluent	Reduction	Range of Reduction
Site	n = 15	TP in mg/L	TP in mg/L	Percent	Percent
North Shore 2012- 2016					
2589	12	5.4	0.49	84%	72-99%
2601	7	9.4	2.2	75%	3-97%
2625	0	12.2	-	-	-
2637	9	14.2	0.93	95%	88-97%
2685	0	9.9	-	-	-
North Shore 2019- 2020					
2661	6	15.5	0.67	95%	91 - 99%
Four Mile Road 2018 - 2021					
1000	10	17.7	1.97	81%	46 - 99%
All Sites Mean	44	12.1	1.3	86%	3-99%

Monitoring of the Eastview Development properties also showed that the septic systems were effectively nitrifying effluent. Nitrate concentrations increased from below detection in the raw effluent to an average of 6.8 mg/L in the treated effluent. This was accompanied by pH being lowered from an average of 6.9 to 6.0, indicating that a) the groundwater was acidic, thus favouring phosphorus mineralization and b) nitrification of ammonia within the aerobic tile field was contributing acidity to the effluent. Both nitrification and acidification of the effluent confirm that the septic systems were operating effectively for conventional treatment as well as for phosphorus abatement.

4.2 Shoreline Buffers

Shorelines link terrestrial and aquatic ecosystems, acting as a transition zone between land and water. They are biological hotspots and highly productive habitats that provide a myriad of ecological services, including maintenance of water quality, flood protection, and wildlife habitat (HESL 2021b). Residential development is often concentrated around shorelines, and most development-related impacts to freshwater habitats occur in the nearshore environment. Natural shoreline vegetation is commonly cleared during development and replaced partially or completely by manicured lawn. Shorelines may also be altered by the addition of docks, boathouses, paths, and seawalls. Shoreline development is increasing in many jurisdictions and has been identified as the main threat to lake health in the United States (Amato et al. 2016). If not properly managed, waterfront development can degrade sensitive shoreline habitats, and alter the ecological integrity of adjacent lakes and rivers.

Shoreline buffers can play an important role in protecting lake health. The physical separation they provide between upland human activity and the aquatic environment can aid in mitigating the effects of development and site alteration on water quality and wildlife habitat, while providing erosion and flood control. In general, larger buffers are better at consistently providing a range of protective functions. A 15 m buffer has been found to be the minimum size necessary to maintain physical and chemical functions while 30 m is the minimum necessary to maintain biological functions (Beacon et al. 2012; Castelle et al. 1994; HESL 2021b). Efficient removal of some pollutants (notably sediment) can occur in buffers of 10-20 m width, but other pollutants (such as nutrients) may require buffer widths of 30 m or more for effective attenuation. Water quality improvements generally increase with buffer size (e.g., 10 m removes 65% of sediment from overland runoff while 30 m removes 85% of sediment from overland runoff; Sweeney and Newbold 2014). Larger buffers are also better at protecting the diversity of aquatic and terrestrial species that rely on shorelines.

The scientific literature demonstrates that a 30 m buffer provides a range of ecological services, and this buffer size is commonly recommended in the peer-reviewed literature focused on shoreline development, aligning with Provincial guidance. While smaller buffers provide some benefits for water quality and aquatic habitat protection, larger buffers provide more ecological services, more completely. Buffers will likely become more important in protecting lake health as climate change impacts on freshwater systems continue to intensify. The City of North Bay currently requires a 15 m buffer and a 30 m shoreline setback for new dwellings to help reduce any phosphorus loading to Trout Lake from shoreline development.

4.3 Erosion and Sediment Control

An Erosion and Sediment Control (ESC) plan can help mitigate the impacts of development in the short-term (i.e., Construction Mitigation Plan) and long-term (i.e., Stormwater Management Plan) by encouraging infiltration of stormwater to the subsurface. A construction mitigation plan should be developed to (CISEC Canada 2011):

- Utilize a multi-barrier approach;
- Retain existing vegetation;
- Minimize land disturbance area;
- Slow down and retain runoff to promote settling;
- Divert runoff from problem areas;
- Minimize slope length and gradient of disturbed areas;
- Maintain overland sheet flows and avid concentrate flows; and
- Store/stockpile soil away from watercourses, drainage features, and tops of steep slopes.

A variety of BMPs can be employed to accomplish these goals depending on the site conditions. The effectiveness of BMPs is contingent on proper installation and maintenance, including inspection.

Stormwater management features to minimize long-term stormwater runoff from waterfront development include provisions to maximize infiltration and limit stormwater runoff. Specific options include proper re-contouring, discharging of roof leaders, use of soak away pits and other measures to promote infiltration, grassed and vegetated swales, filter strips, roof leaders and French drains. Stormwater management options are often site-specific and the best approach will be dictated by site characteristics and the nature of the proposed development. The Site Plan Agreements for development on Trout Lake commonly include ESC measures to mitigate short-term construction-related impacts and stormwater management techniques such as infiltration trenches and soak away pits to infiltrate roof runoff.

5. Lakeshore Capacity Assessment

Ontario's Lakeshore Capacity Model (LCM) was developed to determine a lake's development capacity through an assessment of TP loadings and lake response (MOE 2010). The LCM is a steady-state mass balance model that estimates hydrologic and phosphorus loading from natural (watershed runoff and atmospheric deposition) and human (septic systems and land disturbance) sources and links them together considering lake dynamics to predict total phosphorus concentrations in lakes. The Province of Ontario recommends the use of the LCM to determine the Provincial Water Quality Objective (PWQO) for phosphorus and the amount of shoreline development that can occur to maintain phosphorus levels within that threshold. The PWQO for inland lakes on the Precambrian Shield allows for a 50% increase in phosphorus concentration from development over levels that would occur in the absence of any development on the lake (i.e., "Background" + 50%) to a maximum concentration of 20 μg/L.

MECP completed a Lakeshore Capacity Assessment of Trout Lake in 2018 (MECP 2018). Modelled spring overturn TP concentrations were 10.66 µg/L for Four Mile Bay and 11.42 µg/L for Trout Lake - Main Basin, both of which were substantially higher than measured values of 5.88 µg/L and 4.19 µg/L, respectively. MECP determined that the model could not be used as a planning tool because it overpredicted the spring overturn concentrations by greater than 20%. We developed an updated LCM, including updated input variables, as part of an exploratory exercise to determine if a more accurate model could be developed and used as a lake management tool to inform development capacity.

5.1 Input Data

The Lakeshore Capacity Assessment utilized the assumptions and recommended model inputs, coefficients and constants provided by the MECP (MOE 2010), HESL (2021a), MECP Lake Capacity Assessment: Trout Lake (MECP 2018), the MNRF's Flow Assessment Tool (MNRF 2020) and results of GIS analysis completed by HESL (Table 4).

Table 4. Data used in the Lakeshore Capacity Assessment.

Type of Data	Inputs	Source
Physical	Lake area and depth	MECP Lake Capacity Assessment: Trout Lake (MECP 2018)
	Catchment and wetland area	Ontario Flow Assessment Tool and GIS analysis completed by HESL
Development	Lots and occupancies	MECP Lake Capacity Assessment: Trout Lake (MECP 2018)
Water chemistry	Total phosphorus	HESL (2021a)
	Dissolved oxygen	MECP Lake Capacity Assessment: Trout Lake (MECP 2018)
Hydrological	Annual runoff	MECP Lake Capacity Assessment: Trout Lake (MECP 2018)

5.2 Measured Total Phosphorus Data

Measured TP data were compared with modelled TP results to determine the ability of the Lakeshore Capacity Model to accurately estimate TP concentrations. MECP recommends the use of at least two years of data for model validation, and that differences between measured and modelled results be less than 20% to confidently use the model to assess capacity (MOE 2010). Annual ice-free mean TP concentrations for the Main Basin and Four Mile Bay measured between 2002 and 2019 are 4.57 µg/L and 5.63 µg/L, respectively (HESL 2021a).

5.3 Modelling Approach

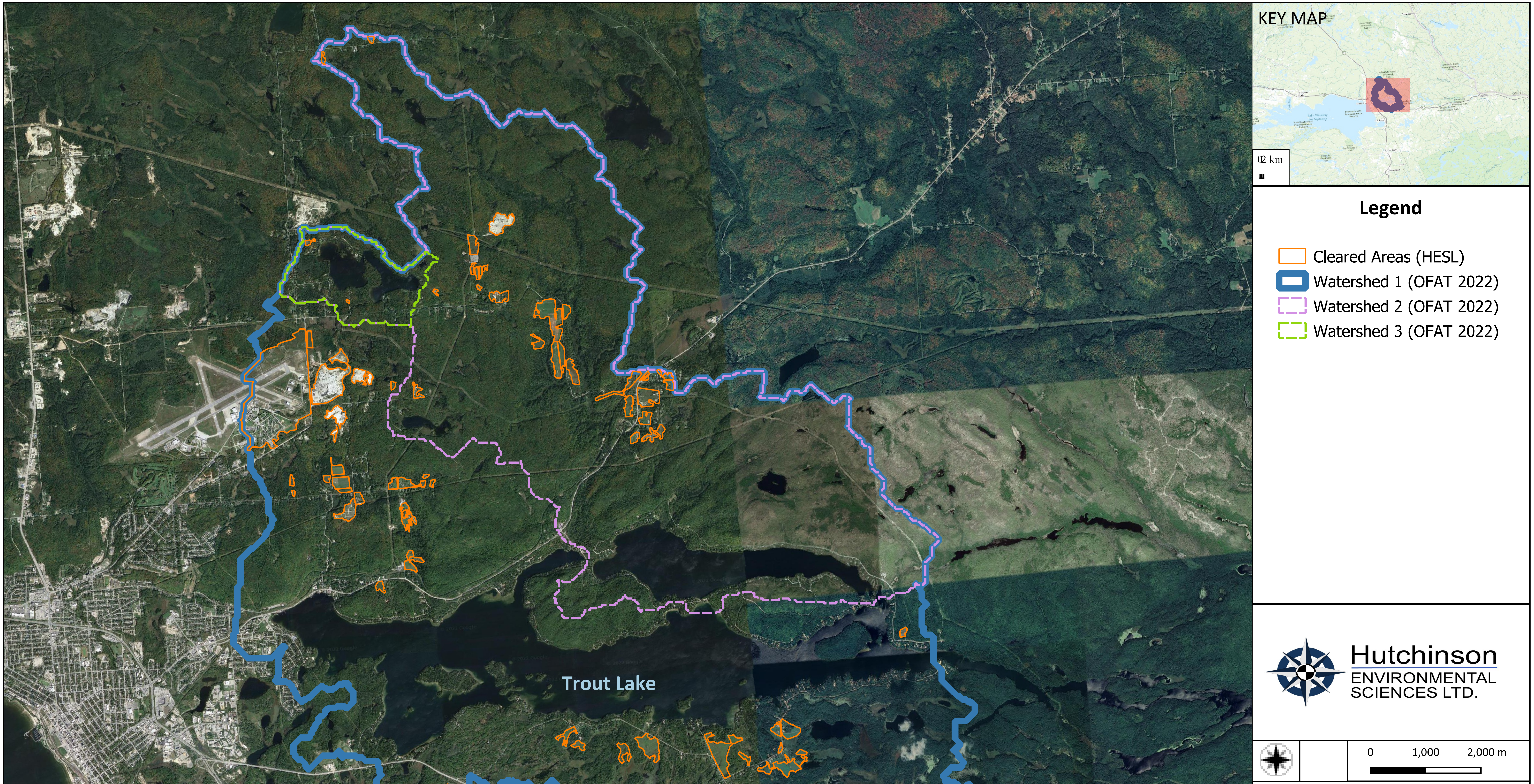
Trout Lake was modelled using the LCM following the Province's guidance in the Lakeshore Capacity Assessment Handbook (MOE 2010). Four different basins were modelled independently: Four Mile Lake (West), Four Mile Lake (East), Four Mile Bay and Trout Lake (Main Basin) and linked together.

Input parameters and calculation results used to model TP concentrations in Four Mile Bay and Trout Lake are provided in Appendix B. Detailed methods and assumptions of the model are provided in MOE (2010). The following provides a description and brief rationale for the selection of various coefficients and assumptions used in the model.

The lake and catchment areas, runoff, % wetland and % cleared land of the study lakes and subwatersheds are presented in Table 5. The % cleared land values used in MECP (2018) ranged from 11.01% - 21.49%. We calculated the % cleared land for each subwatershed through GIS analysis and established lower values than those presented in MECP (2018; Figure 3; Table 5). A chapter on Watershed Characteristics and TP Export is included in *Lakeshore Capacity Study – Trophic Status* (Dillon et al. 1986) which provides the reasoning for the % cleared land "switch" (i.e. > or < 15% cleared land) used in the current LCM. Dillon and Kirchner (1975) utilized the cut-off of 15% cleared land to categorize "Forest + Pasture" land use as opposed to "Forest" land use and noted that the TP load in both igneous and sedimentary geological classifications approximately doubled in watersheds with the "Forest + Pasture" land use. Dillon (unpublished manuscript) noted similar results after examining data from 69 watersheds. No reasoning is provided for the 15% cut off but it is an attempt to differentiate between forested and pasture lands and account for the observed differences in TP loading rates. The Trout Lake watershed contains little pasture or agricultural lands. Some "cleared land" such as residential development and Canadian Forces North Bay is present, but those lands are less than 15% in each sub watershed, stormwater is likely treated from these areas as part of development requirements and TP loadings from these areas are likely smaller than values for pasture lands reported by Dillon and Kirchner (1974) and Dillon (unpublished manuscript) as a result. We suggest that the % cleared land values, presented in Table 5, are more appropriate than those used in MECP (2018) and resulted in a marked improvement in the ability of the LCM to accurately predict measured TP concentrations.

Table 5. Lake and Catchment Areas of Study Lakes.

Lake	Lake Area (ha)	Catchment Area (ha)	% Wetland	% Cleared
Four Mile Lake (West)	48.30	122.40	12.90	0.8
Four Mile Lake (East)	34.76	145.68	3.59	0.2
Four Mile Bay	324.66	4,289.04	4.81	2.7
Trout Lake – Main Basin	1562.25	5,912.39	10.98	7.1



Trout Lake Watershed Study and Management Plan - Existing Conditions, Issues, Opportunities and Constraints

Project No.: 210014	**Figure 3:** Cleared Land in Trout Lake Sub-Catchments
Date: 2022-03-15	
By:SA **Checked:BP**	
Orthophotograph Date: 2019.	

C:\Users\SarahAitken\Hutchinson Environmental Sciences Ltd\2021 Projects - 210014 - Trout Lake Lakecap\Job\GIS\Watershed Layers\2022-01-11_Figure 3. Trout Lake_Cleared Areas.qgz - Sarah Aitken

TP loading from land area in each watershed was determined using the following equation per recommendations in Paterson et al. (2006):

$$TP\ (kg/yr) = catchment\ area\ (km^2) * (0.47 * \%\ wetland\ area^2 + 3.82)$$

A TP loading rate of 0.167 kg/ha/yr was used to calculate TP loads to the surface of the lakes from atmospheric deposition.

Development numbers were gathered by JLR for input into the LCM. JLR selected all lots within 300 m of the shoreline of the three lakes included in the LCM and inflowing streams. MOE (2010) recommends that all septic systems located within 300 m of a shoreline be included in the LCM. Dillon et al. (1986) stated "this 300 metre zone is immediately adjacent to the lake and is therefore considered sensitive in terms of lake water quality protection." The assumption that all anthropogenic sources of TP within 300 m or any inflowing tributary should be included in the LCM is not scientifically valid (as discussed in Sections 4 and 5.3.1). Hutchinson (2002) noted that the 300 m assumption is arbitrary, has neither been substantiated or tested, and it is difficult to defend technically, given the TP geochemistry described in Sections 4 and 5.3.1., and is somewhat counterintuitive as a septic system has 100% impact at 299 m and 0% impact at 301 m. The selection of all lots within 300 m is therefore a conservative approach to defining existing development.

Municipal Property Assessment Corporation (MPAC) data were gathered for each lot and used to inform occupancy categorization. Phosphorus loads from the 320 lots adjacent to Trout Lake that are on sanitary servicing were not included in the LCM but an overland runoff load of 0.04 kg of TP/lot/yr was included for those lots.

Table 6. Existing Development Numbers used in the Lakeshore Capacity Model.

Waterbody	Permanent	Seasonal	Vacant Lots of Record
Four Mile Lake - West	24	1	3
Four Mile Lake - East	21	7	7
Four Mile Bay	204	68	39
Trout Lake – Main Basin	772	110	151

TP loads from septic systems located within 300 m of the shoreline of the lake were calculated assuming a loading rate of 0.66 kg/capita/yr for each septic system. Septic usage rates of 2.56 capita yrs/yr for permanent residences and 0.69 capita yrs/yr for seasonal residences were used following guidance in MOE (2010). All developed lots included an overland runoff load of 0.04 kg of TP/lot/yr.

A settling velocity of 12.4 m/yr was used to indicate that oxic conditions are present in the bottom waters of Four Mile Bay and Trout Lake, while a settling coefficient of 7.2 m/yr was used to indicate anoxic conditions are present in the bottom waters of Four Mile Lake. Settling coefficients were informed by dissolved oxygen profiles collected between August 15 and September 15, and inputs included in MECP (2018).

5.3.1 Phosphorus Retention and Sensitivity Analysis

A phosphorus retention coefficient was applied to reduce TP loads from septic systems to better reflect the current scientific understanding associated with adsorption and mineralization of phosphorus from effluent as proven through scientific literature (Section 4.1), localized monitoring results as described in Section 4.1.1 and generalized soil conditions in the Trout Lake watershed. A sensitivity analysis was also completed to showcase the impact of varying TP retention rates on model accuracy (Table 7). The model overpredicted measured TP concentrations by >100% at 0% TP retention. MECP (2018) contained zero attenuation of the septic TP load which was the primary reason why those results were not useful for management purposes. Model accuracy was most accurate at TP retention rates of 90% - 100% (Table 7).

Table 7. Sensitivity analysis results showing the difference between measured and modelled TP concentrations at various septic TP retention coefficients.

TP Retention	Four Mile Bay	Trout Lake
0%	107.9	122.4
10%	96.6	108.8
20%	85.4	95.3
30%	74.1	81.7
40%	62.8	68.2
50%	51.6	54.7
60%	40.3	41.1
70%	29.0	27.6
80%	17.8	14.1
90%	6.5	0.5
100%	-2.4	-1.7

A review of available soil mapping was completed to help determine an appropriate septic TP retention coefficient. Soils in the Trout Lake watershed are low in total calcium and are acidic, and the watershed is apart of the Precambrian Crystalline Basement, which is the same geological formation where Robertston et al. (2019) observed 97% retention within 10 m of tile fields in non-calcareous soils (Ontario Geological Survey 2000). The quaternary geology of the study area is comprised primarily of bedrock and glaciofluvial outwash deposits. The bedrock is undifferentiated igneous and metamorphic rock, exposed at the surface or covered by a discontinuous, thin layer of drift (soil), which was derived from native bedrock (igneous and metamorphic rock). The glaciofluvial outwash deposits are gravel and sand, including proglacial river and deltaic deposits. McBean et al. (1992) noted that the Trout Lake watershed contains predominantly moraine and glaciofluvial deposits with some bedrock outcropping to the north and flat to rolling glaciolacustrine plain, punctuated with bedrock outcroppings and wetland deposits to the south. Bedrock and the parent material of glaciofluvial outwash derived from native bedrock (igneous and metamorphic rock) both typically have high concentrations of total iron and aluminum. The Lakeshore Capacity Assessment Handbook recommends such soils (i.e., soil with <1% calcium and >1% iron + aluminum) to attenuate septic-related phosphorus in basins of at-capacity lakes. Furthermore, where soils are thinner, filter beds are typically constructed out of imported filter sand to provide the required vadose zone thickness to meet Ontario Building Code requirements.

