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SWAT Modelling of Agricultural BMPs and Analysis of BMP Cost Effectiveness in the Gully Creek Watershed

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Executive Summary

The Gully Creek watershed, in the service area of the Ausable Bayfield Conservation Authority (ABCA), is a representative lakeshore watershed of the Lake Huron Basin. It has an undulating landscape and is dominated by agricultural landuse activities. Evident sediment and nutrient transport from these lakeshore watersheds has become one of the major identified concerns to near shore water quality. In response to these growing concerns over the role conventional agricultural practices may be playing in contributing to the degradation of water quality, farmers, conservation authorities and governments have worked together to promote and implement best management practices (BMPs) - farm practices that focus on maintaining agricultural productivity and profitability while protecting the environment. Examples of BMPs include conservation tillage practices, nutrient management planning, the use of cover crops, and the construction of Water and Sediment Control Basins (WASCoBs). Historically, best management practices have been evaluated at a plot, individual, or a field scale to assess their effectiveness, and to support them being called BMPs. Less effort has been undertaken to evaluate their individual or combined effects at a watershed scale.

In 2010, the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) established the Watershed Based BMP Evaluation (WBBE) project. The Gully Creek watershed, along with the Zurich and Ridgeway watersheds were selected as study sites for the WBBE program. By building upon ABCA's previous BMP initiatives and monitoring program, the WBBE program invested in establishing monitoring systems for evaluating existing and newly-established BMPs in the study area, primarily conservation tillage, nutrient management planning, cover crops, and WASCoBs. With a monitoring system in place, the potential was then established to assess BMP impacts at a watershed scale using a modelling approach. Modelling would enable the simulation of watershed processes and BMP effects over a broader range of climate conditions than could be observed within the study duration.

The overall purpose of the modelling component of the study was to adapt the Soil and Water Assessment Tool (SWAT) to examine the water quantity and quality effects of BMP implementation in the Gully Creek watershed. SWAT modelling results were also combined with on-farm economic results to examine BMP cost effectiveness. Specifically, the project had four interrelated objectives:

1) Adapt and set up SWAT for the Gully Creek watershed;
2) Calibrate and validate SWAT to fit into the Gully Creek watershed conditions;
3) Apply the SWAT to examine water quantity and quality effects of various BMP implementation scenarios in the Gully Creek watershed;
4) Examine the cost effectiveness of BMPs.

The SWAT adaptation involved development of a WASCoB module, and modification of SWAT parameters for small lakeshore watershed conditions. The SWAT model setup made use of existing available datasets including a detailed LiDAR-derived DEM, a six-year field-truthed landuse map, soils mapping, hydrography mapping and monitoring locations, WASCoB characterization and location information, local climate data (precipitation and temperature), and detailed crop management information (planting, harvest and tillage dates, fertilizer application rates, etc.). These detailed datasets were acquired from a variety of sources including OMAFRA, Environment Canada, ABCA and through local landowner interviews. The BMPs of special interest, due to their level of adoption in the watershed, included conservation tillage, the implementation of nutrient management planning recommendations, red clover cover crop following winter wheat, and WASCoB construction. SWAT was calibrated and validated using field-measured flow and water quality data at in-stream and field-edge stations. A reasonable model performance was achieved.

The calibrated and validated SWAT model was applied to simulate watershed processes and examine the water quantity and quality effects of various scenarios. Under current field conditions, Gully Creek watershed has a runoff coefficient 0.55, an average sediment loading 3.7 T/ha/yr, an average total nitrogen (TN) loading 31.9 kg/ha/yr, and an average total phosphorus (TP) loading 4.1 kg/ha/yr. The majority of TN loading is in dissolved form but the majority of TP is in particulate form. These characteristics are typical of lakeshore small watersheds in the Lake Huron Basin.

The SWAT model was also set-up to simulate 1978 landuse and management practices in the watershed. In comparing the SWAT run using 1978 crop types and land management with SWAT output under the existing watershed conditions, current practices (the existing scenario) were estimated to be producing just slightly more sediment loading and significantly more nitrate loading. This finding suggests that the natural evolution of agriculture, driven by changing market demand and technological advances in agriculture may be contributing to increased water degradation in recent years.

Of the three land management (agronomic) BMPs evaluated specifically in this study, conservation tillage ranks highest in reducing sediment and TP, but it causes increasing dissolved N loss and, overall, has a minimal TN reduction effect. Cover cropping ranks second in terms of sediment and TP reduction potential, and ranks first in TN reduction potential. Nutrient management planning had the lowest estimated effect on pollution reduction due to the fact that watershed farmers, in most cases, were close to current fertilization application recommendations, leaving limited room for further nutrient reduction without an expected decline in production and profitability. The aggregated effects of three land management BMPs were found to be smaller than the sum of the effects of the individual BMPs.

The WASCoBs as a structural BMP have a pronounced positive effect on reducing sediment, TN, and TP loadings, which are comparable to conservation tillage and cover cropping and were somewhat effective in reducing both particulate and dissolved nutrients. The WASCoBs reduce erosion in channels immediately downstream of the WASCoB sites and also the main channel. They were also found to be the least cost effective practice considered.

For the study area, it was observed that agricultural BMPs exhibit clear spatial patterns in terms of their effectiveness in reducing sediment and nutrient loadings. Typically, land management BMP implementation in the upper portion of the watershed was seen as more effective. The WASCoBs are more effective in sediment and nutrient reduction downstream of the channel network due to their cumulative impacts on water flow in downstream drainage ways. Placement of WASCoBs in high sediment and nutrient generation areas is also more effective. A joint analysis of on-farm economic results and SWAT output shows a spatial pattern of cost effectiveness different from that of BMP costs or water quantity/quality effects. These patterns indicate the importance of spatial targeting of BMPs for water quality improvement and cost effectiveness.

The SWAT modelling efforts and joint analysis of on-farm economic modelling and SWAT modelling outputs indicate that modelling can be an effective way in examining the effects of BMPs. Modelling can be used to expand our thinking to examine the impacts of various BMP scenarios. However, the accuracy of the modelling results is highly dependent on the quality and detail of the input data, the model structure, its calibration and validation, and other factors. Long-term monitoring data and more detailed input data are very important for reducing model uncertainties. This suggest more investments on watershed data collection and continuous monitoring of BMP effects, particularly field-edge monitoring. With various uncertainties, the usefulness of modelling results can be judged by magnitudes and directional correctness. The relative magnitudes of spatial allocation of BMPs may provide helpful references for targeting BMPs at specific locations for water quality improvement in agricultural watersheds.

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1.0 INTRODUCTION

1.1 Project Background

The Gully Creek watershed, in the service area of the Ausable Bayfield Conservation Authority (ABCA), is a representative lakeshore watershed of the Lake Huron Basin. It has an undulating landscape and is dominated by agricultural landuse activities. Evident sediment and nutrient transport from these lakeshore watersheds has become one of the major identified concerns to near shore water quality. In response to these growing concerns over the role conventional agricultural practices may be playing in contributing to the degradation of water quality, farmers, conservation authorities and governments have worked together to promote and implement best management farm practices that focus on maintaining agricultural activity and farm profitability while protecting the environment (called "Best Management Practices" or BMPs). Examples of BMPs include conservation tillage practices, nutrient management planning, the use of cover crops following crop harvest, and the construction of Water and Sediment Control Basins (WASCoBs). The magnitude and extent of the water quantity and quality benefits of these BMPs (such as sediment and nutrient reductions possible with their implementation), however, are not readily quantifiable. Understanding the cost effectiveness of these practices would be valuable for both the landowner and society when deciding what practices are most cost effective in meeting both agricultural production and environmental goals.

In 2010, Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) established a Watershed Based BMP Evaluation (WBBE) program. The Gully Creek watershed, along with the Zurich and Ridgeway watersheds were selected as the study sites for the WBBE program. By building upon ABCA's previous BMP initiatives and monitoring program, the WBBE program invested in establishing monitoring systems for evaluating existing and newly-established BMPs in the study area – primarily conservation tillage (Chisel plough or vertical tillage in fall after corn and no-till practices following soybeans and wheat), cover crops, and WASCoBs. With a monitoring system in place, the BMP effects could possibly be assessed at the watershed scale. A modelling component was also built into the project to simulate watershed hydrologic and nutrient fate processes under a broader range of climate conditions than could be observed over the study duration. The calibrated model was then used to examine the water quality effects of various BMP practices and combinations present or possible in the watershed. The hydrologic modelling outputs were combined with on-farm economic modelling results to evaluate the cost effectiveness of the BMP scenarios.

1.2 BMP implementation and monitoring initiatives

The ABCA has been working for many years with landowners in its jurisdiction to implement BMPs. With investment from the OMAFRA WBBE program, ABCA enhancements on BMP implementation and monitoring focused on three key Lake Huron shoreline watersheds: Gully Creek, Zurich, and Ridgeway. In each of these watersheds, ABCA staff encouraged landowners in the area to adopt BMPs to potentially reduce P loading. They also built an enhanced site-scale and watershed-scale monitoring program to assist with measuring the effects of the BMPs implemented on water quality and quantity.

The Gully Creek watershed was selected as the focus watershed for modelling BMP effects. In the watershed, landowners were contacted to discuss their current practices and identify potential opportunities for further BMP implementation. Four BMPs in common use by landowners in the area, conservation tillage, nutrient management planning, red clover cover crop after winter wheat harvest, and WASCoB construction were all studied more intensely. The study also set up a more intense water monitoring program, both near the watershed outlet at Highway 21 and two (2) in-stream upper watershed station locations. Field-edge monitoring at selected locations where the four key BMPs being considered were implemented was also undertaken over the course of the study.

1.3 Project objectives

The purpose of the modelling component of the WBBE project was to adapt the Soil and Water Assessment Tool (SWAT) to examine the water quantity and quality effects of BMP implementation in the Gully Creek watershed. SWAT modelling results were also combined with on-farm economic results to examine BMP cost effectiveness. Specifically, the project had four interrelated objectives:

1) Adapt and set up the SWAT for the Gully Creek watershed;
2) Calibrate and validate the SWAT model to represent the Gully Creek watershed conditions;
3) Apply the SWAT to examine water quality benefits of various BMP implementation scenarios in the Gully Creek watershed; and
4) Examine the cost effectiveness of BMPs.

2.0 STUDY AREA

2.1 Location

The Gully Creek watershed is representative of a series of small watersheds located along the shoreline of Lake Huron (Figure 2-1). The watershed covers 14.3 km^2 within the larger North Gullies study area, and is located in northwest portion of the ABCA service area. The township of Goderich and Clinton are located 14 km north and 10 km east of the watershed, respectively. Similar to other lakeshore streams, Gully Creek discharges directly into Lake Huron, thus having the potential to directly influence near shore water quality. The watershed has been classified as an Environmentally Sensitive Area (Brock et al., 2010; Veliz et al., 2006).

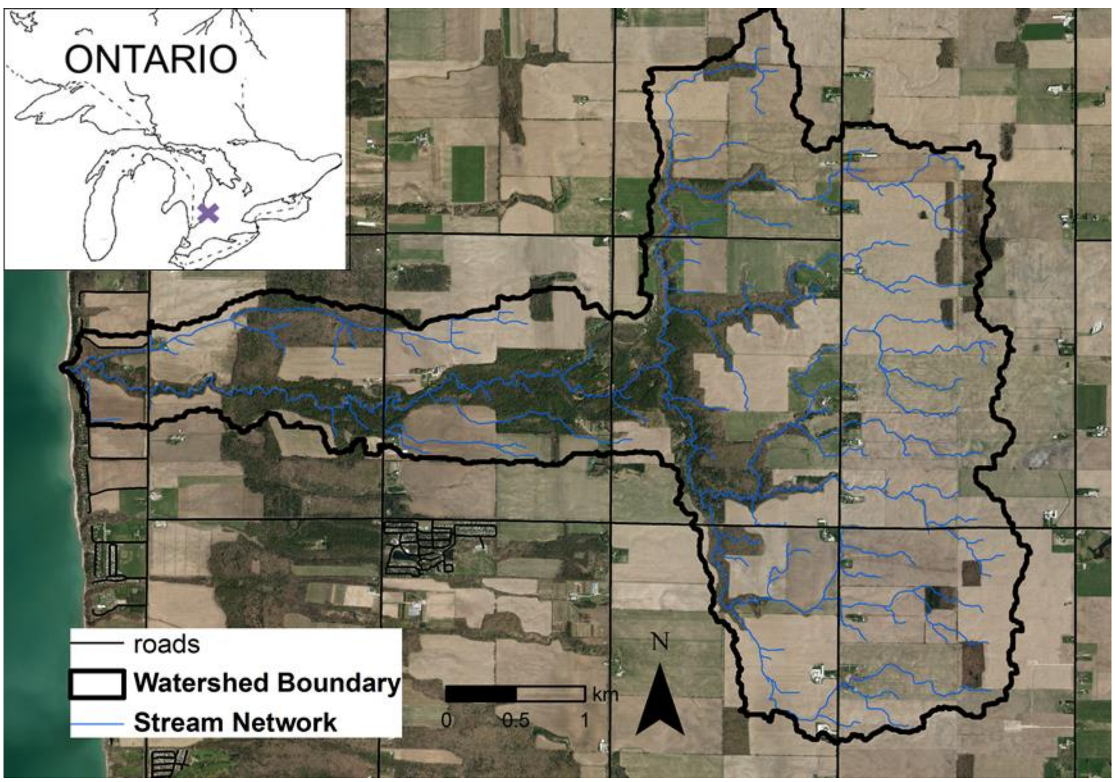


Figure 2-1: Gully Creek watershed located in Ausable Bayfield Conservation Authority

2.2 Topography, soil and landuse

The Gully Creek watershed has an undulating terrain, typical of the small lakeshore watersheds that outlet along Lake Huron's eastern shore (Figure 2-2). Land elevations of the watershed range from 176 to 281 m (Figure 2). The average slope in the watershed is 6% with a minimum of 0% in flat areas and as high as 95% in incised gully areas (typically greater than 9% in riparian areas).

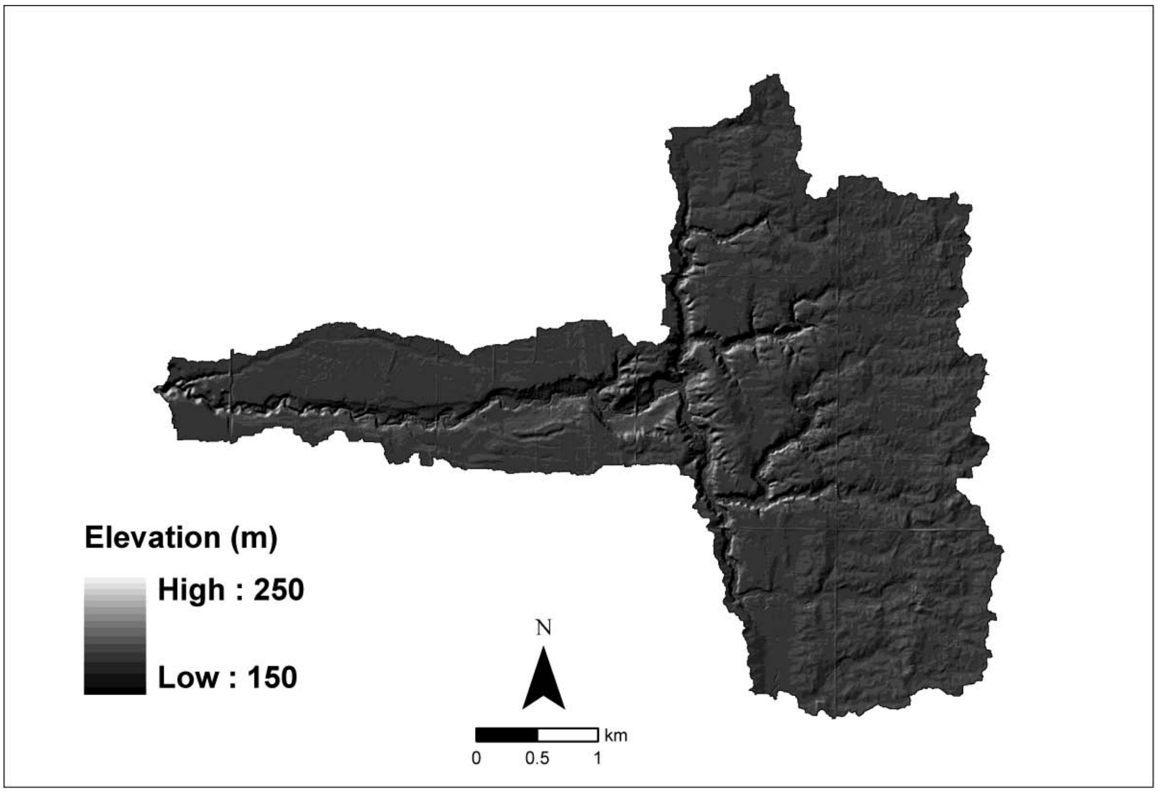


Figure 2-2: Topography of Gully Creek watershed (Source data: OMAFRA, 2012)

The map of soil type distribution according to the soil classification system of the Canada-Ontario Soil Survey for Huron County is shown in Figure 2-3. The soil name and areal extent corresponding to each soil code within the Gully Creek watershed are presented in Table 2-1 (see also Appendix A-1). In the upper reach area, the landscape is rolling and clay loam is the dominating soil. The low reach area is flat with a greater proportion of sandy loam soil.

