A Synthesis Report of the Watershed Based Best Management Practices Evaluation, Huron

A report prepared for the Ontario Ministry of Agriculture and Food
September 16, 2013

Prepared by Jane Simmons[1], Brynn Upsdell Wright[1], Mari Veliz[1] and Kevin McKague[2]

[1] Ausable Bayfield Conservation Authority, Exeter, Ontario, N0M 1S5
[2] Ontario Ministry of Agriculture and Food, Woodstock, Ontario, N4T 1W2

Acknowledgements: The authors thank the landowners in the Gully Creek, Spring Creek, Zurich Drain, and Ridgeway Drain watersheds, and Joe Vermunt and Paul Nairn of the Huron County Federation of Agriculture, for their cooperation and insights. Major contributions to the report were made by Dr. Wanhong Yang, Dr. Yongbo Liu, and Anatoliy Oginskyy of the Watershed Evaluation Group at the University of Guelph. Technical support from Mark Lowenstine, Ross Wilson, Abigail Gutteridge, Tracey McPherson, Hope Brock, Kate Monk, and Alec Scott of the Ausable Bayfield Conservation Authority, and Dr. Stewart Sweeney and Gabrielle Ferguson of the Ontario Ministry of Agriculture and Food, is gratefully acknowledged. Finally, we would like to thank Jacqui Empson Laporte of the Ontario Ministry of Agriculture and Food, and Dr. Pradeep Goel and Scott Abernethy of the Ontario Ministry of the Environment, for their advisory support. Funding for this project was provided by the Ontario Ministry of Agriculture and Food and the Ministry of Rural Affairs through the Canada-Ontario Agreement respecting the Great Lakes. The views expressed in this report are the views of the authors and do not necessarily reflect those of the Ontario Ministry of Agriculture and Food or the Ministry of Rural Affairs.

AUSABLE BAYFIELD CONSERVATION
CREATING AWARENESS | TAKING ACTION

Ontario

The photographs on this page demonstrate the variability in flow conditions in Gully Creek, with low-flow conditions on the left and high-flow conditions on the right.

TABLE OF CONTENTS

1.0 INTRODUCTION ... 1
1.1 Project background ... 1
1.2 Objectives ... 1
1.3 Study area ... 2
2.0 GENERAL METHODS ... 4
2.1 Selection of best management practices ... 4
2.2 Land use and land management data ... 4
2.3 Water quality monitoring ... 5
2.4 Environmental model (Soil and Water Assessment Tool) ... 8
2.5 Field-scale evaluation ... 9
2.6 Economic model ... 9
3.0 RESULTS AND DISCUSSION ... 10
3.1 Agricultural practices in study area ... 10
3.1.1 Historical land use: comparison of 1978 to present ... 10
3.1.2 Land management practices ... 12
3.1.3 Summary ... 12
3.2 Water quality variation in near-shore watersheds ... 13
3.2.1 Measured water quality at watershed outlets ... 13
3.2.2 Modelled water quality at watershed outlet ... 16
3.2.3 Summary ... 21
3.3 Effects of best management practices ... 21
3.3.1 Watershed-scale environmental effects ... 21
3.3.2 Field-scale environmental effects ... 23
3.3.3 Economic effects ... 25
3.3.4 Enhancing best management practice effectiveness with models ... 26
3.3.5 Model limitations ... 28
3.3.6 Summary ... 28
4.0 CONCLUSIONS ... 28
4.1 Lessons learned ... 28
4.2 Recommendations and next steps ... 30
5.0 REFERENCES ... 31

LIST OF TABLES

Table 1-1: Summary of watershed characteristics for the Watershed Based Best Management Practices Evaluation, Huron, within the Ausable Bayfield Conservation Authority jurisdiction. . 2
Table 2-1: Watershed-scale monitoring locations for Gully Creek, Spring Creek, Zurich Drain, and Ridgeway Drain. 5
Table 3-1: Percentage of fields and agricultural land with best management practices in the Gully Creek watershed based on landowner interviews, windshield surveys, and nutrient management software.......... 12
Table 3-2: Mean suspended solids and nutrient concentrations under low-flow and high-flow conditions between 2010 and 2012.......... 14
Table 3-3: Mean suspended solids and nutrient concentrations under high-flow conditions between 2010 and 2012. 14
Table 3-4: Summary of field-scale best management practice assessment results.......... 24
Table 4-1: Summary of lessons learned through the Watershed Based Best Management Practices Evaluation, Huron.......... 29

LIST OF FIGURES

Figure 1-1: Study area for the Watershed Based Best Management Practices Evaluation, Huron, within the Ausable Bayfield Conservation Authority jurisdiction. 3
Figure 2-1: Map of the Gully Creek and Spring Creek watersheds showing watershed-scale monitoring locations. 6
Figure 2-2: Map of the Zurich Drain and Ridgeway Drain watersheds showing watershed-scale monitoring locations. 7
Figure 3-1: Comparison of land use in 1978 and 2011 for the Gully Creek watershed. 10
Figure 3-2: Land use in the Gully Creek watershed, estimated from 1978 aerial photo interpretation. 11
Figure 3-3: Land use in the Gully Creek watershed, from 2011 windshield surveys. 11
Figure 3-4: Total suspended solids, total phosphorus, and soluble reactive phosphorus concentrations under low-flow and high-flow conditions at the watershed outlets between 2010 and 2012. 15
Figure 3-5: Nitrate-nitrogen concentrations under low-flow and high-flow conditions at the watershed outlets between 2010 and 2012. 16
Figure 3-6: Total phosphorus and nitrate-nitrogen concentrations at the outlet of Gully Creek from samples collected hourly during a storm event in October 2011. 16
Figure 3-7: Comparison of measured and modelled (Soil and Water Assessment Tool) stream flows at the Gully Creek outlet. 17
Figure 3-8: Comparison of measured and modelled (Soil and Water Assessment Tool) total phosphorus loadings at the Gully Creek outlet. 17
Figure 3-9: Change in average simulated water quality indicators at the Gully Creek watershed outlet from the historical (1978) to existing (2011) land use and management scenarios. 19
Figure 3-10: Simulated average monthly stream flow and total sediment loading at the Gully Creek outlet, averaged 2002 – 2011. 19
Figure 3-11: Simulated average monthly surface runoff, subsurface runoff, and sediment yield (without channel erosion) in the Gully Creek watershed under existing conditions, averaged 2002 – 2011.. 20
Figure 3-12: Simulated average monthly stream flow and total phosphorus and total nitrogen loadings at the outlet of Gully Creek, averaged 2002 – 2011.. 21
Figure 3-13: Simulated change in sediment and nutrient loadings under four best management practice scenarios compared with a base scenario (existing conditions), 2002 – 2011. 22
Figure 3-14: Estimated decrease in channel erosion downstream of existing and future Water and Sediment Control Basins over the period 2002 to 2011. 23
Figure 3-15: Estimated cost of implementing best management practices at the field scale. 26
Figure 3-16: Simulated sediment yield in the Gully Creek watershed at the field scale, averaged 2002 – 2011.. 27
Figure 3-17: Environmental and economic impacts of implementing a conservation tillage best management practice on corn fields in the Gully Creek watershed, 2009................................... 27

1.0 INTRODUCTION

1.1 Project background

The near-shore area of the Great Lakes is an important aquatic ecosystem that provides many residents of Ontario with drinking water and recreational opportunities. However, nutrient impacts can negatively affect the ecological integrity of the near-shore and limit human uses of water resources. Non-point source pollution from agricultural and other human activities is one of the major contributors of nutrients to the lakes. As a result, managing agricultural activities in the Great Lakes Basin is crucial for restoring and protecting the ecosystem. Efforts to manage agricultural non-point source pollution though the Canada Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA) and other programs have led to notable improvements in ecosystem health; however, there continues to be symptoms of an impacted ecosystem. Olson and Kalishcuk (2009) proposed that combinations of practices are required to effectively manage nutrients. The challenge is to identify nutrient management decisions that are sustainable on both individual and societal bases and to demonstrate the environmental and economic effectiveness of various best management practices (BMPs). To address this challenge, the Watershed Based Best Management Practices Evaluation (WBBE) program was funded to look at the effects of suites of management practices at both the field and sub-watershed scales (OMAFRA 2010).

1.2 Objectives

In 2010, the Ausable Bayfield Conservation Authority (ABCA) and the Huron County Federation of Agriculture received funding under the WBBE program to study the effects of agricultural best management practices. The specific objectives of the WBBE, Huron, project were to:

1. Conduct analyses to evaluate the effects of BMPs on water quality at both the farm/field and small watershed scales;
2. Estimate the private and public costs of BMP implementation; and
3. Develop and report on appropriate environmental and economic performance indicators.[1]

The WBBE, Huron, study had a nested monitoring design and a modelling component to evaluate the environmental effectiveness of BMPs at the field and small-watershed scales. A preliminary economic evaluation, which focused on the economic implications of these practices for the private landowner, was also completed in this study. The purpose of this synthesis report is to summarize environmental findings at the field and watershed scales and provide a socioeconomic context to the findings.

[1] This is discussed in the final report provided to the Ontario Ministry of Agriculture and Food and Ministry of Rural Affairs in March 2013.

1.3 Study area

The study area for the WBBE, Huron, is composed of several small watersheds that drain directly into Lake Huron, including: the Bayfield North watersheds, the Zurich Drain watershed, and the Ridgeway Drain watershed (Figure 1-1). This study expands on past water quality improvement efforts undertaken in each of the watersheds.

Best management practices have been implemented most recently in the Gully Creek watershed, so it was selected in this study for in-depth investigation and for detailed modelling with a water quantity and quality simulation model. The Gully Creek watershed is 15 square kilometres and the creek is the largest tributary in the Bayfield North watersheds. It is one of the few cold water streams found in the ABCA jurisdiction. Close to 70 per cent of the land draining into Gully Creek is cropland. The remaining 30 per cent is forests, shrubs, and meadows (Table 1-1).

To help inform the relationship between land use and water quality, strategic monitoring was conducted in three additional watersheds (Table 1-1). Historical water quality data were available for the Zurich and Ridgeway drains, which led to both watersheds being selected for this study. Because of its high percentage of forest cover (>60 per cent) and close proximity to the Gully Creek watershed, the Spring Creek watershed in the Bayfield North watersheds was also monitored.

TABLE 1-1: 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.

FIGURE 1-1: STUDY AREA FOR THE WATERSHED BASED BEST MANAGEMENT PRACTICES EVALUATION, HURON, WITHIN THE AUSABLE BAYFIELD CONSERVATION AUTHORITY JURISDICTION.

2.0 GENERAL METHODS

2.1 Selection of best management practices

Four BMPs that were observed to have been commonly implemented in the study area in the past were chosen for comprehensive evaluation:

- Conservation tillage,
- Cover crop,
- Nutrient management, and
- Water and Sediment Control Basins (WASCoBs).

An opportunity to evaluate a fifth BMP – a grass filter strip – arose during the course of the project, so it was also included in the study. The BMPs evaluated in this project thus included agronomic management practices (tillage, cover crop, and nutrient management) as well as structural practices (WASCoBs and grass filter strips). 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 the pollutant in primary aquatic systems (*i.e.*, swales, grassed waterways, WASCoBs, and ditch BMPs). This study 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.

2.2 Land use and land management data

Land use and land management data (*e.g.*, fertilizer and tillage practices) were collected over the course of this study by combining a variety of techniques: one-on-one landowner land management surveys, periodic windshield crop surveys, and aerial photo interpretation. Ontario's nutrient management planning software (NMAN3) (OMAFRA 2012a) was used to organize and analyse much of these data. This information was also compiled in spreadsheets and, where appropriate, linked to GIS maps of the study area.

The land use and land management data were used to better characterize the current and historical land cover conditions within the study area and were fed into the environmental and economic models used in this study. Additional provincial and regional land use GIS data sets, including the Land Resource Information System (for non-agricultural lands) (OMNR 2008) and Agricultural Resources Inventory (OMAFRA 2011), were also used for setting up the environmental model.

2.3 Water quality monitoring

To compare water quality between watersheds and to inform the water quantity and quality components of the environmental model calibration, eight water quality stations were monitored throughout the study area (Figures 2-1 and 2-2). From November 2010 to December 2012, flow data were collected at five sites and, at all of the sites, water quality was monitored monthly and during high rainfall, snowmelt, and flooding events. Water was analysed for sediment and nutrients (phosphorus and nitrogen), as well as a number of physicochemical indicators, such as pH and dissolved oxygen (Table 2-1).

TABLE 2-1: WATERSHED-SCALE MONITORING LOCATIONS FOR GULLY CREEK, SPRING CREEK, ZURICH DRAIN, AND RIDGEWAY DRAIN.

Watershed	Site Code	Outlet	UTM Coordinates		Data Collected	Notes
			Easting	Northing		
Gully	GULGUL2	Outlet	443075	4829234	All data [a]	Global [b], ISCO [c]
	GULGUL5		446412	4829264	All data	ISCO
Spring	GULGO39N1	Outlet	443055	4827048	No benthic	ISCO
	GULGO39N2		444730	4826900	No quantity/benthic	Grab only
Zurich	GULZUR8	Outlet	442763	4806216	All data	Grab only
Ridgeway	GULRW3	Outlet	441615	4800565	All data	ISCO
	GULRW5		446456	4799362	No quantity	Grab only
	GULRW6		448569	4799144	No quantity	Grab only

[a] All data includes water quantity (level and flow), physicochemical indicators (temperature, conductivity, total dissolved solids, dissolved oxygen, and pH), total suspended solids, nutrients (total ammonia, nitrate, nitrite, total Kjeldahl nitrogen, total phosphorus, and soluble reactive phosphorus), *Escherichia coli*, and benthic invertebrates. *Escherichia coli* and benthic invertebrate data are discussed in Upsdell Wright and Veliz 2013.

