Healthy Lake Huron – Clean Water, Clean Beaches

Southeastern Lake Huron Tributary Water Quality Synthesis and Modelling (October 2010 to September 2017)

Prepared for: Environment Canada

Prepared by: Dan Bittman and Mari Veliz

March 28, 2018

Acknowledgments: Water monitoring staff at the different conservation authorities included: Jo-Anne Harbinson, Shaun Anthony, Mat Shetler, Abbie Gutteridge, Leslie Coleman, and Jessica Van Zwol. The authors would like to acknowledge the technological and technical expertise provided by Mark Lowenstine. His ongoing commitment to trouble-shooting ISCOs and other field equipment and data crunching has been invaluable. GIS expertise and field assistance has been provided by Elizabeth Hawkins. Aaron Clarke was instrumental in providing database management and support. Water quality analysis was provided by the Ministry of the Environment and Climate Change, with Pradeep Goel and Scott Abernethy ensuring that adequate laboratory allocation resources were provided. Annual water quality data assembly and synthesis of results was funded by Environment and Climate Change Canada – Great Lakes Issues Management and Reporting Section. Ongoing support has gratefully been provided through the Ontario Ministries of Agriculture, Food and Rural Affairs and Environment and Climate Change. The views expressed in this report are the views of the authors and do not necessarily reflect those of the funding support agencies.

Environnement et Changement climatique Canada

Environment and Climate Change Canada

Ontario

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. The proportion of land area represented by the priority watersheds to the total land area of all the Lake Huron tributaries is 0.4 percent. As improved water quality is a goal of the Healthy Lake Huron Initiative, this study has provided detailed synthesis for water quality information from October 2010 to September 2017.

Typically, concentrations of nutrients (nitrate-nitrogen and total phosphorus) in six Lake Huron watersheds exceeded standards established to prevent eutrophication; however, some improvement was identified during the study period. A Soil and Water Assessment Tool (SWAT) was developed for Garvey-Glenn Drain and Gully Creek which showed substantial reductions in loads of total phosphorus, total suspended solids, and nitrogen could be attributed to adoption of BMPs. Using conventional methods, a significant reduction in nutrient concentrations (nitrate-N) were observed only in Trick's Creek. However, by adjusting concentrations for streamflow variability, significant declines in nutrients could be detected in Gully Creek as well. Pollutant loads appeared to be driven largely by changes in total flow volume between years. Not surprisingly, the largest percentage of pollutant loads was transported during the spring freshet in March, while the lowest percentage of loads occurred during the dry summer months. Water samples from several small lakeshore tributaries outside of the sentinel watersheds were investigated and nutrient and sediment load information was summarized.

Accurate estimates of pollutant loads are required to evaluate trends in water quality. Numerous studies have reported that infrequent sampling and type of sampling method can yield large uncertainties in the estimation of nutrient and sediment loads. To help manage the number of samples collected without increasing uncertainty, a number of different sampling strategies were evaluated for their accuracy and precision at estimating annual loads compared to reference ('true') loads. From our analysis, collecting only one low-flow and one event-flow sample per month could drastically reduce sampling effort, without compromising load estimation accuracy, in Shashawandah Creek. A suitable sampling strategy for the remaining priority watersheds could not be determined in the current study; however, the possibility of streamlining current sampling regimes is encouraging.

Table of Contents

List of Figures

List of Tables

1.0 Project Background

The nearshore 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 nearshore waters (Smith *et al.* 2015). For example, in 1977, algae were observed as a thin coating at relatively few beaches along the southeast 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 (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 loads 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 nearshore areas along the southeast shore are safe and clean. Currently, partners are coordinating actions to implement agricultural best management practices that are aimed at lowering the amount of phosphorus entering Lake Huron in five key watersheds (Figure 1). Monitoring of water quality in the priority watersheds is being coordinated by four conservation authorities (conservation authority name is in parentheses):

- Pine River sub-watershed – South Pine River (Saugeen Valley Conservation Authority);
- North Shore sub-watershed – Garvey-Glenn Drain (Maitland Valley Conservation Authority);
- Bayfield North sub-watershed – Gully Creek (Ausable Bayfield Conservation Authority);
- Main Bayfield watershed – Trick's Creek and Bayfield River (Ausable Bayfield Conservation Authority); and
- Lambton Shores tributaries in Lambton County – Shashawandah Creek (St. Clair Region Conservation Authority).

1.1 Report Objectives and Format

This report summarizes the different approaches to evaluating water quality data collected from the priority watersheds along the southeast shore of Lake Huron. The objectives of the project were to:

1) assemble water quality data (total suspended solids, total phosphorus, phosphate-phosphorus, and nitrate-nitrogen concentrations) in each of the five priority watersheds and Bayfield River for the period October 2010 to September 2017;
2) optimize water quality sampling strategies by determining optimal trigger levels for ISCO automatic samplers based on water level (*e.g.,* 90th percentile of stage/flow);
3) calculate seasonal and annual loads for the five priority streams (2010-2017) and Bayfield River (2014-2017) to spatially and temporally compare loadings; and
4) evaluate changes in water quality over time without the influence of streamflow using flow-adjusted concentrations.

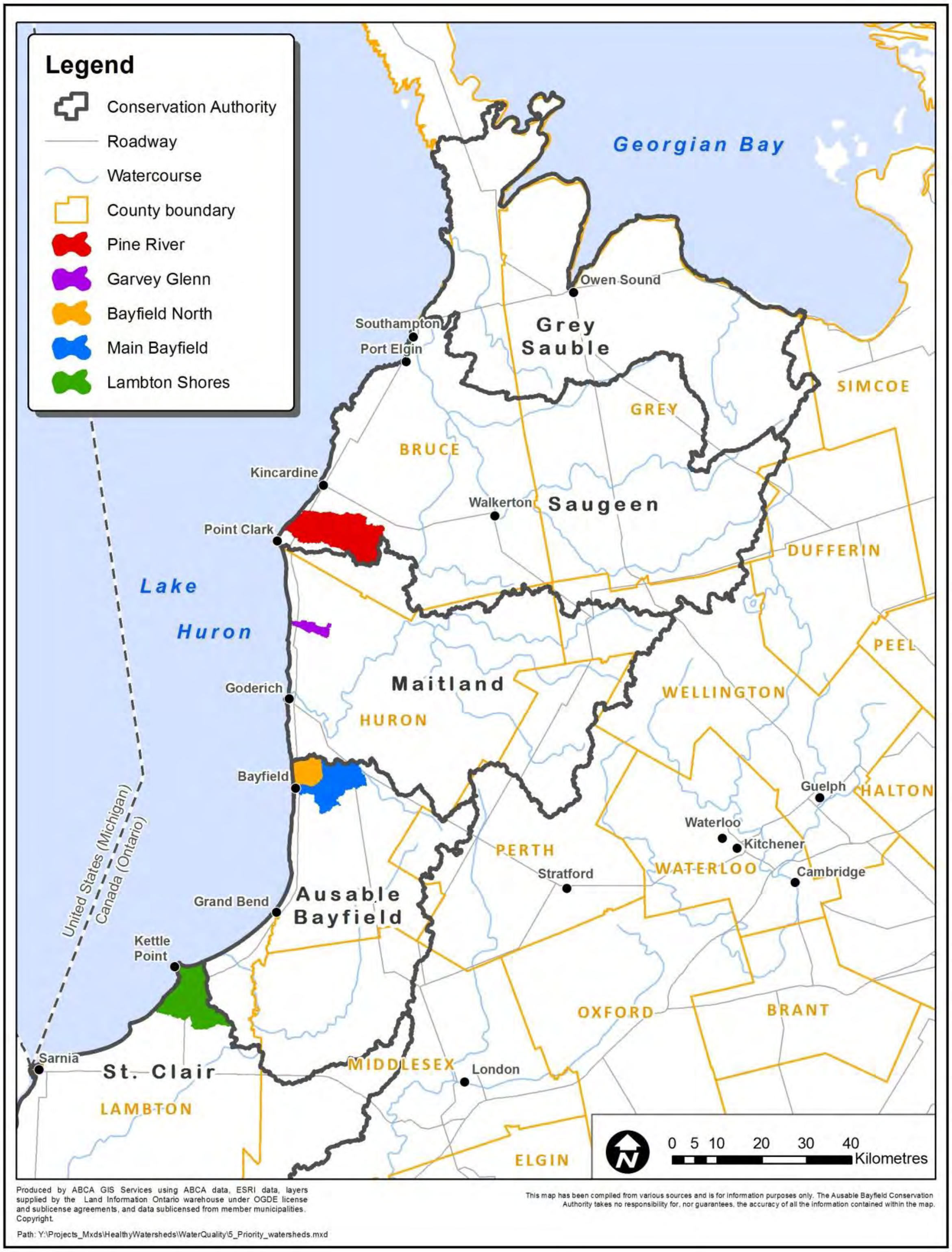

Figure 1: Location of the five priority watersheds in the Healthy Lake Huron – Clean Waters, Clean Beaches Initiative.

To address these project objectives, the remainder of the report is organized into three sections:

1) Methods;
2) Results and Discussion, including:
    a. A comparison of various load estimation sampling strategies; and
    b. An analysis of spatial and temporal patterns in water quantity and quality indicators.
3) General conclusions and next steps.

2.0 Watershed Monitoring

2.1 Site Selection

The priority Lake Huron watersheds are typically small, except for the Bayfield River watershed, and mostly drain agricultural landscapes (Table 1). A more complete description of the watersheds can be found in other reports (Emmons & Olivier Resources, Inc. *et al.* 2014, LaPorte *et al.* 2012, King *et al.* 2014, Brock *et al.* 2010, Schnaithmann *et al.* 2013, Van Zwol *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 monitoring stations).

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]
Bayfield River	46,305	-	-	-	-	-	-	-
Garvey-Glenn Drain	1,286	28.0	39.3	10.7	4.7	2.2	11.4	3.7
Gully Creek	1,040	20.7	31.4	19.0	0.0	3.7	20.7	4.4
Shashawandah Creek	2,681	20.2	31.5	18.9	8.6	4.9	11.9	4.0
South Pine River	2,788	24.1	23.3	13.5	11.6	10.5	14.0	3.0
Trick's Creek	2,116	24.4	21.5	9.5	0.8	7.9	16.9	19.1

[A] Includes soya and edible beans.
[B] Includes agricultural fields where the crop type was listed as unknown or was another crop including spring cereals, canola, and vegetables.
[C] Includes riparian corridors, ditches, scrub land, woodlands and wetlands.
[D] Includes urban land, roads, pits, farmsteads, farm access roads, and ponds.
- Data not available for this report

2.2 Field Methods

2.2.1 Water Quantity Monitoring

Water level (also referred to as water stage) data were collected every five minutes at all stream gauges except for the Varna and Pine River stream gauges, which collected data hourly and every fifteen minutes, respectively. A WaterLOG H-3553 Compact Combo Bubbler System was used to measure water stage, with a twelve-volt, 100-amp-hour valve-regulated lead acid battery and solar panel providing power, and an FTS Axiom H2 Datalogger logging and transmitting data through a Geostationary Operational Environmental Satellite (GOES) antenna. This continuous record of stage was translated to stream 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. High and low stages and flows are particularly important for the development of the rating curve; however, it was unsafe to obtain manual measurements of flow in the streams when they were in peak-flow conditions. Instead, a theoretical equation related to the shape, size, slope, and roughness of the channel at the stream gauge was used to iteratively determine the stage-discharge relationship at higher stages and flows. This relationship differs between stream gauging stations and can also change over time at a specific station. More details on the water quantity monitoring methods can be found in Upsdell Wright *et al.* 2015a.

2.2.2 Water Quality Monitoring

Many water quality monitoring programs involve a random sampling strategy, whereby samples are collected on pre-determined days of the month. However, rain, rain-on-snow, and snowmelt events (herein referred to as events) are important because high concentrations of some pollutants, particularly sediment and phosphorus, are transported during these events (Upsdell Wright and Veliz 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 watershed plans and BMPs. Therefore, water quality monitoring for this study included sample collection when water was running across the landscape in order to improve the accuracy of pollutant load estimates.

For the purposes of this study, water samples were collected year-round under both low-flow and high-flow conditions. 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 study used the same approach. Continuous flow data from October 2010 to September 2017 were used to establish the low-flow conditions. A threshold was set at the 80th percentile of the continuous flow record for each of the sites to separate low flow from event flow. Low-flow grab samples were collected monthly between October 1, 2010, and September 30, 2017. High-flow events were sampled with an ISCO® 6712 automated sampler at each of the six stations. 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 analyzed for nutrients and suspended solids by the Ministry of the Environment and Climate Change (MOECC) laboratory in Etobicoke and ALS Laboratory in Waterloo. There are different analytical approaches to estimating the bioavailable forms of phosphorus. In this study, phosphate-phosphorus (orthophosphate) was measured.

Approximately 2,800 tributary water quality samples were collected between October 1, 2012, and September 30, 2017. An additional 245 water quality samples were collected in Gully Creek between October 1, 2010, and September 30, 2012. It is important to note that a change in laboratory analysis method for total phosphorus occurred at MOECC in November 2012.

In the study period (2010 to 2017), all of the watersheds had at least 60 events (Table 2). Gully Creek experienced 155 events during a seven-year period, whereas only 68 events were documented at Bayfield River over four years. 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. A more detailed account of the field methods for monitoring water quality is provided in Upsdell Wright *et al.* 2015a.

Table 2: Number of storm events and water quality samples in Healthy Lake Huron watersheds (October 2010 to September 2017).

Watershed	Water Years	Total Number of Events	Number of Events Sampled	Total Number of Samples
Bayfield River	2013 - 2017	68	34	329
Garvey-Glenn Drain[a]	2012 - 2017	81	45	434
Gully Creek	2010 - 2017	155	90	983
Shashawandah Creek[a]	2012 - 2017	85	44	457
South Pine River[a]	2012 - 2017	85	31	271
Trick's Creek	2012 - 2017	121	75	610

[a] Incomplete flow record for 2013 water year.

2.3 Data Analysis Methods

For this report, both the monthly and annual flow-weighted mean concentrations and the loads have been summarized. Dickinson (in Upsdell Wright *et al.* 2015b) suggested that, if the focus of the study is on concentration targets or limiting ecological conditions, 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.

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

2.3.1 Mass Loads

Mass loads are the product of stream flow (volume per time) and concentration (mass per volume). A mass load (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 study, monthly and annual loads were calculated.

Equation 1

Mass Load (kilograms) = $\sum_{i=1}^{n} \frac{c_i + c_{int}}{2} q_j$

Where,

n = total number of samples
i = number of a particular sample
c_i = concentration measured at the day and time of the *i*th sample
q_j = inter-sample mean flow
c_{int} = linearly interpolated concentration value between samples

2.3.2 Flow-Weighted Mean Concentrations

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

Equation 2

Flow-Weighted Mean Concentration (mg/L) = $\frac{Mass\ Load\ (kg)}{Total\ Stream\ Flow\ Volume\ (L)} \times 1000$

2.3.3 Mass Export Coefficients

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.

Equation 3

Mass Export (kg/ha) = $\frac{Mass\ Load\ (kg)}{Watershed\ Area\ (ha)}$

2.3.4 Flow-Adjusted Concentrations

Flow-adjusted concentrations (FAC) allow us to differentiate times when load is influenced by changes in flow (natural streamflow variability) or when anthropogenic impacts (*e.g.,* land management actions) affect loads (Sprague and Lorenz 2009). Flow-adjusted concentrations are determined by developing a regression between flow and concentration for each priority watershed using locally weighted regression and smoothing scatterplots (LOWESS) with a smoothing factor of 0.5 (*e.g.,* Helsel and Hirsch 2002, Stammler *et al.* 2017). The flow portion of the regression was removed by subtracting each observed concentration by the modelled concentration (resulting from the regression equation) to calculate a residual concentration, or FAC. In this case, the residuals are estimates of what the concentrations would have been if no streamflow-related variability occurred (*i.e.,* if streamflow conditions were constant). It is important to note that the results of the flow adjustment may not represent all the changes in water quality that result from anthropogenic influence and management actions, only those separate from flow (Langland *et al.* 2004).

2.3.5 Stream Flashiness Index

Stream flashiness reflects how streamflow responds during runoff events, and includes factors, such as the magnitude and frequency of floods and low flow periods and the rates of change of flow during those periods (Baker *et al.* 2004). Streams characterized as 'flashy' respond rapidly to precipitation events. Changes in land use (*e.g.,* conversion of cropland to forestland), land management practices (*e.g.,* improvements in agricultural drainage, adoption of conservation tillage, or implementation of structural BMPs), or hydrologic regimes largely influence how a stream will respond to precipitation events (Baker *et al.* 2004). The Richards-Baker (R-B) Stream Flashiness Index measures a stream's flashiness based on mean daily flows, and is calculated by dividing the sum of the absolute values of day-to-day changes in mean flow by total discharge during that time interval (Equation 4). A large value indicates greater variability between days.

Equation 4

$$R - B\ Index\ (dimensionless) = \frac{\sum_{i=1}^{n} |q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i}$$

Where,

q = mean daily flow in day i (m^3/s)

2.3.6 Spatial and Temporal Patterns

Loads are typically calculated annually and based on a water year (*e.g.*, 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 six watersheds along the southeast shore of Lake Huron, mass load, flow-weighted mean concentration, flow-adjusted concentrations, and mass export values were calculated for the period between October 1, 2010, and September 30, 2017. Water quality was analyzed for nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P), total phosphorus (TP), and total suspended solids (TSS).

Annual pollutant transport is typically defined by seasonal changes, in which greater loads occur during large, infrequent storm events (usually during winter and spring) and smaller loads occur during smaller, more frequent storm events and low-flow periods (usually during fall and summer). It may not be surprising that 80 to 90 percent of total loads occur during only 10 to 20 percent of the time (Richards 1998). For this reason seasonal loads were calculated to evaluate variations in loading throughout the year. Limnological seasons were used in this study and defined as fall (October-November), winter (December-March), spring (April-May), and summer (June to September). Separating the months in this way effectively groups the seasons into similar climatic conditions based on precipitation and temperature. Additionally, pollutant loads and stream flow volumes were determined for individual months to assess monthly patterns across all streams during the study period.

2.3.7 Trends in Monthly Water Quality and Quantity Data

Regression analyses were performed to evaluate trends in water quality and quantity data for the six watersheds during the current study period. A non-parametric approach (Mann-Kendall trend test and Sen's slope estimation) was used to evaluate the trends in monthly log-transformed flow volumes and flashiness, flow-weighted mean concentrations, flow-adjusted concentrations, and mass loads (*i.e.*, improving trend, no trend, declining trend). Some of the strengths of a Mann-Kendall trend test is that it does not require the datasets to be normally distributed and results are not impacted by the magnitude of extreme values (as with linear regression trend tests). A trend was found to be statistically significant when the magnitude of the change was large relative to the variation of the data around the trend line (*i.e.,* $p<0.05$). Monthly values were used instead of annual values to limit the effect of outliers and to retain inter-annual variability. Additionally, median monthly FACs were calculated for each water quality indicator to minimize the influence of extreme high or low concentration values and to remain consistent with the monthly flow-weighted mean concentration time series datasets.

The average rate of change (%) in monthly flow volumes and flashiness, flow-weighted mean concentrations, flow-adjusted concentrations, and mass loads were determined based on Sen's slope coefficient using Equation 5.

Equation 5

$$Average\ monthly\ rate\ of\ change\ (\%) = \left(10^{\beta} - 1\right) \times 100$$

Where,

β = Sen's slope coefficient

Caution must be used when comparing trends between FACs and FWMCs as they involve two different methods of calculation. Therefore, results of the FAC trend tests (*p*-value and Sen's slope) prior to and after flow adjustment were compared to determine whether discharge influenced trends in TP, phosphate-P, nitrate-N, and TSS. A significant positive trend in flow-adjusted concentrations suggests that the concentration of nutrients or sediment in the stream is being augmented by additions from artificial or anthropogenic sources. A non-significant trend in flow-adjusted concentration indicates that additions of pollutants from anthropogenic sources, if present at all, are not significantly influencing the overall concentration of pollutants in the stream. A significant decreasing trend in flow-adjusted concentrations suggests that the loading of nutrients to the system from anthropogenic sources is decreasing.

2.3.8 Shoreline Tributary Water Quality Monitoring Inventory

Small tributaries (<5000 ha) along the shore of Lake Huron were identified by staff at the Ausable Bayfield Conservation Authority, Maitland Valley CA, St. Clair Region CA, and Saugeen Valley CA. These tributaries were inventoried on the basis of having continuous water quantity (stage and/or flow) data and some water quality data to calculate nutrient and sediment loads.

Six tributaries along Lake Huron were identified where both water quantity (stage/flow) and water quality data exist (Table 3). However, only Spring Creek, Ridgeway Creek, and Zurich Drain were used for this analysis as they had readily available flow and water quality data. The main branch of Pine River was excluded due to a lack of water quality information (≤8 samples per year). Duffus Creek was excluded because a rating curve to convert stage into flow was not yet been developed. Griffins Creek was excluded because it is part of a nutrient project run by the Ministry of Environment and Climate Change (MOECC) and further inquiry with MOECC to access the data had not yet been initiated. With additional resources, the excluded site may be used for analysis in future reports.

Table 3: Potential sites to calculate future nutrient and sediment loads

Conservation Authority	Site ID	Latitude	Longitude	Period of stage measurements	Period of water quality collection
ABCA	Spring Creek	43.594	-81.705	2011 - 2016	2010 - 2013
ABCA	Ridgeway Drain	43.356	-81.720	2010 - 2016	2010 - 2015
ABCA	Zurich Drain	43.407	-81.707	2010 - 2016	2006 - 2015
MVCA	Griffins Creek	43.920	-81.714	unknown	2005 - 2014
SCRCA	Duffus Creek	43.182	-81.968	2012 - Present	2013 - Present
SVCA	Pine River	44.094	-81.727	2003 - Present	2002 - Present

Ausable Bayfield Conservation Authority (ABCA), Maitland Valley Conservation Authority (MVCA) Saugeen Valley Conservation Authority (SVCA), St. Clair Region Conservation Authority (SCRCA)

2.3.9 Reference Mass Load Calculations

Continuous records of both stream flow and concentrations are needed to calculate loads. Since the concentrations of pollutants are not typically monitored continuously, load-estimation methods are used to calculate loads. Generally, there are five types of load-estimation methods: averaging, numeric integration, ratio, regression, and interpolation (Preston *et al* 1989, Richards 1998, Moatar and Meybeck 2005). Averaging techniques determine load based on multiplying the average concentration by the average flow over a period of time. Numeric integration involves multiplying a concentration by the total flow over a period of time and then summing the time intervals. Ratio estimators determine load by multiplying the mean daily load by a flow ratio (derived by dividing the average flow for the period of interest by the average flow for the days on which water quality samples were collected). A total load is then calculated by multiplying the adjusted load by 365 days. Regression approaches determine load based on fitting a relationship between flow and concentration. Finally, an interpolation approach assumes a linear relationship between consecutive measured concentrations, which are then multiplied together with flow over a period of time (*e.g.*, Equation 1).

Water quality data and flow measurements from the priority watersheds were used to calculate a reference load (or 'true' load) for total phosphorus with a linear interpolation method (Equation 1). The gauging stations (see Appendix A) were chosen for this analysis because they had reliable flow and exhaustive water quality sampling records. Well-sampled datasets (*i.e.,* the full range of flows were sampled) were selected to calculate the reference loads for each station. As a result, five years of data were used for Gully Creek and Trick's Creek, while the remaining sites included only two years of data.

The datasets included a total of 2,118 water quality samples that were collected from the gauging stations between October 2012 and September 2017 (Table 4). Low-flow grab samples and high-flow event samples were collected with an ISCO automated sampler. Due to time constraints and computational intensity, only total phosphorus (TP) was used for the analysis (see section 2.3.10 for additional information).

Table 4: Number of water quality samples by watershed for calculating reference loads.

Watershed	Water Year(s)	Total Number of Samples
Bayfield River	2016 - 2017	173
Garvey-Glenn Drain	2014 - 2015	257
Gully Creek	2013 - 2017	736
Shashawandah Creek	2013, 2017	192
South Pine River	2016 - 2017	150
Trick's Creek	2013 - 2017	610

2.3.10 Mass Load Estimation Sampling Strategies

Water quality sampling programs are based largely on fixed-period and random sampling regimes that usually include daily or monthly sampling (*e.g.,* Kronvang and Bruhn 1996, Zamyadi *et al.* 2007, Williams *et al.* 2015). These methods appear to be effective for large watersheds in which variability in pollutant concentrations and flow is low compared to small watersheds (*e.g.,* Tate *et al.* 1999, Williams *et al.* 2015). However, daily sampling requires frequent sampling and resources as well as costly laboratory analyses, while monthly sampling in small flashy watersheds is inadequate to represent the range of flows, resulting in large uncertainties. For instance, Williams *et al.* (2015) suggested that to estimate annual loads accurately (±10%) in small watersheds would require sampling every 13–26 hours for dissolved phosphorus and every 2.7–17.5 days for nitrate-N. Bittman *et al.* (2017) found that daily sampling of TP, phosphate-P, nitrate-N, and TSS would facilitate annual load estimates to within ±15% of 'true' loads. This frequency of sampling is not possible for most sampling programs. The primary goal of this study is to manage the number of samples collected without increasing uncertainty. Therefore, we endeavoured to limit the amount of samples while maintaining accurate load estimation by systematically choosing, and restricting the amount of, low-flow and peak-flow samples collected each year.