Table 2-1: Soil types and areal extent of the Gully Creek Watershed

Code	Soil type	Area (km^2)	Area (%)
HUO	Huron Clay Loam	8.19	57.42
BAY	Brady Sandy Loam	1.79	12.51
BKN	Brookston Clay Loam	1.51	10.59
ZAL	Bottom Land	1.37	9.62
PTH1	Perth Clay Loam	1.05	7.33
BUF	Burford Loam	0.36	2.53
Total		14.27	100

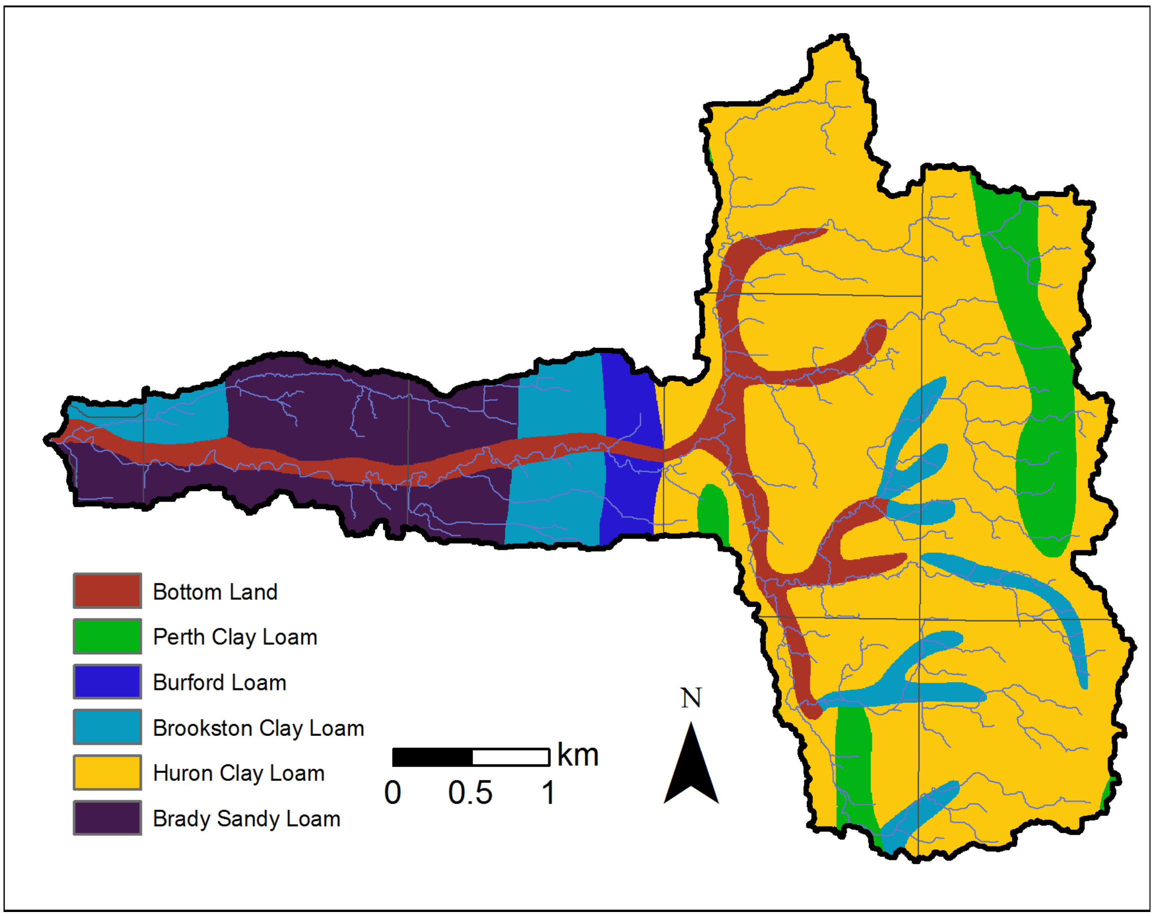


Figure 2-3: Soil types in the Gully Creek watershed (Source data: OMAFRA soil GIS database)

Crop and landuse distribution within the Gully Creek watershed for the year of 2011 is shown in Figure 2.4. The landuse names and associated area and percentage within the Gully Creek watershed are listed in Table 2-2 (see also Appendix A-1). About 70% of the land is agricultural and 25% is natural vegetation, including trees, shrubs and grasses. This natural vegetation primarily buffers the main channel. Corn, soybean and winter wheat are the main three crops grown in the watershed.

Table 2-2: Landuse and areal extent of the Gully Creek watershed in 2011

Category	Name	Area (ha)	Percent (%)	Sub-Total (ha)
Agricultural	Corn	345.98	24.25	1001 ha (70%)
	Winter Wheat	266.24	18.66	
	Soybean	345.83	24.23	
	Hay	23.08	1.62	
	Barley	7.17	0.50	
	Pasture	13.68	0.96	
Grasses	Grass	12.00	0.84	20.35 ha (1.4%)
	Tall Fescue	6.89	0.48	
	Roughland	0.80	0.06	
	Wetland	0.65	0.05	
Forest	Orchard	1.87	0.13	343.7 ha (24%)
	Deciduous	53.46	3.75	
	Coniferous	15.60	1.09	
	Forest Mixed	272.80	19.12	
Other	Water	15.01	1.05	60.94 ha (4%)
	Urban	37.19	2.61	
	Transportation	8.74	0.61	

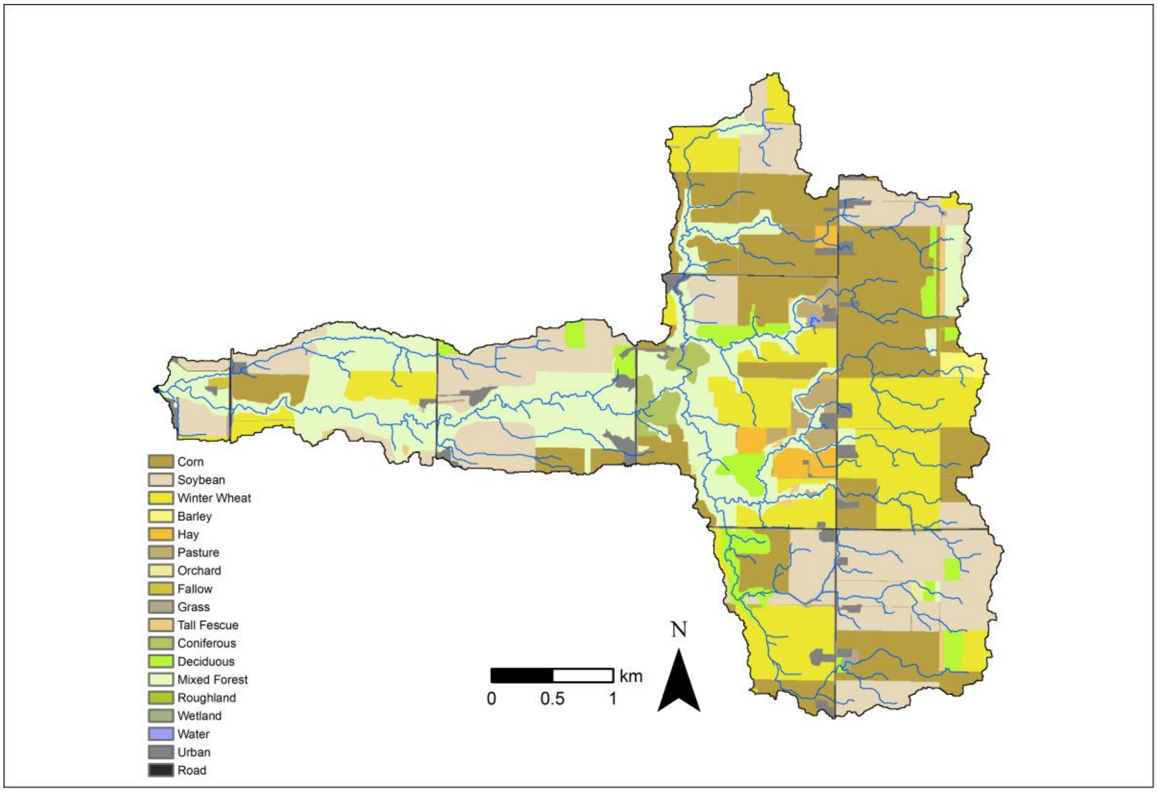


Figure 2-4: Landuse in Gully Creek watershed in 2011

2.3 Climate and Hydrology

A weather station was setup in the Gully Creek watershed in April 2011 and data from this station was used to provide climate input for the model calibration and validation component of the study. Climate data from nearby stations were also used to develop a synthesized climate series covering a broader period from January 2001 to March 2012.

The Gully Creek watershed has a climate with pronounced seasonal variations. The growing season begins in the middle of April and ends in late October with an annual average of 160 frost free days. Approximately 60% of the observed precipitation occurs primarily as rainfall from April to October while the remainder falls as snow and sometimes rain during the five winter months. The average annual observed precipitation (Py) was 1,055 mm over 2001 - 2011 with a standard deviation of 165 mm. The maximum annual precipitation of 1,416 mm occurred in 2008, and the minimum was 811 mm, occurring in 2007. The maximum daily precipitation (Pmax) is 86 mm, recorded on

September 25, 2005. The average annual temperature (Ty) is 7.7 °C and ranged from 9.0 °C (2001) to 6.6 °C (2008) with a standard deviation of 0.8 °C. In 2011 annual precipitation (Py) was 1,162 mm, and the measured annual runoff was 779 mm, giving a runoff coefficient of 0.66.

A summary of monthly average precipitation (Pm), temperature (Tm), discharge (Qm) and runoff (Rm) for the Gully Creek watershed from September 2010 to March 2012 (based on the period with flow data at GULGUL2 station) is presented in Table 2-3. A graphical presentation of monthly precipitation, temperature and runoff for the Gully Creek watershed over this period is shown in Figure 2-5.

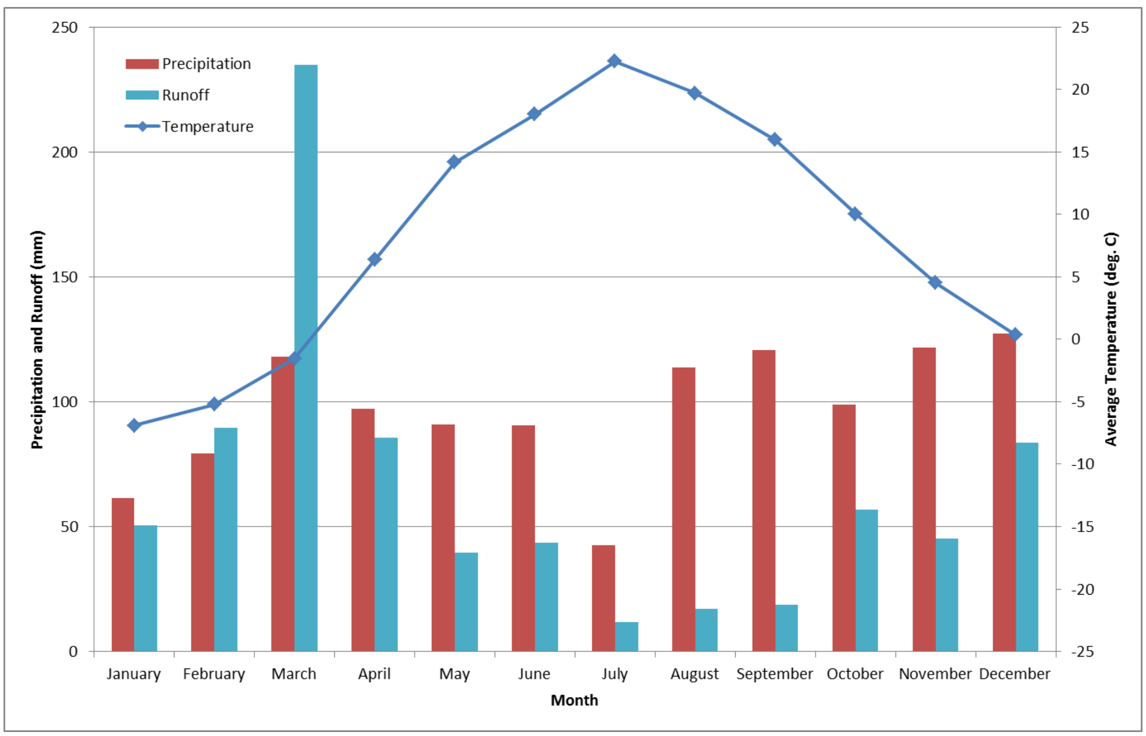


Figure 2-5: Monthly distribution of measured precipitation, temperature and runoff in Gully Creek watershed in 2011

Table 2-3: Monthly measured precipitation, temperature and runoff in Gully Creek watershed

Month	Year	P_m (mm)	T_m (°C)	Q_m (m^3/s)	R_m (mm)	$R_m/\Sigma R_m$ (%)	R_m/P_m (%)	$R_m/\Sigma P_m$ (%)
September	2010	108	15	0.070	14	1.30	13.1	0.82
October	2010	74	10	0.087	18	1.67	24.7	1.05
November	2010	94	4	0.110	22	2.04	23.8	1.29
December	2010	113	-4	0.248	52	4.78	46.3	3.02
January	2011	61	-7	0.239	50	4.61	82.1	2.92
February	2011	79	-5	0.471	90	8.18	113	5.18
March	2011	118	-2	1.114	235	21.4	198	13.6
April	2011	97	6	0.421	86	7.83	88.4	4.96
May	2011	91	14	0.188	40	3.62	43.6	2.29
June	2011	90	18	0.214	44	3.99	48.3	2.52
July	2011	43	22	0.056	12	1.07	27.5	0.68
August	2011	114	20	0.082	17	1.57	15.1	0.99
September	2011	121	16	0.092	19	1.71	15.5	1.08
October	2011	99	10	0.270	57	5.20	57.6	3.29
November	2011	122	5	0.222	45	4.13	37.0	2.61
December	2011	127	0	0.397	84	7.63	65.7	4.83
January	2012	96	-2	0.497	105	9.57	108	6.05
February	2012	41	-1	0.270	53	4.85	130	3.07
March	2012	43	7	0.280	53	4.81	124	3.05
Average		91.1	6.7	0.280	58	5.26	66.5	3.33

Temperature has a symmetrical distribution with higher values in summer from June to August, and low values in winter. However, the monthly flow and precipitation distribution is highly asymmetric. Monthly runoff peaks in March (21.4% of the total runoff in 2011) because of snowmelt. Low or no flow happened at Highway 21 station in summer season from July to September (1.07%, 1.57% and 1.71% of the total runoff in 2011) because of the high evapotranspiration and low soil moisture content during the summer period. There is no clear correlation between rainfall and runoff in the Gully

Creek watershed as indicated in Table 2-3 and Figure 2-5. Baseflow is an important portion of the total runoff (about 55% in 2011 based on flow separation analysis using SWAT tool), which provides contribution to the total runoff at the watershed outlet (Figure 2-6).

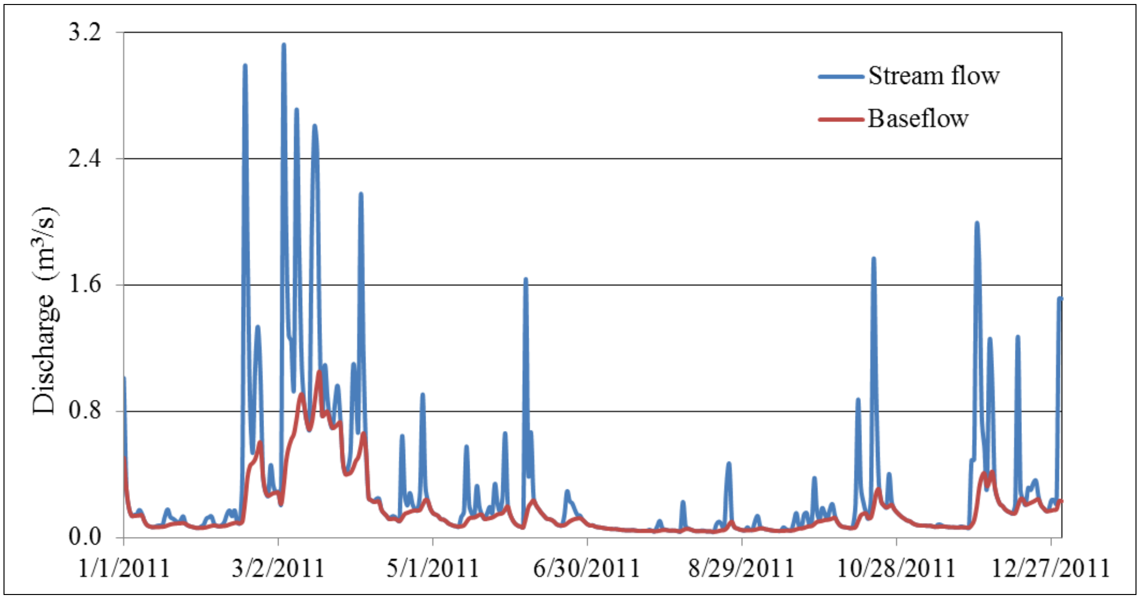


Figure 2-6: Baseflow separation at station GULGUL2 of the Gully Creek watershed in 2011

3.0 DATA COLLECTION AND PREPARATION

3.1 GIS data

Geospatial data required for SWAT setup include topography, soil, landuse, stream networks and others. These data were prepared using the available data from OMAFRA, Ontario Ministry of Natural Resources (OMNR), and ABCA.

Table 3-1: GIS data available for Gully Creek watershed

Name	Type	Source	Description
Topography	raster	OMAFRA, 2012	5×5 m LiDAR DEM
Soil	shape	OMAFRA soils GIS	Soils Ontario
Landuse	shape	OMAFRA, 2009-11	Agricultural Resources Inventory
		ABCA, 2012	Landowner and Windshield Survey
		MNR, 2007	Land Cover Information System (ELC)
Stream network	shape	ABCA	
Berms	shape	OMAFRA, 2012	(unpublished)
Transportation	shape	MNR, 2006	Ontario Road Network 2005

3.2 Climate data

Weather data required for SWAT setup include precipitation and temperature at a daily scale. Temperature data were used to calculate Potential Evapotranspiration (PET) in SWAT using the Hargreaves equation. A weather station was setup for the WBBE project in April 2011. A synthesized climate dataset was developed based on similar climate pattern in the various available datasets from Gully Creek, Varna, and London stations (Table 3-2). The climate data collected at Exeter and Goderich were not used in the model simulation in this study as they showed a distinct difference when compared against climate measurements taken at the Gully Greek watershed for the period from April 29, 2011 to March 28, 2012. The locations of these stations considered for climate data relative to the study area are shown in Figure 3-1.

