NEW DIRECTIONS RESEARCH PROGRAM
AUSABLE BAYFIELD CONSERVATION AUTHORITY

MONITORING AND PREDICTING VARIABLE SOURCE AREAS IN SMALL AGRICULTURAL WATERSHEDS

SYNTHESIS REPORT – DRAFT

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1.0 INTRODUCTION

1.1 Background

The nearshore area of the Great Lakes provides many residents of Ontario with drinking water and recreational opportunities (e.g., swimming and fishing). Of increasing concern, however, is the resurgence of eutrophication and nearshore algal fouling, which limit both the human uses and the ecological integrity of the waters of these lakes. Factors that result in impacts on the nearshore are complex and one of the key complicating factors is rural non-point source pollution that varies both temporally and spatially. As a result, reducing agricultural non-point source pollution is an important goal for federal and provincial agencies.

Non-point source pollution is influenced by water flow generated preferentially on the landscape by variable source areas (VSAs). Variable source area hydrology suggests that a relatively small portion of the watershed drives the majority of runoff. The abundance of these runoff generating sources is driven by parts of the landscape where the soil saturates to the surface (Qiu *et al.* 2007) and may increase or decrease depending on temporal and spatial variability. Land characteristics such as soil moisture conditions, slope, restrictive underlying soil types, and shallow water tables tend to control the location and extent of the VSAs (Qiu *et al.* 2007). The identification of these areas can be challenging with monitoring alone; however, identifying these areas would help watershed managers and producers strategically locate agricultural best management practices (BMPs). Furthermore, the magnitude of the water quantity and quality benefits of these BMPs (such as sediment and nutrient reductions) has been difficult to document at the watershed scale over the short-term (less than ten years) (Gowda and Veliz 2014). A New Directions Research Program study was undertaken in 2013 through 2016 to continue monitoring in one agricultural watershed and provide insights on agricultural water management models that predict VSAs and the effectiveness of various BMPs.

The purpose of this report is to summarize and discuss findings from this study of VSAs. The report provides a high-level overview of findings and direction for future work by the stakeholders that are addressing agricultural non-point source pollution.

1.2 Objectives

The goal of this New Directions study was to provide insights into the development and application of agricultural water management models in partnership with researchers, resource practitioners, and rural landowners. The specific objectives were to:

1. Monitor one watershed to identify the sources of runoff in a watershed and to quantify the effect of management practices, such as grassed areas and Water and Sediment Control Basins (WASCoBs) on the quantity and quality of water from VSAs;

2. Develop and evaluate rural water management models that identify sources of runoff in an agricultural watershed;
3. Build capacity in a local watershed agency to predict VSAs and to work with landowners in the management of the VSAs; and
4. Develop and deliver outreach and education to multiple agricultural stakeholders about a model that identifies VSAs and determines the effect of water management practices, such as grassed areas and WASCoBs, on the amount and quality of stream flow.

1.3 Study Area

The Bayfield North Watersheds area is approximately 40 square kilometres in size and consists of 20 small streams flowing directly into Lake Huron within the Ausable Bayfield Conservation Authority (ABCA) jurisdiction (Figure 1.1). The watershed area extends eight kilometres inland from the shore of Lake Huron and is dominated by agriculture, some natural environment, recreational areas, and limited settled areas. Studies were conducted mainly in the Gully Creek watershed with monitoring sites at the VB Drain and the SB sub-watershed. The KVBAY Water and Sediment Control Basin, just south of the Gully Creek watershed, was also monitored. The locations for each of these study areas are provided in Figure 1.1.

Gully Creek: The Gully Creek watershed is located in Huron County and, at 15 square kilometres, is the largest tributary in the Bayfield North watersheds within the Ausable Bayfield Conservation Authority jurisdiction (McPherson and Veliz 2015). Close to 70% of the land draining into Gully Creek is cropland. The remaining 30% is forest, shrubs, and meadows.

VB Drain: This Municipal Drain and its watershed are located at the east edge of the Gully Creek watershed. The drain consists of a Main Drain with three branches (Branch A, Branch B, and Branch C). The Van Beets Municipal Drain was constructed in 2013 and 2014 (Burnside 2015).

SB Subwatershed: The SB subwatershed is located on the east edge of the Gully Creek watershed, directly south of the VB Municipal Drain. Currently, the property is an open field with a well-defined low run that flows westerly to a culvert under Whys Line (Burnside 2015).

Water and Sediment Control Basin Monitoring Station (KVBAY): Monitoring stations were set up in a field to the south of Gully Creek. During the study period, different field crops in various stages of development were present at this site (i.e., corn, soybean, wheat).