[b] A Global Water sampler, deployed in May 2011, was set to collect 500 millilitres every hour for a high-flow composite sample when triggered with a rise in water level.

[c] ISCO samplers, deployed in June 2011, were set to collect hourly samples over a 24-hour period when triggered with a rise in water level.

High and low flows were identified by visual inspection of the hydrographs and data from each watershed outlet were analysed by computing average sediment and nutrient concentrations. Concentrations of total phosphorus (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). For all water quality indicators, a non-parametric Kruskal-Wallis test was applied to determine if significant differences in water quality could be observed between high-flow and low-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. For Gully Creek, daily loads were estimated by combining the measured concentration data with flow data collected for model calibration.

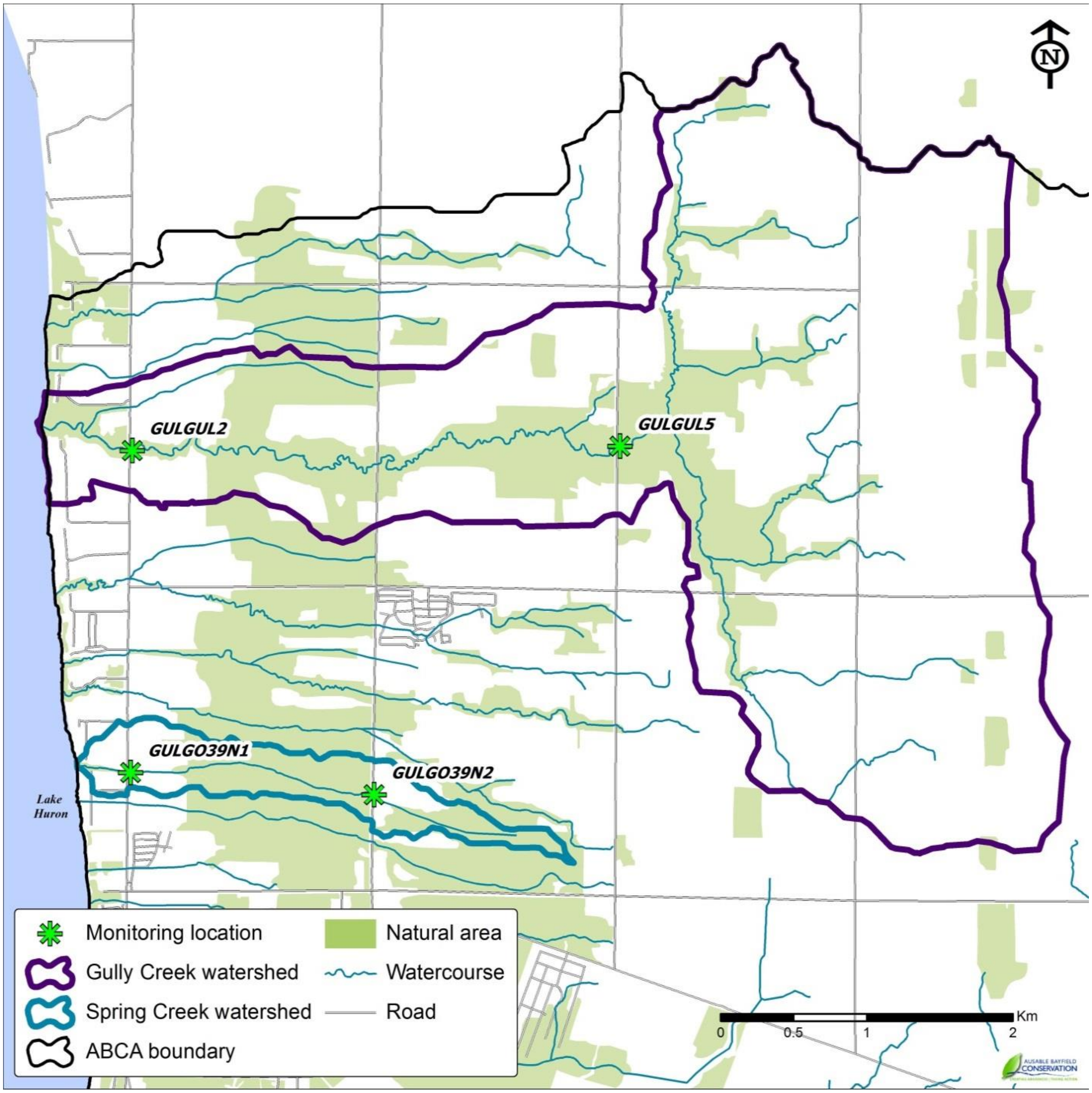

FIGURE 2-1: MAP OF THE GULLY CREEK AND SPRING CREEK WATERSHEDS SHOWING WATERSHED-SCALE MONITORING LOCATIONS.

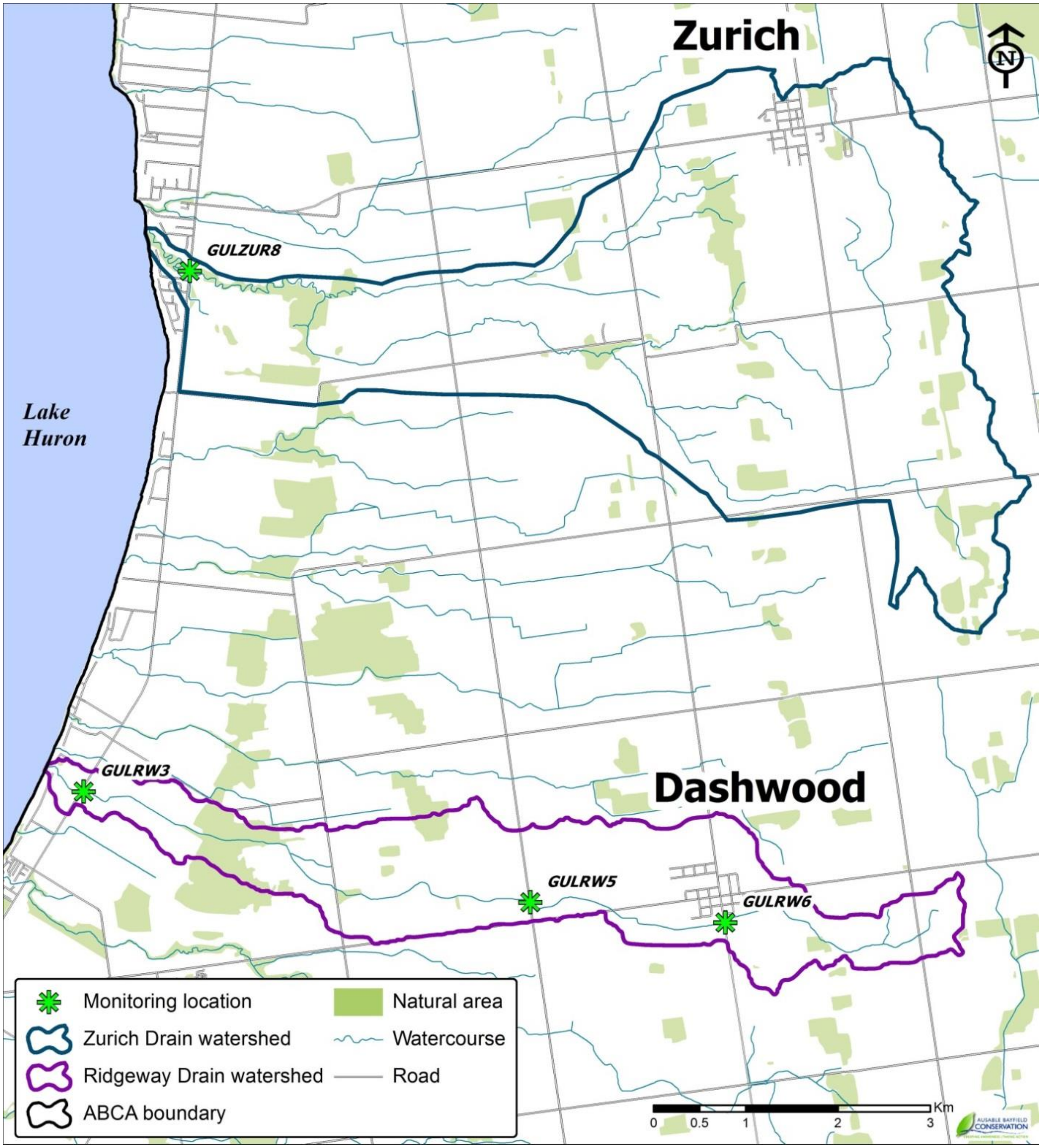

FIGURE 2-2: MAP OF THE ZURICH DRAIN AND RIDGEWAY DRAIN WATERSHEDS SHOWING WATERSHED-SCALE MONITORING LOCATIONS.

2.4 Environmental model (Soil and Water Assessment Tool)

The Soil and Water Assessment Tool (SWAT) is a hydrologic and water quality model designed for use in large, ungauged river basins. The University of Guelph's Watershed Evaluation Group adapted the model to simulate hydrologic processes and to assess BMP performance in the Gully Creek watershed. The model adaptation involved development of a Water and Sediment Control Basin (WASCoB) module, and modification of parameters for small lakeshore watershed conditions. The model was set up with a variety of spatial and temporal data sets, including a LiDAR-based digital elevation model for the area (OMAFRA 2012b); a land use layer based on the Land Resource Information System (OMNR 2008) and the Agricultural Resources Inventory (OMAFRA 2011); a digital soil layer based on the Ontario soil survey (Hoffman *et al.* 1952); climate data from the ABCA and Environment Canada; WASCoB locations and descriptions derived from the LiDAR; and crop management information obtained from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), ABCA, and direct landowner interviews. These various sources of information were combined in the model to produce an existing (base) watershed model scenario. This base condition incorporated a number of existing BMPs that were already established in the watershed, including 18 existing WASCoBs and the management and tillage practices identified through the landowner interviews and windshield surveys for the 2008 through 2013 cropping seasons. The model was calibrated with flow and water quality data collected from four in-stream stations during the same general time period (2010 through 2012).

Once calibrated to the existing watershed observations, the SWAT model was then applied to simulate watershed processes and to examine the water quantity and quality effects of implementing additional or removing the existing four BMPs (conservation tillage, nutrient management, cover crop, and WASCoBs), relative to the calibrated existing (base) scenario. The effects of the various BMPs were estimated at both the field and watershed scales. The conservation tillage scenario represented in the SWAT simulated the following tillage practices after crop harvest: fall chisel-plough or vertical tillage[2] of the corn stover, no tillage (no-till) of the wheat or spring grain stubble (straw removed), and no tillage (no-till) of the soybean or dry bean residue. The nutrient management scenario used recommended phosphorus and nitrogen fertilizer rates as determined by the NMAN3 software (OMAFRA 2012a). The cover crop scenario simulated the effect of under-seeding winter wheat with red clover. The clover was assumed to be ploughed down (moldboard plough) in late October and cultivated twice the following spring to prepare the subsequent crop's seedbed. The nitrogen fertilization rate for the subsequent crop was reduced by 60 kilograms per hectare due to the assumed provision of nitrogen from the red clover plough-down. For the WASCoB scenarios, the LiDAR-derived dimensions of constructed (existing) and planned (future) WASCoBs were incorporated into the SWAT model. The WASCoB scenarios then estimated the effects of removing existing WASCoBs (no WASCoB scenario) or adding planned WASCoBs (existing and future WASCoB

---

[2] The fall chisel-ploughing or vertical tillage practice simulated in the SWAT was assumed to disturb the soil to a maximum depth of 25 centimetres and have a residue mixing efficiency of 5 per cent.

scenario) to assess the water quantity and quality differences relative to the existing watershed condition (existing WASCoB scenario).

2.5 Field-scale evaluation

Field-scale monitoring was undertaken to assess the environmental, and in one case, also the economic effectiveness of the five BMPs selected for investigation. The primary methodology used in this study was side-by-side comparisons of adjacent field plots. An upstream-downstream study and a before, after, control, impact (BACI) design were also attempted. Sampling took place between the fall of 2011 and spring of 2013. It included in-stream and edge-of-field event-based water sampling for flow, suspended sediment, and nutrients, as well as in-field composite soil sampling and crop yield monitoring. A number of evaluations were planned, but did not produce results due to implementation challenges. The lessons learned from these challenges are discussed in Section 4.1.

2.6 Economic model

An economic evaluation was undertaken for the Gully Creek watershed to assess the same four agricultural BMPs as in the environmental modelling exercise. The evaluation was performed with a custom spreadsheet model that simulates net returns for a particular BMP scenario. The main measure used in the economic evaluation of BMP effectiveness was the private cost, which is defined as the difference between the net returns with and without the BMP. Assumptions related to cropping, tillage, fertilizer, and residue management were based on landowner interview and windshield survey data collected from 2008 through 2010. Crop prices were from Ontario's historical crop prices (OMAFRA 2012c) and costs were based on OMAFRA's crop cost enterprise budgets (OMAFRA 2007, 2008, and 2009a). Differences in yields and profitability were also measured as part of the field-scale assessment of nutrient management recommendations to supplement the modelling.