A phosphorus retention coefficient of 86% was utilized for all developed lots on all lakes and inflowing watercourses that are privately serviced, which is the same as the mean TP reduction noted during monitoring of the Eastview Estates septic systems (see Section 4.1.1). Monitoring was completed on new systems that might function better and therefore retain more TP than other older systems indicating that 86% reduction may overestimate the retention of older sewage treatment systems, but it is important to note that:

- samples discussed in Section 4.1.1 were collected in the tile bed which likely underestimates TP retention if it was measured at the downgradient end of the septic bed mantle,
- the LCM predicted measured TP concentrations most accurately at 90% - 100% septic TP retention,
- peer-reviewed scientific literature indicates that septic TP retention is commonly >90% (see Section 4.1), and most importantly,
- soils and vegetation located in the buffer zone between the septic bed and the lakeshore provide additional attenuation of phosphorus that is not considered by the monitoring results, nor is it typically considered in peer-reviewed literature.

5.4 Results

Measured and modelled values were compared to determine the ability of the LCM to accurately model phosphorus concentrations in Trout Lake. The Province recommends that differences between measured and modelled results be less than 20% to confidently use the LCM to assess capacity (MOE 2010). The modelled ice-free mean TP concentrations representing existing conditions for Four Mile Bay and Trout Lake - Main Basin were 6.25 µg/L and 4.84 µg/L, respectively. Modelled TP concentrations are 11% and 5.9% higher than measured values of 5.64 µg/L and 4.57 µg/L, indicating good correspondence between measured and modelled values (Table 8). Improved model fit when compared to MECP (2018) was the result of updated estimates of the percentage of cleared land in the watershed, the incorporation of septic a phosphorus attenuation coefficient and, to a lesser extent, updated development numbers.

Table 8. Modelled and Measured TP Concentrations for Four Mile Bay and Trout Lake – Main Basin.

Lake	Scenario	TP
Four Mile Bay	Existing Modelled TP_{IF} (µg/L)	6.25
	Existing Measured TP_{IF} (µg/L)	5.64
	% difference between modelled and measured:	*+11*
Trout Lake - Main Basin	Existing Modelled TP_{IF} (µg/L)	*4.84*
	Existing Measured TP_{IF} (µg/L)	*4.57*
	% difference between modelled and measured:	*+5.9*

The background TP concentrations predicted by the model were 5.18 µg/L (Four Mile Bay) and 3.76 µg/L (Trout Lake – Main Basin) which represent the TP concentration from natural watershed loading only. These correspond to background + 50% objectives of 7.77 µg/L (Four Mile Bay) and 5.64 µg/L (Trout Lake – Main Basin) to protect against nuisance algal blooms (Table 9). The municipal MWQO of 7 µg/L was lower than the PWQO for Four Mile Bay and was therefore used to determine capacity as part of a precautionary approach. Four Mile Bay and Trout Lake – Main Basin are both under capacity for development as the existing modelled TP concentrations are less than the PWQO of Background + 50%.

Table 9. Modelled TP Concentrations and PWQOs for Four Mile Bay and Trout Lake – Main Basin.

Lake	Scenario	TP (µg/L)
Four Mile Bay	Modelled Background TP_{IF} (µg/L)	5.18
	PWQO of Background + 50% (µg/L)	7.77
	Minimum MWQO (µg/L)	7.00
	Existing Modelled TP_{IF} (µg/L)	6.25
Trout Lake (Main Basin)	Modelled Background TP_{IF} (µg/L)	3.76
	PWQO of Background + 50% (µg/L)	5.64
	Existing Modelled TP_{IF} (µg/L)	4.84

Additional capacity for development on Trout Lake was calculated assuming sewage treatment in future on-site septic systems achieves 86% retention of septic-related TP as was noted in local monitoring and was applied to existing development. All future development was also assumed to be permanent occupancy as part of a conservative approach.

The maximum number of lots that can be developed on Four Mile Bay and Trout Lake (main basin), in addition to the build out of vacant lots of record and conversion of seasonal to permanent residences, is 81 lots on Four Mile Bay and 414 lots on Trout Lake (main basin) according to the Lakeshore Capacity Model. The additional lots increase modelled TP concentration in Four Mile Bay and Trout Lake (main basin) to 6.99 µg/L and 5.63 µg/L, respectively, which are less than the MWQO in Four Mile Bay (7 µg/L) and PWQO in Trout Lake (main basin; 5.64 µg/L). The development of the maximum number of allowable lots is not recommended due to uncertainties associated with climate change (Section 3.0), downstream impacts (Section 6.0) and Best Management Practices (Section 4.0), and simply because much fewer lots are available based on minimum lot size and frontage requirements. The project team requested that 20% of the maximum capacity of lots be considered which equates to 20 lots on Four Mile Bay (or inflowing streams) and 83 lots on Trout Lake (or inflowing streams). The addition of these lots results in TP concentrations of 6.70 µg/L in Four Mile Bay and 5.23 µg/L in Trout Lake (main basin; Table 10).

Three development scenarios, 1) the build out of existing vacant lots of record, 2) the build out of existing vacant lots of record + the conversion of all seasonal residences to permanent use, and 3) the build out of existing vacant lots of record + the conversion of all seasonal residences to permanent use + development of 20% of the remaining capacity (i.e. 20 lots on Four Mile Bay or inflowing streams and 83 lots on Trout Lake Main Basin or inflowing streams) were used to model future TP concentrations in Four Mile Bay and Trout Lake – Main Basin (Table 10).

The build out of vacant lots of record on Four Mile Lake (west), Four Mile Lake (east) and Four Mile Bay were included in the assessment of Four Mile Bay since it is theoretically the downstream receiving waterbody. The build out of existing vacant lots of record increased TP from 6.25 µg/L to 6.44 µg/L, which is less than the MWQO of 7 µg/L (Table 10). Development of vacant lots plus conversion of seasonal residences to permanent use resulted in a TP concentration of 6.63 µg/L in Four Mile Bay.

The build out of vacant lots of record on Trout Lake (main basin), as well as upstream lakes, increased TP concentration from 4.79 µg/L to 5.03 µg/L (Table 10). Development of vacant lots of record plus conversion of seasonal residences to permanent use resulted in a TP concentration of 5.13 µg/L. All development scenarios resulted in modelled TP concentrations that were less than the respective PWQO.

Table 10. Future Development Scenarios and LCM Capacity Considerations.

Lake	Development Scenario	Details	Modelled TP_{IF} (µg/L)	PWQO of Background + 50% Guideline	MWQO	Development Appropriate
Four Mile Bay	Build out of Vacant Lots of Record	• 3 additional permanent lots on Four Mile Lake (west) • 7 additional permanent lots on Four Mile Lake (east) • 39 additional permanent lots on Four Mile Bay	6.44	n/a	7.00	Yes
	Build out of Vacant Lots + Conversion of all Lots from Seasonal to Permanent	• 3 additional permanent lots + 1 seasonal lot on Four Mile Lake (west) converted to permanent • 7 additional permanent lots on Four Mile Lake (east) + 7 seasonal lots on Four Mile Lake (east) converted to permanent • 39 additional permanent lots on Four Mile Bay + 68 seasonal lots on Four Mile Bay converted to permanent	6.63	n/a	7.00	Yes
	Build out of Vacant Lots + Conversion of all Lots from Seasonal to Permanent + Development of 20 additional Permanent Lots	• 3 additional permanent lots + 1 seasonal lot on Four Mile Lake (west) converted to permanent • 7 additional permanent lots on Four Mile Lake (east) + 7 seasonal lots on Four Mile Lake (east) converted to permanent • 59 additional permanent lots on Four Mile Bay + 68 seasonal lots on Four Mile Bay converted to permanent	6.70	n/a	7.00	Yes
Trout Lake (Main Basin)	Build out of Vacant Lots of Record	• 3 additional permanent lots on Four Mile Lake (west) • 7 additional permanent lots on Four Mile Lake (east) • 39 additional permanent lots on Four Mile Bay • 151 additional permanent lots on Trout Lake (Main Basin)	5.03	5.64	n/a	Yes

	Build out of Vacant Lots + Conversion of all Lots from Seasonal to Permanent	• 3 additional permanent lots + 1 seasonal lot on Four Mile Lake (west) converted to permanent • 7 additional permanent lots on Four Mile Lake (east) + 7 seasonal lots on Four Mile Lake (east) converted to permanent • 39 additional permanent lots on Four Mile Bay + 68 seasonal lots on Four Mile Bay converted to permanent • 151 additional permanent lots on Trout Lake (Main Basin) + 110 seasonal lots on Trout Lake (Main Basin) converted to permanent	5.13	5.64	n/a	Yes
Trout Lake (Main Basin)	Build out of Vacant Lots of Record + Conversion of all Lots from Seasonal to Permanent + Development of 83 additional Permanent Lots	• 3 additional permanent lots on Four Mile Lake (west) • 7 additional permanent lots on Four Mile Lake (east) • 59 additional permanent lots on Four Mile Bay • 234 additional permanent lots on Trout Lake (Main Basin)	5.23	5.64	n/a	Yes

5.4.1 Lake Trout Habitat

Lake Trout (*Salvelinus namaycush*) are a sensitive fish species that have specific temperature and oxygen requirements including a criterion of 7 mg/L of dissolved oxygen, measured as the MVWHDO at the end of summer (see Section 2.3). Phosphorus enrichment can cause increased consumption of oxygen from deeper portions of a lake through decomposition of algae, and this may degrade the coldwater habitat favoured by lake trout in the late summer period.

Molot et al. (1992) developed an empirical modelling approach where end of summer MVWHDOs can be predicted based on spring overturn phosphorus concentration and lake morphometry. Clark et al. (2002) applied the model to a variety of lakes that were outside of the range of calibration used in the original model and found that the model performed well for lakes that are larger and deeper than those used by Molot et al. (1992). The model was used to predict MVWHDO in Four Mile Bay and Trout Lake – Main Basin based on current modelled spring overturn TP concentrations and future modelled spring overturn TP concentrations to determine how increased nutrient loading would affect MVWHDO and Lake Trout habitat. It is recognized that the model does not accurately predict measured MVWHDO, but the process does provide an estimate of how increased TP concentrations directly impact MVWHDO in Trout Lake.

Contour volumes for each depth strata required to inform the modelling were gathered from MOE (1995) and Belfry (1997).

The modelled current spring overturn TP concentrations in Four Mile Bay (6.86 µg/L) and Trout Lake – Main Basin (5.45 µg/L) corresponded with predicted MVWHDO of 8.93 mg/L and 11.0 mg/L, respectively (Table 10). Note that spring overturn TP concentrations differ from ice-free TP concentrations discussed in Section 4.4 and are calculated based off of ice-free concentrations in the Lakeshore Capacity Model (i.e. spring overturn TP = ice-free TP + 0.563/0.992 [MOE 2010]). Future modelled spring overturn TP concentrations in Four Mile Bay of 7.05 µg/L, 7.25 µg/L and 7.32 µg/L, resulted in MVWHDO of 8.86 mg/L, 8.78 mg/L and 8.76 mg/L, respectively, or declines of 0.07 mg/L to 0.17 mg/L from existing modelled concentrations. Future modelled spring overturn TP concentrations in Trout Lake (main basin) of 5.64 mg/L, 5.74 mg/L and 5.84 mg/L, resulted in MVWHDO of 10.9 mg/L, or declines of 0.1 mg/L from existing modelled concentrations. Modelled changes in Lake Trout habitat associated with development scenarios are therefore relatively minor (0.07 to 0.17 mg/L).

Table 11. Modelled Spring Overturn TP Concentrations and Predicted MVWHDO.

Scenario	Four Mile Bay		Trout Lake - Main Basin	
	Modelled TP (µg/L) Spring Overturn	Predicted MVWHDO (mg/L)	Modelled TP (µg/L) Spring Overturn	Predicted MVWHDO (mg/L)
Existing Conditions	6.86	8.93	5.45	11.0
Future Conditions - build out of vacant lots	7.05	8.86	5.64	10.9
Future Conditions - build out of vacant lots and conversion of occupancy	7.25	8.78	5.74	10.9
Future Conditions - build out of vacant lots + conversion of occupancy + development of 20 lots on Four Mile Bay and 83 lots on Trout Lake (main basin)	7.32	8.76	5.84	10.9

6. Impact on Downstream Lakes

Turtle Lake and Lake Talon are located downstream of Trout Lake and MECP completed Lakeshore Capacity Assessments for each lake (MECP 2017a and 2017b). Theoretically, phosphorus loads associated with future development on Trout Lake could cause increased TP concentrations and decreased MVWHDO concentrations in Turtle Lake and Lake Talon, so an impact assessment was completed.

Turtle Lake is located immediately downstream of Trout Lake. It receives inflow from Trout Lake, Loren Lake, Barse Lake and Pine Lake before flowing into the Mattawa River and Talon Lake (MECP 2017a). Turtle Lake has a surface area of 257 ha, a maximum depth of 56 m, it supports a naturally reproducing Lake Trout population and contains one developed lot. Spring overturn TP concentrations collected in 2004-2006 and 2014-2015 ranged from 4.03 µg/L to 8.51 µg/L and averaged 5.31 µg/L, which is very low and similar to Trout Lake. Four dissolved oxygen and temperature profiles collected in 1994, 1996, 2014 and 2015 were used to calculate MVWHDO concentrations of 5.88 mg/L to 6.76 mg/L (average = 6.32 mg/L); all concentrations were below the Provincial guideline of 7 mg/L. MECP (2017a) determined that Turtle Lake was at capacity because MVWHDO concentrations were less than the 7 mg/L criterion designed to protect Lake Trout habitat.

Lake Talon has a surface area of 1415 ha, a maximum depth of 60 m and four distinct basins (MECP 2017b). Turtle Lake, Otter Lake, Cahill Lake, Magee Lake and Sheedy Lake are the main inflows to Lake Talon. It also supports a natural reproducing Lake Trout population and approximately 300 residences. Spring turnover TP measured between 2004 and 2015 ranged from 5.44 µg/L to 22.1 µg/L; average concentrations varied between Basin 1 (17.8 µg/L) and the other three basins (8.7 – 9.9 µg/L). MVWHDO concentrations were calculated for two basins in Lake Talon, average MVWHDO in Basin 1 and 3 was 0.20 mg/L and 7.15 mg/L, respectively. MECP determined that Basin 1 is at capacity because of elevated TP concentrations and low MVWHDO, while the main basin (Basin 3) is also at capacity because MVWHDO are close the to 7 mg/L criterion.

Several limitations were noted in MECP's assessments:

- Dissolved oxygen data measured in Turtle Lake were heavily interpolated in 1994 and 1996,
- Maximum depth measurements at the same sampling location in Turtle Lake varied between 40 and 50 m in depth between sampling events,
- Only one sampling location was used to characterize oxygen concentrations throughout the entire 257 ha Turtle Lake,
- MECP (2017b) noted that Lake Talon should be modelled as a three-basin lake but was modelled as a two-basin system because of data limitations.

Additionally, it is debatable whether the MVWHDO of 7 mg/L should be applied to all basins in Lake Trout lakes. For example, Basin 1 (Kaibuskong Bay) in Lake Talon contained MVWHDO concentrations ranging from 0.00 mg/L to 0.42 mg/L, and it is unlikely that Kaibuskong Bay has ever provided high quality Lake Trout habitat as MVWHDO concentrations were likely <7 mg/L prior to European colonization due to morphometry and other natural factors so the criterion should not be a major emphasis in such instances.

The best tool to quantify impacts on downstream watercourses is the LCM. The outflow TP loads associated with three development scenarios were calculated and are presented in Table 12. The outflow TP load under existing conditions is 282 kg/yr, 293 kg/yr (+11.1 kg/yr) if all vacant lots are built out, 298 kg/yr (+16.7 kg/yr) if all vacant lots are built out and all seasonal residences are converted to permanent occupancy, and 304 kg/yr (+22.6 kg/yr) if all vacant lots are built out, all seasonal residences are converted to permanent occupancy and additional lots are developed on Four Mile Bay and Trout Lake (main basin; Table 12). The impact of modelled increases in TP loads on Turtle Lake and Lake Talon should be evaluated through modelled changes in TP and MVWHDO concentrations in those lakes (see recommendations in Section 10).

Table 12. Modelled Changes in the Outflow TP Load from Trout Lake Associated with Three Development Scenarios.

Development Scenario	TP_{IF} (µg/L)	Outflow TP Load (kg/yr)
Existing Conditions	4.84	281.62
Future Conditions - build out of vacant lots	5.03	292.59
Future Conditions - build out of vacant lots and conversion of occupancy	5.13	298.20
Future Conditions - build out of vacant lots + conversion of occupancy + development of 20 lots on Four Mile Bay and 83 lots on Trout Lake (main basin)	5.23	304.2

7. Recreational Capacity

Recreational Carrying Capacity is generally assessed through changes to the amount of boaters on a lake as a result of a proposed waterfront development. Capacity is considered for safety purposes but boating traffic can have negative impacts on water quality through the generation of wakes which erode soft shorelines. Eroded soil degrades water quality and is a source of phosphorus that will reduce light penetration, diminish recreational values and aesthetics, as well as cause direct and indirect impacts to fish, invertebrates and aquatic plants (Kerr 1995). Sediment re-suspension can increase phosphorus concentrations, thereby increasing primary production and reducing dissolved oxygen concentrations through the decomposition of organic matter.

7.1 Capacity Based on Lake Surface Area

A standardized approach to assess the current and proposed level and type of boating activity does not exist in Ontario. The Official Plan of Seguin Township, Ontario (Seguin Township 2015) includes a provision for recreational capacity on lakes. It allows for 1 residential unit for every 1.6 ha of offshore lake surface area (i.e. beyond the 30 m nearshore area) or 1 tourist unit for every 0.8 ha. This approach reduces crowding of the lake, limits the number of boats and is easily implemented. Following this simple methodology, Four Mile Bay is over capacity while Trout lake – Main Basin is under capacity for further development (Table 13).

Table 13. Recreational Carrying Capacity of Four Mile Bay and Trout Lake – Main Basin.

