Land Use and Land Management in the Watershed Based Best Management Practices Evaluation, Huron

A report prepared for the Ontario Ministry of Agriculture and Food
August 23, 2013

Prepared by Abigail Gutteridge, Jane Simmons, and Mari Veliz
Ausable Bayfield Conservation Authority

Acknowledgements: The authors thank the landowners in the Gully Creek, Spring Creek, Zurich Drain, and Ridgeway Drain watersheds, and Jim Ginn of the Municipality of Central Huron, for their assistance with the surveys and insights into land management. Contributions to the report were made by Dr. Wanhong Yang and Dr. Yongbo Liu from the University of Guelph and Jacqui Empson Laporte of the Ontario Ministry of Agriculture and Food. Kevin McKague from the Ontario Ministry of Agriculture and Food provided instructive comments on an earlier draft. Finally, we would like to thank Dr. Stewart Sweeney and Gabrielle Ferguson of the Ontario Ministry of Agriculture and Food for their advice. 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 above photo was taken in August 2012 and depicts Gully Creek entering Lake Huron in Huron County, Ontario. The photo is courtesy of Daniel Holmes Photography.

Table of Contents

List of Tables

List of Figures

1.0 Introduction

The evaluation of the effects of best management practices (BMPs) on water quality at the watershed scale requires that specific terrestrial conditions are summarized. Watershed conditions that broadly influence water quality include land use and land management, soil, and topography. It was necessary to summarize these conditions to gain a more complete understanding of a watershed, and the effect that BMPs may have on the water quality within the watershed.

The purpose of this report is to provide background information about the collection of land use and land management, soil, and topography data for the Watershed Based Best Management Practices Evaluation (WBBE), Huron.

2.0 Methods

2.1 Land Management Monitoring

There are several ways to gain an understanding of the land use and land management practices within a watershed. Four methods were used over the course of the WBBE, Huron, project. These methods included landowner surveys from individual interviews, windshield surveys, aerial photo interpretation, and the completion of nutrient management plans for agricultural fields within the Gully Creek watershed.

2.1.1 Landowner Surveys

It was determined in the early stages of this project that the best way to gain information regarding BMPs and agricultural practices used in the study area was to speak directly with the watershed landowners. With the assistance of a Community Ambassador, who was a local Municipal Councillor and the Chair of the Ausable Bayfield Conservation Authority (ABCA) Board of Directors (2010 and 2011), one-on-one interviews with landowners and producers provided detailed information on cropping practices. In addition, interviews revealed past practices and BMPs that landowners have completed on their own, including BMPs of which agencies may not be aware. Finally, interviews allowed for the promotion of new BMPs that would address landowner needs.

A survey was developed for collecting information from landowners within the study area. Landowner surveys have been used by the ABCA in past studies. The survey for this project was adapted from previously used surveys from Environment Canada and from the Watershed Evaluation Group (WEG) at the University of Guelph. Staff members from the ABCA and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) discussed data that would be needed for a modelling component of this study as the survey was designed.

Landowners were contacted over the winter and early spring of 2011. Surveyed watersheds included Gully Creek, Spring Creek, and Ridgeway Drain. Surveys had been completed in the Zurich Drain watershed in 2005 and 2006. Since this watershed was not being modelled or intensively monitored for this project, Gully Creek, Spring Creek, and Ridgeway Drain became the focus watersheds for surveying landowners on an individual basis.

Data collected during the landowner interviews included a wide range of cropping and farm practices, and some general information regarding the farm landscape and BMPs (**Table 2.1**).

Table 2.1: Information collected during landowner survey interviews.

Category	Information
General Farm/Farmstead Information	Percentage of land in watershed Environmental Farm Plans and Nutrient Management Plans Septic system details
Livestock Production Information	Livestock type Livestock housing details Livestock numbers Deadstock removal methods
Manure Storage Systems	Storage type and details Storage capacity
Implemented Best Management Practices (BMPs)	Type of BMP Date implemented Total expense of BMP Amount reimbursed Effect on yield
BMP Interest	Type of BMP Where BMP should be implemented Assistance needed to complete BMP
Field Information	Soil type and characteristics Natural feature surrounding the field Tile drainage details Erosion issues Erosion control measures implemented Pasturing details (if applicable)
Cropping Information (Actual 2008-2010, planned 2011-2013)	Crop rotation for each field from 2008-2013 Crop yields Planting and harvest dates Primary and secondary tillage types and dates Fertilizer type, date, rate and method of application Pesticide type, date, rate and method of application Crop residue at time of planting

Once collected, this information was entered into a spreadsheet designed by the WEG to be used in a Soil and Water Assessment Tool (SWAT) model for Gully Creek. The data were also entered into nutrient management software (NMAN3) to give an overall view of the farm, and to help determine nutrient management at the farm scale.

2.1.2 Windshield Crop Surveys

One-on-one surveys with landowners provide detailed information. By contrast, windshield surveys of the agricultural fields complement the landowner surveys by providing general farming practices within a particular watershed.

In 2009 and 2010, students employed by the OMAFRA completed windshield surveys for the Bayfield North watersheds, including Gully Creek and Spring Creek. All agricultural fields were surveyed for crop type, tillage type, row direction, row width, crop residue type, and residue percentage. In addition, farmsteads and rural businesses were visually surveyed for information such as livestock type, manure storage type, and feed storage type.