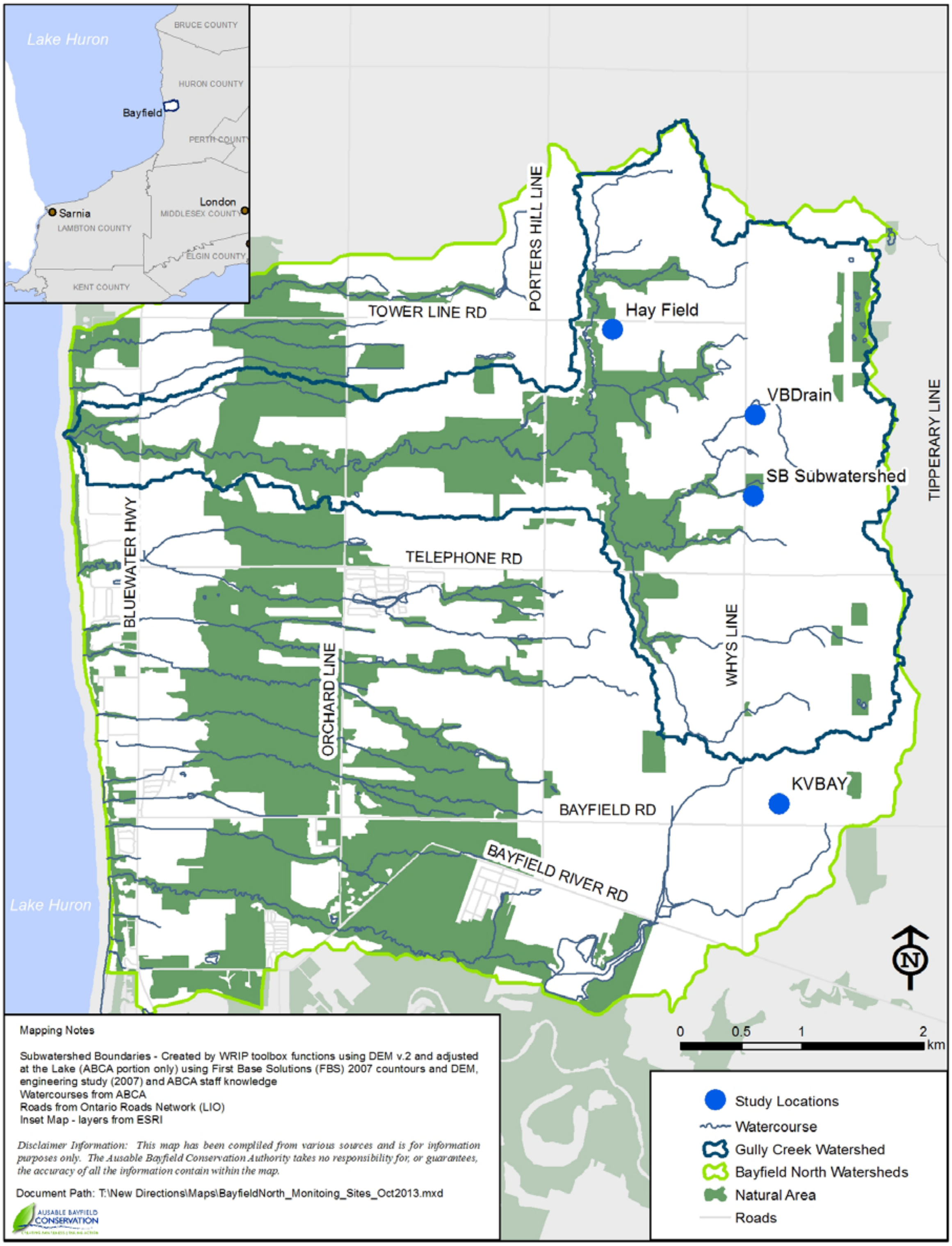

Figure 1.1. Gully Creek watershed and study locations with the Bayfield North Watersheds study area.

2.0 METHODS

2.1 Monitoring Variable Source Areas and Best Management Practices

The ABCA has been collecting watershed-scale and field-scale data for the purpose of evaluating BMPs since 2008. Many of the methods used to collect these data are documented in the Water Quality Monitoring Guidance Manual for the Healthy Lake Huron Initiative (Upsdell Wright *et al.* 2015). Methods are summarized below and specific monitoring data used in each study can be found in the original reports, which are referenced throughout this section.

2.1.1 Effect of Watershed-wide Best Management Practice Adoption

Since 2008, when outreach to landowners was initiated, at least 85 agricultural BMPs have been implemented in the Gully Creek watershed. Over a five-year period (2011-2015), water quality and flow data were collected on the main channel of Gully Creek and analyzed to compare estimated annual flow-weighted mean concentrations and mass export coefficients (Bittman *et al.* 2016). Water quality data was collected prior to 2011, however, reliable flow information was not collected during that period to develop load estimates.

2.1.2 Effect of Perennial Cover on Variable Source Areas

In 2013, the ABCA and the Huron County Federation of Agriculture received funding under the New Directions program to study the effects of agricultural best management practices (Bittman *et al.* 2016). A number of different investigations were conducted during this study; however, for the purposes of this report, the focus will be on those related to perennial cover. The two investigations related to perennial cover were (1) the conversion of a cropped field to a hay field; and (2) the effect of vegetative cover around a WASCoB.

Conversion from Cropped Field to Hay Field: Surface runoff was collected from this site from June 2011 to March 2012 for a previous study (Upsdell Wright *et al.* 2013). However, it was observed in October 2013, that the change in land management eliminated a concentrated flow path that had previously been used for water quality monitoring. Monitoring was discontinued and attempts were made to observe flow versus no-flow at this field over time.

Effect of Vegetative Cover around a WASCoB: Water stage and water quality data were collected from March 2012 to November 2015 at the KVBAY WASCoB (Bittman *et al.* 2016). Stage measurements were taken in the ponding area of the WASCoB with a level logger. The stage (in metres) was converted to outflow (in cubic metres per second) following methods documented by Wilson (2016). Water quality samples were collected from the Hickenbottom outlet during storm events with an ISCO automated sampler and were submitted to a laboratory for nutrient and sediment analyses. Data management and processing tasks for this investigation required a substantial time investment for the 3.5 years of data. These tasks included quality assurance and quality control of stage, water quality, and precipitation datasets; conversion of stage data to outflow; maintenance of the data in formats compatible with a database; calculation of runoff coefficients; and estimation of loads. A variety of statistical techniques and models were used to analyze these data. Details can be found in the full report (Bittman *et al.* 2016).

2.1.3 Effectiveness of Water and Sediment Control Basins

Water samples were collected from March 2012 to September 2015 at the hickenbottom outlet of the WASCoB and at up to five different heights (0, 5, 10, 15, 20 centimetres) on the rill path into the basin. Samples were analyzed for nutrient and sediment concentrations. In addition to water quality, the outflow was measured and the inflow estimated using methods documented by Wilson (2016). The data were analyzed to compare inflow and outflow peak flow and loads.

2.2 Modelling Variable Source Areas

There are a number of different modelling approaches available to watershed managers to identify VSAs and potentially to help strategically locate BMPs. However, there are a number of challenges with using models. To assess these challenges, five models were selected for comparison in this study. The selected models, described further in the following section, are the:

- Soil and Water Assessment Tool (SWAT);
- Agricultural Non-Point Source Pollution (AGNPS) Model;
- Guelph model for evaluating effects of Agricultural Management systems on Erosion and Sedimentation (GAMES);
- Geographic Information Systems (GIS) based assessment; and
- Rural Stormwater Management Model (RSWMM).