Waterbody	Offshore Area (ha)	# Lots/1.62 ha	Existing Developed Waterfront Lots	Capacity
Four Mile Bay	288.1	178	264	No
Trout Lake - Main Basin	1437.1	887	609	Yes

7.2 Capacity Based on Minimum Lot Frontages

The Official Plan for the Municipality of East Ferris requires a minimum frontage of 60 m for waterfront lots while the City of North Bay requires 60 m for rural residential lakefront lots on Trout Lake (Municipality of East Ferris 2015). This puts a physical limit on the "lake capacity" and further restrictions are imposed by the need to avoid environmentally sensitive areas such as wetlands, areas of steep slope or where the water table does not allow septic system installation. Shoreline perimeters of 13.37 km and 58.23 km were determined through GIS analysis for Four Mile Bay and Trout Lake (main basin) respectively and used to estimate the "physical capacity" or the available shoreline for lot development as the number of 60m lots. Sensitive areas such as wetland were not excluded from the measurement and so capacity is overestimated from that perspective, and it is recognized that there are a variety of existing lot frontages, but the results are provided as an approximation for comparison to the current degree of development and to provide a general estimate of how many lots could be developed on each waterbody based on existing development requirements.

Following this simple methodology, Four Mile Bay is over capacity while Trout lake – Main Basin is under capacity for further development (Table 14).

Table 14. Minimum Lot Frontage Capacity of Four Mile Bay and Trout Lake – Main Basin.

Waterbody	Shoreline Perimeter (m)	# Lots/60 m	Existing Developed Waterfront Lots	Capacity
Four Mile Bay	13,370	219	264	No
Trout Lake – Main Basin	58,230	954	609	Yes

8. Inflowing Streams

A number of streams and wetlands flow into both Four Mile Bay and Trout Lake - Main Basin, including Four Mile Creek which flows out of Four Mile Lake and empties into Four Mile Bay. Previous sections have been focused on determining development capacity on Four Mile Bay and Trout Lake - Main Basin; however the majority of the remaining developable land is located adjacent to Four Mile Creek (B. Hillier, personal communication, January 2022), and therefore that development scenario needs to be discussed. Provincial guidance defines the primary influence area of shoreline development as units built within 300 m distance of the shoreline or any inflowing stream. Within this area it is further assumed that all sewage treatment systems contribute 100% of phosphorus inputs to the adjacent waterbody. This is inconsistent with the current academic research on phosphorus dynamics which has shown that a) sewage treatment systems and native soils attenuate phosphorus through adsorption and mineralization as discussed in Section 3.1.1, and b) watercourses (and floodplains) exert a strong influence on phosphorus cycling and subsequent phosphorus loading to downstream waterbodies.

Nutrient processing in floodplains largely dictates nutrient concentrations in adjacent watercourses by transforming nutrient forms and loads from upstream sources and from watercourses through complex biotic and abiotic processes (HESL 2017). Within watercourses, biotic (aquatic vegetation, periphyton, microorganisms) and abiotic processes (hydrology, morphology, sediment characteristics, water chemistry and groundwater supply) are also paramount to consider (Hoffmann et al. 2009; Reddy et al. 1999; Withers and Jarvie 2008). Phosphorus reduction efficiencies (i.e., how phosphorus is transformed in a reach of a watercourse) are typically measured through mass balance studies or estimates of phosphorus uptake lengths along river reaches. A quantification of the phosphorus reduction efficiency of Four Mile Creek and other inflowing watercourses would be noteworthy so that impacts of development on the watercourses and downstream Four Mile Bay could be quantified but although water chemistry data was available to complete an assessment for Four Mile Creek, water quantity (i.e., flow) data was not. As a result, phosphorus reduction efficiencies of Four Mile Creek are discussed based on concepts in scientific literature, and a recommendation for a mass balance study for Four Mile Creek and other major inflowing watercourses is included in Section 10.

Floodplains, riparian buffers and in-stream processes combine to determine phosphorus reduction efficiencies in watercourses which may vary spatially and temporally in each of these interrelated environments (HESL 2017). Phosphorus retention efficiencies from various studies are presented in Table 15 and demonstrate the wide range of phosphorus reduction in watercourses due to site-specific factors.

Table 15. Phosphorus Reduction Efficiencies of Rivers from Various Studies.

Total Phosphorus Reduction Efficiency	Primary Influencing Factors Investigated	Reference
28% after restoration	3 stage restoration including streams and wetlands	Richardson et al. 2011
Duffin Creek = 92%, Nottawasaga River = 44%	Seasonality, hydrology	Hill 1982
<10% - >30%	Flow conditions	House 2003
50% of SRP	Biological uptake during spring	
60%	Downstream of sewage treatment plant	Withers and Jarvie 2008

Phosphorus uptake lengths are a component of the ‘spiralling’ concept (Withers and Jarvie 2008). Briefly, a phosphorus spiral is the distance required for a phosphate ion to cycle from dissolved form to particulate/organic and back to dissolved form. Uptake length is the distance in the stream between dissolved form and particulate/organic form caused by biological assimilation (i.e., sorption), while turnover time refers to the length of watercourse required for the transition from particulate/organic form back to dissolved form.

Withers and Jarvie (2008) reported stream uptake lengths for three generalized stream/catchment types: 1) first order/upland/pristine watercourses, 2) second-fourth order/rural/agricultural watercourses, and 3) fifth order/large rivers/urban and agricultural influence (Table 16). Soluble reactive phosphorus (SRP) lengths were variable within each stream/catchment type, ranging from 2 m - 530 m in the first category, 23 m – 3,460 m in the second and 4,140 m - 85,000 m in the third, highlighting the challenges associated with typifying phosphorus reduction efficiencies because of the variability imposed by site-specific features. Lower uptake lengths in first order streams suggests more efficient phosphorus retention driven by the inherent abiotic and biotic characteristics of those watercourse types. A summary of the key characteristics of high and low order streams that influenced phosphorus retention is presented in (Table 17).

Table 16. Range in SRP Uptake Lengths (summarized from Withers and Jarvie 2008).

Stream/Catchment Type	Range in SRP Uptake Lengths (m)
First Order/Upland/’Pristine’	
First order deciduous woodland stream, eastern Tennessee	22-97
First order forested streams, upper Peninsula, Michigan	98-530
Streamside artificial stream experiments, North Carolina	<10-140
Forested upland streams, New Hampshire	2-85
First order upland stream, Scotland	85-115
First order streams	24-161
Second-fourth order/rural/agricultural	
Second order rural watershed, Wisconsin	169-1,667
Second order stream	23-223
Third order stream	99-743
Fourth order stream	71-907
Channelized streams in NW Kentucky and SE Indiana	1,370
Restored streams in NW Kentucky and SE Indiana	380
Reference streams in NW Kentucky and SE Indiana	518
Sawtooth Mountain Lake district, Idaho (streams with no lake influence)	877-3,460
Sawtooth Mountain Lake district, Idaho (streams downstream of lakes)	781-848
Fifth order/large river/urban and agricultural influence	
Fifth order stream; agricultural and urban influence	4,140-36,7000
Fifth order stream	16,175-61,350

Large urban river, Georgia	11,000-85,000

Table 17. Key Attributes and In-Stream Processes in Low Order and High Order Watercourses (summarized from Withers and Jarvie 2008).

Stream Type	Physical Attributes	Chemical Attributes	Biological Attributes
Low order	• Low water volume to bed ratio • Shallow streams allow light penetration through water column to stream bed • Gravel and boulder substrates • Water temperatures more responsive	• Efficient bed sediment P exchange • Greater self-cleansing capacity	• Greater benthic and epilithic algal growth • Gravel substrates provide anchorage points for benthic algae • Heterotrophic activity dependent on riparian vegetation
High order	• High water volume to bed ratio • Poorer degree of light penetration in deeper water • Fine sediment substrate • Water temperature less responsive • Longer water retention times • Floodplains and open water expand phosphorus retention zones	• P exchange dominated more by interaction with suspended sediments in the water column • Small self-cleansing capacity	• Phytoplankton become more dominant as water depth and residence time increases • Submerged macrophytes root in marginal sediments

Four Mile Lake is the source of Four Mile Creek which has two main tributaries: the southwestern tributary which discharges from Hillside Lake and a northwestern tributary that drains seasonally inundated areas (Fitchko et al. 1996). Four Mile Creek drains a relatively small watershed with Four Mile Lake acting as the most upstream extent. The Creek has a moderate to low gradient, coarse to fine sand predominates, and it is a high order watercourse due to its relatively small drainage area and the limited number of upstream, inflowing watercourses. The watershed of Four Mile Creek is also relatively unaltered as much of the drainage area remains in a natural state despite a historical zinc derailment and ongoing issues associated with Polyfluoroalkyl Substances due to Aqueous Fire Fighting Foam (HESL 2021a).

The phosphorus reduction efficiency of Four Mile Creek and other inflowing watercourses could not be quantified with available data as part of this study but the watercourses appear to share many of the attributes listed in Table 16 and Table 17 (i.e. lower order), that indicate lower uptake lengths and higher phosphorus reduction efficiencies. Nutrient retention processes in floodplains would likely reduce phosphorus loads associated with future development from impacting adjacent watercourses while additional attenuation of TP in watercourses would likely further reduce TP loads to downstream Four Mile Bay.

9. Conclusions

Water quality data was reviewed to understand the health of Trout Lake and a variety of management tools were examined to inform development capacity and lake management. A summary of each capacity consideration, related guideline and result for both Four Mile Bay and Trout Lake - Main Basin are presented in Table 18.

A variety of management tools were examined, and multiple lines of evidence were used to inform the management of Trout Lake because of the importance of Trout Lake as a drinking water source and recreational amenity. The review of monitoring data focused on TP and MVWHDO as those parameters are typically linked with development impacts, datasets were the most robust and can be compared with municipal and provincial guidelines, and results directly inform development capacity modelling. Average annual TP concentrations in Four Mile Bay exceeded the municipal guideline of 7 μg/L in three years; no exceedances of the PWQO (10 μg/L) or trends in TP were observed (Table 18). Average annual TP concentrations in Trout Lake – Main Basin did not exceed the municipal or PWQO, and no trends were noted. When all monitoring sites in both Four Mile Bay and Trout Lake – Main Basin were combined, a subtle long-term decline was noted but the change was not statistically significant and was subject to high year-to-year variability (HESL 2021a). Considerable variability in monitoring results were noted up until 2013, when sample analysis at the DESC began, confounding the interpretation of exceedances of the MWQO in Four Mile Bay (2008, 2009 and 2011). Phosphorus concentrations were low in Trout Lake – Main Basin and relatively low in Four Mile Bay indicating that management of the lake has been successful from a nutrient loading perspective. A recommendation for consistent laboratory analysis is presented in Section 10.1 in hopes of reducing TP variability moving forward.

MVWHDO was analyzed because of the importance of Lake Trout habitat and the relationship between nutrient loading and dissolved oxygen decline but the data were limited and heavily interpolated, so the usefulness of those data are constrained (Table 18). A single MVWHDO value in 1994 fell below the Municipal objective in Trout Lake – Main Basin, while no concentrations below the PWQO were recorded. Multiple MVWHDO concentrations lower than the Municipal objective in Four Mile Bay have been recorded (1993, 1994, 2015, 2018), and one concentration (1994) was lower than the Provincial objective. Recommendations related to collection and interpretation of MVWHDO are presented in Section 10.1.

Additional stressors apart from waterfront development on Trout Lake impose uncertainties in lake management such as climate change while there is also uncertainty associated with waterfront development as impacts can be varied and include septic effluent, boat use, stormwater generation, changes to wildlife habitat, etc., although Lakeshore Capacity Assessment is solely focused on nutrient loading from septics and to a lesser degree stormwater. Climate change has the potential to increase TP concentrations, decrease MVWHDO concentrations and increase algal growth in Trout Lake. The interactive effects are difficult to predict in a multi-stressor system, but recommendations have been developed to better monitor TP and MVWHDO concentrations in relation to climate change and other impacts as presented in Section 10. The uncertainty related to the variety of impacts from waterfront development, and not solely septic impacts, were addressed by analyzing multiple lines of evidence and developing a series of recommendations that are designed to mitigate a wide variety of environmental impacts associated with existing and future development, and improve monitoring.

Waterfront BMPs are commonly implemented to limit the impacts of shoreline development on adjacent waterbodies. Peer-reviewed scientific literature indicates that septic effluent TP is largely attenuated in Precambrian Shield soils. Nine septic systems in the Eastview Estates Development on Trout Lake were monitored as part of a Site Plan Agreement and the average TP attenuation was determined to be 86%. Attenuation is anticipated to be higher prior to runoff into Trout Lake because samples were collected in the tile bed which underestimates TP retention if it was measured at the downgradient end of the septic bed mantle. Furthermore, soils and vegetation located in the buffer between the septic bed and the lakeshore would provide additional attenuation of phosphorus. Recommendations related to septic system monitoring are provided in Section 10.2.

Shoreline buffers can play an important role in protecting lake health, acting as a physical barrier between upland human activity and the aquatic environment. This barrier mitigates the effects of development and site alteration on water quality and wildlife habitat, while providing some measure of erosion and flood control. In general, larger buffers are better at consistently providing a range of protective functions. The scientific literature demonstrates that a 30 m buffer provides a range of ecological services, and this buffer size is commonly recommended in the peer-reviewed literature focused on shoreline development, aligning with Provincial guidance. The City of North Bay currently requires a 15 m buffer and 30 m shoreline setback for new dwellings to help reduce phosphorus loading to Trout Lake from shoreline development.

An Erosion and Sediment Control (ESC) plan can help mitigate the impacts of development in the short-term (i.e. Construction Mitigation Plan) and long-term (i.e. Stormwater Management Plan) by encouraging infiltration of stormwater to the subsurface. Stormwater management features include provisions to maximize infiltration and limit stormwater runoff. Specific options include proper re-contouring, discharging of roof leaders, use of soak away pits and other measures to promote infiltration, grassed and vegetated swales, filter strips, roof leaders and French drains. Stormwater management options are often site-specific and the best approach will be dictated by site characteristics and the nature of the proposed development. The Site Plan Agreements for development on Trout Lake commonly include ESC measures to mitigate short-term construction-related impacts and stormwater management techniques such as infiltration trenches and soak away pits to infiltrate roof runoff.

The LCM is the tool typically used to determine the development capacity of lakes located on the Precambrian Shield in Ontario. The Trout Lake Lakeshore Capacity Model completed by MECP in 2018 was refined by HESL based on a) incorporation of a phosphorus retention coefficient for septic-related phosphorus loads as supported by peer-reviewed scientific literature, local monitoring data and soil mapping, b) revision of the amount of cleared land based on GIS analysis and a description of cleared land definition in Dillon et al. (1986) and c) updated development numbers provided by JLR. Revisions resulted in a LCM which accurately predicted measured TP concentrations in Four Mile Bay and Trout Lake – Main Basin within 11% and 5.9%, respectively (Table 18). Development capacity remains on both Four Mile Bay and Trout Lake – Main Basin based on the PWQO of Background + 50%. Development scenarios including the build out of vacant lots of record, conversion of seasonal to permanent residences, and the development of additional lots, were modelled and all development scenarios resulted in modelled TP concentrations that were less than the respective MWQO or PWQO.

Modelled MVWHDO were predicted based on modelled existing and future TP concentrations in Four Mile Bay and Trout Lake – Main Basin to link increased TP loads and concentrations associated with future scenarios with declines in MVWHDO. Future modelled increases in TP concentration associated with future development were predicted to result in minor reductions in MVWHDO (i.e., 0.07 mg/L - 0.017 mg/L)

Nutrient loading associated with future development inputs on Trout Lake could theoretically cause increased total phosphorus concentrations and decreased MVWHDO concentrations in downstream waterbodies, including Turtle Lake and Lake Talon. MECP (2017) and MECP (2017b) determined that Turtle Lake and Lake Talon were at development capacity primarily because MVWHDO concentrations were <7 mg/L but a number of data limitations were noted in the assessments. The maximum increased downstream TP load associated with the future development scenarios is +22.6 kg/year. Lakeshore Capacity Modelling should be completed to quantify the change in total phosphorus in Turtle Lake and Lake Talon.

Recreational capacity as measured through lake surface area (1 lot/1.62 offshore surface area of the lake) and minimum lot frontage (60 m of shoreline/shoreline perimeter) equations indicates that there is capacity for future development on Trout Lake – Main Basin but Four Mile Bay is overcrowded (Table 18).

Most of the remaining development potential is adjacent to Four Mile Creek and other inflowing watercourses. Development adjacent to Four Mile Creek and the related loading of nutrients to downstream waterbodies (i.e., Four Mile Bay) would be largely mitigated by attenuation in the septic system, floodplain and watercourse, especially if development follows a precautionary approach that includes implementation of waterfront BMPs such as those required as part of existing Site Plan Agreements.

Multiple lines of evidence considered in this report indicate that there is development capacity on Trout Lake (Table 18), with the exception of occasional guideline exceedances of both measured TP and MVWHDO, while climate change and downstream impacts introduce uncertainty moving forward. Measured phosphorus data were complicated by considerable year to year variability which was likely driven by differences in laboratory procedures and MDLs, while MVWHDO datasets were heavily interpolated which limited the impacts of those findings.

Waterfront BMPs are effective tools to limit development impacts on Trout Lake and have been successfully implemented through Site Plan Agreements. Any future development adjacent to Four Mile Creek, other inflowing tributaries, Four Mile Bay or the main basin of Trout Lake should include suitable waterfront BMPs such as those associated with sewage treatment systems, and those that are routinely implemented as part of Site Plan Agreements (i.e., shoreline buffers and ESC control). Recommendations included in Section 10.0 should also be implemented to improve monitoring and ensure that monitoring results are routinely used to assess the effectiveness of development policy and inform necessary revisions to the management of Trout Lake moving forward.

Table 18. Lake Management Tools and a Summary of the Development Capacity Focused Results.

Capacity Consideration	Capacity Guideline	Results		Indication of Development Capacity	
		Four Mile Bay	Trout Lake - Main Basin	Four Mile Bay	Trout Lake - Main Basin
Measured total phosphorus[1]	Municipal - Ice Free TP of 7 µg/L	Exceedances in 2008, 2009 and 2011[1]	No exceedances	No[1]	Yes
	Provincial - 10 µg/L	No exceedances	No exceedances	Yes	Yes
	Trend	No trend	No trend	Yes	Yes
Measured MVWHDO[2]	Municipal - 8 mg/L	Exceedances in 1993, 1994, 2015, 2018[2]	Exceedance in 1994[2]	No[2]	No[2]
	Provincial - 7 mg/L	No exceedances	No exceedances	Yes	Yes
Lakeshore Capacity Assessment	Background + 50%	Under capacity	Under capacity	Yes	Yes
Recreational carrying capacity	# Lots/1.62 ha surface area	Over capacity	Under capacity	No	Yes
Minimum lot frontages	# Lots/61 m of frontage	Over capacity	Under capacity	No	Yes

Notes:

[1] *Exceedances appear to be driven by variability associated with laboratory processes and MDL as discussed in Section 2.1.*

[2] *Data are limited and heavily interpolated as discussed in Section 2.3.*

10. Recommendations

10.1 Water Quality Monitoring and Reporting

Despite the numerous monitoring programs that have been completed in Trout Lake, data to track and assess emerging limnological issues typical of temperate freshwater lakes in Ontario is limited. For example, decreased concentrations of calcium as a long-term consequence of industrial development, smelting and acid precipitation, and increased chloride concentrations due to salting of roadways have increasingly become issues in lakes across Ontario. Long-term records of calcium concentrations are not available in the Trout Lake monitoring data and are limited to data collected during the Watershed Management Study in 1986. Data from 1986 suggest calcium concentrations may be depleted in Four Mile Bay and therefore warrant ongoing monitoring to assess the risk to aquatic organisms that are sensitive to calcium decline. Likewise, despite increased chloride concentrations between 1977 and 1986, discussed in the Watershed Management Study (Conestoga Rovers and Associates 1988), chloride has not been measured in the water quality data available since 1990.