Table 3-2: Climate data collected for the Gully Creek watershed

Station	Start Date End Date	Latitude	Longitude	Frequency	Notes
Gully Creek ABCA	April 29, 2011 March 28, 2012	43°36'53" N	81°40'52" W	Hourly	No snow data
Varna Enviro. Canada	April 6, 1989 March 31, 2012	43°33'4" N	81°35'22" W	Hourly	No snow data
London Enviro. Canada	July 1, 1940 July 19, 2012	43°01'59" N	81°09'04" W	Daily	Includes snow data
Exeter Enviro. Canada	Feb 1 , 1961 April 15, 2008	43°21'00" N	81°30'00" W	Daily	Includes snow data
Goderich Enviro. Canada	Dec. 30, 1994 July 19, 2012	43°45'00" N	81°42'00" W	Daily	Includes snow data, Missing Jan, Feb, Mar, Dec 01 - 04

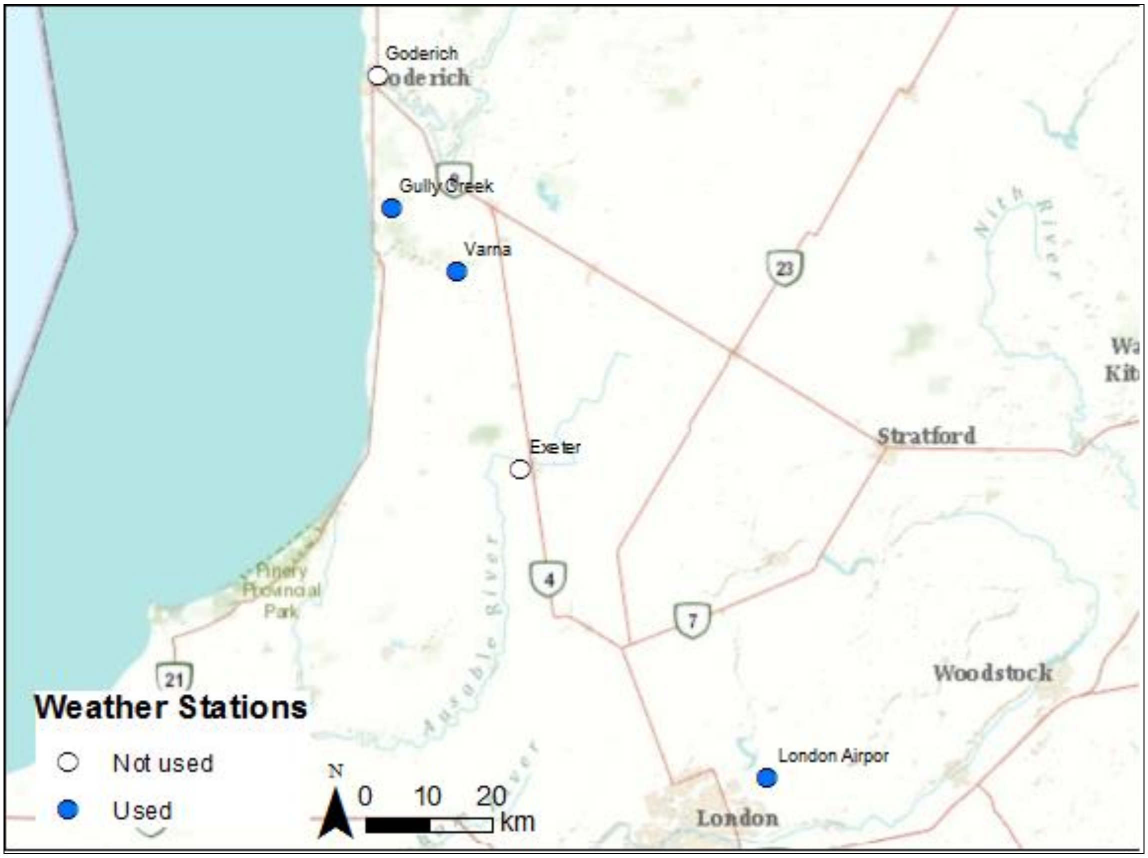


Figure 3-1: Location of precipitation and temperature stations

3.3 Flow and water quality data

Data used in SWAT calibration and validation included stream flow (discharge), sediment loading, and nutrient (P and N) loading at a daily scale. These data were prepared using data collected by ABCA from various monitoring points within the study watershed (Table 3-3). The locations of these stations are shown in Figure 3-2.

Table 3-3: Flow and water quality data available for the Gully Creek watershed

Name	Description	Drainage Area (km^2)	Flow (year)	Sediment (year)	Nutrient (year)
GULGUL2*	Main Branch	12.71	2010-2012	2010-2012	2010-2012
GULGUL3*	Main Branch	0.900	2011	2011	2011
GULGUL4*	Headwaters	0.470	---	2011	2011
GULGUL5*	Headwaters	10.56	2011	2011	2011
ETTILE1	Tile Drain		---	2011	2011
ETTILE2	Tile Drain		---	2011	2011
ETRUNOFF1	Field		---	2011	2011
BBCULV1	Culvert		---	2011	2011
BBTILE1	Tile Drain		---	2012	2012
BBFIELD1	Edge of Field		---	2012	2012
KVBAY-IM	WASCoB Inlet		---	2012	2012
KVBAY-HB	WASCoB Hickenbottom		---	2012	2012

Note: Stations with asterisks were used for calibration.

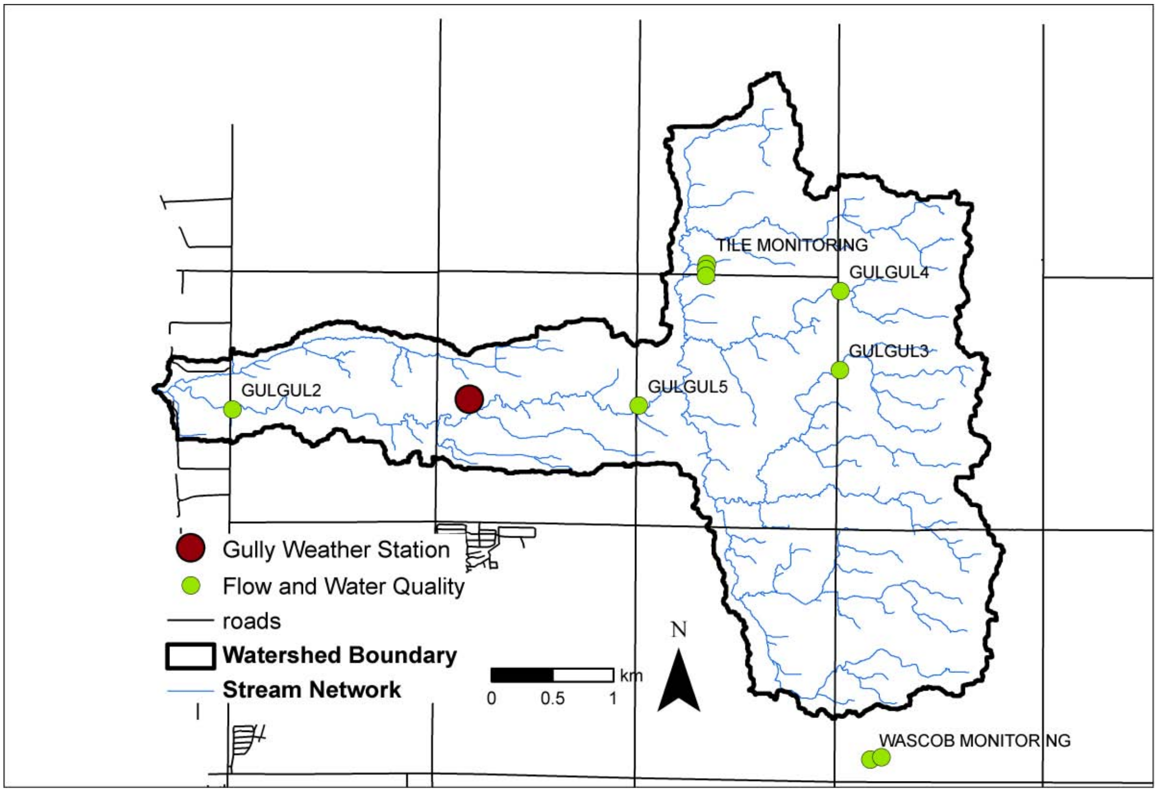


Figure 3-2: Locations of flow and water quality stations

3.4 Land management data

Under the WBBE program, the ABCA conducted a land management survey in March 2011. The survey included collecting land management data for the 2008, 2009, 2010 historical years and also included a forecasting of the crop production plans for 2011, 2012, and 2013 crop years. The survey data were compared with 2009, 2010, and 2011 agricultural inventory (AgRI) field-observed data collected by OMAFRA. AgRI data were collected from field reconnaissance and may be more accurate than survey data, particularly for the forecast (2011-2013) crop years as they observed what was actually growing in the fields at the time of the survey. Together, both datasets acted as confirmation or checks for the other data source. OMAFRA and ABCA staff, familiar with both datasets used both of these sources of cropping information to arrive at a final field-verified land management dataset for a 6-year period (typically two crop rotation cycles). Key parameters included in the land management dataset are described in Table 3-4.

Table 3-4: Land management data for the Gully Creek watershed

Items	Description
Land features	Land ID, area and physical location
Crop	Crop name
Fall tillage	Number of implementation, tillage type, number of tillage passes, and date for each tillage pass
Spring tillage	Tillage type, number of tillage passes, and date for each tillage pass
Planting	Seeding week and month
Harvest	Harvest week and month
Straw management	Type of straw management, crop residue after straw management
Fertilizer, Nitrogen	Rate and date applied
Fertilizer, Phosphate	Rate and date applied
Manure	Manure type, rate, and date applied

4.0 SWAT SETUP

4.1 Overview of the SWAT

The SWAT is a process based watershed model for assessing land management practice impacts on water, sediment, nutrient and other agricultural chemical yields in a watershed with varying soils, landuse and management conditions over a long period of time. The model performs continuous simulations at a daily time step. Weather, soil properties, topography, vegetation, and land management practices are the main inputs to the SWAT for simulating hydrologic and water quality processes in a watershed (Arnold et al., 1998; Neitsch et al., 2005). SWAT simulates flow, sediment, crop growth, and nutrient cycling. Therefore, it can be used to assess predictive scenarios with alternative input data, such as climate, land cover change and landuse practices, on runoff, sediment and nutrient yields. The model is intended for long term simulations and is not capable of conducting detailed single-event flood routing. Although data intensive, the integration of SWAT into GIS makes it convenient to use readily available datasets from various sources of climate, soil, topography, and landuse information.

The SWAT has eight major components including hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. Additional components such as canopy storage, water redistribution within the snow and soil profile, lateral subsurface flow, reservoirs, ponds and wetlands, tributary channels, and return flow are also integrated into the hydrological component. Within the SWAT land phase hydrologic cycle (Figure 4-1), climate conditions in the watershed provide the moisture and energy inputs, and determine the relative importance of different components of the hydrologic cycle. The watershed is divided into a number of subbasins, which are grouped based on climate, hydrologic response units (HRU), ponds, ground water, and main channels. HRUs are lumped land areas within the subbasin comprised of unique land cover, soil, and management combinations. The daily water budget in each HRU is computed based on daily precipitation, runoff, evapotranspiration, percolation, and return flow from the subsurface and ground water flow.

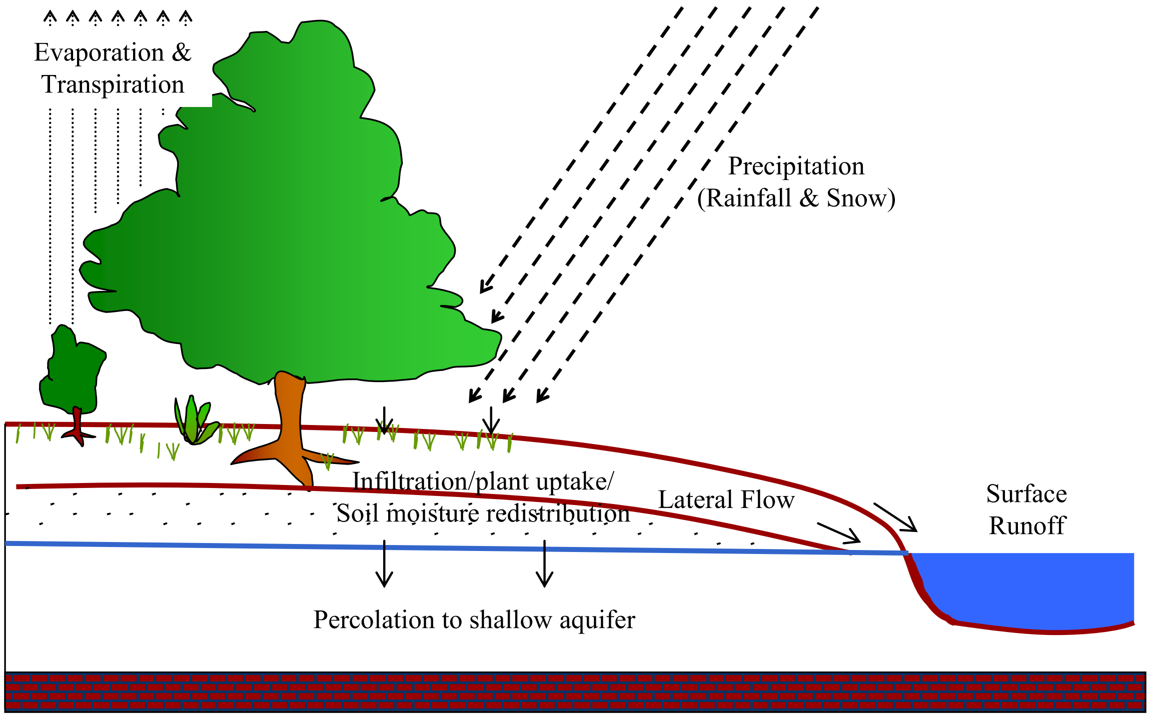


Figure 4-1: Schematic of SWAT land phase hydrologic cycle

(Source: Neitsch et al., 2005)

SWAT has been applied widely in various watersheds across the world for long-term continuous simulations of flow, sediment and nutrient transport with encouraging results. The major benefit of the model is its applicability to decision-making in the area of land management, including cropping patterns, fertilizer applications, pesticide applications and other management practices that can have substantial impacts on water quality and quantity within a watershed (Van Liew et al., 2007). In addition, the model has been useful to study impacts of climate changes on long term water yields, and the impacts of certain management scenarios on long term sediment and nutrient loads (Wu and Johnston , 2007; Zhang et al., 2007). Despite the advantages of the model, SWAT is challenging to use due to its extensive data input requirements and difficulties in selecting appropriate parameters for model calibration. Limitations, some critics of SWAT also point out, include its practice of lumping parameters arbitrarily into subbasins, the subjective approach that is used to select parameter coefficients, its limitations in simulating short-term flooding events, and the overall complexity of the model (Benaman et al., 2005; Migliaccio et al., 2007). Borah and Bera (2004), who conducted a literature review of seventeen SWAT applications, found SWAT to be suitable for predicting yearly flow volumes, sediment and nutrient loads. Monthly predictions are generally good, except for months having extreme storm events and extreme hydrologic conditions. Daily predictions are generally less accurate. In addition, the current SWAT HRU scheme does not include interaction among HRUs, and therefore, the effects of BMP locations and their interactions within a subbasin are not taken into account (Arnold and Fohrer, 2005).

In the 2005-2013 Watershed Evaluation of BMPs (WEBs) program in Agriculture and Agri-Food Canada (AAFC), the Guelph Watershed Evaluation Group (WEG) extended SWAT to characterize snow redistribution, add frozen soil conditions, and also develop/redevelop BMP modules including small dam/reservoir, manure holding pond, conservation tillage, forage conversion, and grazing management. These developments led to the Canadian version of SWAT (called CanSWAT) which has been applied to the WEBs pilot site – the South Tobacco Creek watershed in Manitoba to examine water quantity and quality effects of various BMP scenarios (Liu et al. 2013). Due to data and resource limitations, CanSWAT was not applied to the Gully Creek watershed modelling. However, in this project SWAT was extended to develop a BMP module for the water and sediment control basins (WASCoBs). SWAT parameters were also modified for characterizing small lakeshore watershed conditions.

4.2 Watershed delineation

As the first step of SWAT model setup, watershed delineation involves delineating stream network and subbasins, and calculating subbasin and reach parameters using available GIS data. The subbasin outlets are defined by outlets of stream tributaries, monitoring sites, and control basin and tile drain locations. The GIS data used for watershed delineation were based on 5-m LiDAR DEM (resampled from a 1-m LiDAR DEM) along with a watershed boundary layer, a stream network layer, monitoring station locations, berm location, and tile drain outlet location point data. The DEM was modified by forcing an artificial channel through known road culverts. The rationale for setting monitoring stations as subbasin outlets was to define drainage areas for monitoring stations and to aid in calibrating and validating the SWAT model for both in-stream (including outlet) stations and field-edge locations. The reason for setting water and sediment control basin (WASCoB) locations and tile drain outlets as subbasin outlets was to accommodate simulating WASCoB effects on water quality, as each WASCoB has a specific drainage area and is also linked to the tile drain outlet through a surface tile inlet (hickenbottom) connection. Delineating the study area watershed and subbasin boundaries involved:

1. Defining the stream network based on the hydrologically corrected DEM using an area threshold value of 0.5 ha (200 cells). This ensured all monitoring sites and WASCoB locations could be located on the delineated streams;
2. Creating the main tributary, monitoring station, WASCoB location, and tile drain outlet shape file and adding these locations into the outlet table. This was done manually by adjusting these locations to the nearest stream network using the SWAT delineation tool.
3. Delineating the subbasins, using SWAT's watershed delineation tool;
4. Calculating subbasin parameters, using SWAT's watershed delineation tool.

A total of 64 subbasin outlets were defined and accommodated the establishment of 15 main tributary outlets, 7 monitoring station points, 18 existing WASCoB locations, 14 future WASCoB locations, and 10 tile drain outlet points. The reach characteristics including length, slope, bankfull width and depth are listed in Appendix A, Table A-2. The total derived reach length in the Gully Creek watershed is 38 km, and the derived length weighted averaged slope, bankfull width and depth are 1.8%, 2.15 m, and 0.16 m respectively. The subbasin parameters including subbasin area, average slope, length, slope length, and mean elevation are summarized in Appendix A, Table A-3. The total drainage area derived from LiDAR DEM was calculated to be 1,427 ha, with an average slope and elevation of 6.3% and 247 m. The subbasin areas ranged from 0.6 ha to 175 ha, with an average of 22 ha. Among the 64 subbasins, 28 are under 10 ha, 18 are within

10 to 20 ha, 11 are between 20 and 50 ha, 3 are from 50 to 100 ha, and 4 are above 100 ha. The delineated subbasin map is shown in Figure 4-2.