Windshield surveys were also completed in 2011 and 2012 throughout the WBBE, Huron, study area. Staff from the ABCA and students from the OMAFRA surveyed the Bayfield North watersheds (including Gully Creek and Spring Creek), the Zurich Drain watershed, and the Ridgeway Drain watershed. Crop type, tillage type, row direction, row width, crop residue type and percentage, as well as farmstead and rural business information, were recorded on paper maps in the field (**Figure 2.1**).

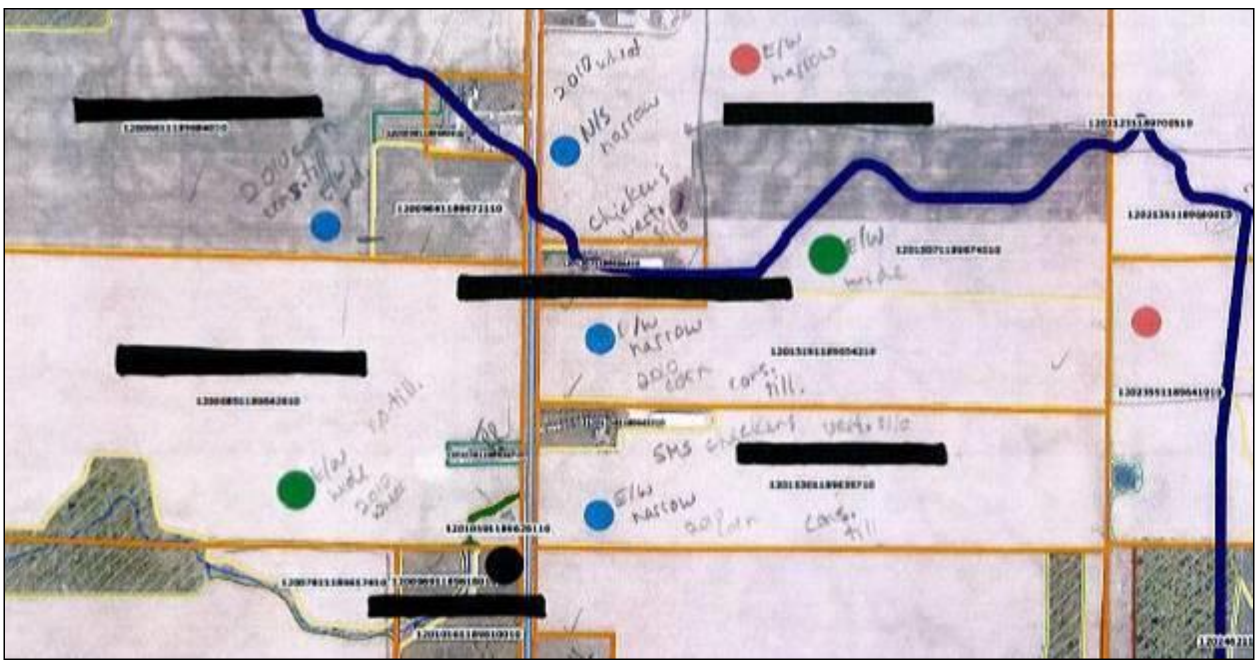

Figure 2.1: Field notes example from 2011 windshield surveys.

After completing the field portion of this exercise, the information collected was entered into a geodatabase. Attributes were assigned to each field as identified in a 2010 aerial photo, with the field Agricultural Resource Inventory (AgRI) layer as the base layer. If there was more than one crop for a single field, the field was split and a letter representing the part of the field was added onto the AgRI field identification code (*e.g.*, E for the east portion of the field and W for the west portion).

Once the data were entered into the geodatabase, the various attributes (such as crop type and tillage type) could be mapped. This provided a watershed-wide view of the typical agricultural practices. Also, when these data are collected over the course of several years, patterns in crop rotations and tillage practices begin to emerge. Knowing what is happening on the broader landscape of a watershed may help to explain the water quality within that watershed.

2.1.3 Aerial Photography Interpretation

Determining the environmental impact of changing land use within a watershed is a difficult task, as there is very little in the way of water quality data or detailed land use information from more than ten years ago. However, aerial photography from past years does provide a tool for piecing together a picture of the historic watershed. The process for determining crop types based on black and white aerial photography had two components: stereoscopes were used to view a three-dimensional image of the fields (**Figure 2.2**), and an ArcMap was created so that a 1978 layer was available for mapping. Once a project was set up in ArcMap, the corresponding scanned aerial photographs were imported into the project and georeferenced. With OMAFRA's AgRI layer of fields in the Gully Creek watershed, a new layer of fields was created to match the layout of the land as seen in the 1978 aerial photography.