Our assessment of water clarity in Trout Lake demonstrated a significant decline in Delaney Bay near the City of North Bay between 2005 and 2019 (HESL 2021a). Numerous potential causes may contribute to long-term changes in water clarity however determining causation is difficult in the absence of recent monitoring data. Several key parameters that may inform of the changes in water clarity are not currently collected as part of routine monitoring on Trout Lake including suspended solids, dissolved organic carbon and ongoing phytoplankton monitoring. The dataset should be expanded to included parameters that help determine causative factors.

Recommendation #1 - increase the parameter list for samples collected in Trout Lake to include emerging limnological issues (calcium and chloride) and explanatory variables (total suspended solids, dissolved organic carbon and phytoplankton).

Significant annual variability in TP data was noted and when all sites were combined from both Four Mile Bay and Trout Lake - Main basin, annual averages ranged from 1.90 µg/L to 7.61 µg/L (HESL 2021a). Variability appears to be driven by differences in either sampling methodology or more likely, changing laboratory procedures and MDLs.

Recommendation #2 - implement a consistent sampling methodology, increase QA/QC procedures such as the collection of duplicate samples, and continue to use a water quality laboratory with a proven track record of delivering consistent low level TP results such as the Dorset Environmental Science Centre, which has been utilized since 2013.

Monitoring of Four Mile Creek is part of the regular monitoring program on Trout Lake, however the Trout Lake Creeks monitored during the Watershed Management Study (Conestoga Rovers and Associates 1988) have not been sampled since 1990 according to our review (HESL 2021a). An updated assessment of the water quality of all Trout Lake Creeks sampled during the last Watershed Management Study would inform the relative contributions of each sub-watershed to Trout Lake and may help focus and refine management objectives. The assessment of inflowing watercourses should also include quantification of flow and mass balance modelling to help determine the phosphorus reduction efficiencies of the watercourses under investigation to better inform potential TP attenuation associated with development adjacent to these inflowing watercourses.

Recommendation #3 - expand the water quality monitoring program to include inflowing tributaries and complete mass balance modelling to determine the phosphorus reduction efficiencies of each watercourse which can be used to help inform management decisions.

Dissolved oxygen and temperature measurements have been gathered from standardized locations, but the maximum depths of measurements have not been consistent between years (HESL 2021a). The variability of depth measurements limits the ability to calculate MVWHDO concentrations and compare concentrations over time. MVWHDO provides a means of tracking the impacts of watershed development, on lake health and Lake Trout habitat quality over time so standardized profile locations and related depths should be implemented and strictly adhered to.

A strong correlation between MVWHDO concentrations and sampling date is apparent in the current dataset with elevated concentrations being associated with earlier sampling dates (e.g., 2001, 2002 and 2006). Maintaining consistent sampling timing will be vital for long-term comparison of MVWHDO concentrations.

Recommendation #4 - complete a thorough review of dissolved oxygen data that has been collected and develop a standardized and repeatable approach for collecting suitable data and calculating MVWHDO concentrations in Four Mile Bay, Trout Lake – Main Basin, Turtle Lake and Lake Talon. NBMCA completed a thorough analysis of MVWHDO in 2018 in Trout Lake so that approach should be reviewed to determine if it can be adopted as a standardized assessment approach.

Annual monitoring reports should be completed including analysis of water quality parameters against guidelines, most notably, TP and MVWHDO data against Provincial and Municipal guidelines, as well as a trend analysis. Annual monitoring reports should be circulated to City staff to inform potential development and related planning policies.

Recommendation #5 - complete and distribute annual monitoring reports to the City of North Bay and include comparisons of data to Municipal and Provincial Water Quality Objectives to provide an ongoing dataset to inform planning policy.

Downstream impacts associated with the development scenarios should be quantified. The best tool to quantify impacts on downstream watercourses is the LCM and dissolved oxygen model (Molot et al. 1992).

Recommendation #6 - develop a LCM and dissolved oxygen model for each of Turtle Lake and Lake Talon to quantify the impact of increased TP loads associated with the three development scenarios on TP concentrations and MVWHDO concentrations in Turtle Lake and Lake Talon. Combine the findings with updated MVWHDO evaluations in Turtle Lake and Lake Talon (Recommendation #4) and other available monitoring data to better determine downstream impacts.

10.2 Septic System Monitoring

Not all septic monitoring sites were sampled at the required frequency from 2012 – 2016 and no rationale is provided for missing samples. Sites 2625 and 2685 need to be examined by a qualified expert to determine a) why the treated effluent sampling port at Site 2625 was always dry (is it properly located or was it sampled during periods of no occupancy?), and b) why there is no monitoring port at Site 2685. In both cases, sampling should be re-initiated to establish the effectiveness of the septic system.

Recommendation #7 - sampling at Sites 2625 and 2685 should be reinitiated to establish the effectiveness of those septic systems.

It is not clear if septic monitoring results have been reviewed and compared to development requirements prior to this study.

Recommendation #8 - examine the septic system monitoring results as they are received so that immediate corrective action can be taken in the event of missing samples or anomalous results.

The septic monitoring results provided did not indicate the locations of the treated effluent sampling piezometers and so they may not have been located at the edge of the mantle on the downgradient side of the tile field where treatment would be maximized. HESL (2010) recommended that samples should be taken from a) the outlet chamber of the primary septic tank, and b) from each of two piezometers located in the center of the tile field and in the mantle downgradient of the field itself.

Recommendation #9 - follow up on the results for those systems not averaging at least 93% phosphorus removal by conducting more sampling and/or installing an additional piezometer at the furthest downgradient point in the tile field.

Septic systems monitored as part of the Eastview Estates attenuated a large proportion of TP which aligns with peer-reviewed scientific literature. Septic systems can however fail and act as a pollutant source to Trout Lake or inflowing streams so inspections should continue to be completed and maintenance required. Some systems can get overwhelmed due to short-term rentals and large amounts of wastewater generated in a short timeframe since systems are often not adequately sized in such circumstances.

Recommendation #10 - develop a septic inspection program that provides a better understanding of system functionality than visual observations of obvious system failures, such as inspections completed during home inspections.

Recommendation #11 - complete a thorough septic inspection on any short-term rentals to determine if the systems can adequately treat wastewater generated by such uses.

10.3 Site Evaluation Reports

Site Evaluation Reports (SERs) have been routinely completed by environmental consultants on behalf of proponents to inform Site Plan Agreements and support waterfront development applications. The overarching goal of the SERs is to evaluate site conditions and develop recommendations and BMPs to show 93% reduction from potential TP export. Typical BMPs included in the SERs include:

- The use of mineral rich soils for septic tile field and mantle or tertiary treatment systems
- Septic system monitoring and maintenance requirements
- Infiltration trenches and soakaway pits for roof runoff
- 30 m natural buffer with 4 m wide path
- No lawn fertilizers
- No treated lumber
- Installation of silt fences, check dams and straw bales during construction

Recommendation #12 - develop a comprehensive and fulsome list of BMPs and development standards that are automatically applied to all waterfront development applications so that a protective approach to development is implemented as part of all waterfront developments.

Recommendation #13 - complete a review of septic system technologies such as the EcoFlo Biofilter and Waterloo Biofilter, and soil requirements for leaching bed systems that have proven to attenuate phosphorus (e.g. <1% $CaCO_3$, >1% acid-extractable concentrations of iron and aluminum [MOE 2010]) to determine appropriate sewage system requirements that will minimize impacts on Trout Lake.

10.4 Other

Recommendation #14 - an influx of new residents that value manicured lawns and are not familiar with waterfront BMPs and lake stewardship could negatively impact Trout Lake. Regulatory BMPs on existing and future development should be encouraged through education, stewardship and enforcement.

Recommendation #15 - repeat the Trout Lake Management Study in the near future (e.g. 3 – 5 years) to assess the health of Trout Lake in response to ongoing climate change, effectiveness of BMPs, and progress related to the Recommendations provided here-in, utilizing any new updated lake capacity tools, so that appropriate changes to planning policy can be developed and implemented.

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Appendix A. Trout Lake Watershed Study and Management Plan – Background Report

Hutchinson

Environmental Sciences Ltd.

Trout Lake Watershed Study and Management Plan – Background Report

Prepared for: The Corporation of the City of North Bay
Job #: J210014

June 7, 2022

Draft Report

1-5 Chancery Lane, Bracebridge ON P1L 2E3 | 705-645-0021

June 7, 2022 HESL Job #: J210014

Beverley Hillier
City of North Bay
Manager, Planning and Building Services

Dear Ms. Hillier:

Re: Trout Lake Watershed Study and Management Plan – Background Report

Our approach to the development of a management plan for Trout Lake included several phases, the first of which was designed to review the existing relevant lake water quality and land use planning information for the study area.

In this Background Report, we have gathered water quality data from multiple sources and where sufficient data were available, assessed both the spatial and temporal variability in Trout Lake. Our goal was to characterize water quality conditions in relation to municipal (total phosphorus = 7 µg/L, mean volume weighted hypolimnetic dissolved oxygen = 8 mg/L) and Provincial Water Quality Objectives, and assess the impact of historical development on water quality in Trout Lake. Data and monitoring efforts have also been reviewed to provide recommendations related to future monitoring based on our findings and to provide a metric with which to track the effectiveness of management recommendations.

In general, we found no significant change over time in nutrient concentrations in Trout Lake, however we did note different water quality in Four Mile Bay compared to the main basin of Trout Lake. In Delaney Bay we noted a decrease in water clarity over time, however supplementary data to support the cause of this change was limited.

We have drafted several recommendations on future monitoring in Trout Lake but expect these to continue to evolve as the project proceeds. Please do not hesitate to contact me if you have any questions or concerns.

Sincerely,
Per. Hutchinson Environmental Sciences Ltd.

Brent Parsons, M.Sc.
brent.parsons@environmentalsciences.ca

Signatures

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Kristopher R. Hadley, Ph.D.
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Founder and Senior Aquatic Scientist

Executive Summary

J.L. Richards and Associates Limited (JLR) and Hutchinson Environmental Sciences Limited (HESL) were retained by the City of North Bay (City), Municipality of East Ferris (East Ferris) and the North Bay-Mattawa Conservation Authority (NBMCA) to complete the Trout Lake Watershed Study and Management Plan (Trout Lake Study). This Background Report is the first deliverable of the project and includes a review of existing and relevant lake water quality information to determine the general health of the lake and how water quality may have changed over time.

A wide variety of background reports and datasets were gathered to characterize water quality conditions in Trout Lake and compare water quality conditions spatially and temporally. General limnology conditions were characterized based on data extracted from reports and provided by NBMCA, but more intense statistical analyses and reporting focused on total phosphorus, mean volume weighted hypolimnetic dissolved oxygen, Secchi disk depth and phytoplankton assemblages.

Historical and more recent data indicate that water quality in Trout Lake is excellent and nutrient concentrations are low. Significant monitoring effort has been invested in the management of water quality of Trout Lake and there is little evidence of a marked impact of development on the lake. Long-term phosphorus data collected from 2000 to 2019 has not shown any significant change in concentrations at the eight long-term monitoring locations on the lake, suggesting that any potential phosphorus loading form recent (i.e., 20 years) development has not occurred or has not been captured by the current monitoring program. Historical data analysis (1975 – 2002) from previous reporting (1977 – 1986 [CRA 1988], 1975 – 2002 [GLL 2002]) have not recorded an increase in phosphorus in the lake over time.

Ice free average total phosphorus concentrations have however exceeded the municipal Minimum Water Quality Objective of 7 μg/L at individual sites and in specific years when sites are combined. Total phosphorus concentrations are variable year-to-year but it is clear that concentrations are higher in Four Mile Bay, with annual MWQO exceedances in 2008 (8.32 μg/L), 2009 (7.69 μg/L) and 2011 (8.98 μg/L; Table 3). Mean volume weighted hypolimnetic dissolved oxygen concentrations were also different between Four Mile Bay and the Main Basin resulting in multiple concentrations lower than the municipal regulations (8 mg/L) in Four Mile Bay (1993, 1994, 2015, 2018) and only a single concentration lower than municipal regulations in the Main Basin (1994). Note however that the data which MECP used to complete these calculations were heavily interpolated.

A significant decrease in water clarity measured through Secchi Disk Depth in the most developed basin of Trout Lake (i.e., Delaney Bay) may suggest a localized impact of runoff from urban development, roads and railroads on water quality within the Bay. Exploration of policies and practices to control sediment, erosion and runoff into the lake from urban areas may help to mitigate further reductions in water clarity within Delaney Bay.

Future project phases will include a more quantitative assessment of the impact of development on water quality through evaluation of the Lakecap Model of nutrient status, of water quality data in relation to development data at a broad scale as well as evaluation of more site-specific monitoring data associated with individual development applications (i.e., lot level or subdivision level). Subsequent stages will be focused on consultation and development of management recommendations and related reporting.

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1. Introduction

J.L. Richards and Associates Limited (JLR) and Hutchinson Environmental Sciences Limited (HESL) were retained by the City of North Bay (City), Municipality of East Ferris (East Ferris) and the North Bay-Mattawa Conservation Authority (NBMCA) to complete the Trout Lake Watershed Study and Management Plan (Trout Lake Study). The Trout Lake Study is being completed in partnership with the City, Municipality of East Ferris, North Bay-Mattawa Conservation Authority (NBMCA) and in consultation with a variety of residents and stakeholders. The Trout Lake Study is being completed to review lake water quality data to understand the health of the lake, determine the effectiveness of management actions to date, and adjust the management approach to reflect this new understanding and evolving best practices in this field.

The project will be completed using a three-phase process as described in Table 1. This Background Report is the first deliverable of the project and includes a review of existing and relevant lake water quality information to determine the general health of the lake and whether water quality has changed over time. The general description of lake health and trends over time are important building blocks for the Trout Lake Study and will be expanded in future project phases and deliverables to try and determine if development has impacted water quality in the lake. Updated management recommendations will be developed based on data presented in this report, future Lakeshore Capacity Modelling and review of municipal best practices for planning and consultation.

Table 1. Project Phases and a Summary of the Related Scope and Deliverables from each Phase.

Phase	Scope	Deliverables
Understanding	Review existing and relevant lake water quality and land use planning information	Background Reports
	Complete Lakeshore Capacity Modelling	Updated Lakeshore Capacity Model
	Review municipal best practices and synthesize information from the Background Report and Lakeshore Capacity Model	Issues, Opportunities and Constraints Report
Directions	Consultations with residents and stakeholders to receive feedback	Directions Report
Planning	Consultation with public and stakeholders on Directions Report	Final Report

2. Methodology

Trout Lake is a deep, clear, oligotrophic lake with excellent water quality (Miller Environmental Services Ltd. 2000). It has an area of 1,887 ha and is comprised of two basins: Four Mile Bay and Trout Lake (MECP undated). Four Mile Creek is the main inflow to the lake and the main outflow is the Mattawa River which flows to Turtle Lake. Maximum depth of Four Mile Bay is 27 metres, while the deepest basin of Trout Lake is 63 metres deep, with an average depth of 16.9 m across Trout Lake.

A wide variety of background reports and datasets were gathered to characterize water quality conditions in Trout Lake and to compare water quality conditions spatially and temporally.

2.1 Background Material

2.1.1 Reports

The following reports were reviewed as part of the background review:

- Trout Lake Watershed Management Study (CRA 1988)
- Inventory Information for the Trout Lake Watershed (NBMCA 1985)
- Phosphorus Control Site Plan – Lot 6 – Eastview Development (HESL 2011)
- An Integrated Approach to Watershed Management Planning for Trout Lake, Ontario (McBean et al. 1990)
- Hydrodynamic and Water Quality Numerical Modelling in Trout Lake (MECP 2019)
- Preliminary Evaluation of the Water Quality of Trout Lake (MOE 1973)
- Review of the Vulnerability Scoring and Adjustment to IPZ Delineation for the North Bay Intake (HESL, 2016)
- Return of the Ouananiche to Trout Lake (Fitchko et al. 1996)
- Trout Lake Reservoir – A Water Balance Study (Rees 1974)
- TLCA News – Summer 2021 (Trout Lake Conservation Association, 2021)
- Lake Capacity Assessment: Trout Lake (MECP, Undated)
- Trout Lake Parasite Study (Miller Environmental Services Ltd. 2000)
- Trout Lake Pollution Control Plan Sewage Disposal Systems Inventory and Analysis (Northland Engineering Limited and Beak Consultants 1992)
- Trout Lake Pollution Control Plan – Limnology and Hydrology (Northland Engineering Limited and Beak Consultants Limited 1992)
- Trout Lake Rainwater Water Quality Analysis for Phosphorus (1987)
- Water Quality Modelling and Assessment: Trout Lake (Gartner Lee Limited 2002)

2.1.2 Datasets

Data were extracted from some of the reports listed in Section 2.11 to characterize water quality conditions in Trout Lake. Data from different datasets or reports were not, however, combined to characterize long-term trends, as differences in sampling and laboratory methodologies, minimum detection limits and sampling locations would impose too many uncertainties in the analysis. Pertinent findings from individual reports were however referenced to help describe limnological conditions or inform findings.

General limnology conditions were characterized based on data extracted from reports and provided as electronic files by NBMCA. Statistical analyses and reporting were focused, however, on key indicators of water quality that are routinely linked to development impacts: total phosphorus, mean volume weighted hypolimnetic dissolved oxygen, Secchi disk depth and phytoplankton assemblages based on the availability and quality of data provided.

A variety of independent datasets were provided by Ministry of Northern Development, Mines, Natural Resources and Forestry (MNDMNRF) and North Bay-Mattawa Conservation Authority (NBMCA). Long-term water quality datasets provided by the NBMCA included data for 47 parameters, however the frequency and period of record of these samples varied significantly. The vast majority of parameters were only sampled in a few sampling events and have not been sampled in over a decade. Total phosphorus and Secchi disk depth provided the most complete long-term records in the data provided: from 2000 to 2019 for total phosphorus and 2005 - 2019 for Secchi disk depth. A total phosphorus dataset from 1986 - 1993 was also reviewed but analysis of phosphorus was focused on data from 2002 onwards (2002 – 2019) because of improvements in collection and low-level analytical methodologies such as field filtering and sampling directly into glass tubes that are later used during laboratory analysis (Clark et al. 2010).