A preliminary analysis was conducted to look at the combined environmental and economic effectiveness of the conservation tillage practice on corn. In the Gully Creek watershed, the BMP was evaluated on a field-by-field basis to determine if it had an environmental benefit (*i.e.*, reduction in total phosphorus yield), economic benefit (*i.e.*, reduction in cost for the producer), both, or neither. If the BMP was not implemented on a particular field (*i.e.*, the field was not planted in corn), that was also noted. This analysis examined the effects of only one BMP applied to one crop type in one particular year, as the combined effectiveness of multiple BMPs applied over multiple years can be complicated and depends on a number of factors such as the previous crop, existing crop, and the amount of precipitation in a given year.

3.0 RESULTS AND DISCUSSION

3.1 Agricultural practices in study area

3.1.1 Historical land use: comparison of 1978 to present

Important land use changes took place in the Gully Creek watershed between 1978 and 2011 (Figures 3-1 to 3-3). Many of these changes have been a result of the natural evolution of agriculture in southern Ontario over that time period. Natural cover has remained relatively stable in that time, but agricultural field sizes have more than doubled, from an average of 9 hectares per field in 1978 to nearly 24 hectares in 2011. As a result, land is divided by fewer fencerows and treed windbreaks. Moreover, about 30 per cent of the watershed was used as pasture and forage (hay) fields in 1978, compared with less than 2 per cent in 2011. The decrease in pasture and hay means that less land is now in perennial cover. Similar to today, corn tended to be the dominant crop in 1978; however, spring grains were 13 per cent more prevalent and soybeans and winter wheat were grown only sporadically in the late 1970s. This differs from the recent trend of a corn-soybean-wheat crop rotation, which now dominates over 60 per cent of the land in the watershed. These landscape and land management changes mean that, without best management practices, soil is naturally more prone to erosion and more nutrients are available for runoff than in the 1970's. The environmental implications of this are discussed further in Section 3.2.2.

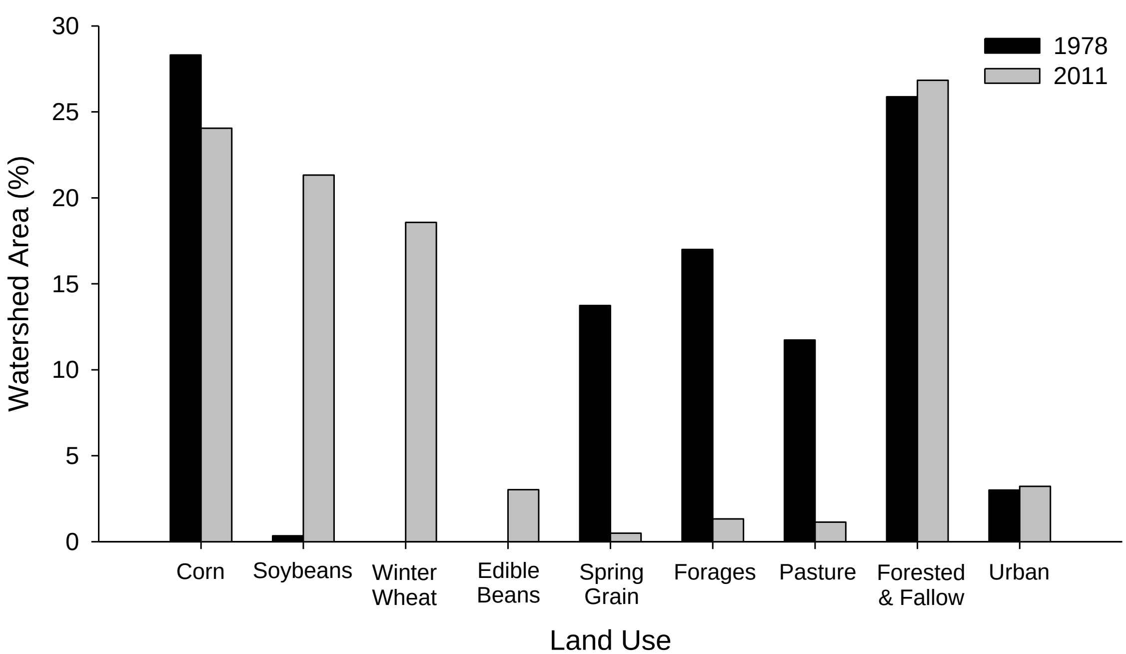

FIGURE 3-1: COMPARISON OF LAND USE IN 1978 AND 2011 FOR THE GULLY CREEK WATERSHED.

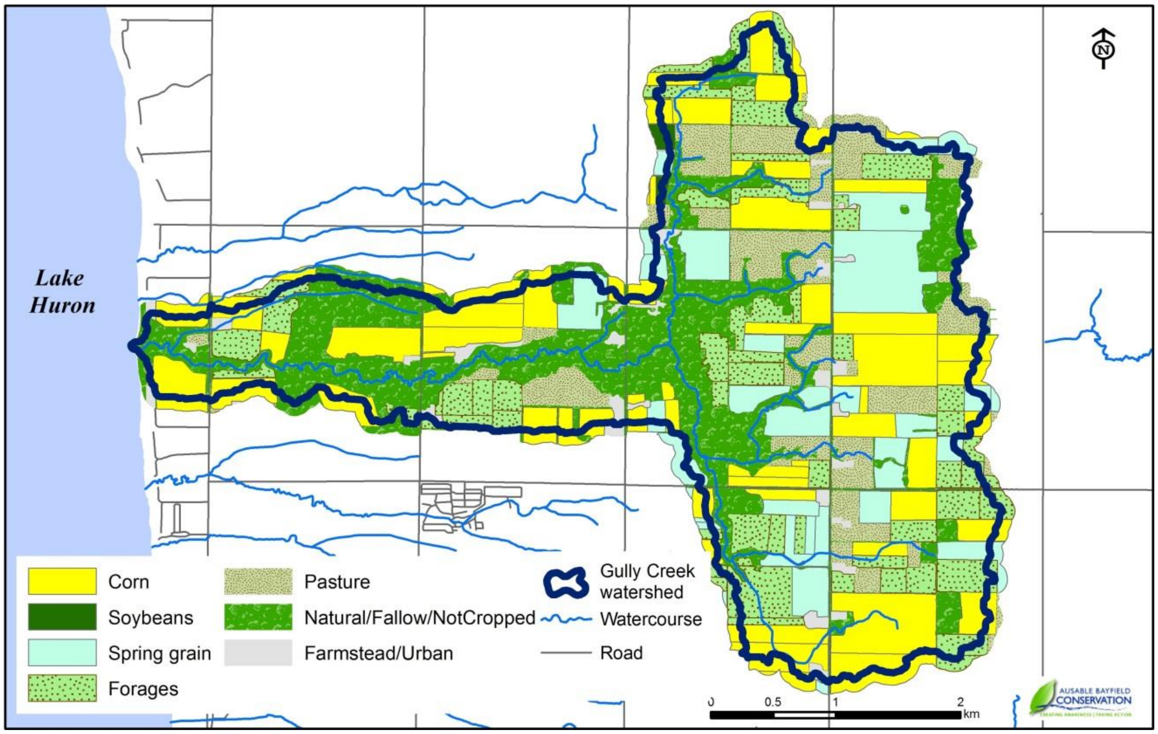

FIGURE 3-2: LAND USE IN THE GULLY CREEK WATERSHED, ESTIMATED FROM 1978 AERIAL PHOTO INTERPRETATION.

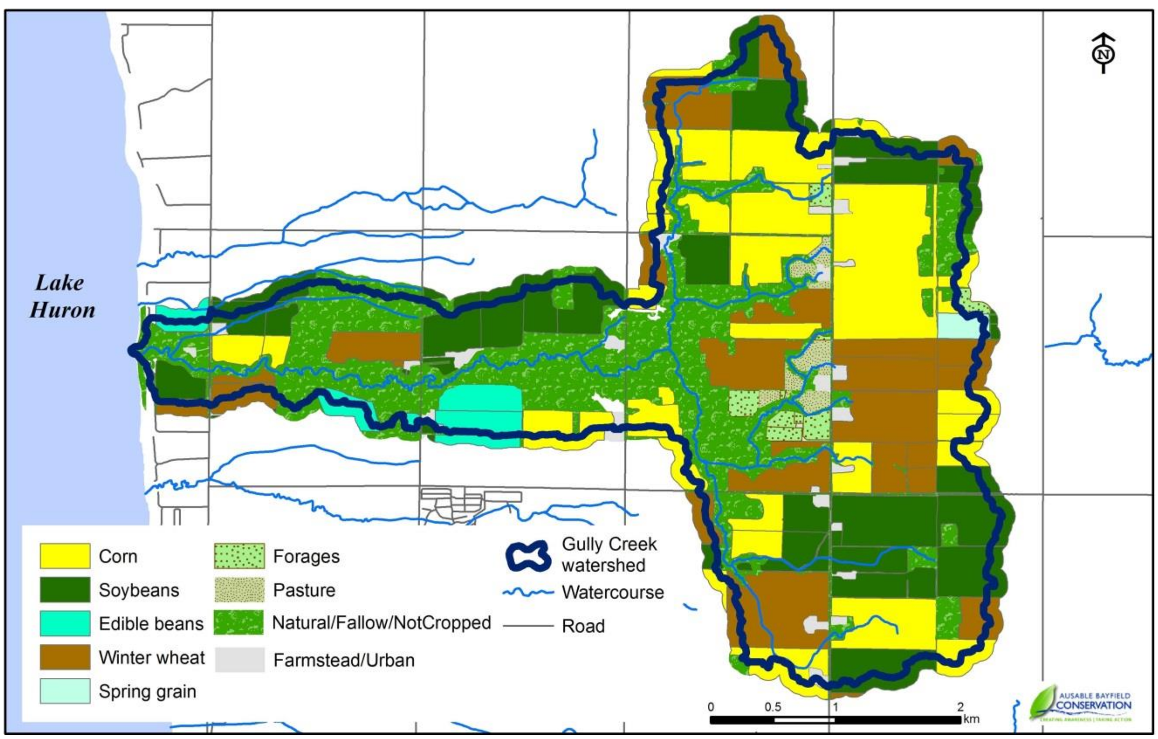

FIGURE 3-3: LAND USE IN THE GULLY CREEK WATERSHED, FROM 2011 WINDSHIELD SURVEYS.

3.1.2 Land management practices

Existing provincial geospatial data sets (*e.g.*, Land Resource Information System and Agricultural Resources Inventory) did not contain detailed information about crop types and cropping systems. Landowner interview and windshield survey data helped to identify the number of existing and potential BMPs in the Gully Creek watershed (Table 3-1).

TABLE 3-1: PERCENTAGE OF FIELDS AND AGRICULTURAL LAND WITH BEST MANAGEMENT PRACTICES IN THE GULLY CREEK WATERSHED BASED ON LANDOWNER INTERVIEWS, WINDSHIELD SURVEYS, AND NUTRIENT MANAGEMENT SOFTWARE (NMAN3).

Coverage	Conservation Tillage [a]	Nutrient Management [b]		Cover Crop [c]
		Phosphorus	Nitrogen	
Percentage of fields	57	98	94	0
Percentage of agricultural land	72	---	---	0

[a] Conservation tillage includes all land with at least 30 per cent residue cover after planting. Data were from 2011 windshield surveys.

[b] Nutrient management includes all land with phosphorus or nitrogen application rates that do not result in a best management practice or regulatory "red flag" within Ontario's nutrient management planning software (NMAN3). This was based on NMAN3 analysis of data collected through the 2011/2012 landowner interviews, covering the 2009 crop year.

[c] Cover crop data were based on landowner interviews conducted in 2011 and 2012, covering 67 per cent of the land area for the crop years 2008 to 2013.

Over 70 per cent of the land surveyed in the Gully Creek watershed was being managed with some form of conservation tillage practice and over 90 per cent of the fields were receiving nutrients in the range accepted by the NMAN3 software (OMAFRA 2012a). Cover crops, however, were virtually unplanted by landowners in this watershed. This shows that there is a fairly high adoption rate of BMPs, such as nutrient management, that have been supported by regulation or outreach programs. However, not all BMPs are currently used with the same frequency.

During the study period, BMP adoption rates and interest increased. Approximately 15 BMPs were identified or implemented (9 BMPs completed, 4 BMPs to be completed in 2013, 2 BMPs to be completed in the future) in the Gully Creek watershed through focused on-farm engagement made possible by this study. Of these 15 BMPs, 8 were agronomic BMPs, 6 were structural BMPs, and 1 was a fragile land retirement BMP.

3.1.3 Summary

Overall, the first part of this study showed that a substantial proportion of landowners are implementing BMPs. As land use continues to change and new BMPs are adopted, it will be important to understand the watershed-wide effects of implemented BMPs on water quality. This is discussed further in the following section.

3.2 Water quality variation in near-shore watersheds

3.2.1 Measured 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. 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.