2.2.1 Soil and Water Assessment Tool

In 2014, researchers from the University of Guelph assessed the Soil and Water Assessment Tool's (SWAT) ability to predict VSAs (Golmohammadi 2016). In the first part of this assessment, the SWAT was applied to identify areas that contributed to flow in the watershed. The model results were compared to observed flow/no-flow data collected in the watershed. The second part of the assessment involved using a simple methodology developed by Lee and Huang (2013) to examine the capability of the SWAT to predict time-varying flow contributions in the study watershed. In this approach, temporal variation in the flow-contributing area during storm events was estimated using the ratio between the current precipitation index (CPI) and the partial contributing area (PCA).

The SWAT, developed by the United States Department of Agriculture's Agricultural Research Service, is a watershed-level water quantity and quality simulation model that operates on a daily time step and is capable of simulating a number of land use and land management practices (Douglas-Mankin *et al.* 2010). The main inputs are land use, soil, topographic, and climatic data; the outputs include stream flow and instream water quality estimates. The SWAT is a semi-distributed model; thus, watersheds are partitioned into a number of sub-basins, which are further divided into hydrological response units (HRUs) based on unique combinations of land cover, soil, and slope class. For each HRU, loadings of water, sediment, nutrients, and pesticides are determined and routed to the sub-basin outlet.

Key model functions: continuous rainfall-runoff simulation; reservoir and channel routing; hydraulic calculations; pollutant loading or pollutant removal by a BMP. Not able to treat urban drainage systems.

2.2.2 Agricultural Non-Point Source Pollution Model

The researchers from the University of Guelph also assessed the Agricultural Non-Point Source Pollution (AGNPS) Model's ability to predict VSAs (Golmohammadi 2016). In this assessment, the AGNPS was used to simulate streamflow and the modelled data were compared to flow/no-flow monitoring data collected at various monitoring points.

The United States Department of Agriculture's Agricultural Research Service, in cooperation with the Minnesota Pollution Control Agency and the Natural Resource Conservation Service, developed the AGNPS model in the early 1980s (Young *et al.* 1989; Young *et al.* 1995). The model was developed to analyze and provide estimates of runoff water quality from agricultural watersheds ranging in size from a few hectares to 20,000 hectares. The AGNPS model uses rainfall depth and duration (i.e., events) as precipitation input. Because it is easy to use, flexible, and relatively accurate, the AGNPS model is widely applied throughout the world to investigate various water quality problems.

Key model functions: distributed-parameter, event-based runoff simulations; determining effect of management decisions (i.e., BMPs); modelling processes affecting the transport of sediments, nutrients, and pesticides in surface runoff.

2.2.3 Guelph model for evaluating effects of Agricultural Management systems on Erosion and Sedimentation

The Guelph model for evaluating effects of Agricultural Management Systems on Erosion and Sedimentation (GAMES) was developed as a screening tool for watershed management at the University of Guelph (Dickinson *et al.* 1986). It was applied to identify locations at high-risk of fluvial erosion and areas delivering the majority of sediments to streams (Golmohammadi 2016).

The GAMES model operates by creating discrete cells with identical characteristics of land use, soil type, and slope class(HRUs). The soil loss and sediment delivery from each cell is calculated for each season. The input parameters are similar to the SWAT and include land slope, channel slope, soil type, soil erodibility, cropping factors, and location and efficiency of sediment-detention structures. This model relies on a rainfall and runoff factor rather than specific precipitation data, making the model best suited to the prediction of long-term averages rather than specific events.

Key model functions: determining soil loss and sediment delivery to watershed stream channel; identifying seasonal variation in the distribution of soil erosion and sediment loss; using rainfall erosion index for prediction of long-term averages.

2.2.4 Geographic Information Systems

The ABCA applied precision-conservation Geographic Information Systems (GIS) technologies to identify VSAs and determine the types of BMPs suited to different locations (McPherson and Veliz 2016).

Five different individual and combined GIS-based approaches were used:

1. Areas with a potential for sheet erosion (PSE) were identified with a landscape-level application of the Revised Universal Soil Loss Equation (RUSLE));
2. The landscape's risk of gully erosion was assessed with a Stream Power Index (SPI) derived from a one-metre Digital Elevation Model (DEM);
3. The two risks above were combined to identify priority sub-watersheds for BMPs designed to reduce sediment loading;
4. Fields were prioritized according to a runoff risk assessment and methods of identifying areas where the generation of surface runoff is likely (Tomer *et al.* 2013a);
5. Convergent foot slopes were combined with a Topographic Index (TI) based on Tomer *et al.* (2013a) to identify other potentially-wet areas.

These approaches require GIS inputs including a high-resolution DEM, soil types, and vegetation or land use.

Key model functions: identifying VSAs; using GIS inputs without the requirement of meteorological data; highlighting areas with high risk for generating surface erosion; a simplistic technique that can be applied without modelling expertise.

2.2.5 Rural Stormwater Management Model

The purpose of the Rural Stormwater Management Model (RSWMM) project (Emmons & Olivier Resources, Inc., 2014) was to extend a stormwater model, typically used in urban areas, to represent the hydrology, hydraulics, and hydrogeology in rural areas. After the RSWMM was developed, R.J. Burnside & Associates Limited (Burnside) was retained by the ABCA to evaluate the abilities of the RSWMM to assess the effectiveness of WASCoBs in a small sub-watershed of Gully Creek (R.J. Burnside & Associates Limited, 2015). In each of the sub-watersheds studied, constructed improvements (i.e., WASCoBs and a piped drain) in the watershed were added to the model and modelled results were compared to the measured results.