2.1.2.1 Total Phosphorus

Phosphorus is often the primary limiting nutrient in freshwaters in support of macrophyte and algal growth. Phosphorus enters lakes via external loading from the watershed, precipitation and, in certain conditions, through internal loading from sediments at the lake bottom. Effluent from sewage treatment systems and stormwater runoff may have particularly high loadings and as a result phosphorus concentrations are commonly used to assess the impacts of development on water quality. Excessive growth of plants and algae and subsequent decomposition can result in lowering of dissolved oxygen concentrations in deep hypolimnetic waters due to the oxygen requirements of bacteria and this may degrade fish habitat and in extreme cases result in “fish kills”, a phenomenon where water temperature near the surface of the lake is too warm and oxygen concentrations of the water near the bottom are too low to support fish resulting in a mass die-off.

The City of North Bay has established a more stringent Minimum Water Quality Objective through its Official Plan of a measured ice-free seasonal average phosphorous concentration of 7 µg/L. Provincial water management policies and guidelines provide the following interim water quality objective for total phosphorus:

- To avoid nuisance concentrations of algae in lakes, average total phosphorus concentrations for the ice-free period should not exceed 20 µg/L;
- A high level of protection against aesthetic deterioration will be provided by a total phosphorus concentration for the ice-free period of 10 µg/L or less. This should apply to all lakes naturally below this value.

Preliminary data screening noted a significant number of non-detects in the total phosphorus data in 2010. Two-thirds of all sampling collected and analyzed in 2010 were below the analytical detection limit of 2 µg/L (n = 87), which was highly unusual compared to data collected in other years and to our knowledge analyzed at the same laboratory. It is not apparent from the metadata provided if there was a laboratory or sampling methodological issue during 2010 sampling and therefore data was retained in the analysis. We did, however, run site-by-site temporal analysis on data with and without 2010 to ensure it did not significantly impact our results or interpretations of the data.

2.1.2.2 Mean Volume Weighted Hypolimnetic Dissolved Oxygen

Mean Volume Weighted Hypolimnetic Dissolved Oxygen at the end of summer is often analyzed in relation to Lake Trout habitat guidelines of 7 mg/L (MOE 2010). The Municipalities of East Ferris and North Bay have identified a more conservative mean volume weighted hypolimnetic dissolved oxygen target of 8 mg/L. As mentioned in section 2.1.2.1, development can lead to phosphorus loading which in turn, can lower Mean Volume Weighted Hypolimnetic Dissolved Oxygen through decomposition of increased growth of plants and algae.

The volume of the hypolimnion must be determined to calculate mean volume weighted hypolimnetic dissolved oxygen from profiles of dissolved oxygen concentration measured between the lake surface and the bottom. The hypolimnion is the bottom section of a stratified lake and the upper boundary of the hypolimnion is determined based on a temperature gradient between two depth strata that is <1°C/m. MOE (2010) policy dictates that sampling is completed between August 15 and September 15 to capture the time of year when oxygen stress in the hypolimnion is the greatest.

2.1.2.3 Secchi Disk Depth

Secchi Disk Depth provides a measure of water clarity which is one indication of the productivity of the lake. For Precambrian Shield lakes, Secchi depth is primarily determined by the amount of dissolved organic carbon in the water (Dillon et al. 1986), and this is a function of the amount of wetland in the watershed (Dillon and Molot 1997). High algae growth, however, reduces the penetration of light through the water column and reduces the measured Secchi Depth beyond that related to dissolved organic carbon. Decreases in Secchi Depth over time may therefore be indicative of increased productivity by, for example shoreline disturbance and development activities that increase total suspended solids or phosphorus loading from the watershed.

2.1.2.4 Phytoplankton

As part of recent monitoring programs, data collection has included fluoroprobe measurement of photosynthetic pigments in the water column to estimate algae composition and concentration with depth. Algae is a diverse group of photosynthetic eukaryotic micro-organisms which is comprised of hundreds of thousands of individual species with variable environmental optima and tolerances. As a result, the species present in a lake or stream may be indicative of the environmental conditions including the water quality. Changes in algae, as a result of changes in water quality, may serve as an early warning indicator of risk to other aquatic organisms. Algae data from fluoroprobe measurements in Trout Lake were limited to 2016-2019 and the period of record varied between years. Our analysis focussed on late-August/early-

September data at one sampling location (TL4) as data was consistently available in all four monitoring years. We assessed concentrations of pigments from four algal phyla recorded by the fluoroprobe with depth through the water column. Results were compared between years as a measure of interannual variability and to determine if marked differences in algal community or abundance could be linked to activity on the lake as part of future analyses.

2.1.3 Outliers

In relatively small datasets like the Trout Lake dataset, the calculation of average total phosphorus concentration is sensitive to outliers, that is, extreme values that may represent analytical errors or rare events, but which are not representative of the average site condition. Rosner's ESD Many-Outlier Procedure (Rosner's Test; Rosner, 1983) was performed in the R statistical Software Environment, using the "rosnerTest" function of the "EnvStats" package (Millard, 2013), to identify outliers in total phosphorus concentrations collected since 2000 for each Trout Lake monitoring site. This procedure detects high and low extreme values and is not limited for multiple outliers. Statistically significant outliers (at $p<0.05$) were reviewed and removed from the dataset for further analyses.

2.1.4 Censored Data

Censored data are measurements which fall below the detection limit of the laboratory analysis. There is no universally accepted method of treating censored data. For this review, we substituted the value of the detection limit for any data below detection. When a substantial portion of the data is below detection, however, concentrations are overestimated, and statistical analyses may be biased (ANZECC 2000). Parameter records which contained >30% non-detects were therefore not considered for any analyses of statistical inference, e.g., spatial comparisons.

2.1.5 Temporal Trends

We used the Shapiro-Wilk test to assess the normality of the data and determine the most appropriate statistical techniques for its analysis (R Core Team 2013). Non-parametric techniques were shown to be the most appropriate and therefore Mann Kendall Trend analysis was performed using the "mk.test" and "sens.slope" functions of the "Trend" package in R (Pohlert 2017) to assess any long-term changes in total phosphorus concentrations over time (2000-2019) for each site.

The significance of water quality differences between sites was tested using the non-parametric Kruskal Wallis test. Where statistically significant ($p < 0.05$) differences were identified, we performed pairwise post-hoc Dunn's tests to identify which sites differed significantly. Kruskal Wallis and Dunn's tests were performed in R using the core "kruskal.test" function and the "dunntest" function of the Simple Fisheries Stock Assessment Methods (FSA v0.8.11; Ogle, 2021) package. Results were corrected following the Benjamini–Hochberg procedure (Benjamini and Hochberg 1995) to adjust p-values to account for Type I error of multiple comparisons.

2.2 Sampling Locations

Sampling on Trout Lake has taken place over multiple water quality monitoring programs and several watershed management studies. Eight core sampling stations have been consistently sampled across multiple monitoring programs and special studies (Figure 1). Sample locations and related descriptions are provided in Table 2. Several other stations have been sampled, however the consistency of sampling at these stations limits their usefulness in assessing potential long-term change in water quality.

Table 2. Sampling Location and Related Descriptions.

Sampling Location	Description
TL1	Trout Lake - Delaney Bay
TL2	Trout Lake - Dugas Bay
TL3	Trout Lake - Central Western Portion
TL4	Trout Lake - Central Portion
TL5	Trout Lake - Eastern Portion Near Outflow
TL6	Four Mile Bay - Western Portion
TL7	Four Mile Bay - Eastern Portion
TL8	Trout Lake - One Mile Bay

3. Results

3.1 Background Review Findings

The Trout Lake Watershed Management Study (CRA 1988) was a comprehensive assessment of the Trout Lake watershed that aimed to provide an assessment of watershed conditions, evaluate the relationship between the watershed activities and water quality issues and present management strategies for implementation on Trout Lake. The study found excellent water quality in 1986, with no exceedances of Provincial Water Quality Objectives except for colour and organic nitrogen which exceeded drinking water objectives. An increase in total phosphorus was noted between 1986 and 1987 sampling years, however a decrease in chlorophyll a during the same period suggests that the increase in phosphorus did not have a measurable biological impact on the lake. Both lake and stream water quality differed spatially and temporally between the 1986 and 1987 sampling years. Water quality trend assessment compared 1977 and 1986 water quality and found no discernible decline in water quality over the period of record, beyond increased chloride concentrations.

Nearshore measurements did not substantially differ from deep water measurements with the exception of higher nearshore bacteria concentrations (i.e., total coliforms and fecal coliforms) as would be expected due to runoff from urban and developed areas and from natural fecal sources such as waterfowl (CRA

1988). Findings on nearshore and deep-water comparisons were consistent between both the "Preliminary Evaluation of the Water Quality of Trout Lake" (MOE, 1973) and the Trout Lake Watershed Management Study (CRA, 1988).

More recent water quality assessment on the lake was performed in 2002 by Gartner Lee Limited (GLL, 2002) and focused on nutrient concentrations dating back to 1975. Over the 27-year period of record considered, no increase in phosphorus concentrations was noted and the data showed evidence of decreasing concentrations.

Three noteworthy more uncommon stressors to water quality were also noted in the background review: a spill of zinc and lead concentrate, a spill of formaldehyde and introduction of Polyfluoroalkyl Substances (PFAS) in waterways upstream of Trout Lake. The scope of the report and project at large is to define general lake conditions, but these are briefly described for informative purposes and to acknowledge that various anthropogenic stressors associated with various types of development can occur that are often not predicted.

The impact and recovery from an environmental disaster in 1967 was described in "Return of the Ouananiche to Trout Lake" (Fitchko et al. 1996). Trout Lake was one of the few successful stocking efforts of Atlantic salmon ("Ouananiche ") in Ontario and resulted in a documented self-propagating population. On March 7th, 1967, a train derailment near Four Mile Creek resulted in the spill of zinc and lead concentrate which increased concentrations of zinc to 0.39 mg/L in Four Mile Creek downstream of the spill site in September 1979 (Bowman 1979). These concentrations were well above the Provincial Water Quality Objective of 0.03 mg/L (Ministry of the Environment 1984) and the background levels of Trout Lake (<0.01 mg/L). The spilled resulted in the extirpation of the Atlantic salmon spawning in Four Mile Creek. Following a period of remediation, zinc concentrations declined to below Provincial Water Quality Objective (i.e., 0.03 mg/L) by 1994/1995 and evidence suggests that the self-sustaining population of Atlantic salmon has been re-established.

In 2012, an overturned tanker truck north of Silver Lady Lane in North Bay leaked Formaldehyde into Trout Lake resulting in a health advisory notice being issued to residents that draw drinking water from the lake, however North Bay's municipal water supply was not affected by the spill (NBPSDHU 2012).

The Trout Lake Conservation Association 2021 newsletter reviewed as part of the background research on Trout Lake included an ongoing discussion of the impacts and risks associated with polyfluoroalkyl substance. Polyfluoroalkyl substances are man-made chemicals with a wide range of applications whose original source into Trout Lake is thought to be via Aqueous Fire Fighting Foam. The provincial government has developed a polyfluoroalkyl substances working standard for eleven different polyfluoroalkyl substances chemicals of 70 ng/L which are now being applied to Trout Lake. The issues are being investigated by the Department of National Defence and a remediation agreement between the Department of National Defence and the City of North Bay has been approved.

3.2 General Lake Characteristics

Total alkalinity is low in Four Mile Bay (7 – 8 mg/L) and Trout Lake (13.4 – 13.8 mg/L), while pH indicates neutral acidity (Four Mile Bay = 6.83 – 7.20; Trout Lake = 7.24 – 7.52; MECP undated). Dissolved organic carbon is relatively low as well (3.3 – 5.3 mg/L), indicating that Trout Lake doesn't likely have naturally high total phosphorus concentrations.

Total ammonia concentrations in Four Mile Bay (0.005 – 0.011 mg/L) and Trout Lake (0.005 – 0.009), nitrate concentrations in Four Mile Bay (0.031 mg/L – 0.202 mg/L) and Trout Lake (0.033 – 0.194 mg/L) and nitrite concentrations in Trout Lake (0.001 mg/L) were also very low and lower than relevant Canadian Water Quality Guidelines (MECP, undated).

Temperature and oxygen profiles are presented for selected basins of the lake using NBMCA data for 2019 and followed typical seasonal stratification found in dimictic lakes. Note that a full open water season of dissolved oxygen profiles were not available for 2021 at the time of reporting but will be added at a later date. Stratification, the separation of the lake into distinctive thermal layers which do not mix, was established at the 6-7m depth in May/June in Trout Lake and Four Mile Bay and persisted throughout the summer until fall overturn in late September to mid-October (Figure 2). The establishment of thermal stratification in lakes prevents mixing of water between the warm surface waters (epilimnion) and the relatively cool deeper water (hypolimnion) and as a result prevents oxygen rich surface water from mixing with oxygen depleted bottom waters. As oxygen is consumed in the deep water over time by bacterial decomposition and other processes, anoxia may develop and result in internal phosphorus loading to the lake. Development of anoxia in the main basin of Trout Lake does not occur (Figure 3) as there is little loss of dissolved oxygen during the early summer or under ice in February. In Four Mile Bay, dissolved oxygen did not typically fall below 2 mg/L in the hypolimnion, however one occurrence of low oxygen concentration (0.8 mg/L) was documented on June 18, 2007. Long-term data from One Mile Bay (TL8) showed the onset of anoxia by September early such that it is likely susceptible to anoxic conditions on an annual basis (Figure 4).

Figure 1. Map of Sampling Stations on Trout Lake and Four Mile Bay.

Figure 2. 2019 Temperature Profiles from the Central Basin of Trout Lake (TL4) and Four Mile Bay (TL6).

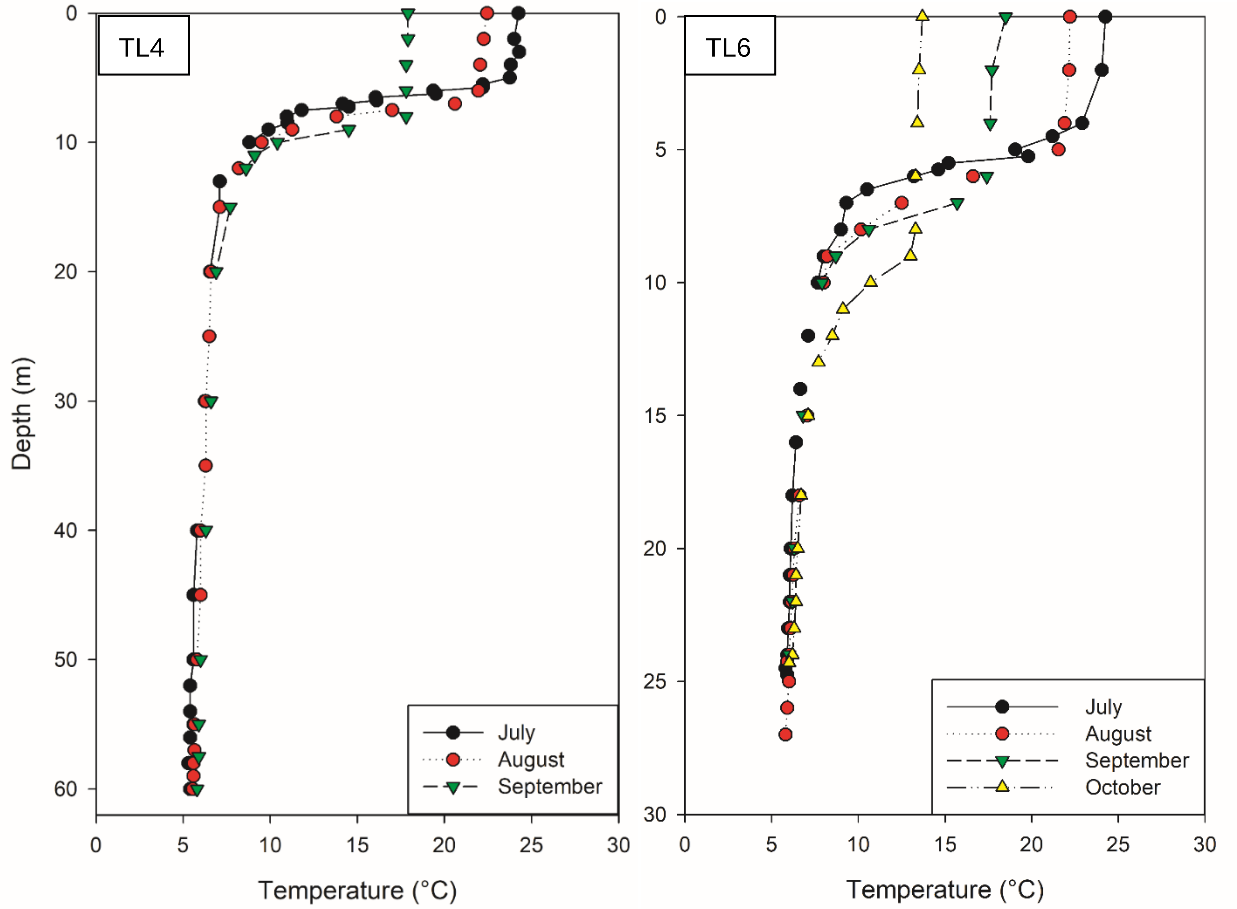


Figure 3. 2019 Dissolved Oxygen Profiles from the Central Basin of Trout Lake (TL4) and Four Mile Bay (TL6).