Water quality indicators varied spatially and temporally between the four watersheds (Tables 3-2 and 3-3 and Figures 3-4 and 3-5). Except for Spring Creek, the streams had higher concentrations of total suspended solids (TSS), total phosphorus (TP), and soluble reactive phosphorus (SRP) during high-flow events compared with low-flow events. Nitrate-nitrogen (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. During high-flow events, 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.

The lack of significant increases in water quality indicator concentrations at Spring Creek during high-flow periods was originally thought to be attributable to the abundance of natural cover. However, it is challenging to separate the land use effects from the effects of the Huron Clay Loam soil 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.

Water quality was also examined graphically on an event-by-event basis. It was observed that total phosphorus concentrations generally increased with increasing flow and decreased with decreasing flow (Figure 3-6). The relationship between nitrate-N concentrations and stream flow was less clear, however (Figure 3-6). Typically, nitrate-N concentrations decreased as flow increased, and then nitrate-N concentrations increased and remained elevated after the event. The timing of sampling can therefore affect the measured nutrient concentrations and is an important consideration for future study design. Nutrient concentrations during high flows frequently exceeded concentrations considered to minimize eutrophication, in some cases by an order of magnitude. Surface water quality data need to reflect storm runoff – the time when BMPs need to be effective.

Overall, watershed-scale monitoring showed that it is difficult to relate changes in stream water quality at the watershed outlet with specific changes in land use and land management. With adequate measured data, however, modelling showed good potential as a means to relate observed land management practices to observed water quality. The following section describes watershed water quality based on the results of a water quality simulation model.

TABLE 3-2: MEAN SUSPENDED SOLIDS AND NUTRIENT CONCENTRATIONS UNDER LOW-FLOW AND HIGH-FLOW CONDITIONS BETWEEN 2010 AND 2012.

Watershed	Forests and Shrubs [a] (%)	Total Suspended Solids			Total Phosphorus			Soluble Reactive Phosphorus			Nitrate-nitrogen		
		Low Flow (mg/L)	High Flow (mg/L)	*p*-value [b]	Low Flow (mg/L)	High Flow (mg/L)	*p*-value [b]	Low Flow (mg/L)	High Flow (mg/L)	*p*-value [b]	Low Flow (mg/L)	High Flow (mg/L)	*p*-value [b]
Gully	27	35	486	0.00	0.044	0.615	0.00	0.018	0.104	0.00	4.3	4.6	0.99
Spring	64	8	6	0.58	0.022	0.058	0.04	0.006	0.008	0.64	2.6	1.7	0.01
Zurich	14	22	315	0.00	0.039	0.299	0.00	0.016	0.065	0.00	3.4	5.5	0.03
Ridgeway	8	52	107	0.00	0.152	0.497	0.00	0.070	0.274	0.00	8.2	8.7	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 3-3: MEAN SUSPENDED SOLIDS AND NUTRIENT CONCENTRATIONS UNDER HIGH-FLOW CONDITIONS BETWEEN 2010 AND 2012.

Watershed	Forests and Shrubs [a] (%)	Total Suspended Solids		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]	Mean (mg/L)	Significant Differences [b]
Gully	27	486	A	0.615	A	0.104	A	4.6	A
Spring	64	6	B	0.058	B	0.008	B	1.7	B
Zurich	14	315	A, B	0.299	A, B	0.065	A, B	5.5	A
Ridgeway	8	107	B	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.)

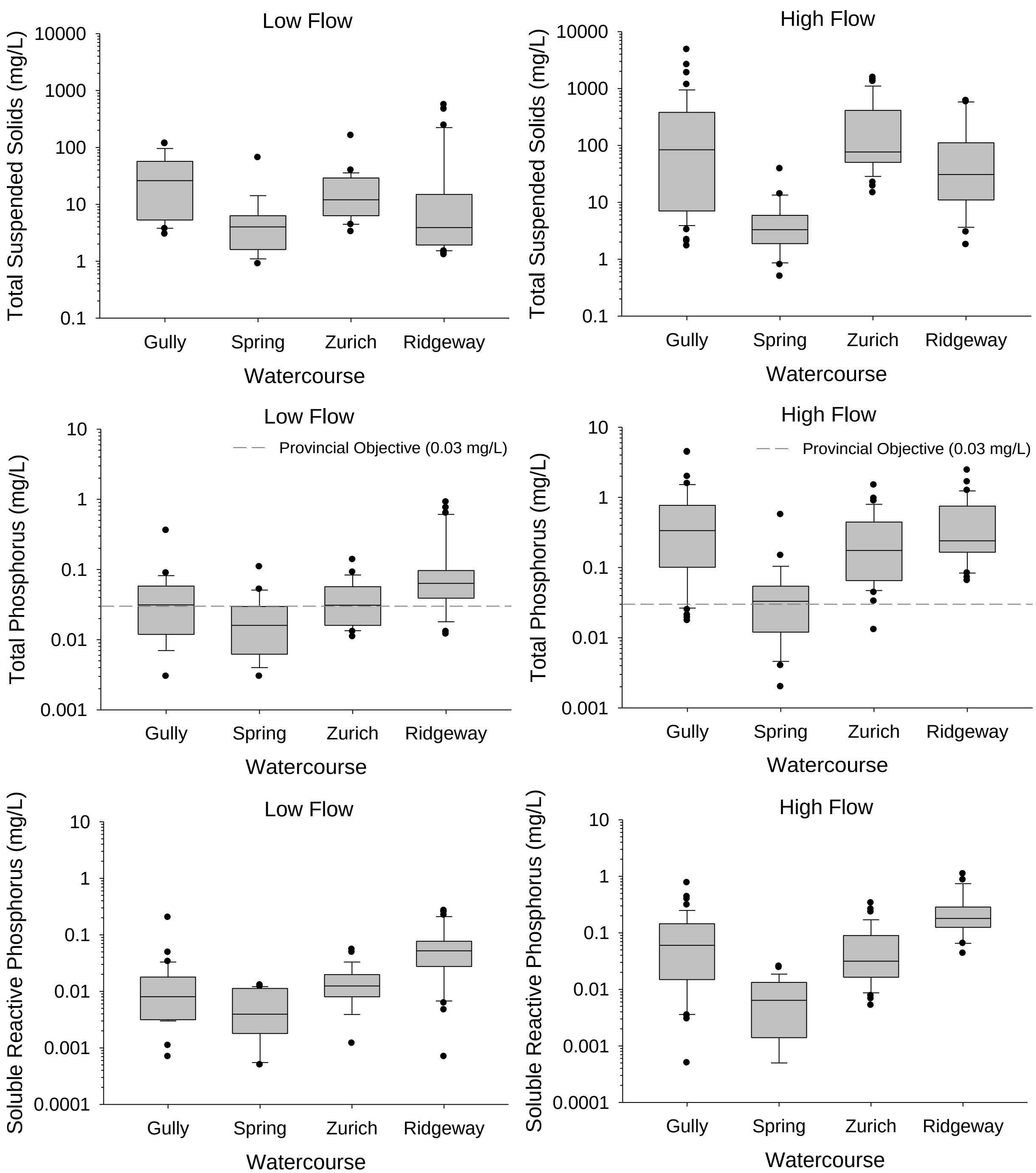

FIGURE 3-4: TOTAL SUSPENDED SOLIDS, TOTAL PHOSPHORUS (TP), AND SOLUBLE REACTIVE PHOSPHORUS CONCENTRATIONS UNDER LOW-FLOW AND HIGH-FLOW CONDITIONS AT THE WATERSHED OUTLETS BETWEEN 2010 AND 2012. DASHED GRAY LINES INDICATE TP STANDARD TO PREVENT EUTROPHICATION. (BOX PLOT GRAPHS SHOW OUTLIERS (·), THE 10TH 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.)

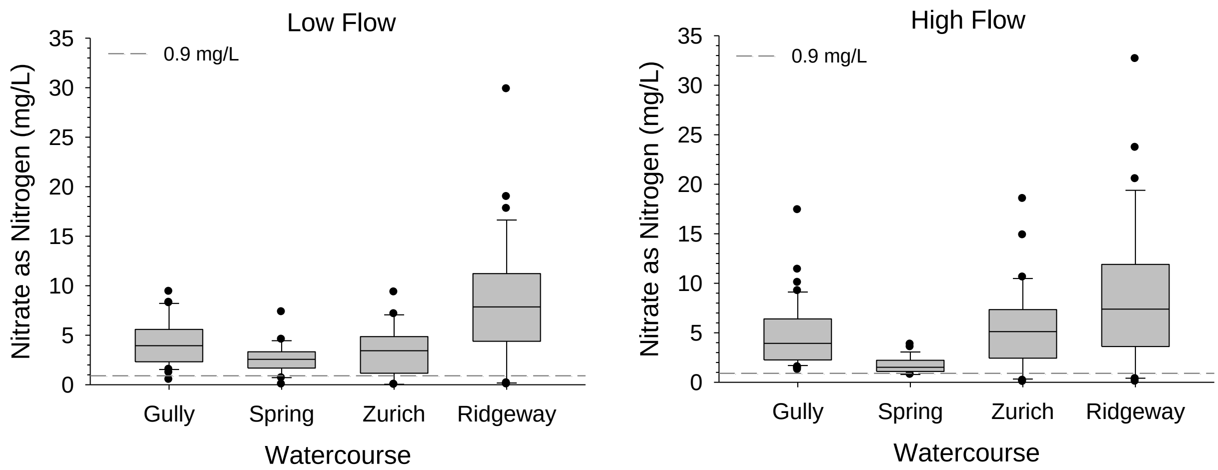

FIGURE 3-5: NITRATE-NITROGEN CONCENTRATIONS UNDER LOW-FLOW AND HIGH-FLOW CONDITIONS AT THE WATERSHED OUTLETS BETWEEN 2010 AND 2012. DASHED GRAY LINES INDICATE LIMITS TO PREVENT EUTROPHICATION. (BOX PLOT GRAPHS SHOW OUTLIERS (·), THE 10TH AND 90TH PERCENTILES AS HORIZONTAL BARS, THE 25TH AND 75TH PERCENTILES AS THE BOTTOM AND TOP OF THE BOX, AND THE MEDIAN AS A HORIZONTAL LINE WITHIN THE BOX.)

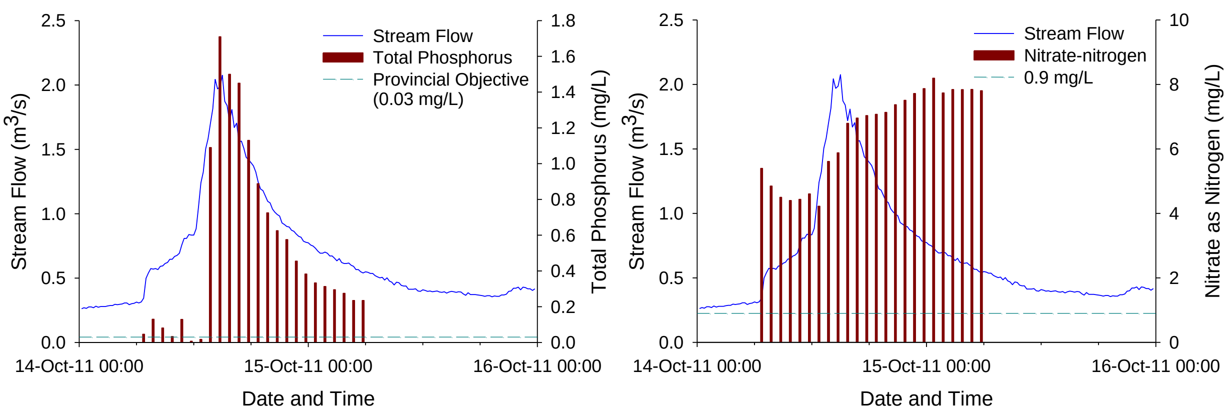

FIGURE 3-6: TOTAL PHOSPHORUS AND NITRATE-NITROGEN CONCENTRATIONS AT THE OUTLET OF GULLY CREEK FROM SAMPLES COLLECTED HOURLY DURING A STORM EVENT IN OCTOBER 2011. DASHED LIGHT BLUE LINES INDICATE NUTRIENT LIMITS TO PREVENT EUTROPHICATION.

3.2.2 Modelled water quality at watershed outlet

To evaluate flow, sediment, and nutrient transport at both the field (see Section 3.3.4) and watershed scales, the Soil and Water Assessment Tool (SWAT) was set up and calibrated with data from four stations in the Gully Creek watershed (Yang *et al.* 2013). The flow calibration results were very good with evaluation criteria well within an acceptable range, even at the daily scale (Figure 3-7; Nash and Sutcliffe 1970). The sediment and nutrient calibration was also reasonable (Figure 3-8).

