Water Quality Monitoring for the Watershed Based Best Management Practices Evaluation, Huron

A report prepared for the Ontario Ministry of Agriculture and Food
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1.0 Introduction

The near-shore area of the Great Lakes provides many residents of Ontario with drinking water and recreational opportunities (*e.g.*, swimming and fishing). However, nutrient, sediment, and bacterial impacts can sometimes limit both the human uses and the ecological integrity of these near-shore waters. Agricultural activities contribute non-point sources of nutrients, sediment, and bacteria to the near-shore waters of the Great Lakes, but these contributions have been difficult to quantify due to the temporal and spatial variability of their sources. Reducing non-point source pollution is an important goal for federal and provincial agencies and local communities.

Agricultural Best Management Practices (BMPs) can help to reduce non-point sources of nutrients, sediment, and bacteria and improve surface water quality. There are many different practices that could be considered BMPs, including:

- nutrient and manure management practices (*e.g.*, following nutrient management guidelines and building adequate manure storage);
- field soil erosion reduction strategies (*e.g.*, conservation tillage and cover crops);
- structural practices (*e.g.*, Water and Sediment Control Basins – WASCoBs);
- fragile land retirement; and
- tile drain management approaches.

Kroger *et al.* (2012) outlined a framework that puts nutrient and sediment management practices into three tiers, with first-tier practices avoiding the introduction of nutrients and sediment into the aquatic system and additional tiers controlling their distribution. The first tier, input management (*i.e.*, nutrient management), avoids the introduction of the pollutant. The second tier controls the movement of the pollutant through field management (*i.e.*, conservation tillage). A third management strategy is to treat or trap the pollutant in primary aquatic systems (*i.e.*, swales, grassed waterways, WASCoBs, and ditch BMPs).

The Watershed Based BMP Evaluation (WBBE), Huron, looked at the effectiveness of Avoid, Control, and Trap/Treat (ACT) BMPs by assessing the BMPs for their environmental effectiveness at the field and watershed scales and for the resulting economic costs from the producer's perspective. (See Simmons *et al.* 2013 for a review of the broader study.) This report provides a summary of the water quality information collected at the small watershed scale.

2.0 Methods

2.1 Study Area

The WBBE, Huron, project developed from previous watershed planning efforts within the Ausable Bayfield Conservation Authority (ABCA) jurisdiction. The study area for the project was composed of several small watersheds that drain into Lake Huron, and focussed on four of these watersheds: Gully Creek, Spring Creek, Zurich Drain, and Ridgeway Drain (Figure 2.1).

Figure 2.1: Study area for the Watershed Based Best Management Practices Evaluation, Huron, within the Ausable Bayfield Conservation Authority jurisdiction.

Best management practices have been implemented most recently in the Gully Creek watershed, so it was selected in this study for in-depth monitoring and for modelling with a water quantity and quality simulation model. The Gully Creek watershed is 15 square kilometres and almost 70 per cent of the watershed is cropland. The remaining 30 per cent is mostly forests, shrubs, and meadows (Table 2.1). Gully Creek is the largest tributary in the Bayfield North watersheds and it is one of the few cold water streams found in the ABCA jurisdiction.

Table 2.1: Summary of watershed characteristics for the Watershed Based Best Management Practices Evaluation, Huron, within the Ausable Bayfield Conservation Authority jurisdiction.

Watershed	Study Type	Area (km^2)	Forests and Shrubs [a] (%)
Gully Creek	In-depth monitoring and modelling	15	27
Spring Creek	Strategic monitoring	1	64
Zurich Drain	Strategic monitoring	25	14
Ridgeway Drain	Strategic monitoring	9	8

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

To help inform the relationship between land use and water quality, strategic monitoring was conducted in three additional watersheds (Table 2.1). The historical water quality data available for the Zurich and Ridgeway drains led to these watersheds being selected for this study. In both of these watersheds, cropland is the predominant land use. Spring Creek in the Bayfield North watersheds was also monitored because of its high percentage of forest cover (greater than 60 per cent) and close proximity to Gully Creek. Due to the larger size of the Zurich Drain watershed (25 square kilometres) and the lower current uptake of BMPs in this area, monitoring efforts were focussed more on the other three watersheds in this study.

2.2 Field Data Collection

Within the four study watersheds, eight locations were monitored to provide information on surface water quality at the watershed scale, beginning in March 2010 and ending in December 2012 (Table 2.2 and Figures 2.2 and 2.3). Monitoring involved the collection of a suite of water quantity and quality information (Table 2.3).

2.2.1 Water Quantity

Water level data were collected with continuous level loggers (Hobo® U20 or Diver®) that recorded water level at 15-minute intervals. Manual measurements of flow were also collected periodically with a flow meter (Marsh-McBirney Flo-Mate™ Model 2000). Data from the level loggers were then related to the instantaneous flow measurements to provide a continuous flow dataset (Figure 2.4).

Table 2.2: Watershed-scale monitoring locations for Gully Creek, Spring Creek, Zurich Drain, and Ridgeway Drain.

Watershed	Site Code	UTM Coordinates		Location Description
		Easting	Northing	
Gully Creek	GULGUL2	443075.15	4829233.67	Gully Creek upstream of Highway 21
	GULGUL5	446411.78	4829263.70	Gully Creek upstream of Porter’s Hill Line
Spring Creek	GULGO39N1	443055.30	4827048.47	Spring Creek upstream of Highway 21
	GULGO39N2	444730.10	4826900.01	Spring Creek upstream of Orchard Line
Zurich Drain	GULZUR8	442762.86	4806215.93	Zurich Drain upstream of Highway 21
Ridgeway Drain	GULRW3	441614.65	4800564.62	Ridgeway Drain upstream of Highway 21
	GULRW5	446455.72	4799362.10	Ridgeway Drain upstream of Blackbush Line
	GULRW6	448568.97	4799143.78	Haugh Extension upstream of Bronson Line

Table 2.3: Water quantity and quality information monitored at each watershed-scale station for Gully Creek, Spring Creek, Zurich Drain, and Ridgeway Drain.

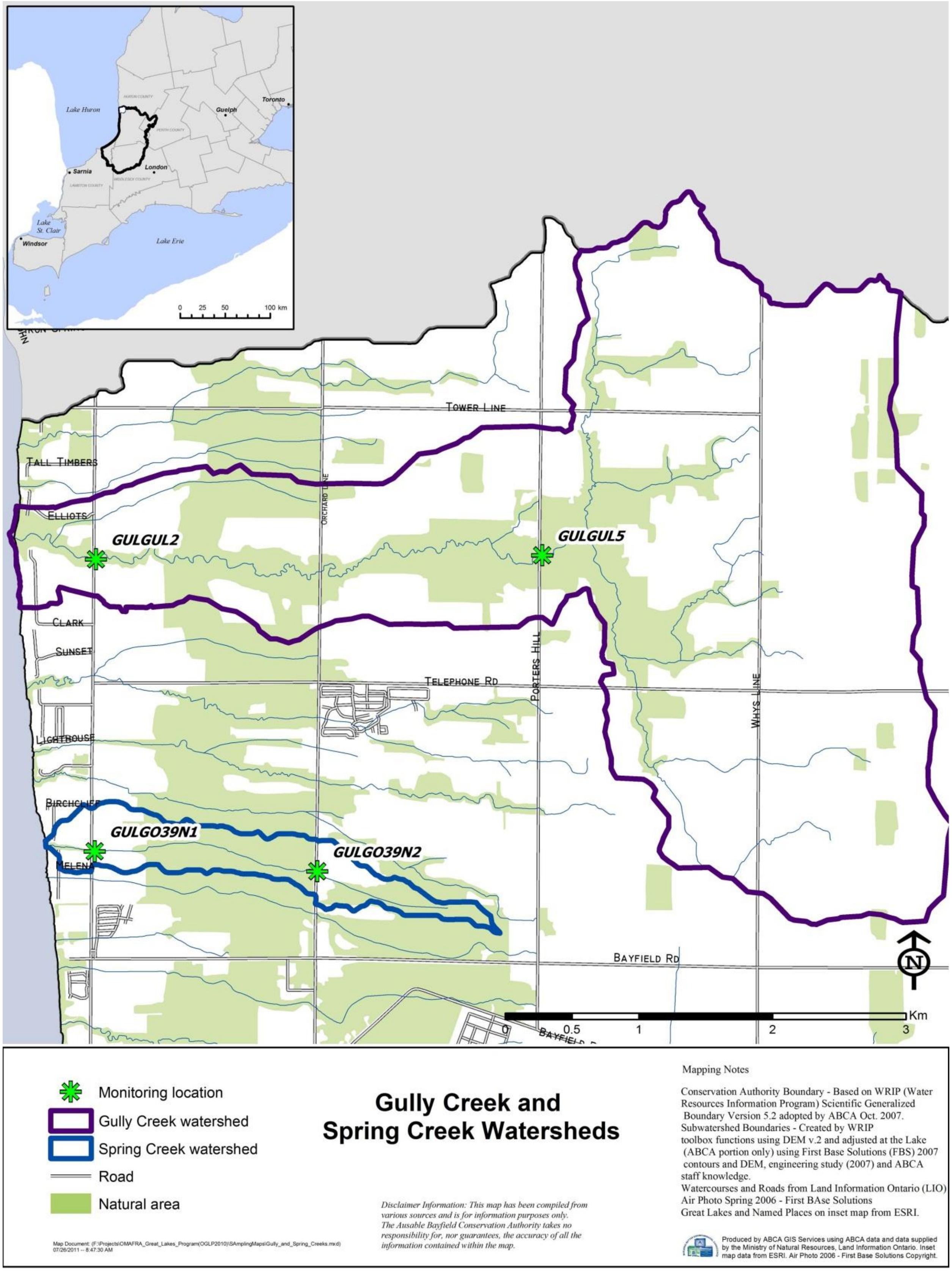
Watershed	Site Code	Water Level and Flow	Physicochemical Parameters[a]	Nutrients[b], Sediment[c], and Bacteria[d]	Benthic Macro-invertebrates
Gully Creek	GULGUL2	X	X	X	X
	GULGUL5	X	X	X	X
Spring Creek	GULGO39N1	X	X	X	
	GULGO39N2		X	X	
Zurich Drain	GULZUR8	X	X	X	X
Ridgeway Drain	GULRW3	X	X	X	X
	GULRW5		X	X	X
	GULRW6		X	X	X

[a] Physicochemical parameters include temperature, conductivity, total dissolved solids, dissolved oxygen, and pH.