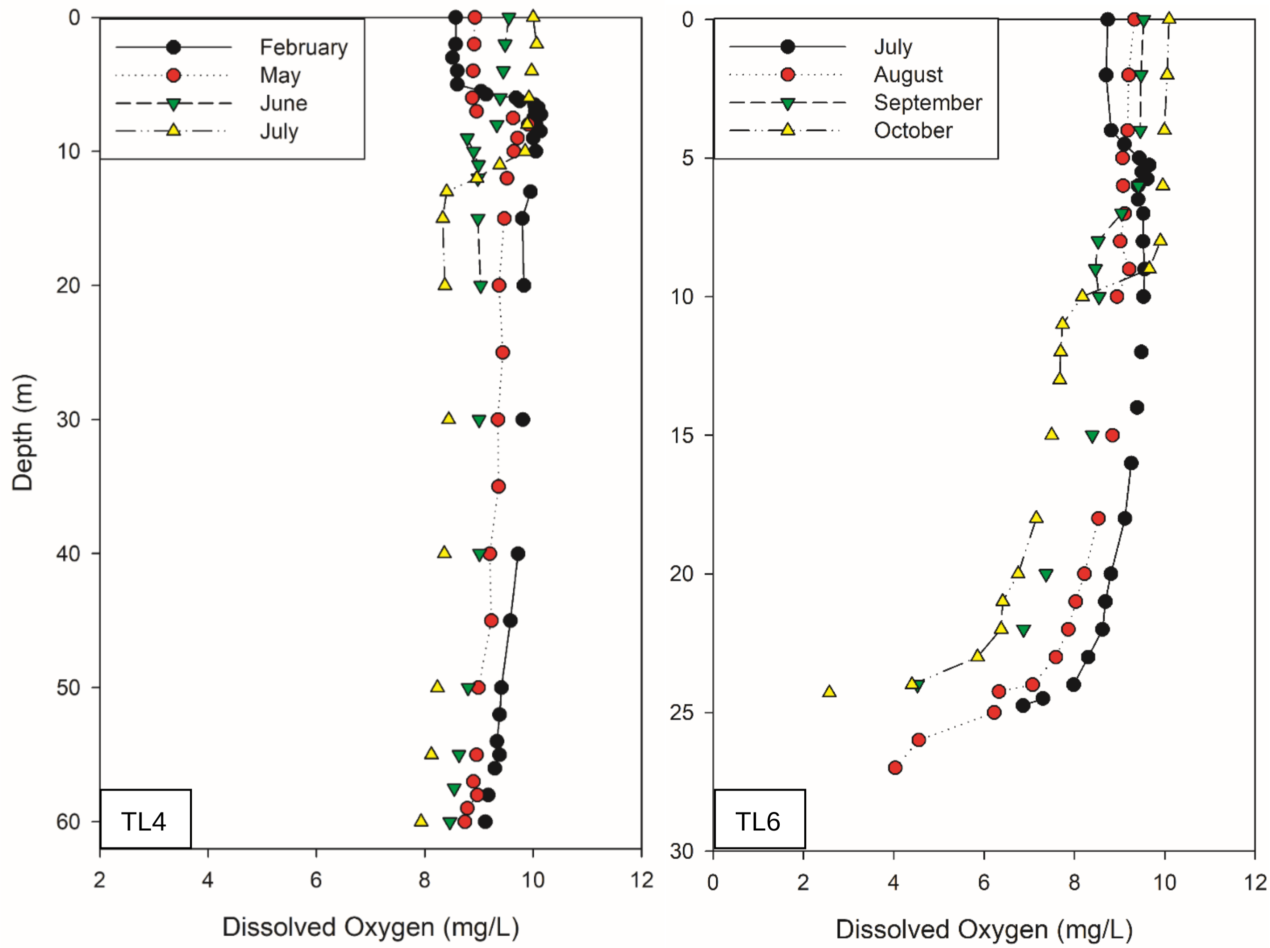
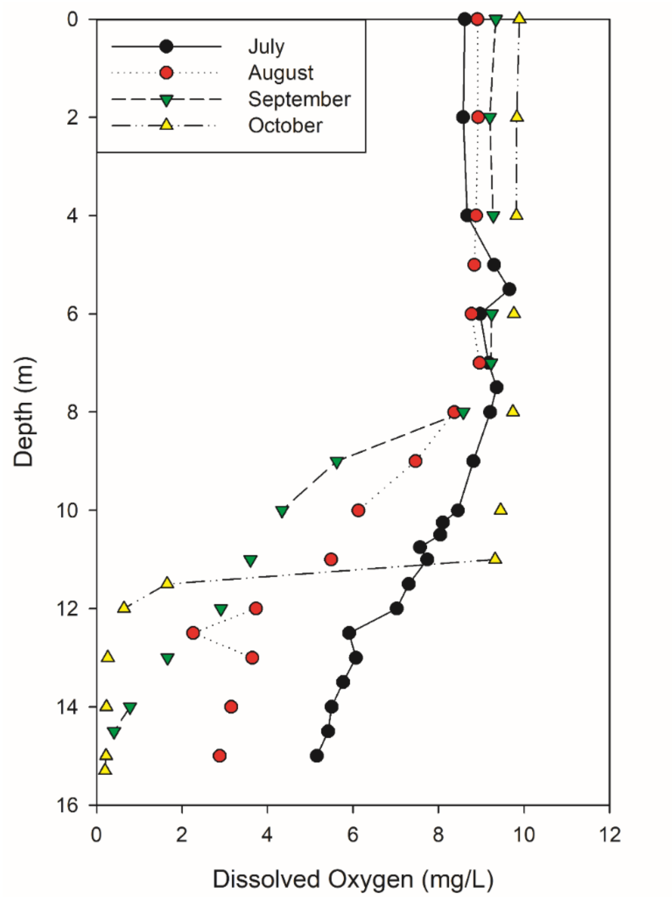


Figure 4. 2019 Dissolved Oxygen Profiles from the One Mile Bay of Trout Lake (TL8).



3.3 Total Phosphorus

3.3.1 Combined Sites

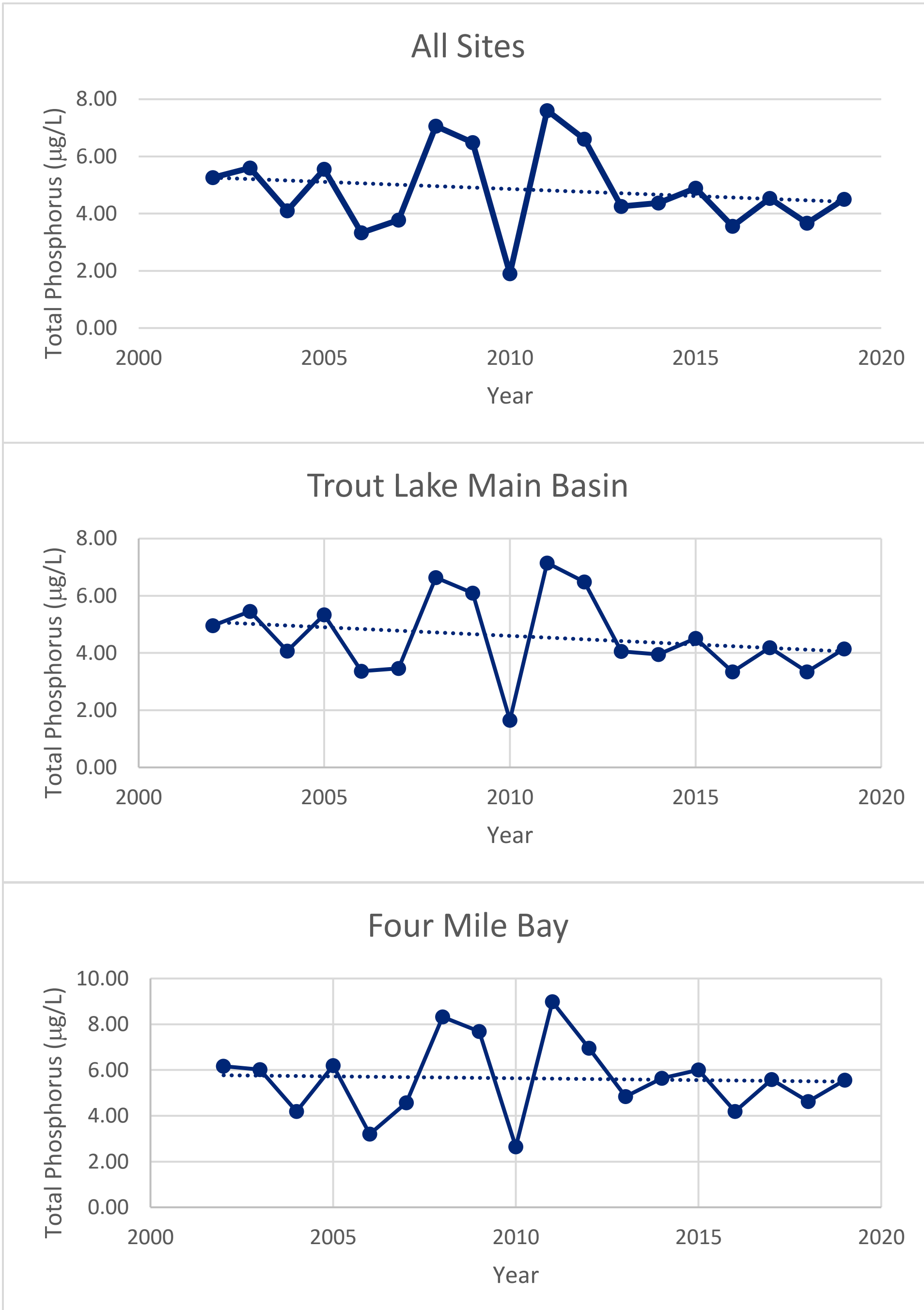
Annual average total phosphorus concentrations in Trout Lake, when all sites were combined, were highly variable and ranged from 1.90 to 7.61 µg/L with average concentrations exceeding the City's Minimum Water Quality Objective (7 µg/L) in 2008 (7.1 µg/L) and 2011 (7.6 µg/L; Table 3). Average annual total phosphorus concentrations in the main basin (Sites TL1-5 and TL8) ranged from 1.7 to 6.1 µg/L and exhibited no exceedances of the City of North Bay's Minimum Water Quality Objective (ice-free average of 7 µg/L), while Four Mile Bay (Sites TL6 and TL7) ranged from 3.2 to 9.0 µg/L with annual Minimum Water Quality Objective exceedances in 2008 (8.32 µg/L), 2009 (7.69 µg/L) and 2011 (8.98 µg/L; Table 3).

When average annual total phosphorus concentrations were calculated for all sites, Trout Lake Main Basin and Four Mile Bay, a declining pattern was noted (Figure 5) but low R^2 values (0.003 – 0.05) indicate that the pattern is highly variable. Concentrations were generally elevated in 2008, 2009, 2011 and 2012, and extremely low in 2010.

Table 3. Average Annual Ice-Free Total Phosphorus (µg/L) Concentrations in Trout Lake.

Year	TL1	TL2	TL3	TL4	TL5	TL6	TL7	TL8	All Sites	Trout Lake Main Basin	Four Mile Bay
2002	4.56	5.33	4.90	4.88	4.50	6.45	5.89	5.60	5.26	4.96	6.17
2003	6.02	6.15	6.18	4.14	5.20	5.83	6.20	5.06	5.60	5.46	6.02
2004	3.39	4.40	4.74	3.54	4.73	4.52	3.87	3.64	4.10	4.07	4.20
2005	4.85	4.35	5.80	4.60	7.50	6.22	6.18	4.92	5.55	5.34	6.20
2006	3.98	4.54	2.59	3.47	2.60	3.21	3.20	3.03	3.33	3.37	3.21
2007	3.28	3.63	3.48	3.24		4.04	5.10	3.66	3.78	3.46	4.57
2008	7.00	5.67	5.71	6.13	7.50	8.25	8.39	7.83	7.06	6.64	8.32
2009	6.82	5.64	5.64	6.18	6.18	7.82	7.55	6.09	6.49	6.09	7.69
2010	1.27	1.55	1.52	1.67	2.44	2.60	2.68	1.47	1.90	1.65	2.64
2011	7.24	7.88	7.21	6.42	6.66	8.36	9.60	7.49	7.61	7.15	8.98
2012	6.15	4.25	4.98	8.56	7.33	6.15	7.75	7.67	6.61	6.49	6.95
2013	4.48	3.62	3.72	3.86	4.44	4.83	4.85	4.26	4.26	4.06	4.84
2014	4.35	3.55	3.98	3.70	4.20	5.91	5.38	3.91	4.37	3.95	5.65
2015	4.82	4.07	4.46	4.07	4.78	5.84	6.18	4.90	4.89	4.52	6.01
2016	3.97	3.03	2.68	3.50	3.40	4.24	4.14	3.50	3.56	3.35	4.19
2017	4.81	3.84	3.92	4.48	4.12	5.46	5.71	3.93	4.53	4.18	5.59
2018	3.36	3.26	3.12	3.38	3.50	4.62	4.62	3.46	3.67	3.35	4.62
2019	4.12	3.88	3.88	4.19	4.65	5.73	5.39	4.17	4.50	4.15	5.56
								Minimum	1.90	1.65	2.64
								Maximum	7.61	7.15	8.98
								Mean	4.84	4.57	5.63

Figure 5. Annual Average Ice-Free Total Phosphorus for Combined Sites.



Note: trendlines were added to showcase declining patterns in total phosphorus concentrations but data are highly irregular.

3.3.2 Station-by-Station

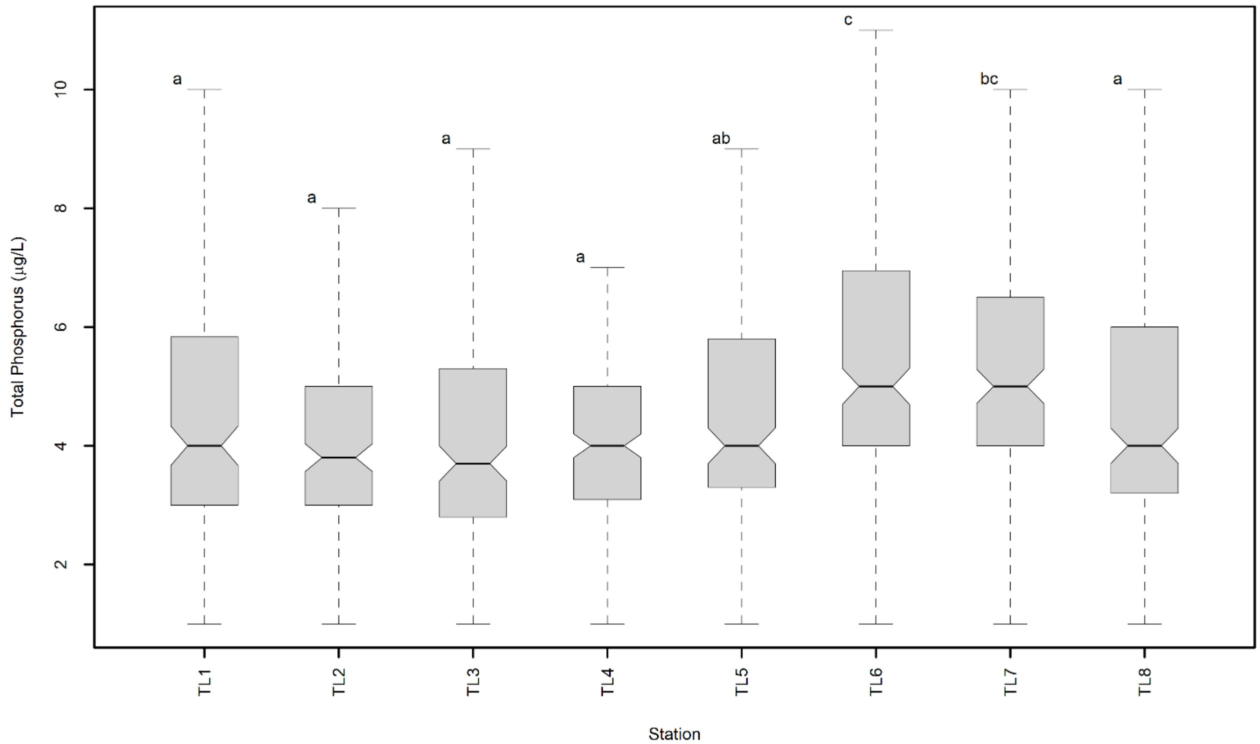
Assessment of site-by-site spatial trends in total phosphorus in Trout Lake showed highly consistent concentrations across all monitoring stations with the exception of TL6 and TL7 in Four Mile Bay (Figure 5). Median ice-free total phosphorus concentrations in Four Mile Bay were 5.0 μg/L (range = 1.0 - 17.0 μg/L) at both monitoring stations, which is significantly higher than the range of 3.7 to 4.0 μg/L (range = 1 – 18 μg/L) at the six long-term monitoring stations in the main basin.

Open water sites (i.e., TL3 and TL4; Figure 1) and large, relatively open water bays (i.e., TL1 and TL2) on Trout Lake have experienced a single exceedance of the City of North Bay's Minimum Water Quality Objective (ice-free average of 7 μg/L) in 2011 (TL1, 2, and 3) or 2012 (TL4), while in isolated bays (TL6, 7 and 8) and near the Mattawa River outflow (TL5) exceedances have occurred in 3 or 4 years. No exceedances of the Municipal Water Quality Objective have been recorded since 2012 at any monitoring station on Trout Lake.

Concentrations of total phosphorus in Four Mile Creek ranged from 2-160 μg/L with the highest concentrations being recorded in July and August during storm events. However, data from other tributaries on Trout Lake are not readily available for comparison to put the Four Mile Creek water quality data into regional perspective.

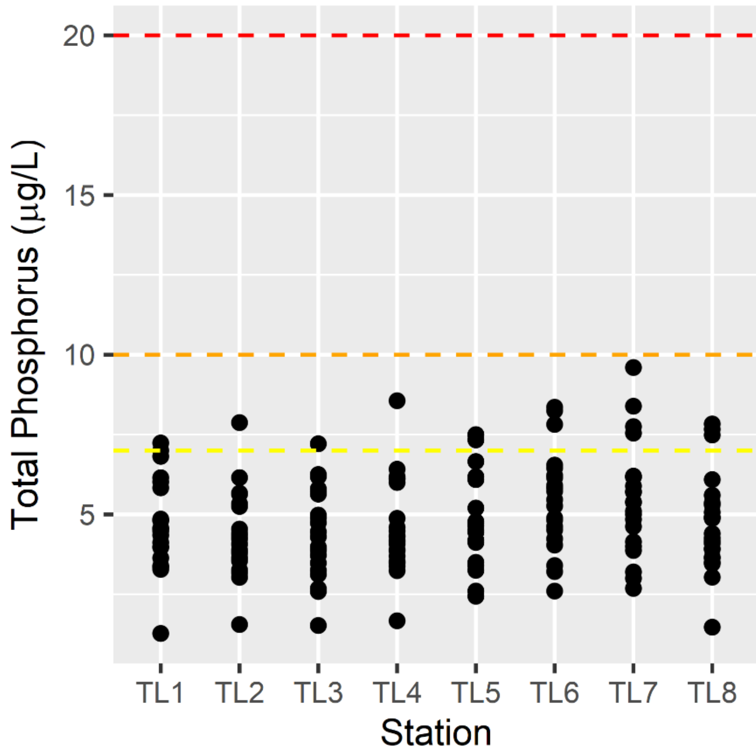
No historical exceedances of the Provincial Water Quality Objective for total phosphorus (10 μg/L) occurred at any of the 8 long-term monitoring stations suggesting a high level of protection against aesthetic deterioration across Trout Lake (Figure 6).

Figure 6. Spatial Trends in Total Phosphorus Concentrations on Trout Lake.



Note: the box and whisker plot shows the data range with the whiskers, the quartile range with the box and the median value with the line through the box. The letters above the upper whiskers showcase which sites were calculated to be statistically similar or different.

