Southeastern Lake Huron Tributary Water Quality Synthesis

(October 2012 to May 2014)

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Executive Summary

Nutrient, sediment, and bacterial impacts have increasingly limited both the human uses and the ecological integrity of the near-shore waters of the Great Lakes. A multi-stakeholder program known as the Healthy Lake Huron – Clean Waters, Clean Beaches Initiative is coordinating efforts to ensure that beaches and near-shore areas along the southeast shore have improved water quality. Currently the stakeholders are working locally to support the implementation of watershed management plans through rural best management practices (BMPs) in five key watersheds. As improved water quality is a goal of the Healthy Lake Huron Initiative, this study has provided baseline synthesis for water quality information from May 2012 to October 2014.

Typically concentrations of nutrients (nitrate-N, total phosphorus and phosphate-P) in the five sentinel watersheds exceeded standards established to prevent eutrophication, even under low flow conditions. Lower nutrient and suspended solid concentrations and loads were noted in Trick's Creek. The physiography in Trick's Creek provides for greater groundwater discharge, higher low flows and land that might be left in forest and wetland because of its limited suitability for agricultural development. This landscape may make for a watershed that is less susceptible to runoff, with improved water quality conditions as a result.

Further efforts to use water quality data to gauge subtle land management changes being implemented across these watersheds require the ongoing collection of water quantity and quality data. To explain these data, climate and land use and land management data are also required. To meet shorter-term objectives, ecosystem models such as the Rural Stormwater Management Model should be employed.

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Project Background

The near-shore area of the Great Lakes provides many residents of Ontario with drinking water and recreational opportunities. However, nutrient, sediment, and bacterial impacts have increasingly limited both the human uses and the ecological integrity of these near-shore waters (Smith et al. 2015). For example, in 1977, algae were observed as a thin coating at relatively few beaches along the south-east shore of Lake Huron. By 2007, almost all rocky portions of the lake-bed at these same sites were covered by algae (Barton et al. 2013). Large and localized accumulations of algae have been washing up on shore and causing odor problems from decaying algal mats.

The Great Lakes Water Quality Agreement (GLWQA, 2012) Lakewide Annex states that Canada and the United States will assemble, assess and report on existing scientific information concerning the state of the waters of each Great Lake including current and future potential threats to water quality. Further, the Canada-Ontario Agreement Respecting the Great Lakes commits agencies to improve the knowledge and understanding of nutrient concentrations and loadings in Great Lakes tributary discharges.

A multi-stakeholder program known as the Healthy Lake Huron – Clean Waters, Clean Beaches Initiative is coordinating efforts to ensure that beaches and near-shore areas along the southeast shore are safe and clean. Currently, partners are focusing on and coordinating actions that are aimed at lowering the amount of phosphorus entering Lake Huron in five key watersheds (site names are in parentheses) (Figure 1):

- Pine River sub-watershed (South Pine River)
- North Shore sub-watershed (Garvey Creek/Glenn Drain)
- North Bayfield sub-watershed (Gully Creek)
- Main Bayfield watershed (Trick's Creek)
- Lambton Shores tributaries in Lambton County (Shashawandah Creek)

Report Objectives

The intent of this report is to:

1) assemble water quality data (total suspended solids, total phosphorus, phosphate-phosphorus, and nitrate-nitrogen concentrations) from a permanent monitoring station in each of the five priority or sentinel watersheds for the period of September 2012 to May 2014;
2) synthesize water quality data to determine the concentrations and loadings of pollutants during low flow and rain, rain-on-snow, and snow melt only event conditions;
3) document methodologies for determining low flow and event concentrations and loads; and
4) identify monitoring and data integration and assessment gaps for ongoing evaluation.

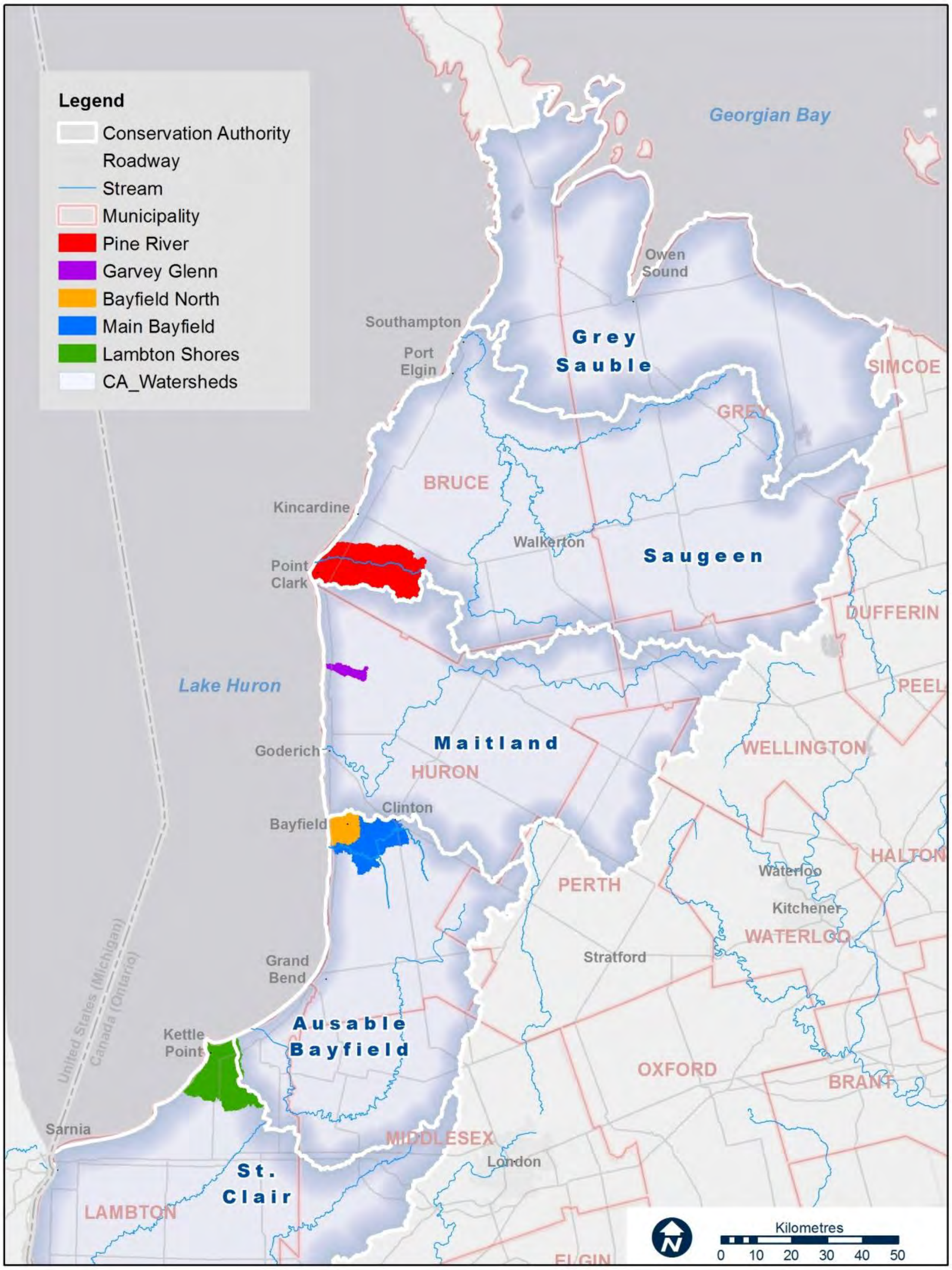

Figure 1: Location of the five watersheds in the Healthy Lake Huron – Clean Waters, Clean Beaches Initiative.