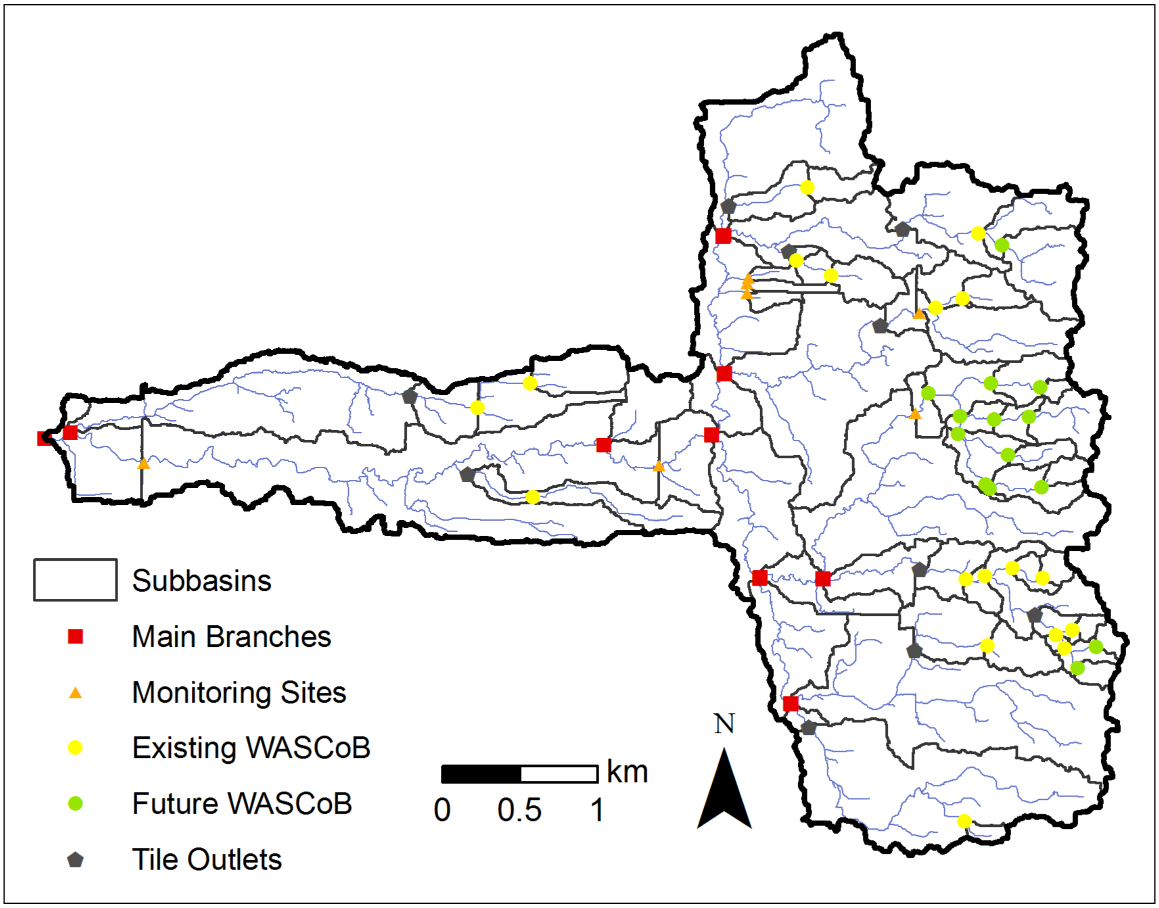


Figure 4-2: SWAT delineated subbasins in the Gully Creek watershed

4.3 Soil characterization

Soil properties are important factors in controlling infiltration and soil water movement, and play a key role in surface runoff, groundwater recharge, evapotranspiration, soil erosion, and the transport of chemicals within the hydrologic cycle. When applied in the United States, SWAT utilizes the comprehensive soils-related information in the Soil Geographic (STATSGO) database and Soil Survey Geographic (SSURGO) database available for all regions of the United States. When SWAT is applied in other jurisdictions, however, users have to develop and format their own soil database to conform to the SWAT model. For the Gully Creek watershed, soil attribute data were obtained from the Soil Landscapes of Canada's online geospatial database, maintained by the Canadian Soil Information Service or CanSIS (http://sis.agr.gc.ca/cansis/). The database contains maps that identify major soil types and their properties across the province by County and Region. These maps, along with the Soil Layer File (SLF) and Soil Name File (SNF), which can also be downloaded from the CanSIS website, were used to prepare the soil attribute datasets for the study area needed by SWAT. Most of the soil input values needed could be directly transferred from the Soil Landscapes of Canada database to the SWAT soils database, while others had to be calculated. Soil-related variables used in the Gully Creek watershed SWAT soil database are listed in Table 4-1. Further details on the method used for acquiring and preparing soil attribute data for this study can be found in Table A-2 of Appendix A.

Table 4-1: Attribute variables in the Gully Creek SWAT soil database

Variable	Definition	Source
SNAM	Soil name	Soil GIS data
NLAYERS	Number of soil horizon layers	Soil GIS data
HYDGRP	Soil hydrologic group	Soil GIS data
SOL_ZMX	Maximum rooting depth of soil profile (mm)	CanSIS
ANION_EXCL	Fraction of porosity from which anions are excluded	Default value is 0.5
SOL_CRK	Potential crack volume of the soil profile expressed as a fraction of the total soil volume	Default value is 0
TEXTURE	Texture of soil layer	Sand, silt and clay percentage
SOL_Z	Depth of the soil layer (mm)	CanSIS
SOL_BD	Soil moist bulk density (g/cm^3)	CanSIS
SOL_AWC	Available water capacity of the soil layer (mm/mm)	Calculation
SOL_K	Saturated hydraulic conductivity (mm/h)	CanSIS
SOL_CBN	Organic carbon content (% soil weight)	CanSIS
CLAY	Clay content (% of soil weight)	CanSIS
SILT	Silt content (% of soil weight)	CanSIS
SAND	Sand content (% soil weight)	CanSIS
ROCK	Rock fragment content (% of total weight)	Calculation
SOL_ALB	Moist soil albedo	Calculation
USLE_K	USLE soil erodibility K factor	Calculation
SOL_EC	Electrical conductivity (dS/m)	CanSIS

4.4 Landuse characterization

The SWAT has a very detailed land cover classification including 97 plant types and 8 urban landuses. The parameter set for each land cover is then created and included in the

SWAT default database (crop.dbf and urban.dbf). This enables the model to simulate hydrologic processes for different landuse areas at the HRU level. This is particularly important when the model is applied to evaluate crop and nutrient management scenarios because different crops have associated with them different management practices such as seeding dates, harvest dates, tillage practices, and fertilizer and manure application rates. In addition, SWAT allows users to set up a crop rotation for a specific HRU.

A total of 29 distinct land cover/use types were identified based on the synthesized land cover/landuse layer for 2011 generated from a combination of direct roadside (windshield) surveys, Ecological Land Classification (ELC) mapping, OMAFRA Agricultural Resource Inventory (AgRI) mapping, and the land management information gathered through the landowner interviews. Because classifying land cover for each type would result in a very large number of HRUs, a reclassification of the land covers was implemented by using a landuse lookup table (see Table 4-2) to group similar crops into one category during model setup.

Table 4-2: Gully Creek landuse classes and corresponding SWAT landuse classes

ID	Gully Creek Landuse	SWAT Landuse	SWAT Code
1	Corn	Corn	CORN (19)
2	Soybean	Soybean	SOYB (56)
3	Edible Beans	Soybean	SOYB (56)
4	Winter Wheat	Winter Wheat	WWHT (28)
5	Barley	Barley	BARL (31)
6	Forages	Hay	HAY (5)
7	Grass Hay	Hay	HAY (5)
8	Pasture	Pasture	PAST (12)
9	Plantation Young	Orchard	ORCD (4)
10	Fallow	Fall Peas	FPEA (62)
11	Fencerow	Meadow Bromegrass	BROM (37)
12	Grass Waterway	Meadow Bromegrass	BROM (37)
13	Riparian	Meadow Bromegrass	BROM (37)
14	Meadow Riparian	Meadow Bromegrass	BROM (37)
15	Meadow Upland	Tall Fescue	FESC (38)
16	Coniferous	Forest-Evergreen	FRSE (8)
17	Deciduous	Forest-Deciduous	FRSD (7)
18	Mixed	Forest-mixed	FRST (6)
19	Shrub/Thicket	Forest-mixed	FRST (6)
20	Shrub/Thicket Riparian	Forest-mixed	FRST (6)
21	Plantation Mature	Forest-mixed	FRST (6)
22	Woodland	Forest-mixed	FRST (6)
23	Roughland	Range Brush	RNGB (16)
24	Marsh	Wetland – non-forested	WETN (11)
25	Water	Water	WATR (18)
26	Ditch	Water	WATR (18)
27	Farmstead	Urban Residential-Low	URLD (4)
28	Urban	Urban Residential-Low	URLD (4)
29	Road	Urban Transportation	UTRN (7)

4.5 Hydrologic response unit definition

SWAT divides all subbasins up into one or more representative HRUs (Hydrologic Response Units). Subdividing a subbasin into areas (HRUs), having unique landuse, soil and slope combinations, enables the model to reflect differences in runoff, erosion, nutrient loading and other hydrologic processes for different land covers and soils. In order to balance the representation details of landuse, soil and slop combinations and the complexity caused by increased number of HRUs, threshold values (minimum percentage of a feature in a subbasin) were determined respectively for landuse (10%), soil type (20%), and slope (4 classes) in this study. SWAT predicts runoff, sediment and nutrient loading separately for each HRU and routes to the outlet to obtain the total runoff, sediment and nutrient yield of the watershed.

The HRU distribution was created based on the Gully Creek soil, 2011 landuse, and the slope classes listed in Table 4.3. Most of the agricultural areas fell within the slope classes 0-2%, 2-5%, and 5-9% and most of the riparian areas were located in slope class > 9% (see Table 4-3 and Figure 4-3). In HRU definition, the threshold value of landuse percentage over a subbasin area was set at 10%, the soil class percentage over landuse area was set at 20%, and the slope class percentage over soil area was set at 10%, which resulted in a total of 518 HRUs. The resulting HRUs had a minimum size of 0.02 ha and a maximum size of 48 ha with an average size of 2.7 ha. This number of HRUs was thought to be of sufficient detail to characterize heterogeneity of the Gully Creek watershed.

The HRU distribution was based on the 2011 crop distribution. Crops however change from year-to-year on a field yet the HRU definition is fixed once the model has been built. To address this, year-to-year land cover changes (i.e. crop rotations), within each HRU are represented using a tool developed by the Guelph Watershed Evaluation Group that allows detailed data inputs to schedule management operations within an HRU. The schedule of operations input for each HRU was based on land management time-series data that were assembled through the landowner interview and roadside survey activities in the Gully Creek watershed. A classification of landuse, soil types, and slopes used in the HRU distribution is presented in Appendix A-1.

Table 4-3: Slope classes and area percentages in the Gully Creek watershed

Slope (%)	Class	Watershed Area (%)	Agricultural Area (%)
0-2	A, B	21	23
2-5	C	42	50
5-9	D	20	22
> 9	E - H	17	5

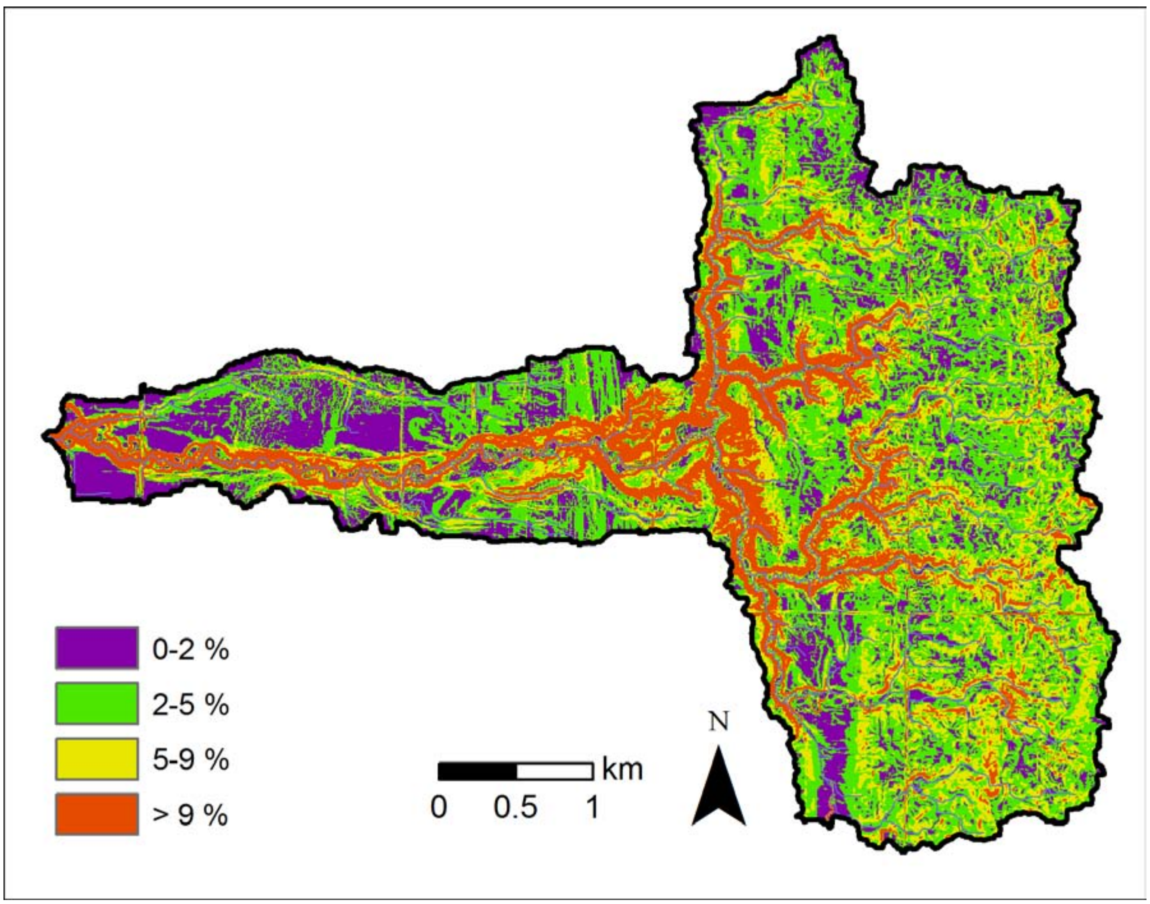


Figure 4-3: Slope classes in the Gully Creek watershed for SWAT setup

4.6 Tile drain definition

Subsurface tile drainage is a very common agricultural practice found in the Gully Creek watershed. The tile drainage GIS layer was obtained from OMAFRA, with data as recent as 2009. Figure 4-4 shows that majority of the crop fields have tile drainage installed. However, there were no data on location, amount, dimensions (such as tile diameter), and other construction-related details of the tile drain system.

To simplify the SWAT setup and given the extent of known tile drainage (see Figure 4-4), it was assumed that all agricultural land was tile drained in agricultural areas of the Gully Creek watershed. The tile drainage function in the SWAT requires three parameters: depth to drain, time to drain soil to field capacity, and tile drain lag time. Based on personal communications with staff at ABCA and OMAFRA, these tile drain input variables were estimated based on a combination of soil and field slope. For "time taken to drain soil to field capacity" and "tile drain lag time", we assumed 24 hours and 3 hours to be reasonable estimates (Table 4-4). However, these values are likely to vary with each field and more detailed characterization of tile drain can be setup in SWAT if more detailed data are available.

Table 4-4: Tile drainage parameter values for SWAT setup

Soil type	Depth to surface drain (mm)	Time to drain soil to field capacity (hours)	Tile drain lag time (hours)
Huron Clay Loam	900	24	3
Perth Clay Loam	900	24	3
Brady Sandy Loam	900	24	3
Bottom Land	900	24	3
Brookston Clay Loam	900	24	3
Burford Loam	900	24	3

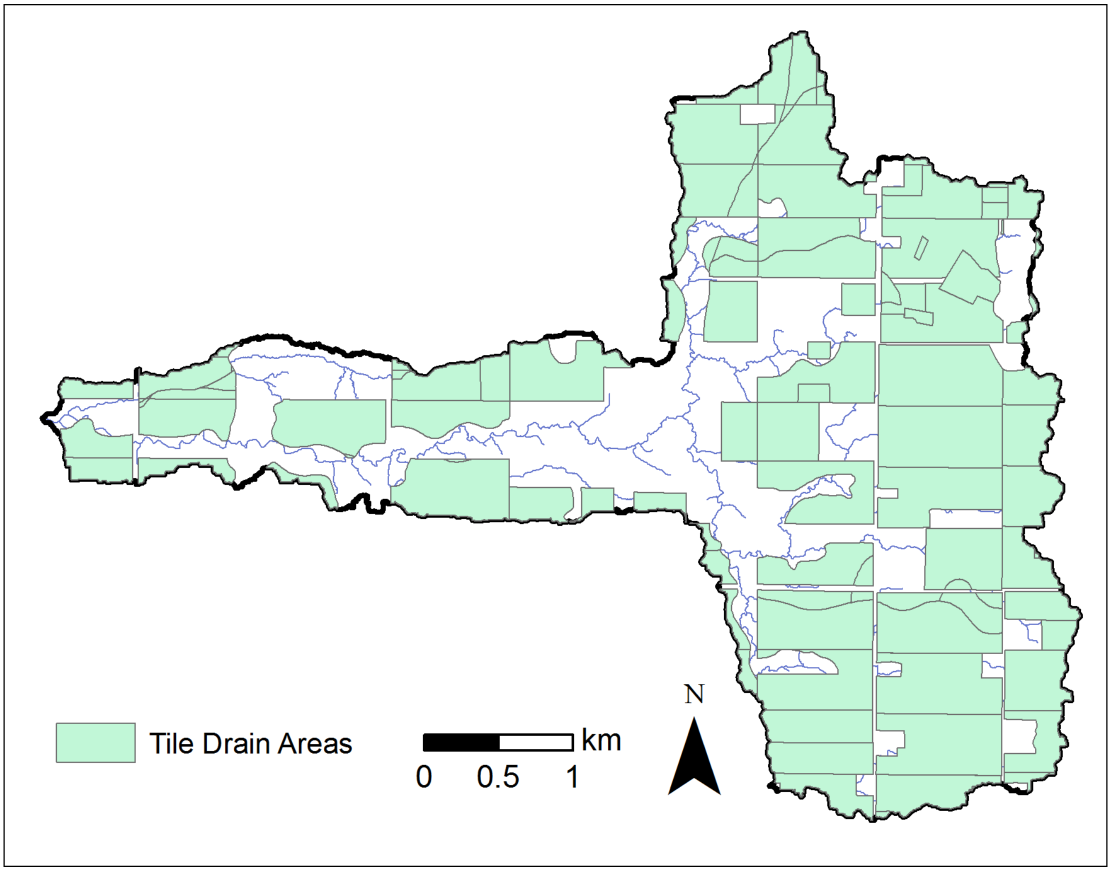


Figure 4-4: Tile distribution in the Gully Creek watershed (Source: OMAFRA)

4.7 Land management definition

Land management data are important inputs to the SWAT for reasonably simulating runoff, sediment and water quality processes in agricultural watersheds. Land management information includes planting date, harvest date, irrigation events, nutrient application dates and rates, pesticide application dates and rates, tillage operations and timing, and others. In this study, a land management survey was conducted in early 2011 to collect information on most (about 67%) of the cropped area in the Gully Creek watershed. Information collected from the land management survey was enhanced with data collected by OMAFRA's agricultural resource inventory data work as well as direct windshield surveys completed by ABCA staff to create synthesized land management datasets. Four key land management datasets were prepared: (a) planting details for 6 growing seasons, (b) fertilizer application details, (c) harvest and straw management details, and (d) tillage operation details. The land management data covered the period from 2008 to 2013 (about two crop rotation cycles for most fields). The data from 2008 to 2010 were historical (actual) information as provided through the landowner surveys and verified using the OMAFRA AgRI mapping for the same time period. The predicted data for 2011 – 2013 crop years were based on landowner plans as provided through the landowner interviews conducted in early 2011. As the project proceeded, the producer's planned practices were verified by the windshield surveys conducted in the 2011 and 2012 growing seasons. The number of crop rotation years was set to 3 in the SWAT general management file to account for representative land management in the watershed as this appeared to be the most dominant crop rotation cycle.