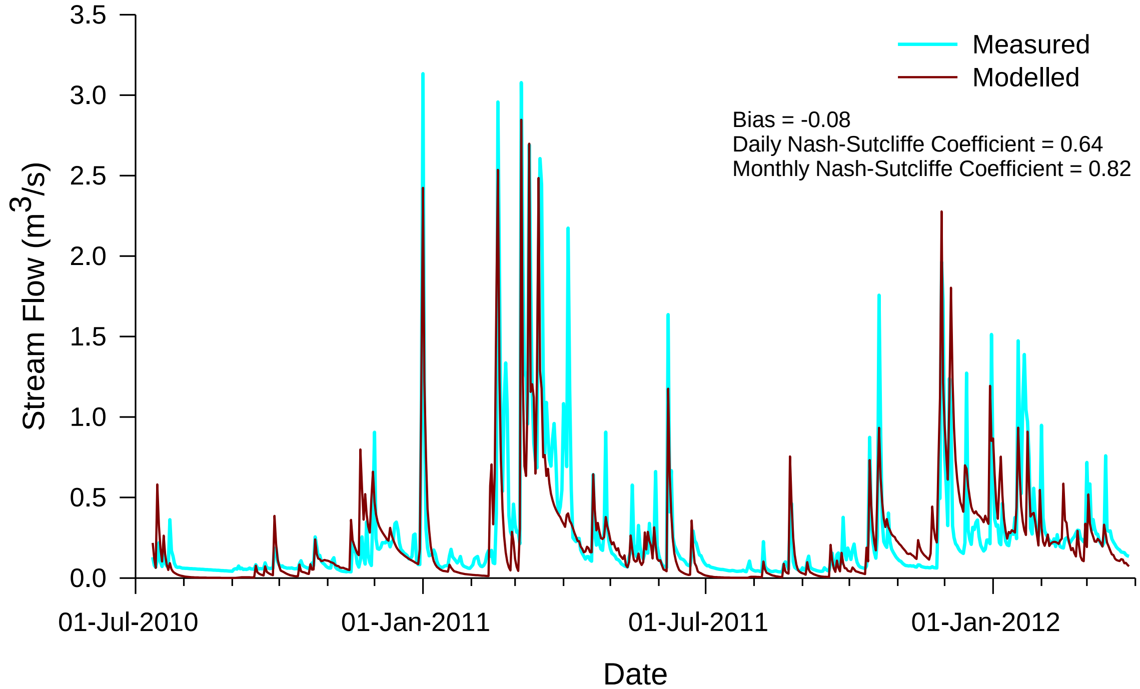

FIGURE 3-7: COMPARISON OF MEASURED AND MODELLED (SOIL AND WATER ASSESSMENT TOOL) STREAM FLOWS AT THE GULLY CREEK OUTLET.

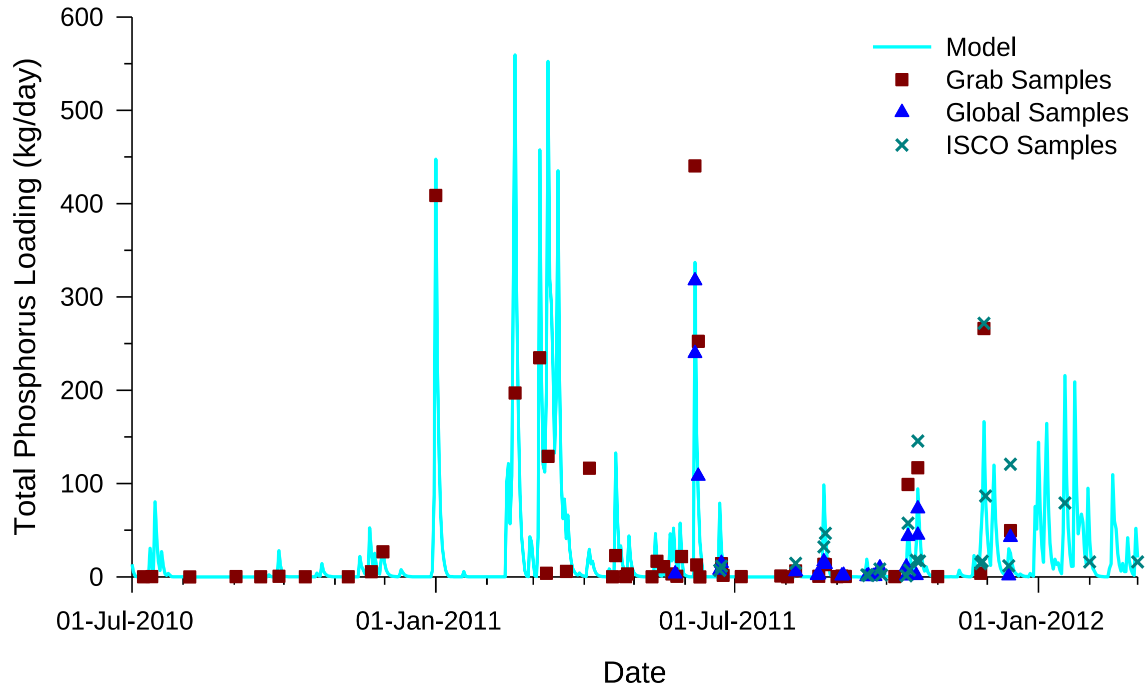

FIGURE 3-8: COMPARISON OF MEASURED AND MODELLED (SOIL AND WATER ASSESSMENT TOOL) TOTAL PHOSPHORUS LOADINGS AT THE GULLY CREEK OUTLET.

The calibrated model was first used to look broadly at the effect of changing land use and BMP implementation in the Gully Creek watershed over the last 30 years. The model was run to compare historical and present-day land use conditions, with precipitation and temperature data from 2002 to 2011 driving the model. Based on the air photo interpretation exercise (see Section 3.1.1), it was reasonable to assume that the evolutionary land use changes would have naturally led to increased sediment loading. However, comparing simulated water quality at the watershed outlet under crop types and land management conditions for 1978 relative to existing conditions (2011) showed that sediment and total phosphorus loads in Gully Creek may have decreased (Figure 3-9). Although there were a number of assumptions made to develop the 1978 land use layer (Gutteridge *et al.* 2013) and the declines in fencerows and windbreaks were not incorporated into this layer, a comparison of the 1978 and existing (2011) scenarios suggests that BMPs, implemented over that time period to help retain sediment and nutrients, may be compensating for the loss of other erosion deterrents that occurred over that same timeframe.

For total nitrogen loading, however, the simulation showed a substantial increase under existing land management conditions (Figure 3-9). An explanation for this increase in nitrogen loss under the current land management practices is not clear. The model simulations did assume higher average nitrogen fertilization rates under the existing (2011) scenario (180 kilograms per hectare) than were assumed under the historical (1978) scenario (120 kilograms per hectare), while phosphorous application and tillage practices remained similar between the two scenarios. The higher nitrogen fertilization rates modelled in the existing scenario were intended to account for the higher yields possible from today's corn hybrids than were possible with the historical corn varieties. The expectation was that a higher yielding corn would require more nutrients and would use the additional fertilizer assumed to be applied in the existing scenario. There are at least three potential model shortcomings that could account for the increase in nitrogen loadings between the 1978 and 2011 scenarios: the crop growth model embedded in the SWAT may not be properly representing the corn's genetic change; the effects of soybean atmospheric fixation on environmental losses of nitrogen are not fully understood and therefore not effectively modelled in the SWAT; and the SWAT may not be fully capturing the extent of differences in subsurface tile drainage between the two time periods. Despite these shortcomings, the modelling does show a trend towards higher nitrogen loadings, which is consistent with water quality observations in the region over the same time period. Variation in watershed water quality over time underscores the importance of understanding changes in water quality so that appropriate BMPs can be adopted.

The model was also used to examine seasonal variation in water quality under existing land use conditions and observed climate data covering 2002 through 2011. It showed that the majority of stream flow was concentrated in December through March, with the highest flows typically occurring in March (Figure 3-10). High flows were caused by snowmelt and seasonal rainfall. Stream flow during other months was much lower and could be nearly zero in the summer. During the summer season, the moderately high infiltration capacity of the soil and high evapotranspiration demand minimized runoff from upland areas, except during unusually intense storm events.

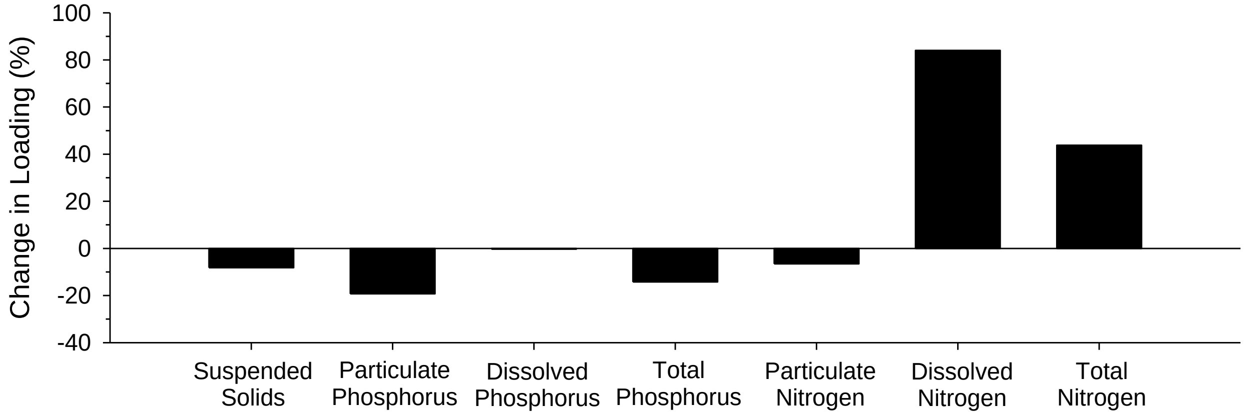

FIGURE 3-9: CHANGE IN AVERAGE SIMULATED WATER QUALITY INDICATORS AT THE GULLY CREEK WATERSHED OUTLET FROM THE HISTORICAL (1978) TO EXISTING (2011) LAND USE AND MANAGEMENT SCENARIOS.

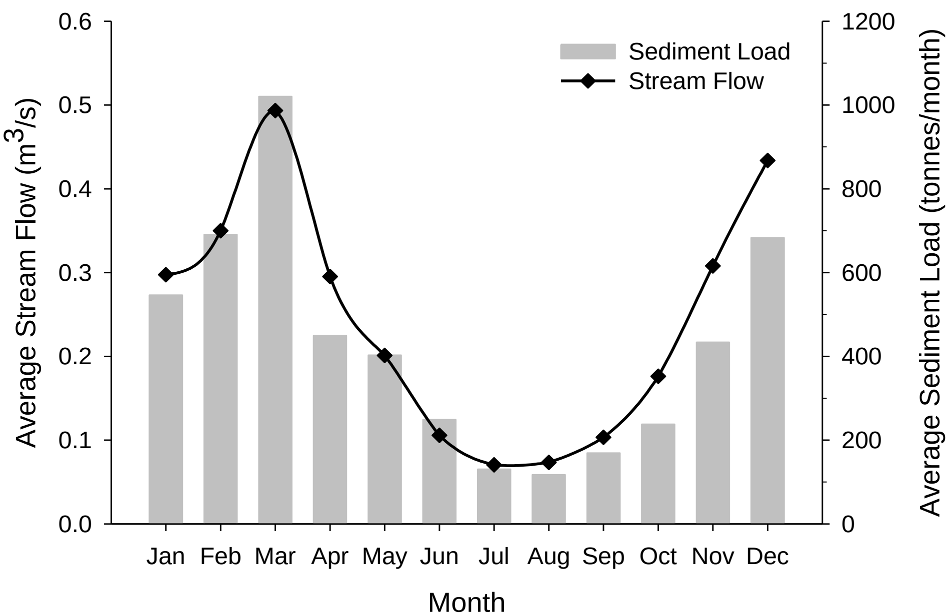

FIGURE 3-10: SIMULATED AVERAGE MONTHLY STREAM FLOW AND TOTAL SEDIMENT LOADING AT THE GULLY CREEK OUTLET, AVERAGED 2002 – 2011.

Simulated sediment loading was generally proportional to flow (Figure 3-10), but further analysis made it possible to differentiate between overland and channel erosion. In Gully Creek, it was estimated that channel erosion (including concentrated flow paths in fields) contributed 57 per cent of the total sediment load at the watershed outlet and the remainder was overland erosion. This means that channel erosion is an important contributor to overall sediment loading at the outlet, at least for this incised lakeshore channel. Modelling also showed that sediment yield from overland flow was relatively small from April through November because of the low rate of surface runoff (Figure 3-11). For example, in April, the total runoff was high, but the sediment yield was small because the majority of the runoff was from subsurface flow (including tile and lateral subsurface flow), which has a much lower sediment concentration than surface runoff.