Methods

Site Selection

The five Lake Huron watersheds are small and mostly drain agricultural landscapes (Table 1). A more complete description of the watersheds is found in other reports (Emmons & Olivier Resources, Inc. et al. 2014, Van Zwol et al. 2012, Schnaithmann et al. 2013, Brock et al. 2010, King et al. 2014, LaPorte et al. 2012). Water quality monitoring stations were selected to be as far downstream as possible in the watershed, but remaining outside of the lake-effect zone. Stations were co-located with reliable flow gauging stations so that water quality results could be combined with stream discharge measurements for the computation of loads (see Appendix A for maps of the study watersheds and sites).

Table 1: Watershed size and land use (based on 2013 cropping year) upstream of sampling location in each study sub-watershed.

Sub-watershed	Size (ha)	Corn (%)	Soya Beans (%)[A]	Winter Wheat (%)	Other Crops (%)[B]	Hay/Pasture (%)	Natural/Roughland (%)[C]	Other (%)[D]
South Pine River, above Ripley gauge	2788.4	24.1	23.3	13.5	11.6	10.5	14.0	3.0
Garvey Glenn, at Kerry's Line gauge	1286.1	28.0	39.3	10.7	4.7	2.2	11.4	3.7
Gully Creek, at Porter's Hill Line	1140.4	20.7	31.4	19.0	0.0	3.7	20.7	4.4
Main Bayfield , at Trick's Creek gauge (Bayfield Road)	2115.5	24.4	21.5	9.5	0.8	7.9	16.9	19.1
Shashawandah Creek, above Kinnard Road	2681.4	20.2	31.5	18.9	8.6	4.9	11.9	4.0

[A] Included soya and edible beans

[B] Included agricultural fields where the crop type was listed as unknown or was another crop including spring cereals, canola, and vegetables.

[C] Included riparian corridors, ditches, scrub land, woodlands and wetlands.

[D] Included urban, roads, pits, farmsteads, farm access roads, ponds.

Water Quantity

Water level (also referred to as water stage) data were collected every five (5) minutes at each stream gauge. A WaterLOG H-3553 Compact Combo Bubbler System was used to measure water stage a 12V Gel Cell battery and solar panel were the source of power, and a FTS Axiom H2 Datalogger logged and transmitted data with a GOES antenna. This continuous record of stage was translated to river discharge by applying a stage-discharge relationship (also called a rating curve). A stage-discharge relationship was developed for each stream gauge by measuring the flow of the stream with a flow meter (Marsh-McBirney Flo-Mate™ Model 2000). For each measurement of discharge there is a corresponding measurement of stage. It was particularly important to manually measure high and low stages and flows because these measurements are important for the development of the rating curve. It may be difficult to get manual measurements in streams when they are in peak-flow conditions. In this current study we did not sample extremely high flows due to safety reasons. We used a theoretical equation related to the shape, size, slope, and roughness of the channel at the stream gauge to iteratively determine the stage/discharge relationship. This relationship is different for every stream gauge and can also change overtime at the specific location. See Skinner et al. 2015 for more detail.

Water Quality

Many water quality programs involve a random sampling strategy, whereby samples are collected on pre-determined days of the month. However, rain, rain on snow, and snowmelt event (herein referred to as event sampling) is important because high concentrations of some pollutants particularly sediment and phosphorus are transported during events (Upsdell et al. 2013. The monitoring and modelling results in the Watershed Based Best Management Practices Evaluation study found that intermittent channels that form across the land contribute to poor water quality during storm events (Simmons et al. 2013). Further, practices to address rural water quality nutrient enrichment issues are undertaken to reduce the formation and/or the effects of these intermittent channels on the landscape. To understand the effectiveness of watershed plans and rural best management practices (BMPs) on water quality, it is imperative to collect *event data* prior to and after the establishment of the BMPs. A water sampling program that reflects the times when water is running across the landscape must be used to obtain accurate estimates of pollutant loads that will be needed to evaluate the effectiveness of watershed plan related actions.

For this report, we have provided a summary of both the concentrations at low and high flows and the loads. Dickinson (in Upsdell-Wright et al. 2015) suggests that, if the focus of the study is on concentration targets or standards, then concentration values are needed. However, if the focus of the study is on land use management or Great Lakes impacts, then load estimates are needed. Past water quality reports completed by the Ausable Bayfield Conservation Authority have reported findings as concentrations (see http://www.abca.on.ca/publications.php for past reports). However, calculating loads is important for comparing the contributions that are made from the different watersheds to Lake Huron.

For the purposes of this study, water samples were collected year-round. Richards (1998) has shown that the 80th percentile of flow is an appropriate division for separating runoff events from low flow periods for Lake Erie tributaries in Northwest Ohio. This report used the same approach. Mean daily flow data from October 2012 to May 2014 were used to establish the low flow conditions. A threshold was set at the 80th percentile of the mean daily flow for each of the sites to separate low flow from event flow. Low-flow grab samples were collected monthly between October 1, 2012, and May 31, 2014. High-flow events were sampled with an ISCO® 6712 automated sampler at five sites (South Pine, Garvey Glenn, Gully, Trick's and Shashawandah). The ISCO® samplers were set to trigger with a rise in water level and to collect samples throughout the hydrograph, attempting to capture samples at the onset of the event, mid-way up the rising limb of the hydrograph, at the peak, mid-way down the falling limb and at the end of the event.

Water samples were primarily analyzed for nutrients and suspended solids by the Ministry of the Environment and Climate Change (MOECC) laboratory in Etobicoke; however, on occasion, samples were submitted for analysis to ALS Laboratory in Waterloo. There are different analytical approaches to estimating the bioavailable forms of P. In this study, phosphate-P was measured.

Approximately 938 tributary water quality samples were collected between October 1, 2012, and May 31, 2014.

A more detailed account of the field methods for monitoring water quality is provided in Skinner et al. 2015.

Load Computations

Water quality indicator concentrations (total phosphorus, phosphate-phosphorus, nitrate-nitrogen, and total suspended solids) from the ISCO samples collected during each event were converted to loads (mass per time), flow weighted mean concentrations (FWMC) (mass per volume) and export coefficients (mass per watershed area). These computations help to remove the variability associated with event discharge and watershed size.

Mass load (mass per time, Equation 1) is a calculation of the total mass of a substance, usually expressed in kilograms, that is transported past a particular point on a stream or river over a given time period, often annually (Cooke 2000). In this report, loads were calculated for different events. Loads are the product of stream flow (volume per time) and concentration (mass per volume). Continuous records of both stream flow and concentrations are needed to calculate loads. Typically, water quality is not monitored continuously and load-estimation methods are used to calculate loads. Generally, there are three types of load-estimation methods: averaging, ratio and regression (Richards 1998). An averaging method was best suited to calculate event loads for this report.

Equation 1

Mass Load (kg) = $\sum c_i q_i t_i$

Where

i = 1 to *n* (number of samples)

c_i = sample concentration (mg/L)

q_i = instantaneous stream flow (L/sec)

t_i = time interval (seconds)

In a flow-proportionate sampling program, an individual water sample does not characterize the event. To estimate the average concentration, each sample must be weighted to represent a particular portion of the hydrograph (Equation 2) (Cooke 2000). FWMC are concentrations that are adjusted for stream flow over a given period – in this study, the length of the event. This computation allows for comparisons between streams with different flows or the same stream at different times.