Three steps were completed when preparing SWAT management input data for the Gully Creek watershed at the HRU level: (a) cleaning of the raw land management data at field scale, (b) preparation of SWAT management database at field scale on a yearly basis, and (c) conversion of field management data into SWAT HRU text input files. Step (a) (data cleaning) involved correcting inaccuracies, removing anomalies, eliminating duplicate records, filling missing records of the dataset, and checking entries for consistency. This process was required to make the necessary transformation from the original (excel) dataset into a format that was readily available for use in the SWAT. The conversion of field management data into SWAT HRU text input files was performed using a computer program based on a lookup table linking each field with the appropriate set of HRU's using an area weighted approach developed by the Guelph Watershed Evaluation Group. The variables and preparation processes for the second step are described in more detail in the sections to follow.

4.7.1 Planting operations

Specifying the planting operation in SWAT initializes the growth of a specific land cover type in the HRU. Because the HRU structure was fixed using the 2011 landuse data, this operation becomes a key factor to change and characterize crop type and land cover within the HRU over the entire simulation period. The major variables and explanations of the planting operation input required by SWAT are described in Table 4-5. Further details can be found in the SWAT manual (Neitsch et al. 2005). A sample planting operation table used in the model can be found in Appendix B-1.

Table 4-5: Variable and sources of planting operation in the Gully Creek watershed

Variable	Definition	Source
Month	Month of operation	Synthesized land management datasets (Seedmonth)
Day	Day of operation	Synthesized land management datasets (Seedweek)
MGT_OP	Management operation number	MGT_OP = 1
Plant_ID	Land cover identification number	Table 4-2
Heat_Units	Heat units to reach maturity	SWAT crop database
CNOP	Operational SCS runoff curve number for moisture condition II	Obtained from SWAT database reflecting the practice of landuse changes

The multiple years of data for planting operation practices were prepared by completing the following steps:

(a) re-classify the landuse layer for each year using created landuse lookup table;

(b) overlay the re-classified landuse with the HRU distribution based on the 2011 landuse information;

(c) re-assign each HRU's landuse type by selecting the landuse having the largest portion within the HRU;

(d) define the seeding date by choosing the date for the area that covers largest part of the HRU; and

(e) create the HRU planting attributes using available data and lookup tables.

For simplification purposes, the areas within the HRU that did not belong to the major soil-landuse combinations were not included in this process. The planting parameters were therefore assigned to HRUs within each subbasin as delineated from the 2011 landuse data. The practice of landuse change is reflected by Plant_ID, operation date and

CNOP which are assigned for each year and for each HRU based on the updated landuse information. The final results are stored in the SWAT mgt2 database in the format as described in the SWAT manual (Neitsch et al. 2005).

4.7.2 Fertilizer application

SWAT's fertilizer operation simulates the application of fertilizer and manure to the land. Information required in the fertilizer operation includes the timing of the operation (month and day or fraction of plant potential heat units), the type of fertilizer/manure applied, the amount of fertilizer/manure applied, and the depth distribution of fertilizer application as described in Table 4-6. A sample fertilizer management table used in the model is presented in Appendix B-2.

Table 4-6: Variables and sources of fertilizer application data in the Gully Creek watershed

Variable	Definition	Source
Month	Month of operation	Synthesized land management datasets (FertMo)
Day	Day of operation	Synthesized land management datasets (FertDate)
HUSC	Fraction of total base zero heat units at which operation takes place	Required If MONTH and DAY are not provided. The default value is 0.20.
MGT_OP	Management operation number	MGT_OP = 3
FERT_ID	Fertilizer identification number from fertilizer database	1 - Elemental nitrogen, 2 - Elemental phosphorous, 45 - Beef manure, 47 - Hog manure, 52 - Chicken manure.
FRT_KG	Amount of N and P applied to HRU (kg/ha)	Calculated using the area-weighted mean method
FRT_SURFACE	Fraction of fertilizer applied to top 10mm of soil	The default FRT_SURFACE value is 0.20

Preparing the detailed multi-year datasets of fertilizer application practices entailed completing the following steps:

(a) calculate the amount of elemental N, elemental P and manure applied (kg/ha) for each fertilizer and manure application at field level (Land-ID); define how and when the fertilizer was applied, i.e. assign values to Fertwsedn (nitrogen used with seeding), Fertwsedp (phosphorous used with seeding), Fertbron (nitrogen with a broadcasting method), Fertbrop (phosphorous used with a broadcasting method), Fertbansn (nitrogen used with banding method in spring), Fertbansp (phosphorous used with banding method in spring), Fertbanfn (nitrogen used with banding method in fall), Fertbanfp (phosphorous used with banding method in fall), and Manrat (rate of manure) application rate in kg/ha on a yearly bases with attributes of their application dates;

(b) estimate the land ID compositions and their area partitions for each HRU from the landuse data;

(c) (calculate the area-weighted mean N and P application rate for each HRU, including those areas which do not belong to the major landuse–soil combinations in the subbasin;

(d) re-calculate the average N and P application rate for each HRU by redistributing the fertilizer amount applied to the non-major landuse–soil combination areas into other HRUs within the subbasin, based on their area of coverage;

(e) assign a fertilizer and manure application date by choosing the application date for the area that covers largest part of the HRU; and

(f) create HRU fertilizer application attributes, using available data for each application year.

This is a complex process involving GIS overlay, grid computation, area-weighted average, and date identification for each year and for each fertilizer application. This task is implemented using a computer program developed by the Guelph Watershed Evaluation Group. The final fertilizer application input data prepared for each HRU and for each year are ultimately stored in the SWAT "mgt2" database.

4.7.3 Harvest and straw management

The harvest and kill operation in SWAT stops plant growth in the HRU. The fraction of biomass specified in the land cover's harvest index is removed from the HRU as yield. The remaining fraction of plant biomass is converted to residue on the soil surface. The information required by the harvest and kill operation is the timing of the crop harvest operation. The practice of straw management is also represented in this operation by updating the moisture condition II curve number according to the straw management practices (Table 4-7 and Table 4-8). A sample harvest and straw management table used in the model is presented in Appendix B-1.

Table 4-7: Variables and sources of harvest and straw management data in the Gully Creek watershed

Variable	Definition	Source
Month	Month of operation	Synthesized land management datasets (HarvMonth)
Day	Day of operation	Synthesized land management datasets (HarvWeek)
MGT_OP	Management operation number	MGT_OP = 5
CNOP	SCS runoff curve number for moisture condition II	Estimated for each HRU based on straw management practices Table 4-8

Preparing the detailed multi-year datasets describing harvest and straw management practices involved completing the following steps:

(a) classify the reported straw management practices on a field into categories and assign CNOP/CN2 ratio for each category, using one of the proposed values listed in Table 4-8;

(b) estimate the land ID compositions and their area partitions for each HRU for the landuse data, similar to what was done in the fertilizer data preparation;

(c) calculate the average CNOP/CN2 for each HRU, excluding those areas which do not belong to the major landuse–soil combinations in the subbasin;

(d) assign a harvest date by choosing the date for the area that covers largest part of the HRU, and

(e) create HRU harvest and straw management attributes using available data and lookup tables.

Similar to what was done when describing the planting operations, the areas that do not belong to the major soil-landuse combinations in the subbasin are not considered to be changing the CNOP values and the harvest date. The harvest parameters for each application year were therefore assigned to HRUs within each subbasin, as delineated from the 2011 landuse data layer. The Gully Creek land management data included estimates of residue cover data from the synthesized land management datasets. In SWAT, the straw management practices are represented by the CNOP value. Straw management activities are assumed to occur right after harvest. The final harvest and straw management input data are prepared for each HRU and for each year and are stored in SWAT's "mgt2" database. The missing data are filled based on the general assumptions listed in Table 4-9.

Table 4-8: Straw management practices and associated CNOP/CN2 ratio

Straw management code	Straw management type	Residue cover	Impact	CNOP/CN2
1	20R	20%	High	1.10
2	25R	25%	Medium to High	1.075
3	30R	30%	Medium to High	1.075
4	50R	50%	Medium	1.05
5	60R	60%	Low to medium	1.025
6	70R	70%	Low to medium	1.025
7	75R	75%	Low to mdeium	1.025
8	80R	80%	Low	1.00
9	90R	90%	Low	1.00
10	100R	100%	Low	1.00

Table 4-9: General assumptions on residue cover for different crops

Crop code	Crop name	Straw management code	Straw management type	Residue cover
1	Corn	1	20R	20%
2	Soybean (edible beans)	7	75R	75%
3	Winter wheat	4	50R	50%
4	Barley	4	50R	50%
5	Grass hay	10	100R	100%
6	Forages	10	100R	100%
7	Pasture	10	100R	100%
8	Fallow	4	50R	50%

4.7.4 Tillage operation

The tillage operation redistributes residue, nutrients, and pesticides in the soil profile. SWAT requires users to provide information on the timing of the tillage operation(s) and the type of tillage operation(s). As a result of tillage operation entries, the moisture condition II curve number is automatically adjusted by SWAT during the model run to reflect the tillage effect on runoff generation. For fields within the Gully Creek watershed for which a landowner survey was completed, tillage data were available. For fields that did not have a landowner survey to reference tillage practices against, tillage practice assumptions were used. The variables and sources of tillage operation practices in the Gully Creek watershed are listed in Table 4-10. A sample tillage table used in the model is presented in Appendix B-3.

Table 4-10: Variables and sources of tillage operation in the Gully Creek watershed

Variable	Definition	Source
Month	Month of operation	Synthesized land management datasets
Day	Day of operation	Synthesized land management datasets
HUSC	Fraction of total base zero heat units at which operation takes place	The default value is 0.10 for tillage before planting, and 1.35 for tillage after harvest
MGT_OP	Management operation number	MGT_OP = 6
TILL_ID	Tillage implementation code	Table 4-11
CNOP	SCS runoff curve number for moisture condition II	Used the proposed values in Table 4-11

The multiple years of data for tillage practices were prepared by completing the following steps:

(a) classify the observed tillage operations into five general categories (High, Medium to high, Medium, Medium to low, and Low) and assign a CNOP/CN2 ratio for each category using the proposed ratios listed in Table 4-11;

(b) estimate the land ID compositions and their relative proportions in each HRU from the landuse data (similar to what was done for the fertilizer data preparation);

(c) calculate average CNOP/CN2 for the HRUs, excluding those areas which do not belong to the major landuse-soil combinations in the subbasin;

(d) define the tillage type by choosing the type that covers the largest part of the HRU;

(e) assign the tillage date from the defined tillage type, and

(f) create HRU tillage operation attributes, using available data and lookup tables.

The areas that do not belong to the major soil-landuse combinations in the subbasin are not included in the HRU tillage data preparation in this study because:

(a) these areas are small compared to the subbasin area;

(b) the tillage practice gets redistributed into other HRUs which has little effect on the final results; and

(c) it simplifies the datasets and dataset preparation.

The tillage parameters for each application year were assigned to HRUs within each subbasin as delineated from the 2011 landuse data layer.

Table 4-11: Tillage operation types and associated CNOP/CN2 ratio

Tillage Type	Tillage code	Tillage ID	Depth (mm)	Mixing efficiency	Erosion potential	CNOP/ CN2
Chisel Plow (CHPLLE15)	CHISPLOW	59	150	0.30	Medium to high	0.975
Generic Conservation Tillage	CONSTILL	3	100	0.25	Low	1.00
Culti-packer Pulverizer	CULPKPUL	19	40	0.35	Low to medium	0.925
Disk Plow (DKPLGE23)	DISKPLOW	61	100	0.85	Medium to high	0.975
Field Cultivator (FLDCLT15)	FLDCULT	7	100	0.30	High	0.90
Harrow (HRW10BAR)	HARROW	16	25	0.20	Low	1.00
Moldboard Plow (MLDBGE10)	MLDBOARD	56	150	0.95	High	0.90
No tillage done	NOTILL	108	0	0.00	low	1.00
Deep Ripper-Subsoiler	RIPSUBS	77	350	0.25	High	0.90
Rolling Cultivator (ROLLT15)	ROLLCULT	11	25	0.50	Low	1.00
Generic Zero Tillage	ZEROTILL	4	25	0.05	Low	1.00

4.8 Summary

The Gully Creek watershed's SWAT model was set up to ensure subbasin outlets were located at significant locations for characterizing watershed processes and evaluating BMP effects. It was also important to determine a reasonable number of subbasins and HRUs for the modelling. In subbasin delineation, major outlets of the tributaries, monitoring stations, and exiting/future berm locations were set up as subbasin outlets for model calibration, validation and BMP assessment. Another important step in the model set-up was to incorporate landowner and field-observed survey data with reasonable assumptions to characterize land management in the Gully Creek watershed. To convert field management data into HRUs, an HRU land-lookup table was created using GIS as presented in Appendix B-4. A computer program was developed to automatically convert field-level land management data into HRU parameters. Similarly, a computer program was also developed to convert SWAT HRU outputs back to field/farm scales. The two add-on tools developed by the Guelph watershed Evaluation Group extended SWAT's capability to characterize and simulate field-level BMP effects.

5.0 CHARACTERIZATION OF BMPs

This modelling component of the WBBE project focused on using SWAT to help evaluate the environmental and economic effects of four BMPs – conservation tillage, nutrient management planning, fall cover crop establishment, and the use of water and sediment control basins (WASCoBs). The calibrated SWAT model was run a number of different times to examine the effects of these various BMPs.

5.1 Conservation tillage

Conservation tillage is any combination of tillage and planting practices that reduce the loss of soil and water relative to losses with conventional tillage (Unger, 2006). It includes any tillage method that retains protective amounts of crop residuals on the soil surface. Generally, a tillage system that leaves a 30% or greater cover of crop residuals on the soil after planting is considered to be a conservation tillage method. In the Gully Creek watershed, various conservation tillage practices were observed to be used. The SWAT modelling for the Gully Creek watershed simulated the following tillage practices as defined in the SWAT manual: Chisel plow, generic conservation tillage, culti-packer pulverizer, disk plow, field cultivator, harrow, moldboard plow, no tillage done, deep ripper-subsoiler, rolling cultivator, and generic zero tillage. For conservation tillage, these practices (chisel plow/Vertical tillage following corn, and no-till following soybeans and wheat) were defined for the cropping system with corresponding tillage parameters within SWAT (Neitsch et al., 2005).

5.2 Nutrient management

Inputs required by SWAT to characterize the fertilizer application practices within the Gully Creek watershed include date of application (month, day, year), fertilizer type (N and P), and fertilizer amount. Input files describing the fertilizer application in the watershed were setup for both the existing fertilization practices followed by the area landowners (as determined through the landowner surveys) and the Nutrient Management Plan (NMP) recommended BMP fertilization rates as determined using Ontario's NMAN3 nutrient management planning software. The Nutrient management planned rates represented optimal fertilizer rates, balancing soil tests, manure availability and future fertilization needs, without sacrificing crop yield. If the producer's historical fertilization rates were different than the recommended rates for reaching the optimal yield goal, then the historical rates were adjusted upward or downward as necessary to match the NMAN software's estimated optimal fertilization rate for N and P.

The land management data collected through the landowner survey covered about 67% of the crop field area in the Gully Creek watershed. For the fields without survey data, averages of the surveyed fertilizer rates were used as an estimate of what fertilizer amounts were likely being applied to those fields not surveyed. Optimal fertilization rates for those unsurveyed fields were estimated through NMAN3 using the average crop yields observed in the area. A summary of the assumed existing and assumed optimal fertilizer rates for the unsurveyed fields are listed in Table 5-1. While there was significant field-to-field variability in application rates that is not evident by reviewing the average values provided in Table 5-1, in general, the average application rates for N and P were not widely different between the existing rates and the NMP rates for most fields surveyed.

Table 5-1: Existing and optimal fertilizer rate for the Gully Creek watershed

Crop	Elemental N (kg/ha)		Elemental P (kg/ha)		Yield (T/ha)
	Existing rate	NMAN3 rate	Existing rate	NMAN3 rate	
Grain Corn	179	174	38	24	11.0
Soybeans	4	1	5	10	3.1
Winter Wheat (Straw removed)	110	100	12	2	5.9
Dry beans	53	60	33	9	2.2
Hay	0.0	60	0	0	7.1
Pasture	0.0	0	0	0	4.3
Barley	71	45	19	0	3.5
Hay (alfalfa)	0	60	0	0	8.5

Notes: 1. The existing rate is based on Gully Creek averages. 2. For NMAN3, the following soil test values were assumed: P - 28 K – 251 (the average of soil tests results in the Gully Creek watershed). 3. The crop yields presented here were used in NMAN3 as the basis for determining BMP fertilization rates on fields for which no landowner-supplied yield values were available 4. Based on the relatively low recommendations for P fertilization, the P was assumed to be applied as a banded application with the planter at planting as opposed to a broadcast P application.

5.3 Cover crop

As a BMP, cover crops have the benefit of reducing soil erosion for the period they are providing vegetative cover. There are many different types of cover crops and various opportunities for farmers to establish cover crops, depending on their cropping patterns. For the Gully Creek setting, however, which is dominated by a corn, soybean, winter wheat rotation, it was assumed that a red clover cover crop, planted after wheat harvest and plowed in the late fall before next crop was probably the most viable and readily acceptable cover crop opportunity. To represent this red clover BMP option in SWAT, the various land management input files were modified to simulate the seeding of red clover in the early spring of the year when winter wheat is grown in the field. The red clover was simulated to remain growing on the field after wheat harvest until it was ploughed down in the late fall in preparation for next year's crop. A total of 66 kg/ha of N was assumed to be supplied to the next year's crop through the red clover ploughdown.