This study adapted a Monte Carlo simulation strategy documented in Kronvang and Bruhn (1996), Birgand *et al.* (2011) and Williams *et al.* (2015). Monte Carlo simulations are used to help make decisions involving significant uncertainty, such as choosing the best load estimation strategy from a number of different strategies. Without this kind of analysis we might inadvertently choose a load estimation strategy that is inaccurate and/or imprecise.

In the current study, Monte Carlo simulations were used to sub-sample the reference datasets to assess the effect of sampling strategy on annual load estimates. Sampling based on selecting peak-flow (> 90th percentile of flow; Table 5) and low-flow samples (< 90th percentile of flow) were used to generate a variety of sample collection scenarios.

Table 5: Peak-flow to low-flow separation used for Monte Carlo analysis based on the 90th percentile of flow/stage (October 2012 to September 2017).

Watershed	Water Years	Flow (m^3/s)	Stage (m)
Bayfield River	2013 - 2017	23.617	1.571
Garvey-Glenn Drain	2012 - 2017	0.500	0.813
Gully Creek	2012 - 2017	0.578	1.523
Shashawandah Creek	2012 - 2017	0.826	1.495
South Pine River	2012 - 2017	0.856	2.332
Trick's Creek	2012 - 2017	0.718	6.485

Scenarios were generated by randomly sub-sampling the reference datasets, including: one peak-flow and one low-flow samples per month, two peak-flow and one low-flow samples per month, three peak-flow and one low-flow samples per month, one peak-flow and two low-flow samples per month, and one peak-flow and three low-flow samples per month (Table 6). Monthly peak-flow samples were excluded from the analysis in the event that flows were below the 90th percentile of annual flow (*e.g.,* a dry month). Annual total phosphorus loads were then calculated using Equation 1 based on the subsampled discharge and TP concentration data for each iteration of the Monte Carlo simulation. Birgand *et al.* (2011) suggested that 200 iterations per dataset are required to sufficiently represent the distribution of the values. Therefore, in the current study, 200 iterations were generated for each stream's dataset and the different sampling frequencies (200 iterations per water year x 18 water years x 6 sampling strategies = 21,600 iterations in total).

Table 6: Summary of the sampling strategies used in the Monte Carlo simulation analysis.

Sampling strategy (#)	Number of low-flow samples per month (<90th percentile of flow)	Number of peak-flow samples per month (>90th percentile of flow)	Maximum number of samples per year
1	1	1	24
2	1	2	36
3	1	3	48
4	2	1	36
5	2	2	48
6	2	3	60

It is important to note that the Monte Carlo simulation was extremely time consuming and computationally intensive. For instance, computation of 200 subsampled iterations took between 30 and 120 minutes to complete, depending on the size of the dataset. Additionally, a Microsoft Access database program was developed in-house from the ground-up specifically to complete the uncertainty analysis.

2.3.11 Mass Load Uncertainty Analysis

An uncertainty analysis was performed to determine the relative difference between each station's reference loads for TP and the loads estimated from the Monte Carlo simulation. The uncertainty was calculated as the percentage difference between the estimated load and the reference load (Equation 6).

Equation 6

$$Uncertainty\ (\%) = \left(\frac{Estimated\ Load - Reference\ Load}{Reference\ Load}\right) \times 100$$

Following each iteration of the Monte Carlo simulation, the difference between the estimated load and reference load was calculated, which resulted in a distribution of uncertainty values. From this distribution, the minimum and maximum bias of the TP load was determined. The minimum bias values typically characterized sampling primarily low-flow conditions while maximum bias values characterized sampling primarily storm events, or high-flow conditions.

A number of studies (*e.g.,* Kronvang and Bruhn 1996, Guo *et al.* 2002, Haggard *et al.* 2003, Zamyadi *et al.* 2007) have suggested comparing the estimated loads to the reference load (or 'true' load) using the root mean square error (RMSE in %). The RMSE incorporates an estimation of accuracy (*i.e.,* bias, or the distance between the estimated load and the true load) and precision (*i.e.,* standard deviation, or the spread of the bias about the mean). The value of the RMSE was computed from the distribution of uncertainty values for each sampling strategy. The RMSE (%) was calculated as the standard deviation of the residuals (uncertainty values) to help identify the best sampling strategies to use for the Healthy Lake Huron watersheds (Equation 7).

Equation 7

$$RMSE\ (\%) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Uncertainty\ (\%))^2}$$

Where,

n = total number of samples in the uncertainty distribution
Uncertainty (%) = result from Equation 4

In addition, a commonly reported margin of uncertainty was used to describe load estimates within ±10% of the 'true' or reference load (*e.g.,* Harmel and King 2005, Williams *et al.* 2015).

3.0 Results and Discussion

3.1 Spatial and Temporal Patterns

Annual mass load, flow-weighted mean concentration, flow-adjusted concentrations, and mass export were calculated for four water quality indicators (nitrate-nitrogen, phosphate-phosphorus, total phosphorus, and total suspended solids) using a linear interpolation algorithm.

3.1.1 Flow-Weighted Mean Concentrations

In all six watersheds, annual flow-weighted mean TP and nitrate-N concentrations exceeded concentrations that are considered to minimize eutrophication (Figure 2): the Provincial Water Quality

Objective for TP (0.03 mg/L; OMOEE 1994) and a concentration identified by the Canadian Council of Ministers of the Environment for nitrate-N (0.9 mg/L; CCME 2012). Mean flow-weighted mean TP concentrations exceeded 0.15 mg/L for all watersheds, excluding Trick's Creek and Bayfield River, which had mean concentrations of 0.08 mg/L and 0.14 mg/L, respectively. Total phosphorus concentrations ranged from 0.15–0.67 mg/L in Gully Creek, 0.13–0.35 mg/L in Pine River, 0.09–0.21 mg/L in Garvey-Glenn Drain, 0.06–0.12 mg/L in Trick's Creek, 0.12–0.21 mg/L in Shashawandah Creek, and 0.09–0.18 mg/L in Bayfield River.

Flow-weighted mean concentrations for nitrate-N exceeded 3.0 mg/L for all watersheds. Nitrate-N concentrations ranged from 3.59–6.37 mg/L in Gully Creek, 3.93–7.33 mg/L in Pine River, 5.60–7.89 mg/L in Garvey-Glenn Drain, 3.06–4.20 mg/L in Trick's Creek, 3.42–10.18 mg/L in Shashawandah Creek, and 4.77–7.10 mg/L in Bayfield River.

Total suspended sediment concentrations ranged from 138–618 mg/L in Gully Creek, but were only between 25–188 mg/L in the remaining watersheds.

Phosphate-P concentrations ranged from 0.06–0.19mg/L in Gully Creek, 0.05–0.07 mg/L in Pine River, 0.06–0.13 mg/L in Garvey-Glenn Drain and Shashawandah Creek, and 0.02–0.06 mg/L in Bayfield River and Trick's Creek (Appendix B).

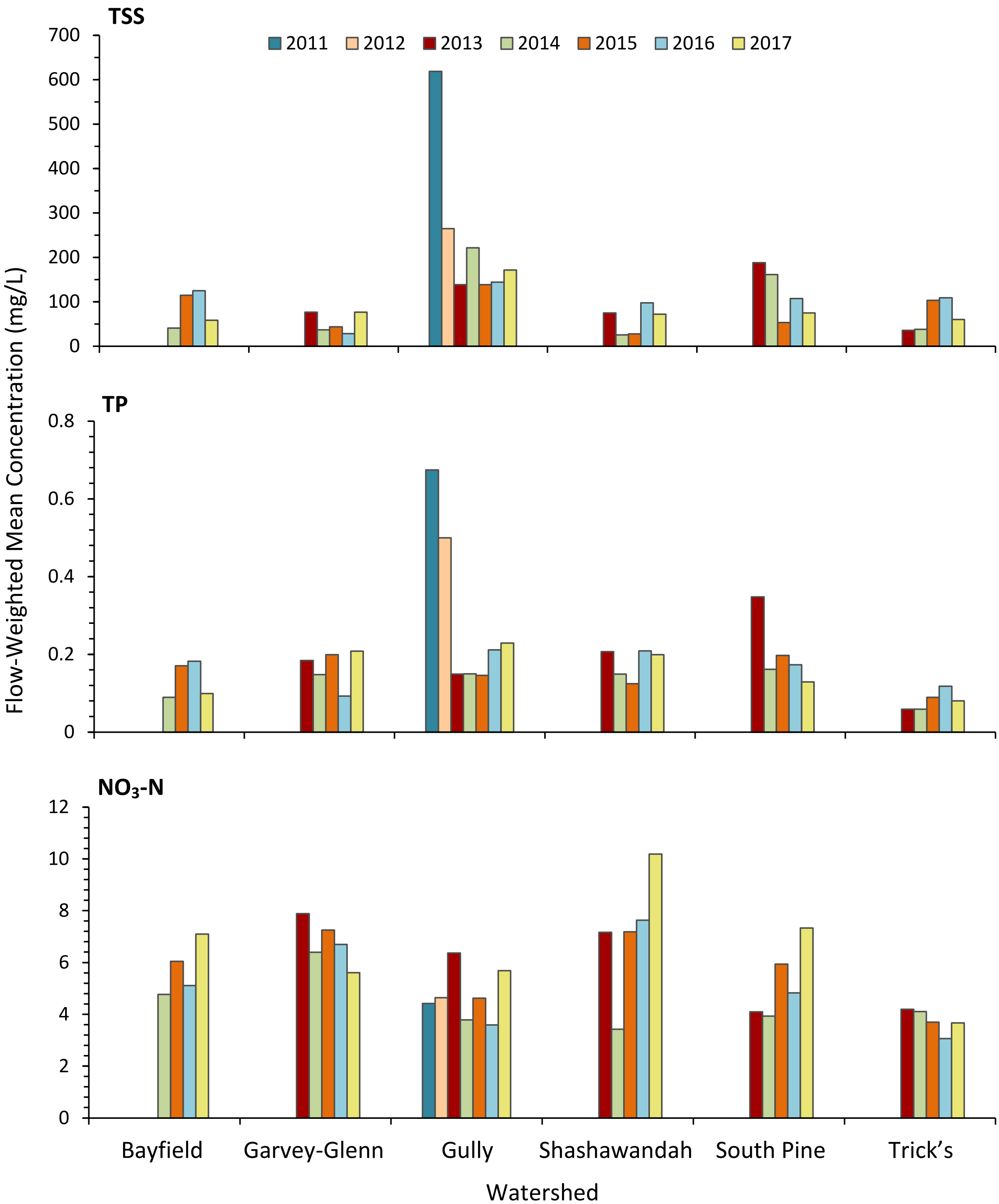

Figure 2: Annual flow-weighted mean concentrations in the Healthy Lake Huron watersheds (October 2010 to September 2017). Notes: 1) GULGUL5 monitoring station data were used to estimate FWMC for the 2012 to 2017 water years. GULGUL2 monitoring station data were used for the 2011 water year. 2) A change of laboratory analysis method for total phosphorus occurred in November 2012 at the Ministry of the Environment and Climate Change.

3.1.2 Total Annual Loads

Total annual loads in the six watersheds varied noticeably by water quality indicator and monitoring station (Figure 3). Sediment loads in Garvey-Glenn Drain ranged from 222–816 tons, while loads in Bayfield River were between 16,773–29,526 tons. Three watersheds, including the South Pine River, Trick's Creek, and Shashawandah Creek had a similar range of annual sediment loads during the study period (308–2,076 tons), while sediment loads in Gully Creek ranged from 800–5,135 tons. Additionally, Bayfield River contributed the greatest loads for total phosphorus (34–43 tons) and nitrate-N (1,203–1,962 tons), while loads for these indicators were comparable among the remaining watersheds (0.7–5.6 tons and 24–161 tons, respectively). Annual phosphate-P loads ranged from 10–19 tons in Bayfield River, while loads in the remaining watersheds were only between 0.19 tons in Trick's Creek to 2.00 tons in Shashawandah Creek (Appendix C).

The total TP load to Lake Huron from the priority tributaries, including Bayfield River, ranged from 31–51 tons per year and averaged 42 tons per year between October 2014 and September 2017. In comparison, Dolan and Chapra (2012) reported total phosphorus loads for all Lake Huron tributaries ranging from 1,084–3,572 tons per year and averaged 2,140 tons per year between 1994 and 2008. As a result, on average the priority tributaries accounted for less than 2% of the total annual total phosphorus load to Lake Huron. The proportion of land area represented by the priority watersheds to the total land area of all the Lake Huron tributaries is 0.4% (54,100 ha ÷ 13,410,000 ha).

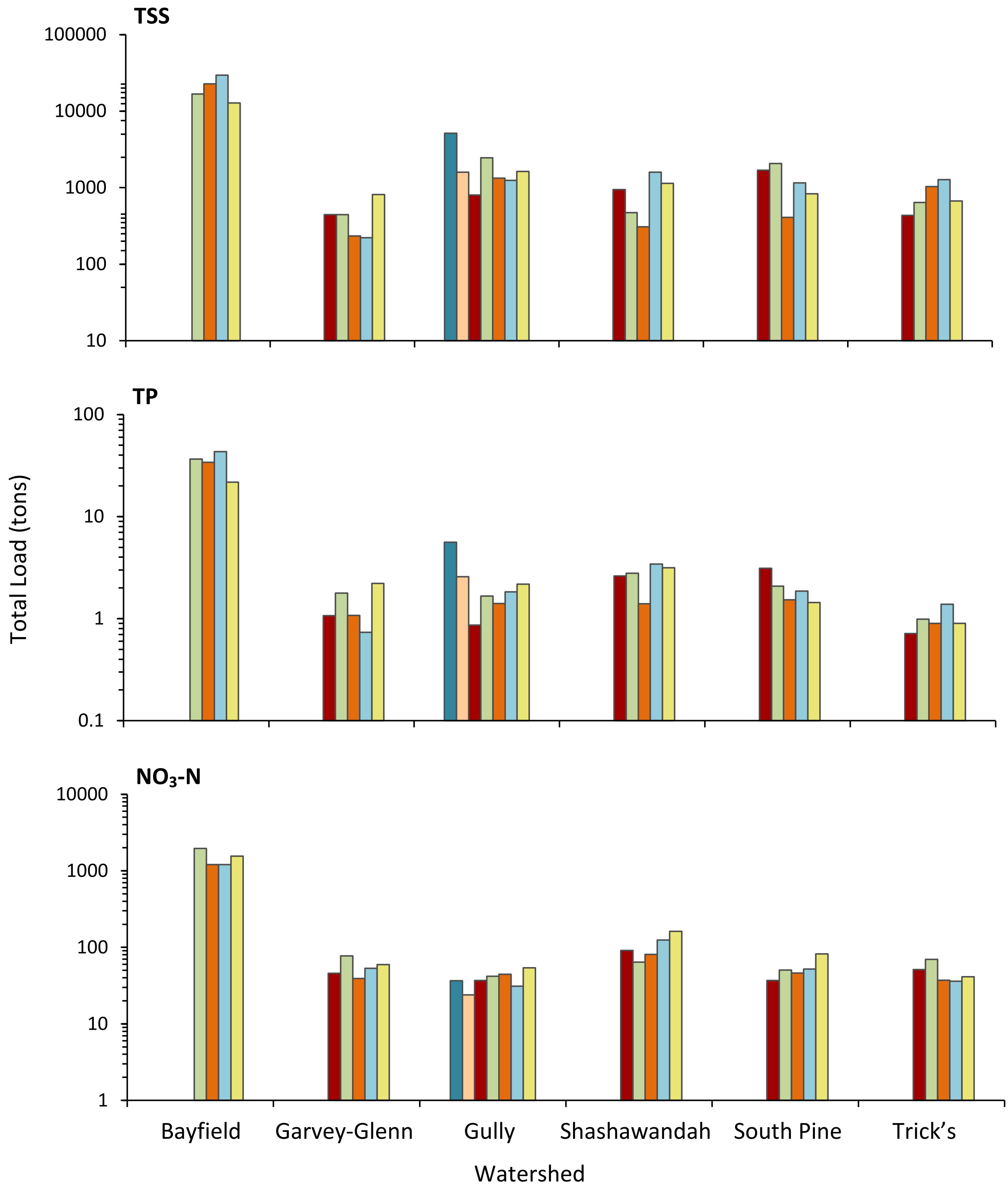

Figure 3: Annual total loads in the Healthy Lake Huron watersheds (October 2010 to September 2017). Notes: 1) GULGUL5 monitoring station data were used to estimate FWMC for the 2012 to 2017 water years. GULGUL2 monitoring station data were used for the 2011 water year. 2) A change of laboratory analysis method for total phosphorus occurred in November 2012 at the Ministry of the Environment and Climate Change.

3.1.3 Mass Export Coefficients

Mass export coefficients for total phosphorus in the six watersheds were higher than the range of values found in other streams in Southwestern Ontario (Table 7). The mean TP export coefficient for the six watersheds was 1.09 kg/ha, ranging from 0.34 kg/ha in Trick's Creek during the 2013 water year to 4.40 kg/ha in Gully Creek during the 2011 water year (Figure 4).

Table 7: Summary of annual total phosphorus mass export coefficients in agricultural, urban, and forested tributary catchments in Southwestern Ontario.

Land Use Type	Area	Mean (and Range) of TP Export Coefficient (kg/ha/year)	Reference
Agricultural	Lake Huron Tributaries	1.09 (0.34 to 4.40)	This report
Agricultural	Southwestern Ontario	(0.10 to 1.50)	PLUARG 1978
Agricultural/Urban/Forest	Lake Simcoe Tributaries	0.36 (0.08 to 2.21)	LSRCA 2010
Agricultural	Southwestern Ontario	0.92 (0.20 to 1.89)	OMOE 2012
Agricultural/Urban	Hamilton, Ontario	0.87 (0.14 to 1.40)	Long *et al.* 2015

Sediment mass export coefficients ranged from 769–4,038 kg/ha in Gully Creek. The remaining watersheds had a similar range of annual sediment mass export coefficients during the study period (115–745 kg/ha). In addition, Bayfield River, Garvey-Glenn Drain, Gully Creek, and Shashawandah Creek contributed loads between 24 –60 kg/ha for nitrate-N . Nitrate-N mass export loads in Pine River and Trick's Creek ranged between 13 and 33 kg/ha. Export loads for phosphate-P ranged between 0.36–1.24 kg/ha in Garvey-Glenn Drain and Gully Creek, while the range was 0.09–0.75 kg/ha in remaining stations (Appendix D).

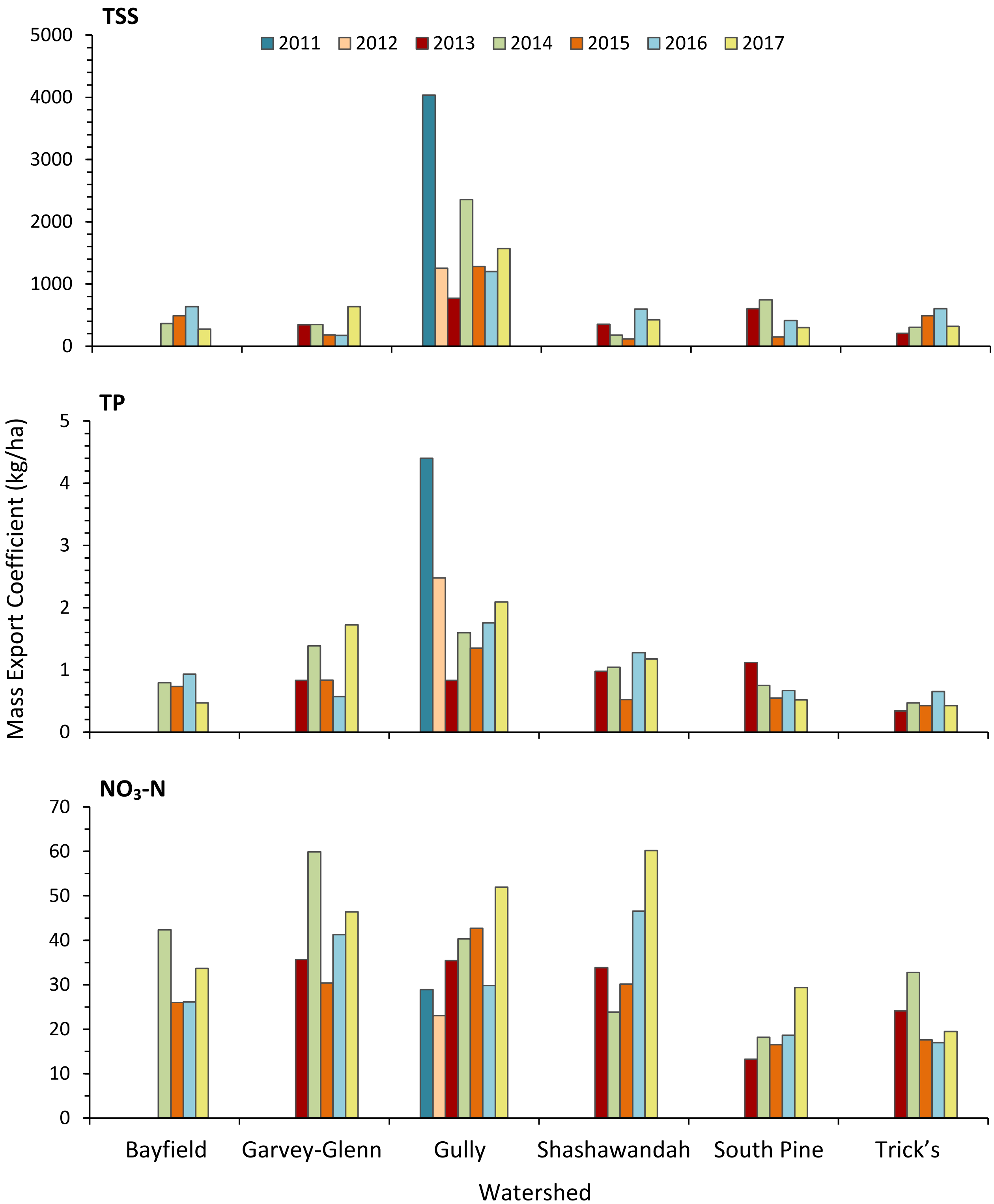

Figure 4: Annual mass export coefficients in the Healthy Lake Huron watersheds (October 2010 to September 2017). Notes: 1) GULGUL5 monitoring station data were used to estimate FWMC for the 2012 to 2017 water years. GULGUL2 monitoring station data were used for the 2011 water year. 2) A change of laboratory analysis method for total phosphorus occurred in November 2012 at the Ministry of the Environment and Climate Change.

3.1.4 Trends in Water Quantity and Flow-Weighted Mean Concentrations

Monthly flow volumes, flashiness, and flow-weighted mean concentrations were determined for the priority watersheds over a four- to seven-year period with the expectation that patterns in water quality and flow may be detected. Statistically significant trends in flow were observed at only two monitoring stations (Table 8, Figure 5, Appendix H). Bayfield River saw a decrease in flow volume of approximately 35% per year over a four year period. A reduction of this magnitude can be explained by the fact that monitoring began during a consistently wet year (2013) and subsequent years were drier. By comparison, Gully Creek saw an increase in flow volume of 11% per year over a seven year period. Although flow increased in Gully Creek, stream flashiness actually decreased by about 9% per year during the same period (Figure 5). This reduction may be an indication that BMPs are helping to hold back water upstream of the monitoring station. Stream flashiness did not change significantly at the remaining monitoring stations (Table 8, Appendix I).

No statistically significant trends in water quality were determined for Bayfield River, Garvey-Glenn Drain, Gully Creek, and Shashawandah Creek between October 2010 and September 2017 (*i.e.,* all p-values were greater than 0.05; Table 8, Figure 6, Appendix E). By contrast, significant declines in flow-weighted mean concentrations of TP (Gully Creek), TSS (Garvey-Glenn Drain, Gully Creek, South Pine River), and nitrate-N (Gully Creek) were observed between October 2010 and September 2016 (see Bittman *et al.* 2017). A possible reason for this discrepancy is that the 2017 water year had a number of very large rainfall events throughout the year (including one event that exceeded 100 millimetres of rain) which resulted in elevated pollutant concentrations. These differences exemplify the volatility of shorter-term monitoring trends and highlights the need to collect longer term data sets (*e.g.,* >15 years) to reduce the impact of extreme data. An alternative method for analyzing trends using flow-adjusted concentrations was performed to remove completely the effect of discharge on pollutant concentrations for comparison (see section 3.1.5).

In the current study, nitrate-N concentrations decreased significantly by 7% per year in Trick's Creek, while monthly nitrate-N concentrations increased by 13% per year in South Pine River. A significant increase in suspended sediment of 23% per year was observed in Trick's Creek.

Table 8: Water quality and quantity trends in monthly concentrations for the priority watersheds.