Equation 2

$$\text{Flow-Weighted Mean Concentration (kg/L)} = \frac{\text{Mass Load (kg)}}{\text{Total Stream Flow Volume (L)}}$$

The total mass export coefficient or unit area load (Equation 3) is an estimate of the amount of the constituent that is lost per hectare of watershed for the given time period, such as the event.

Equation 3

$$\text{Mass Export (kg/ha or kg/km}^2\text{)} = \frac{\text{Mass Load (kg)}}{\text{Watershed Area (ha or km}^2\text{)}}$$

Data Analysis

Event load, FWMC for events, mass export for events and low-flow concentrations were calculated for the water quality indicators: total phosphorus (TP), phosphate-phosphorus (phosphate-P), nitrate-nitrogen (nitrate-N), and total suspended solids (TSS). A median value was calculated from the FWMC from each event. By contrast, a median value was calculated from each grab sample for low flows. The average and median are both measures of central tendency and can be the same or nearly the same. However, if there are a few extreme values, the average can be significantly influenced by the few values, making it not very representative of the majority of the values in the data set. Under these circumstances, typical of water quality data, the median value gives a better representation of central tendency than the average value.

Concentrations of TP and nitrate-N were compared with concentrations that are considered to minimize eutrophication: the Provincial Water Quality Objective for TP (0.03 milligrams per litre; MOEE 1994) and a concentration identified by the Canadian Council of Ministers of the Environment for nitrate-N (0.9 milligrams per litre; CCME 2012). For each water quality indicator, a non-parametric Kruskal-Wallis test was applied to determine if significant differences could be observed between the watersheds in concentrations under low-flow and high-flow conditions and in event mass loads and export coefficients. A post-hoc Dunn's test was used for pairwise comparisons of the watershed concentrations and loads.

Loadings are typically calculated annually and based on a water year (October 1 to September 30). The United States Geological Survey uses a water year with an October 1 start date, as it is the time of year least likely to have major storm events on either side of that date. Use of this date is thought to avoid inflating or reducing the overall load for that year due to variations in major discharge events. For the purposes of the current study, to better understand baseline water quality conditions in the five watersheds along the southeast shore of Lake Huron, we calculated loads and flow-weighted mean concentrations for most events from the period between October 1, 2012, and May 31, 2014. Loadings are typically calculated annually and "standards" for annual loads for TP are currently being developed for different watersheds in the Great Lakes. Annual load calculations for each watershed have not been completed for this report. Instead, event loads were calculated.

Results and Discussion

In this 15-month period, most of the watersheds had nearly 30 events (Table 2). Shashawandah Creek had 35 events. Due to incomplete data collection, only 14 events were documented in the South Pine River. Not all events were sampled. Some events were missed due to decisions made *a priori* about the size of the event, equipment malfunctions, and staffing issues (*i.e.,* holidays and other work priorities). These considerations might be more of an issue in organizations with limited capacity. In the future, we will need to ensure that we have a good range of events sampled at all watersheds.

Table 2: Storm events in Healthy Lake Huron priority watersheds (October 2012 to May 2014).

Watershed	Number of storm events	Events sampled	Low-flow samples
South Pine River, above Ripley gauge	14*	6	5
Garvey Glenn, above Kerry's Line gauge	26	13	18
Gully Creek, at Porter's Hill Line	28	19	35
Main Bayfield , at Trick's Creek gauge	27	17	21
Shashawandah Creek, above Kinnard Road	35	10	12

* incomplete flow record

Nitrate-Nitrogen

The fate of nitrogen in natural systems is complex, as it is utilized by all plants and is subject to many biological processes that can bind and transform nitrogen. Nitrogen occurs naturally in rocks and groundwater. Nitrogen is an element that stimulates plant (and algal) growth. The forms of nitrogen found in water include nitrite (NO_2) and nitrate (NO_3). Nitrate is the primary source of nitrogen for aquatic plants. All forms of inorganic nitrogen (nitrite and ammonia) have the potential to undergo nitrification to nitrate. Nitrite is unstable in aerated water and is generally considered to be an indicator of pollution through improper disposal of sewage or organic waste. Nitrates are highly soluble and can move into shallow groundwater systems. Manure and fertilizer application are thought to contribute nitrates to watercourses in agricultural areas. Laboratories typically report nitrate-N and nitrite-N together, however the nitrite-N component is usually relatively small compared to the nitrate-N component.

The water quality guideline for nitrate, established by the Canadian Council of Ministers of the Environment (CCME), for the protection of aquatic ecosystems is at 2.93 mg/L of nitrate-N. Above this level, nitrate can be toxic to fish and amphibian eggs. In rural areas, potential sources of nitrogen are agricultural and lawn fertilizer, manure, septic systems, sewage treatment effluent and atmospheric deposition. Nitrate is soluble in water and therefore can easily be transported in water in overland runoff or into streams via diverted infiltrating water from tile drainage or aquifers.

In the five watersheds, all measurements of nitrate-N concentrations exceeded concentrations that might minimize eutrophication (0.9 milligrams per litre; Canadian Council of Ministers of the Environment 2012) (Figure 2). Median concentrations of nitrate-N at low and high flows in all watersheds also exceeded the concentration established for the protection of aquatic life from direct toxic effects (2.93 milligrams per litre; Canadian Council of Ministers of the Environment 2012) (Table 3). In past analysis of Lake Huron tributaries, Upsdell et al. 2013 found nitrate-N concentrations were not different during events compared to low-flow periods. Likewise, for most of the watersheds in this study there was no difference in nitrate-N concentrations between low-flow and high-flow conditions. However, in this study, concentrations of nitrate-N in Shashawandah Creek were higher ($p = 0.015$) under high-flow compared to low-flow conditions and may need further investigation. Concentrations of nitrate-N in high-flow conditions were higher in Shashawandah compared to Trick's Creek (Table 4). The load and export coefficients of nitrate-N during events were not different across the watersheds (Table 5 and Figure 2).