5.4 Water and Sediment Control Basins (WASCoBs)

Water and Sediment Control Basins (WASCoBs) were found to be a commonly implemented BMP in the study area. A WASCoB is intentionally designed to slow and divert underground stormwater runoff, thus reducing ditch, gully, and channel erosion downstream of the structure. It may also have a small effect on increasing groundwater recharge and trapping upstream sediment and nutrients in the ponding area. Prior to this study, SWAT had no module specifically designed to simulate the water quantity and quality effects of WASCoBs. In this project, a WASCoB module was developed for SWAT, which is an important innovation and advancement achieved by this project.

5.4.1 Conceptual Design

WASCoBs are typically located along upland concentrated flow pathways within a subbasin of a watershed. Water flowing into the WASCoB originates from the drainage area above the WASCoB point. Using the study area's detailed LiDAR/geographic data, a stage-volume (storage) relationship could be developed for the ponding area behind each existing or proposed WASCoB berm. SWAT's hydrologic routines can estimate the amount of water draining to the WASCoB pond for modeled storm events. This volume combined with the stage-volume relationship and an estimate of the tile size and gradient servicing the WASCoB's outlet can then be used determine the discharge rate from the WASCoB. Under normal conditions water enters a riser pipe and is conveyed to the main stream channel through the tile drain outlet pipe. If the volume of the water stored behind the WASCoB's berm exceeds the principal storage volume, water flows through the emergency overflow spillway (i.e. overtops the berm). This overflow travels overland to the main stream channel. This conceptualization will form the basis of the WASCoB module design. Modelling of WASCoBs in the Gully Creek watershed consisted of four main steps:

- Setup the SWAT subbasin delineation such that each WASCoB in the watershed was identified as a subbasin outlet point. The drainage area above the WASCoB was calculated using SWAT's watershed delineation algorithm. The main purpose for setting the WASCoB's berm location as a subbasin outlet was to allow for evaluating the effect of the WASCoB at each individual site.

- Develop a stage-storage relationship for the WASCoB's ponding area and stage-discharge relationships for the tile outlet and emergency overflow outlet (if applicable).
- Identify the maximum stage possible for each WASCoB before spillway flow or overtopping occurs (i.e. water depth when it would begin to crest or overflow).
- Route the runoff water through the outlet (i.e. The surface inlet connected to a subsurface drainage tile) and the emergency spillway flow (if necessary).

5.4.2 WASCoB Storage Volumes

There are three important storage volumes for each WASCoB. These are the principal storage volume (i.e. normal storage), the emergency storage volume (i.e. maximum), and the dead storage. The principal storage volume is the storage volume to the crest of the emergency overflow spillway. The emergency storage volume is the storage to the top of the WASCoB or berm. The dead storage is the volume of water below the riser pipe inlet slots or holes. The threshold volumes and surface area were determined or estimated by OMAFRA staff using the LiDAR DEM. In cases where there was no emergency spillway the maximum volume was set equal to the normal storage volume. If the dead storage volume was not known, it was assumed to be zero. If the total runoff volume estimated by SWAT from the upstream watershed is less than the WASCoB's dead storage, there will be no outflow from the structure and all of the runoff water is stored in the pond. If the calculated storage is between the dead storage and the principle storage, outflow is through the WASCoB's surface inlet and associated tile drain outlet pipe. Outlet flows are based on the storage-discharge curve for the outlet pipe. If the calculated storage is above the principle storage, the pipe outflow is set at its capacity, and spillway flow is estimated using a water balance method (i.e. by assuming emergency storage volume goes through the spillway and then if there is a volume over the emergency spillway it goes over the entire berm). In this case, the end storage is set to the principle storage, and the spillway and overtop flow volume is estimated by the total storage minus pipe flow volume calculated using the pipe's maximum flow rate. In reality, berm overtopping seldom occurs as observed in the field.

Table 5-2 summarized the characteristics of all of the existing and proposed WASCoBs identified within the Gully Creek watershed. Note that WASCoBs shown with a "*" beside the WASCoB number in the table denotes future berms, while the rest are existing berms. For all berms, the dead depth, dead volume, dead area, and dead discharge are set to 0 to indicate that the inlet is close to the bottom of the pond before the berm. The "Area" entries in the table denote the drainage area of the upstream subbasin. The Prin_D, Prin_V, Prin_A, and Prin_Q columns in the table denote the principle depth, volume, surface area, and discharge. Emerg_D, Emerg_V, Emerg_A, and Emerg_Q in the table denote the emergency depth, volume, surface area, and discharge. Day_Cap in the table denotes the daily discharge capacity of the riser pipe. Rece_R is the reach number where the tile line servicing the WASCoB outlets.

Table 5-2: WASCoB characteristics in the Gully Creek watershed

Berm	Subbasin	Area (ha)	Prin_D (m)	Prin_V (m^3)	Prin_A (ha)	Prin_Q (m^3/s)	Emerg_D (m)	Emerg_V (m^3)	Emerg_A (ha)	Day_ Cap (m^3)	Rece_R
1*	1	0.173	0.67	190	0.0693	0.034	0.67	190	0.069	2,938	6
2*	4	1.146	0.62	81	0.0499	0.030	0.62	81	0.050	2,592	5
3*	7	1.233	0.58	154	0.0716	0.027	0.58	154	0.072	2,333	5
4	9	0.142	1.18	2,625	0.516	0.079	1.18	2,625	0.516	6,826	5
5	10	1.107	1.10	2,655	0.558	0.071	1.10	2,655	0.558	6,134	5
6	14	0.174	0.46	82	0.053	0.019	0.46	82	0.053	1,642	19
7	15	0.193	0.94	812	0.2371	0.056	0.94	812	0.237	4,838	19
8*	20	1.107	1.00	2,747	0.4945	0.102	1.00	2,747	0.495	8,813	47
9	21	1.157	0.66	267	0.1172	0.033	0.66	267	0.117	2,851	30
10*	22	0.121	0.68	560	0.1805	0.034	0.68	560	0.181	2,938	47
11*	23	1.143	1.98	10,602	1.1586	0.173	1.98	10,602	1.159	14,947	47
12	25	1.184	1.00	4,987	1.3	0.062	1.00	4,987	1.300	5,357	30
13*	27	1.147	1.49	2,129	0.3579	0.112	1.49	2,129	0.358	9,677	47
14*	28	0.150	1.07	3,923	0.969	0.068	1.07	3,923	0.969	5,875	47
15*	29	0.151	1.40	153	0.0552	0.038	1.40	153	0.055	3,283	47
16*	32	1.115	0.99	4,280	0.9069	0.061	0.99	4,280	0.907	5,270	47
17*	36	0.154	0.86	506	0.1842	0.049	0.86	506	0.184	4,234	47
18*	40	1.106	0.60	505	0.1983	0.028	0.60	505	0.198	2,419	47
19*	41	0.142	0.71	352	0.1117	0.037	0.71	352	0.112	3,197	47
20*	42	0.016	0.48	342	0.1491	0.020	0.48	342	0.149	1,728	47
21	43	1.182	0.26	30	0.0276	0.008	0.26	30	0.028	691	37
22	44	0.140	0.53	91	0.0428	0.024	0.53	91	0.043	2,074	51
23	46	1.204	0.58	234	0.1194	0.027	0.58	234	0.119	2,333	51
24	48	0.137	0.64	103	0.0747	0.031	0.64	103	0.075	2,678	51
25	50	0.145	0.51	176	0.1067	0.022	0.51	176	0.107	1,901	51
26	53	0.124	0.79	351	0.0933	0.043	0.79	351	0.093	3,715	46
27*	55	0.112	0.31	40	0.0309	0.011	0.31	40	0.031	950	46
28	56	0.131	1.01	597	0.1455	0.063	1.01	597	0.146	5,443	46
29	57	1.107	1.40	6,068	1.164	0.102	1.40	6,068	1.164	8,813	61
30	59	0.146	1.00	1,567	0.4113	0.062	1.00	1,567	0.411	5,357	46
31*	60	0.137	0.75	873	0.3066	0.040	0.75	873	0.307	3,456	46
32	64	0.128	0.87	640	0.2137	0.050	0.87	640	0.214	4,320	62

5.4.3 Stage-Storage and Stage-Discharge Curves

As discussed, the stage-storage relationship for each of the WASCoBs in the study area were determined by OMAFRA staff using OMAFRA's 1m x 1m DEM derived from the 2011 LiDAR data. The extent of the ponding surface area behind each WASCoB berm was estimated from contour maps showing each 15 cm (6") contour interval, beginning with the lowest point in the ponding area and extending to elevation of the emergency overflow spillway. This area-depth information was then used to estimate the volume of pond storage at each elevation increment using the contour stage storage method.

Ideally the capacity of the outlet pipe (i.e. tile drain) would be greater than the intake capacity of the perforated riser and discharge would be a function of the intake capacity of the riser alone. In practice this is often not the case but instead the discharge is influenced by the capacity of the tile drain pipe. For the initial setup of the model, we have assumed that the tile drain has no effect on discharge capacity and that discharge will be limited only by the capacity of the riser pipe. Discharge has been estimated using equations provided by OMAFRA and which are used to characterize different surface inlets within OMAFRA's Agricultural Erosion Control Structures design software (AgErosion) – a computerized version of OMAFA Publication 832 Agricultural Erosion Control Manual: A Design and Construction Manual (2008). This method will overestimate outflow from the WASCoB during wet periods when the tile drain capacity is less than the riser pipe capacity. Alternative methods of estimating the discharge from the WASCoB can be considered. The effects of the tile drain could be included in subsequent model set-ups by modifying the discharge curves of each WASCoB based on available information or reasonable assumptions. The extra effort needed to do this for this study however, was not deemed necessary. Combining the stage-area-volume and stage-discharge curves, the volume-area and volume-discharge curves could be created for each berm, providing input to the WASCoB module in SWAT. The inflow volume to the WASCoB is obtained from the SWAT reach output upstream of the WASCoB from which the average surface area and average discharge of the WASCoB can be estimated using the WASCoB module. A sample volume-area-discharge curve for Berm ID-10 is given in Table 5-3 and Figure 5-1.

Table 5-3: Sample volume-area-discharge curve data for WASCoB ID-10

Volume (m^3)	Surface area (ha)	Discharge (m^3/s)
0	0	0
16	0.029	0.002
98	0.082	0.008
269	0.146	0.016
549	0.226	0.026
955	0.314	0.037
1,498	0.410	0.049
2,180	0.499	0.063
2,655	0.558	0.071

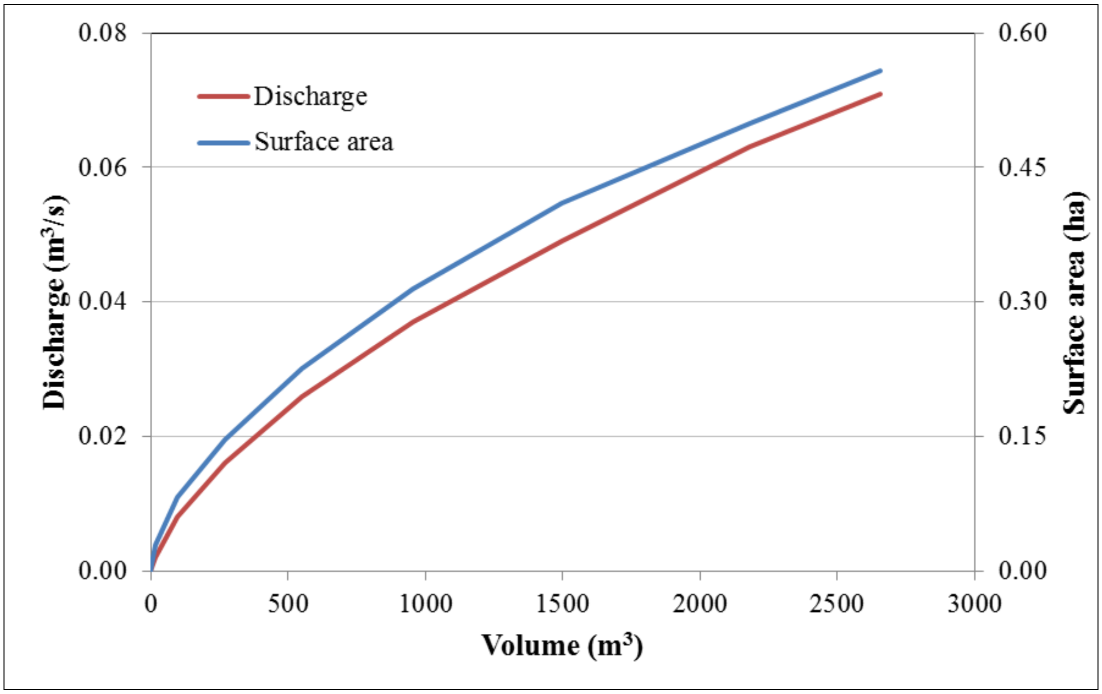


Figure 5-1: Volume-area-discharge curve used for WASCoB ID-10 simulation

5.4.4 Routing

Routing refers to the transport of water from the point of runoff initiation through to its discharge point. For the WASCoB subroutine, the routing procedure was broken down into two possible pathways. The first pathway involves routing the flow from the riser pipe to the main channel through the associated subsurface tile drain discharge pipe. The second pathway entails routing flow from the emergency overflow spillway along the SWAT delineated surface pathway or channel to the open ditch. Discharge out of the WASCoB through the drainage pipe is routed using the small dam module developed by the Guelph Watershed Evaluation Group in the AAFC WEBs program. The small dam module works by calculating the equivalent storage and equivalent discharge based on the storage-discharge rating curve, defined for the WASCoB, using a daily time step. The transfer function in the SWAT is then used to route this outflow from the WASCoB to the outlet (discharge point) of the tile drain (Table 5-4). The tile drain outlet point for each WASCoB was determined from air photo interpretation and by OMAFRA staff. In the case where no known tile drain outlet was located nearby it was assumed that the tile outlet to the nearest reach of the main stream channel. Flow from the emergency spillway is routed from the WASCoB subbasin outlet along the SWAT delineated overland channel that leads to the main stream using the SWAT channel routing algorithm. In other words, the overflow water would follow the same runoff pathway it would have taken if no WASCoB had been constructed in the vicinity.

Table 5-4: Parameters in the SWAT transfer function used to route WASCoB water

Parameter	Value	Definition
Command	4	Water transfer command
DEP_TYPE	2	Water source type, 2 - reservoir
DEP_NUM		Water source number, obtained from Table 5-2
DEST_TYPE	1	Destination type, 1 - reach
DEST_NUM		Destination number, obtained from Table 5-2
TRANS_AMT		Daily pipe discharge capacity, obtained from Table 5-2
TRANS_CODE	4	Code of water transfer method, 4 - transfer actual amount of water calculated based on the pipe rating curve (new development in SWAT for the Gully Creek WASCoBs)

6.0 SWAT CALIBRATION

6.1 Calibration strategy

Model calibration is the procedure that adjusts model input variables to optimize the agreement between measured data and model simulation results. Model validation is the process that demonstrates a given hydrologic model being capable of making accurate predictions for periods outside of the calibration period. A good validation result shows that the calibrated model is a good simulator of the measured data and does not over-fit the measured data in the calibration period. Because of the short period of available flow and water quality monitoring data in the Gully Creek watershed, all the data were used for model calibration while no model validation was performed. In order to make the best use of all available data to improve model performance, a multi-site, multi-period, and multi-objective calibration strategy was conducted in this study. Calibration efforts were focused on improving model predictions at Gully Creek's outlet GULGUL2 and three inside stations GULGUL3, GULGUL4, and GULGUL5 (Figure 3-2). Flow calibration focused on daily and monthly predictions. Water quality calibrations including sediment, nitrogen and phosphorus loading focused on point predictions rather than continuous daily and monthly predictions because of the in-field grab sampling frequency available to compare the modelled output against.

The calibration period at GULGUL2 was from July 12, 2010 to March 28, 2012. For GULGUL3, GULGUL4, and GULGUL5 the calibration period was from April 15, 2011 to December 31, 2011. These periods were selected for calibration because all reliable input data were available (climate, flow, sediment, nutrient and land management). The model calibration incorporated the existing BMPs observed to be already present in the watershed including 18 WASCoBs at various locations, existing conservation tillage and other land and nutrient management practices, as documented through the individual landowner surveys and the windshield surveys. The climate data prepared for the period of 2000-2001 were used for model warm-up so that the impacts of uncertain initial conditions on the model were minimized and then the model was run from 2002 to 2012.

The Gully Creek SWAT model was manually calibrated using the iSWAT interface developed by Yang et al. (2006). The iSWAT interface has a generic format that allows parameter aggregation on the basis of HRUs, soil, landuse, and subbasin specifications. This enables calibration to occur with multi-variables, multi-sites and multi-objectives realized within the modelling framework. The manual calibration was conducted for those parameters deemed most sensitive based on the parameter sensitivity analysis and SWAT user manual recommendations and guidance. Other (less sensitive) parameters were set to their default values and were not adjusted during the process of model calibration.

The general setup for the SWAT simulation in the Gully Creek watershed is presented in Table 6-1. Detail descriptions of parameter setup for snowmelt, flow, and sediment and nutrient yields are presented in following sections. The skewed normal method is used for sub-daily rainfall distribution when estimating soil erosion with the Modified Universal Soil Loss (MUSLE) equation. Potential Evapotranspiration (PET) is calculated in the model using Hargreaves method. Surface runoff is simulated using the SCS CN method and the flow is routed in the channel using the Muskingum method. The change of channel dimensions was kept active in the model. However, because of the small watershed area and short stream reaches, the process of in-stream water quality and Algae/CBOD/Dissolved Oxygen were not left active in the model. The option of simulating crack flow was also not set active in the model to reflect the field soil conditions in the watershed.