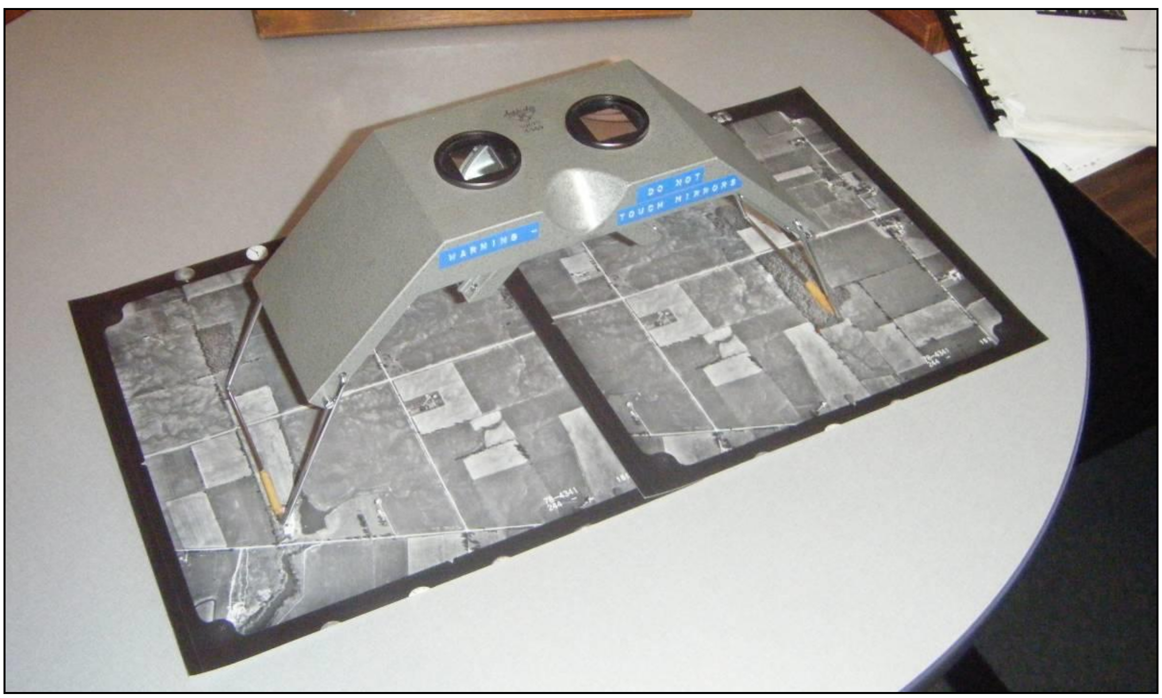

Figure 2.2: Aerial photography interpretation helped to determine land use in the Gully Creek watershed for 1978.

Each field in the 1978 layer was attributed a crop type. This proved to be a difficult task, as the photographs were black and white and the point during the year that the photographs were taken was not known. The use of an OMAFRA layer that displayed cropping systems from the early 1980s enabled experienced staff members to determine the crops that were planted in the Gully Creek watershed in 1978. These data were provided to the WEG modellers for use in a historic SWAT modelling scenario.

The size of fields along the Eighth Concession of the former Goderich Township in the Gully Creek watershed were examined on both the 1978 and 2011 land use maps. The analysis included those fields that were partially in the Gully Creek watershed.

2.1.4 Nutrient Management at the Watershed Scale

Agricultural producers use many tools to help determine the best land management practices to employ on their farms. One such tool is Ontario's nutrient management software program called NMAN3 (OMAFRA 2012). This tool assists producers and Certified Crop Advisors in developing appropriate nutrient management strategies and plans for farm properties. In this project, NMAN3 was used to design SWAT modelling scenarios.

Most often, NMAN3 is used for a single farm, which can consist of several different properties and fields. Fertilizer rates and quantities are based on the needs of the individual field. For the purposes of this study, NMAN3 was used to evaluate the entire Gully Creek watershed, rather than a single farm.

Information collected from the landowner surveys, supplemented by data collected from the windshield surveys, was entered into NMAN3 in order to obtain this broader view of watershed processes. Average fertilizer inputs were determined for the watershed and these average values were assigned to any fields in the watershed that had not been surveyed.

In addition to calculating average fertilizer inputs, NMAN3 also provided information on optimal fertilizer inputs, based on soil type and crop rotations. These optimal inputs were used for the SWAT modelling to create a best-case scenario for nutrient reduction within the Gully Creek watershed.

2.2 Soil Monitoring

Information on soil type and nutrient inputs into the soil is necessary when modelling watershed processes. Soil data, however, is not as readily available, or as easy to collect, as land management and water quality data.

Many landowners test soils according to the crop rotation, often prior to a corn crop. Thus, soils may be tested only every three years. Soil monitoring provides landowners with an indication of the amount of fertilizer that may need to be applied to a field. If the appropriate soil indicators are collected, such as soil organic matter content, soil data collected over the course of many years can also provide a measure of the overall health of the soil.

A few landowners within the Gully Creek watershed were willing to share their soil test results during the landowner surveys that were conducted.

Soil testing was also completed within the Gully Creek watershed as part of the monitoring component for evaluating a BMP at the field scale (**Figure 2.3**). On farm G1, where a nutrient reduction trial was conducted with a corn crop, composite soil samples (composed of 30-centimetre soil cores) were collected twice during the cropping year and analyzed for nitrogen. These data were provided to the WEG for setting up the SWAT model of the Gully Creek watershed.