The United States Environmental Protection Agency's (USEPA) Storm Water Management Model (SWMM) is a computer program that computes dynamic rainfall-runoff for single-event and long-term (continuous or period-of-record) runoff quantity and quality from developed urban and undeveloped or rural areas (James *et al.*, 2010). The SWMM has undergone many revisions. The RSWMM builds upon PCSWMM, which is a GIS-based spatial decision-support system, for USEPA SWMM5. Inputs to the RSWMM include GIS and survey data, water quantity and meteorological data, and water quality data (Emmons & Olivier Resources, Inc., 2014).

Key model functions: continuous and single-event rainfall-runoff simulation; reservoir and channel routing (includes pipes, channels, pumps, and regulators); hydraulic calculations; pollutant loading. Limited ability to account for rural land cover and BMPs.

2.3 Building Local Watershed Agency Capacity

The purpose of sharing lessons learned with other watershed agencies is to improve and speed up the implementation of similar studies. The first approach used to build local watershed agency capacity was meetings and conferences and the second approach was to document monitoring approaches in the Water Quality Monitoring Guidance Manual for the Healthy Lake Huron Initiative (Upsdell *et al.* 2015).

2.3.1 Meetings and Conferences

Meetings were held with extension staff and other organizations, including the Ontario Ministry of Agriculture, Food and Rural Affairs and the Lake Huron Technical Committee. Additionally, in 2015, meetings were held with Agriculture and Agri-Food Canada. Findings were also presented at the Latornell Conservation Symposium on November 17, 2015, and the Environmental Sustainability in Agriculture Meeting at Western University on April 16, 2016.

2.3.2 Monitoring Guidance Manual

The Water Quality Monitoring Guidance Manual for the Healthy Lake Huron Initiative (Upsdell *et al.* 2015) is a practical guide for conservation authorities implementing similar monitoring programs. This report had been distributed to other conservation authorities undertaking extensive monitoring programs and is available on the ABCA website[1].

2.4 Developing and Delivering Outreach and Education

The primary premise of outreach and education is to engage multiple stakeholders in taking actions appropriate to their sector to address non-point source agricultural runoff. Several innovative and conventional approaches to delivering outreach and education were applied as part of the work done under the New Directions funding program, including (1) one-on-one landowner meetings; (2) presentations to agricultural and community groups; (3) outreach to municipal drainage engineers; and (4) GIS modelling and property drain walks (Gutteridge, 2016). A detailed list of potential stakeholders and approaches used to deliver outreach and education is provided in Appendix ‘A’.

2.4.1 One-on-one Landowner Meetings

During the period from March 31, 2014, to September 30, 2015, 17 informal one-on-one landowner meetings were held at producers’ properties. These meetings were used to describe the role of VSAs across the landscape and document producers’ experiences maintaining these areas. During the meetings, detailed land management data were collected for each field owned or rented by the landowner. Information was also collected about BMPs that the landowner had implemented in the past or was interested in employing in the future. Landowners were also asked for their assistance to monitor VSAs on their properties.

2.4.2 Presentations to Agricultural and Community Groups

In addition to informal meetings with producers, five presentations have been made to share findings with local landowners. These presentations reached a wide range of audiences. This included local landowners at presentations to community associations, local Rotary clubs, and farmer organizations. Presentations were also made at larger events and meetings, including the Annual National Farmers Union meeting, FarmSmart, the Soil Health Roadshow (Farm and Food Care), and a meeting of the Board of the Ontario Pork Producers.

A comprehensive list of presentation audiences and dates can be obtained from the ABCA.

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[1] http://www.abca.on.ca/downloads/EC-Field-Data-Collection-Processing-Guidance-Manual-2015-07-02.pdf

2.4.3 Outreach to Municipal Drainage Engineers

An innovative education approach applied in this program involved the involvement of the local drainage community. As described in section 2.2.5, Burnside was retained by the ABCA to evaluate the abilities of the RSWMM to assess the effectiveness of WASCoBs in a small sub-watershed of Gully Creek (R.J. Burnside & Associates Limited 2015). This was done as a practical learning exercise for both the consulting firm and the ABCA. Preliminary findings from this work were presented at the Drainage Engineer's Conference in October 2014 and a follow up presentation was made in 2015

2.4.4 GIS Modelling and Property Drain Walks

As noted in section 2.2.4, a GIS modelling approach was used to identify VSAs and determine the types of BMPs suited to different locations. As part of the verification process for this modelling, maps produced by the model were brought out to the field when ABCA staff walked the corresponding properties with landowners. Landowners were later given a brief report of the findings and were offered technical and funding assistance to implement BMPs.

3.0 RESULTS AND DISCUSSION

3.1 Monitoring Variable Source Areas and Best Management Practices

In general, conservation authority staff found it difficult to capture water samples to monitor "edge-of-field" runoff to evaluate the impact of various vegetative covers on runoff volume and quality. It was easier to capture water samples at WASCoBs. In addition to monitoring WASCoB effectiveness, this may prove to be a useful avenue for monitoring changes in crop type and land management at these locations over time. It is important to note, however, that a number of factors, including the need to remove sampling equipment to accommodate field crop activities, also complicate in-field sampling. The findings of each specific investigation are summarized below.

3.1.1 Effect of Watershed-wide Best Management Practice Adoption

Annual flow-weighted mean concentrations and mass export coefficients were estimated for Gully Creek over the period from 2011 to 2015. Due to a change in laboratory methods for testing for total phosphorus (TP) in 2013, changes in TP over time cannot reliably be assessed. Water quality trends were difficult to detect over the five-year time period; however, the flow-weighted mean concentration and mass export coefficient for phosphate-phosphorus (which was not affected by the change in laboratory method) tended downward. The flow weighted mean concentration of total suspended solids (also not affected by the change in laboratory method) also tended downward.

3.1.2 Effect of Perennial Cover on Variable Source Areas

Conversion from Cropped Field to Hay Field: In a previous study (Upsdell Wright *et al.*, 2013) documented that a five-metre-wide grassed ditch reduced phosphorus and sediment in surface runoff from the upland contributing area. In 2013, a hay field was extended into cropland that was within the upland contributing area. As noted in section 2.1.2, in October 2013, it was observed that the change in land management eliminated a concentrated flow path that had previously been used for monitoring. Monitoring was discontinued and attempts were made to observe flow versus no-flow at this field over time. The number of observations while the field was in hay was not sufficient to draw formal conclusions about the effects. Anecdotally, however, these observations suggest that conversion from cropland to hay may decrease flow potential during storm events.