Table 6-1: General setup for SWAT simulation in the Gully Creek watershed

Rainfall distribution for MUSLE	Skewed normal
PET method	Hargreaves method
Rainfall/Runoff/Routing	Daily Rain/SCS CN Method/Daily
Crack flow	Not active
Algae/CBOD/Dissolved Oxygen	Not active
Channel routing method	Muskingum
Channel dimensions	Active
In-stream water quality	Not active

For flow simulation, model performance was qualitatively evaluated using time series plots and quantitatively evaluated using two model performance statistics: bias and the Nash–Sutcliffe coefficient (NSC) (Nash and Sutcliffe, 1970). Both of these statistics were completed on data at the daily and monthly time scales. Model bias can be expressed as the relative mean difference between predicted and observed stream flows for a sufficiently large simulation sample, reflecting the ability of reproducing the water balance. This is perhaps the most important criterion for comparing whether a model is working well in practice.

$$Bias = \sum_{i=1}^{N} Qs_i \Big/ \sum_{i=1}^{N} Qo_i - 1 \qquad (6\text{-}1)$$

where Bias is the model bias, Qsi and Qoi are the simulated and observed stream flows on day i (m3/s), and N is the number of days over the simulation period. Model bias measures the systematic under or over prediction for a set of predictions. A lower bias value indicates a better fit, and the value 0.0 represents a perfect simulation of observed flow volume. The Nash-Sutcliffe coefficient describes how well the stream flows are simulated by the model. As pointed out by Kachroo and Natale (1992), this efficiency criterion is commonly used for model evaluation, because it involves standardization of the residual variance, and its expected value does not change with the length of the record or the scale of runoff.

$$NSC = 1 - \sum_{i=1}^{N} \left(Qs_i - Qo_i \right)^2 \Big/ \sum_{i=1}^{N} \left(Qo_i - \overline{Qo} \right)^2 \qquad (6\text{-}2)$$

where NSC is the Nash-Sutcliffe efficiency. The NSC value can range from a negative value to 1. A NSC value below zero indicates that average measured stream flow would have been a better predictor of the modeled stream flow than SWAT was. A perfect model prediction has NSC value of 1. Generally, model simulations with a Nash-Sutcliffe score >0.8 are considered good and a score >0.6 is considered acceptable.

Sediment and water quality sampling in the Gully Creek watershed includes grab, ISCO, and composite stormwater unit distributed by Global Water Inc. (global). Grab sampling is based on rainfall events. An ISCO sampler sets to collect hourly samples over a 24-hour period when triggered with a rise in water level. A global sampler can be set to collect 500 millilitres every hour into a single bottle for a high-flow composite sample when triggered with a rise in water level. Because sediment and other water quality constituents are grab or grab-like samples with much lower measurement frequency and much higher uncertainty to represent daily average values, the above three evaluation criteria used to evaluate flow simulation would not be useful tools to appropriately evaluate the model's simulation performance of pollutant loadings. Therefore, the water quality predictions in this study were mainly evaluated graphically with time series plots together with three additional statistical measures: root mean square error (RMSE), root mean squared deviation CV (RMSE) and the correlation coefficient (CORR). The RMSE is a measure of the differences between values predicted by the model and the values observed. Complete details as to how these various statistical measures of model performance are calculated can be found in Table C-1 of Appendix C. Results of the calibration analyses are discussed later in Section 6.3

6.2 Sensitivity analysis

Sensitivity analysis of model parameters is valuable in assisting with model calibration. In order to improve SWAT calibration efficiency and to perform a quicker qualitative analysis, only the most sensitive parameters are adjusted within an acceptable (plausible) range, while other parameters remain at their default value in the calibration process. The extension program in SWAT2009, developed by Van Griensven et al. (2002), was used to analyze the sensitivity of flow parameters for the Gully Creek watershed. The program used in the parameter sensitivity analysis is based on the One-factor-At-a-Time (OAT) approach (Morris, 1991). Starting from a set of initial parameter values, this approach evaluates parameter sensitivities by allowing only one parameter to be changed in each model run according to a random schedule, while other parameter values remain constant. The sensitivity for each input parameter is quantified by calculating the mean value of partial effects after 10 model runs, and variance provides a measure of how uniform these effects are.

We selected 27 parameters associated with runoff generation and flow routing in the SWAT model (see Table 6-2) on which to conduct the sensitivity analysis. The objective function was based on the errors between observed and calculated daily discharges at the GULGUL2 station measured between July 12, 2010 and March 28, 2012. Ten (10) random model runs were implemented for each parameter. The averages of the ranges in the sensitivity analysis were specified as the initial values for the snowmelt related parameters, while the SWAT default values were taken as the initial values for other parameters. The sensitivity analysis results, including mean, variance and the rank are presented in Table 6-2. Figure 6-1 gives a graphical representation of the parameter sensitivities.

Table 6-2: SWAT flow parameter sensitivity analysis for the Gully Creek watershed

Parameter	Type	File	Mean	Variance	Rank	Description
CN2	sub	mgt	2.62	2.76	1	Initial SCS CN II value
ESCO	sub	hru	0.794	0.732	2	Soil evaporation compensation factor
SOL_Z	sub	sol	0.764	0.393	3	Soil depth (mm)
SOL_AWC	sub	sol	0.617	0.088	4	Available soil water capacity (mm/mm)
SMFMN	bas	bsn	0.374	0.142	5	Melt factor for snow on Dec. 21 (mm/°C-day)
SLOPE	sub	hru	0.333	0.060	6	Average slope steepness (m/m)
SOL_K	sub	sol	0.285	0.042	7	Saturated hydraulic conductivity (mm/hr)
TIMP	bas	bsn	0.259	0.134	8	Snow pack temperature lag factor
SMFMX	bas	bsn	0.193	0.027	9	Melt factor for snow on Jun. 21 (mm/°C-day)
CANMX	sub	hur	0.170	0.011	10	Maximum canopy storage (mm)
SMTMP	bas	bsn	0.138	0.022	11	Snowmelt base temperature (°C)
GWQMN	sub	gw	0.137	0.087	12	Threshold depth for return flow (mm)
RCHRG_DP	sub	gw	0.087	0.062	13	Deep aquifer percolation factor
ALPHA_BF	sub	gw	0.074	0.039	14	Baseflow alpha factor (days)
SFTMP	bas	bsn	0.043	0.0101	15	Snowfall temperature (°C)
GW_REVAP	sub	gw	0.032	0.0104	16	Groundwater "revap" coefficient
SOL_ALB	sub	sol	0.030	0.0014	17	Moist soil albedo
CH_K2	sub	rte	0.022	0.0015	18	Channel hydraulic conductivity (mm/hr)
BIOMIX	sub	mgt	0.019	3×10^{-4}	19	Biological mixing efficiency
EPCO	sub	hru	0.005	3.5×10^{-5}	20	Plant uptake compensation factor
SURLAG	bas	bsn	0.003	2.6×10^{-5}	21	Surface runoff lag time (days)
REVAPMN	sub	gw	0.0017	2.8×10^{-5}	22	Threshold depth for "revap" (mm)
CH_N	sub	rte	0.0013	1×10^{-6}	23	Manning's n value for main channel
SLSUBBSN	sub	hru	0.0012	1×10^{-6}	24	Average slope length (m)
GW_DELAY	sub	gw	0.0008	7×10^{-6}	25	Groundwater delay (days)
TLAPS	sub	sub	0	0	26	Temperature lapse rate (°C/km)
BLAI	sub	crp	0	0	27	Maximum potential leaf area index

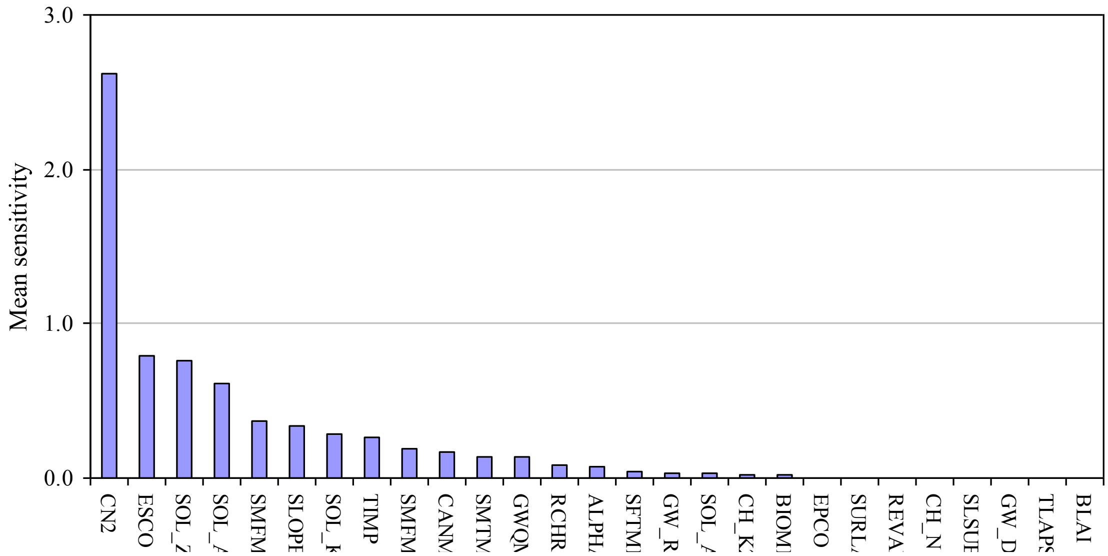


Figure 6-1: Mean sensitivity of SWAT parameters for flow calibration

Among the selected flow parameters, CN2 has the highest sensitivity with mean sensitivity value of 2.62 and variance of 2.96. The parameter SOL_Z also has a higher mean sensitivity value (0.393). This parameter was fixed in the soil database reflecting the actual soil characteristics, and therefore was not used in the calibration process. The 20 remaining parameters with sensitivity value greater than 0.002 (CN2, ESCO, SOL_AWC, SMFMN, SOL_K, SLOPE, TIMP, SMFMX, CANMX, SMTMP, GWQMN, RCHRG_DP, ALPHA_BF, SFTMP, GW_REVAP, SOL_ALB, CH_K2, BIOMIX, EPCO, SURLAG, and REVAPMN) were considered as the key calibration variables for the manual calibration scheme applied. Other parameters listed in Table 6.2 were left at their default values specified during model setup.

Because sediment and water quality observed data were from grab samples with lower observation frequency, parameters related to loading and transport of sediment and nutrients were not included in the sensitivity analysis but were adjusted by means of manual calibration.

6.3 Flow Calibration

Flow calibration in this study focused on improving model performance at the four flow monitoring stations. The Gully Creek watershed is located in the eastern shore of Lake Huron with significant snowmelt. The majority of stream flow is concentrated in March, April and May from snowmelt and partially from rainfall during snowmelt, while stream flow in other months is much less and may become zero in summer, autumn and winter periods. In summer, the moderately high infiltration capacity of the soil, combined with the high evapotranspiration potential, prevents runoff on the upland except during unusually intense storm events. Therefore, calibration of SWAT snowmelt parameters is a key step in the Gully Creek watershed modelling.

The snowmelt in the SWAT is calculated on an HRU basis and is a linear function of the snow pack temperature, maximum air temperature, the melting rate, and the areal coverage of snow. Snowmelt is included with rainfall in the calculations of runoff and percolation. The melt factor is defined to allow a seasonal variation with maximum and minimum values occurring on summer and winter solstices. When the mean daily air temperature is less than the snowfall temperature, the precipitation within an HRU is classified as snow and the liquid water equivalent of the snow precipitation is added to the snowpack. The snowpack increases with additional snowfall, but decreases with snowmelt or sublimation. Five snow and snowmelt-related parameters (SFTMP, SMTMP, SMFMX, SMFMN, and TIMP) were selected in the model calibration for the Gully Creek watershed, and the final specified parameter values are listed in Table 6-3.

Along with the identified snowmelt-related parameters, the parameters CN2, ESCO, SOL_AWC, SOL_K, CANMX, GWQMN, RCHRG_DP, ALPHA_BF, GW_REVAP, SOL_ALB, CH_K2, BIO_MIX, EPCO, and SURLAG, as listed in Table 6-3, were also adjusted at the same time to match flows observed at GULGUL2, GULGUL3, GULGUL4 and GULGUL5 on daily basis. The parameters of CN2, SOL_K, SOL_ALB, and SOL_AWC have spatial patterns that may vary from HRU to HRU. For simplification purposes, calibration of these four parameters was implemented by fixing their spatial patterns and allowing them to change by multiplying a coefficient within a predefined range. The final CN2 value was increased by 1.0% and SOL_AWC value was decreased by 10% from the default parameter set, while SOL_K and SOL_ALB values remained the same as the default parameter value chosen. The parameters of SLOPE (average slope steepness) and SLSUBBSN (average slope length) for each HRU were obtained from the 5 m DEM. SWAT allows the adjustment of these two parameters based on the DEM cell size and the delineated HRU area with an acceptable range of -20% to 20% (Neitsch et al., 2005). In this study, these two parameters were also adjusted manually in conjunction with sediment calibration at the three stations (Table 6-3). The calibrated SWAT model was then used to simulate the daily stream flows for both the simulation periods. The simulation results were compared with the corresponding observed values at daily, monthly, and annual time steps. The comparison of observed and simulated daily stream flow at GULGUL2 for the simulation years of July 12, 2010 – March 28, 2012 is shown in Figure 6-2. The comparisons of observed and simulated daily stream flow at GULGUL3, GULGUL4 and GULGUL5 for the simulation years of July 15, 2010 – March 28, 2012 are shown in Figure 6-3, Figure 6-4 and Figure 6-5. The evaluation results summarized in Table 6-4 show that SWAT reproduced flow at the GULGUL2, GULGUL3, and GULGUL5 stations, very well for the calibration period.

Table 6-3: SWAT runoff and routing parameters adjusted when calibrating the Gully Creek watershed modelling

Parameter	Definition	File	Value	Sensitivity
SFTMP	Snowfall temperature (°C)	bsn	1.50	Moderate
SMTMP	Snowmelt base temperature (°C)	bsn	-1.00	High
SMFMX	Melt factor for snow on June 21 (mm/d)	bsn	6.50	High
SMFMN	Melt factor for snow on December 21 (mm/d)	bsn	2.50	High
TIMP	Snow pack temperature lag factor	bsn	1.00	High
CN2	Initial SCS curve number for moisture condition II	mgt	0.01*	High
ESCO	Soil evaporation compensation factor	hru	0.997	High
SOL_AWC	Soil available water content	sol	-0.10*	High
SOL_K	Saturated hydraulic conductivity (mm/hr)	sol	0.00*	High
CANMX	Maximum canopy storage (mm)	hru	5.00	High
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	gw	0.00	High
RCHRG_DP	Deep aquifer percolation fraction	gw	0.01	Moderate
ALPHA_BF	Baseflow alpha factor (days)	gw	0.50	Moderate
GW_REVAP	Groundwater "revap" coefficient	gw	0.15	Moderate
SOL_ALB	Moist soil albedo	sol	0.00*	Moderate
CH_K2	Channel hydraulic conductivity (mm/hr)	rte	10.0	Moderate
BIO_MIX	Biological mixing efficiency	mgt	0.30	Moderate
EPCO	Plant uptake compensation factor	hru	0.03	Moderate
SURLAG	Surface runoff lag time (days)	bsn	0.50	Moderate