Figure 2.3: Soil sampling in the Gully Creek watershed.

Additionally, some fields were sampled as part of an OMAFRA soil health study. Four landowners chose to participate, with the number of fields sampled totalling more than 25 per cent of the watershed. Soil was sampled for phosphorus, pH, organic matter, potassium, magnesium, calcium, as well as several other indicators.

2.3 Defining Watershed Topography

In the spring of 2011, the OMAFRA flew over the Gully Creek watershed with a Light Detection and Ranging (LiDAR) technology. The data collected during this flight was used to create one-metre and five-metre digital elevation models (DEMs) that were required for the SWAT modelling of the watershed. The one-metre DEM provided detailed elevation data, but it proved to be too detailed for the SWAT modelling, given the size of the Gully Creek watershed. Thus, the five-metre DEM was used for setting up the SWAT model.

3.0 Results

3.1 Land Management Monitoring

3.1.1 Landowner Surveys

In total, 29 landowners in the three surveyed watersheds (Gully Creek, Spring Creek, and Ridgeway Drain) participated by completing a survey. These landowners account for approximately 70 per cent of the agricultural land in the watersheds (**Table 3.1**). This level of survey completion left some gaps on the landscape, but the information gathered provided a good basis for developing the SWAT model for the Gully Creek watershed.

Table 3.1: Landowners and agricultural land surveyed in the Gully Creek, Spring Creek, and Ridgeway Drain watersheds.

	Gully Creek	Spring Creek	Ridgeway Drain
Number of Landowners Surveyed	18	5	6
Percentage of Landowners Surveyed	57	88	50
Percentage of Agricultural Land Surveyed	67	92	71

The SWAT model is based on Hydrologic Response Units (HRUs), which are determined by combinations of soil type, slope, and crop type. The landowner surveys gathered data on the current field crop, and also the crop rotation for a six-year span, from 2008 to the plan for 2013. This crop information provided the basis for the creation of the HRUs. Additionally, knowledge of the crop rotations allowed the modellers to determine various scenarios for modelling cover crops. Other data gathered through the landowner surveys that were helpful in setting up the SWAT model included tillage type, fertilizer types and rates of applications, manure use and rates of application, and the WASCoB locations.

The landowner surveys also provided an opportunity to learn more about the number and types of BMPs that landowners have been implementing over the years. Some of these data were also helpful for the modelling process, specifically, to create different scenarios for evaluating the effects of four BMPs (conservation tillage, cover crop, nutrient management, and WASCoBs). Overall, it was found that landowners in the Gully Creek watershed had implemented over 100 BMPs of various types on their farms in the years leading up to the project. Approximately 35 of these BMPs were implemented during the watershed planning process that occurred in the Bayfield North Watersheds, which includes Gully Creek, from 2008 to 2010.

The landowner surveys, in combination with the windshield surveys and nutrient management analysis with NMAN3, provided an estimate of the uptake of three agronomic BMPs that were the focus of this project (conservation tillage, cover crop, and nutrient management) (**Table 3.2**). 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. 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.

Table 3.2: Percentage of fields and agricultural area with best management practices in the Gully Creek watershed based on landowner surveys, 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.

Another benefit of completing the landowner surveys was that they allowed staff to speak directly with landowners about projects that they may be interested in implementing on their farms. Many landowners were willing to employ BMPs. Working directly with the landowners to identify and implement these BMPs allowed staff to find additional funding to help implement these practices. Approximately 15 opportunities for BMP implementation were identified in the Gully Creek watershed during the course of this project, 9 of which have been implemented and 4 of which are being implemented in 2013 (2 have yet to be implemented). Several of these BMPs were evaluated as part of this project.

3.1.2 Windshield Crop Surveys

The windshield crop surveys provided vital information for the SWAT modelling, such as crop tillage types, which are required for building the HRUs. These surveys resulted in a more complete overview of the general cropping processes in the watershed. Since windshield survey data were available for several years (2009 to 2012) for some parts of the study area, information on crop rotation patterns was available for designing scenarios for the Gully Creek watershed SWAT model.

A comparison of the windshield survey and landowner survey datasets showed that crop type matched between the two datasets approximately 80 per cent of the time. The discrepancies between the two types of survey can be attributed to landowners changing crop types (if they were surveyed during the planning stage, before they planted their crops) or to errors made by staff conducting the windshield surveys (crop type is not always easily visible and some fields are not readily visible from the road). For the SWAT modelling, data regarding crop type for past cropping years was derived from the landowner surveys. If there was a discrepancy between the landowner and windshield surveys for cropping years during the course of this project, the on-the-ground observations from the windshield surveys were used.

3.1.3 Aerial Photography Interpretation

The historic land use mapping exercise yielded several observations and conclusions. For instance, field sizes were much smaller in 1978 than at present. Between 1978 and 2011, agricultural field sizes have more than doubled, from an average of 9 hectares per field in 1978 to nearly 24 hectares in 2011. These larger field sizes mean that there are fewer opportunities for the landscape to be divided by fencerows and treed windbreaks (**Figures 3.1 and 3.2**).

The percentage of land that is used for pasture and forage has changed considerably over the past 30 years, from 30 per cent of the watershed area in 1978 to less than 2 per cent in 2011 (**Figure 3.3**). With this decrease in pasture and hay, less land is now in perennial cover.