[b] Nutrients include total ammonia, nitrate, nitrite, total Kjeldahl nitrogen, total phosphorus, and soluble reactive phosphorus.

[c] Sediment is total suspended solids.

[d] Bacteria is *Escherichia coli* (*E. coli*).



Mapping Notes

Conservation Authority Boundary - Based on WRIP (Water Resources Information Program) Scientific Generalized Boundary Version 5.2 adopted by ABCA Oct. 2007.
Subwatershed Boundaries - Created by WRIP toolbox functions using DEM v.2 and adjusted at the Lake (ABCA portion only) using First Base Solutions (FBS) 2007 contours and DEM, engineering study (2007) and ABCA staff knowledge.
Watercourses and Roads from Land Information Ontario (LIO)
Air Photo Spring 2006 - First BAse Solutions
Great Lakes and Named Places on inset map from ESRI.

Disclaimer Information: This map has been compiled from various sources and is for information purposes only. The Ausable Bayfield Conservation Authority takes no responsibility for, nor guarantees, the accuracy of all the information contained within the map.

Map Document: (F:\Projects\OMAFRA_Great_Lakes_Program(OGLP2010)\SAmplingMaps\Gully_and_Spring_Creeks.mxd)
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Produced by ABCA GIS Services using ABCA data and data supplied by the Ministry of Natural Resources, Land Information Ontario. Inset map data from ESRI. Air Photo 2006 - First Base Solutions Copyright.

Figure 2.2: Watershed-scale monitoring locations in Gully Creek and Spring Creek.

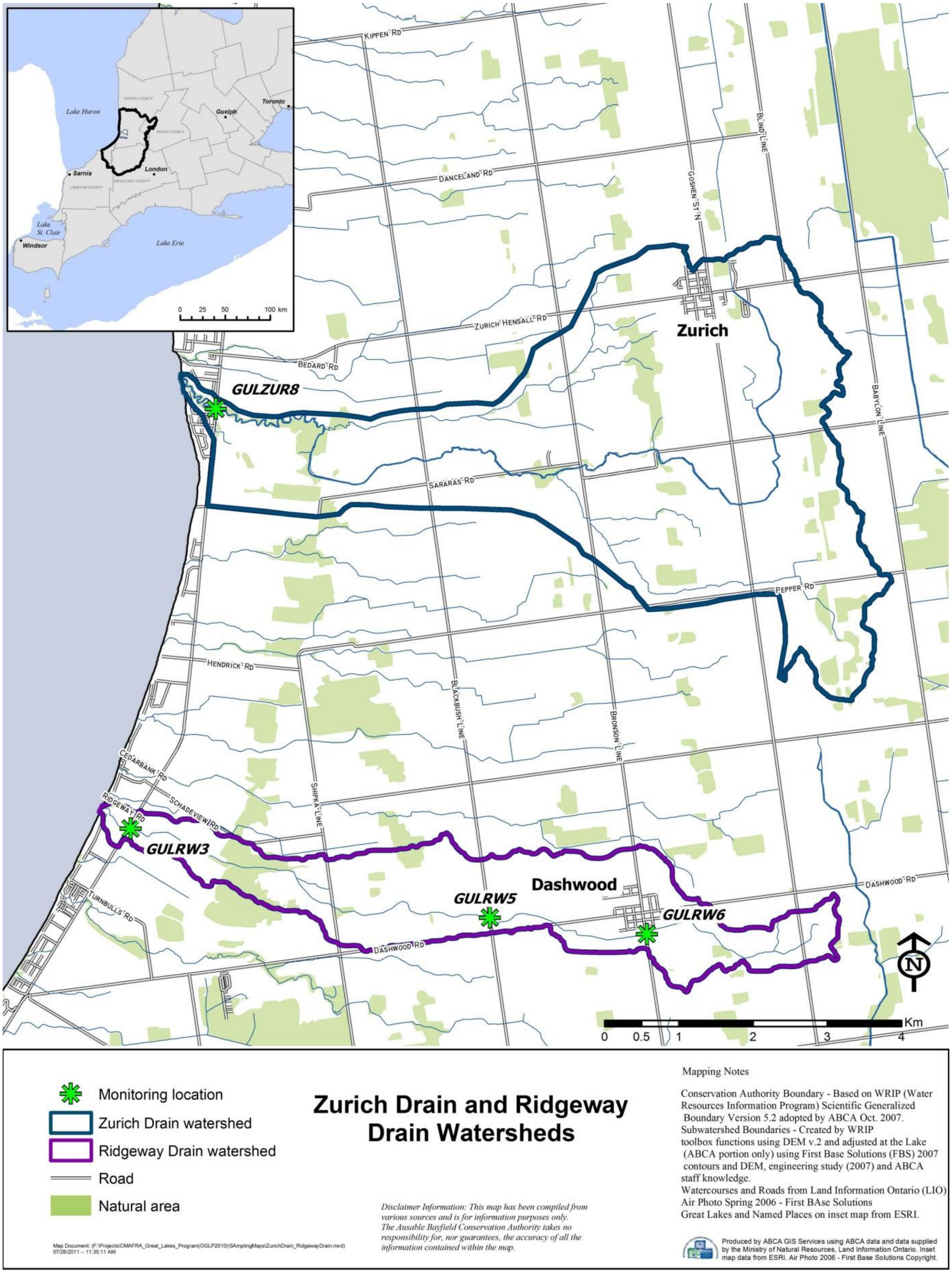

Figure 2.3: Watershed-scale monitoring locations in Zurich Drain and Ridgeway Drain.

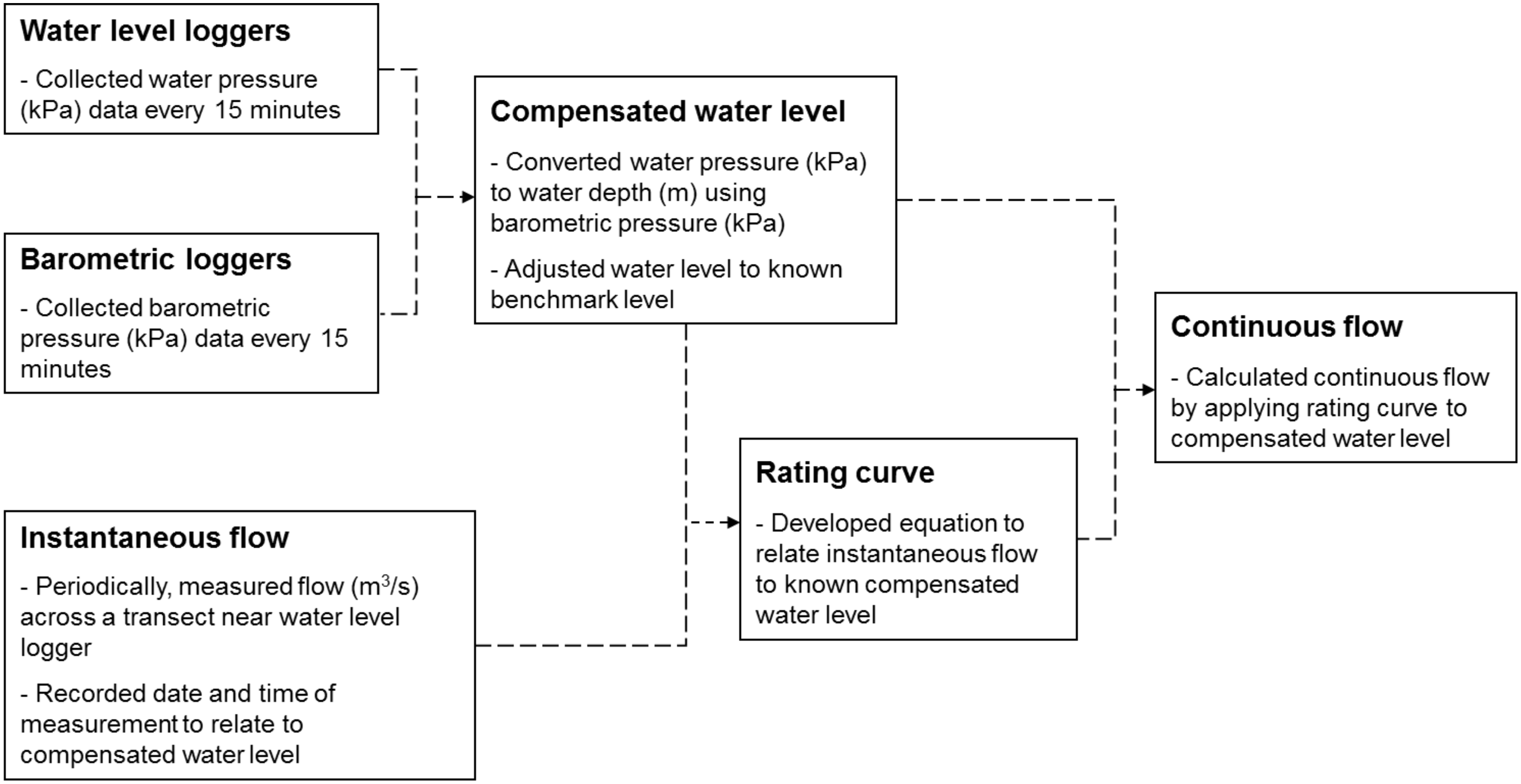

Figure 2.4: Method for deriving a continuous water flow dataset from water level loggers and instantaneous flow measurements.