Effect of Vegetative Cover around a WASCoB: Data from the WASCoB were analyzed to look at the effect of changes in land cover on runoff and water quality. When looking generally at the runoff coefficient (ratio of runoff volume to precipitation volume) and the presence or absence of flow (flow vs. no-flow data), it was found that flow was less likely to occur in the growing season than in the non-growing season. When the effect of crop type was considered in the non-growing season, corn residue and soybean residue produced higher runoff coefficients than other types of cover and were more likely to generate flow (runoff). In contrast, in the same season, oat cover crop produced the smallest runoff coefficient and flow was less likely to occur under oat cover than under other crop types. Regression equations were also developed for six different crop types. When precipitation, soil moisture conditions, and season were known, regression equation accuracies predicted the occurrence of flow/no-flow under corn, winter wheat, corn residue, and soybean residue reasonably well. These findings are summarized in Table 3.1.

Table 3.1 Summary of Effect of Vegetative Cover Results

Growing Conditions	Crop Type	n[3]	Mean Seasonal Runoff Coefficient[4]	Ratio of Flow to No-flow	Regression Equation Accuracy
Growing[1]	Corn	28	0.03	Less likely to generate flow*	87%
	Soybean	9	0.008	Equally likely to generate flow	
	Winter wheat	15	0.11	Equally likely to generate flow	87%
	Oat cover crop	5	0.003	Equally likely to generate flow	
	Corn residue	8	0.007	Equally likely to generate flow	
	Winter wheat stubble	3	No runoff	Equally likely to generate flow	
Non-Growing[2]	Corn	3	No runoff	Equally likely to generate flow	
	Oat cover crop	5	No runoff	Less likely to generate flow*	
	Corn residue	22	0.28	More likely to generate flow*	84%
	Soybean residue	25	0.26	More likely to generate flow*	81%
	No cover	1	0.02	Equally likely to generate flow	

1. Growing season is defined as May 1 to September 30.
2. Non-growing season is defined as October 1 to April 30.
3. n = number of rainfall events
4. Mean seasonal runoff coefficients include both runoff events and non-runoff events. Runoff coefficients greater than 1, due to snowmelt, were excluded from the table (including two corn residue, two soybean residue, and one no cover).
5. * indicates statistically significant flow.

Loads could be estimated for 19 of the 61 events that generated runoff. Water quality data were available for only these 19 events, as equipment periodically had to be removed from the fields to accommodate cropping activities and equipment occasionally malfunctioned, particularly during winter. Loads were estimated for nitrate-nitrogen, phosphate-phosphorus, total phosphorus, and suspended solids. For each parameter, once loads were standardized by their corresponding event runoff coefficients, they mostly tended to fit in a relatively narrow range;

however, there were events that resulted in exceptionally high loads. In some cases, these high loading events were attributable to antecedent conditions, intense storm events, or land management (*e.g.*, after fertilizer application), but in other cases, there was no clear reason. It was noted that more data at this site, and others, would help to identify patterns in loading from runoff.

3.1.3 Effectiveness of Water and Sediment Control Basins

The effectiveness of WASCoBs was evaluated on the basis of monitored reductions in peak flow and the difference between inflow and outflow loads. Reductions in the peak flow into and out of the WASCoB occurred on all but two occasions (59 out of 61 events). The reduction in peak flow ranged from 1 to 97% with a mean reduction of 31%. In general, the higher the runoff volume, the higher the percentage reduction in peak flow.

Inflow and outflow data were available for 14 events and it was found that there were statistically significant decreases in concentrations for phosphate-phosphorus, total phosphorus, and suspended solids. Nitrate-nitrogen loads did not show a statistically significant difference between the WASCoB inflow and outflow. Overall, this suggests that a WASCoB may reduce phosphorus and suspended solids loads in surface runoff.

3.2 Modelling Variable Source Areas

3.2.1 Ability to Simulate Critical Temporal Events (*e.g.*, spring runoff)

Of the five models used, only the SWAT and RSWMM are able to model temporal variability continuously (*e.g.*, daily or hourly). The AGNPS model can simulate temporal events as it is an event-based model that uses rainfall depth and duration. The GAMES model can be used to assess average conditions in each season, but is not sensitive to short-term fluctuations in conditions. The GIS model does not allow for simulation of temporal events because precipitation data are not among the model inputs. Key findings related to the ability of each model to simulate critical temporal events are summarized below:

- The SWAT is designed to operate on a daily time step and the model includes a snow cover and snowmelt component. An examination of the performance of the modelled river discharge showed that calibration statistics at monthly and daily time steps were within acceptable ranges established in the literature (Golmohammadi, 2016).

- The AGNPS model was calibrated with five events for which observed flow was available (Golmohammadi, 2016). Calibration statistics were presented for this model, but not discussed.

- The RSWMM can be set up to run continuously or for single rainfall events. As part of this study, it was run for a continuous period from April 2013 to June 2014. During model set-up, it was found that the model had a flooding and runoff error that would be considered relatively high. This issue aside, modelled water quality data were reported to show discrepancies when compared to the observations. In general, the model tended to underestimate the peak concentration and overestimate the duration of runoff events. When modelled water quantity data were compared with observed data, the model tended to overestimate flow rates (i.e., the model was conservative). It was also noted in the report that, for a year with minimal snow or multiple melts during the winter months, the program might not accurately model these conditions.

- The GAMES model provides insight into seasonal variations in the distribution of soil erosion and sediment yield by modelling watershed responses under spring, summer, and fall erosion indices. These indices are derived from information about the intensity and duration of storms based on geographic location. The model was calibrated with data from July 2010 to December 2011. Modelled output was not compared to observed data or other output from other models. This makes it difficult to assess the models performance.