Station	Water Years	Rate of Change (%/yr)					
		Flow	**Flashiness**	**TP**	**PO_4-P**	**NO_3-N**	**TSS**
Bayfield	2013-2017	**–35***	+3	+5	–20	+7	+30
Garvey/Glenn	2012-2017	–3	–3	0	–4	–8	–13
Gully	2010-2017	**+11***	**–9***	–13	–10	–3	–16
Shashawandah	2012-2017	+3	–10	+2	–3	+7	+9
South Pine	2012-2017	0	–5	–9	–7	**+13***	–16
Trick's	2012-2017	–4	0	+12	+6	**–7***	**+23***

*****Statistically significant trend (p<0.05)

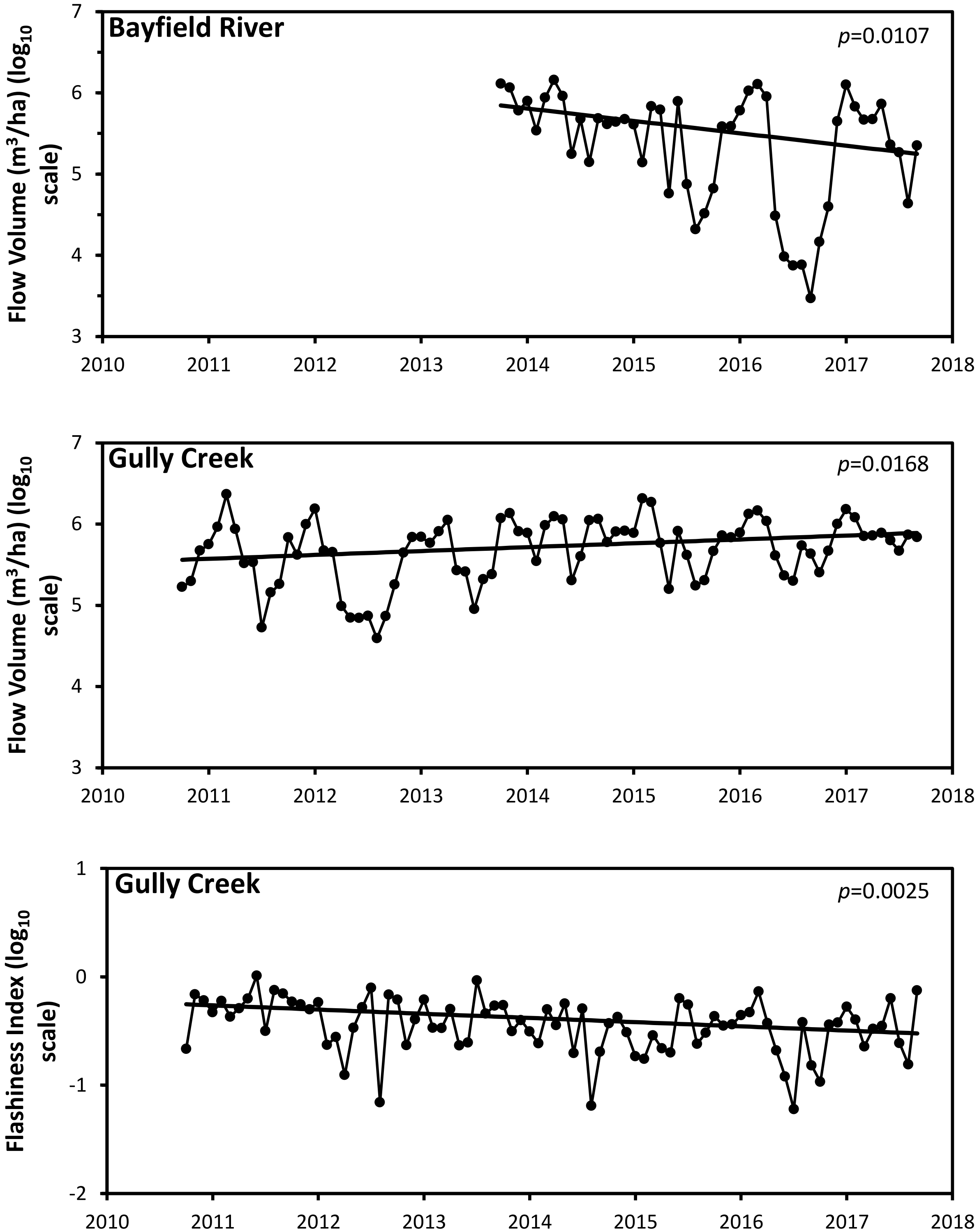

Figure 5: **An example of water quantity trends in monthly flow volume and flashiness index for Bayfield River and Gully Creek (October 2010 to September 2017).**

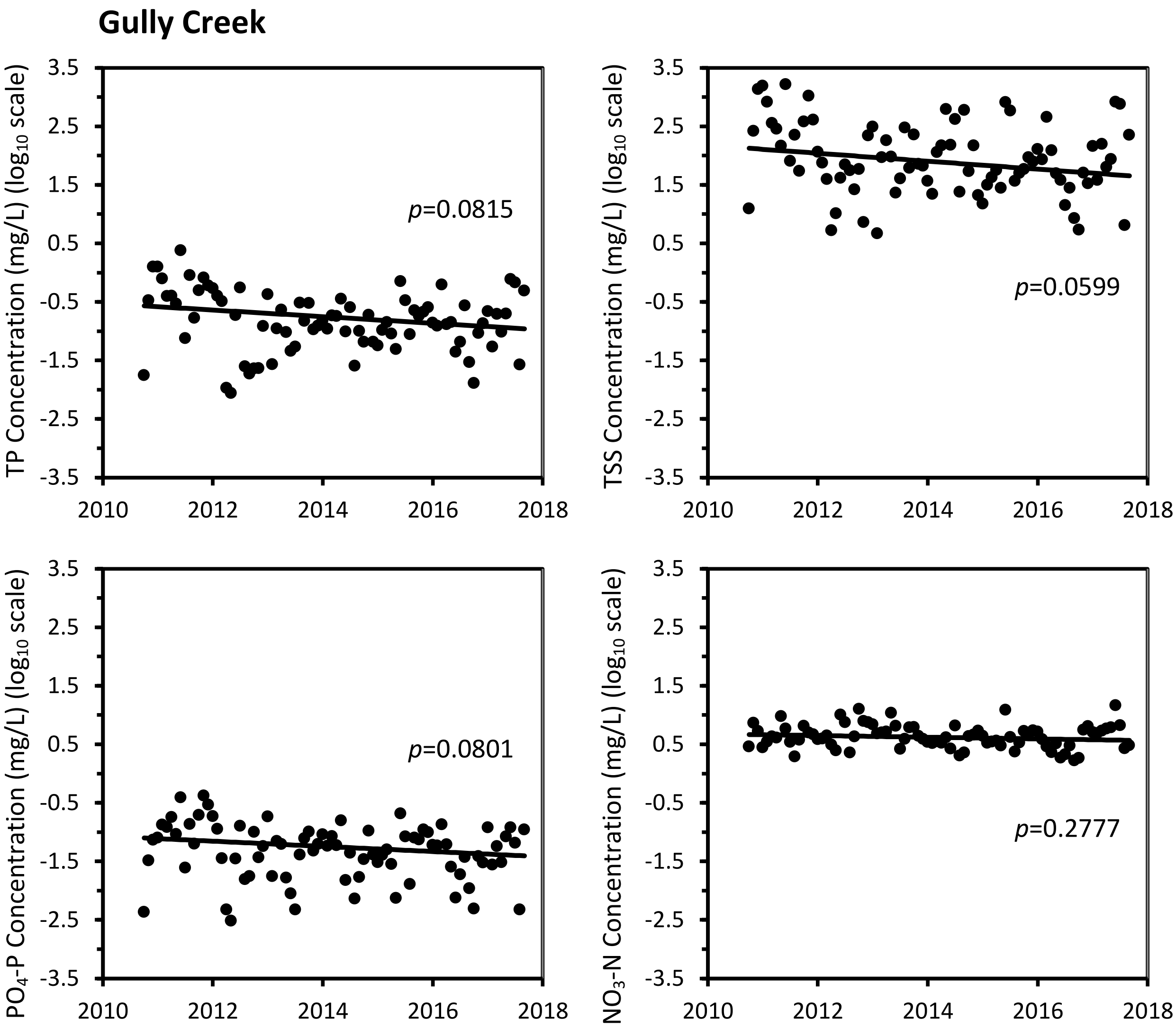

Figure 6: An example of water quality trends in monthly flow-weighted mean concentrations for Gully Creek (October 2010 to September 2017). Note: A change of laboratory analysis method for total phosphorus occurred in November 2012 at the Ministry of the Environment and Climate Change.

3.1.5 Trends in Concentrations Prior to and After Flow-Adjustment

Trends in median monthly flow-adjusted concentrations were determined for the priority watersheds between 2010 and 2017 (Table 9, Figures 7-8, Appendix F). Prior to flow adjustment, no trends in TP were observed across all monitoring stations. However, after adjusting TP concentrations for flow, trends at two stations were found to be statistically significant. Flow-adjusted concentrations of TP declined significantly in Gully Creek, while Trick's Creek saw a significant increase in concentrations.

Declines in flow-adjusted phosphate-P and nitrate-N concentrations were detected in Gully Creek, but were not significant for unadjusted concentrations which suggest improvements in watershed conditions due to factors other than streamflow. Significant reductions in phosphate-P and nitrate-N concentrations prior to and after flow-adjustment were observed in Bayfield River and Trick's Creek, respectively.

A significant increase in suspended sediment was observed prior to and after flow-adjustment.

Table 9: Water quality trends in median monthly flow-adjusted (and unadjusted) concentrations for the priority watersheds (October 2011 to September 2017).

Station	Water Years	Rate of Change (%/yr)			
		TP	**PO_4-P**	**NO_3-N**	**TSS**
Bayfield	2013-2017	–3 (–14)	**–27** (–35***)	+5 (+4)	+14 (–3)
Garvey/Glenn	2012-2017	–1 (+3)	–8 (–2)	–4 (–7)	+8 (+12)
Gully	2010-2017	**–7*** (–10)	**–11**** (–8)	**–9**** (–7)	–9 (–9)
Shashawandah	2012-2017	+4 (+4)	–1 (0)	–3 (+9)	+5 (+1)
South Pine	2012-2017	+4 (–2)	+2 (–1)	+8 (+20)	+11 (–3)
Trick's	2012-2017	**+13*** (+16)	+9 (+9)	**–9* (–7***)	**+28** (+31***)

*****Statistically significant trend (p<0.05)
******Strong statistically significant trend (p<0.01)

Gully Creek

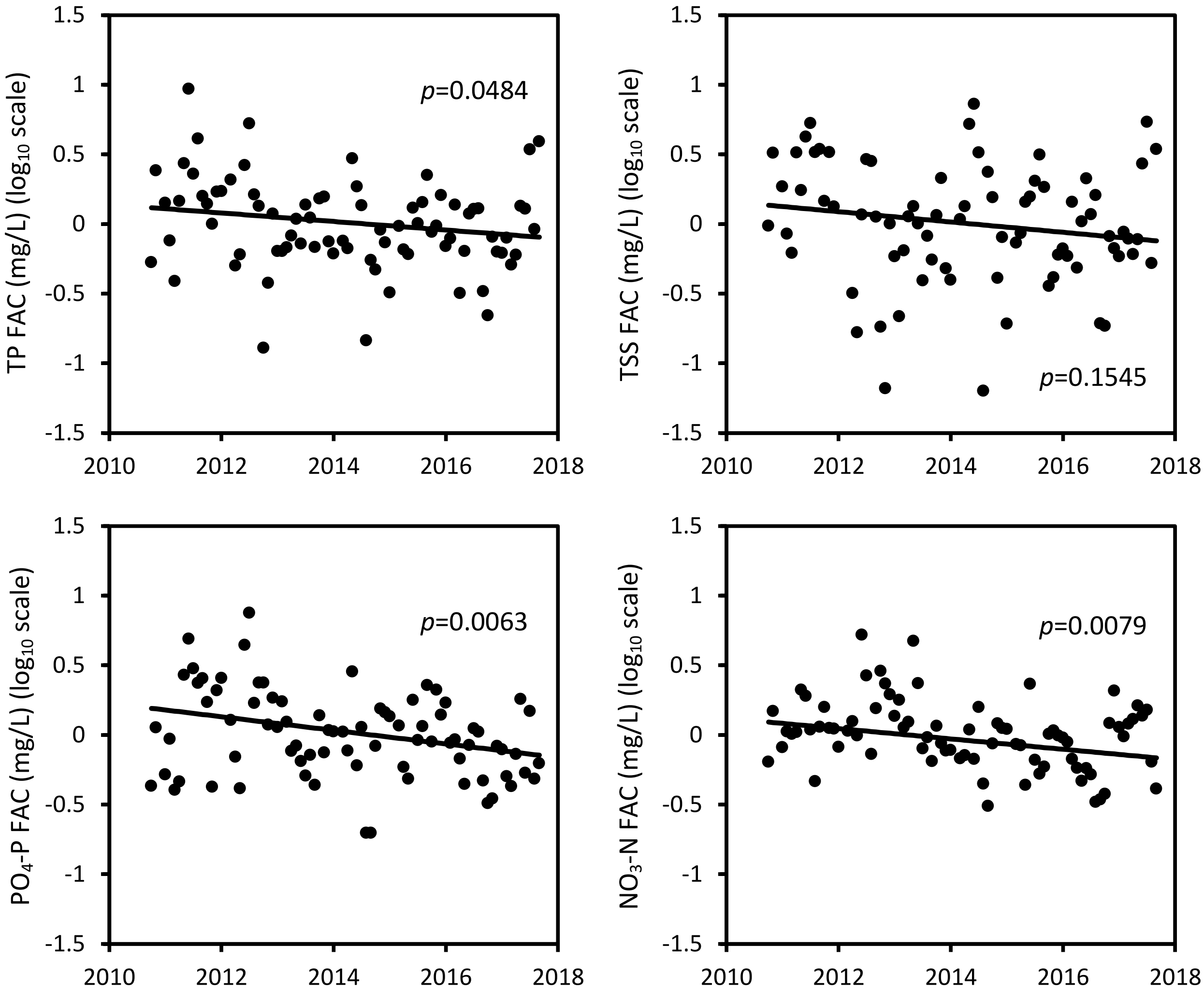

Figure 7: An example of water quality trends in median monthly flow-adjusted concentrations for Gully Creek (October 2010 to September 2017).

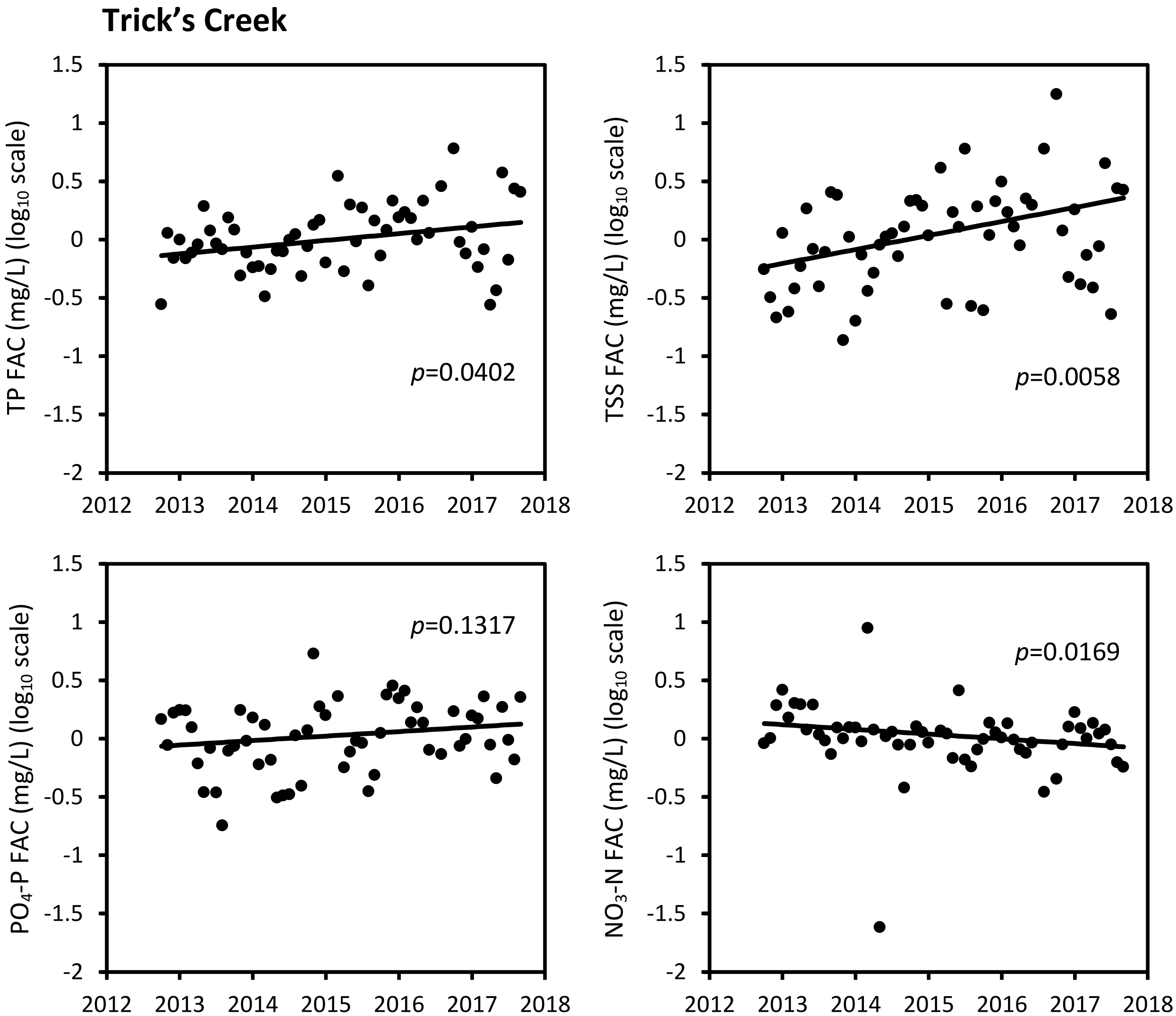

Figure 8: An example of water quality trends in median monthly flow-adjusted concentrations for Trick's Creek (October 2012 to September 2017).

3.1.6 Trends in Water Quantity and Pollutant Loads

Trends in monthly pollutant loads were also determined for the priority watersheds over a four- to seven-year period (Table 10, Figure 9, and Appendix G). Loads for most water quality indicators were largely influenced by flow volume, except for Gully Creek and Trick's Creek. Evidence of a decreasing trend in phosphate-P loads was observed in Bayfield River (62% per year) driven by sizeable reductions in flow during the same period.

Nitrate-N loads decreased significantly in Trick's Creek by 14% per year, while no trends were observed in the remaining watersheds.

Table 10: Water quality and quantity trends in monthly mass loads for the priority watersheds.

Station	Water Years	Rate of Change (%/yr)					
		Flow	**Flashiness**	**TP**	**PO_4-P**	**NO_3-N**	**TSS**
Bayfield	2013-2017	**–35***	+3	–35	**–62***	–29	–14
Garvey/Glenn	2012-2017	–3	–3	–6	–12	–11	–10
Gully	2010-2017	**+11***	**–9***	–2	+1	+7	–5
Shashawandah	2012-2017	+3	–10	+2	–2	+13	+10
South Pine	2012-2017	0	–5	–12	–13	+12	–19
Trick's	2012-2017	–4	0	+5	0	**–14***	+16

*****Statistically significant trend (p<0.05)

No significant reductions in total phosphorus or sediment loads were observed across all priority watersheds. In comparison, a significant reduction in TSS loads was observed in Garvey-Glenn Drain, while a significant increase was observed in Trick's Creek between October 2010 and September 2016 (see Bittman *et al.* 2017).

Due to the complexity of climate and hydrologic conditions, a Soil and Water Assessment Tool (SWAT) was developed for Gully Creek and the Garvey-Glenn Drain to determine the effectiveness of BMP implementation. The University of Guelph's Watershed Evaluation Group (WEG) (2017b) documented that between 2002 and 2016, reductions in TP, TSS, and total nitrogen loads of up to 22, 25, and 18 percent per year, respectively, could be attributed to the current level of BMP adoption in Gully Creek. WEG (2017a) also documented that reductions in TP, TSS, and total nitrogen loads of up to 16, 31, and 13 percent per year, respectively, could be attributed to the existing level of BMP adoption in the Garvey-Glenn Drain. The discrepancy between the modelled results and the monitored results for Gully Creek and Garvey-Glenn Drain are difficult to explain to producers and the broader community. It is hoped that, with more investigation the SWAT model might help us explain the monitoring results further.

Trick's Creek

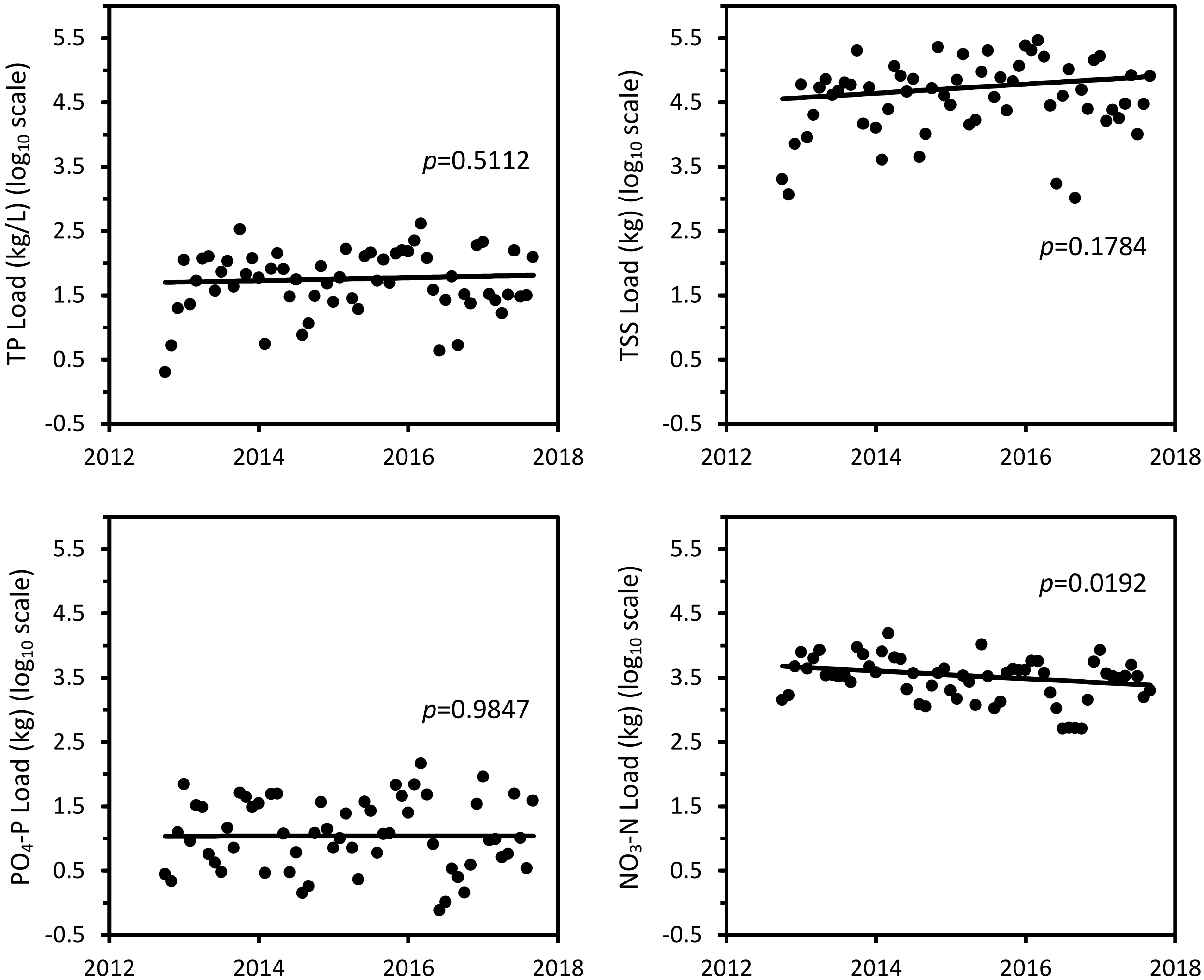

Figure 9: An example of water quality trends in monthly pollutant loads for Trick's Creek (October 2012 to September 2017).

3.1.7 Seasonal Loading of Pollutants

Flow across all streams in this study was largely seasonally driven (Table 11). For instance, flow was most dominant in winter (47% of total annual flow), while less so in the other seasons, particularly summer (14% of total annual flow). The majority of loads also occurred in the winter, ranging from 46% for sediment to 50% for total phosphorus. Loads in fall, spring, and summer each accounted for less than 25% of the total annual load.

Table 11: Percentage of flow and stream loads delivered by season across all the priority watersheds.

Season	Months	Percentage of Annual Total (%)				
		Flow	TP	PO_4-P	NO_3-N	TSS
Fall	Oct-Nov	17	12	14	15	10
Winter	Dec-Mar	47	50	49	47	46
Spring	Apr-May	22	20	21	20	20
Summer	Jun-Sep	14	17	16	18	24

All indicator loads, excluding sediment loads, were greatest in January and March, accounting for 27% of total annual nitrate-N loads, 32% of total annual TP loads, and 35% of total annual phosphate-P loads (Figure 10, Appendix J). The largest proportion of total suspended sediment loads occurred in March and April, making up 31% of total annual loads.