2.2.2 Nutrients, Sediment, and Bacteria

Between April and November, water samples were collected from the eight surface water sites at least once per month and during high-flow events due to rainfall (Appendix). Between December and March, samples were collected once during winter base-flow conditions and during any high-flow events that occurred due to rainfall or rain on snow. Monthly and winter base-flow samples were collected by grab sampling. Whenever grab samples were collected, physicochemical parameters (*e.g.*, water temperature and pH) were also measured with a YSI® 600 QS probe. High-flow events were initially sampled by grab sampling at all of the sites. Beginning in May 2011, a Global Water automatic sampler was deployed at one Gully Creek site (GULGUL2) to collect water samples during high-flow events. This sampler was set to collect an initial sample when the water level began to rise and then 500 millilitres every hour for a high-flow composite sample. It was deployed until the end of 2011. Beginning in June 2011, some high-flow events were sampled with an ISCO® 2700 automatic sampler at four sites (GULGUL2, GULGUL5, GULGO39N1, and GULRW3). The ISCO® samplers were set to trigger with a rise in water level and to collect hourly samples over a 24-hour period. Water samples were primarily analyzed for nutrients, sediment, and bacteria by the Ministry of the Environment (MOE) laboratory in Etobicoke; however, on occasion, samples were submitted for analysis to ALS Laboratory in Waterloo.

2.2.3 Benthic Macroinvertebrates

Samples of benthic macroinvertebrates, another water quality indicator, were collected from the watershed-scale sites in Gully Creek, Zurich Drain, and Ridgeway Drain in October of 2010, 2011, and 2012 (Table 2.3). A three-minute walking-kick technique was employed at each site to ensure that all microhabitats (riffles, runs, and pools) were sampled. Benthic samples were collected with a D-frame net that had a mesh size of 250 micrometres. The samples were initially preserved in a 10 per cent formalin solution and were transferred within a month to a 70 per cent alcohol solution.

In 2010 and 2011, benthic samples were randomly subsampled from a tray with gridlines and at least 200 macroinvertebrates per sample were identified to the family level. In 2012, benthic samples were randomly subsampled by wet weight and at least 200 macroinvertebrates per sample were identified to the lowest possible taxonomic level (genus or species).

2.3 Data Analysis

2.3.1 Watershed Outlets

Water quality indicator concentrations (total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, total suspended solids, and *Escherichia coli*) from the watershed outlets were analyzed for differences between low and high flows at each outlet and between the four outlets at high flows. Low and high flows were primarily identified by visual inspection of the stream flow hydrographs. Because level loggers were not installed in the streams until mid- or late 2010, low and high flows earlier in 2010 were identified by a review of rainfall data from nearby stations maintained by the ABCA.

The water quality dataset was primarily composed of grab samples. For some high-flow events, Global Water and/or ISCO® samples were collected in place of a grab sample. For the purpose of data analysis, ISCO® samples were given priority over Global Water samples and the ISCO® sample collected closest to the time of peak water flow was selected for addition to the dataset. For events during which only Global Water samples were collected, the initial sample was added to the dataset. The MOE laboratory identified some data as being unreliable due to samples exceeding their recommended holding times prior to analysis or to laboratory quality assurance or quality control problems. These unreliable data were removed from the dataset.

Mean concentrations were calculated for each indicator at each outlet under low-flow and high-flow conditions. The percentage of total phosphorus (TP) that was soluble reactive phosphorus (SRP) was also calculated for each outlet under these two flow conditions. Concentrations of TP and nitrate-nitrogen (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). *Escherichia coli* (*E. coli*) concentrations were compared with the Ontario recreational guideline for beaches at which people swim or bathe (100 colony forming units per 100 millilitres of water; MOEE 1994).

For each water quality indicator, a non-parametric Kruskal-Wallis test was applied to determine if significant differences in water quality could be observed between low-flow and high-flow conditions at each watershed outlet and between the watershed outlets under high-flow conditions. A parametric Tukey post-hoc test identified which watershed outlets differed from one another at high flows.

2.3.2 Sites within Watersheds

Water quality was monitored at more than one location in Gully Creek, Spring Creek, and Ridgeway Drain, so water quality indicator concentrations from grab samples were also compared between sites within each of these watersheds. Any data that the MOE laboratory identified as being unreliable were removed from the dataset for each watershed. If an indicator concentration from a particular sampling date was missing or removed for one of the sites in a watershed, then the corresponding concentration (*i.e.*, same indicator, same date) from any other sites in that watershed was also removed from the dataset. The data were divided into low-flow and high-flow conditions by either visually inspecting the stream flow hydrographs at the watershed outlets or by reviewing rainfall data from nearby stations.

Mean concentrations were calculated for each indicator at each site under low-flow and high-flow conditions. For each water quality indicator, a non-parametric Kruskal-Wallis test was applied to determine if significant differences in water quality could be observed between the sites in each watershed under low-flow or high-flow conditions. A parametric Tukey post-hoc test identified which sites in Ridgeway Drain differed from one another.

2.3.3 Benthic Macroinvertebrates

Each benthic macroinvertebrate species has a different tolerance to the variety of stressors and pollutants that may be present in streams. Tolerance values between zero and ten can be assigned to these animals, with zero meaning intolerant to pollution and ten meaning tolerant. The tolerance values for the benthic macroinvertebrates present at a particular site were used to calculate the Hilsenhoff (1987) Family Biotic Index (FBI), as modified by New York State (Smith *et al.* 2009). The FBI provided a score for each site that reflected the water quality within the area that these organisms were surveyed. The scores can range between zero and ten, with zero indicating that water quality is excellent and ten indicating that it is very poor.

Benthic macroinvertebrates were collected from watershed-scale monitoring locations in 2010 through 2012; however, only the data from 2010 had been analyzed at the time that this report was written.

3.0 Results and Discussion

3.1 Influence of Stream Flow on Water Quality at Watershed Outlets

To gain an understanding of variation in water quality at the watershed scale, water quality samples were collected from the outlet of each of the four watersheds at least 47 and up to 79 times (depending on the rainfall amounts in each watershed) between the spring of 2010 and the fall of 2012. At least half of the sampling events at each outlet were during high-flow conditions.

Concentrations of water quality indicators varied at the four watershed outlets depending on stream flow conditions (Tables 3.1 and 3.2 and Figures 3.1 and 3.2). Except for Spring Creek, the streams had higher concentrations of TP, SRP, total suspended solids (TSS), and *E. coli* during high-flow events compared with low-flow events. Nitrate-N concentrations in the streams did not respond in the same manner to high-flow conditions and were possibly diluted in Spring Creek under these conditions. The increase in several water quality indicators under high-flow conditions suggests that surface water quality data need to reflect storm runoff. As this is the time when BMPs need to be effective, water quality information collected with the purpose of evaluating BMPs also needs to reflect high-flow conditions.

Concentrations of TP, nitrate-N, and *E. coli* at the watershed outlets tended to be high relative to water quality standards, even under low-flow conditions (Figures 3.1 and 3.2). At least half of the samples collected during low flows from the Gully Creek, Zurich Drain, and Ridgeway Drain outlets exceeded the Provincial Water Quality Objective for TP to prevent eutrophication (0.03 milligrams per litre) and the provincial recreational guideline for *E. coli* (100 colony forming units per 100 millilitres). At all four of the watershed outlets, more than 75 per cent of the low-flow samples exceeded the nitrate-N concentration considered to minimize eutrophication (0.9 milligrams per litre). Concentrations under high-flow conditions typically exceeded these standards even more frequently, in some cases by an order of magnitude.

The percentage of TP that was SRP also showed some variation between low and high flows and between the watershed outlets (Table 3.3). At the Gully Creek, Spring Creek, and Zurich Drain outlets, the mean percentage of SRP ranged between 35 and 45 per cent under low-flow conditions and decreased to about 25 per cent under high-flow conditions. The decrease in the percentage of SRP under high flows may be due to an increase in particulate phosphorus inputs to these streams from surface runoff and channel erosion. At the Ridgeway Drain outlet, the mean percentage of SRP was elevated compared with the other watershed outlets and was similar under low-flow and high-flow conditions (62 and 66 per cent, respectively). Thus, despite the increases observed in both TP and SRP concentrations at the Ridgeway Drain outlet under high-flow conditions compared with low-flow conditions (Table 3.1), the percentage of TP that was SRP was quite consistent. This suggests that, unlike the other three outlets, as TP concentrations increase at the Ridgeway Drain outlet with higher flows, the ratio of particulate and dissolved phosphorus may remain constant.

Table 3.1: Mean nutrient concentrations and number of samples (*n*) for four watershed outlets under low-flow and high-flow conditions between 2010 and 2012.