- The GIS method is based on topographic characteristics derived from DEMs and other GIS inputs. It does not simulate events.

3.2.2 Ability to Identify Variable Source Areas

There were two principal ways that models were used to identify VSAs. The first was by comparing modelled flow/no flow data with the monitoring data (SWAT and AGNPS) and the second was by looking for areas with high potential to contribute runoff or sediment or nutrient loads (GAMES and GIS). The RSWMM model was not used to look at VSAs. Key findings related to the ability of each model to identify VSAs are summarized below:

- The calibrated SWAT was used to simulate streamflow at 16 monitoring points, upstream of GULGUL5, where flow/no flow data were collected on six dates between January 2013 and May 2014. For the simulation with the best results (delineation of the watershed into 99 subbasins) the SWAT was able to accurately predict flow or no flow for 64 of the 96 observations (66%). Overall, this comparison showed that the SWAT tended to overestimate flow events; however, the results are affected by changing the watershed delineation.

- Once calibrated, the AGNPS model was used to simulate streamflow at 18 flow/no flow monitoring points. Of the 169 observations, the AGNPS model was able to accurately predict flow or no flow for 123 (73%). The report did not discuss whether flow events tended to be over or underestimated.

- Variable source areas were not assessed with the RSWMM.

- The GAMES model results showed that the sediment yield rate is highest during spring, followed by summer, and is lowest during the fall. The mapped results indicated that that the average potential soil erosion rate was relatively small, although the potential erosion rate per unit area had a wide range. This model was reported to clearly identify to hot spot areas of soil erosion and sediment yield to streams, however, the model output was not compared to observations or output from other models.

- Of the 36 fields that ranked high for potential to contribute sediment or generate runoff from a SWAT model created in an earlier study (Simmons *et al.*, 2013), the GIS techniques identified 25 (or 69%) of them as high. The remaining 11 fields that ranked high from the SWAT model were ranked moderate by one or more of the GIS techniques. The GIS technique used to identify fields with a high potential for sheet erosion (PSE) had the most agreement with the SWAT model output, followed by the topographic index (TI) approach. The technique using proximity to a watercourse and slope yielded the poorest agreement.

3.2.3 Ability to Evaluate Strategic Placement of Best Management Practices

The SWAT, AGNPS model, and RSWMM are able to model a wide range of BMPs (including structural BMPs) and can be used to evaluate the effect of BMP placement. GAMES and the GIS model can identify areas were BMPs may be most beneficial (“hot spots”), but they are limited in terms of the types of BMPs that can be simulated. Key findings related to the ability of each model to evaluate strategic placement of BMPs are summarized below:

- The SWAT can be used to model a wide range of BMPs; however, in this assessment, the strategic placement of BMPs was not evaluated. It is relevant to note that the SWAT tended to overestimate the number of flow events, which suggests that the model may also overestimate the impact of certain types of BMPs. Interested readers looking at the strategic placement of BMPs are referred to earlier work documented in the synthesis report for the Watershed Based BMP Evaluation (WBBE), Huron (Simmons *et al.*, 2013).

- The AGNPS model can be used to model a wide range of BMPs; however, in this assessment, the strategic placement of BMPs was not evaluated.

- As mentioned in section 3.2.2, mapping soil erosion potential results provides insight into areas of the watershed that may be best suited to the implementation of BMPs; however, BMPs that can be modelled in GAMES are limited to changes in land use, and were not evaluated as part of this assessment.

- The focus of the RSWMM assessment was WASCoBs. Findings indicate that the model depicts that WASCoBs reduce the rate at which soil is transported, but do not appear to significantly decrease the overall quantity of eroded soil. The RSWMM assumes that, once soil is entrained in water moving across the landscape, it remains entrained until the outlet. The assessment also found that the RSWMM underestimates sand, silt, and clay loading from catchments that are not controlled by WASCoBs, and that the model is conservative in its estimates of the amount of rainfall attenuation that occurs as a result of WASCoB construction.

- When the GIS technique was applied, it was found that not every BMP proposed by the Tomer *et al.* (2013) framework is applicable to the Gully Creek watershed. With its undulating fields and steep ravine, the Gully Creek watershed does not offer opportunities for controlled drainage or a two-stage ditch, but it does offer other BMP opportunities. The first step in the framework, building healthy soils, applies to all fields.

3.2.4 Suitability for Use by Watershed Management Agencies

As shown above, modelling can be a useful tool for watershed managers as it can identify VSAs and locations for BMP implementation. However, with any model, conservation authority staff will need time to learn how it works and become comfortable with how to use it. In this study, the only model that was used directly by conservation authority staff is the GIS-based approach. This approach, used to identify where BMPs could be implemented, draws on tools and skills already available at many conservation authorities. The other models – SWAT, AGNPS, RSWMM, and GAMES (to a lesser extent) – can be used to assess the effectiveness of BMPs, but require specialized training. These models would likely only be suitable for use at a conservation authority level if modelling is conducted in partnership with researchers or modelling specialists.

3.2.5 Summary of Modelling Findings

Table 3.2 Summary of Modelling Results

	SWAT	AGNPS	GAMES	GIS	RSWMM
Ability to Simulate Critical Temporal Events (i.e., spring runoff – discharge and loading)	Can model temporal variability continuously (e.g. at daily or hourly level).	Can simulate temporal events as it is an event-based model, which uses rainfall depth an duration.	Can be used to assess average conditions, but is not sensitive to short-term fluctuations in conditions.	The GIS model does not allow for simulation of temporal events as precipitation data is not an input.	Can model temporal variability continuously (e.g. at daily or hourly level).
Ability to Identify Variable Source Areas	The SWAT model was able to properly predict flow or no-flow for 64 (66%) of the observations, however, SWAT tended to overestimate flow events.	The AGNPS model was able to properly predict flow or no-flow for 123 (73%) of the observations. The report did not discuss whether flow events tended to be over or underestimated.	The GAMES model identified areas of soil erosion and sediment yield to streams, however, the model output was not compared to observations or output from other models.	Of the 36 fields that ranked high for potential to contribute sediment or generate runoff from a SWAT model, the GIS techniques identified 25 or 69.4% of them as high.	Not used in its assessment to look at VSAs.
Ability to Evaluate Strategic Placement of BMPs	In this assessment, the strategic placement of BMPs within SWAT was not evaluated.	In this assessment, the strategic placement of BMPs within AGNPS was not evaluated.	BMPs that can be modelled in GAMES are limited, and were not evaluated in this assignment.	Highlight areas for BMPs, however, not every BMP proposed by the framework is applicable.	The assessment suggests that improvements are needed in how RSWMM models WASCoBs.
Suitability for Use by Watershed Management Agencies	Relatively complex, required partnership with experts.	Relatively complex, required partnership with experts.	Relatively complex, required partnership with experts.	Highly suitable.	Relatively complex, required partnership with experts.