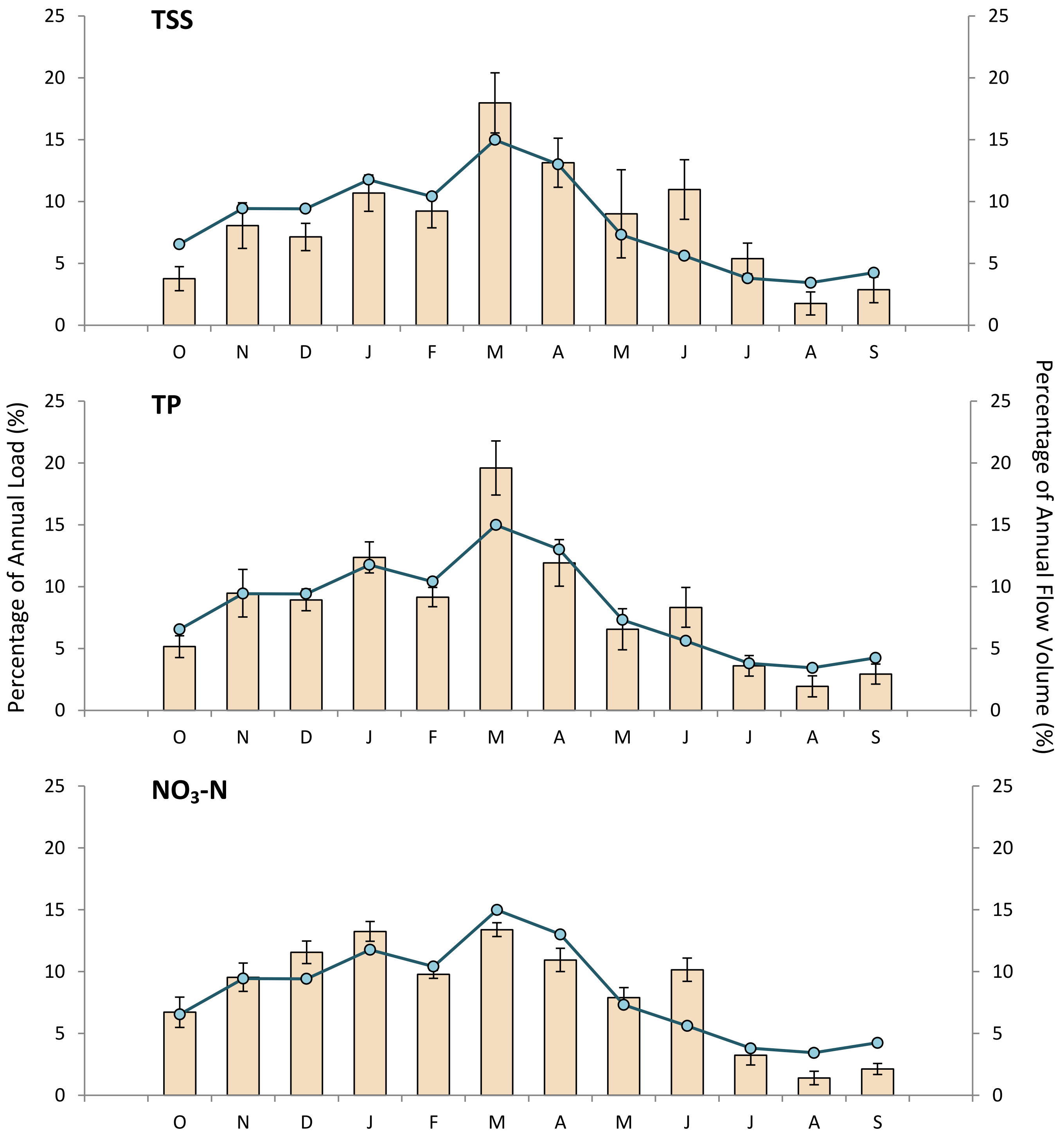

Figure 10: Percentage of annual load (pale bars, left axis) and percentage of annual flow volume (blue line, right axis) averaged across all of the study streams. Error bars are standard error of the mean, representing variability in annual loads among streams.

3.1.8 Shoreline Tributary Water Quality Monitoring Inventory

Water quality data, collected from October 2010 to September 2012, was used to calculate flow-weighted mean concentrations, mass export loads, and mass loads for three small shoreline tributaries in ABCA jurisdiction (Tables 12-14, Appendix K).

Annual flow-weighted mean TP concentrations in Ridgeway Drain and Zurich Drain exceeded the Provincial Water Quality Objective for TP (0.03 mg/L), while TP concentrations in Spring Creek were 50 percent below the target. All three stations exceeded the Canadian Council of Ministers of the Environment objective for nitrate-N (0.9 mg/L). Total phosphorus concentrations were less than 0.02 mg/L in Spring Creek and ranged from 0.57–0.72 mg/L in Ridgeway Drain and 0.34–0.43 mg/L in Zurich Drain (Table 12).

Table 12: Nutrient and sediment flow-weighted mean concentrations for three small lakeshore tributaries outside of the priority watersheds (October 2010 to September 2012).

Site ID	Water Quality Indicator Concentration (mg/L)							
	TP		PO_4-P		NO_3-N		TSS	
	2011	2012	2011	2012	2011	2012	2011	2012
Spring Creek	-	0.015	-	0.002	-	2	-	3
Ridgeway Drain	0.715	0.566	0.280	0.354	9	8	328	153
Zurich Drain	0.425	0.336	0.074	0.066	5	5	642	246

Nitrate-N concentrations were 2 mg/L and 5 mg/L in Spring Creek and Zurich Drain, respectively, and ranged from 8–9 mg/L in Ridgeway Drain.

Phosphate-P concentrations were less than 0.01 mg/L and approximately 0.07 mg/L in Spring Creek and Zurich drain, respectively, and ranged from 0.28–0.35 mg/L in Ridgeway Drain.

Total suspended sediment concentrations ranged from 153–328 mg/L in Ridgeway Drain and 246–642 mg/L in Zurich Drain, while concentrations were only 3 mg/L in Spring Creek.

The difference in concentrations of all water quality indicators in Spring Creek compared to the other stations could be accounted for by several watershed characteristics (*e.g.,* land use, soils, and slope). For instance, Upsdell Wright and Veliz (2013) reported that forest and natural cover in Spring Creek was 64%, while Zurich Drain and Ridgeway Drain were only 14% and 8%, respectively (Table 13). In additions, soils in the Spring Creek watershed were not characterized as having a high runoff potential, while erosive soils in the remaining stations included up to 30% of their watershed area.

Table 13: **Watershed conditions for three small lakeshore tributaries outside of the priority watersheds. Values represent the percentage (%) of watershed area covered by each condition.**

Watershed	Forests and Shrubs[a] (%)	Erosive Soils (%)	Slope Class D[b] or E[c] (%)
Spring Creek	64	0	>85
Ridgeway Drain	8	30	62
Zurich Drain	14	7	>85

[a] Forests and shrubs include coniferous, deciduous, and mixed forests; young and mature plantations; upland and riparian meadow; and shrubs and thicket

[b] Gentle slope

[c] Moderate slope

Annual total phosphorus mass export loads were only 0.18 kg/ha in Spring Creek, but ranged from 1.10–3.63 kg/ha in Ridgeway Drain and 0.60–1.93 kg/ha in Zurich Drain (Table 14).

Table 14: Nutrient and sediment mass export coefficients for three small lakeshore tributaries outside of the priority watersheds (water years 2011 to 2012).

Site ID	Water Quality Indicator Export Coefficient (kg/ha)							
	TP		PO_4-P		NO_3-N		TSS	
	2011	2012	2011	2012	2011	2012	2011	2012
Spring Creek	-	0.183	-	0.029	-	30	-	41
Ridgeway Drain	3.625	1.101	1.418	0.688	44	16	1,661	298
Zurich Drain	1.925	0.597	0.336	0.116	25	9	2,907	438

Nitrate-N mass export loads were 30 kg/ha in Spring Creek and ranged from 16–44 kg/ha in Ridgeway Drain and 9–25 kg/ha in Zurich Drain.

Phosphate-P concentrations were less than 0.03 kg/ha in Spring Creek and ranged from 0.69–1.42 kg/ha in Ridgeway Drain and 0.12–0.34 kg/ha in Zurich Drain.

Total suspended sediment mass export loads ranged from 298–1,661 kg/ha in Ridgeway Drain and 438–2,907 kg/ha in Zurich Drain, while loads were only 41 kg/ha in Spring Creek.

3.1.9 Load Estimation Sampling Strategies

Reference loads were compared against estimated loads from six different sampling strategies across six monitoring stations (Figure 11). The type of sampling strategy substantially affected the uncertainty in total phosphorus loads. In general, the precision and bias of TP load estimates improved with increasing sampling frequency.

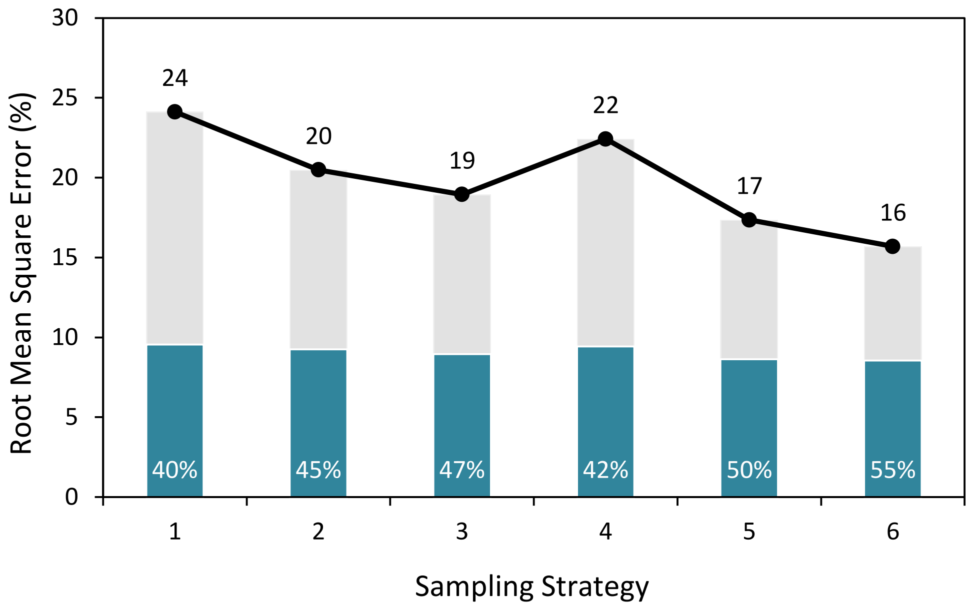

Figure 11: Root mean squared error (%) for six different sampling strategies across six monitoring stations based on the 90th percentile of streamflow. Values shown above the black line are the mean difference between the reference ('true') loads and the estimated loads from the priority watersheds. Values shown on the blue bars are the proportion of estimates from the Monte Carlo simulation that were within ±10% of the reference loads.

Of the six sampling strategies tested, strategy 6 (two low-flow and three peak-flow samples per month) resulted in better estimates of annual TP compared to the other strategies. On average, strategy 6 resulted in TP load estimates within ±16% of the reference loads, and more than half of the load estimates were within ±10% (Figure 11). The method underestimated annual TP loads by up to 54% and maximally overestimated TP loads by 161%. In general, these ranges of values characterize sampling primarily low flows and peak flows, respectively. In comparison, the least precise sampling strategy was strategy 1 (one low-flow and one peak-flow sample per month). On average, strategy 1 resulted in TP load estimates within ±24% of the reference loads, while only 40% of the load estimates were within ±10%. The method underestimated annual TP loads by up to 68% and maximally overestimated TP loads by 202%. Strategy 4 (two low-flow and one peak-flow sample per month) performed only slightly better than strategy 1, even though sampling effort was 50% greater, likely due to the emphasis on sampling low flows rather than peak flows.

Strategy 5 (two low-flow and two peak-flow samples per month) as comparable to strategy 6 with respect to RMSE (±17%), but the proportion of load estimates within ±10% of the reference loads was five points lower.

Strategies 2 (one low-flow and two peak-flow samples per month) and 3 (one low-flow and three peak-flow samples per month) resulted in similar uncertainty values (RMSE ±20%); although the proportion of estimates within ±10% of the reference loads was slightly better for strategy 3 (47%) compared to strategy 2 (45%).

When looking at each monitoring station individually, Shashawandah Creek clearly outperformed the other stations across all sampling strategies (Figure 12). Employing strategy 1 in Shashawandah Creek resulted in mean annual load estimates within ±9% of the reference loads, while load estimates in the remaining stations ranged between ±25% in Bayfield River and Gully Creek to ±33% in Trick's Creek. The gap in uncertainty values between Shashawandah Creek and the other stations narrowed in each of the remaining strategies and was smallest using strategy 6 (RMSE ±7–21% across all stations).

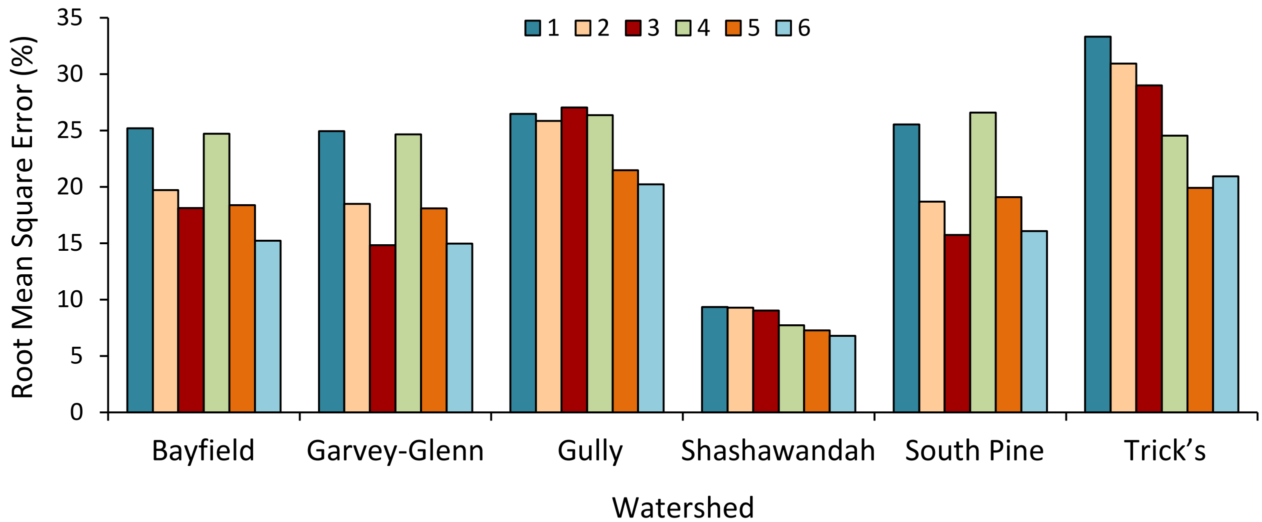

Figure 12: Summary of root mean square error (%) values for different sampling strategies (1–6) and monitoring stations.

In addition, the proportion of load estimates within ±10% of the reference loads was substantially better in Shashawandah Creek compared to the other watersheds. Three-quarters of all the load estimates in Shashawandah Creek were within ±10% of the reference loads using strategy 1, while the next highest proportion was found in South Pine River and Trick's Creek (39%) using the same strategy (Table 15). This means that for each load estimate using only one randomly selected low-flow and peak-flow sample per month, there is a 75% chance of accurately (±10%) estimating the annual load in Shashawandah Creek. The probability increases to 89% using strategy 6 in Shashawandah Creek, while roughly half of the load estimates were within ±10% in South Pine River and Trick's Creek. The results from the uncertainty analysis show promise for limiting the number of samples in some capacity for all the priority watersheds.

Table 15: Summary of the proportion (%) of load estimates from the Monte Carlo simulation that were within ±10% of the reference loads for the priority watersheds.

Watershed	Sampling Strategy					
	1	2	3	4	5	6
Bayfield	31	35	33	36	46	48
Garvey-Glenn	25	35	49	25	33	44
Gully	30	36	38	28	38	44
Shashawandah	75	76	75	81	85	89
South Pine	39	52	59	38	47	54
Trick's	39	37	31	45	50	49

If one of the objectives of a sampling program is to accurately estimate annual loads, while limiting sampling costs, Shashawandah Creek may be an ideal candidate for doing so by collecting only one low-flow and one peak-flow water sample per month. However, it is still advisable to collect samples from as many storm events as possible for consistent load estimation. Further reflection and analysis may be required to improve sample collection optimization for the remaining watersheds.

4.0 Conclusions

This report has provided technical staff from the Healthy Lake Huron program with the opportunity to summarize the water quantity and quality data that has been collected in the priority watersheds along the south east shores of Lake Huron. Monitoring has been undertaken since June 2010 for Gully Creek, the fall of 2012 for four other watersheds, and the fall of 2013 for Bayfield River. It is important to note that prior to the establishment of these priority areas, water samples were not collected with corresponding flow information and were not typically collected during runoff events. To evaluate the effectiveness of land-based 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. Furthermore, as pollutant concentrations are related to discharge condition, calculating the loads of various pollutants is necessary for evaluation. The requirements of sampling runoff events and the use of flow data in combination with water quality data represent a considerable change in human resources for monitoring programs that have been established by the technical staff in the Healthy Lake Huron.

As there are different approaches to determine load, considerable effort was spent to evaluate different sampling strategies. We chose to focus our evaluation on the robust data sets collects in all of the priority watersheds for the water years between 2013 and 2017. To help manage the number of samples collected without increasing uncertainty, a number of different sampling strategies were evaluated for their accuracy and precision at estimating annual loads compared to reference ('true') loads. Results from the uncertainty analysis indicated that infrequent sampling can yield large uncertainties in the estimation of nutrient and sediment loads. From our analysis, collecting only one low-flow and one event-flow sample per month could drastically reduce sampling effort, without compromising load estimation accuracy, in Shashawandah Creek. A suitable sampling strategy for the remaining priority watersheds could not be determined in the current study; however, the possibility of streamlining current sampling regimes is encouraging and should be further investigated.

Typically, concentrations of nutrients (nitrate-nitrogen and total phosphorus) in six Lake Huron watersheds exceeded standards established to prevent eutrophication; however, some improvement was identified during the study period. Using conventional methods, a significant reduction in nutrient concentrations (nitrate-N) were observed only in Trick's Creek. However, by adjusting concentrations for streamflow variability, significant declines in nutrients could be detected in Gully Creek as well. In addition, water samples from several small lakeshore tributaries outside of the sentinel watersheds were investigated. Results showed that Spring Creek had lower concentrations of most nutrients and sediment than the other watersheds due in part to favorable watershed conditions.

Pollutant loads appeared to be driven largely by changes in total flow volume between years. Not surprisingly, the largest percentage of pollutant loads was transported during the spring freshet in March, while the lowest percentage of loads occurred during the dry summer months. The variability of event loads should be evaluated to determine how different watershed conditions (e.g., antecedent moisture conditions, rainfall intensity) affect loads in hopes of finding targeted BMPs that help to improve water quality during such conditions.

We have found that monitoring data alone are inadequate to explain variability in pollutant concentrations and loads. If data collection and analysis are to explain causal changes, the building of scenarios may be necessary. Hydrologic models can help to synthesize observations, analyze interactions amongst different processes and fill gaps in information. A Soil and Water Assessment Tool

(SWAT) was developed for the Gully Creek and Garvey-Glenn Drain watersheds to evaluate the relationship between land management practices and hydrologic conditions. This information is useful if we want to get an idea of the amount of nutrients and sediment that can be reduced under different scenarios at the watershed scale. However, there was some discrepancy between the modelled results and monitored data for evaluating BMPs. The SWAT model showed substantial reductions in phosphorus, sediment, and nitrogen loads due BMP implementation, while the monitored results that were not flow-adjusted did not display observable declines.

We are beginning to see positive impacts on small watersheds due to past funded projects. However, better understanding of monitoring results in context of modelling efforts are needed to understand what it takes to reduce pollutant loading, and apply those lessons throughout the Great Lakes basin in an effort to prevent further degradation of the Great Lakes and to sustain the agricultural sector.

4.1 Next Steps

In summary, continued monitoring of watershed data and further analysis of these data sets, would provide water managers with better approaches to understand water quality conditions over time. As discussed above, more analysis is required to:

1) Investigate further the current study's sampling strategies to optimize workload efficiencies using flow separation (*e.g.,* 90th percentile of flow) in the priority watersheds;

2) Evaluate event loads in the priority watersheds to determine how different watershed conditions (*e.g.,* antecedent moisture conditions, rainfall intensity) affect loads and to suggest targeted BMPs to improve water quality during such conditions;

3) Continue using hydrologic process models (*e.g.,* SWAT) to understand the discrepancy in load reductions compared to our monitored results, as well as explain changes in water quality due to BMP implementation and climate variability in the priority watersheds; and

4) Enhance understanding and context of our work to other environmental agencies and groups through workshops and training opportunities, as well as invite a more technical audience to review our work and provide insight and direction for future projects.

5.0 References

Baker, D.B., Richards, R.P., Loftus, T.L., and J.W. Kramer. 2004. A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams. *Journal of the American Water Resources Association* 40(2):503-522.

Barton, D.R., E.T. Howell, and C.-L. Fietsch. 2013. Ecosystem changes and nuisance benthic algae on the southeast shores of Lake Huron. Journal of Great Lakes Research 39(4): 602-611.

Birgand F.,T.W. Appelboom, G.M. Chescheir, and R.W. Skaggs. 2011. Estimating nitrogen, phosphorus, and carbon fluxes in forested and mixed-use watersheds of the Lower Coastal Plain of North Carolina: Uncertainties associated with infrequent sampling. Transactions of the ASABE 54(6): 2099-2110.

Brock, H., A. Gutteridge, and M. Veliz. 2010. Management Plan for the Bayfield North Watersheds. Ausable Bayfield Conservation Authority, Exeter, Ontario. viii + 47 p. http://www.healthylakehuron.ca/docs/Bayfield_North_Watershed_Plan.pdf

CCME (Canadian Council of Ministers of the Environment). 2012. Scientific Criteria Document for the Development of the Canadian Water Quality Guidelines for the Protection of Aquatic Life: Nitrate Ion. CCME, Winnipeg, Manitoba. xx + 206 p. http://www.ccme.ca/files/Resources/supporting_scientific_documents/pn_1470_aql_nitrate_scd_1.0.pdf

Cooke, S.E., S.M. Ahmed, and N.D. MacAlpine. 2000. Introductory Guide to Surface Water Quality Monitoring in Agriculture. Conservation and Development Branch, Alberta Agriculture, Food and Rural Development, Edmonton, Alberta. iv + 29 p.

Dolan, D.M, and S.C. Chapra. 2012. Great Lakes total phosphorus revisited: 1. Loading analysis and update (1994-2008). Journal of Great Lakes Research 38(4): 730-740.

Emmons & Olivier Resources, Inc., Ausable Bayfield Conservation Authority, Computational Hydraulics International, Ministry of the Environment, Ontario Ministry of Agriculture, Food and Rural Affairs, St. Clair Region Conservation Authority, Maitland Valley Conservation Authority, and Saugeen Valley Conservation Authority. 2014. Development of a Rural Stormwater Management Model to Manage Water Quality in the Lake Huron Watersheds. Ausable Bayfield Conservation Authority, Exeter, Ontario. 247 p. http://www.ruralstormwater.com/docs/Rural-Stormwater-Management-Model-Report-FINAL-low-res.pdf

Guo, Y., M. Markus, and M. Demmissie. 2002. Uncertainty of nitrate-N load computations for agricultural watersheds. Water Resources Research 38(10): 1-12.

Haggard, B.E., T.S. Soerens, W.R. Green, and R.P. Richards. 2003. Using regression methods to estimate stream phosphorus loads at the Illinois River, Arkansas. Applied Engineering in Agriculture 19(2): 187-194.

Harmel, R. D., and K.W. King. 2005. Uncertainty in measured sediment and nutrient flux in runoff from small agricultural watersheds. Transactions of the American Society of Agricultural Engineers 48, 1713–1721.

Helsel, D.R. and R.M. Hirsch. 2002. Statistical Methods in Water Resources Techniques of Water Resources Investigations. Book 4, Chapter A3. U.S. Geological Survey, 522 p.

International Joint Commission. 2014. A Balanced Diet for Lake Erie: Reducing Phosphorus Loadings and Harmful Algal Blooms. Report of the Lake Erie Ecosystem Priority.

King, G, C. Van Esbroeck, R. Noble, M. Shetler, and M. Luymes. 2014. Garvey-Glenn Watershed Project. Maitland Valley Conservation Authority, Wroxeter, Ontario. 10 p. http://www.healthylakehuron.ca/docs/GG_Watershed_SWEEP.pdf

Kronvang, B., and J. Bruhn. 1996. Choice of sampling strategy and estimation method for calculating nitrogen and phosphorus in small lowland streams. Hydrol. Proc. 10(11): 1483-1501.

Langland, M.J., Phillips, S.W., Raffensperger, J.P., and D.L. Moyer. 2004. Changes in streamflow and water quality in selected nontidal sites in the Chesapeake Bay Basin, 1985-2003: U.S. Geological Survey Scientific Investigations Report 2004-5259, 50 p.

LaPorte, J. E. Gazendam, A. Mason, A. Farrell, A. Hutter, J. Harbinson, and G. Peach. 2012. Pine River Watershed Integrated Watershed Management Plan. Saugeen Valley Conservation Authority, Formosa, Ontario. 79 p. http://www.healthylakehuron.ca/docs/2012-07-PRPLAN.pdf

Long, T., C. Wellen, G. Arhonditsis, D. Boyd, M. Mohamed, and K. O'Connor. 2015. Estimation of tributary total phosphorus loads to Hamilton Harbour, Ontario, Canada, using a series of regression equations. Journal of Great Lakes Research 41(3): 780-793.