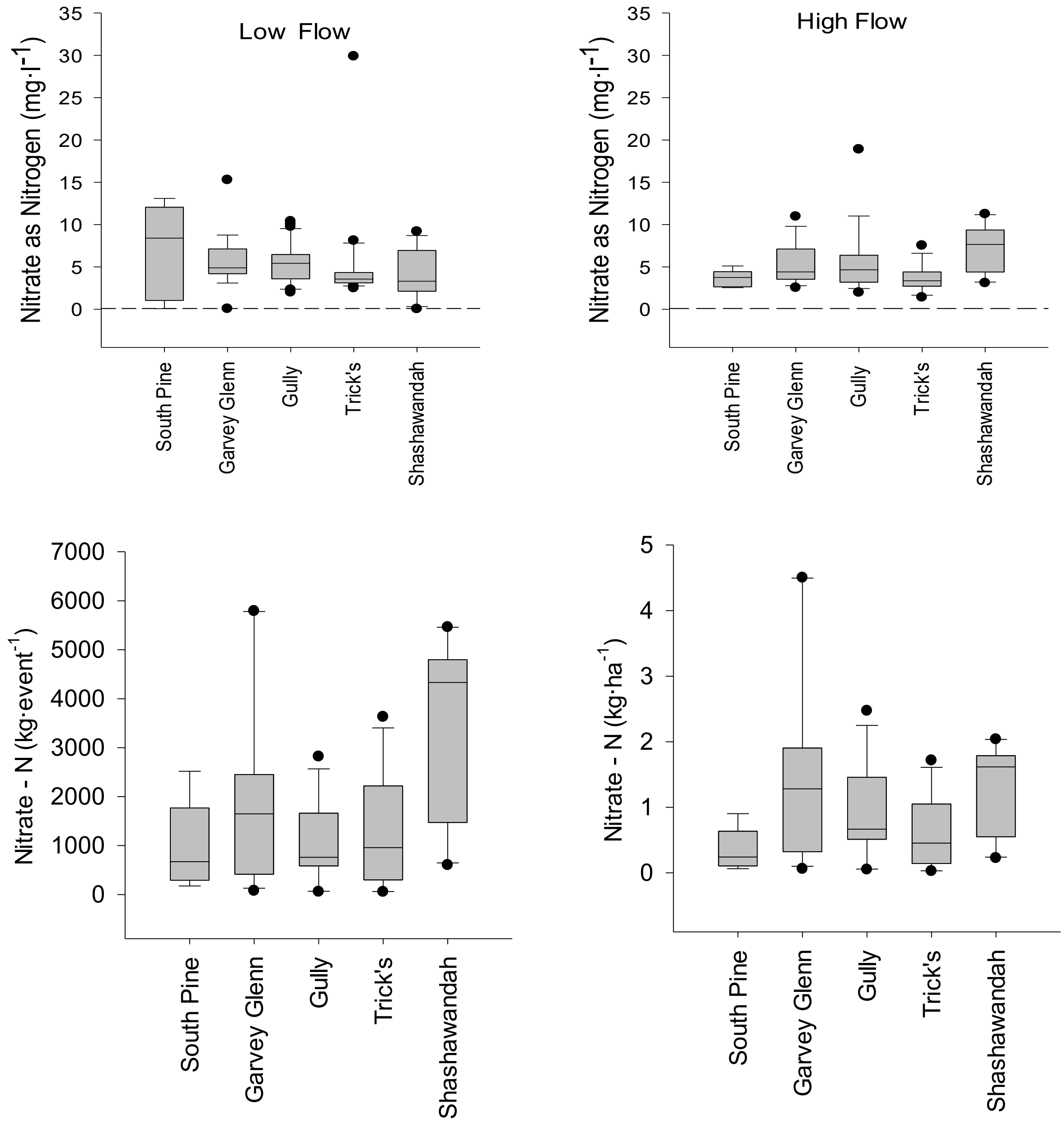

Figure 2: Median nitrate concentrations under low-flow and high-flow conditions (upper panel) and total load and mass export coefficients (lower panel) at five Lake Huron watershed outlets between 2012 and 2014. Dashed gray lines indicate concentrations considered to minimize eutrophication. (Box plot graphs show outliers (·), the 10^{th} and 90^{th} percentiles as horizontal bars, the 25^{th} and 75^{th} percentiles as the bottom and top of the box, and the median as a horizontal line within the box.)

Table 3: Median low-flow and high-flow concentrations ((mg·l^{-1}) in the five Healthy Lake Huron watersheds (October 2012 to May 2014).

Watershed	Nitrate-Nitrogen (mg·l^{-1})		Phosphate-Phosphorus (mg·l^{-1})		Total Phosphorus (mg·l^{-1})		Total Suspended Solids (mg·l^{-1})	
	low flow (*n*)	high flow (*n*)	low flow (*n*)	high flow (*n*)	low flow (*n*)	high flow (*n*)	low flow(*n*)	high flow(*n*)
South Pine	8.4 (5)	3.8 (5)	0.007 (5)	0.092 (6)	0.037 (5)	0.401 (6)	4 (5)	334 (6)
Garvey Glenn	4.9 (18)	4.4 (13)	0.028 (15)	0.077 (12)	0.046 (18)	0.196 (13)	7 (18)	29 (13)
Gully	5.4 (35)	4.7 (19)	0.019 (34)	0.093 (19)	0.021 (35)	0.289 (19)	4 (33)	214 (18)
Trick's	3.6 (20)	3.4 (17)	0.005 (20)	0.024 (17)	0.009 (20)	0.087 (17)	3 (20)	48 (17)
Shashawandah	3.3 (12)	7.7 (10)	0.018 (11)	0.165 (10)	0.037 (12)	0.30 (10)	8 (12)	83 (9)

Table 4: Summary of results from Dunn's pairwise comparisons of watershed conditions (low-flow and high-flow concentrations, total load per event and mass export coefficient) for nitrate-nitrogen, phosphate-phosphorus, total phosphorus and total suspended solids.

Water quality indicator	Low-flow concentrations	High-flow concentrations	Total load per event	Mass export coefficient
Nitrate-nitrogen	No differences	Trick's < Shashawandah (p =0.007)	Trick's < Shashawandah (p =0.027)	No differences
Phosphate-phosphorus	Trick's < Garvey Glenn (p <0.001) Trick's < Gully (p <0.001) Trick's < Shashawandah (p =0.001)	Trick's < South Pine (p =0.02) Trick's < Garvey Glenn (p =0.011) Trick's < Gully (p = 0.001) Trick's < Shashawandah (p < 0.001)	Trick's < Shashawandah (p < 0.007)	Trick's < Garvey Glenn (p =0.026) Trick's < Gully (p = 0.035) Trick's < Shashawandah (p =0.003)
Total Phosphorus	Trick's < Garvey Glenn (p < 0.001) Trick's < Gully (p = 0.005) Trick's < Shashawandah (p < 0.001)	Trick's < South Pine (p =0.004) Trick's < Shashawandah (p = 0.004)	Trick's < Shashawandah (p < 0.009)	No differences
Total Suspended Solid	No differences	Trick's < Gully (p = 0.034) Garvey Glenn < Gully (p = 0.012) Garvey Glenn < South Pine (p = 0.036)	No difference	Trick's < Gully (p = 0.027)

Table 5: Median loads and export coefficients for events in the five Healthy Lake Huron watersheds (October 2012 to May 2014).

Watershed	Nitrate-Nitrogen		Phosphate-Phosphorus		Total Phosphorus		Total Suspended Solids	
	Total Load (kg/event)	Export Coefficient (kg/ha)	Total Load (kg/event)	Export Coefficient (kg/ha)	Total Load (kg/event)	Export Coefficient (kg/ha)	Total Load (kg/event)	Export Coefficient (kg/ha)
South Pine	671	0.24	25	0.008	107	0.04	92 355	33
Garvey Glenn	1648	1.28	29	0.02	48	0.04	8 149	6
Gully	760	0.66	14	0.01	51	0.04	50 000	43
Trick's	960	0.45	4	0.002	21	0.009	15 456	7
Shashawandah	4332	1.62	64	0.02	127	0.05	27 925	10

Phosphorus

Phosphorus is an element which encourages plant and algae growth. Eutrophication is the process of reduced oxygen levels in an aquatic environment brought about by excessive plant growth and die-off as a result of elevated nutrients (predominantly phosphorus, but also nitrogen).

Phosphorus ions form ionic bonds with clay through a process called adsorption. Phosphorus therefore often moves attached to soil particles. For this reason, excess phosphorus is very closely associated with rainfall and runoff and is generally found in those areas that have higher clay content soils. Other potential sources of phosphorus are from agricultural and lawn fertilizer, manure, septic systems, sewage treatment effluent and milk-house wash-water. Recently, the phosphate fraction of total phosphorus has received more attention, as it has been implicated in the growth of algae in the nearshore areas of the Great Lakes (International Joint Commission 2014).

A Provincial Water Quality Objective (PWQO) of 0.03 mg/L of total phosphorus has been established to avoid nuisance algae in streams and rivers (MOEE 1994). An objective of 0.02 mg/L is used for lakes during the ice free period to avoid nuisance algae. The PWQO for phosphorus was not established to delimit toxicity, but rather to identify the indirect impacts of excessive phosphorus on aquatic ecosystems through oxygen imbalances. There has been no standard developed for phosphate.