Watershed	Forests and Shrubs[a] (%)	Total Phosphorus					Soluble Reactive Phosphorus					Nitrate-nitrogen				
		Low Flow		High Flow		*p*-value[b]	Low Flow		High Flow		*p*-value[b]	Low Flow		High Flow		*p*-value[b]
		Mean (mg/L)	*n*	Mean (mg/L)	*n*		Mean (mg/L)	*n*	Mean (mg/L)	*n*		Mean (mg/L)	*n*	Mean (mg/L)	*n*	
Gully	27	0.044	27	0.615	47	0.00	0.018	30	0.104	49	0.00	4.3	30	4.6	49	0.99
Spring	64	0.022	20	0.058	25	0.04	0.006	20	0.008	27	0.64	2.6	20	1.7	27	0.01
Zurich	14	0.039	23	0.299	35	0.00	0.016	26	0.065	36	0.00	3.4	25	5.5	36	0.03
Ridgeway	8	0.152	30	0.497	31	0.00	0.070	33	0.274	28	0.00	8.2	31	8.7	32	0.90

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

[b] A *p*-value less than 0.05 indicates a significant difference between low-flow and high-flow conditions.

Table 3.2: Mean suspended solids and *Escherichia coli* concentrations, and number of samples (*n*), for four watershed outlets under low-flow and high-flow conditions between 2010 and 2012.

Watershed	Forests and Shrubs[a] (%)	Total Suspended Solids					*Escherichia coli*				
		Low Flow		High Flow		*p*-value[b]	Low Flow		High Flow		*p*-value[b]
		Mean (mg/L)	*n*	Mean (mg/L)	*n*		Mean (cfu/100 mL)	*n*	Mean (cfu/100 mL)	*n*	
Gully	27	35	29	486	37	0.00	310	26	1789	26	0.00
Spring	64	8	19	6	22	0.58	516	18	999	16	0.09
Zurich	14	22	25	315	34	0.00	618	27	2986	28	0.00
Ridgeway	8	52	32	107	28	0.00	347	32	3399	22	0.00

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

[b] A *p*-value less than 0.05 indicates a significant difference between low-flow and high-flow conditions.

Table 3.3: Mean percentage of total phosphorus that is soluble reactive phosphorus, and number of samples (*n*), for four watershed outlets under low-flow and high-flow conditions between 2010 and 2012.

Watershed	Forests and Shrubs[a] (%)	Low Flow		High Flow	
		Mean (%)	*n*	Mean (%)	*n*
Gully	27	37	26	24	46
Spring	64	39	20	25	25
Zurich	14	43	22	25	34
Ridgeway	8	62	29	66	27

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

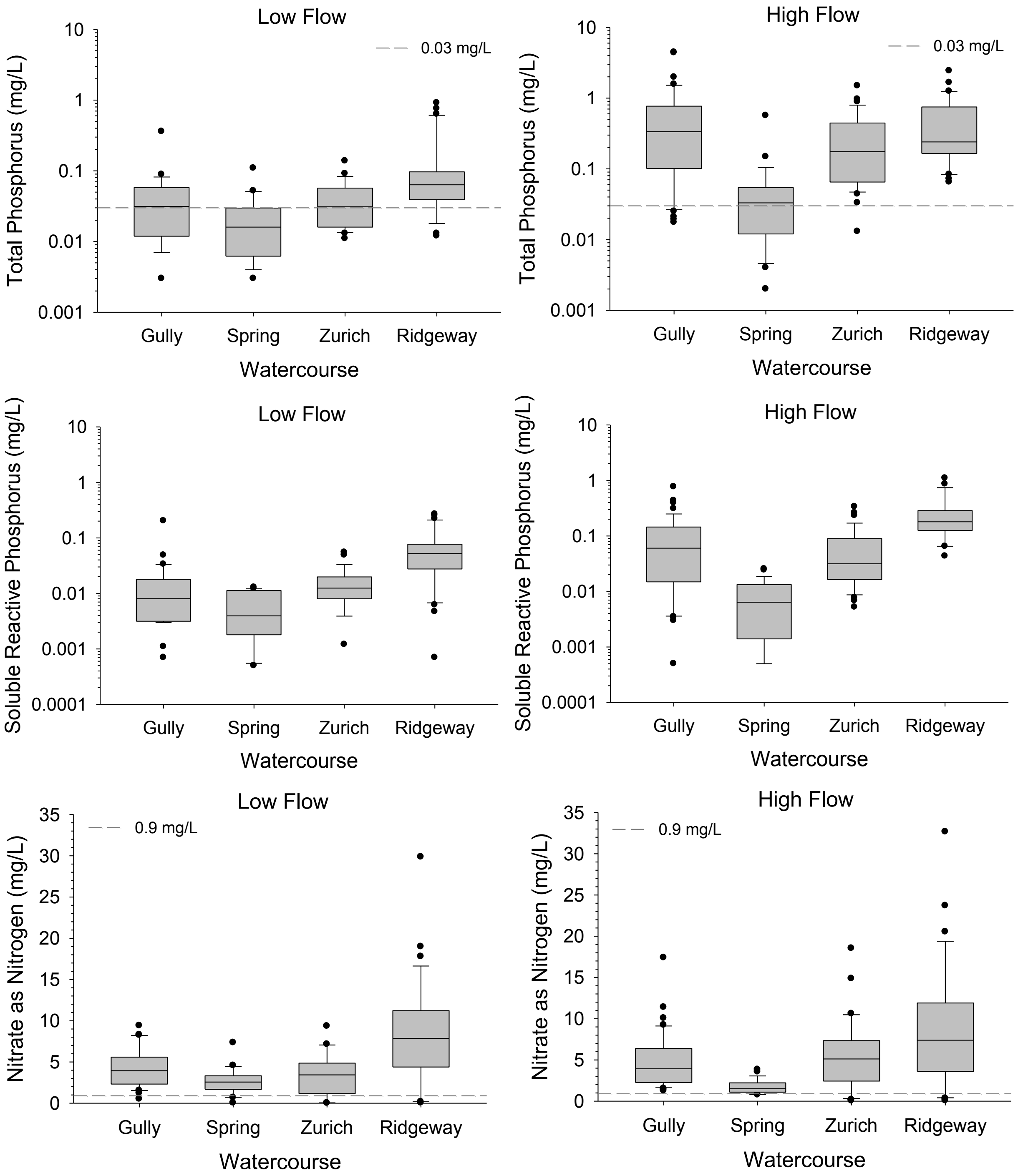

Figure 3.1: Nutrient concentrations under low-flow and high-flow conditions at the watershed outlets between 2010 and 2012. Dashed gray lines indicate concentrations considered to minimize eutrophication. (Box plot graphs show outliers (·), the 10th and 90th percentiles as horizontal bars, the 25th and 75th percentiles as the bottom and top of the box, and the median as a horizontal line within the box.)

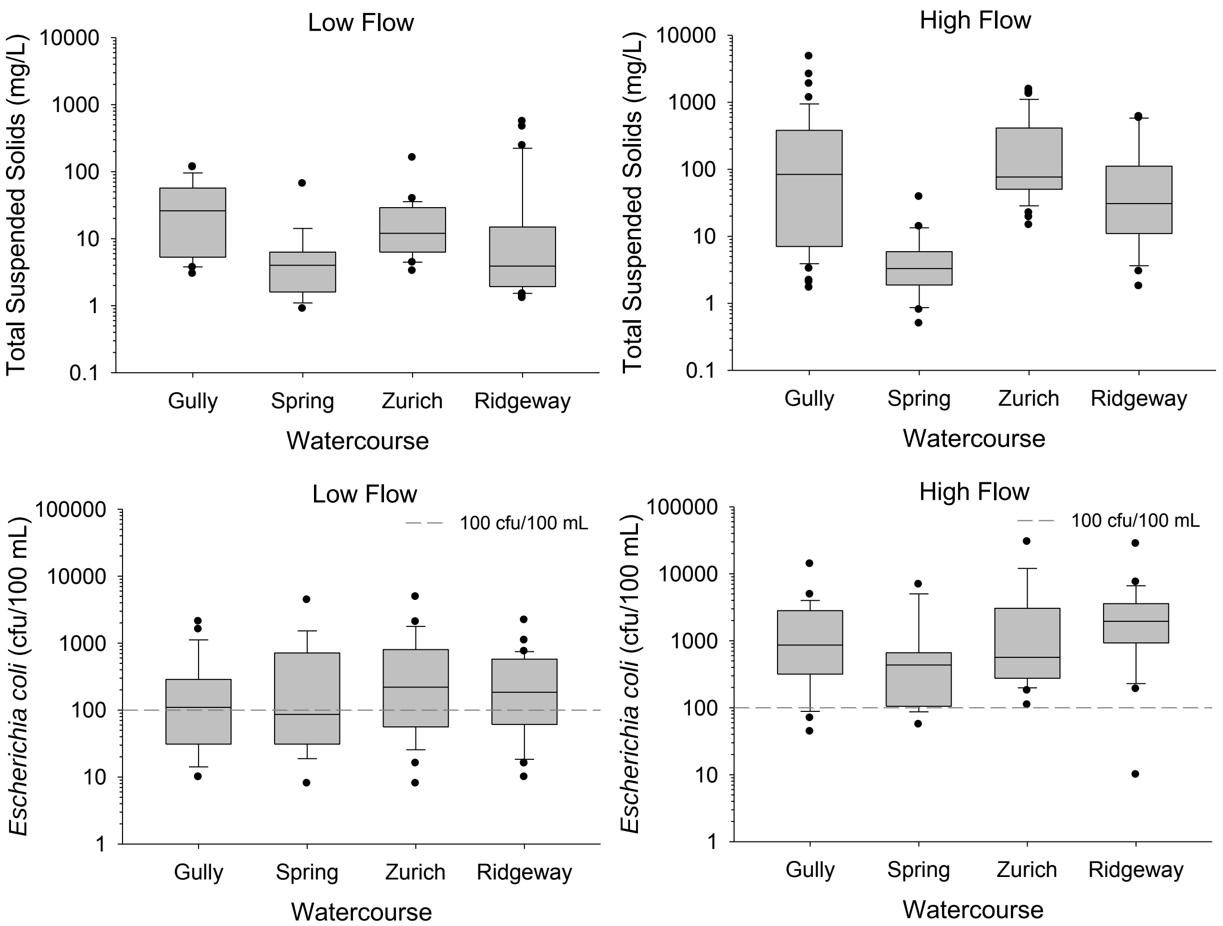

Figure 3.2: Suspended solids and *Escherichia coli* (*E. coli*) concentrations under low-flow and high-flow conditions at the watershed outlets between 2010 and 2012. Dashed gray lines indicate *E. coli* guideline for swimming or bathing. (Box plot graphs show outliers (·), the 10th and 90th percentiles 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.)