LSRCA (Lake Simcoe Region Conservation Authority). 2010. Report on the Phosphorus Loads to Lake Simcoe 2007-2009. LSRCA, Newmarket, Ontario. 18 p. http://www.lsrca.on.ca/pdf/reports/phosphorus_2007_2009.pdf

Moatar, F., and M. Meybeck. 2005. Compared performances of different algorithms for estimating annual nutrient loads discharged by the eutrophic River Loire. Hydrol. Proc. 19(2): 429-444.

Moatar, F., G. Person, M. Meybeck, A. Coynel, H. Etcheber, and P. Crouzet. 2006. The influence of contrasting suspended particulate matter transport regimes on the bias and precision of flux estimates. Sci. Total Environ. 370(2-3): 515-531.

OMOE (Ontario Ministry of the Environment). 2012. Water Quality of 15 Streams in Agricultural Watersheds of Southwestern Ontario 2004-2009: Seasonal Patterns, Regional Comparisons, and the Influence of Land Use. PIBS 8613e. Queen's Printer for Ontario. x + 89 p. https://dr6j45jk9xcmk.cloudfront.net/documents/1180/98-15-streams-in-agricultural-watersheds-en.pdf

OMOEE (Ontario Ministry of Environment and Energy). 1994. Water Management Policies, Guidelines, and Provincial Water Quality Objectives of the Ministry of Environment and Energy. PIBS 3303E. Queen's Printer for Ontario. 64 p. https://dr6j45jk9xcmk.cloudfront.net/documents/3016/moeprovincialwaterqualityobjectivesen.pdf

PLUARG (Pollution from Land Use Activities Reference Group). 1978. Environmental Management Strategy for the Great Lakes System: Final Report to the International Joint Commission from the International Reference Group on Great Lakes Pollution from Land Use Activities. International Joint Commission, Windsor, Ontario. xx + 115 p. http://www.ijc.org/files/publications/ID462.pdf

Preston, S.D., V.J. Bierman, and S.E. Silliman. 1989. An evaluation of methods for the estimation of tributary mass loads. Water Resources Research 25(6): 1379-1389.

Richards, R.P. 1998. Estimation of Pollutant Loads in Rivers and Streams: A Guidance Document for NPS Programs. Water Quality Laboratory, Heidelberg College, Tiffin, Ohio. 134 p. http://141.139.110.110/sites/default/files/jfuller/images/Load_Est1.pdf

Schnaithmann, J., A. Gutteridge, H. Brock, and M. Veliz. 2013. Main Bayfield Watershed Plan. Ausable Bayfield Conservation Authority, Exeter, Ontario. iv + 39 p. http://www.healthylakehuron.ca/docs/Main-Bayfield-Watershed-Plan-FINAL.pdf

Simmons, J., B. Upsdell Wright, M. Veliz, and K. McKague. 2013. A Synthesis Report of the Watershed Based Best Management Practices Evaluation, Huron. Ausable Bayfield Conservation Authority, Exeter, Ontario. iii + 33 p. http://www.abca.on.ca/downloads/WBBE-Huron-Synthesis-2013-09-16.pdf

Smith, D.R., K.W. King, and M.R. Williams. 2015. What is causing the harmful algal blooms in Lake Erie? Journal of Soil and Water Conservation 70(2): 27A-29A.

Sprague, L.A. and D.L. Lorenz. 2009. Regional nutrient trends in streams and rivers of the United States, 1993-2003. Environmental Science and Technology 43: 3430-3435.

Stammler, K.L., Taylor, W.D., and M.N. Mohamed. 2017. Long-term decline in stream total phosphorus concentrations: A pervasive pattern in all watershed types in Ontario. Journal of Great Lakes Research 43(5): 930-937.

Tate, K. W., R. A. Dahlgren, M. J. Singer, B. Allen-Diaz, and E. R. Atwill. 1999. Timing, frequency of sampling affect accuracy of water-quality monitoring. California Agriculture 53(6): 44-49.

Upsdell Wright, B., M. Veliz, and T. Skinner. 2015a. Water Quality Monitoring Guidance Manual for the Healthy Lake Huron Initiative. Ausable Bayfield Conservation Authority, Exeter, Ontario. ii + 17 p.

Upsdell Wright, B.L., E.J. Wilson, M. Veliz, and I.W. Heathcote. 2015b. Proceedings of the Sharing Loading Estimation Experiences Workshop, Guelph, Ontario, January 20, 2015. Ausable Bayfield Conservation Authority, Exeter, Ontario. i + 23 p. http://abca.iwebsmart.net/downloads/Loading-Workshop-Proceedings.pdf

Upsdell Wright, B., and M. Veliz. 2013. Water Quality Monitoring for the Watershed Based Best Management Practices Evaluation, Huron. Ausable Bayfield Conservation Authority, Exeter, Ontario. iii + 32 p. http://www.abca.on.ca/downloads/WBBE-Huron-Water-Quality-Monitoring-2013-09-09.pdf

Van Zwol, J., M. Andreae, and E. Carroll. 2012. Lambton Shores Tributaries Management Plan – Duffus and Ipperwash East Drains. St. Clair Region Conservation Authority, Strathroy, Ontario. 22 p. http://www.healthylakehuron.ca/docs/Lambton_Shores_Management_Plan_Final_-_June_2012_1.pdf

Watershed Evaluation Group (WEG). 2017a. SWAT Modelling and Assessment of Agricultural BMPs in the Garvey-Glenn Watershed. University of Guelph. 86 pp.

Watershed Evaluation Group (WEG). 2017b. SWAT Modelling and Assessment of Agricultural BMPs in the Gully Creek Watershed. University of Guelph. 119 pp.

Williams, M.R., K.W. King, M.L. Macrae, W. Ford, C. Van Esbroeck, R.I. Brunke, M.C. English, and S.L. Schiff. 2015. Uncertainty in nutrient loads from tile-drained landscapes: effect of sampling frequency, calculation algorithm, and compositing strategy. Journal of Hydrology 530: 306-316.

Yang, W., Y. Liu, J. Simmons, A. Oginskyy, and K. McKague. 2013. SWAT Modelling of Agricultural BMPs and Analysis of BMP Cost Effectiveness in the Gully Creek Watershed. Ausable Bayfield Conservation Authority. Exeter, Ontario. 161 pp. http://www.abca.on.ca/downloadfile.php?Item=291

Zamyadi, A., J. Gallichand, and M. Duchemin. 2007. Comparison of methods for estimating sediment and nitrogen loads from a small agricultural watershed. Canadian Biosystems Engineering 49(1-2): 127-136.

Appendix A: Monitoring Stations

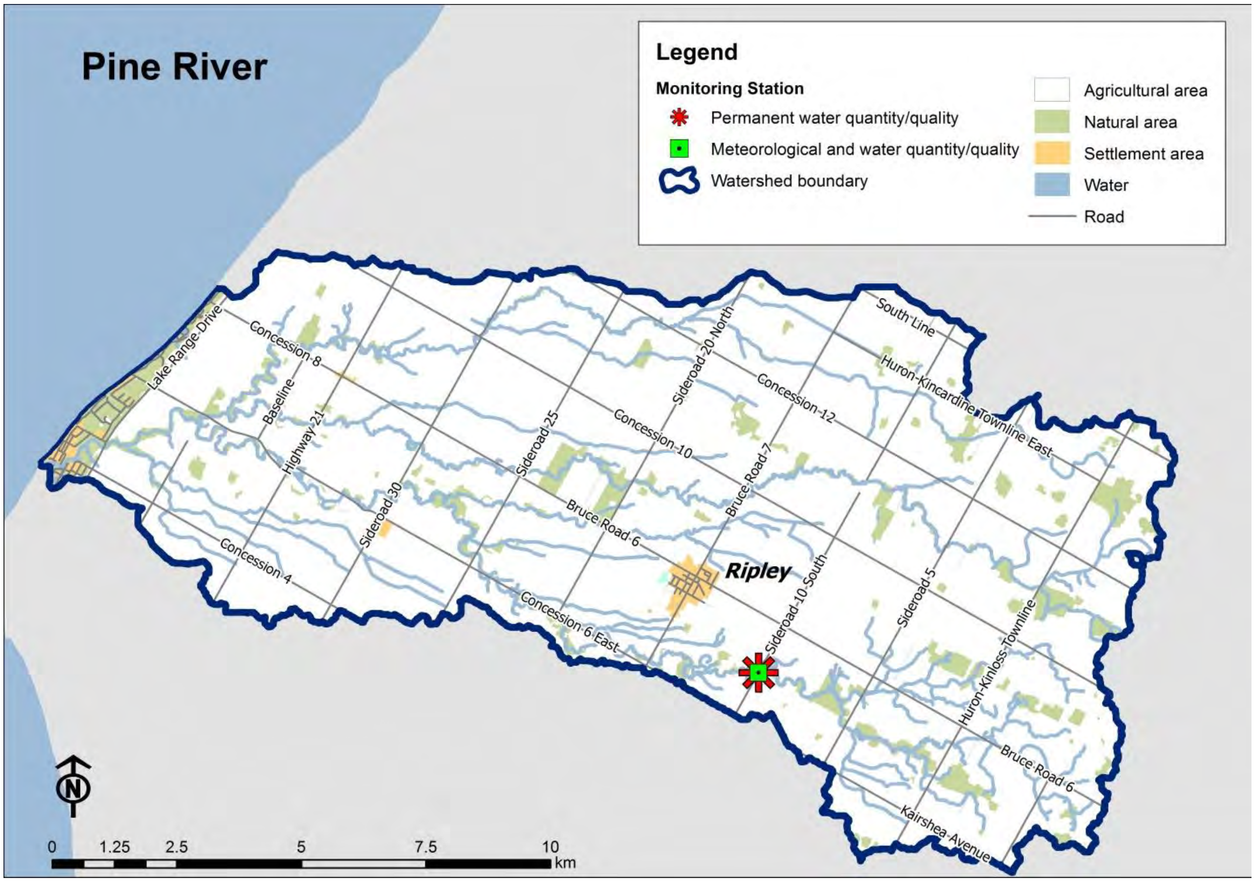

Figure A-1: Location of the water quantity/quality monitoring station (red) in South Pine River.

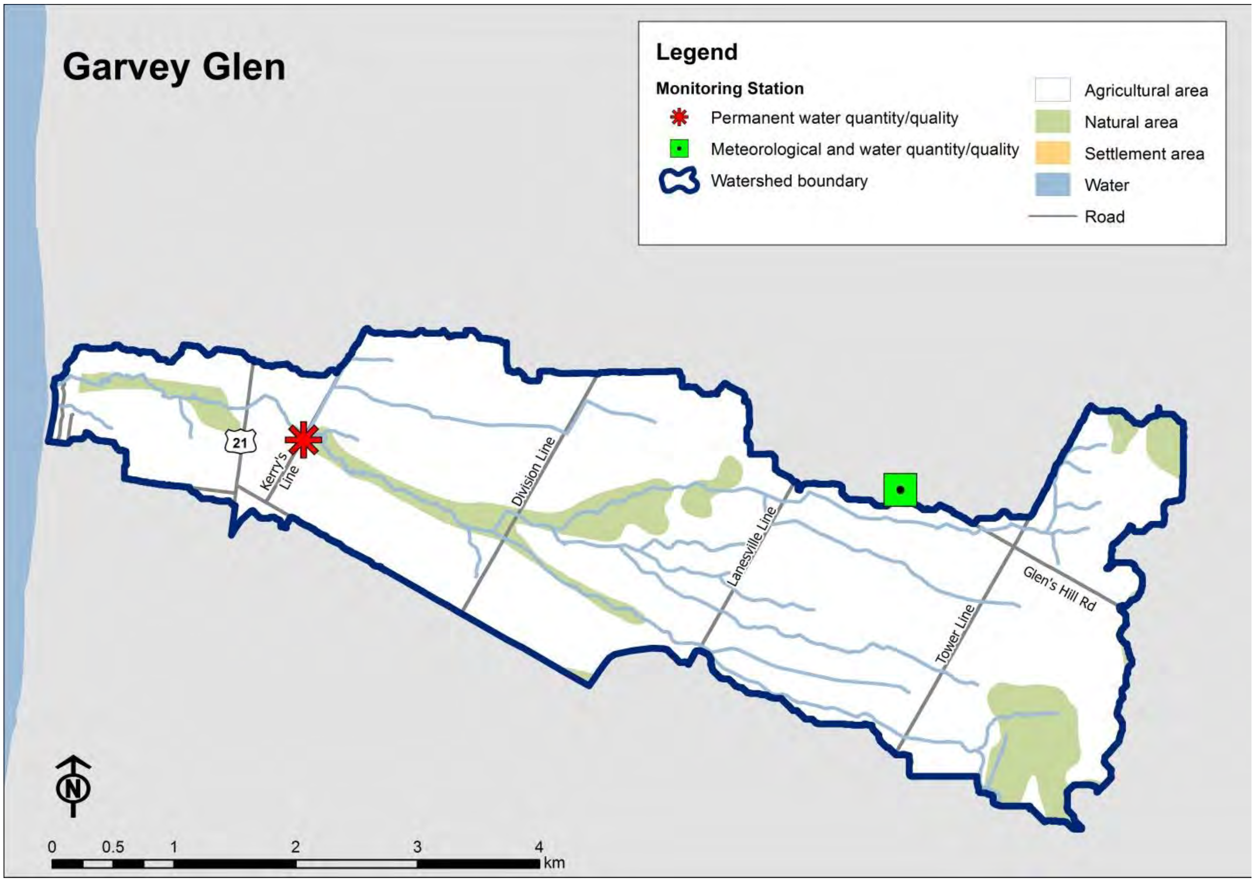

Figure A-2: Location of the water quantity/quality monitoring station (red) in Garvey Creek/Glenn Drain.

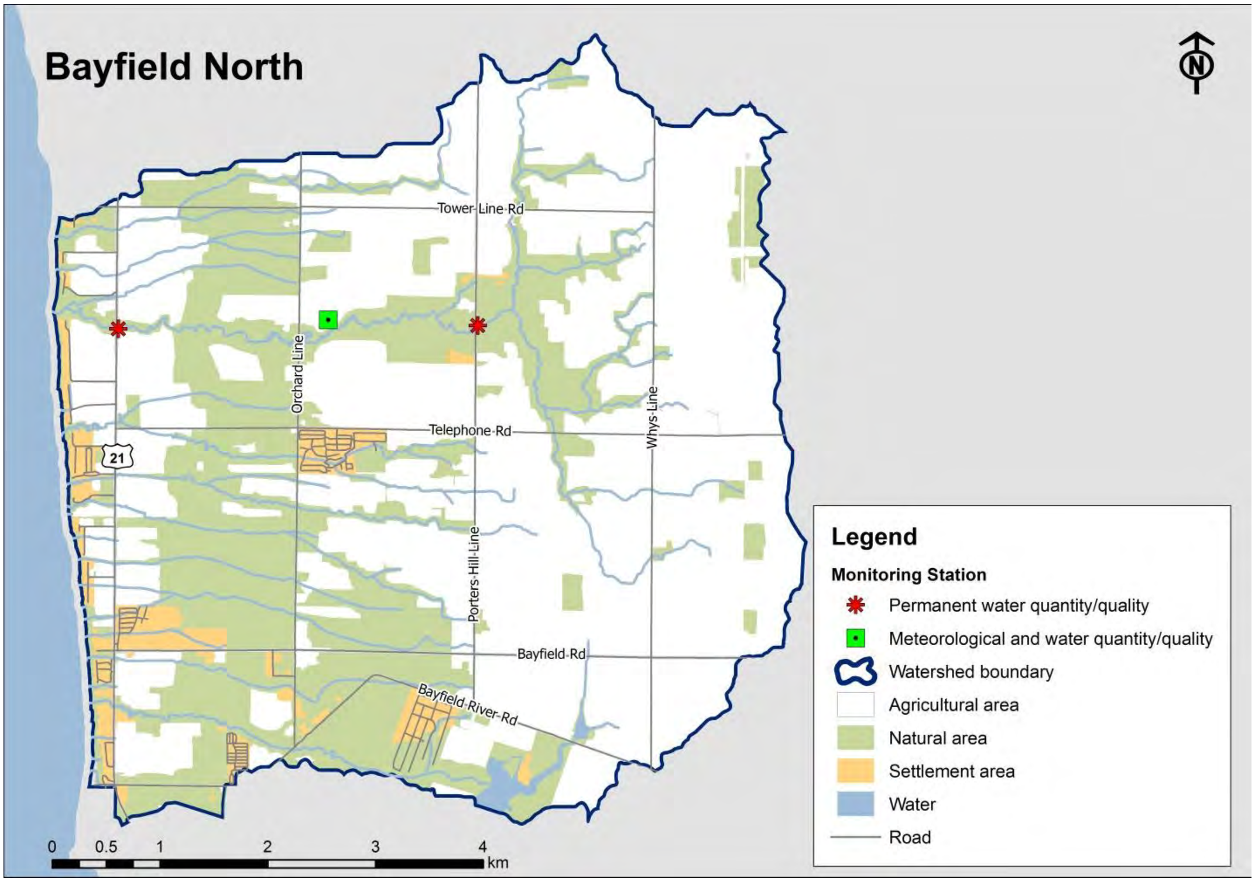

Figure A-3: Location of the water quantity/quality monitoring stations (red) in Gully Creek.

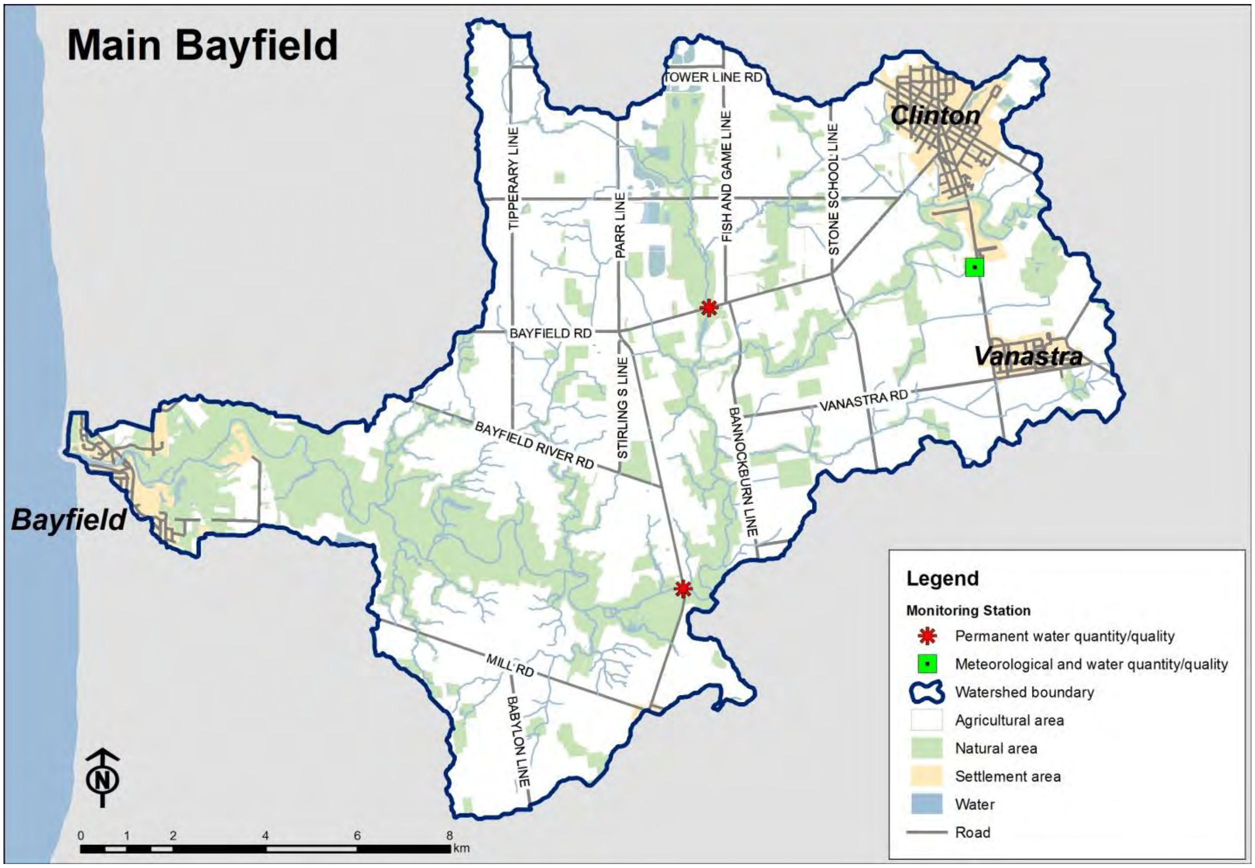

Figure A-4: Location of the water quantity/quality monitoring station (red) in Bayfield River and Trick's Creek.

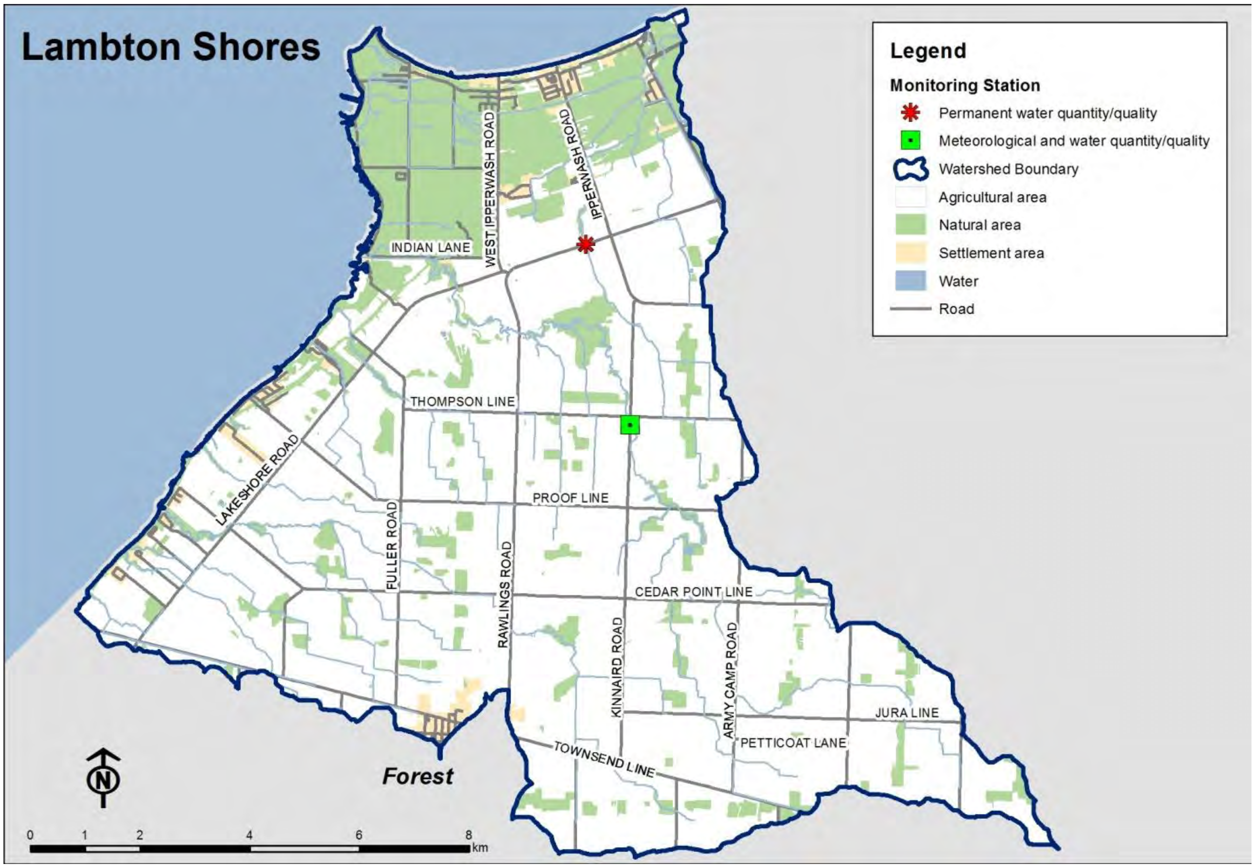

Figure A-5: Location of the water quantity/quality monitoring station (red) in Shashawandah Creek.