Similar to today, corn tended to be the dominant crop in 1978. Spring grains were 13 per cent more abundant in 1978 than in 2011. Soybeans and winter wheat were grown only sporadically in the late 1970s, but a corn-soybean-wheat crop rotation is now practised on more than 60 per cent of agricultural land in the Gully Creek watershed. These landscape and land management changes over the past thirty years mean that, without the intervention of agricultural BMPs, soil is more prone to erosion and nutrients are more available for surface water runoff.

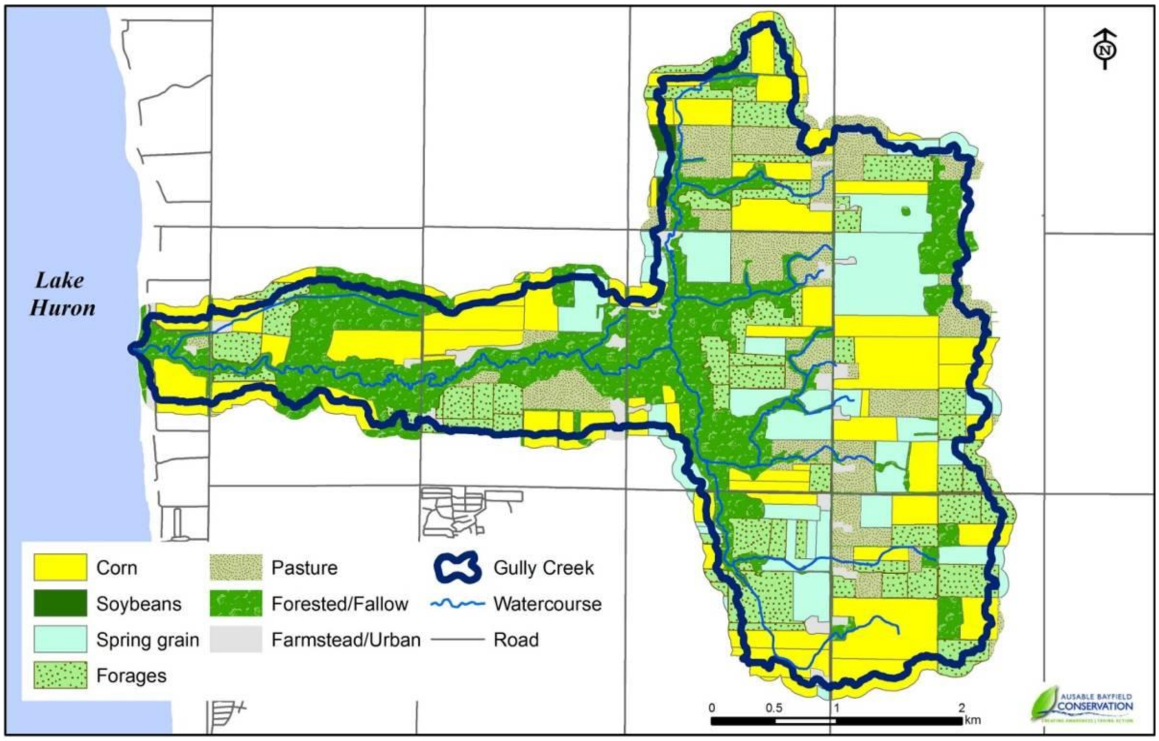

Figure 3.1: Land use in the Gully Creek watershed, estimated from 1978 aerial photography interpretation.