3.3 Building Local Watershed Agency Capacity

3.3.1 Meetings and Conferences

As a result of education about this work provided by conservation authority staff to other practitioners and agencies, similar successful projects have been undertaken in several priority watersheds along the southeast shore of Lake Huron as part of the Rural Stormwater Management Model project and the Healthy lake Huron Project. More recently, the Ontario Soil and Crop Improvement Association implemented a Priority Subwatershed Project through the Great Lakes Agricultural Stewardship Initiative (GLASI). This program has allowed four additional subwatersheds, in the Lake Huron and Lake Erie basins, to undertake intensive BMP implementation and monitoring opportunities that may not have been available otherwise. Work completed in the Gully Creek watershed seemed to inform broader policy initiatives.

3.3.2 Monitoring Guidance Manual

One of the challenges of sharing knowledge with conservation authorities is that it takes time to disseminate information to interested agencies. The intention of the monitoring guidance manual was to expedite learning and the sharing of monitoring protocols with others. By producing a practical manual for watershed agency staff, knowledge was well documented, but there has been no feedback from recipient agencies and there is no way to ensure that best practices are followed in subsequent studies. One potential issue with distributing information this way is the difficulty in knowing if other agencies have found the information useful and applicable. In the future, this type of manual could be improved by applying a more collaborative approach of engaging other agencies that do this work to help develop the guidance manual.

3.4 Developing and Delivering Outreach and Education

3.4.1 One-on-one Landowner Meetings

In total, at least 17 one-on-one producer meetings took place. In many instances, staff met with the producers more than once during the study period. One of the anticipated challenges associated with one-on-one meetings was that producers would not have time to meet with ABCA staff. There were also concerns that producers may have had previous regulatory experience with the conservation authority and be unwilling to meet. In general, however, BMP opportunities were identified through these meetings and at least seven landowners went on to implement some of these projects. The meetings also created opportunities to monitor BMPs at the field scale.

3.4.2 Presentations to Agricultural and Community Groups

One of the key challenges with any workshop is ensuring that best management practices that are suggested are implemented, particularly if there are barriers to implementation. While most large groups appreciated the information presented, it did not appear to impact group members' mindsets or behaviors. In contrast, presentations delivered to smaller local groups, or individuals led to various actions taking place in the watershed, suggesting that this type of outreach can be beneficial provided it is targeted and timely.

3.4.3 Outreach to Municipal Drainage Engineers

Local drainage engineers were retained to use the RSWMM model as a pilot project to evaluate various BMP scenarios. The technical findings are discussed in section 3.2; however, outreach and education was another critical component of this exercise. The engineering sector was provided with a leadership opportunity to explore water management from a conservation perspective. By using modelling tools with which they were familiar, it was possible to engage local engineers in an exercise evaluating the effectiveness of BMPs.

Nevertheless, there remain barriers to drainage engineers becoming involved with watershed management. Traditionally, drainage approaches have tended to focus mainly on attempts to move water away from an agricultural field in a timely manner. Until there is some need to address water management from a more balanced approach of storage and transport, there may be few opportunities for the drainage community to be involved in watershed management. Another ongoing issue is that there are fundamental modelling challenges with using the RSWMM in a rural setting (*i.e.*, representation of agricultural land use). This could be addressed by continuing efforts to adapt the PCSWMM for use in rural watersheds; however, the feasibility and practicality of undertaking such efforts needs further investigation.

3.4.4 GIS Modelling and Property Drain Walks

Few landowners agreed to BMP implementation immediately as a result of the modelling results and property drain walks. However, many chose to call on the conservation authority for implementation assistance in the months following the visits.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary of Findings

The major findings of this New Directions study, which was undertaken to provide insights on agricultural water management models that predict VSAs, are categorized by the four study objectives below.

Objective #1: Monitor one watershed to identify the sources of runoff in a watershed and to quantify the effect of management practices, such as grassed areas and Water and Sediment Control Basins (WASCoBs) on the quantity and quality of water from VSAs.

- It was difficult to monitor improvements in water quality over time; however, monitoring how frequently areas are contributing (*i.e.*, flow versus no-flow monitoring data) may provide a good measure of improvements in water quantity due to management practices.
- Our anecdotal findings at the field edge that highlighted the importance of management activities corresponded with current literature (Tomer et al. 2013) that also recommended management actions were fundamental to flow generation in the first instance.
- Changes in water flow over multiple fields throughout a watershed are difficult to capture with traditional monitoring techniques. Likewise, it was difficult to measure the effectiveness of the other management practices, cover crop, nutrient management, and conservation tillage at the field-edge or watershed scale, however, monitoring WASCoB inflow and outflow "in-field" showed promise as a method of monitoring the effect of vegetative cover on runoff quality and quantity.

Objective #2: Develop and evaluate rural water management models that identify sources of runoff in an agricultural watershed.

- Five different models were assessed that can be used to identify sources of runoff in an agricultural watershed. SWAT and AGNPS can be used to simulate critical events, identify VSAs based on flow/no-flow, and evaluate the strategic placement of BMPs, however, they require a great deal of modelling expertise and input data. On the other hand, simple models like the GIS approach are limited in terms of simulation capabilities but can be used by watershed mangers to identify areas to target for BMP implementation reasonably well.
- SWAT tended to overestimate the number of flow events at various points in the watershed. Might this observation have some implications for how SWAT measures the effectiveness of BMPs?