The behaviour of phosphorus at the Ridgeway Drain outlet sets it apart from the other watersheds. Several watershed characteristics – such as land use, soils, and slope – could account for this difference. A lower percentage of the Ridgeway Drain watershed area is covered in forests, shrubs, and meadows than the other watersheds (Table 3.3). These naturalized areas may not always be situated so that they filter water from areas with other land uses before it reaches a stream, but they can reduce the percentage of the watershed area that acts as a potential source of nutrients and sediments to a stream. The Ridgeway Drain watershed also differs from the other watersheds in terms of its soil types and soil infiltration capacities. For example, 30 per cent of the area in the Ridgeway Drain watershed that has soil with a high runoff potential (Hydrological Soil Group D, Chisholm 1981) is in agricultural land uses, compared with only 8 per cent in the Gully Creek watershed, 7 per cent in the Zurich Drain watershed, and none of the Spring Creek watershed. There is a potential for differences in field soil phosphorus between the watersheds, but the limited data available for the Ridgeway Drain and Gully Creek watersheds did not show a significant difference. The slope of the landscape could also contribute to differences in phosphorus; however over 85 per cent of the Gully Creek, Spring Creek, and Zurich Drain watershed areas had gentle to moderate slopes (Slope Class D or E), compared with only 62 per cent of the Ridgeway Drain watershed. (The rest of the Ridgeway Drain watershed was level or nearly level.) These watershed characteristics may partly explain the unique behaviour of Ridgeway Drain in terms of phosphorus; however, there may be other factors that play a role and the relationship between watershed characteristics may be important as well. More analysis of existing watershed information might help to explain differences between the watersheds.

Water quality indicator data obtained during high-flow events with the ISCO® automatic samplers showed that the timing of sampling can affect indicator concentrations and is an important consideration for future study design. It was observed that TP concentrations generally increased with increasing flow and decreased with decreasing flow (Figure 3.3). The relationship between nitrate-N concentrations and stream flow was different, however. Typically, nitrate-N concentrations decreased as flow increased, and then nitrate-N concentrations increased and remained elevated after the event (Figure 3.3). This difference in the patterns of TP and nitrate-N stream concentrations during an event may reflect a difference in the pathways they take from landscape to stream. Phosphorus may travel to these streams mainly through surface runoff, whereas nitrate may travel mainly through subsurface flow. A post-event decline in nitrate-N concentrations was not captured through the monitoring with the ISCO® samplers, which typically took place over a period of 24 hours and up to a maximum of 36 hours. Future monitoring of nitrate-N could be improved by extending sampling after an event to capture an eventual decline in concentrations.

Use of the ISCO® samplers provided better data than relying on grab samples or the Global Water samplers. Grab samples could be collected only when staff was available and it was safe to do so. This typically resulted in a maximum of two samples per event, with no consistency in how the timing of sampling corresponded to the stream flow hydrograph (*e.g.*, consistently collecting samples that corresponded to the rising limb, peak, or falling limb of the hydrograph). In contrast to the discrete hourly samples that the ISCO® samplers were able to collect, the Global Water samplers were able to collect only an initial sample as the water level began to rise during an event and a composite sample over a period of time as the event continued.

Gaining familiarity with the behaviour of water quality indicators through the ISCO® samples collected during this project has resulted in fewer event samples needing to be analyzed. For example, hourly ISCO® samples were collected over 24 hours for several high-flow events in Gully Creek. The staff at the ABCA is now comfortable with setting the ISCO® at Gully Creek to collect a sample every two hours over a 48-hour period and then selecting approximately six of these samples for laboratory analysis.

A longer-term temporal analysis of water quality indicators could be undertaken for the Gully Creek and Zurich Drain outlets; however, much of the data that pre-existed this project represent low-flow conditions. For example, data have been collected at the Gully Creek outlet since 2007, but few high-flow events were sampled until the WBBE, Huron, project began in late 2010. Analysis of the current longer-term dataset would provide information for base-flow conditions only. Many BMPs are designed to address higher flow conditions. Therefore, high-flow conditions must also be monitored over the long term to evaluate the effectiveness of BMPs at a watershed scale.

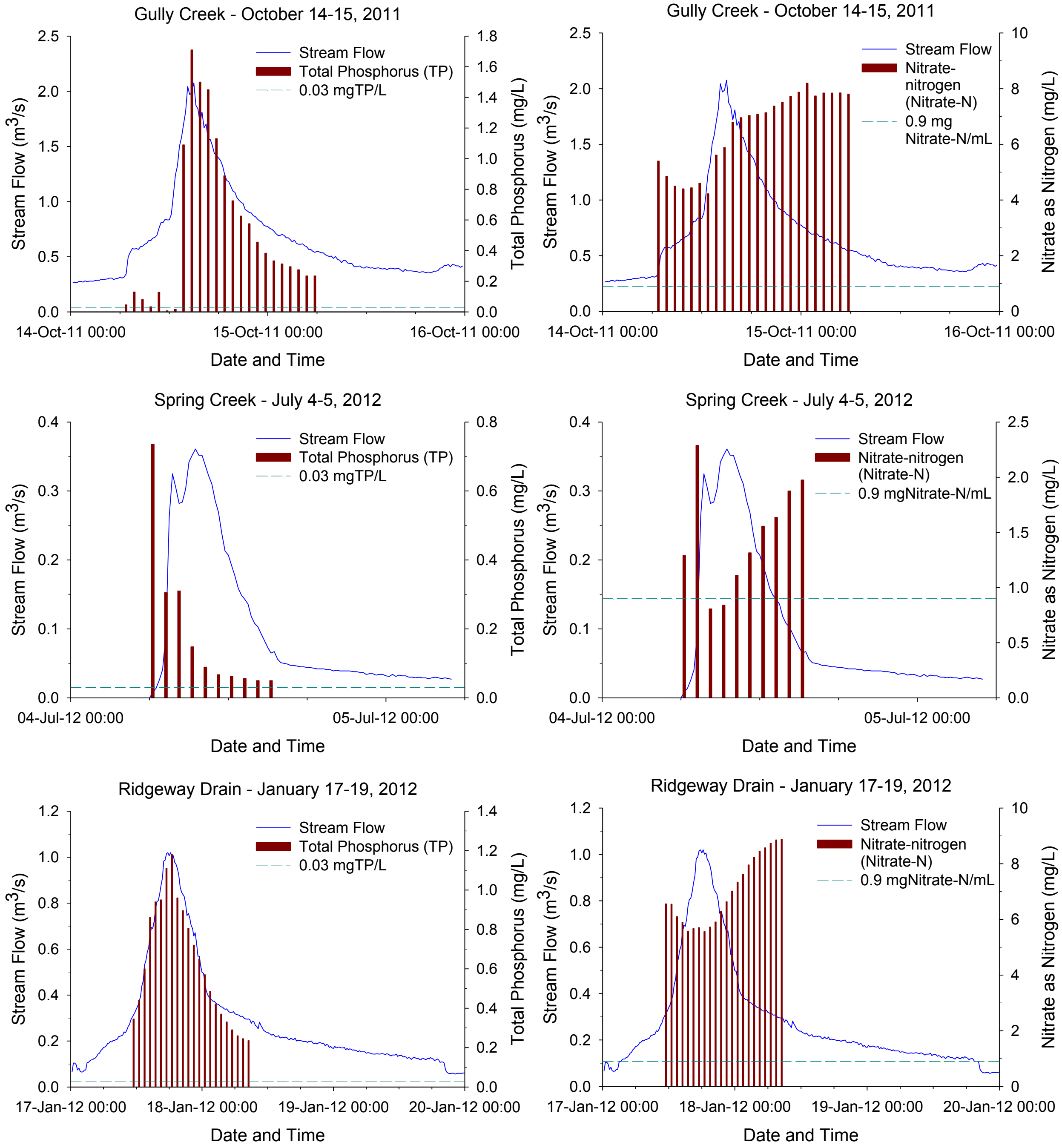

Figure 3.3: Total phosphorus and nitrate-nitrogen concentrations at the outlets of Gully Creek, Spring Creek, and Ridgeway Drain from samples collected hourly during storm events. Dashed light blue lines indicate concentrations considered to minimize eutrophication. Please note that the samples were from different events for each outlet and the graph scales differ between the outlets.