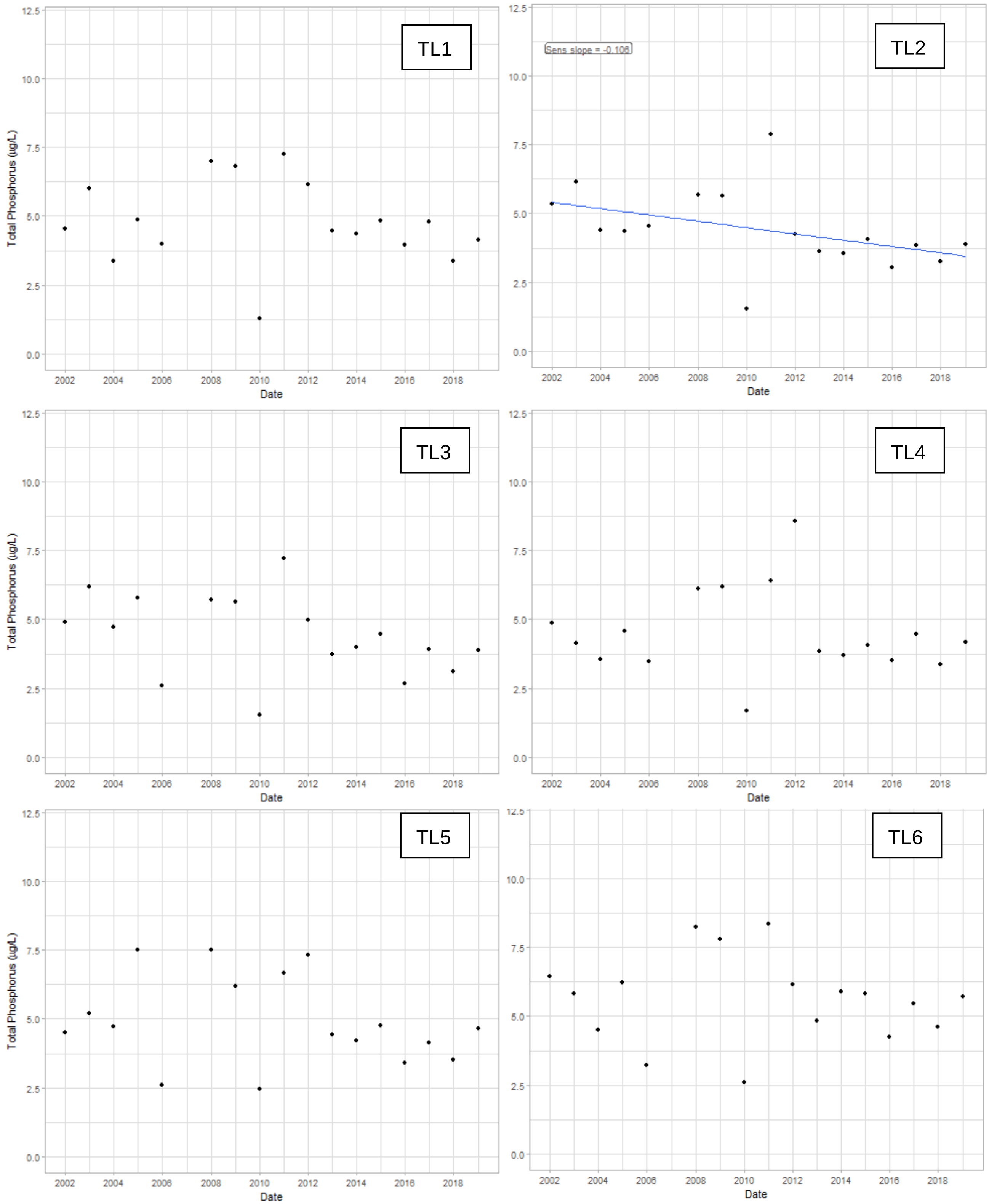
Figure 7. Comparison to Municipal Guidelines and Provincial Guidance.

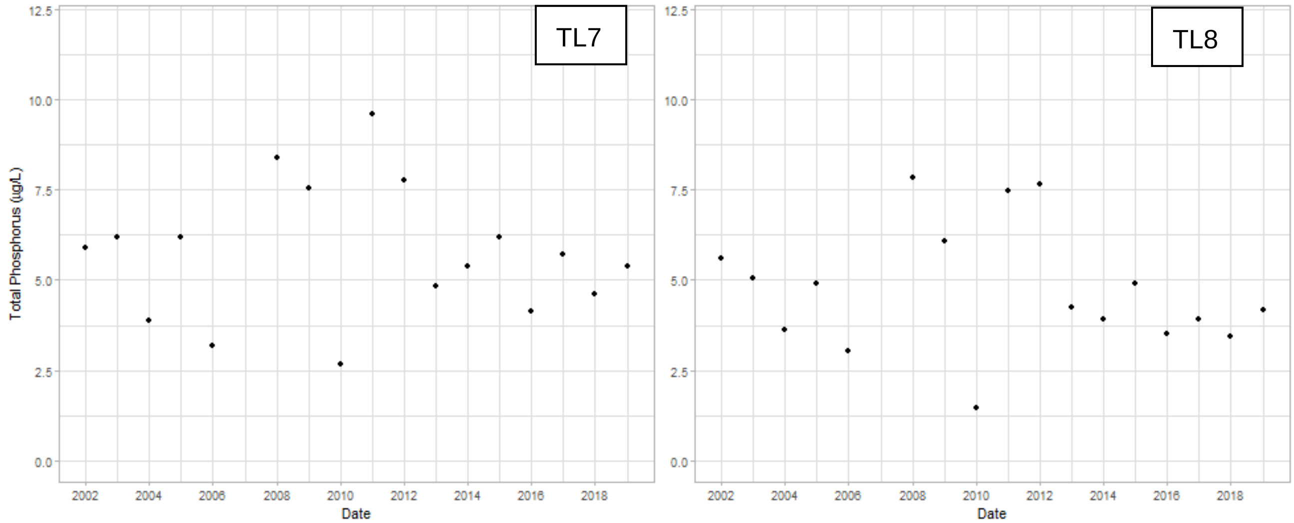


Notes: Yellow = Municipal guidance 7 mg/L; Orange = Provincial Water Quality Objective

Temporal trend analysis of long-term monitoring data was also performed station-by-station as described in Section 2.1.2. We found no significant increases in average annual total phosphorus concentrations at any of the water quality stations but a declining trend was noted at TL2 - Dugas Bay (Figure 8). Analysis of long-term trends in total phosphorus data excluding 2010 resulted in an additional decreasing trend in total phosphorus at site TL3 as well, however this does not change our interpretation of these data, nor the recommendations that follow.

Figure 8. Temporal Trends in Total Phosphorus Concentrations in Trout Lake at Individual Sites.





Note: a trendline was added to TL2 to highlight the presence of a declining trend in total phosphorus concentrations.

3.4 Mean Volume-Weighted Hypolimnetic Dissolved Oxygen

Mean volume-weighted hypolimnetic dissolved oxygen is the average concentration of dissolved oxygen measured in late summer in the hypolimnion that has been volume-weighted to account for the morphometry of the lake. Mean volume-weighted hypolimnetic dissolved oxygen concentrations have ranged between 7.8 and 11.1 mg/L in the 9 years of monitoring data available (MECP undated). Data collected and presented in the MECP Lake Capacity Assessment of Trout Lake were collected at every other metre depth from the surface to ~60m depth at the deepest basin of Trout Lake in 1987, 1989, 1994, 2001, and 2002 (TL4). Data between measured intervals were interpolated for the purpose of mean volume-weighted hypolimnetic dissolved oxygen calculations to increase the resolution of the dataset to include data for each 1m of water depth. In 2006, data were collected every 1m from the surface to 25 m depth and then collected every 5 m to 57 m and interpolated. In 2014 and 2015 data were collected at 1m intervals from the surface to 53 m and 58 m depth respectively. In all sampling years, data were extrapolated beyond the maximum measured depth to a depth of 72 m, despite a reported maximum depth in the basin of 63 m. It is unclear how data were extrapolated or why this extrapolation took place. In Four Mile Bay, oxygen profile data were collected every 1 m from the surface to 30 m depth in 2014 and 2015, however in 1993 data were only collected to 28 m depth. In 1994 and 2002 profiles were collected at 2m intervals from the surface to 30 m and 29 m depths respectively and then interpolated.

Ontario has adopted a mean volume-weighted hypolimnetic dissolved oxygen concentration of 7 mg/L (measured between August 15th and September 15th) as a criterion to protect lake trout habitat. The Municipal regulations for Trout Lake add a layer of conservatism to the Provincial Objective, setting an objective for mean volume-weighted hypolimnetic dissolved oxygen at 8 mg/L. Based on data available from 9 years of monitoring (i.e., 1987, 1989, 1994, 2001, 2002, 2006, 2014, 2015 and 2018) in the main basin of Trout Lake only a single value in 1994 fell below the Municipal objective. No mean volume-weighted hypolimnetic dissolved oxygen concentrations below provincial guidance have been recorded.

In Four Mile Bay, mean volume-weighted hypolimnetic dissolved oxygen was recorded less frequently than in Trout Lake (Table 3). Concentrations ranged from 6.94 to 9.3 mg/L, were lower than the Provincial

Objective in 1994 (6.9 mg/L) and lower than the municipal regulation in 4 out of 6 years. Mean Volume Weighted Hypolimnetic Dissolved Oxygen concentrations were consistently lower in Four Mile Bay than in Trout Lake, but the difference was not statistically significant based on the limited data available (Table 3; n=6).

In Trout Lake no significant change (p>0.05) in mean volume-weighted hypolimnetic dissolved oxygen was measured over the period of record based on our temporal analysis of annual mean volume-weighted hypolimnetic dissolved oxygen concentrations (Figure 9). A strong correlation between mean volume-weighted hypolimnetic dissolved oxygen concentrations and sampling date is apparent in the current dataset with elevated concentrations being associated with earlier sampling dates (e.g., 2001, 2002 and 2006). Maintaining consistent sampling timing will be vital for long-term comparison of mean volume-weighted hypolimnetic dissolved oxygen concentrations.

Figure 9. Temporal Assessment of Mean Volume Weighted Hypolimnetic Dissolved Oxygen in Trout Lake.

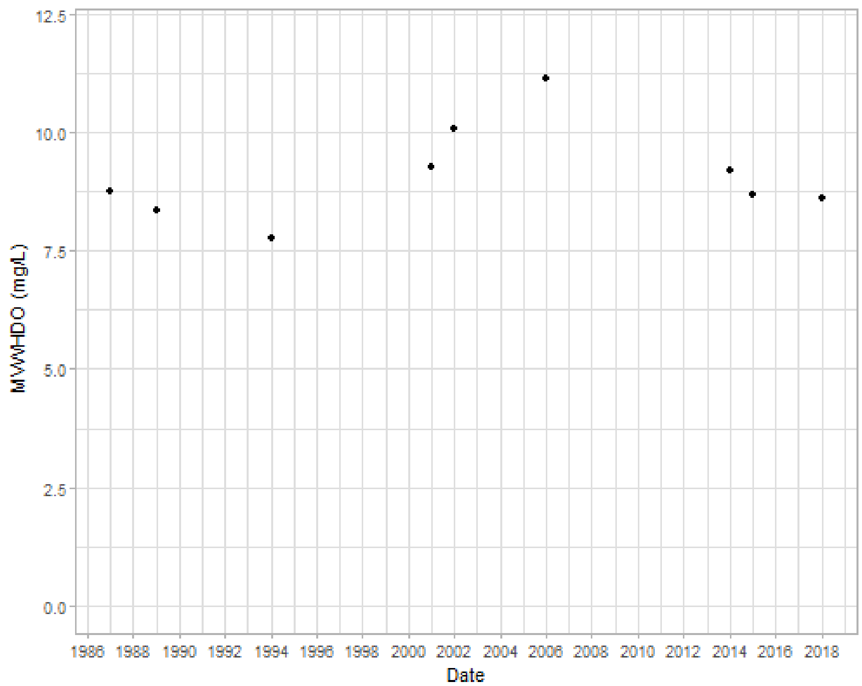


Table 4. Mean Volume Weighted Hypolimnetic Dissolved Oxygen Concentrations from Long-term Monitoring Data.

	Mean Volume Weighted Hypolimnetic Dissolved Oxygen (mg/L)	
Date	Four Mile Bay	Trout Lake
1987-09-14		8.77
1989-09-14		8.36
1993-09-15	7.94	
1994-09-14	6.94	7.78
2001-08-21		9.25

2002-08-27	9.3	10.07
2006-08-16		11.12
2014-09-02	8.4	9.18
2015-09-11	7.59	8.69
2018-09-11	7.61	8.6

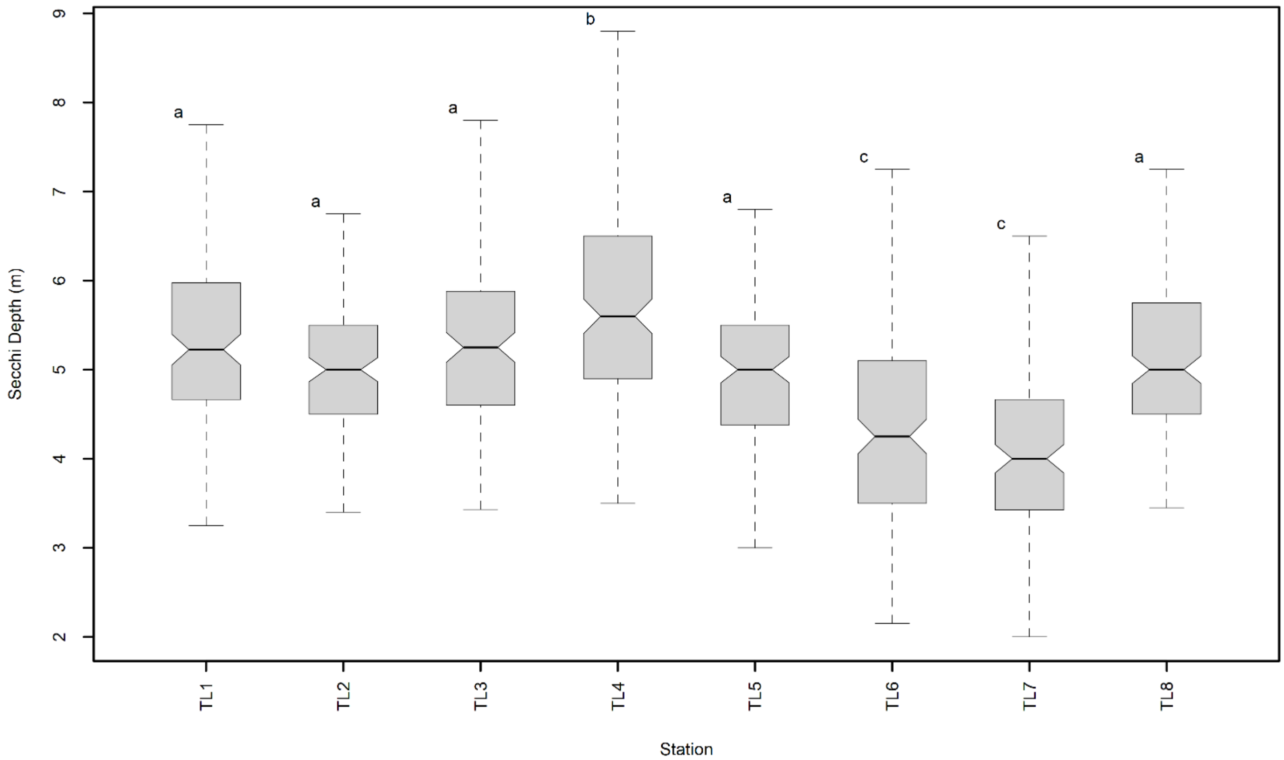
3.5 Secchi Disk Depth

Secchi depth is a measure of water transparency and is often applied in lake management as an indicator of productivity and trophic status in lakes. We assessed spatial and long-term linear trends in Secchi depth as part of our assessment of the current and historical water quality in Trout Lake.

3.5.1 Spatial Trends in Secchi Depth

Assessment of spatial trends in Secchi depth in Trout Lake showed consistent water clarity across the majority of monitoring stations in Trout Lake. The deep-water station at TL4 had significantly higher water clarity than any other site, as it is less likely to be directly impacted by run-off from storm activity or other watershed disturbances or inputs. Secchi depth in Four Mile Bay (TL6 and 7) was significantly lower than elsewhere on the lake, likely as a result of either higher productivity of algal assemblages, higher dissolved organic carbon concentrations, or as a result of suspended sediments from the inflow of Four Mile Creek. Median Secchi depth measurements in Four Mile Bay were 3.9 - 4.0 m and ranged between 5.0 and 5.4 m at the six other long-term monitoring stations (Figure 9).

Figure 10. Spatial Trends in Secchi Disk Depth on Trout Lake.