- Collecting and managing the required field data required to calibrate and validate more complex models (e.g. SWAT and AGNPS) could be challenging and allocating the resources required is difficult for one agency but will be necessary.
- Overall, models ranged in terms of complexity, input data required, and type of information obtained. There may not be one right model for all situations and the information obtained in this study may help watershed managers choose the right model for their needs based on the model characteristics and desired output.

Objective #3: Build capacity in a local watershed agency to predict VSAs and to work with landowners in the management of the VSAs.

- Models that can be used by the conservation authority, such as the GIS framework, are more likely to be used at the conservation authority level and output from models can be used to conduct outreach with landowners. This was demonstrated by the GIS modelling and field walks conducted in Gully Creek and neighbouring watersheds.
- Creating monitoring guides provided a valuable means of documenting successful approaches to conducting research predicting VSAs, however, more collaborative approaches will be important so that all agencies are learning.

Objective #4: Develop and deliver outreach and education to multiple agricultural stakeholders about a model that identifies VSAs and determines the effect of water management practices, such as grassed areas and WASCoBs, on the amount and quality of stream flow.

- The conservation authority successfully reached out to multiple stakeholders regarding the findings of this study and other similar work. Generally, information presented locally to small groups led to more behaviour and attitude changes than when presented to larger groups. This highlights the importance of targeted outreach.
- Since 2015, there has been significant policy changes to encourage landowners to work with their certified crop advisors to develop management solutions to soil erosion problems (*e.g.* GLASI, etc.).

4.2 Recommendations and Research Opportunities

The following table presents recommendations and future research areas for policy makers, researchers, and practitioners in this field.

Table 4.1 Research Opportunities

Research Opportunity	Rational	Stakeholders
Monitoring: Collect longer term (> 2 years) water quality and quantity data in WASCoBs under various crop type and land management scenarios.	Additional data is required to understand the effect of crop type on VSAs. It was easier to capture water samples at WASCoBs then at edge of field and changes may also be identified more easily at this scale then at the watershed scale.	Conservation Authority
Monitoring/Modelling: Deploying additional divers at monitoring station in the watershed to verify flow/no-flow from models.	This study relied on visual observation to verify the modelled flow/no-flow data. Divers would enable more data to be collected for verification. This will help to assess the models performance at identifying VSAs.	Conservation Authority Researchers
Modelling: Conduct further investigation into the overestimation of flow events in models such as SWAT.	These models are frequently used to evaluate the effectiveness of BMPs and if they overestimate flow events, they may diagnose the effectiveness of BMPs inaccurately.	Government Researchers
Modelling/Outreach: Extend GIS modelling to other areas and continue to verify the results, through engagement with landowners on “Creek Walks”.	This will improve watershed managers understanding of the advantages and limitation of the GIS model. These opportunities can also be used to present BMP opportunities to landowners.	Conservation Authority Landowners
Outreach: In addition to “Creek Walks” implement a standardized survey tool for documenting landowner landuse and agricultural activities.	Comprehensive information will help to inform future monitoring and modelling exercises.	Certified Crop Advisors Conservation Authority
Outreach: Develop experiential learning programs that allow watershed mangers to run monitoring programs in their own watersheds.	There were limits to how extensively monitoring guidance documents were applied and watershed managers need/want to learn experientially.	Government Agencies Conservation Authority

4.3 Conclusion

As concerns about resurgence of eutrophication and nearshore algal fouling continue, there is an ever-increasing need to address agricultural non-point source pollution. Identifying VSAs and helping watershed managers and producers strategically locate BMPs is an important part of addressing this issue. This study has shown that monitoring, modeling, and outreach advancements will continue to improve the way that VSAs are identified and that BMPs are implemented. It will be critical to continue to monitor WASCoBs, as this study has demonstrated that the effect of land management changes can be measured at this scale. This additional monitoring data will help to develop models that better predict flow/no-flow from VSAs, which will be important in watersheds where intensive monitoring cannot be undertaken.

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APPENDIX 1: Potential Stakeholders and Outreach and Education Opportunities

Stakeholder	Approach	Benefits	Further Considerations
Landowners	One-on-one Extension - Conservation Authority (CA)	CA staff understand watershed implications of practices and can suggest meaningful approaches to address potential water quality issues. Experienced CA staff can usually bring agronomic considerations into the discussion.	Producer might not have time to meet with CA staff for only an environmental assessment. Producer might have had previous regulatory experience with CA.
	One-on-one Extension – Certified Crop Advisors (CCA)	Some farmers already take cropping advice from the CCA.	CCA might lack understanding of watershed processes. Sometimes in the employ of the agricultural input suppliers, there is the potential for a conflict of interest.
	Workshops	Provides information to many producers. Attendees often request further extension.	Producer may not have time to take a workshop. Approaches learned may not get practiced if there are other more specific barriers.
	Presentations	Shares information to many Producers.	
Conservation Authority Monitoring Technicians	Meetings	Technical assistance to explain field methods and results.	
	Share Stream Monitoring Manual	Learning details of the installation and operation of the equipment can be expedited.	

Stakeholder	Approach	Benefits	Further Considerations
	Monitoring – Management Practices	A comprehensive survey tool that documents past and planned planting, harvesting, and tillage practices. Windshield survey that documents crops and tillage practices.	Surveys take producer time. To identify actions the planting, harvesting and tillage practices identified in the survey or windshield survey needs to be translated by an agronomist.
Researchers	Meetings	Meeting three times per year gives an opportunity for practitioners and researchers review collected data and provide guidance on next steps for data collection or interpretation	
Drainage Community	Pilot project	Provided an important sector with a leadership opportunity to explore water management from a different perspective	

- This is not a complete table of all the potential stakeholders that might be involved, but stakeholders that were engaged with the ABCA from October 2013 to January 2015.