Except in Trick's and Gully Creeks, median concentrations of TP in low-flow conditions exceeded the Provincial Water Quality Objective of 0.03 milligrams per litre to prevent the effects of eutrophication (Table 3). Except in Garvey Glenn, median concentrations of TP in high-flow conditions were approximately ten times greater than under low-flow conditions. Trick's Creek tended to have lower concentrations of TP compared to the other watersheds under low-flow and high-flow conditions (Table 4, Figure 3).

Except for Trick's Creek, streams typically had approximately 0.04 kg/ha of TP moving for each event (Table 5). Further investigation of annual loads will be important to compare loads to different areas in the Great Lakes Basin.

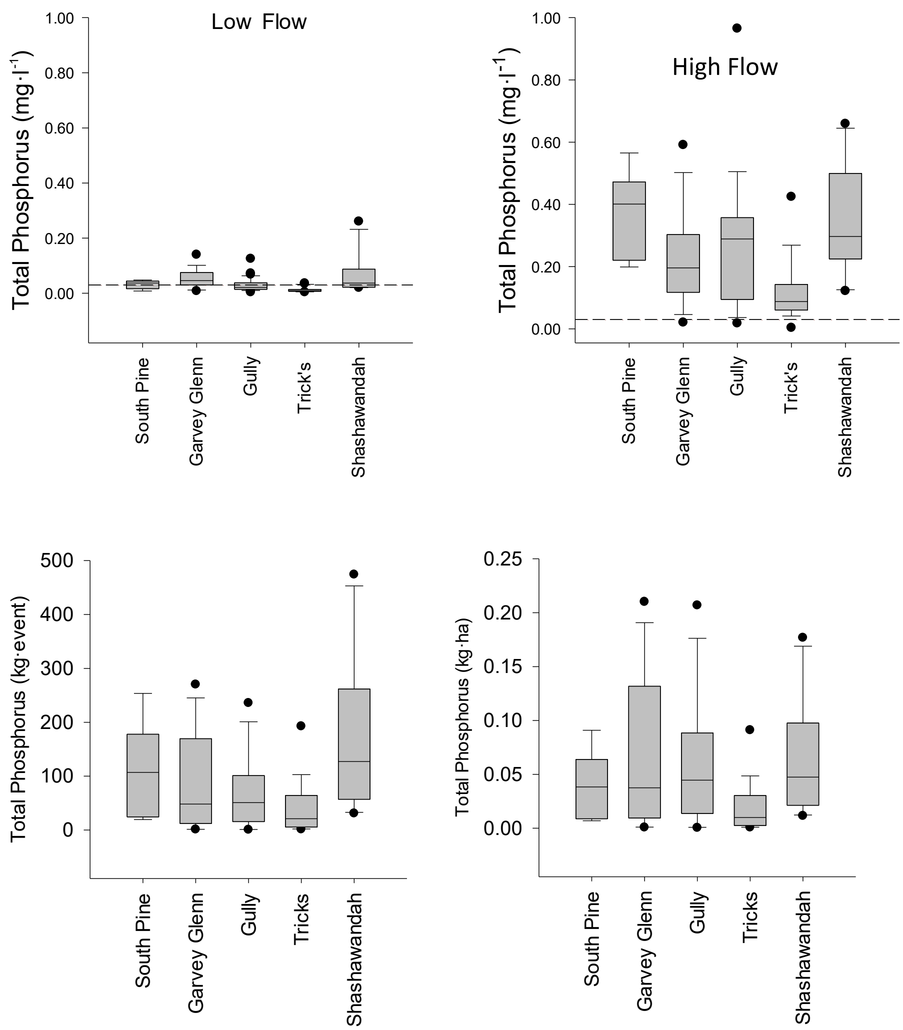

Figure 3: Median total phosphorus concentrations under low-flow and high-flow conditions (upper panel) and total load and mass export coefficients (lower panel) at five Lake Huron watershed outlets between 2012 and 2014. Dashed gray lines indicate concentrations considered to minimize eutrophication. (Box plot graphs show outliers (·), the 10th and 90th percentiles as horizontal bars, the 25th and 75th percentiles as the bottom and top of the box, and the median as a horizontal line within the box.)

Similar to the findings for TP, under low flow conditions, concentrations of phosphate-P were lower at Trick's than the other watersheds (Figure 4, Table 4). Currently there are no standards or load targets established for phosphate-P.