3.2 Watershed Comparison under High-flow Conditions

At the onset of the study, it was hypothesised that stream water quality would reflect differences in land use and that, due to a high presence of natural cover, water quality would be best in Spring Creek. Analysis of data from high-flow events confirmed that Spring Creek had significantly lower TSS than Gully Creek, significantly lower TP and SRP than Gully Creek and Ridgeway Drain, and significantly lower nitrate-N than all three other outlets (Tables 3.4 and 3.5). *E. coli* did not differ significantly between the outlets under high-flow conditions.

The significantly lower concentrations of nutrients and sediment in Spring Creek relative to other watershed outlets during high-flow periods was originally thought to be attributable to the abundance of natural cover. However, it is challenging to separate land use effects from the effects of soil, such as the Huron Clay Loam that is present in the headwaters of Gully Creek, but absent from the Spring Creek watershed. This speaks to the difficulty of accounting for variation in soil, slope, and land use in comparative watershed BMP assessment studies.

3.3 Within-watershed Site Comparison

Concentrations of nutrients, suspended solids, and *E. coli* were compared between sampling sites within each watershed to determine if these water quality indicators differed between upstream and downstream locations on each watercourse. In Gully Creek, TSS concentrations were significantly higher at the more downstream site (GULGUL2) than further upstream (GULGUL5) under both low-flow and high-flow conditions (Table 3.6 and Figure 3.4). This is probably reflective of channel erosion that takes place between these two sites, as other watershed inputs are limited along this reach of the stream. The other indicators did not differ significantly between the two sites in Gully Creek. None of the indicators differed significantly between the two sites in Spring Creek (Table 3.7).

More differences were noted between the sites in Ridgeway Drain. Under low-flow conditions, TP and SRP concentrations were significantly higher at a mid-stream site (GULRW5) than at sites further upstream (GULRW6) and downstream (GULRW3) (Table 3.8 and Figure 3.5). Also under low flows, TSS concentrations were significantly higher at the most upstream site (GULRW6) than at the other two sites. Further investigation of watershed land use and management could be helpful in understanding these differences in phosphorus and sediment concentrations under low flows.
Only one indicator differed significantly between the Ridgeway Drain sites under high-flow conditions: *E. coli* concentrations were significantly higher at the mid-stream site (GULRW5) than at the most upstream site (GULRW6) (Table 3.8 and Figure 3.5). This is likely indicative of a localized source of *E. coli* near the mid-stream site.

Table 3.4: Mean nutrient concentrations for four watershed outlets under high-flow conditions between 2010 and 2012.

Watershed	Forests and Shrubs [a] (%)	Total Phosphorus		Soluble Reactive Phosphorus		Nitrate-nitrogen	
		Mean (mg/L)	Significant Differences [b]	Mean (mg/L)	Significant Differences [b]	Mean (mg/L)	Significant Differences [b]
Gully	27	0.615	A	0.104	A	4.6	A
Spring	64	0.058	B	0.008	B	1.7	B
Zurich	14	0.299	A, B	0.065	A, B	5.5	A
Ridgeway	8	0.497	A	0.274	C	8.7	C

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

[b] Letters in the significant differences columns indicate differences in the water quality indicators between the watersheds based on parametric Tukey post-hoc tests. (Watersheds that do not share the same letter were significantly different in terms of that indicator.)

Table 3.5: Mean suspended solids and *Escherichia coli* concentrations for four watershed outlets under high-flow conditions between 2010 and 2012.

Watershed	Forests and Shrubs [a] (%)	Total Suspended Solids		*Escherichia coli*	
		Mean (mg/L)	Significant Differences [b]	Mean (mg/L)	Significant Differences [b]
Gully	27	486	A	1789	A
Spring	64	6	B	999	A
Zurich	14	315	A, B	2986	A
Ridgeway	8	107	B	3399	A

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

[b] Letters in the significant differences columns indicate differences in the water quality indicators between the watersheds based on parametric Tukey post-hoc tests. (Watersheds that do not share the same letter were significantly different in terms of that indicator.)

Table 3.6: Mean nutrient, suspended solids, and *Escherichia coli* concentrations and number of grab samples (*n*) for two sampling locations in Gully Creek under low-flow and high-flow conditions in 2011 and 2012.

Indicator	Low Flow					High Flow				
	GULGUL2		GULGUL5		*p*-value [a]	GULGUL2		GULGUL5		*p*-value [a]
	Mean	*n*	Mean	*n*		Mean	*n*	Mean	*n*	
Total Phosphorus (mg/L)	0.028	13	0.026	13	1.00	0.762	20	0.440	20	0.27
Soluble Reactive Phosphorus (mg/L)	0.011	16	0.014	16	0.60	0.147	20	0.179	20	0.66
Nitrate-nitrogen (mg/L)	3.5	16	3.7	16	0.79	4.8	20	5.5	20	0.74
Total Suspended Solids (mg/L)	28	15	9	15	0.00	643	19	208	19	0.03
Escherichia coli (cfu/100 mL)	341	14	259	14	0.96	2868	13	2008	13	0.23

[a] A *p*-value less than 0.05 indicates a significant difference between low-flow and high-flow conditions.

Table 3.7: Mean nutrient, suspended solids, and *Escherichia coli* concentrations and number of grab samples (*n*) for two sampling locations in Spring Creek under low-flow and high-flow conditions in 2011 and 2012.

Indicator	**Low Flow**					**High Flow**				
	GULGO39N1		**GULGO39N2**		***p*-value** [a]	**GULGO39N1**		**GULGO39N2**		***p*-value** [a]
	Mean	***n***	**Mean**	***n***		**Mean**	***n***	**Mean**	***n***	
Total Phosphorus (mg/L)	0.024	18	0.031	18	0.91	0.028	16	0.043	16	0.41
Soluble Reactive Phosphorus (mg/L)	0.006	18	0.004	18	0.16	0.009	16	0.004	16	0.15
Nitrate-nitrogen (mg/L)	2.4	18	1.9	18	0.20	1.5	16	1.2	16	0.12
Total Suspended Solids (mg/L)	9	17	8	17	0.77	8	14	12	14	0.57
Escherichia coli (cfu/100 mL)	608	15	278	15	0.51	1596	9	964	9	0.27

[a] A *p*-value less than 0.05 indicates a significant difference between low-flow and high-flow conditions.

Table 3.8: Mean nutrient, suspended solids, and *Escherichia coli* concentrations and number of grab samples (*n*) for three sampling locations in Ridgeway Drain under low-flow and high-flow conditions between 2010 and 2012.

Indicator	**Low Flow**							**High Flow**						
	GULRW3		**GULRW5**		**GULRW6**		***p*-value** [a]	**GULRW3**		**GULRW5**		**GULRW6**		***p*-value** [a]
	Mean	***n***	**Mean**	***n***	**Mean**	***n***		**Mean**	***n***	**Mean**	***n***	**Mean**	***n***	
Total Phosphorus (mg/L)	0.067	24	0.117	24	0.069	24	0.00	0.453	26	0.579	26	0.551	26	0.34
Soluble Reactive Phosphorus (mg/L)	0.045	24	0.090	24	0.043	24	0.00	0.279	25	0.387	25	0.457	25	0.24
Nitrate-nitrogen (mg/L)	8.6	24	10.4	24	7.8	24	0.18	9.2	28	10.4	28	8.6	28	0.53
Total Suspended Solids (mg/L)	5	26	4	26	13	26	0.00	95	25	96	25	60	25	0.23
Escherichia coli (cfu/100 mL)	231	27	1584	27	1248	27	0.37	3342	21	5146	21	807	21	0.00

[a] A *p*-value less than 0.05 indicates a significant difference between low-flow and high-flow conditions.

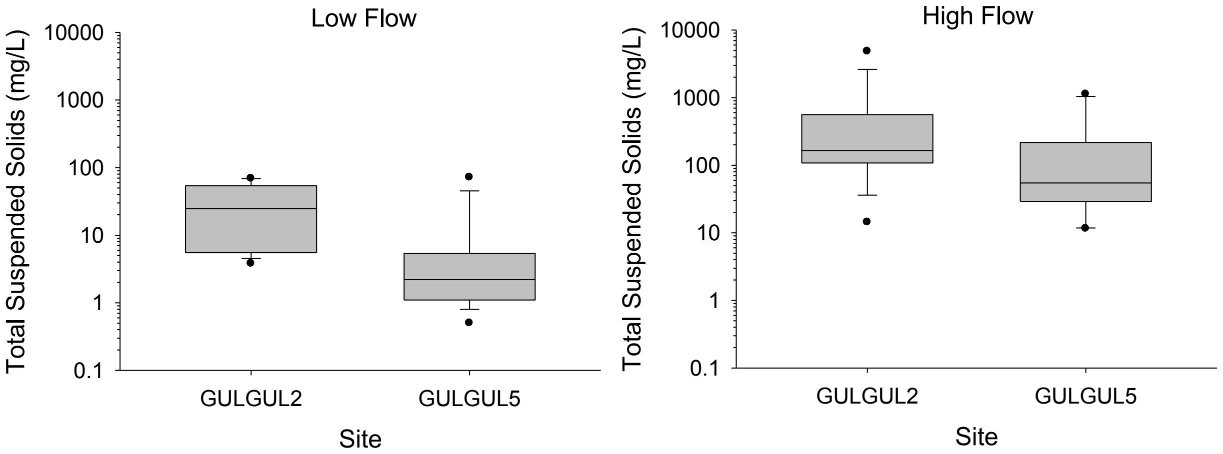

Figure 3.4: Suspended solids concentrations under low-flow and high-flow conditions at two locations in Gully Creek in 2011 and 2012. (Box plot graphs show outliers (·), the 10th and 90th percentiles as horizontal bars, the 25th and 75th percentiles as the bottom and top of the box, and the median as a horizontal line within the box.)