Appendix B: Phosphate-Phosphorus Flow-Weighted Mean Concentrations

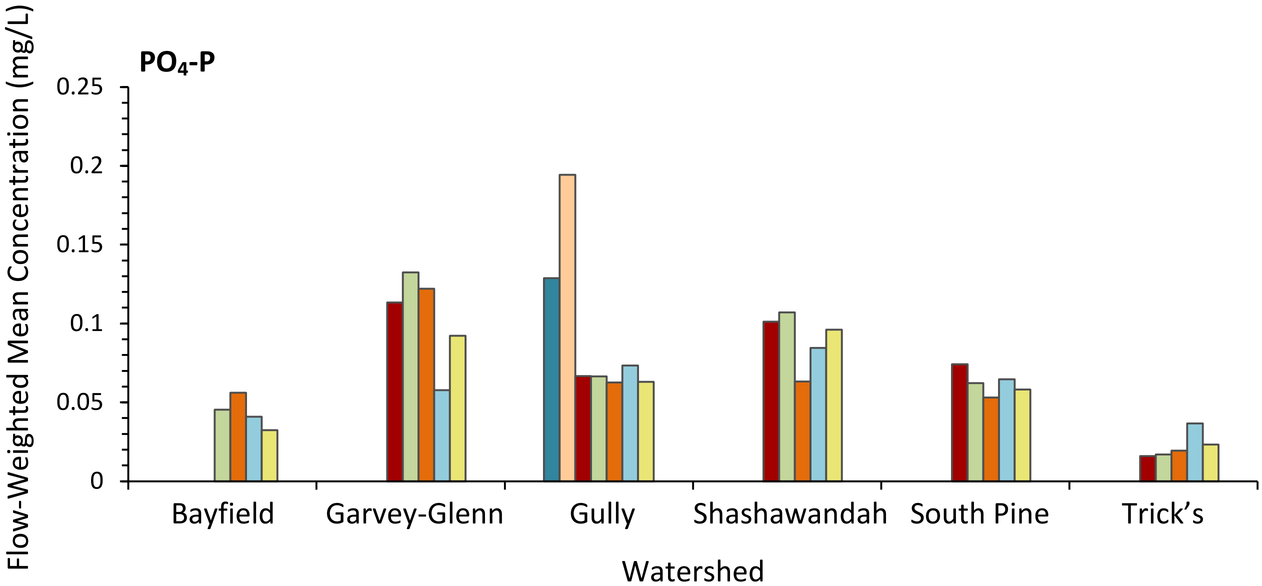

Figure B-1: Annual flow-weighted mean phosphate-P concentrations in the Healthy Lake Huron watersheds (October 2010 to September 2017). Notes: GULGUL5 monitoring station data were used to estimate FWMC for the 2012 to 2016 water years. GULGUL2 monitoring station data were used for the 2011 water year.

Appendix C: Phosphate-Phosphorus Total Loads

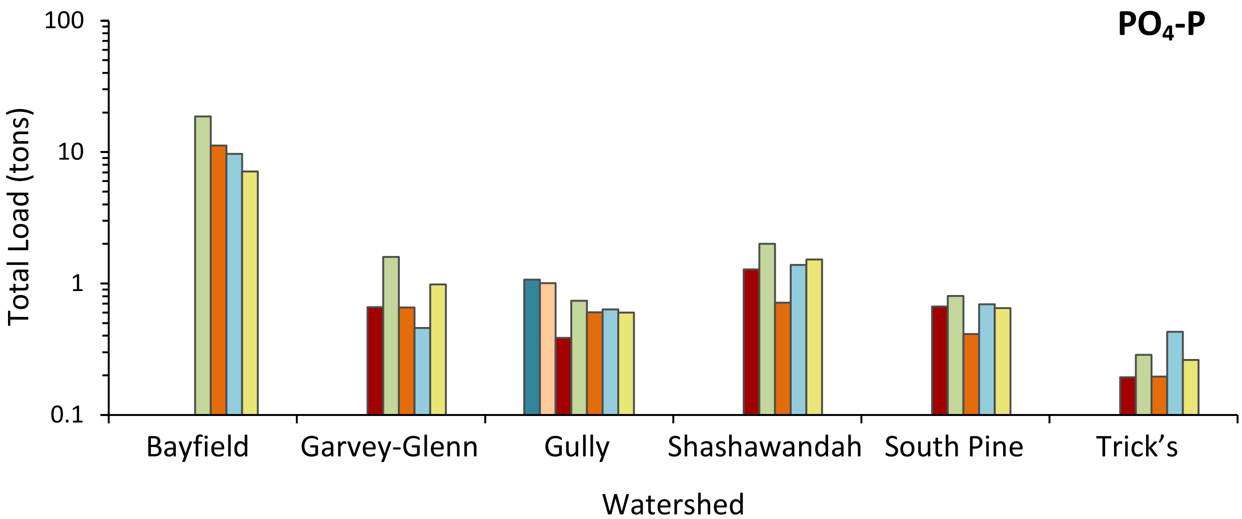

Figure C-1: Annual phosphate-P loads in the Healthy Lake Huron watersheds (October 2010 to September 2016). Notes: GULGUL5 monitoring station data were used to estimate FWMC for the 2012 to 2016 water years. GULGUL2 monitoring station data were used for the 2011 water year.

Appendix D: Phosphate-Phosphorus Mass Export Coefficients

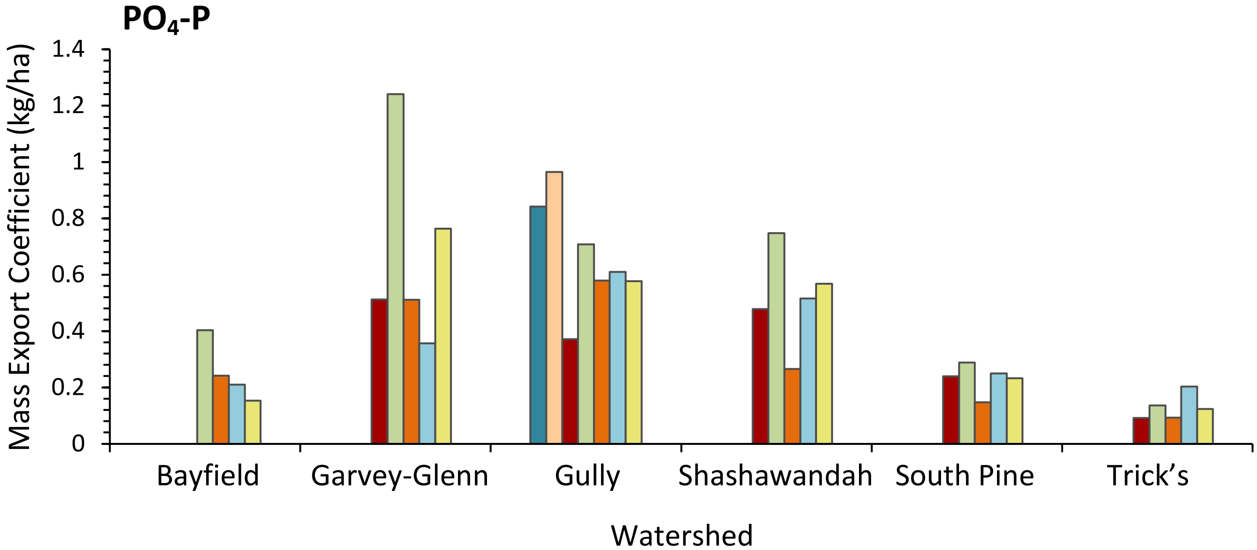

Figure D-1: Annual phosphate-phosphorus mass export coefficients in the Healthy Lake Huron watersheds (October 2010 to September 2016). Notes: GULGUL5 monitoring station data were used to estimate FWMC for the 2012 to 2016 water years. GULGUL2 monitoring station data were used for the 2011 water year.

Appendix E: Trends in Monthly Flow-Weighted Mean Concentrations

Bayfield

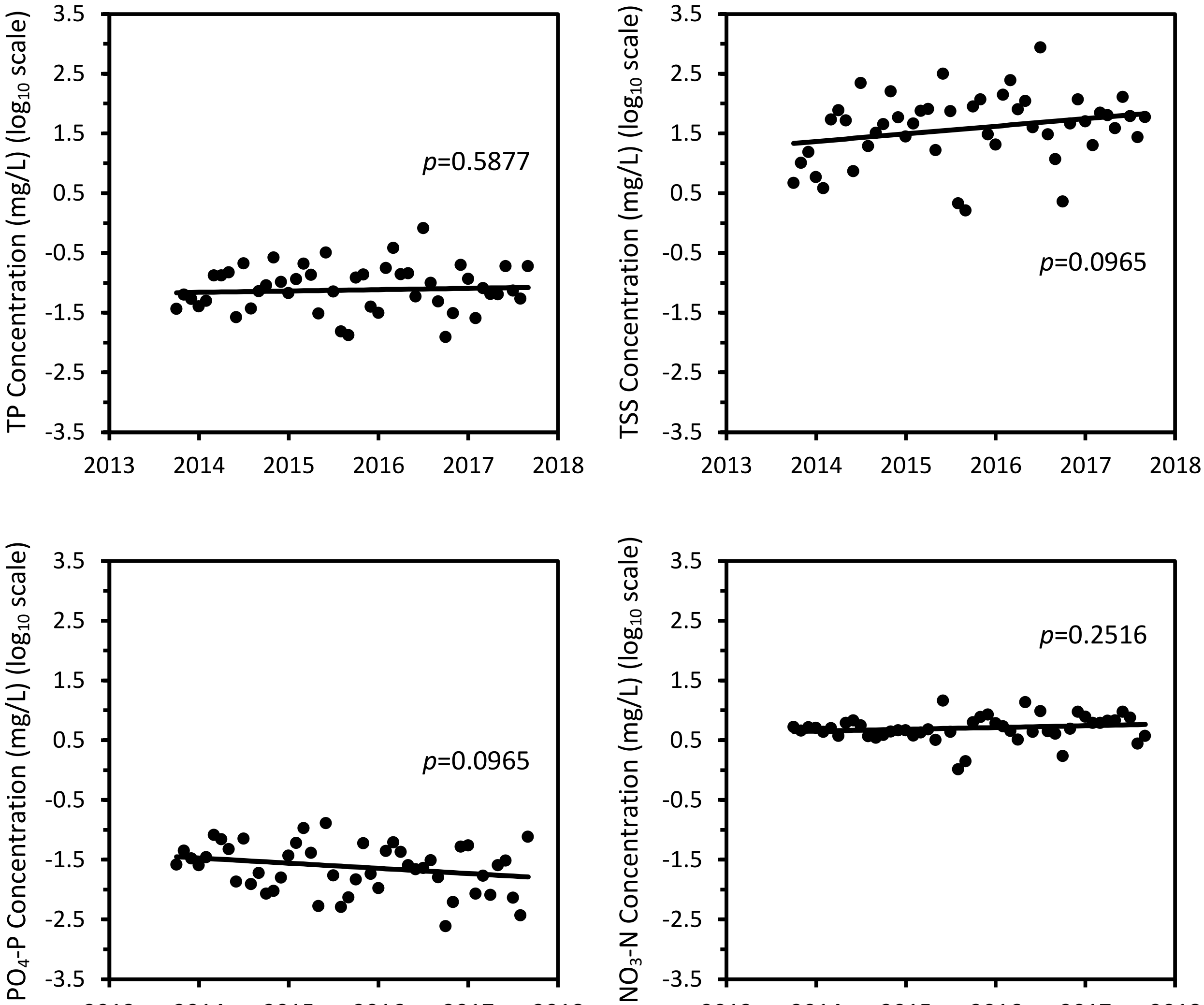

Figure E-1: Water quality trends in monthly flow-weighted mean concentrations for Bayfield River (October 2013 to September 2017).

Garvey-Glenn

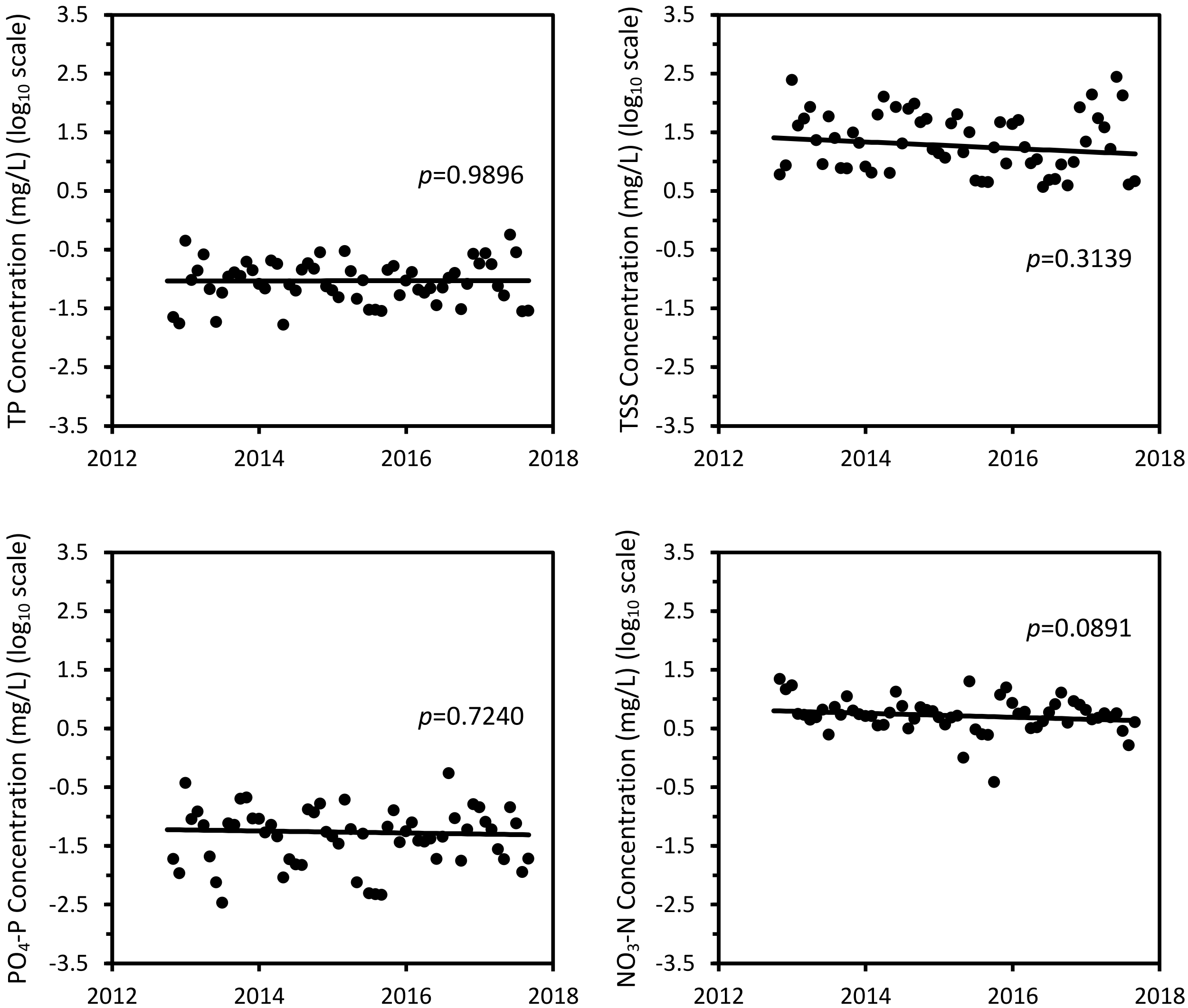

Figure E-2: Water quality trends in monthly flow-weighted mean concentrations for Garvey-Glenn Drain (November 2012 to September 2017).

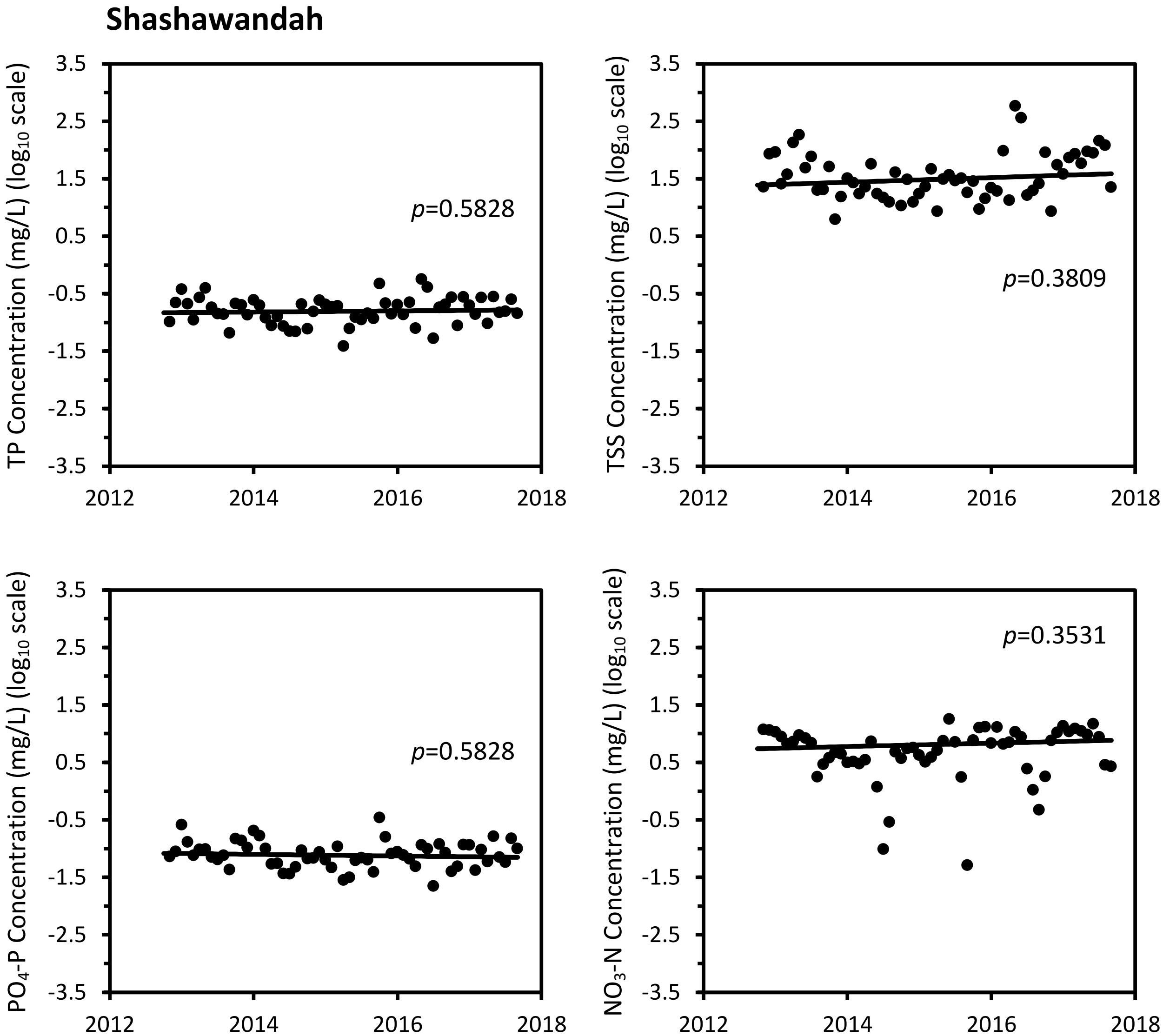

Figure E-3: Water quality trends in monthly flow-weighted mean concentrations for Shashawandah Creek (November 2012 to September 2017).

South Pine

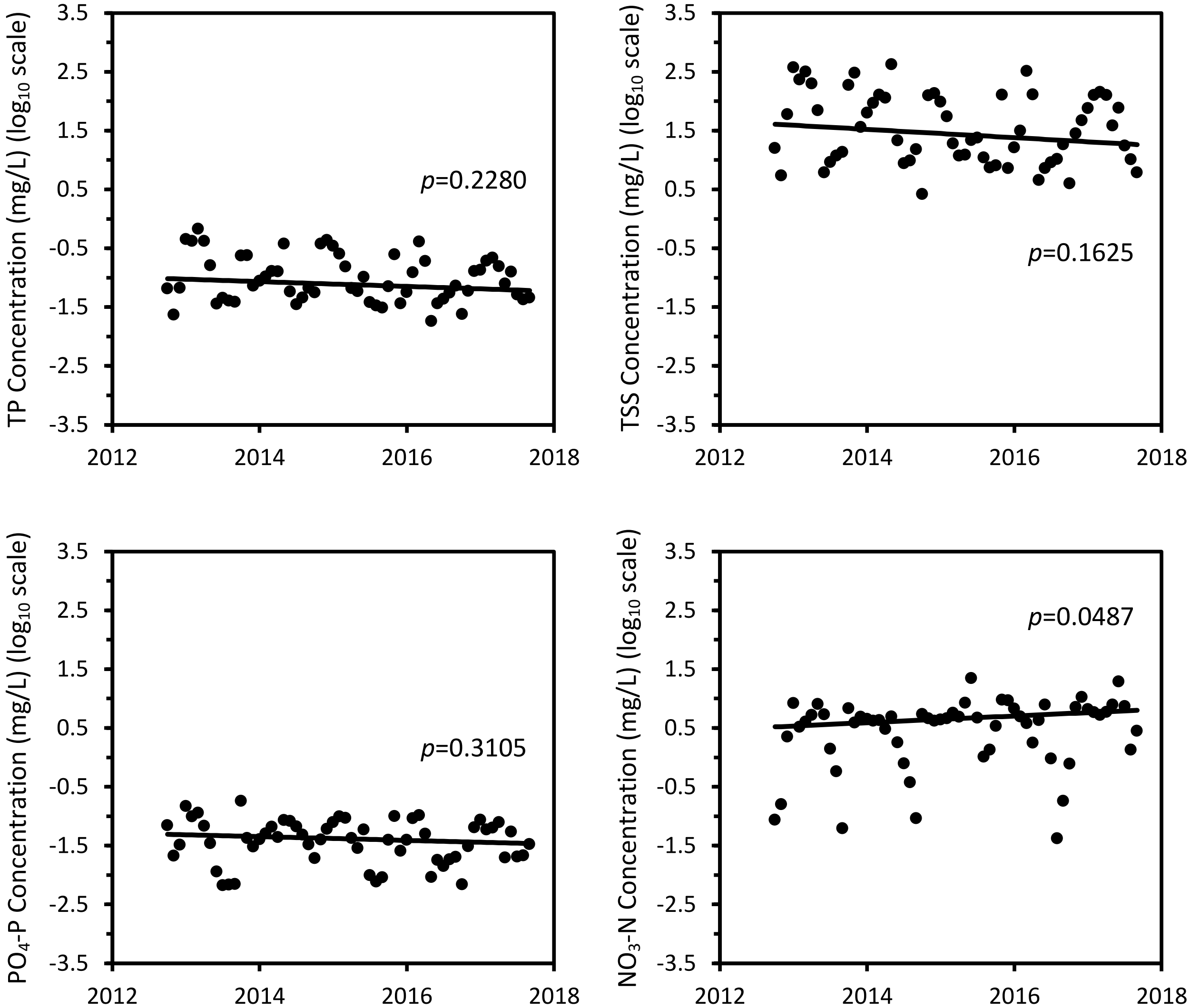

Figure E-4: Water quality trends in monthly flow-weighted mean concentrations for South Pine River (October 2012 to September 2017).

Trick's

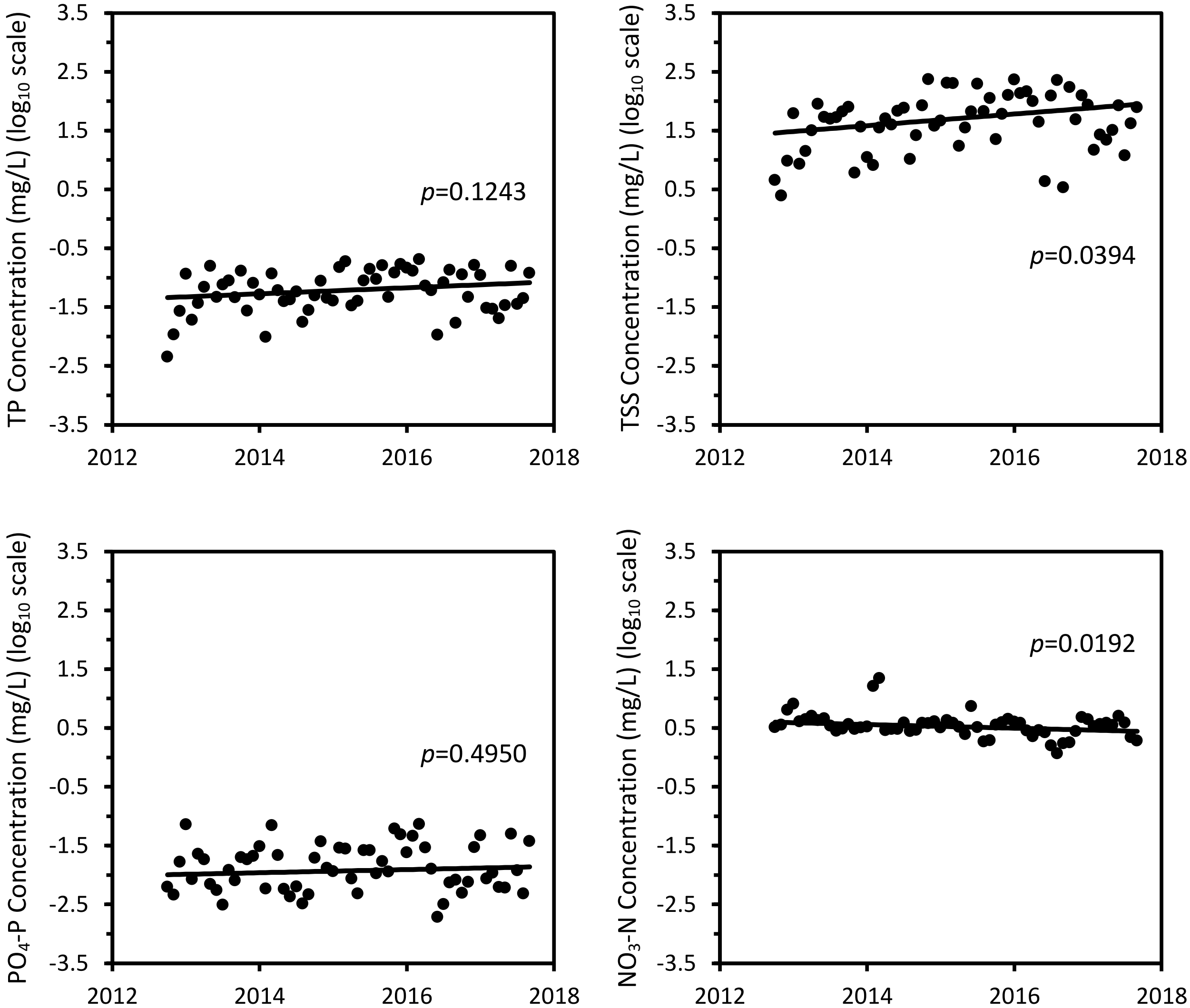

Figure E-5: Water quality trends in monthly flow-weighted mean concentrations for Trick's Creek (October 2012 to September 2017).