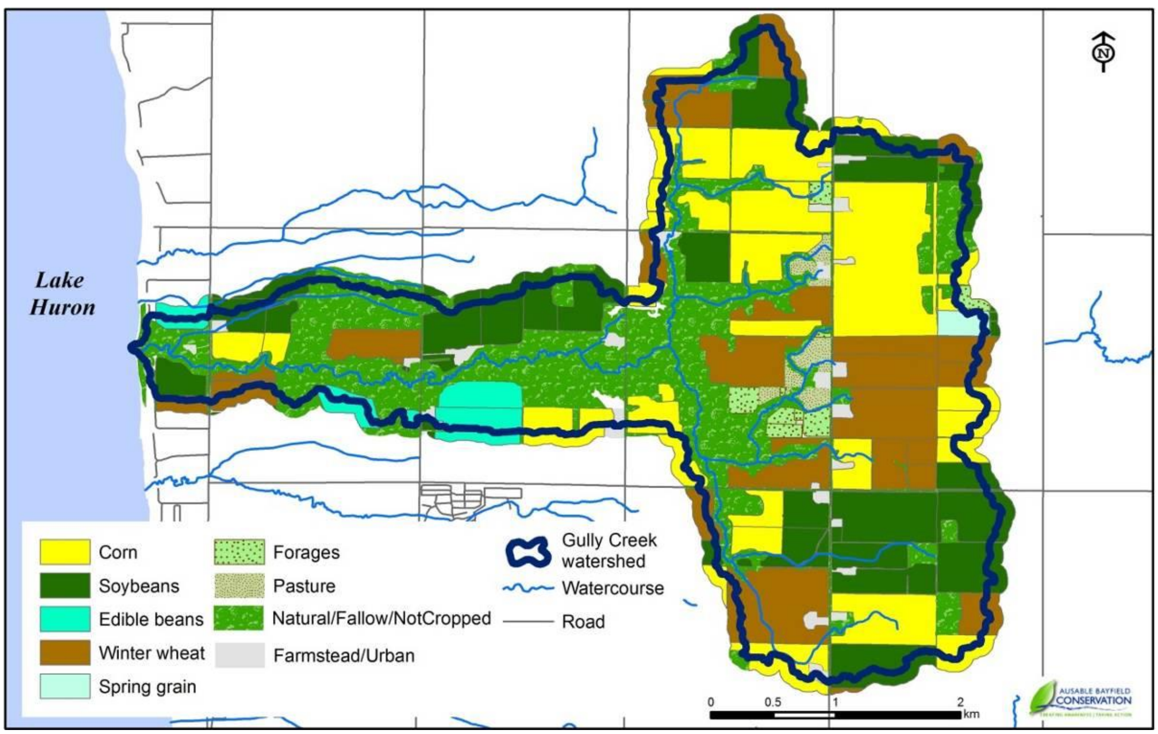

Figure 3.2: Land use in the Gully Creek watershed, from 2011 windshield surveys.

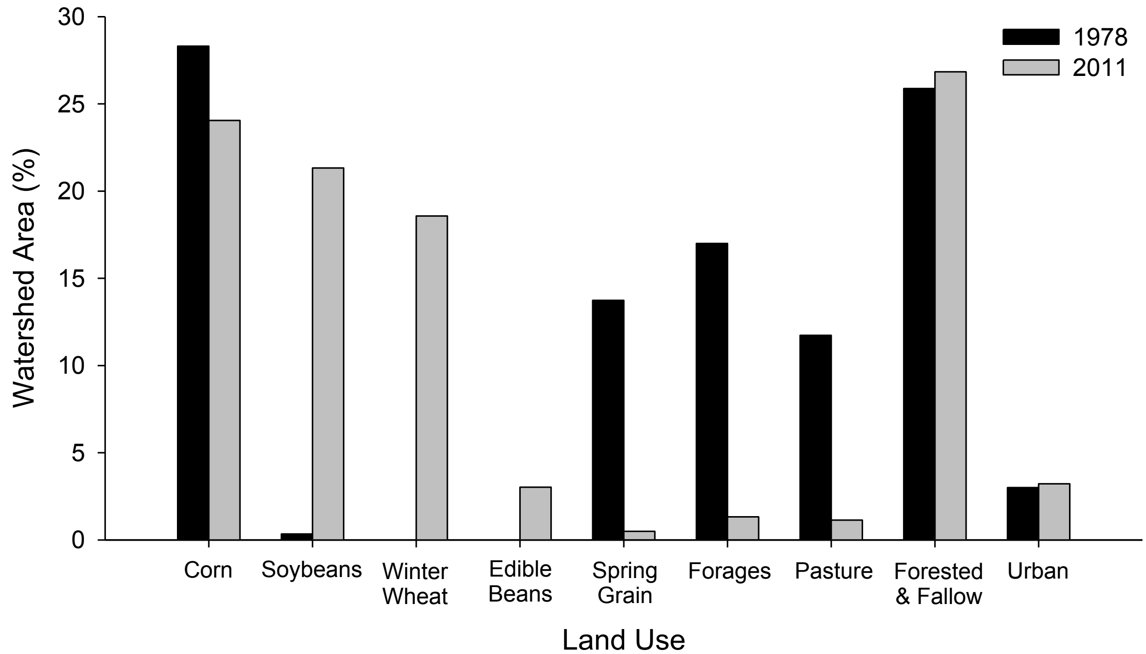

Figure 3.3: Comparison of land use in 1978 and 2011 for the Gully Creek watershed.

3.1.4 Nutrient Management at the Watershed Scale

The NMAN3 software was a useful tool for staff and modellers with respect to running different scenarios in the SWAT modelling. Data from the landowner surveys were entered into NMAN3 in order to determine average fertilizer inputs for the Gully Creek watershed (**Table 3.3**). These data were then used in the SWAT modelling to create a base scenario that reflected existing watershed conditions.

Table 3.3: Nutrient inputs assumed for fields that were not surveyed in the Gully Creek watershed, calculated with nutrient management software (NMAN3) from landowner survey results.

Crop	Elemental N* (kg/ha)	Elemental P* (kg/ha)	Elemental K* (kg/ha)	Yield (T/ha)
Grain Corn	180	38	--	11.0
Soybeans	0	0	--	3.1
Winter Wheat (straw removed)	110	12	--	5.9
Dry Beans	50	30	--	2.4
Spring Barley	45	0	0	3.5
Forage (3-cut alfalfa)	0	0	0	11.0
Hay	0	0	0	8.6
Pasture	0	0	0	4.3

***** N – nitrogen; P – phosphorus; K – potassium.

Nutrient management information at the watershed-scale was used not only to create a base scenario for the SWAT modelling, but also to create scenarios that reflected the implementation of nutrient management BMPs. The NMAN3 software provided recommended fertilizer rates (**Table 3.4**) that depended on location and soil type. These recommended rates were used in the SWAT modelling to create several scenarios with optimal fertilizer inputs.