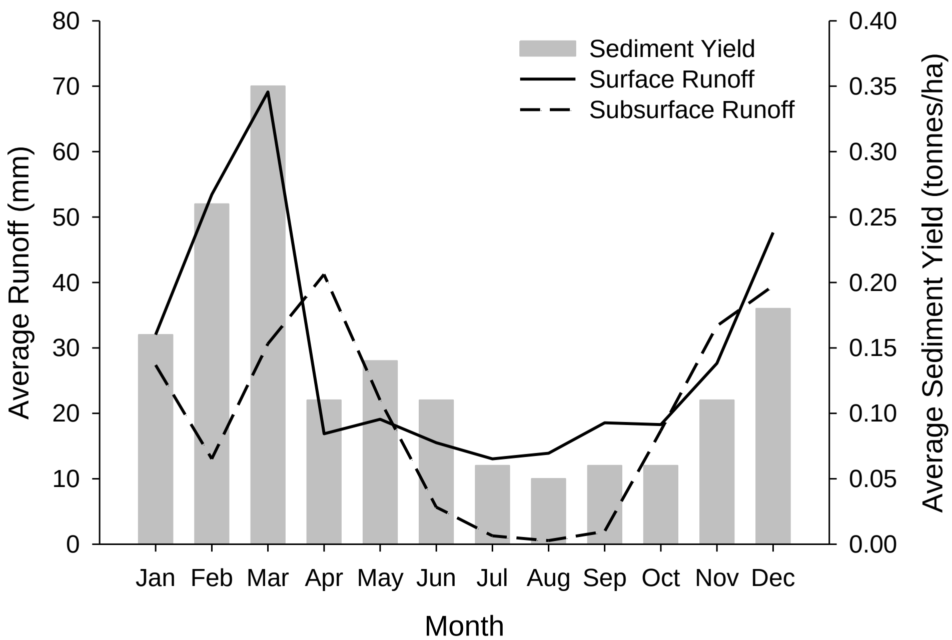

FIGURE 3-11: SIMULATED AVERAGE MONTHLY SURFACE RUNOFF, SUBSURFACE RUNOFF, AND SEDIMENT YIELD (WITHOUT CHANNEL EROSION) IN THE GULLY CREEK WATERSHED UNDER EXISTING CONDITIONS, AVERAGED 2002 – 2011.

Total phosphorus loading (Figure 3-12) tended to mirror the increase in stream flow from January to March and then declined and remained relatively low for the rest of the year. Total nitrogen loading (Figure 3-12) seemed to have a delayed response to the high flows in March, as it peaked in May. Nitrogen loading then declined and appeared to be proportional to stream flow. The differences in seasonal loadings of phosphorus and nitrogen may be caused by a variety of factors, including the timing of fertilizer application, plant uptake, soil mineralization, and active subsurface tile drainage flow.

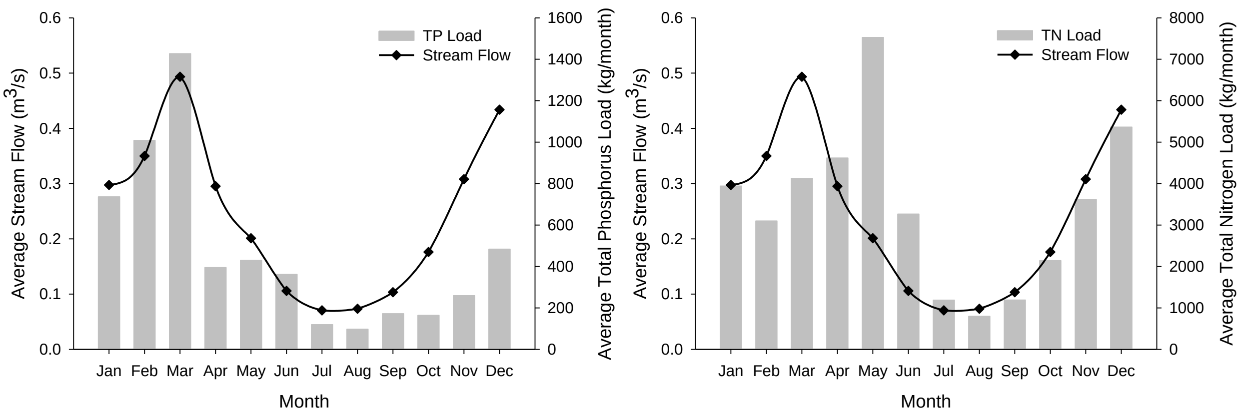

FIGURE 3-12: SIMULATED AVERAGE MONTHLY STREAM FLOW AND TOTAL PHOSPHORUS (TP) AND TOTAL NITROGEN (TN) LOADINGS AT THE OUTLET OF GULLY CREEK, AVERAGED 2002 – 2011.

3.2.3 Summary

It is important to understand the spatial and temporal variation in water quality so that trends can be identified and appropriate BMPs can be adopted. The monitoring and modelling results suggest that the high concentrations of nutrients during spring snowmelt and prolonged periods of rainfall are key considerations when implementing future BMPs. To better understand the effectiveness of specific BMPs, five different BMPs were researched at the watershed and field scales. The following section looks in detail at the effectiveness of these BMPs from an environmental and economic perspective at both the field and watershed scales.

3.3 Effects of best management practices

3.3.1 Watershed-scale environmental effects

The environmental effects of the three land management BMPs and the one structural BMP were assessed at the watershed scale with a computer simulation model. The results estimated differences in the effectiveness of each BMP in the Gully Creek watershed (Figure 3-13).

Conservation tillage applied to all row crops (corn, wheat, and soybeans) was more effective than the red clover cover crop and nutrient management BMPs at reducing sediment and total phosphorus loadings to Gully Creek. Conservation tillage, however, did increase dissolved nitrogen loading. Nutrient management had little impact on sediment and nutrient loadings. This is likely because nutrient application rates per unit of crop produced were, on average, already near or within the optimal range according to the NMAN3 software (OMAFRA 2012a). A red clover cover crop applied to all fields following the harvest of winter wheat effectively reduced loadings of sediment, total phosphorus, and total nitrogen to Gully Creek. When the three land management BMPs were combined, the effect on water quality was less than the sum of the effects of the individual practices. This demonstrates that BMP effects are not necessarily additive. For example, improvements from conservation tillage had to be negated in order to facilitate additional fall ploughing in order to plough down and effectively kill the red clover cover crop prior to the next crop year.

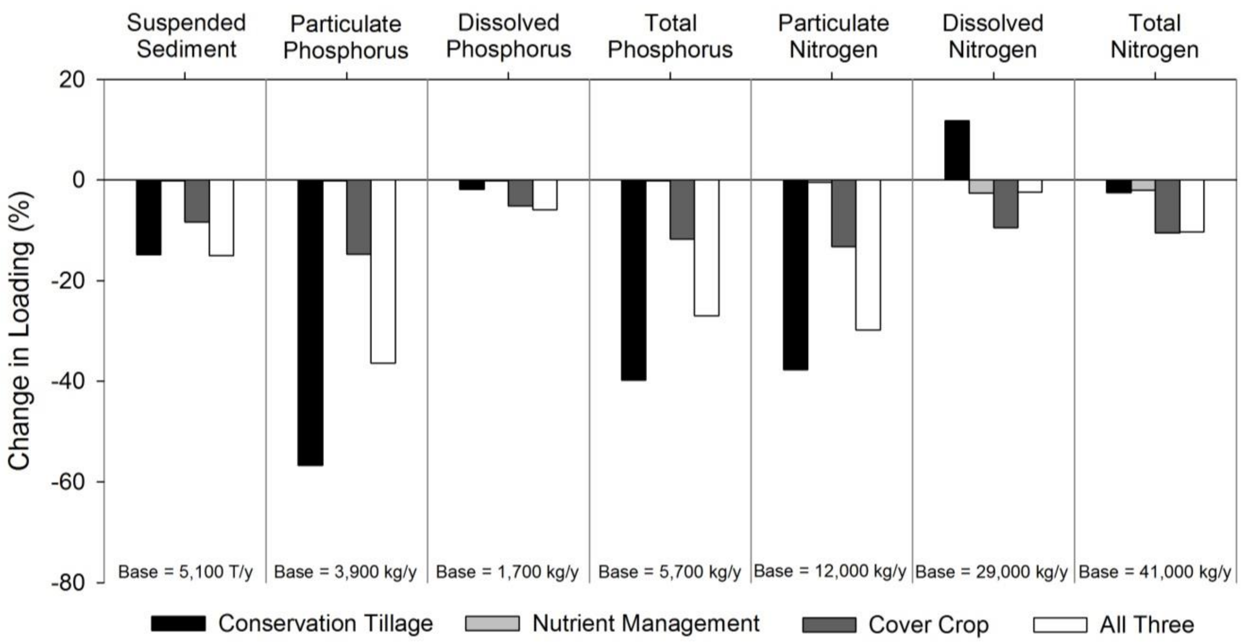

FIGURE 3-13: SIMULATED CHANGE IN SEDIMENT AND NUTRIENT LOADINGS UNDER FOUR BEST MANAGEMENT PRACTICE SCENARIOS COMPARED WITH A BASE SCENARIO (EXISTING CONDITIONS), 2002 – 2011.

When the structural BMP was examined, it was estimated that WASCoBs were effective, but somewhat less effective relative to the conservation tillage and cover crop BMPs. Their use did lead to reductions in sediment and nutrient loadings to Gully Creek, more so downslope of their locations by reducing estimated erosion in downstream watercourses, including the main Gully Creek channel (Figure 3-14). This is significant because it is very difficult to measure the in-stream effects of BMPs due to the number of factors influencing in-stream water quality. Modelling enhancements, combined with a more intensive water sampling scheme, made it possible to isolate the watershed-scale effectiveness of WASCoBs both upslope and downslope of their locations. The modelling was also able to separate out the effects of land management changes and weather variability from other factors.

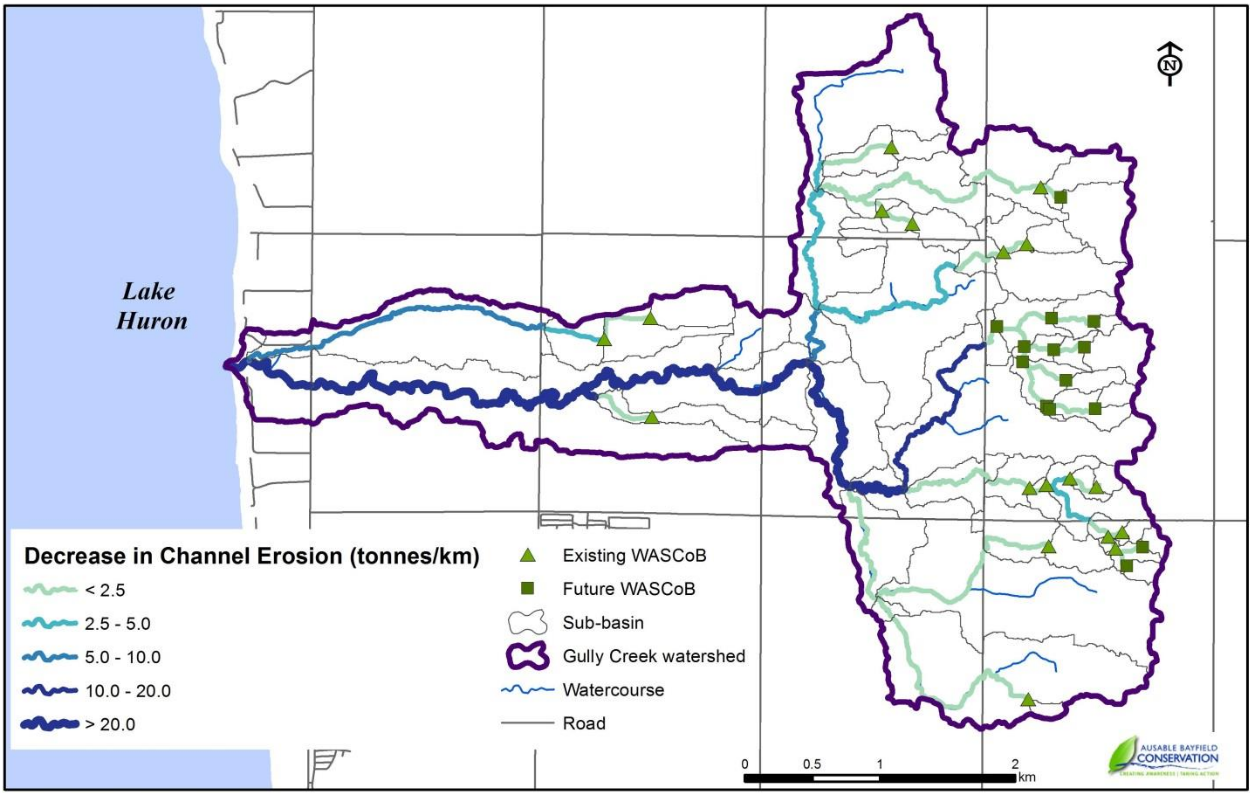

FIGURE 3-14: ESTIMATED DECREASE IN CHANNEL EROSION DOWNSTREAM OF EXISTING AND FUTURE WATER AND SEDIMENT CONTROL BASINS (WASCOBS) OVER THE PERIOD 2002 TO 2011.

3.3.2 Field-scale environmental effects

The field-scale monitoring results provided insight into the environmental efficacy of the various practices (Table 3-4; Upsdell Wright *et al.* 2013). A legume cover crop increased the amount of nitrogen in the soil during the early spring, which may mean that less additional nitrogen needs to be applied prior to the growing season, making less fertilizer nitrogen available to runoff. Following nutrient management recommendations at one field site, as opposed to the landowner's traditional fertilization rates, lowered the soil nitrate concentration in the late spring, suggesting that reducing the fertilizer application rate may result in less nitrogen being available for loss during rainfall events in late spring or early summer. Weather conditions at the same site, however, also resulted in optimum corn growth that year, encouraging high nitrogen uptake and a higher yield on the more heavily fertilized (control) test strip. This left very little difference in residual soil nitrogen between the control and treatment strips.