Appendix F: Trends in Flow-Adjusted Concentrations

Bayfield River

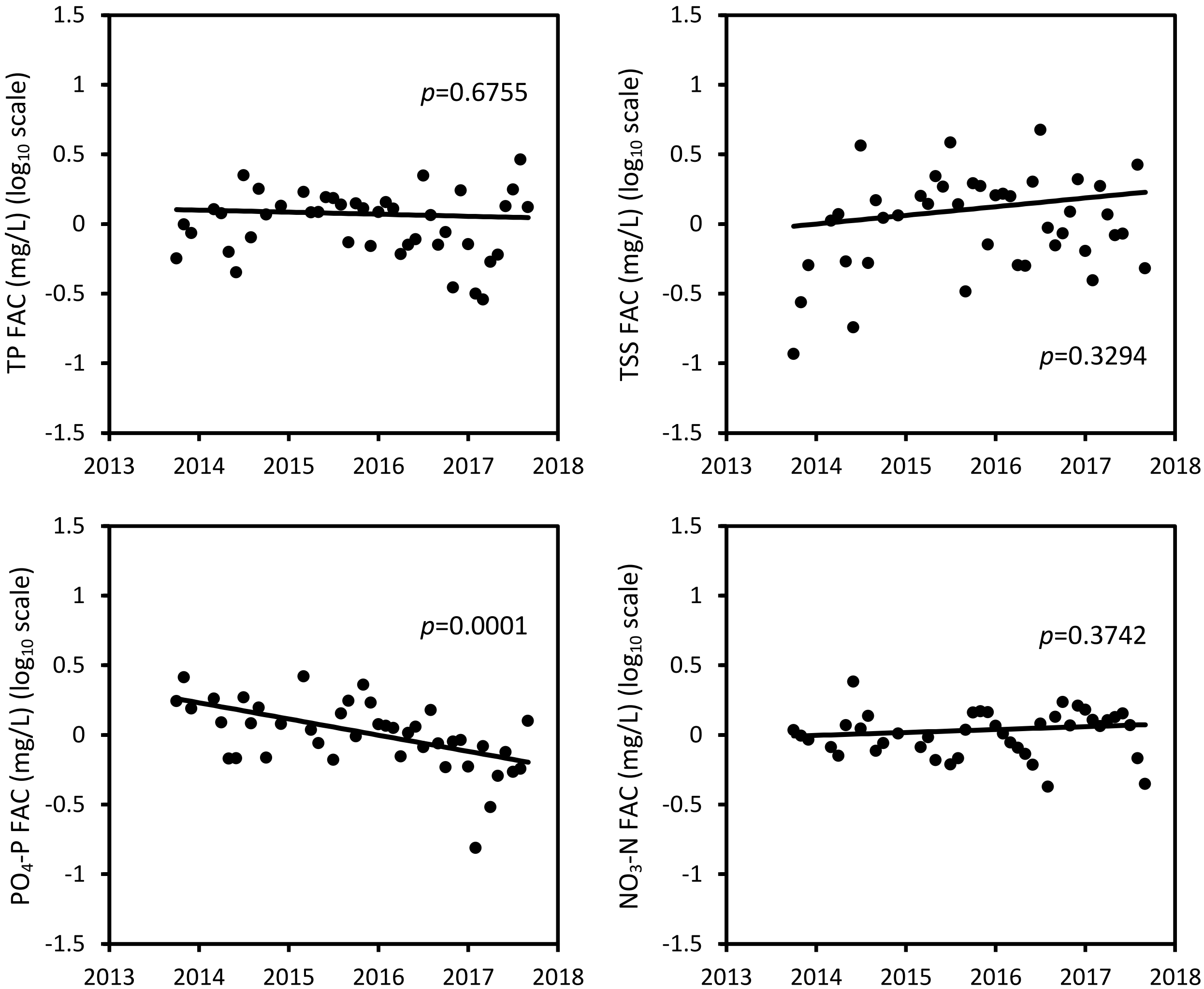

Figure F-1: Water quality trends in median monthly flow-adjusted concentrations for Bayfield River (October 2013 to September 2017).

Garvey-Glenn Drain

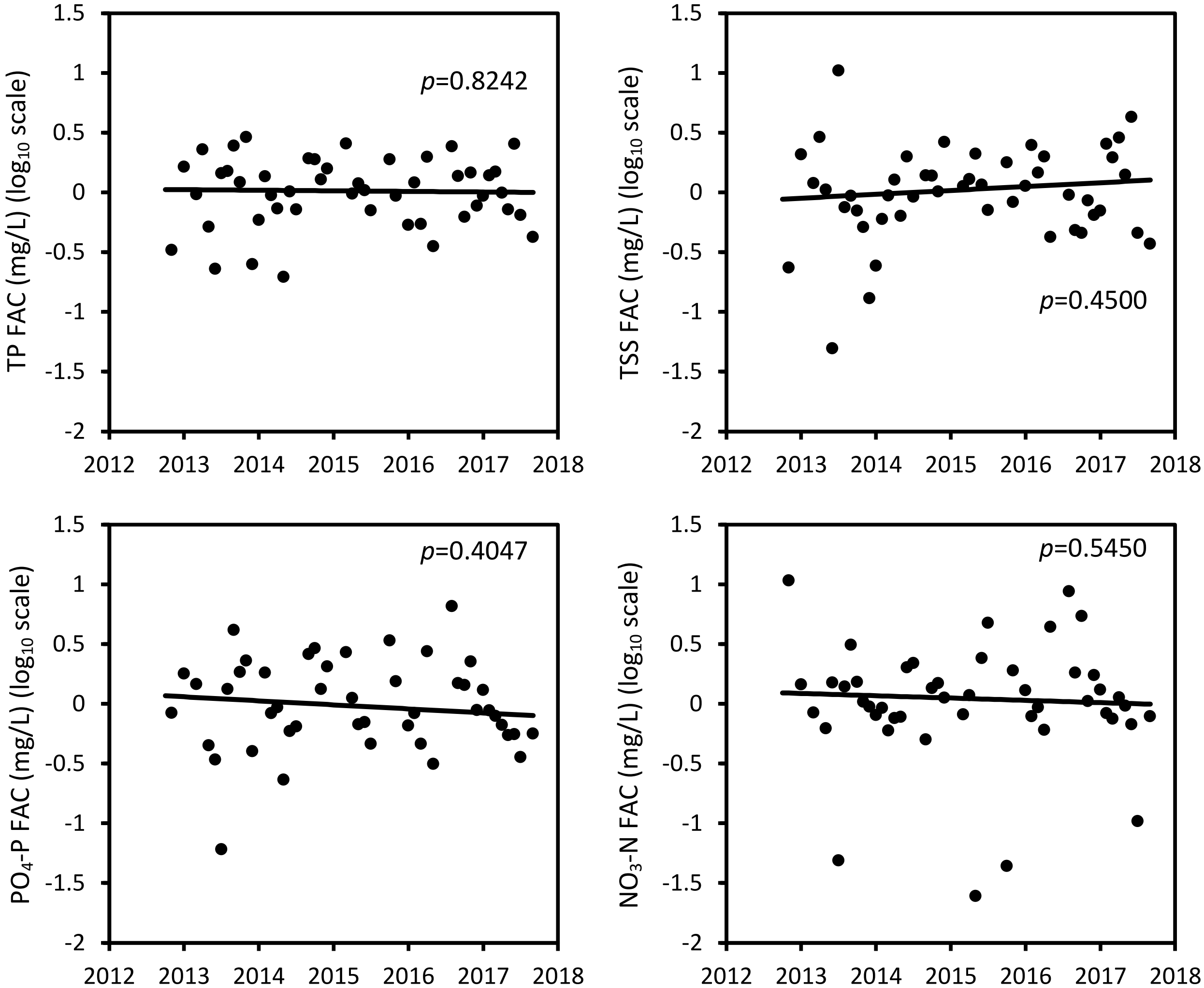

Figure F-2: Water quality trends in median monthly flow-adjusted concentrations for Garvey-Glenn Drain (October 2012 to September 2017).

Shashawandah Creek

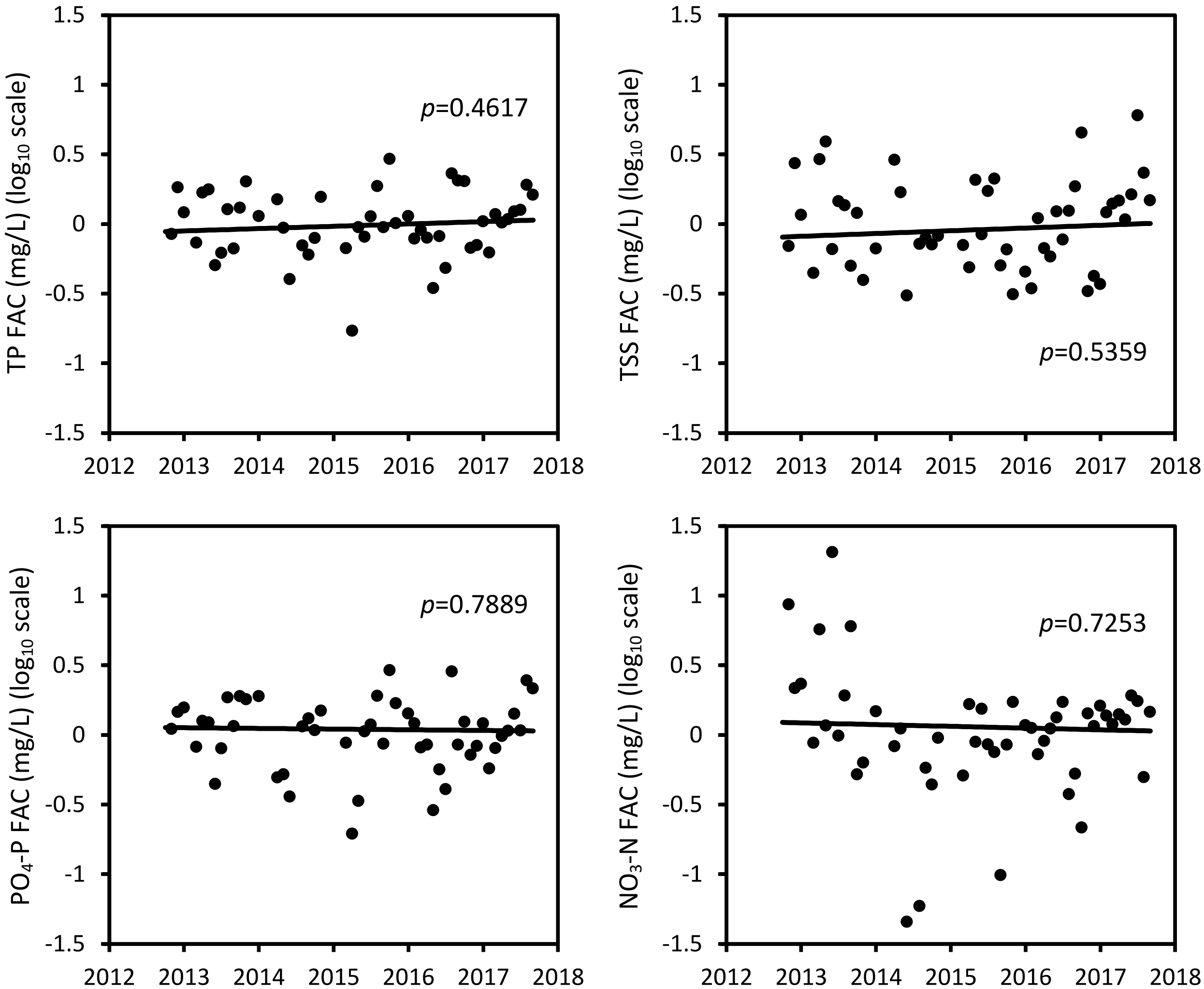

Figure F-3: Water quality trends in median monthly flow-adjusted concentrations for Shashawandah Creek (October 2012 to September 2017).

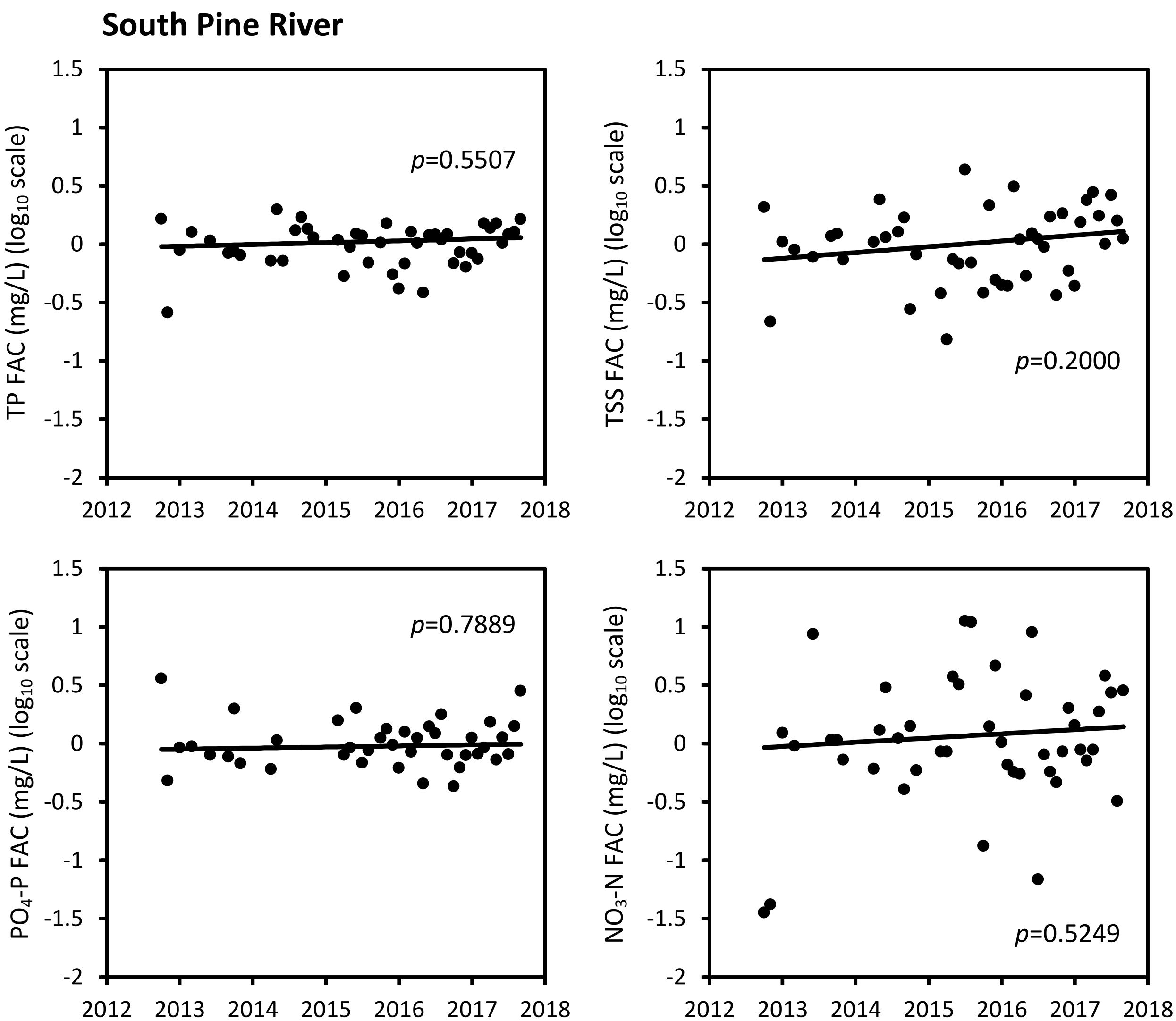

Figure F-4: Water quality trends in median monthly flow-adjusted concentrations for South Pine River (October 2012 to September 2017).

Appendix G: Trends in Monthly Loads

Bayfield

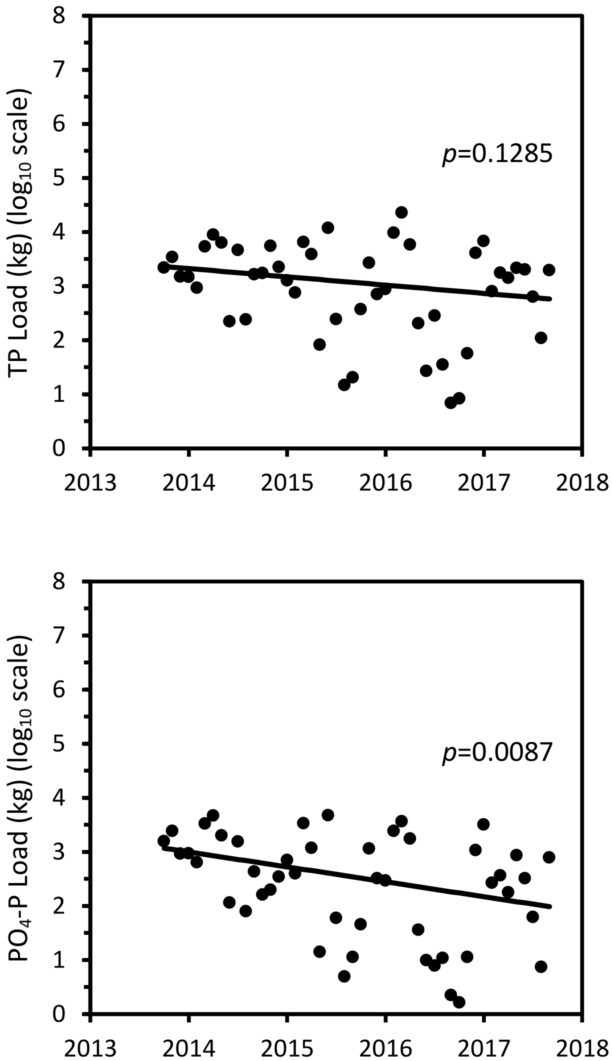

Figure G-1: Water quality trends in monthly pollutant loads for Bayfield River (October 2013 to September 2017).

Gully

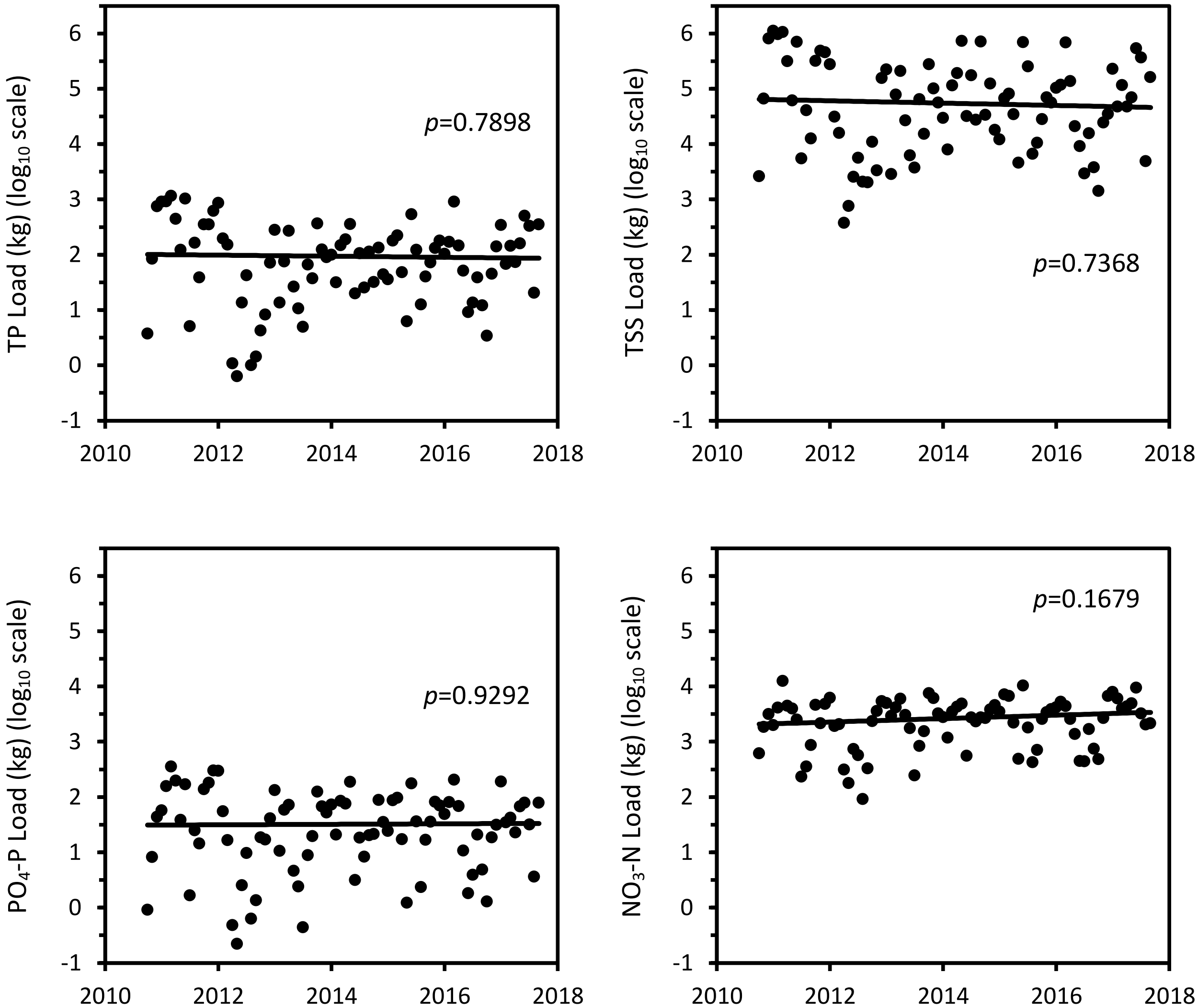

Figure G-2: Water quality trends in monthly pollutant loads for Gully Creek (October 2010 to September 2017).

Garvey-Glenn

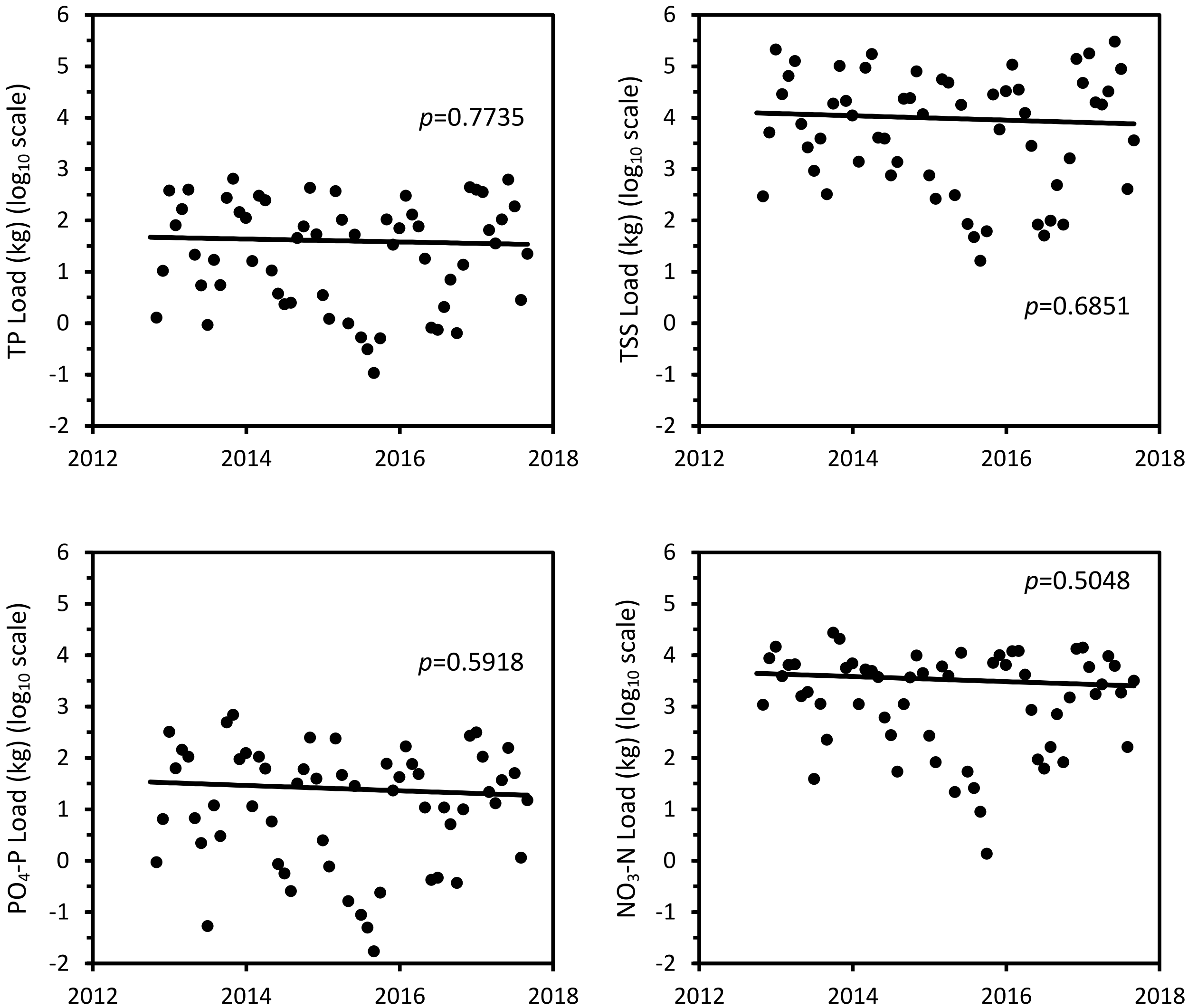

Figure G-3: Water quality trends in monthly pollutant loads for Garvey-Glenn Drain (November 2012 to September 2017).