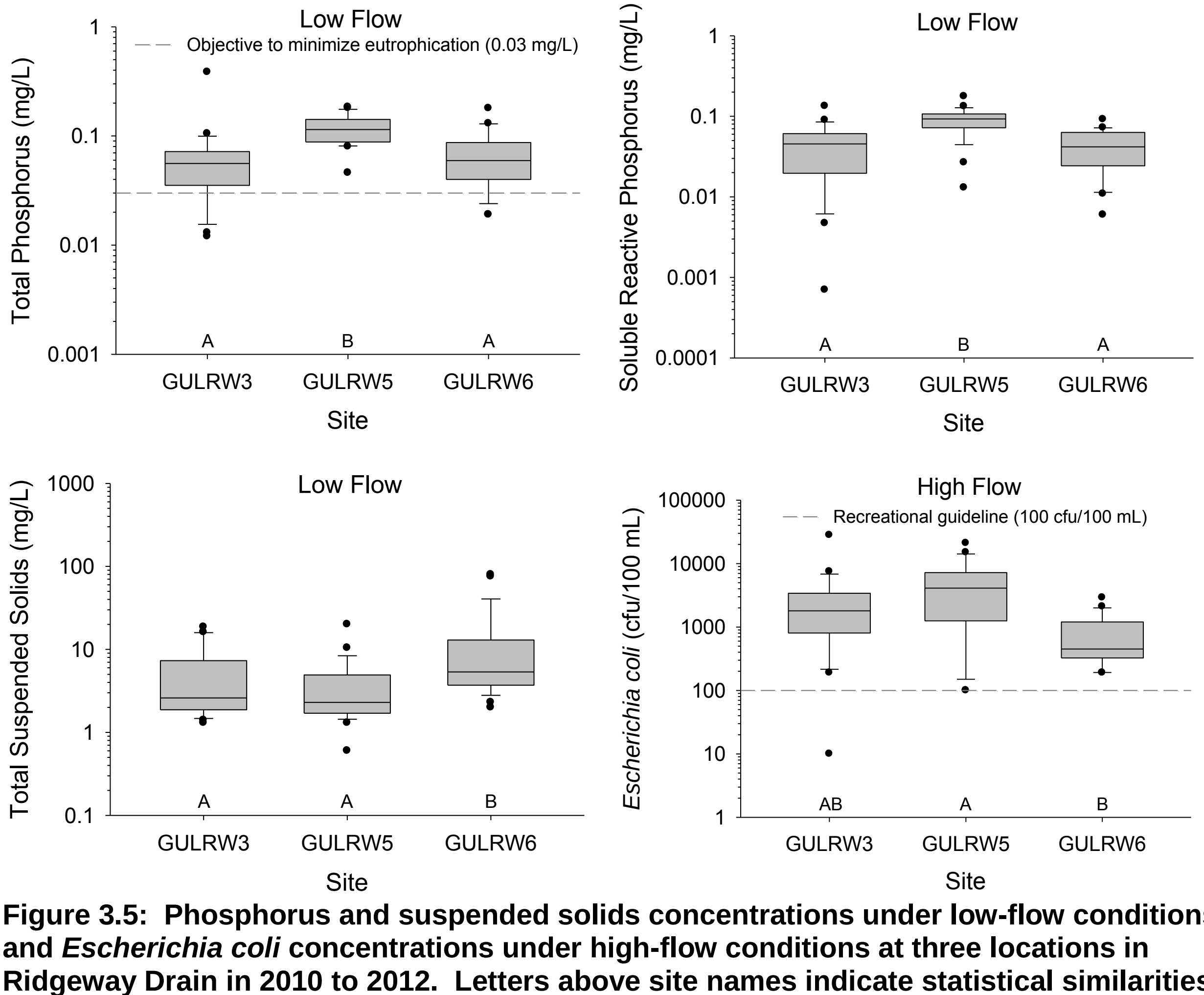

Figure 3.5: Phosphorus and suspended solids concentrations under low-flow conditions and *Escherichia coli* concentrations under high-flow conditions at three locations in Ridgeway Drain in 2010 to 2012. Letters above site names indicate statistical similarities or differences between sites. (Box plot 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.)

3.4 Benthic Macroinvertebrates

The FBI values for benthic macroinvertebrates collected in 2010 from sites in Gully Creek, Zurich Drain, and Ridgeway Drain were indicative of fair to poor water quality (Table 3.9). The three sites monitored in Ridgeway Drain suggest that water quality was more degraded in the headwaters than at the outlet. Analyzing the macroinvertebrate data from 2011 and 2012 might provide further information on the health of these watersheds.

Table 3.9: Family Biotic Index values, and corresponding water quality conditions, for benthic macroinvertebrates at sites in Gully Creek, Zurich Drain, and Ridgeway Drain in 2010.

Watershed	Site Code	Family Biotic Index	Water Quality
Gully Creek	GULGUL2	5.46	Fair
Zurich Drain	GULZUR8	5.25	Fair
Ridgeway Drain	GULRW3	5.85	Fairly Poor
	GULRW5	6.21	Fairly Poor
	GULRW6	6.53	Poor

4.0 Conclusions

Watershed-scale monitoring showed temporal and spatial differences in stream water quality. Most notably, concentrations of TP, SRP, TSS, and *E. coli* were elevated under high-flow conditions. Nitrate-N concentrations also responded to high-flow conditions, but the response to flow was different from the other water quality indicators. During high-flow conditions, concentrated flow paths linked variable source areas (VSAs) on the landscape to stream channels downstream and resulted in elevated nutrient, sediment, and bacteria concentrations. Furthermore, in the Gully Creek watershed, elevated stream flow in the channel also contributed to higher concentrations of particulate matter measured at the watershed outlet.

The use of automatic samplers enabled the collection of several samples per site during high-flow events. This highlighted the variability in water quality data depending on how the timing of sampling corresponds to the stream flow hydrograph during an event.

A spatial analysis of water quality highlighted differences between Ridgeway Drain and the other three study watersheds. Further investigation of the water quality data in relation to watershed characteristics (*e.g.*, soils and land use and management) could provide a better understanding of these differences.

Overall, watershed-scale monitoring showed that it is difficult to link changes in stream water quality to the implementation of BMPs. Long-term monitoring of high-flow water quality – with concurrent collection of climate, slope, soil, and land use and management information – will be necessary to evaluate the range of BMP effectiveness. Furthermore, the identification of VSAs that are typically generating water flow would provide some context as to how much of the landscape needs remediation and help to strategically locate BMPs.

5.0 References

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Appendix

Table A.1: Date and type of sampling events monitored in Gully Creek between 2010 and 2012, and number and type of samples collected from two monitoring locations.

Date	Type of Sampling Event			Number of Samples					
				GULGUL2				GULGUL5	
	Monthly	Rain	Rain on Snow	Grab	Global Initial	Global Composite	ISCO®	Grab	ISCO®
16-Mar-10	X			1					
28-Apr-10	X			1					
13-May-10	X			1					
27-May-10	X			1					
03-Jun-10		X		1					
07-Jun-10		X		1					
10-Jun-10	X			1					
28-Jun-10		X		1					
08-Jul-10	X			1					
13-Jul-10		X		1					
05-Aug-10	X			1					
02-Sep-10	X			1					
17-Sep-10		X		1					
28-Sep-10		X		1					
14-Oct-10	X			1					
09-Nov-10	X			1					
23-Nov-10		X		1					
30-Nov-10		X		1					
01-Jan-11			X	1					
18-Feb-11			X	1					
05-Mar-11			X	1					
09-Mar-11	X			1					
10-Mar-11			X	1					
21-Mar-11			X	1					
04-Apr-11		X		1					
18-Apr-11	X			1				1	
20-Apr-11		X		1				1	
26-Apr-11		X		1				1	
27-Apr-11		X		1				1	
12-May-11	X			1				1	
15-May-11		X		1				1	
19-May-11		X		1				1	
24-May-11		X		1				1	
26-May-11		X			1	1			
27-May-11		X		1					
30-May-11		X		1				1	
07-Jun-11	X	X		1	2	2		1	
08-Jun-11		X		1					
09-Jun-11		X		1	2	1		1	
10-Jun-11		X		1					

Date	Type of Sampling Event			Number of Samples					
				GULGUL2				GULGUL5	
	Monthly	Rain	Rain on Snow	Grab	Global Initial	Global Composite	ISCO®	Grab	ISCO®
22-Jun-11		X			1	1	1		
23-Jun-11		X		1			22	1	
24-Jun-11		X		1				1	
05-Jul-11	X			1				1	
29-Jul-11		X		1				1	
02-Aug-11	X			1				1	
07-Aug-11		X		1	1	1	3	1	
20-Aug-11		X			1	1			
21-Aug-11		X		1				1	
24-Aug-11		X		1	1	2	13	1	
25-Aug-11		X		1			11	1	
01-Sep-11		X		1				1	
04-Sep-11		X		1	1	1		1	
06-Sep-11	X			1				1	
19-Sep-11		X			1	1	2		
20-Sep-11		X					10		
23-Sep-11		X			1	1			
27-Sep-11		X			1	1	24		
28-Sep-11		X					11		
06-Oct-11	X			1				1	
13-Oct-11		X			2	2	8		
14-Oct-11		X		1			17	1	
15-Oct-11		X					7		
19-Oct-11		X			1	1	2		
20-Oct-11		X		1		1	23	1	
21-Oct-11		X					10		
01-Nov-11	X			1				1	
27-Nov-11		X		1			10	1	
28-Nov-11		X					14		
29-Nov-11		X		1			14	1	18
30-Nov-11		X					22		6
14-Dec-11		X			1	1	12		
15-Dec-11		X		1			12	1	
17-Jan-12			X				14		8
31-Jan-12		X					4		
01-Feb-12		X					20		
01-Mar-12		X					19		20
02-Mar-12		X					5		1
13-Mar-12		X					23		22
14-Mar-12		X					1		1
04-Apr-12	X			1				1	
02-May-12	X			1				1	
03-May-12		X					1		
04-May-12		X					15		