Table 3.4: Recommended nutrient inputs for the Gully Creek watershed, derived from nutrient management software (NMAN3).

Crop	Elemental N* (kg/ha)	Elemental P* (kg/ha)	Elemental K* (kg/ha)	Yield (T/ha)
Grain Corn	174	24	--	11.0
Soybeans	0	0	--	3.1
Winter Wheat (straw removed)	100	0	--	5.9
Dry Beans	60	0	--	2.4
Spring Barley	45	0	0	3.5
Forage (3-cut alfalfa)	0	0	0	11.0
Hay	0	0	0	8.6
Pasture	0	0	0	4.3

***** N – nitrogen; P – phosphorus; K – potassium.

3.2 Soil Monitoring

Landowners representing two or three farms in the Gully Creek watershed agreed to provide soil sampling results as part of the landowner survey that they completed. These results included the percentage of organic matter, phosphorus (sodium bicarbonate extraction), potassium, and pH.

Soil nitrate concentrations were monitored as part of the field-scale evaluation of a nutrient reduction trial on the G1 farm. These results are discussed in Upsdell Wright *et al.* (2013).

Soil sampling that was conducted as part of the OMAFRA soil health study covered more than 25 per cent of the agricultural land within the Gully Creek watershed. Most of the fields sampled had phosphorus concentrations that were indicative of a rare or low crop yield response to phosphorus fertilizer (**Figure 3.4**).

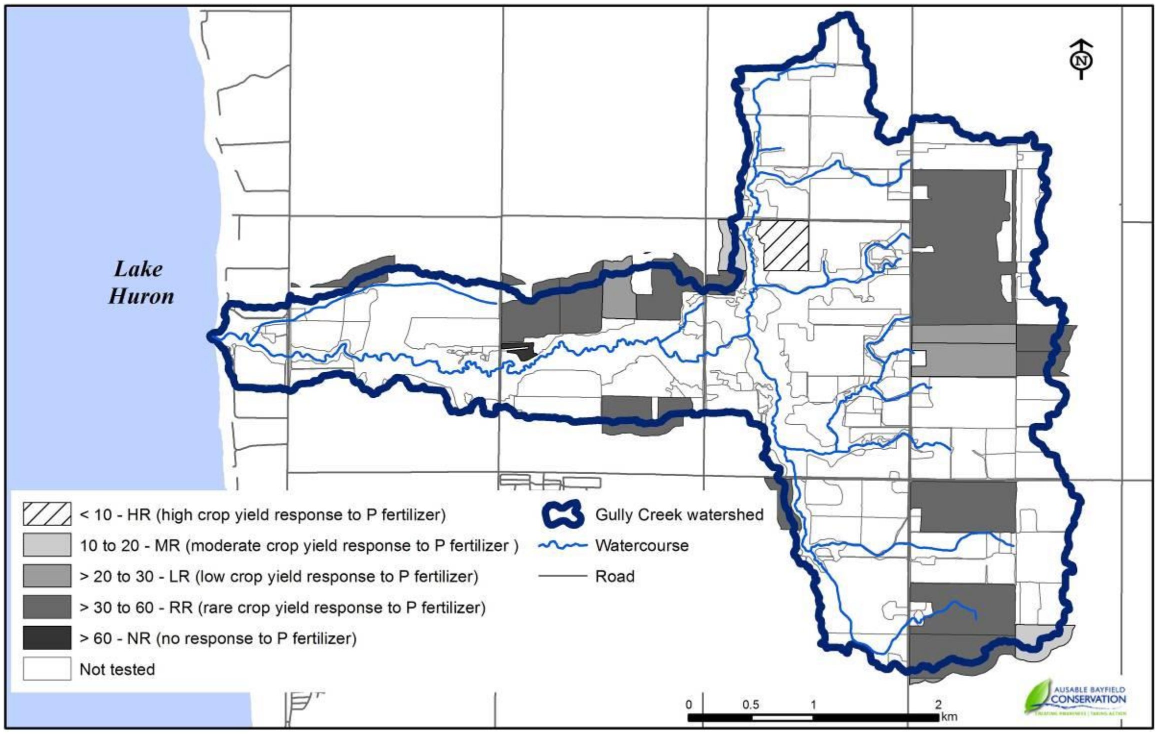

Figure 3.4: Soil test phosphorus concentrations (parts per million) in the Gully Creek watershed.

The soil layer for the SWAT modelling was derived from external sources, such as the Soil Landscapes of Canada geospatial database. Soil data collected from the Gully Creek watershed was, however, useful in other aspects of the modelling. For example, these data were used in the NMAN3 program to create the recommended nutrient inputs for several of the SWAT modelling scenarios.

It also seemed, from discussions during the landowner survey process, that many landowners relied on their historic understanding of their soil characteristics and did not rely on soil monitoring results for management decisions.