Shashawandah

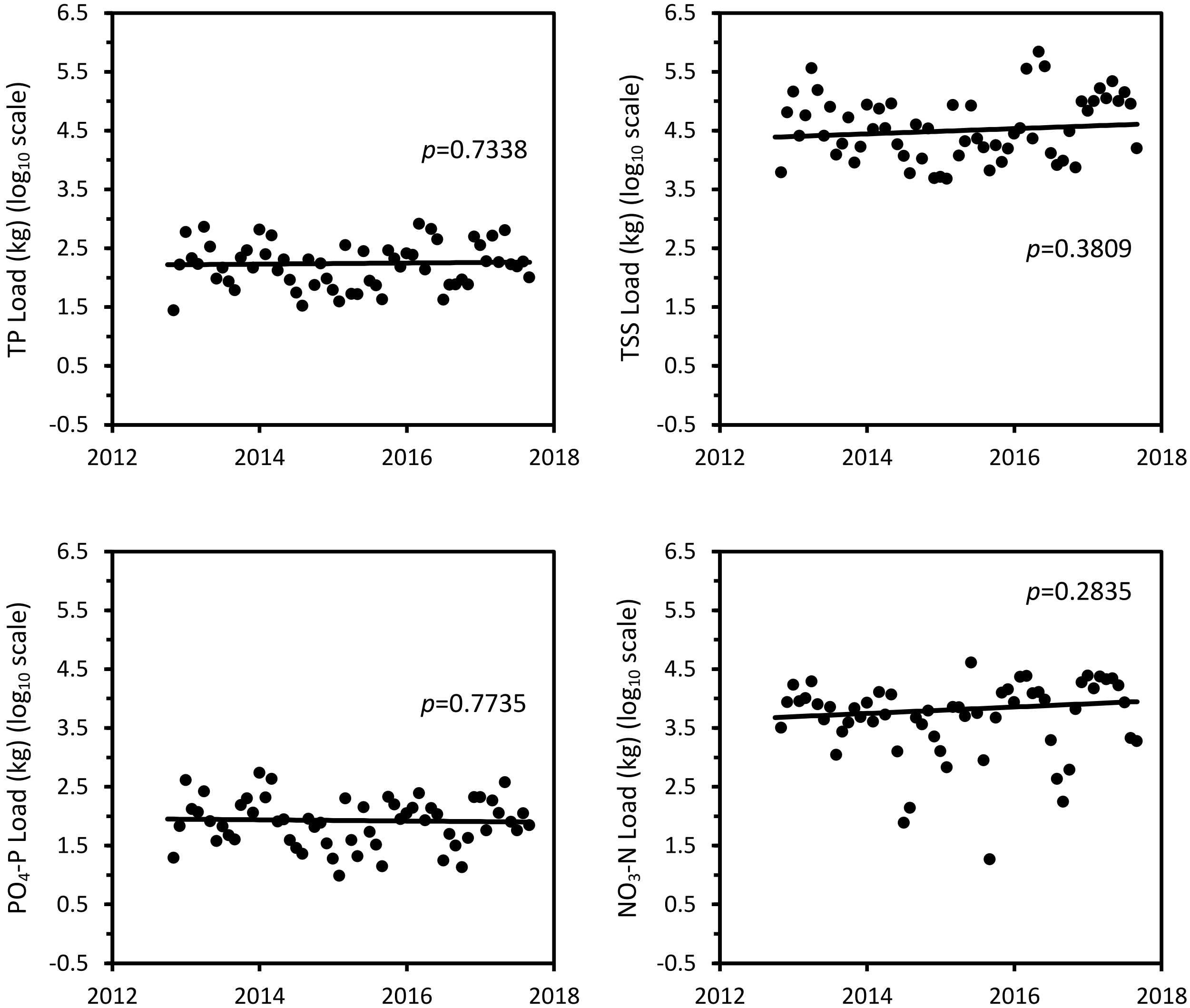

Figure G-4: Water quality trends in monthly pollutant loads for Shashawandah Creek (November 2012 to September 2017).

South Pine

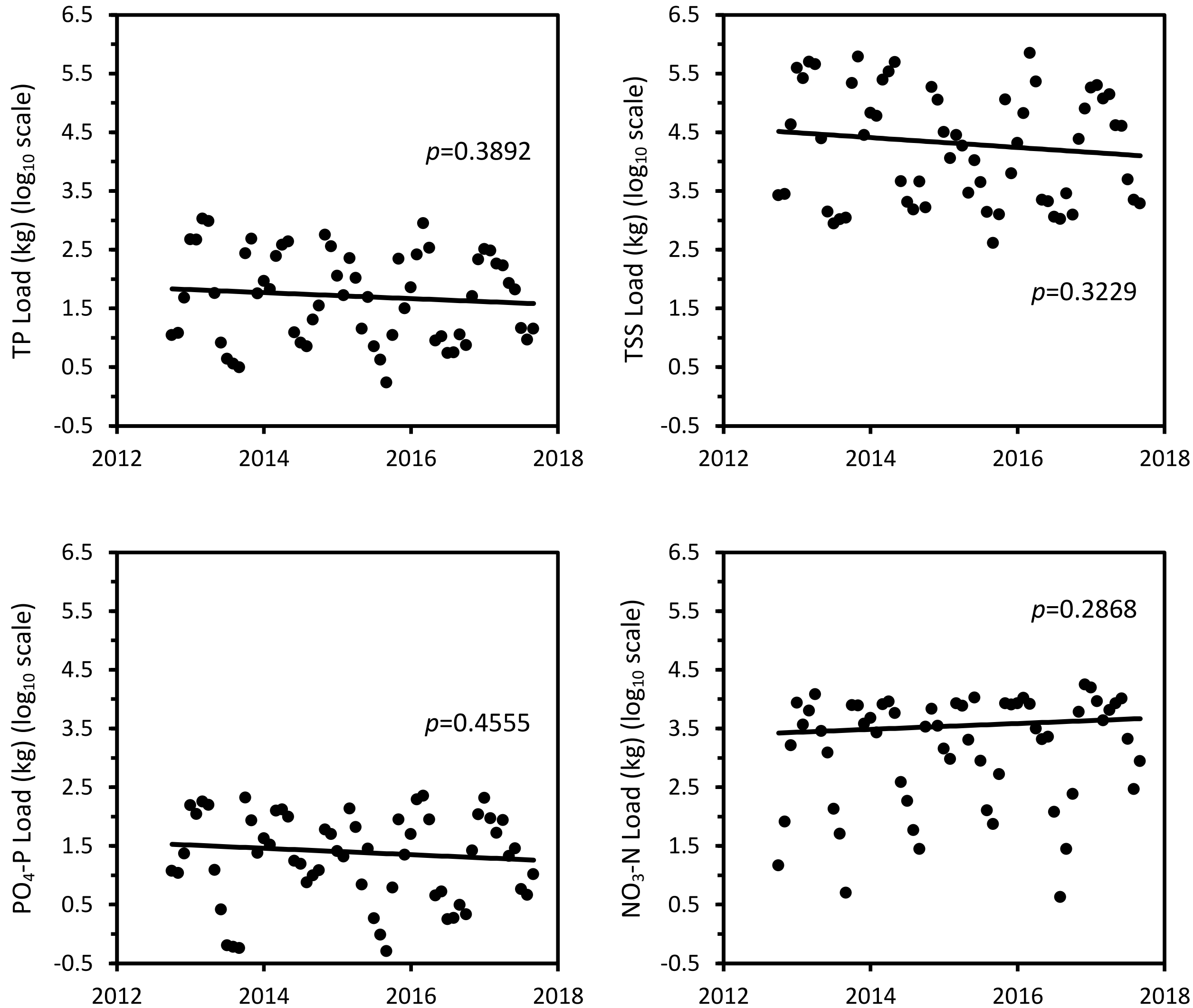

Figure G-5: Water quality trends in monthly pollutant loads for South Pine River (October 2012 to September 2017).

Appendix H: Trends in Monthly Streamflow Volume

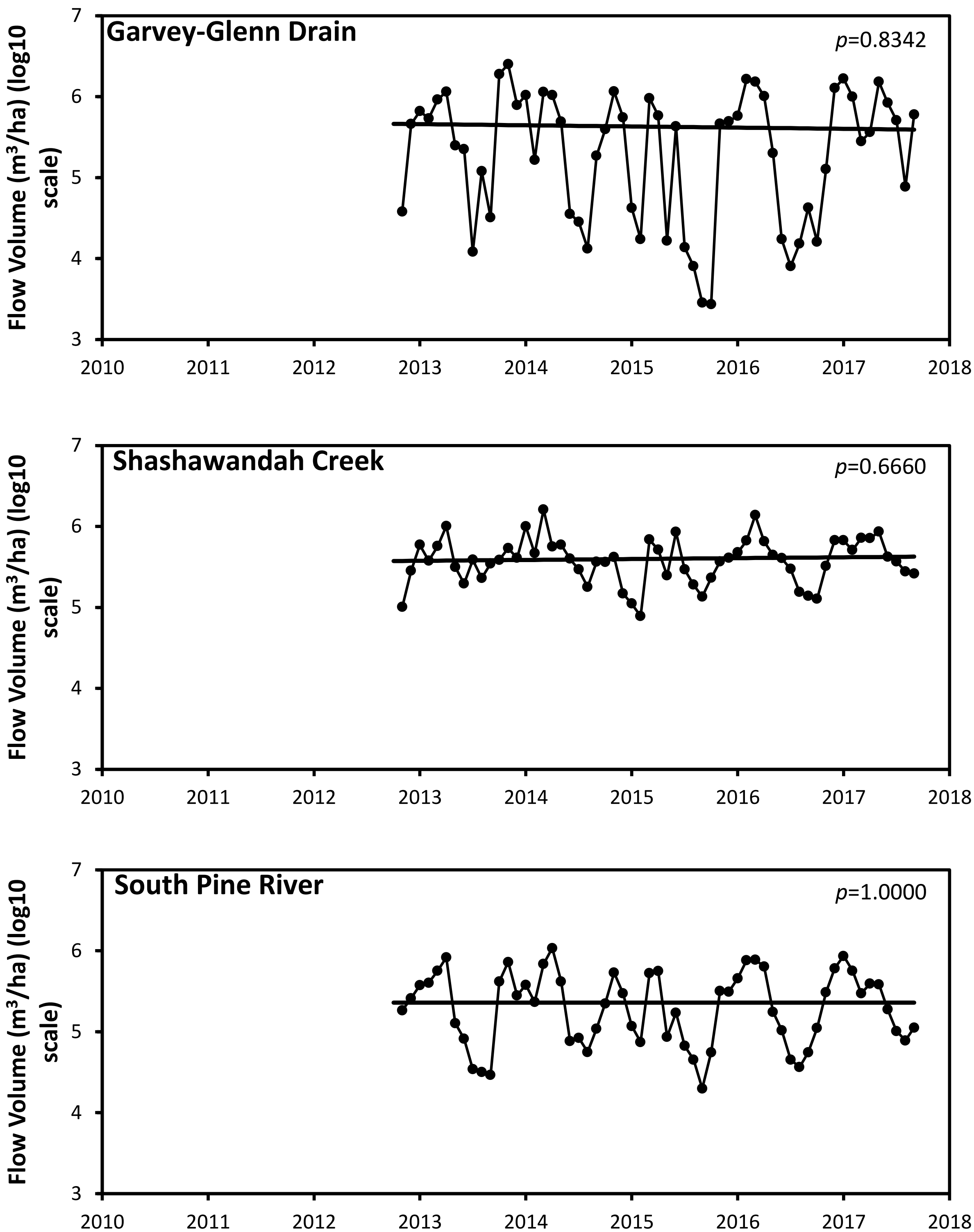

Figure H-1: **Trends in monthly flow volume for Garvey-Glenn Drain, Shashawandah Creek, and South Pine River (October 2010 to September 2017).**

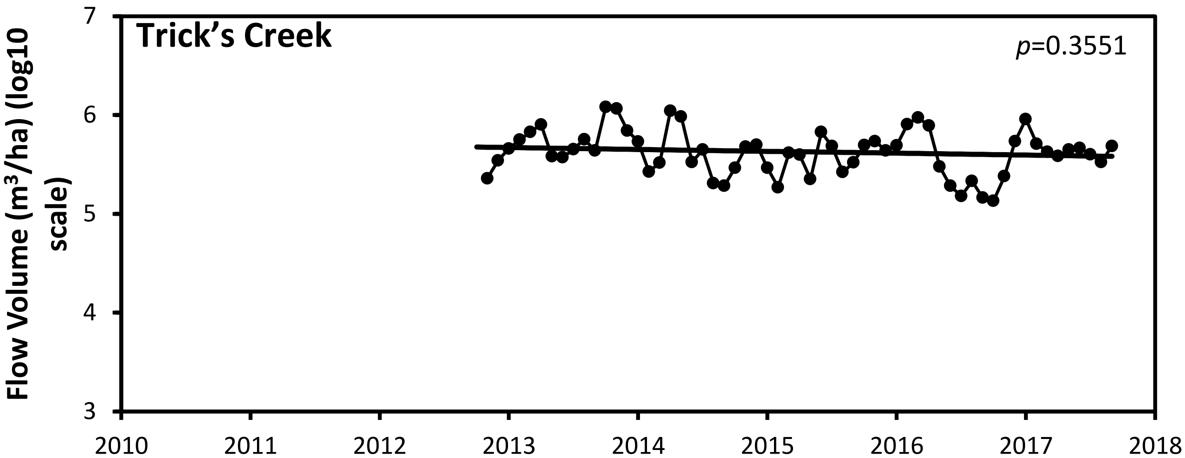

Figure H-2: **Trends in monthly flow volume for Trick's Creek (October 2010 to September 2017).**

Appendix I: Trends in Monthly Stream Flashiness Index

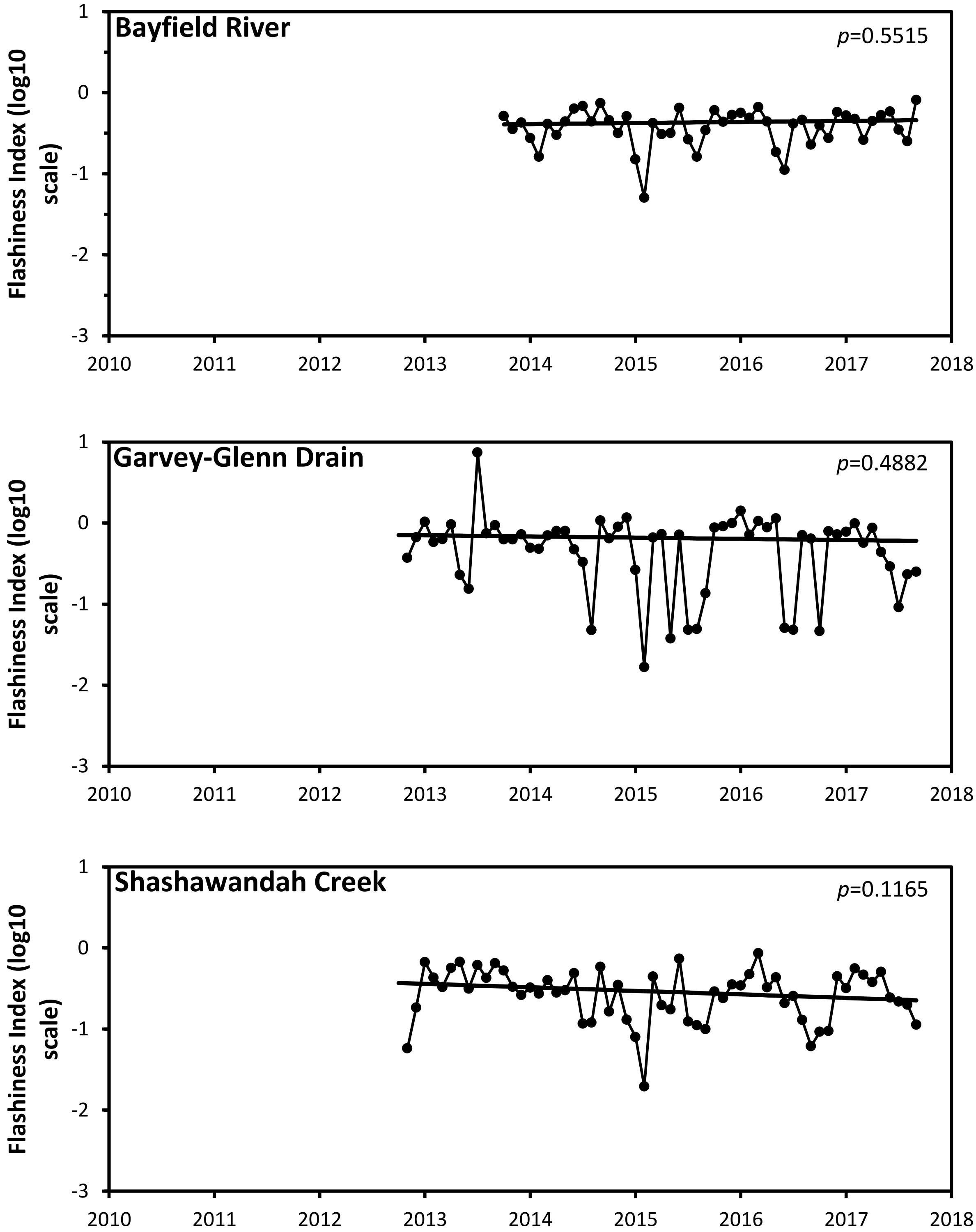

Figure I-1: **Trends in monthly flashiness index for Bayfield River, Garvey-Glenn Drain, and Shashawandah Creek (October 2010 to September 2017).**

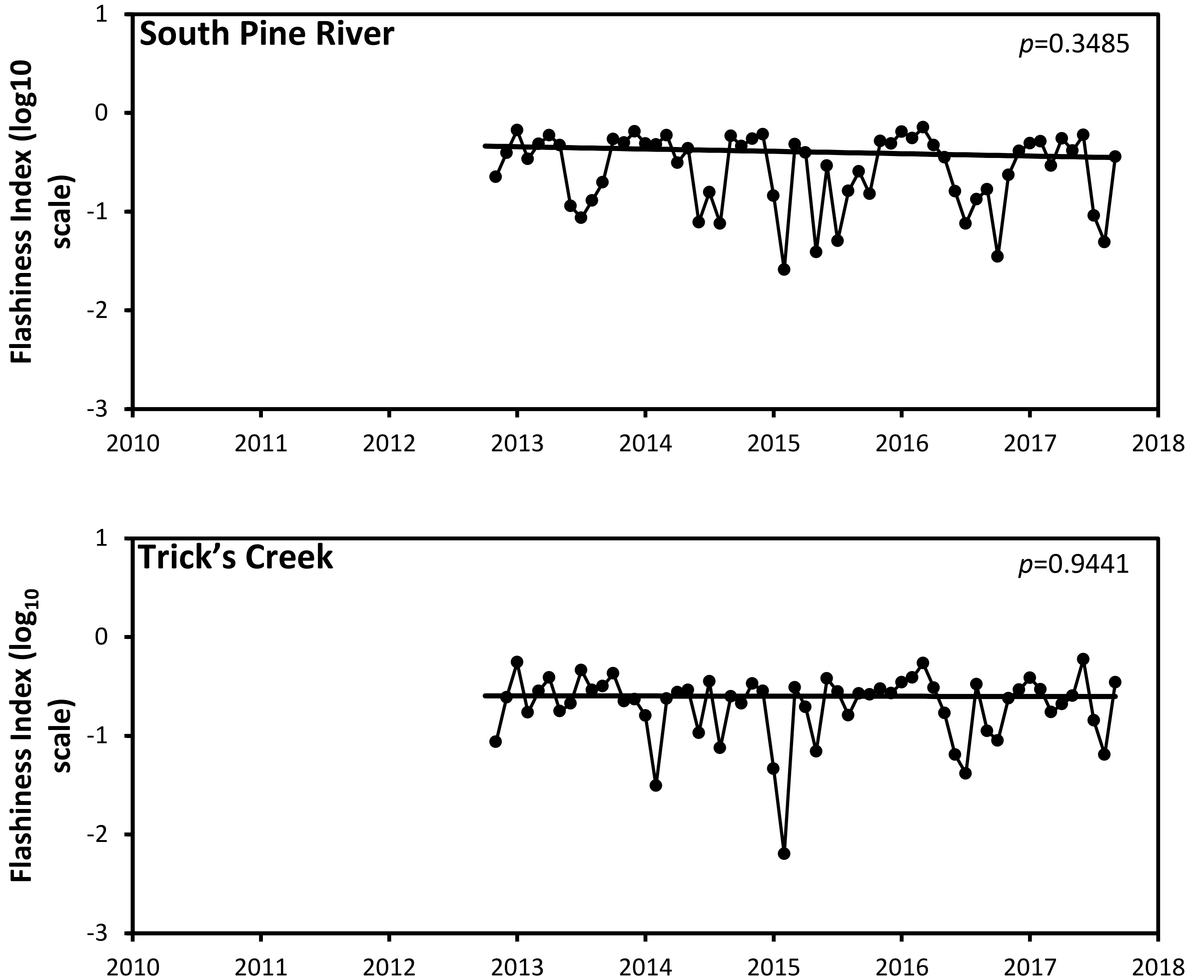

Figure I-2: **Trends in monthly flashiness index for South Pine River and Trick's Creek (October 2010 to September 2017).**

Appendix J: Seasonal Phosphate-Phosphorus Loads Averaged Across All Monitoring Stations

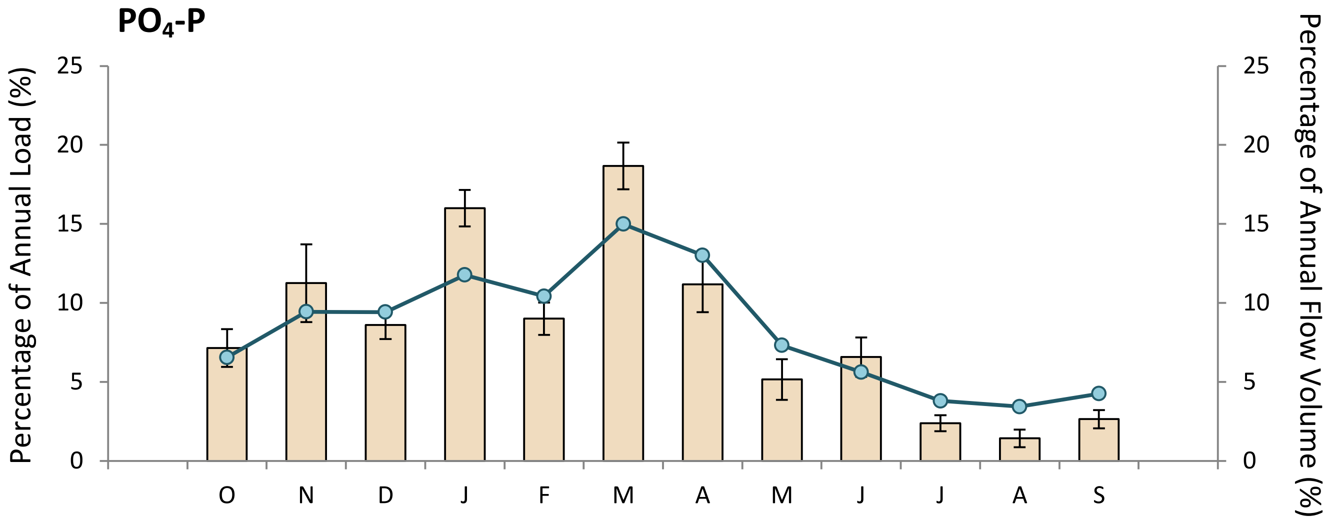

Figure J-1: Percentage of annual load (pale bars, left axis) and percentage of annual flow volume (blue line, right axis) averaged across all of the study streams. Error bars are standard error of the mean, representing variability in annual loads among streams.

Appendix K: Nutrient and Sediment Loads for Three Small Lakeshore Tributaries

Table K-1: Nutrient and sediment loads for three small lakeshore tributaries outside of the priority watersheds (water years 2011 to 2012).

Site ID	Water Quality Indicator Load (kg)							
	TP		PO_4-P		NO_3-N		TSS	
	2011	2012	2011	2012	2011	2012	2011	2012
Spring Creek	-	17	-	3	-	2,829	-	3,884
Ridgeway Drain	3,332	1,012	1,303	633	40,108	14,272	1,526,506	273,681
Zurich Drain	4,775	1,480	834	289	61,251	22,153	7,211,793	1,086,186