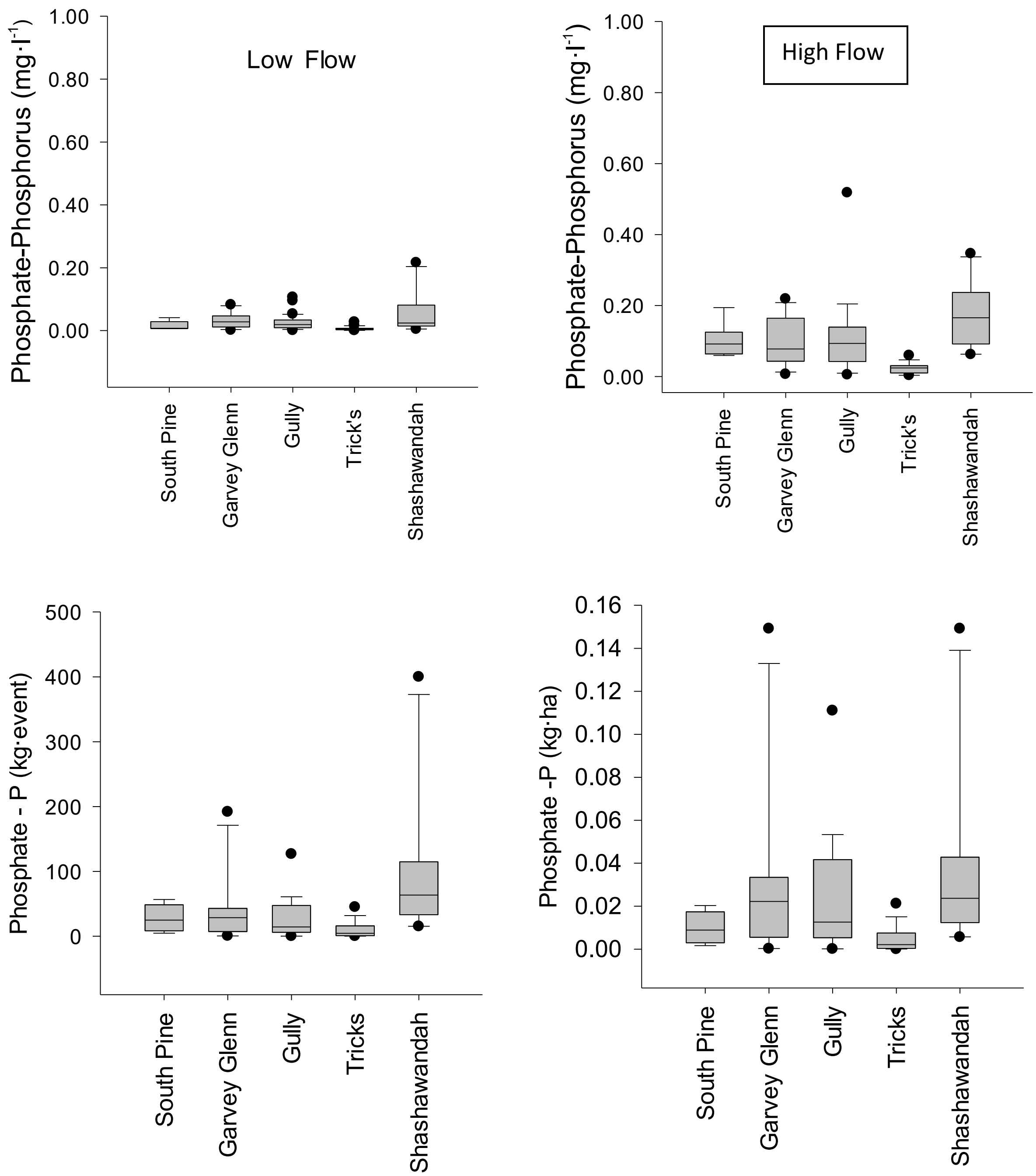

Figure 4: Median phosphate-phosphorus concentrations under low-flow and high-flow conditions (upper panel) and total load and mass export coefficients (lower panel) at five Lake Huron watershed outlets between 2012 and 2014. Dashed gray lines indicate concentrations considered to minimize eutrophication. (Box plot graphs show outliers (·), the 10th and 90th percentiles as horizontal bars, the 25th and 75th percentiles as the bottom and top of the box, and the median as a horizontal line within the box.)

Total Suspended Solids

Concentrations of TSS were low under low-flow conditions and did not vary across the watersheds. Under high-flow conditions, concentrations of TSS were considerably higher in all creeks compared to low-flow conditions. During events, the concentration of TSS in Gully Creek was higher compared to Trick's and Garvey Glenn watersheds (Table 4).

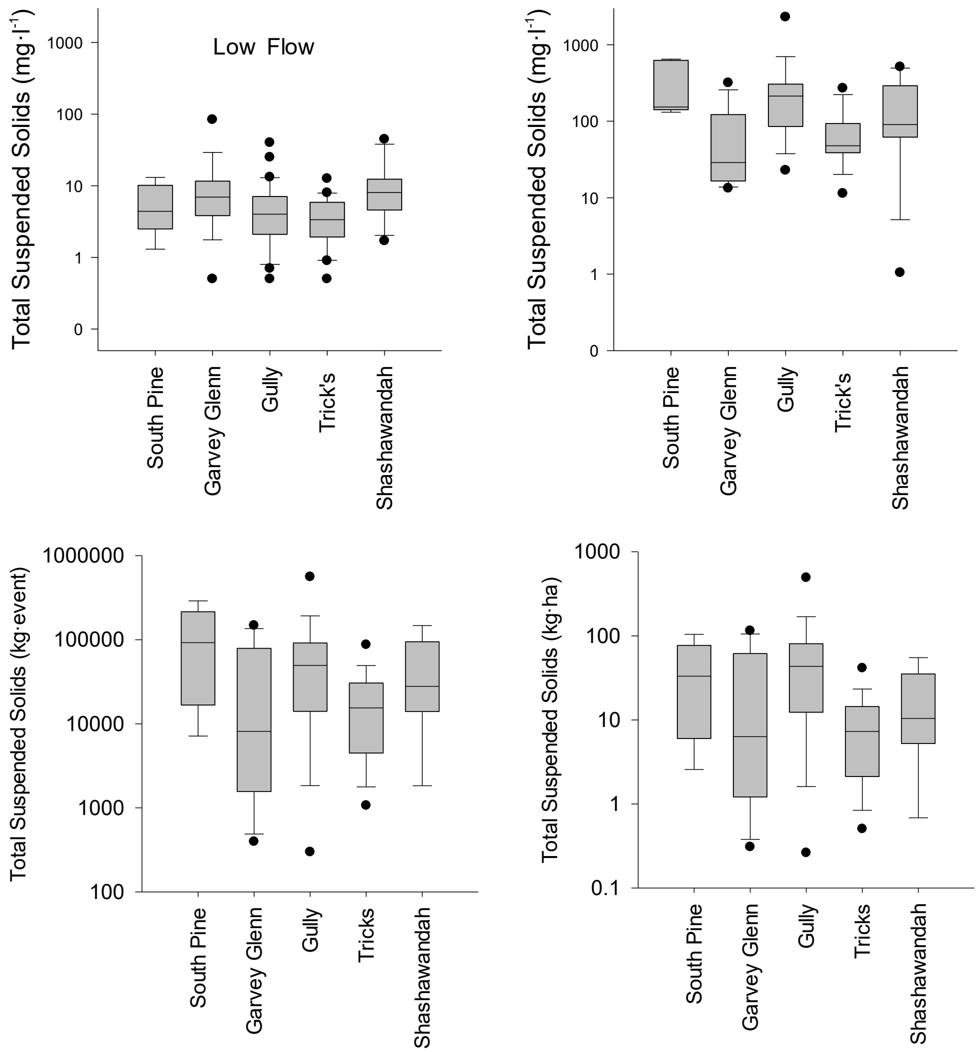

Figure 5: Median total suspended solids concentrations under low-flow and high-flow conditions (upper panel) and total load and mass export coefficients (lower panel) at five Lake Huron watershed outlets between 2012 and 2014. Dashed gray lines indicate concentrations considered to minimize eutrophication. (Box plot graphs show outliers (·), the 10th and 90th percentiles as horizontal bars, the 25th and 75th percentiles as the bottom and top of the box, and the median as a horizontal line within the box.)

With more focus on the effects of phosphorus on the Great Lakes there has been less emphasis of the loads of nitrate or TSS. In the current study, the variability within the watersheds for these constituents has overwhelmed any differences that median load values might suggest (Figures 3 and 5, Table 5).

Conclusions and Next Steps

This analysis has provided the Healthy Lake Huron Initiative with summary baseline water quality conditions (2012-14) against which to measure change over time. Typically concentrations of nutrients (nitrate-N, TP and phosphate-P) in the five Lake Huron watersheds exceeded standards established to prevent eutrophication, even under low flow conditions.

Except for Trick's Creek, the five Lake Huron watersheds have similar nutrient and suspended solid concentrations and loads. The main land use difference in the Trick's Creek watershed is the high percentage of land designated as "other". In Trick's Creek, nineteen per cent of the landscape has this classification, compared to three to four percent in the other sentinel watersheds. In the case of Trick's Creek, gravel pits are a dominant feature. The physiography that makes for aggregate extraction also provide landscapes that have groundwater discharge, higher low flows and land that might be left in forest and wetland because of its limited suitability for agricultural development. This landscape may make for a watershed that is less susceptible to runoff, with improved water quality conditions as a result.

Annual load calculations for each watershed have not been completed for this report. It is important to calculate annual load, as this seems to be the preferred parameter for comparison across watersheds. We are in the process of evaluating different methodologies for determining total load. The three types of load-estimation methods (averaging, ratio and regression) are available in different software packages. Data analysis through a software package would permit the determination of annual, seasonal, and event loads. Further analysis should involve looking at the usefulness of loads at these different time scales for evaluating watershed plans and BMPs.

In a recent workshop that reviewed various approaches to calculating load, participants were tasked with suggesting approaches to evaluating land management actions with water quality data (see Upsdell Wright et al. 2015). At this workshop, it was acknowledged that aside from the application of ecosystem models (such as SWAT or the Rural Storm Water Management Model - RSWMM), there was limited experience in Ontario of using water quality data to evaluate land management decisions.