3.3 Defining Watershed Topography

The DEM was beneficial for several reasons. First, it helped to better define watershed boundaries during the set-up of the SWAT model by accurately defining slopes. These boundaries included the Gully Creek watershed boundary as well as nested subwatershed boundaries that defined Hydrologic Response Units (HRUs) for the SWAT modelling. The DEM was also used to calculate water flow direction and accumulation throughout the Gully Creek watershed. Finally, the DEM was helpful for identifying the locations of Water and Sediment Control Basins (WASCoBs) and estimating the size of water ponding areas behind each WASCoB. All of this information was critical for setting up and calibrating the SWAT model.

4.0 Discussion

The land use and land management data that were collected over the course of this project were important inputs into the SWAT modelling for the Gully Creek watershed.

Fertilizer rates applied to fields in the Gully Creek watershed were variable; however, the average rates did not differ much from the rates recommended by the NMAN3 software. This was also apparent from the SWAT modelling outputs. When nutrient and sediment loadings were compared between the base scenario (actual fertilizer application rates) and the scenario with the NMAN3-recommended rates, there was very little difference. Total nitrogen loading was reduced by two per cent and total phosphorus and sediment loadings were reduced by less than one per cent when the recommended rates were followed (Yang *et al.* 2013). Thus, most landowners in the Gully Creek watershed appear to be already using good practices with respect to nutrient application to agricultural fields.

The 1978 aerial photography interpretation provided land use data to the SWAT modelling for the creation of a historical control scenario. A comparison of this historical scenario with the base scenario (existing conditions) helped to elucidate water quality changes that resulted from evolving land uses, rather than the implementation of BMPs. Many assumptions were made in terms of cropping practices for the 1978 scenario, but the aerial photography interpretation of land use provided a reasonable estimate of historical conditions for comparison with existing and possible future scenarios.

The windshield crop surveys served a dual purpose with respect to this project. They provided a more complete picture of the watershed farming practices and helped to fine-tune the landowner survey data (and, in turn, the SWAT model), as some producers changed their cropping plans from the time the survey was completed to the time the crop was planted.

Windshield surveys also provided a generalized interpretation of the land use and management within the watershed. When these types of data are mapped, it may be possible to determine where the nutrients will be applied in a given year, based on crop type. Also, areas of high potential for erosion can be identified based on different land management practices.

Climate conditions, soil type, slope, and land use and management are key determinants of the extent of variable source areas (VSAs) in the uplands. Variable source areas are areas of the landscape from which surface runoff is generated to different extents (Hewlett and Hibbert 1967). For example, VSAs tend to be larger during wetter months (spring or fall) and smaller during drier months (summer). They are often located in low areas of the landscape (*e.g.*, where slopes converge) or where a shallow soil layer restricts water infiltration (Qiu *et al.* 2007). During the course of this project, land use (*i.e.*, cropped land or perennial cover) and land management (*i.e.*, tillage practices) were also observed to influence the spatial and temporal extent of VSAs. These land conditions potentially affect the water quantity and quality conditions of water coming from these areas as well. Therefore, documenting land use and land management can assist in interpreting the reasons for differences in water quality in different parts of the watershed.

The landowner surveys were a critical part of this project. The survey was originally developed to collect farming and economic data for use in the SWAT modelling. Staff members were able to collect very detailed farming information in many cases, which contributed to the overall confidence in the model. In the one-on-one setting, the landowners shared their considerable working knowledge of the land. This detailed information made the model more representative of the actual watershed conditions.

Another purpose of the landowner surveys was to encourage the implementation of BMPs. Completing the survey together allowed for a discussion between staff and landowners about land management and provided an opportunity for landowners to undertake BMPs they had previously identified, but had not had the resources (*i.e.*, time and/or money) to implement. When community engagement began in the Bayfield North Watersheds, it occurred at a community level and some BMPs were implemented due to the enhanced availability of staff to provide technical assistance. During the WBBE, Huron, project, staff were able to connect with more individual landowners, which facilitated the implementation of more BMPs.

It is hoped that staff will be able to use the monitoring and modelling results to encourage the implementation of more BMPs that will be beneficial for the producers, and will have the greatest positive impact on water quality in the watershed. On-going discussions with landowners and other agricultural-environmental stakeholders will be required to highlight the relationship between land conditions and water quality. This project broadly identified the role of land management actions on the extent of VSAs and the quality of water coming from those areas. More research will be required to quantify the relationship between VSAs and water quality and quantity under different land management scenarios.

This study also highlighted that data related to soil conditions were not usually available at the field scale and were not typically current. Furthermore, the soil monitoring data that did exist was found to be sporadic and the soil indicators were mainly useful for crop production. Information about soil health, such as organic matter, was lacking. We understand that the Ontario Ministry of Agriculture and Food is undertaking a project to identify appropriate indicators for soil health. This is an important first step in understanding the relationship between soil health and the spatial and temporal extent of a VSA, and will help to inform the relationship between land conditions and water quality.

5.0 References

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

Hewlett, J. D., and A. R. Hibbert. 1967. Factors affecting the response of small watersheds to precipitation in humid regions. *In* Forest Hydrology, W. E. Sopper and H. W. Lull (eds.), 275-290. Pergamon Press, Oxford.

Qiu, Z., M. T. Walter, and C. Hall. 2007. Managing variable source pollution in agricultural watersheds. Journal of Soil and Water Conservation 62(3):115-122.

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.