A grass filter strip (actually a grassed roadside ditch) was found to decrease total suspended solids, total phosphorus, and soluble reactive phosphorus as runoff passes through. However, this is likely dependent on the size of the contributing water catchment and the flow path that runoff follows prior to reaching the filtering area.

TABLE 3-4: SUMMARY OF FIELD-SCALE BEST MANAGEMENT PRACTICE ASSESSMENT RESULTS.

Best Management Practice	Study Design	Performance Indicators		Results from Literature [a]
		Change in Water Quality [a]	Change in Soil Quality	
Conservation Tillage (no-till)	Side-by-side comparison (two sites)	Could not compare due to cropping changes.	Unable to collect samples. Could not compare due to cropping changes.	Decreased TP, increased SRP, and both increased and decreased TN loadings. [b]
Cover Crop	Side-by-side comparison (two sites)	Could not collect samples due to lack of runoff (dry year).	Soil nitrate was higher on plots with cover crop in April and June 2012 (before corn was planted and when corn was 15 to 30 cm high).	Decreased TP, SRP, nitrate, and TSS loadings. [c]
Nutrient Management	Side-by-side comparison (two sites)	No sampling planned.	In June 2011, soil nitrate was lower on plots that received less fertilizer. In October 2011, both plots had similar, low soil nitrate.	Decreased TP, SRP, nitrate, and TSS loadings. [d]
Grass Filter Strip	Upstream and downstream comparison (one site)	Surface runoff samples showed declines in TP, SRP, and TSS, but no clear change in nitrate.	No sampling planned.	No change in water quality indicators. [e]
Water and Sediment Control Basins	Before-after-control-impact study (one site) Upstream and downstream comparison (one site)	Reduced magnitude of peak flow and TSS concentrations, but no clear change in nutrients.	No sampling planned.	Decreased TP, SRP, and TSS loadings. [f]

[a] SRP – soluble reactive phosphorus; TN – total nitrogen; TP – total phosphorus; TSS – total suspended solids.

[b] Beak Consultants Limited 1994; Gaynor and Bissonnette 1992; McIsaac *et al.* 1995; Stuart *et al.* 2010; Tan *et al.* 1998; Yates *et al.* 2006.

[c] Beak Consultants Limited 1994; Makarewicz *et al.* 2009; Simon and Makarewicz 2009.

[d] Makarewicz *et al.* 2009.

[e] Stuart *et al.* 2010.

[f] Bosch *et al.* 2009; Harmel *et al.* 2008; Makarewicz *et al.* 2009; Stuart *et al.* 2010.

Monitoring of a WASCoB at upslope and basin outlet locations showed reduced peak flows and sediment loads at the basin outlet. Based on the field-scale data, the nutrient reduction benefits of WASCoBs were not clear; however, modelling their influence showed benefits at the watershed outlet as a result of decreased downstream channel erosion. Further study is required to ensure that modelling represents actual sediment and nutrient transport processes and that WASCoB outlets are optimized to reduce the transport of sediment and nutrients through tile drains.

It is important to note that some of these findings at the field scale are supported in the literature and some are not. The inconsistent results reflect unique site-scale characteristics, such as land management, soil type, and slope, combined with climatic variability. The effects of these characteristics are complex and make determining water quality and the effectiveness of BMPs challenging. Furthermore, while it was possible to monitor the effects of structural BMPs on water quality, it was very challenging to collect water quality samples to measure the performance of agronomic BMPs. This emphasizes the importance of long-term, strategic research in a number of representative locations.

3.3.3 Economic effects

In addition to looking at the environmental effects of best management practices, the private economic costs were also evaluated. Implementation of cover crop and nutrient management BMPs has the potential to save producers approximately 30 dollars per hectare (Figure 3-15). Conversely, conservation tillage and WASCoBs were estimated to typically cost producers 40 dollars per hectare. It is possible for conservation tillage to save producers money, but this was found to be the case only when no-till corn was planted after soybeans. This finding is highly influenced by the long-term yield data and findings as reported in OMAFRA (2009b).

In a 2011 nutrient management nitrogen rate comparison field trial, crop yield was reduced to an extent that resulted in a lower net return for the producer. In a 2012 trial, however, savings on fertilizer and a minimal reduction in crop yield resulted in a higher net return. This showed that, in the short term, nutrient reduction may result in economic losses or gains for the producer. The economic model, however, showed that, in the longer term, producers tend to experience a net financial gain by applying nutrients to their fields at rates recommended by the NMAN3 software.

Overall, there was a fair bit of variation and uncertainly in the cost and benefits of BMP implementation. Further research is required to understand the sources of this uncertainty so that more accurate estimates can be made. Notably, this study did not include long-term benefits, such as improved soil condition, reduced topsoil loss, or social benefits related to improved water quality.

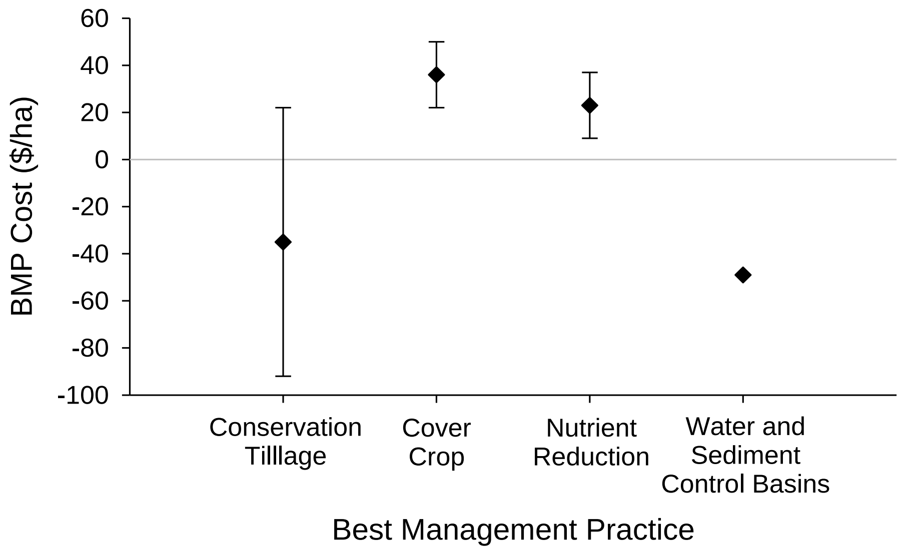

FIGURE 3-15: ESTIMATED COST OF IMPLEMENTING BEST MANAGEMENT PRACTICES (BMPS) AT THE FIELD SCALE. DIAMONDS SHOW AVERAGE COST AND BARS INDICATE STANDARD DEVIATION.

3.3.4 Enhancing best management practice effectiveness with models

From a management perspective, it is important to be able to locate the areas where BMPs can be the most economically and environmentally cost-effective. The SWAT modelling identified fields with higher sediment and nutrient contributions, suitable for targeting BMPs (Figure 3-16). These areas were consistent with observations from experienced conservation authority staff. The SWAT modelling also identified fields where ephemeral concentrated flow paths are likely contributing high sediment and nutrient loads to streams during wet periods and where interception of these flow paths may help to improve water quality.

Another important consideration is the cost-effectiveness of various BMPs. In some situations, a BMP may have environmental benefits and save the producer money; however, in other situations, it may have an environmental benefit but cost the producer money (Figure 3-17). The effectiveness of a BMP typically depends on the soil type, slope, land use, and previous crop type, among other factors. Having an estimate of areas in which a BMP is likely to have both a positive environmental benefit and a positive economic benefit would be valuable for targeting specific areas in the watershed for BMP implementation.

Overall, in the Gully Creek watershed, considerable variation was found to exist across fields in terms of the environmental and economic effectiveness of the conservation tillage, cover crop, and nutrient management BMPs evaluated. It is clear from this analysis that changes in management practices are not always a win-win solution and may help to explain the reluctance of some producers to adopt BMPs. The decision to implement a BMP is not easy and tools that help watershed managers and producers select BMPs and locations where economic and environmental gains can be maximized are valuable.

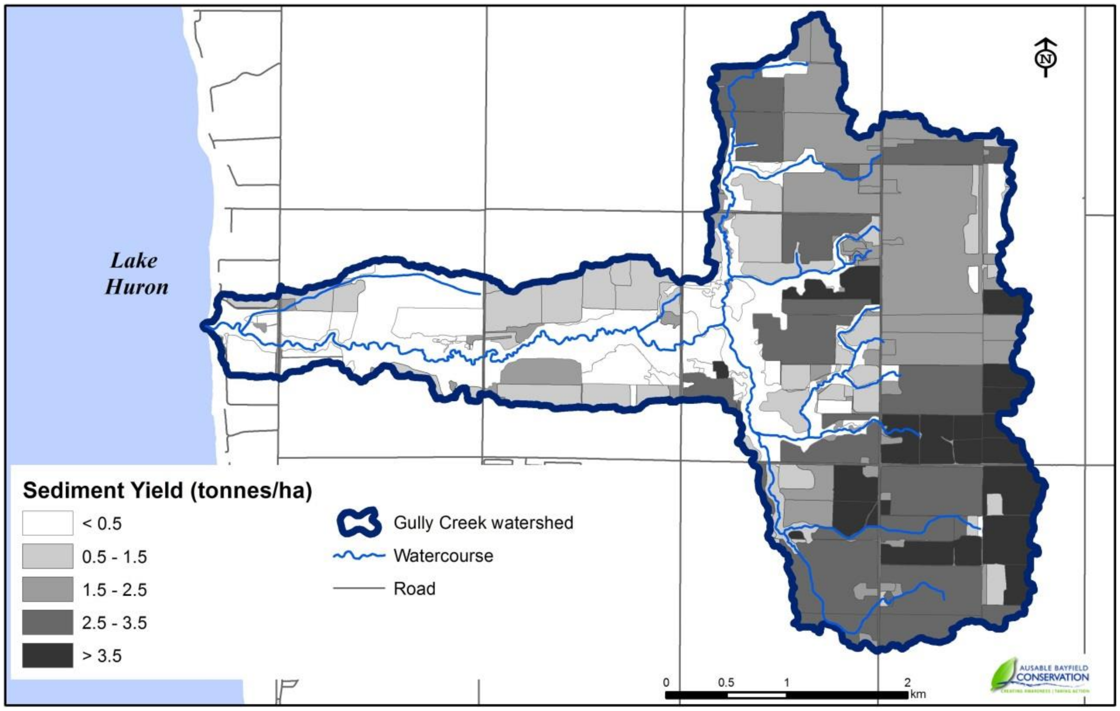

FIGURE 3-16: SIMULATED SEDIMENT YIELD IN THE GULLY CREEK WATERSHED AT THE FIELD SCALE, AVERAGED 2002 – 2011.

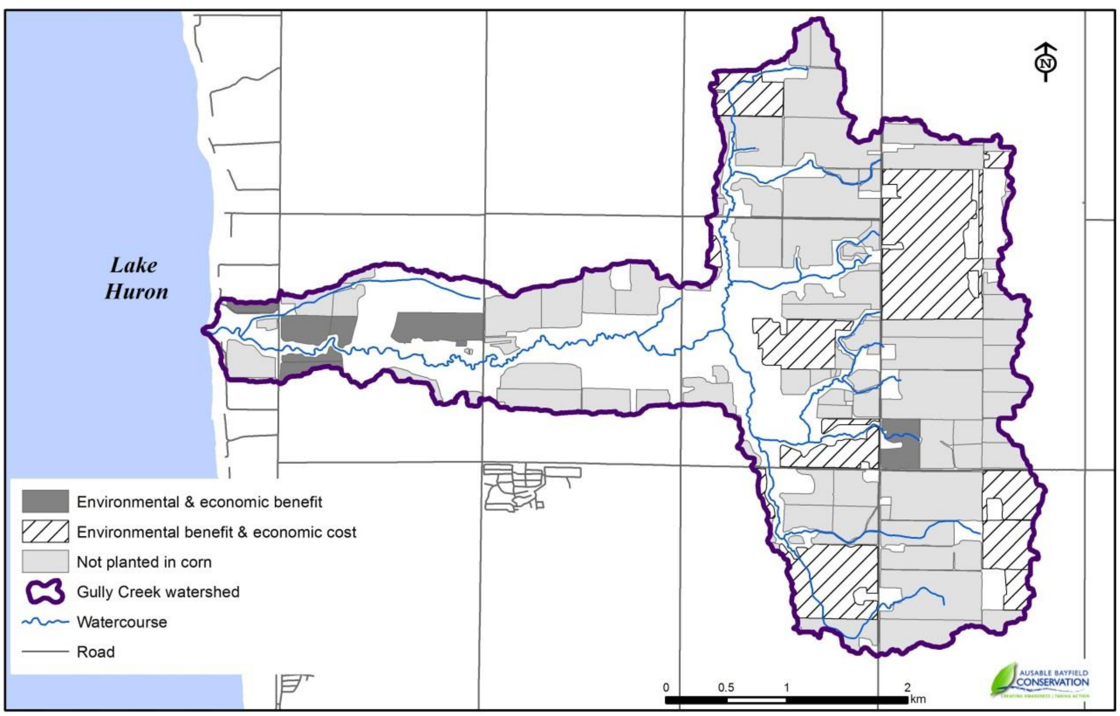

FIGURE 3-17: ENVIRONMENTAL AND ECONOMIC IMPACTS OF IMPLEMENTING A CONSERVATION TILLAGE BEST MANAGEMENT PRACTICE ON CORN FIELDS IN THE GULLY CREEK WATERSHED, 2009.