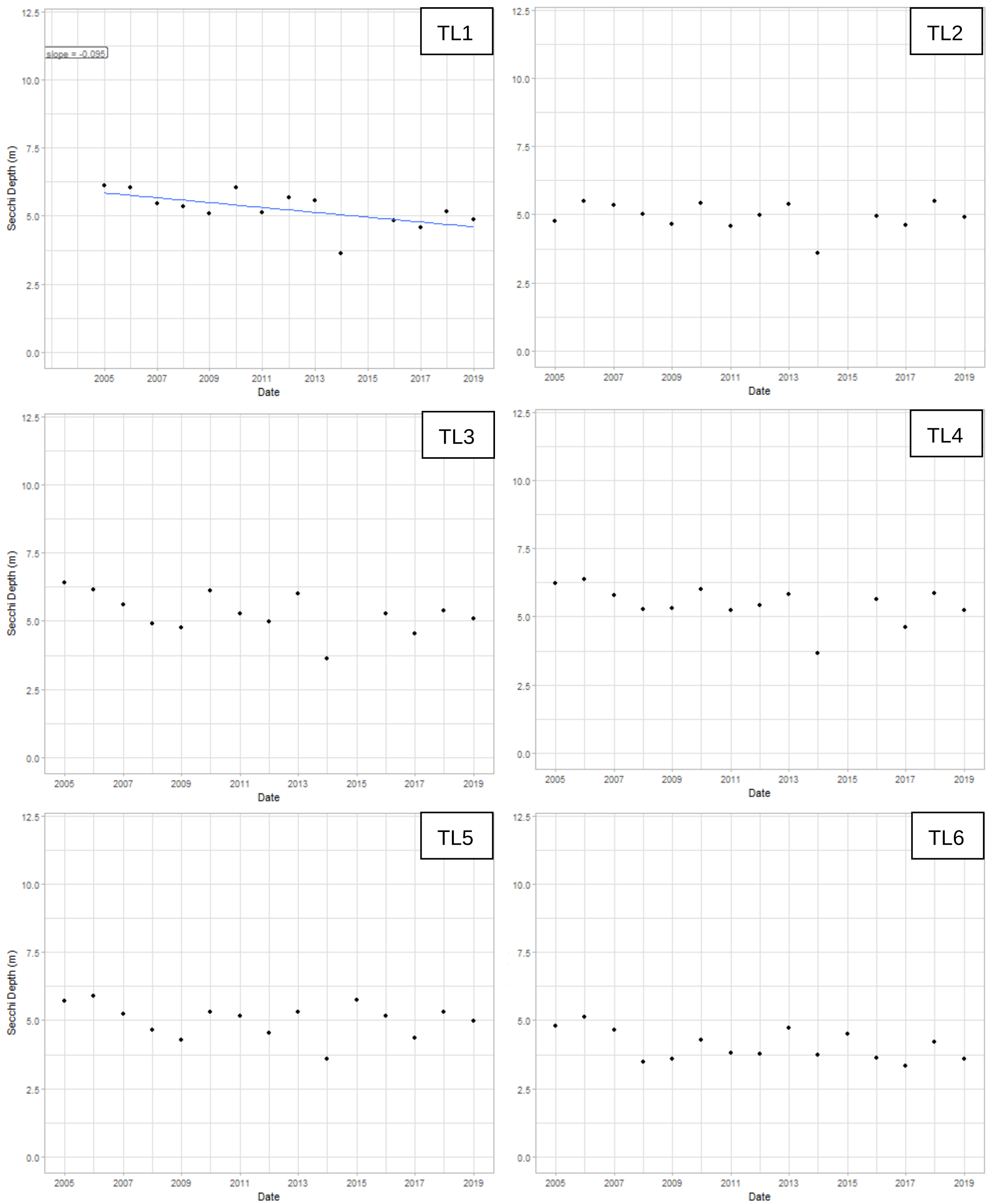


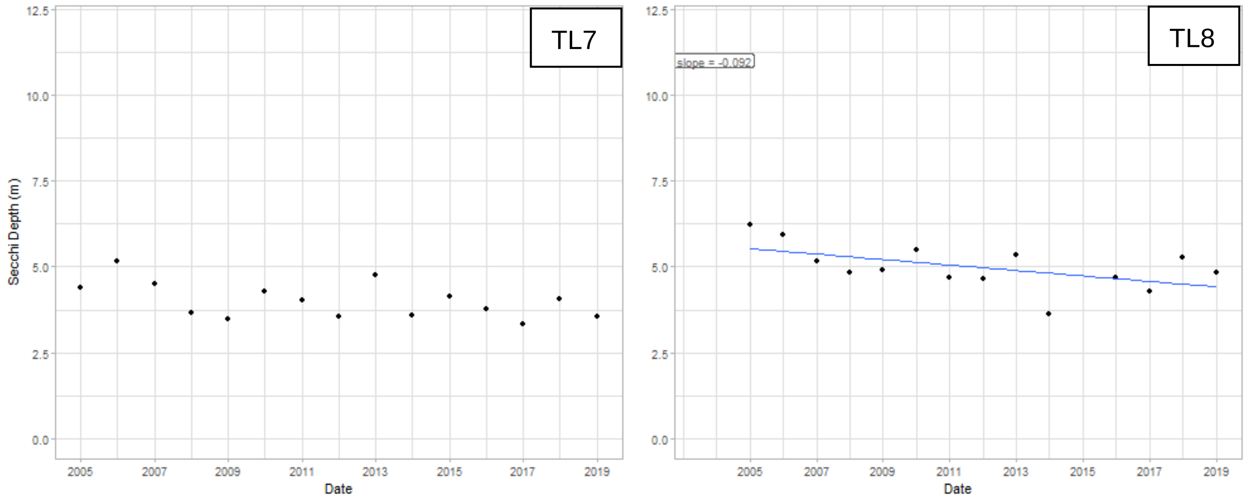
Note: the box and whisker plot shows the data range with the whiskers, the quartile range with the box and the median value with the line through the box. The letters above the upper whiskers showcase which sites were calculated to be statistically similar or different.

3.5.2 Temporal Trends in Secchi Depth

Temporal trend analysis of long-term monitoring data on Trout Lake was performed as described in Section 2.1.2. We found significant ($p<0.05$) long-term decreases in average annual Secchi depth at Delaney Bay (TL1) and One Mile Bay (TL8) since 2005 (TL8; Figure 11). These trends appear to be driven in part by a marked decline in water clarity in 2014, reanalyzing the data without the 2014 data did not change the results at TL1, however the decreasing trend at TL8 was no longer significant when the 2014 data were removed.

Figure 11. Temporal Trends in Secchi Depth on Trout Lake.





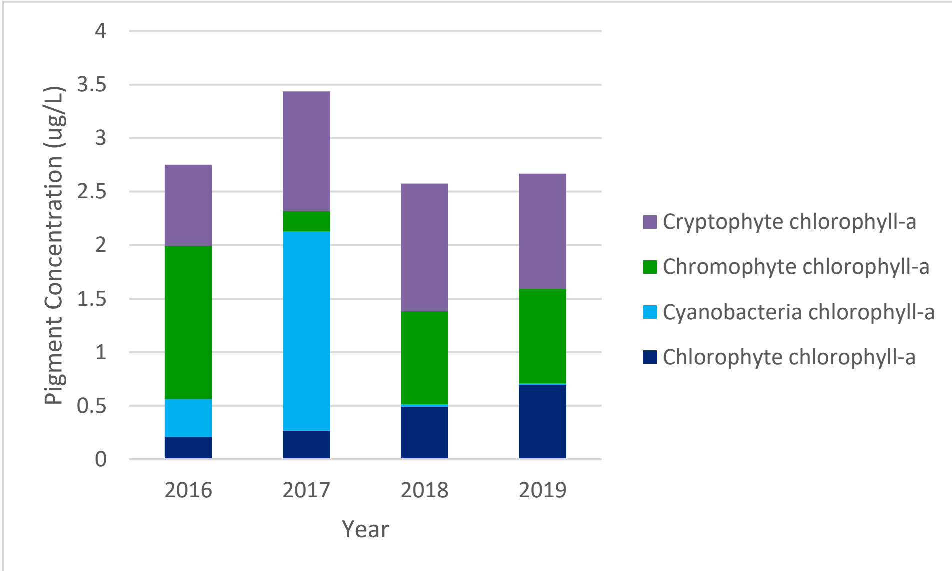
Note: a trendline was added to TL1 and TL8 to highlight the presence of declining trends in Secchi disk depths..

Reduced water clarity in the Delaney Bay basin could be the result of higher TSS loads from local roads, railroads and urban development in the area (Delaney Bay is the most developed area of the lake) or could be the result of higher local algae production or changes in dissolved organic carbon. Palmer et al. (2011) documented increased dissolved organic carbon in south central Ontario lakes between 1981-1990 and 2004-2005 and linked the increases to a warmer climate with increased decomposition of organic matter. The NBMCA fluoroprobe data does not include results from prior to 2016 nor are long-term water quality data on suspended sediments or dissolved organic carbon available and therefore it is difficult to defensibly ascertain the cause of recent declines in water clarity in Delaney Bay.

3.6 Phytoplankton

Fluoroprobe data from 2016 to 2019 showed consistent algal pigment production and community composition results over the course of the four years of late August/Early-September measurements, with the exception of a marked increase in cyanobacterial production in 2017 (Figure 12). Total chlorophyll *a* concentrations ranged from 2.6 to 2.8 μg/L in 2016, 2018 and 2019 but increased to 3.4 μg/L in 2017 as cyanobacteria accounted for 54% of the algal production.

Figure 12. September Phytoplankton Data from Fluoroprobe Surveys of Trout Lake.



Seasonal phytoplankton succession in northern, temperate waterbodies is driven by changes in nutrients, water stability and light regime. Briefly, winter phytoplankton under the ice is commonly dominated by small motile algae which are adapted to low light, low water temperature and high water column stability, such as Chrysophytes (e.g., *Dinobryon*, *Mallomonas*, and *Synura*) and Cryptophytes (e.g, *Cryptomonas* and *Rhodomonas*).

In the late winter, light availability improves as the snowpack melts, resulting in increased abundance of dinoflagellates and small centric diatoms. As ice cover is lost in the spring, mixing in the water column creates conditions of low stability and high nutrient concentrations. This results in a marked increase in phytoplankton productivity, particularly diatoms, and is frequently the annual peak in phytoplankton biomass. This spring bloom is often dominated by a single species (e.g., *Asterionella*, or *Cyclotella*).

During initial summer stratification increased water temperature stabilizes the water column and light availability increases, while nutrient concentrations decline. Total phytoplankton biomass generally decreases as grazing pressure from zooplankton rapidly increases. By late summer high water temperatures and water column stability often favour chrysophytes and colonial green algae as observed in the fluoroprobe data in 2016, 2018 and 2019. When silica concentrations are high diatoms may replace green algae, however if silica becomes depleted dinoflagellates and cyanobacteria often dominate the late summer phytoplankton assemblage. As plankton consume available nitrogen resources to below detectable concentrations, cyanobacteria can become increasingly dominant. Cyanobacteria are capable of fixing molecular nitrogen from the atmosphere and regulating their buoyancy to take advantage of nutrients outside the photic zone. Certain species of cyanobacteria may also be recruited into the water column directly from resting stages in the sediments, drawing phosphorus directly from lake sediments rather than relying on the limited resources available in the lake water. The marked increase in cyanobacterial production in September of 2017 compared to the other three years on record may be the result of interannual climate variability, however climate data available from the North Bay meteorological station (climate id = 6085680) showed 2017 as the coldest and wettest year of the four, which does not generally support the enhanced growth of cyanobacteria. Water chemistry data on silica are not available to confirm the limiting nutrient hypothesis as a driver of increased cyanobacteria production in 2017.

4. Monitoring Recommendations

Despite a multitude of monitoring programs that have been completed in Trout Lake, data to track and assess emerging limnological issues typical of temperate freshwater lakes in Ontario is limited. For example, decreased concentrations of calcium as a long-term consequence of industrial development, smelting and acid precipitation, and increased chloride concentrations due to salting of roadways have increasingly become issues in lakes across Ontario. Long-term records of calcium concentrations are not available in the Trout Lake monitoring data and were only collected, based on the data reviewed, during the Watershed Management Study in 1986. Data from 1986 suggest calcium concentrations may be depleted in Four Mile Bay and may warrant ongoing monitoring to assess the risk to aquatic organisms that are sensitive to calcium decline. Likewise, despite increased chloride concentrations between 1977 and 1986 discussed in the Watershed Management Study (CRA 1988); chloride has not been measured in the water quality data available since 1990.

Our assessment of water clarity in Trout Lake has demonstrated a significant decline in Delaney Bay and One Mile Bay near the City of North Bay between 2005 and 2019. Numerous potential causes may contribute to long-term changes in water quality however determining causation is difficult in the absence of recent monitoring data. Several key parameters that may inform of the changes in water clarity are not currently collected as part of routine monitoring on Trout Lake including suspended solids, dissolved organic carbon and ongoing phytoplankton monitoring.

Significant differences in total phosphorus between Four Mile Bay and the Main Basin of Trout Lake were observed. Regular monitoring of Four Mile Creek is part of the regular monitoring program on Trout Lake, however the Trout Lake Creeks monitored during the Watershed Management Study have not been sampled since 1990 according to our review. An updated assessment of the water quality of all Trout Lake creeks sampled during the last Watershed Management Study would inform the relative contributions of each sub-watershed to Trout Lake and may help focus and refine management objectives.

Lastly, dissolved oxygen and temperature measurements have been gathered from standardized locations, but the maximum depths of measurements have not been consistent between years. The variability of depth measurements limits the ability to calculate mean volume-weighted hypolimnetic dissolved oxygen concentrations and compare concentrations over time. Mean volume-weighted hypolimnetic dissolved oxygen provides a means of tracking the impacts of watershed development, lake health and Lake Trout habitat quality over time so standardized profile locations and related depths should be implemented.

5. Conclusions and Next Steps

Water quality in Trout Lake is excellent, nutrient concentrations are low and there is no evidence of changing water quality. Significant monitoring effort has been invested in the management of water quality of Trout Lake, however little evidence of a marked impact of development on the lake is apparent. Long-term phosphorus data collected from 2000 to 2019 have not shown any significant change in nutrient concentration at the eight long-term monitoring locations on the lake, suggesting that any potential impacts of recent (i.e., 20 years) development have not occurred or have not been captured by the current monitoring program. Likewise historical data analysis (1975 – 2002) from previous reporting (1977 – 1986 [CRA 1988], 1975 – 2002 [GLL 2002]) has not recorded an increase of nutrients in the lake over time.

Ice free average total phosphorus concentrations have however exceeded the municipal Minimum Water Quality Objective of 7 µg/L at individual sites and in specific years when sites are combined. Total phosphorus concentrations are variable year-to-year but it is clear that phosphorus concentrations are higher in Four Mile Bay, with annual Municipal Water Quality Objective exceedances in 2008 (8.32 µg/L), 2009 (7.69 µg/L) and 2011 (8.98 µg/L; Table 3). Mean volume weighted hypolimnetic dissolved oxygen concentrations were also different between Four Mile Bay and the Main Basin resulting in multiple concentrations lower than the municipal regulations (8 mg/L) in Four Mile Bay (1993, 1994, 2015, 2018) and only a single concentration lower than municipal regulations in the Main Basin (1994). Note however that the data which MECP used to complete these calculations were heavily interpolated.

A significant decrease in water clarity measured through Secchi Disk Depth in the most developed basin of Trout Lake (i.e., Delaney Bay) may suggest a localized impact of urban development, roads and railroads on water quality within the Bay or input of dissolved organic carbon from the catchment. Exploration of policies and practices to control sediment, erosion and runoff into the lake from urban areas may help to mitigate further reductions in water clarity within Delaney Bay.

Future project phases will include a more quantitative assessment of the impact of development on water quality through evaluation of water quality data in relation to development data at a broad scale as well as evaluation of more site-specific monitoring data associated with individual development applications (i.e., lot level or subdivision level). Subsequent stages will be focused on consultation and development of management recommendations and related reporting.

6. References

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Appendix B. Trout Lake Lakeshore Capacity Model

Lakeshore Capacity Model — Four Mile Bay

Anthropogenic Supply		
Shoreline Development Type	Number	Usage (capita years/yr)
Permanent	204	2.56
Extended Seasonal	0	1.27
Seasonal	68	0.69
Resort	0	1.18
Trailer Parks	0	0.69
Youth Camps	0	0.125
Campgrounds/Tent trailers/RV parks	0	0.37
Vacant Lots of Record	39	1.27
Retention by soil (Rs) (0-1)	0.86	
Catchment		
Lake Area (Ao)	324.7	ha
Catchment Area (Ad)	4289.0	ha
Wetland	4.8	%
Cleared	2.7	%
Hydrological Flow		
Mean annual runoff	0.501	m/yr
Lake outflow discharge (Q)	24890821	m3/yr
Areal water loading rate (qs)	7.67	m/yr
Inflow 1	1776184	m3/yr
Inflow 2		m3/yr
Inflow 3		m3/yr
Natural Loading		
Atmospheric Load	54.22	kg/yr
Runoff Load	260.80	kg/yr
Upstream Loading		
Background Upstream Load 1	7.42	kg/yr
Background Upstream Load 2		kg/yr
Background Upstream Load 3		kg/yr
Current Total Upstream Load 1	10.70	kg/yr
Current Total Upstream Load 2		kg/yr
Current Total Upstream Load 3		kg/yr
Future Upstream Load 1	11.19	kg/yr
Future Upstream Load 2		kg/yr
Future Upstream Load 3		kg/yr
Anthropogenic Loading		
Current Anthropogenic Load	63.47	kg/yr
Future Anthropogenic Load	69.61	kg/yr
Areal Load Rate		
Current Total Areal Loading Rate (L_T)	119.88	mg/m2/yr
Future Total Areal Loading Rate (L_{FT})	121.92	mg/m2/yr

Sedimentation		
Is the lake anoxic?	n	
Settling velocity (v)	12.4	m/yr
In lake retention (Rp)	0.62	
Monitoring Data		
Average Measured TPso	5.63	µg/L
Measured vs. Predicted TPso	11.0	%
Is the model applicable?	y	
Over or under predicted?	over	
Modeling Results		
TPlake	6.25	µg/L
TPout	5.97	µg/L
TPso	6.86	µg/L
TPfuture	6.36	µg/L
Phosphorus Thresholds		
TPbk	5.18	µg/L
TPbk+40	7.25	µg/L
TPbk+50	7.77	µg/L
TPbk+60	8.28	µg/L

*if TPbk+40% < TPlake < TPbk+60% cell is orange
*if TPlake > TPbk+60% cell is red

Loads		
Natural Load w/no developmer	322.44	kg/yr
Background + 50% Load	483.66	kg/yr
Current Load	389.19	kg/yr
Future Load	395.82	kg/yr
Outflow Loads		
Background Outflow Load	123.19	kg/yr
Current Outflow Load	148.69	kg/yr
Future Outflow Load	151.23	kg/yr

Lakeshore Capacity Model — Trout Lake

Anthropogenic Supply

Shoreline Development Type	Number	Usage (capita years/yr)
Permanent	772	2.56
Extended Seasonal	0	1.27
Seasonal	110	0.69
Resort	0	1.18
Trailer Parks	0	0.69
Youth Camps	0	0.125
Campgrounds/Tent trailers/RV parks	0	0.37
Vacant Lots of Record	151	1.27
Retention by soil (Rs) (0-1)	0.86	

Catchment

Lake Area (Ao)	1562.3	ha
Catchment Area (Ad)	5912.4	ha
Wetland	11.0	%
Cleared	7.1	%

Hydrological Flow

Mean annual runoff	0.481	m/yr
Lake outflow discharge (Q)	60843839	m3/yr
Areal water loading rate (qs)	3.89	m/yr
Inflow 1	24890821	m3/yr
Inflow 2		m3/yr
Inflow 3		m3/yr

Natural Loading

Atmospheric Load	260.90	kg/yr
Runoff Load	530.97	kg/yr

Upstream Loading

Background Upstream Load 1	123.19	kg/yr
Background Upstream Load 2		kg/yr
Background Upstream Load 3		kg/yr
Current Total Upstream Load 1	148.69	kg/yr
Current Total Upstream Load 2		kg/yr
Current Total Upstream Load 3		kg/yr
Future Upstream Load 1	151.23	kg/yr
Future Upstream Load 2		kg/yr
Future Upstream Load 3		kg/yr

Anthropogenic Loading

Current Anthropogenic Load	237.71	kg/yr
Future Anthropogenic Load	248.66	kg/yr

Areal Load Rate

Current Total Areal Loading Rate (L_T)	75.42	mg/m2/yr
Future Total Areal Loading Rate (L_{FT})	76.28	mg/m2/yr

Sedimentation

Is the lake anoxic?	n	
Settling velocity (v)	12.4	m/yr
In lake retention (Rp)	0.76	

Monitoring Data

Average Measured TPso	4.57	µg/L
Measured vs. Predicted TPso	5.9	%
Is the model applicable?	y	
Over or under predicted?	over	

Modeling Results

TPlake	4.84	µg/L
TPout	4.63	µg/L
TPso	5.45	µg/L
TPfuture	4.90	µg/L

Phosphorus Thresholds

TPbk	3.76	µg/L
TPbk+40	5.26	µg/L
TPbk+50	5.64	µg/L
TPbk+60	6.02	µg/L

*if TPbk+40% < TPlake < TPbk+60% cell is orange
*if TPlake > TPbk+60% cell is red

Loads

Natural Load w/no developmer	915.06	kg/yr
Background + 50% Load	1372.59	kg/yr
Current Load	1178.26	kg/yr
Future Load	1191.76	kg/yr

Outflow Loads

Background Outflow Load	218.71	kg/yr
Current Outflow Load	281.62	kg/yr
Future Outflow Load	284.85	kg/yr