Date	Type of Sampling Event			Number of Samples					
				GULGUL2				GULGUL5	
	Monthly	Rain	Rain on Snow	Grab	Global Initial	Global Composite	ISCO®	Grab	ISCO®
05-Jun-12	X			1				1	
12-Jun-12		X					15		16
13-Jun-12		X					9		8
03-Jul-12	X			1				1	
04-Jul-12		X					13		17
05-Jul-12		X					7		2
07-Aug-12	X			1				1	
28-Aug-12	X							1	
04-Sep-12	X			1				1	
27-Sep-12	X							1	
04-Oct-12	X			1				1	
23-Oct-12		X					14	1	3
24-Oct-12		X					10		11
25-Oct-12	X							1	
30-Oct-12		X					18	1	
31-Oct-12		X					6		
06-Nov-12	X			1				1	
20-Nov-12	X							1	
02-Dec-12		X					17		
03-Dec-12	X	X					7	1	
04-Dec-12		X							6
05-Dec-12		X							6
10-Dec-12		X						1	
Total Number of Samples				66	17	18	466	46	145
Total Number of Samples per Site				567				191	
Total Number of Gully Creek Samples				758					

Table A.2: Date and type of sampling events monitored in Spring Creek between 2010 and 2012, and number and type of samples collected from two monitoring locations.

Date	Type of Sampling Event			Number of Samples		
				GULGO39N1		GULGO39N2
	Monthly	Rain	Rain on Snow	Grab	ISCO®	Grab
09-Nov-10	X			1		
23-Nov-10		X		1		
30-Nov-10		X		1		
01-Jan-11			X	1		
18-Feb-11			X	1		
05-Mar-11			X	1		
09-Mar-11	X			1		
10-Mar-11			X	1		
21-Mar-11			X	1		
04-Apr-11		X		1		
18-Apr-11	X			1		1
20-Apr-11		X		1		1
26-Apr-11		X		1		1
27-Apr-11		X		1		1
12-May-11	X			1		1
15-May-11		X		1		1
19-May-11		X		1		1
24-May-11		X		1		1
30-May-11		X		1		1
07-Jun-11	X			1		1
09-Jun-11		X		1		1
23-Jun-11		X		1		1
24-Jun-11		X		1		1
05-Jul-11	X			1		1
29-Jul-11		X		1		1
02-Aug-11	X			1		1
07-Aug-11		X		1		1
21-Aug-11		X		1		1
24-Aug-11		X		1		1
25-Aug-11		X		1		1
01-Sep-11		X		1		1
04-Sep-11		X		1		1
06-Sep-11	X			1		1
06-Oct-11	X			1		1
14-Oct-11		X		1		1
20-Oct-11		X		1		1
01-Nov-11	X			1		1
27-Nov-11		X		1		1
29-Nov-11		X		1		1
15-Dec-11		X		1		1
13-Mar-12		X			15	1
04-Apr-12	X			1		1
02-May-12	X			1		1

Date	Type of Sampling Event			Number of Samples		
	Monthly	Rain	Rain on Snow	GULGO39N1		GULGO39N2
				Grab	ISCO®	Grab
03-May-12		X			6	
04-May-12		X			12	
04-Jun-12		X			10	
05-Jun-12	X			1		1
04-Oct-12	X					1
15-Oct-12		X			11	
16-Oct-12		X			12	
23-Oct-12		X		1		
30-Oct-12		X		1		
06-Nov-12	X			1		1
Total Number of Samples				46	66	36
Total Number of Samples per Site				112		36
Total Number of Spring Creek Samples				148		

Table A.3: Date and type of sampling events monitored in Zurich Drain between 2010 and 2012, and number and type of samples collected from one monitoring location.

Date	Type of Sampling Event			Number of Samples
	Monthly	Rain	Rain on Snow	GULZUR8 Grab
15-Mar-10	X			1
29-Mar-10	X			1
08-Apr-10		X		1
13-Apr-10	X			1
26-Apr-10	X			1
03-May-10		X		1
10-May-10	X			1
27-May-10	X			1
03-Jun-10		X		1
07-Jun-10		X		1
08-Jun-10	X			1
28-Jun-10		X		1
06-Jul-10	X			1
12-Jul-10		X		1
19-Jul-10		X		1
10-Aug-10		X		1
13-Sep-10	X			1
29-Sep-10		X		1
04-Oct-10	X			1
01-Nov-10	X			1
23-Nov-10		X		1
30-Nov-10		X		1
01-Jan-11			X	1
18-Feb-11			X	1
05-Mar-11			X	1
09-Mar-11	X			1
21-Mar-11			X	1
04-Apr-11		X		1
18-Apr-11	X			1
20-Apr-11		X		1
26-Apr-11		X		1
27-Apr-11		X		1
12-May-11	X			1
15-May-11		X		1
19-May-11		X		1
24-May-11		X		1
30-May-11		X		1
07-Jun-11	X			1
23-Jun-11		X		1
24-Jun-11		X		1
05-Jul-11	X			1
29-Jul-11		X		1
02-Aug-11	X			1

Date	**Type of Sampling Event**			**Number of Samples**
	Monthly	**Rain**	**Rain on Snow**	**GULZUR8 Grab**
07-Aug-11		X		1
21-Aug-11		X		1
24-Aug-11		X		1
25-Aug-11		X		1
06-Sep-11	X			1
06-Oct-11	X			1
14-Oct-11		X		1
20-Oct-11		X		1
01-Nov-11	X			1
27-Nov-11		X		1
29-Nov-11		X		1
15-Dec-11		X		1
13-Mar-12		X		1
04-Apr-12	X			1
02-May-12	X			1
05-Jun-12	X			1
03-Jul-12	X			1
07-Aug-12	X			1
04-Sep-12	X			1
04-Oct-12	X			1
23-Oct-12		X		1
06-Nov-12	X			1
Total Number of Samples				65
Total Number of Samples per Site				65
Total Number of Zurich Drain Samples				65

Table A.4: Date and type of sampling events monitored in Ridgeway Drain between 2010 and 2012, and number and type of samples collected from three monitoring locations.

Date	Type of Sampling Event			Number of Samples			
	Monthly	Rain	Rain on Snow	GULRW3		GULRW5	GULRW6
				Grab	ISCO®	Grab	Grab
15-Mar-10	X			1		1	1
29-Mar-10	X			1		1	1
08-Apr-10		X		1		1	1
13-Apr-10	X			1		1	1
26-Apr-10	X			1		1	1
03-May-10		X		1		1	1
10-May-10	X			1		1	1
27-May-10	X			1		1	1
03-Jun-10		X		1		1	1
07-Jun-10		X		1		1	1
08-Jun-10	X			1		1	1
28-Jun-10		X		1		1	1
06-Jul-10	X			1		1	1
12-Jul-10		X		1		1	1
19-Jul-10		X		1		1	1
10-Aug-10		X		1		1	1
03-Sep-10		X		1		1	1
13-Sep-10	X			1		1	1
29-Sep-10		X		1		1	1
04-Oct-10	X			1		1	1
01-Nov-10	X			1		1	1
23-Nov-10		X		1		1	1
30-Nov-10		X		1		1	1
01-Jan-11			X	1			
18-Feb-11			X	1			
05-Mar-11			X	1			
09-Mar-11	X			1		1	
21-Mar-11			X	1		1	
04-Apr-11		X		1		1	
18-Apr-11	X			1		1	1
20-Apr-11		X		1		1	1
26-Apr-11		X		1		1	1
27-Apr-11		X		1		1	1
12-May-11	X			1		1	1
15-May-11		X		1		1	1
19-May-11		X		1		1	1
24-May-11		X		1		1	1
30-May-11		X		1		1	1
07-Jun-11	X			1		1	1
23-Jun-11		X		1		1	1
24-Jun-11		X		1			
05-Jul-11	X			1		1	1
29-Jul-11		X		1		1	1

Date	Type of Sampling Event			Number of Samples			
	Monthly	Rain	Rain on Snow	GULRW3		GULRW5	GULRW6
				Grab	ISCO®	Grab	Grab
02-Aug-11	X			1		1	1
07-Aug-11		X		1			
21-Aug-11		X		1		1	1
24-Aug-11		X		1		1	1
25-Aug-11		X		1		1	1
07-Sep-11	X			1		1	1
06-Oct-11	X			1		1	1
14-Oct-11		X		1		1	1
20-Oct-11		X		1		1	1
01-Nov-11	X			1		1	1
27-Nov-11		X		1		1	1
29-Nov-11		X		1		1	1
15-Dec-11		X		1		1	1
17-Jan-12			X		12		
18-Jan-12			X		10		
13-Mar-12		X				1	1
04-Apr-12	X			1		1	1
02-May-12	X			1		1	1
05-Jun-12	X			1		1	1
03-Jul-12	X			1		1	1
07-Aug-12	X			1		1	1
04-Sep-12	X			1		1	1
04-Oct-12	X			1		1	1
23-Oct-12		X		1			
06-Nov-12	X			1		1	1
Total Number of Samples				65	22	60	57
Total Number of Samples per Site				87		60	57
Total Number of Ridgeway Drain Samples				204			