3.3.5 Model limitations

Although the models were able to provide some valuable information, they have limitations. The SWAT modelling identified areas with higher sediment yields at the field scale, but sediment and nutrients were observed to be mobilized at the within-field scale. Therefore, there may be limitations to SWAT modelling for addressing storm runoff routing within and between fields. Additionally, because of the short monitoring period at the four stations, considerable uncertainties may exist in the model calibration and BMP assessment results in this study. Continued monitoring of climate, land management, and water quantity and quality is required to improve the modelling reliability in the Gully Creek watershed.

In undertaking the economic modelling exercise, it became clear that it is difficult to conduct a cost-benefit analysis of changes to management practices for both the landowner and society. An attempt was made to estimate changes in net return for the landowner due to BMP implementation, but this analysis did not include longer-term benefits, such as improvements to soil conditions and decreases in nutrient loading.

3.3.6 Summary

Best management practices have the potential to decrease nutrient impacts from agricultural land, particularly if they are tailored to address areas that generate substantial runoff during wet periods of the year (between late fall and spring). However, BMPs may not be cost-effective to the producer in all circumstances. The environmental efficacy is difficult to measure at the field scale and the role of soil conditions, slope, land management, and climate variability may overwhelm the observed benefits of the BMPs at the watershed scale.

Models have potential to enhance program effectiveness and maximize environmental and economic gains, but they need further development to be practical for watershed managers and policy makers. Ongoing research and a longer monitoring period could improve approaches for strategic project implementation. The following section draws on this information and the information from previous sections to summarize key lessons learned from this study and possible next steps.

4.0 CONCLUSIONS

4.1 Lessons learned

As the need to understand the effects of BMPs at both the field and watershed scales continues to grow, it is important to incorporate the lessons learned from this project into future work. Table 4-1 presents the lessons learned in the WBBE, Huron, project that may be of interest to watershed managers, researchers, and policy makers.

TABLE 4-1: SUMMARY OF LESSONS LEARNED THROUGH THE WATERSHED BASED BEST MANAGEMENT PRACTICES EVALUATION, HURON.

Lessons Learned
Watershed-scale considerations
• Most of the sediment and nutrients are transported during high-flow events, so significant changes in base-flow water quality data cannot be expected with the implementation of best management practices (BMPs). Moreover, most BMPs do not need to be effective during base-flow periods when runoff is minimal. Therefore, monitoring watershed water quality and the performance of BMPs during high-flow events is very important.
• It is difficult to directly link BMP implementation to improvements in water quality indicators at the watershed scale. Monitoring at the field scale in selected places with different soil conditions, slope, and land use, along with long-term watershed-scale monitoring, is necessary to evaluate the range of BMP effectiveness.
• The use of automatic samplers enables the collection of several samples per site during high-flow events. This allowed modellers to better calibrate the model for sediment and nutrient loading during these important periods. It also highlighted the variability in water quality data depending on how the timing of sampling corresponds to the stream flow hydrograph during an event.
• Detailed modelling has shown that the magnitude of water quality changes at the watershed scale depends on the existing land use and extent of BMP adoption. Therefore, to conduct practical assessments, environmental and economic modelling must be designed with realistic initial and future management practice scenarios.
Field-scale considerations
• More consistent methods for evaluating the effectiveness of BMPs at the field and watershed scales need to be developed. Additionally, some BMPs are very difficult to monitor because practical methods are not widely available (*e.g.*, measuring water quality changes as a result of planting a cover crop without a concentrated flow path available).
• The edge-of-field and in-basin water samplers developed for field-specific trials can provide valuable data for studies. However, it is not practical to have expensive monitoring equipment that requires significant staff time to operate at all locations where BMPs are implemented.
• Weather can be unpredictable and getting edge-of-field water samples may be difficult during dry years, so evaluations need to be conducted with multiple metrics or over a period of several years.
Collaboration with landowners
• Landowner collaboration is critical to obtaining information for all aspects of BMP studies. Therefore, having the additional resources to work closely one-on-one with landowners helps in achieving BMP implementation and evaluating their effectiveness.
• Agreements with landowners must be clear and contingency plans must be in place. Financial compensation may be necessary to reduce risk to the landowner and give researchers greater control over the experimental design.
• Revisiting landowners with the modelling and monitoring results helps in determining the practicality and validity of the study findings.

4.2 Recommendations and next steps

The key findings and lessons learned throughout this project have led to the development of several recommendation and next steps. The major recommendations are as follows:

- **Plan for the long-term**: To obtain substantive results, plan BMPs at multiple scales so that watershed-scale and field-scale effectiveness can be assessed under representative combinations of land use, soil, and slope over the long-term and during seasonal high-flow events. Moreover, information about climate, land use, management practices, topography, and soil composition are crucial for setting up models and evaluating practices at the field scale. Collecting and interpreting these data will require transfer of knowledge between past and future project leaders as well as funding and research plans that extend over three or more years.

- **Interrupt and address spring flows:** Implement and further evaluate BMPs that interrupt concentrated flow paths and specifically address sediment and nutrient contributions to streams during spring snowmelt and storm events. At the field scale, grass filter strips, cover crop, and conservation tillage have shown potential to address these issues. At the watershed scale, the effects of WASCoBs on peak flows appear beneficial, but sediment and nutrient effects need to be further investigated due to the potential of WASCoBs to increase landscape connectivity to the receiving water bodies.

- **Supplement measurements with models:** Water quality models are useful for explaining spatial and temporal factors that integrate and contribute to water quality changes that cannot be readily measured. Water and Sediment Control Basins are one example of a BMP that may have significant water quality effects at the watershed scale that cannot be measured at the field scale. Therefore, it is important to conduct realistic environmental and economic assessment modelling exercises, informed by the results of field-scale and watershed-scale studies and validated with long-term monitoring data. However, to apply the results of modelling exercises to decision-making, additional modelling and communication tools may be required for watershed managers and policy makers.

- **Engage the community:** Community engagement is the key to implementing rural BMPs and obtaining the land use and land management data required for evaluations. Resources for working directly one-on-one with landowners are crucial to project success. Future projects will benefit from landowners developing questions with researchers, in addition to providing data and input to researchers throughout the study. Model estimates are a useful communication tool, but modelling enhancements are required to ensure that the results are transferable to watershed managers, policy makers, and the public.

5.0 REFERENCES

Beak Consultants Limited. 1994. Soil and Water Environmental Enhancement Program (SWEEP) Pilot Watershed Study Report #6: Evaluation of Conservation Systems, Water Quality. SWEEP Report #74. Beak Consultants Limited, Guelph, Ontario. Retrieved June 2013, from http://agrienvarchive.ca/download/sweep_74.pdf

Bosch, I., J. C. Makarewicz, T. W. Lewis, E. A. Bonk, M. Finiguerra, and B. Groveman. 2009. Management of agricultural practices results in declines of filamentous algae in the lake littoral. Journal of Great Lakes Research 35:90-98.

CCME (Canadian Council of Ministers of the Environment). 2012. Canadian water quality guidelines for the protection of aquatic life: nitrate. In CCME, Canadian Environmental Quality Guidelines. CCME, Winnipeg, Manitoba. 17 pp. Retrieved September 2013 from http://st-ts.ccme.ca/?lang=en&factsheet=140

Gaynor, J., and D. Bissonnette. 1992. The Effect of Conservation Tillage Practices on the Losses of Phosphorus and Herbicides in Surface and Subsurface Drainage Waters. Soil and Water Environmental Enhancement Program (SWEEP) Report #60. Southwestern Ontario Agricultural Research Corporation, Harrow, Ontario. xii + 134 pp. Retrieved June 2013 from http://agrienvarchive.ca/download/sweep_60.pdf

Gutteridge, A., J. Simmons, and M. Veliz. 2013. Land Use and Land Management in the Watershed Based Best Management Practices Evaluation, Huron – DRAFT. Ausable Bayfield Conservation Authority, Exeter, Ontario. ii + 16 pp.

Harmel, R. D., C. G. Rossi, T. Dybala, J. Arnold, K. Potter, J. Wolfe, and D. Hoffman. 2008. Conservation Effects Assessment Project research in the Leon River and Riesel watersheds. Journal of Soil and Water Conservation 63(6):453-460.

Hoffman, D. W., N. R. Richards, and F. F. Morwick. 1952. Soil Survey of Huron County. Ontario Soil Survey Report No. 13. Experimental Farm Service, Canada Department of Agriculture, and Ontario Agricultural College, Guelph, Ontario. 101 pp.

Kröger, R., M. T. Moore, K. W. Thornton, J. L. Farris, D. J. Prevost, and S. C. Pierce. 2012. Tiered on-the-ground implementation projects for Gulf of Mexico water quality improvements. Journal of Soil and Water Conservation 67(4):94A-99A.

Makarewicz, J. C., T. D. Lewis, I. Bosch, M. R. Noll, N. Herendeen, R. D. Simon, J. Zollweg, and A. Vodacek. 2009. The impact of agricultural best management practices on downstream systems: soil loss and nutrient chemistry and flux to Conesus Lake, New York, USA. Journal of Great Lakes Research 35:23-36.

McIsaac, G. F., J. K. Mitchell, and M. C. Hirschi. 1995. Dissolved phosphorus concentrations in runoff from simulated rainfall on corn and soybean tillage systems. Journal of Soil and Water Conservation 50(4):383-387.

MOEE (Ministry of Environment and Energy). 1994. Water Management: Policies, Guidelines, Provincial Water Quality Objectives. MOEE. Retrieved June 2013, from http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079681.pdf

Nash, J. E., and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models, Part I – A discussion of principles. Journal of Hydrology 10:282-290.

Olson, B. M., and A. R. Kalishcuk (eds.). 2009. Nutrient Beneficial Management Practices Evaluation Project 2007 to 2011: 2008 Progress Report. Alberta Agriculture and Rural Development, Lethbridge, Alberta. 344 pp. Retrieved June 2013, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw11955

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2012a. NMAN Software Application. OMAFRA. Retrieved June 2013, from http://apps.omafra.gov.on.ca/NMAN/NMAN3.html

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2012b. LiDAR Digitial Elevation Model. OMAFRA. (Internal digital map file.)

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2012c. Historical Provincial Estimates by Crop, 1981 – 2012. OMAFRA. Retrieved June 2013, from http://www.omafra.gov.on.ca/english/stats/crops/estimate_hist_metric.htm

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2011. Agricultural Resources Inventory (AgRI). OMAFRA. (Digital map file.)

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2010. OMAFRA's Great Lakes Program (OGLP) 2010 Call for Letters of Intent for Watershed Based Best Management Practices Evaluation (WBBE) Projects. OMAFRA. Retrieved June 2013, from http://www.oia.on.ca/file.aspx?id=20a4a494-2377-4858-bb2f-6aa89da3590f

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2009a. Field Crop Budgets 2010. OMAFRA Publication No. 60. OMAFRA, Guelph, Ontario. 25 pp.

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2009b. Agronomy Guide for Field Crops. OMAFRA Publication No. 811. Retrieved July 2013, from http://www.omafra.gov.on.ca/english/crops/pub811/p811toc.html

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2008. Field Crop Budgets 2009. OMAFRA Publication No. 60. OMAFRA, Guelph, Ontario. 25 pp.

OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2007. Field Crop Budgets 2008. OMAFRA Publication No. 60. OMAFRA, Guelph, Ontario. 22 pp.

OMNR (Ontario Ministry of Natural Resources). 2008. Southern Ontario Land Resource Information System (SOLRIS) Land Classification Data, version 1.2. OMNR, Peterborough, Ontario. (Digital map file.)

Simon, R. D., and J. C. Makarewicz. 2009. Storm water events in a small agricultural watershed: Characterization and evaluation of improvements in stream water microbiology following implementation of best management practices. Journal of Great Lakes Research 35:76-82.

Stuart, V., D. B. Harker, T. Scott, and R. L. Clearwater (eds.). 2010. Watershed Evaluation of Beneficial Management Practices (WEBs): Towards Enhanced Agricultural Landscape Planning – Four-year Review (2004/5 – 2007/8). Agriculture and Agri-Food Canada, Ottawa. ix + 142 pp.

Tan, C. S., C .F. Drury, M. Soultani, I. J. vanWesenbeeck, H. Y. F. Ng, J. D. Gaynor, and T. W. Welacky. 1998. Effect of controlled drainage and tillage on soil structure and tile drainage nitrate loss at the field scale. Water Science and Technology 38:103-110.

Upsdell Wright, B., and M. Veliz. 2013. Water Quality Monitoring for the Watershed Based Best Management Practices Evaluation, Huron – DRAFT. Ausable Bayfield Conservation Authority, Exeter, Ontario.

Upsdell Wright, B., M. Veliz, and K. McKague. 2013. Evaluating Best Management Practices at the Field Scale for the Watershed Based Best Management Practices Evaluation, Huron. Ausable Bayfield Conservation Authority, Exeter, Ontario. iii + 30 pp.

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. University of Guelph, Guelph, Ontario. xi + 161 pp.

Yates, A. G., R. C. Bailey, and J. A. Schwindt. 2006. No-till cultivation improves stream ecosystem quality. Journal of Soil and Water Conservation 61(1):14-19.