Ecosystem modelling is an important tool and in the short-term can be used to examine the impacts of various BMP scenarios. For example, we can use the results from this report to look more closely at what is occurring during events as predicted by the RSWMM. While the calibration for the RSWMM project period looked at continuous modeling for a specific period, this study provides us with an opportunity to do calibration work on an event basis. If the calibration is successful, then the model could be used to quickly run scenarios on what impacts might be expected with different BMPs. Longterm monitoring data and more detailed input data are very important for reducing model uncertainties. This suggests more investments on watershed data collection and continuous monitoring of BMP effects, particularly field-edge monitoring (Yang et al. 203).

To use water quality monitoring data to evaluate the effectiveness of the stewardship actions in these watersheds, another suggestion from the workshop was potentially to develop relationships between flow and concentration for the different watersheds. Further analysis of the data for the individual streams is required to see what is driving the relationship between flow and concentration under different storm events.

This report did not attempt to evaluate water quality and flow in relation to climate and land management data in the different streams. Detailed information about relationships between land use, land management and best management practices (BMPs), water quality, climate and flow in each of the creeks will provide better understanding of the contributions that climate and land management have on water quality. In the long-run, understanding these relationships better will help to inform better management practices. To support these efforts, monitoring climate, flow conditions continuously and sampling water quality conditions during storm events will be necessary as BMPs and land use changes occur in the sentinel areas. We also need to document land use and land management conditions. With the collection of data, comes the responsibility of storing the data and making it accessible to the Healthy Lake Huron Initiative partners.

A couple of directions are important to address policy questions such as what percent of the sub-watershed needs no-till or berms or cover crops to get us to an acceptable load. Firstly, more dialogue amongst the water quality practitioners to collaboratively investigate how monitoring data and modelling can be better integrated to inform assessment techniques would be helpful. Even discussion around what is an acceptable load is required. A follow-up loadings workshop to see how other practitioners have used water quality data to address policy objectives would be helpful. Finally, ongoing water quality data collection (including the collection of supporting information) is required to determine how changes in the landscape and climate relate to changes in water quality.

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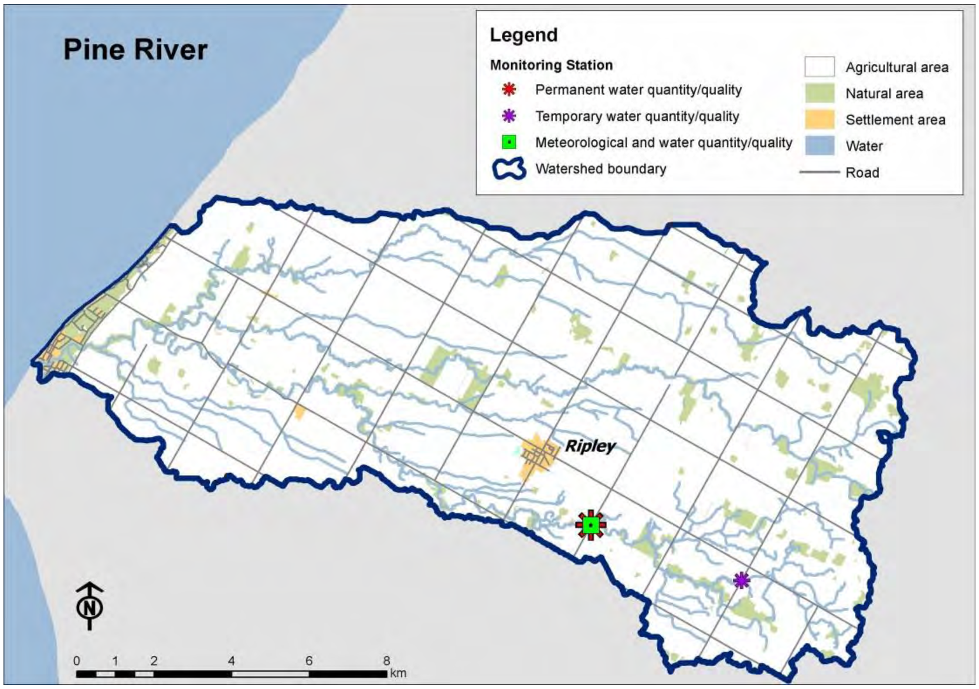
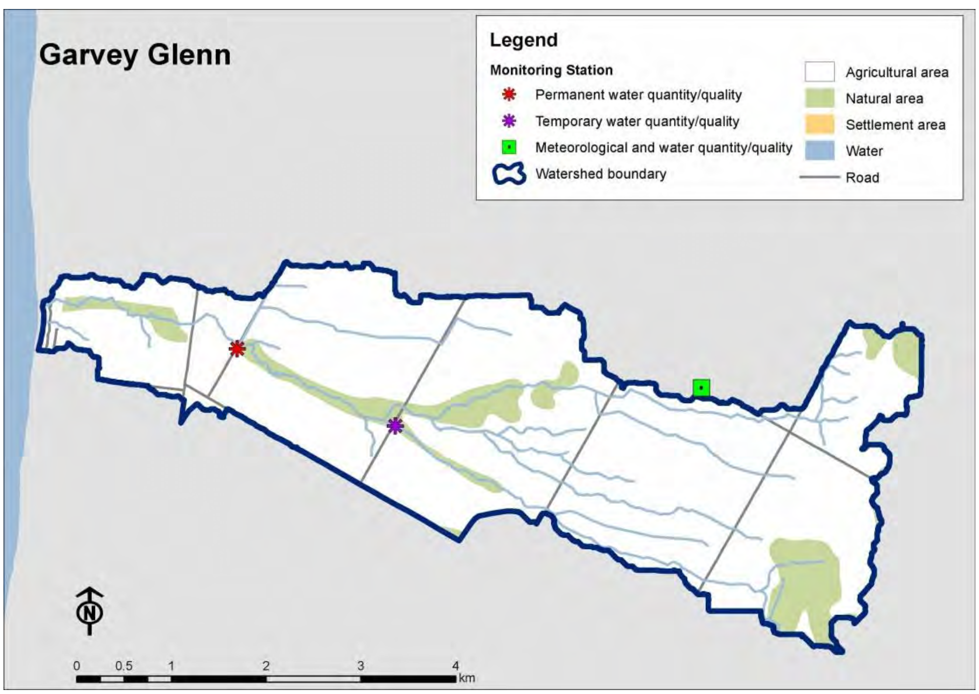
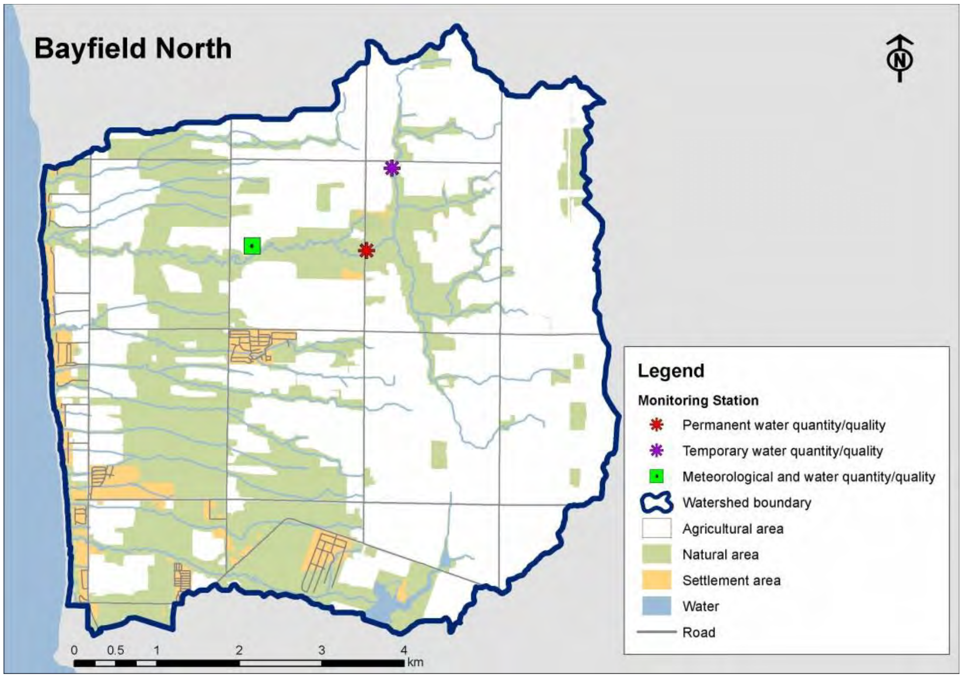
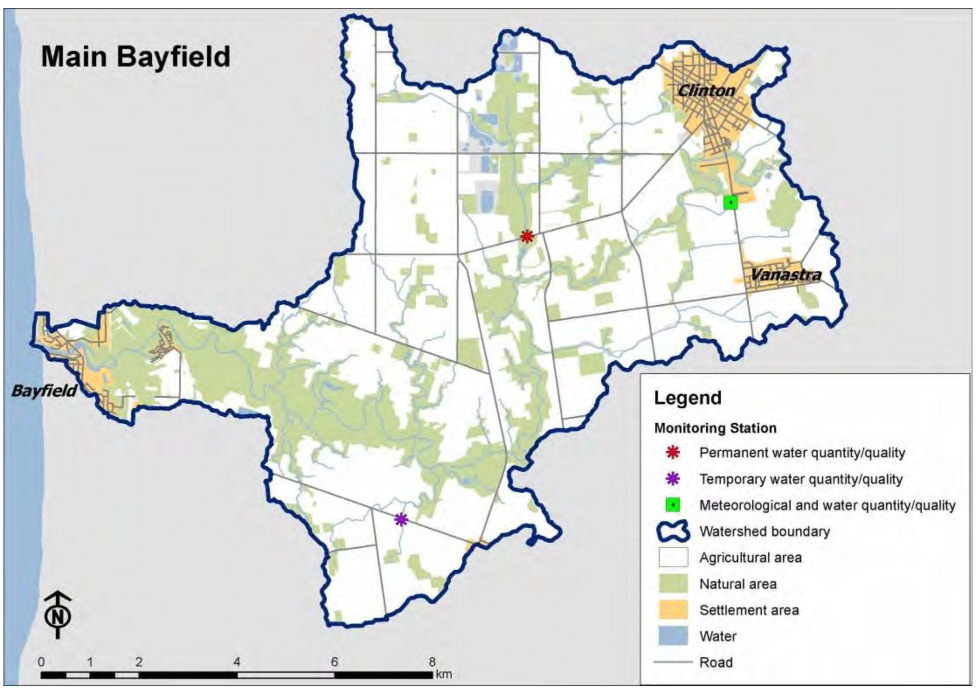
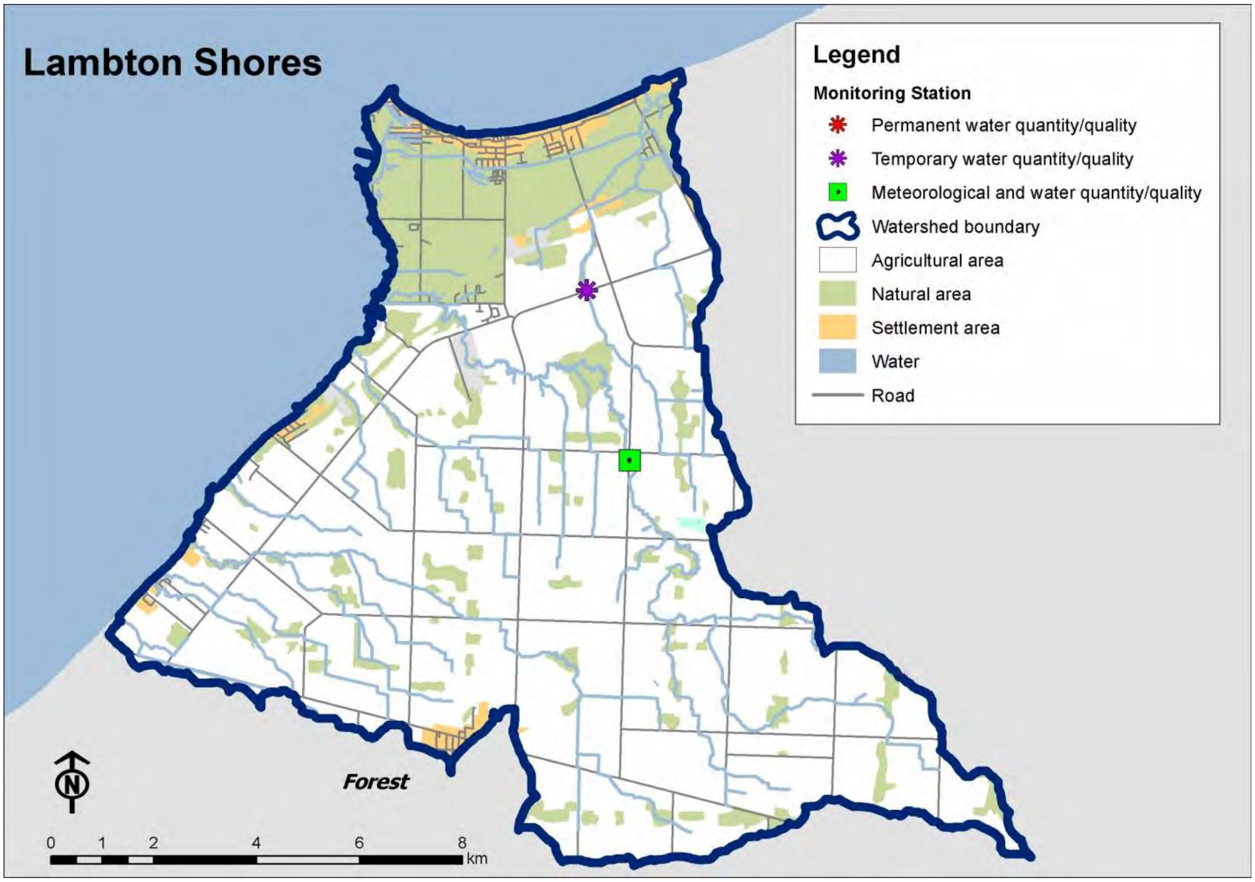
Appendix A: Water sampling sites at strategic sub-watershed locations






Bayfield North
Legend
Monitoring Station
Permanent water quantity/quality
Temporary water quantity/quality
Meteorological and water quantity/quality
Watershed boundary
Agricultural area
Natural area
Settlement area
Water
Road
0 0.5 1 2 3 4 km


Main Bayfield
Clinton
Vanastra
Bayfield
Legend
Monitoring Station
Permanent water quantity/quality
Temporary water quantity/quality
Meteorological and water quantity/quality
Watershed boundary
Agricultural area
Natural area
Settlement area
Water
Road
0 1 2 4 6 8 km


Lambton Shores
Legend
Monitoring Station
Permanent water quantity/quality
Temporary water quantity/quality
Meteorological and water quantity/quality
Watershed boundary
Agricultural area
Natural area
Settlement area
Water
Road
Forest
0 1 2 4 6 8
km