* Ratio of relative parameter change, e.g. CN2 modified = CN2 - 0.1CN2

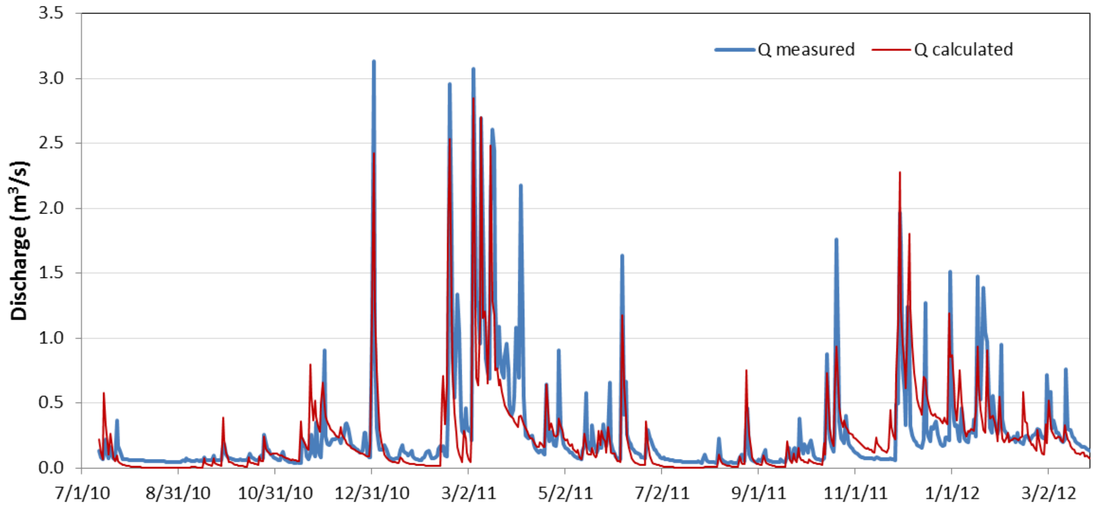


Figure 6-2: Flow calibration at GULGUL2

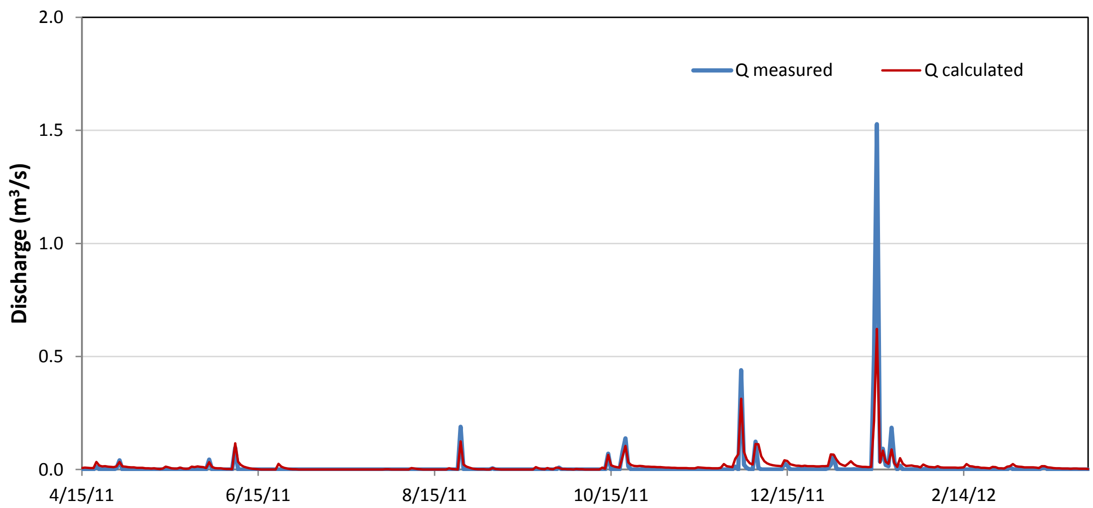


Figure 6-3: Flow Calibration at GULGUL3

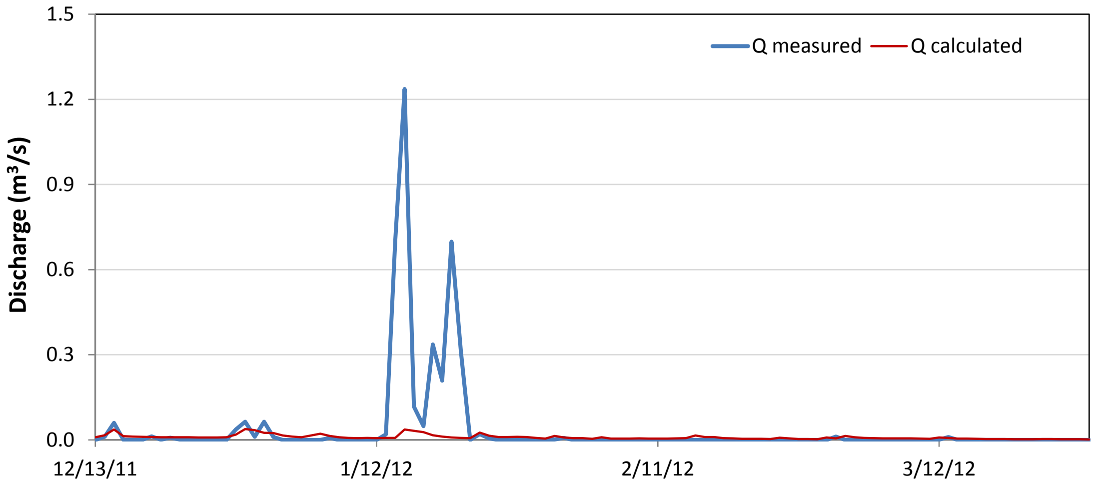


Figure 6-4: Flow Calibration at GULGUL4

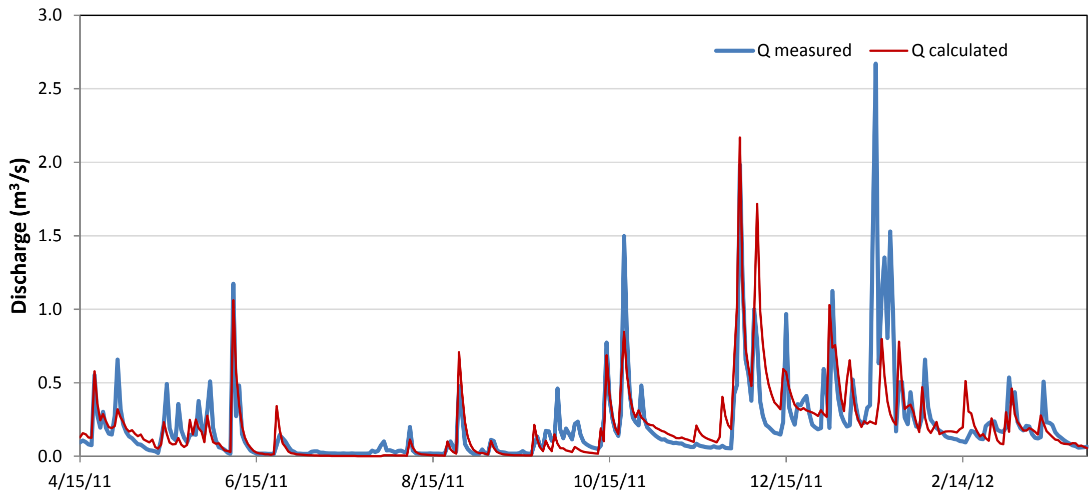


Figure 6-5: Flow Calibration at GULGUL5

Table 6-4: Model performance for flow simulation at the four stations

Station	Period	Bias	Daily NS	Monthly NS
GULGUL2	7/12/2010-3/28/2012	-0.08	0.64	0.82
GULGUL2	4/15/2011-12/31/2011	0.05	0.68	0.84
GULGUL3	4/15/2011-12/31/2011	0.10	0.61	0.80
GULGUL4	12/13/2011-3/28/2012	-	-	-
GULGUL5	4/15/2011-12/31/2011	0.08	0.62	0.81

Because of the effect of ice block and back water in upstream channels, high water levels were observed at GULGUL3, GULGUL4, and GULGUL5 for the 2012 January event leading to very high derived observed flow peaks based on their stage-discharge curves as shown in Figure 6-3, 6-4, and 6-5. These derived flows did not reflect the actual field situation and therefore were not used for calibrating model parameters and evaluating model performance. Model biases at GULGUL2 for the period 7/12/2010-3/28/2012 and 4/15/2011-12/31/2011 are -0.08 and -0.04, and Daily NSC efficiency are 0.64 and 0.68 respectively. Model biases at GULGUL3 and GULGUL5 for the period 4/15/2011-12/31/2011 are 0.10 and 0.08, and daily NSC efficiency are 0.61 and 0.62 respectively. Monthly NSC efficiencies for the three stations are all over 0.80. Given the uncertainties of stream flows at the three monitoring stations, SWAT was able to have a good performance over the simulation period. The model captured the rising and recessing patterns exhibited by the computed stream flows. The model underestimated the flow volume at GULGUL2 for the year 2010 but overestimated the flow volumes at the three stations for the year 2011 (Table 6-4). Overall, the SWAT-simulated stream flows at the three stations matched the measured flows very well in term of magnitude, peak time, and flow volume.

6.4 Sediment Calibration

SWAT simulates sediment loading to streams from upland field using the modified universal soil loss equation (MUSLE) as well as channel bed sediment erosion and deposition. Therefore, the model estimates of sediment loading are for the total sediment transport including suspended sediment and bed-load sediment. Grab samples analysed for sediment concentration are available in 4/2007-12/2011 at GULGUL2, 7/2009-3/2012 at GULGUL3, 3/2011-3/2012 at GULGUL4, and 4/2011-12/2011 at GULGUL5. Sediment concentration data measured in samples taken using Global Water™ stormwater samplers are also available for 5/2011-12/2011 at GULGUL2 and GULGUL3 (Table 6-6). These data were used to calibrate the SWAT sediment loading and transport parameters. The calibration was done manually by comparing the simulated sediment load to the measured load. The measured sediment load was computed by multiplying the measured concentration by the measured discharge, while the simulated sediment load was computed by multiplying the simulated concentration by the simulated discharge.

Thirteen SWAT soil erosion and sediment transport parameters were selected in the sediment manual calibration (see Table 6-5). Special attention was given to the calibration for high flow periods during which the majority of sediment was produced. The parameters of SLOPE and SLSUBBSN are sensitive to runoff, sediment and nutrient loading. The initial setup of these two parameters were derived based on the average HRU slope and slope length, and are affected by the DEM cell size. The final adjusted parameter values of SLOPE and SLSUBBSN are 90% of their respective initial values derived from ArcSWAT for all HRUs in the watershed. The support practice factor, USLE_P, is defined as the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down slope culture. This default USLE_P values can be found from Neitsch et al. (2005) for contour crops on various slopes. The final USLE_P value was adjusted to 75% of the initial default value for all HRUs reflecting partial implementation of conservation tillage in the study watershed. In addition, the value of parameter USLE_K was decreased by 10% for all HRUs reflecting slightly below default soil erodibility condition in the study watershed. The eight channel erosion and sediment routing parameters, SPCON, PRF, SPEXP, CH_EROD, CH_COV, CH_N2, CH_W2, and CH_S2 were adjusted mainly based on the sediment data collected at the two main stream stations, GULGUL2 and GULGUL5. The linear and exponent parameters for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing were set to 0.01 and 2.0 respectively. The peak rate adjustment factor (PRF) was set to 2.0, the channel erodibility factor (CH_EROD) was set to 0.25, the channel cover factor (CH_COV) was set to 0.20, the channel roughness coefficient was set to 0.04, the bank full channel width was adjusted to 80% of the initial value, and the channel slope remained unchanged during model sediment calibration.

Table 6-5: SWAT sediment parameters adjusted when calibrating the Gully Creek watershed modelling

Parameter	Definition	File	Value	Sensitivity
SLSSUBBSN	Average slope length	hru	-0.10*	High
SLOPE	Average slope steepness	hru	-0.10*	High
USLE_K	USLE soil erodibility factor	sol	-0.10*	High
USLE_C	Minimum USLE crop factor	crp	0.00*	Moderate
USLE_P	USLE support practice factor	mgt	-0.25*	High
SPCON	Linear parameter for calculating the maximum Linear parameter for calculating sediment that can be re-entrained during channel routing	bsn	0.01	High
SPEXP	Exponent parameter for calculating sediment re-entrained in channel sediment routing	rte	2.0	Moderate
PRF	Peak rate adjustment factor for sediment routing in the main channel	bsn	2.00	High
CH_EROD	Channel erodibility factor	rte	0.25	High
CH_COV	Channel cover factor	rte	0.20	Moderate
CH_N2	Channel roughness coefficient	rte	0.04	Moderate
CH_W2	Bankfull channel width	rte	-0.20*	Moderate
CH_S2	Channel slope	rte	0.00*	High

Note: * ratio of relative parameter change, e.g. SLOPE modified = SLOPE - 0.1SLOPE

The final SWAT sediment parameter values after model calibration are listed in Table 6-5. The comparison of observed and simulated daily sediment load at GULGUL2 for the simulation period of July 2010 to December 2011 is shown in Figure 6-6. Comparisons of observed and simulated daily sediment load at GULGUL3 and GULGUL4 for the simulation period of November 2010 to December 2011 are given in Figure 6-7 and Figure 6-8 respectively. Comparison of observed and simulated daily sediment load at GULGUL5 for the simulation period of April 2011 to December 31, 2011 is shown in Figure 6-9. The results of statistical model performance (RMSE, CV, and CORR) for the four monitoring stations over the simulation period are provided in Table 6-6.

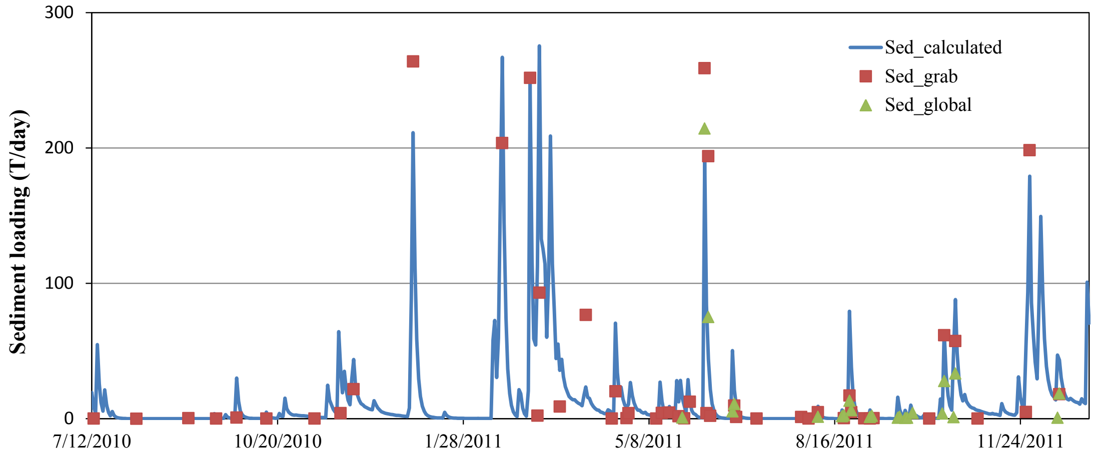


Figure 6-6: Sediment calibration at GULGUL2

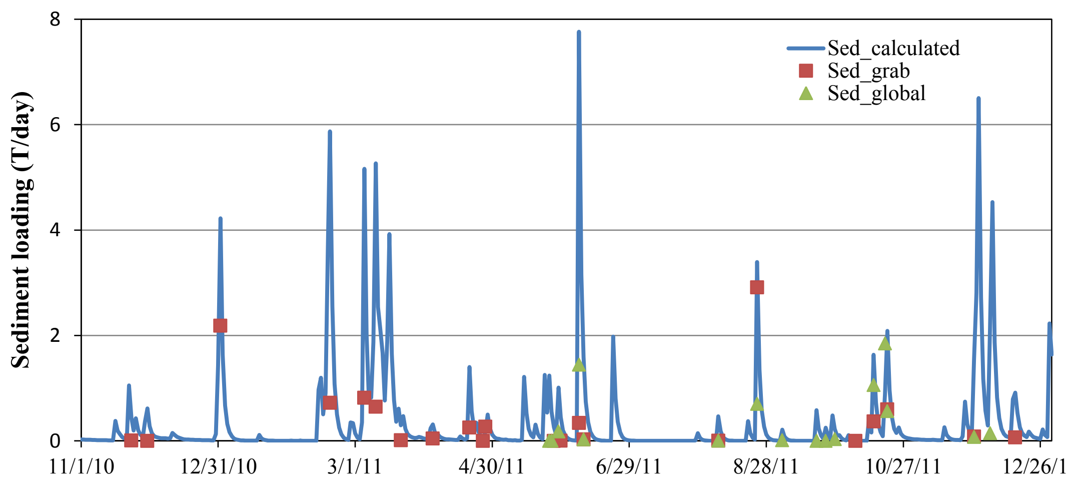


Figure 6-7: Sediment calibration at GULGUL3

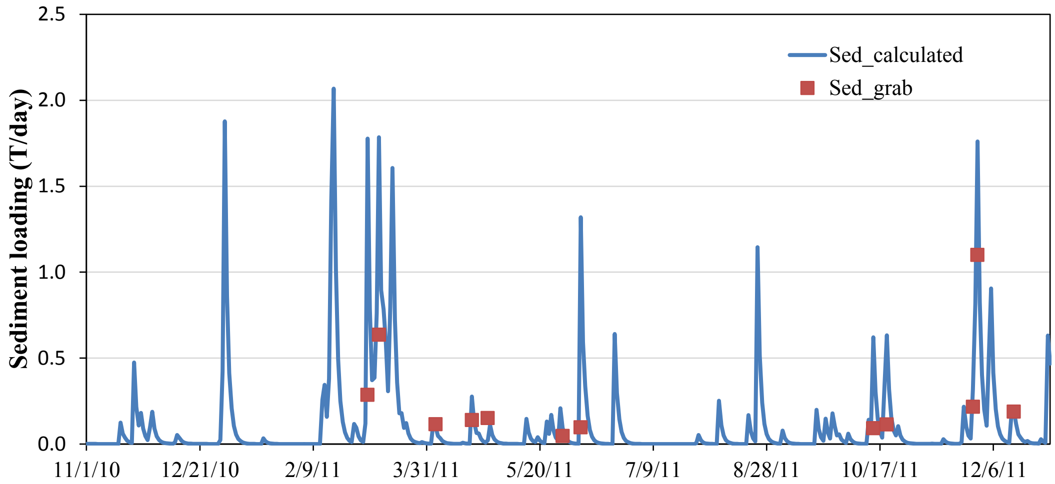


Figure 6-8: Sediment calibration at GULGUL4

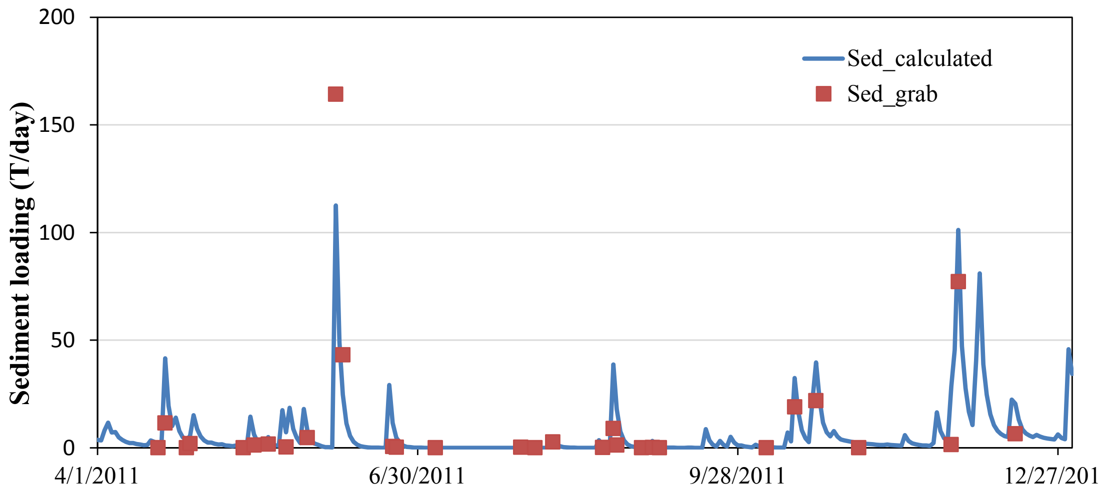


Figure 6-9: Sediment calibration at GULGUL5

Table 6-6: Model performance for sediment loading at the four stations

Station	Type	Period (month/year)	N	RMSE (T/day)	CV	CORR
GULGUL2	Global	5/2011-12/2011	23	2.290	0.124	0.854
GULGUL2	Grab	3/2010-12/2011	58	2.348	0.075	0.806
GULGUL3	Global	5/2011-12/2011	16	1.852	0.704	0.553
GULGUL3	Grab	11/2010-12/2011	23	0.746	0.820	0.510
GULGUL4	Grab	3/2011-12/2011	12	0.453	0.709	0.685
GULGUL5	Grab	4/2011-12/2011	30	1.692	0.137	0.891

Since sediment load is a product of sediment concentration and flow rate, the predicted daily discharge has a great impact on predicted sediment load. This is demonstrated in Table 6-6, where the two mainstream stations GULGUL2 and GULGUL5 show higher CORR values compared to the two field-edge stations GULGUL3 and GULGUL4. In addition, the CORR values calculated for global sediment data are higher than values calculated for grab sediment data at stations GULGUL2 and GULGUL3. This indicates that the grab sampling data may over-estimate or under-estimate the daily average sediment loading compared to a global sampling methodology. Overall, the sediment load predictions appear to agree with the measurements at the four monitoring stations as demonstrated in the above figures and with the above statistical results. The model gives a better performance at the two mainstream stations compared to the two field-edge stations. These sediment parameters are applied to evaluate sediment load at both the field and watershed outlet for various BMP scenarios as discussed in Chapter 7.

6.5 Nutrients Calibration

Phosphorus (P) and nitrogen (N) are two major nutrients that are essential for plant growth and crop production, and are therefore selected for model simulation in the Gully Creek WBBE project. Both nutrients are components of chemical fertilizers, livestock manures and decomposing crop residue. They can be dissolved in water, attached to soil particles or as particles of fertilizer.

6.5.1 Phosphorus Calibration

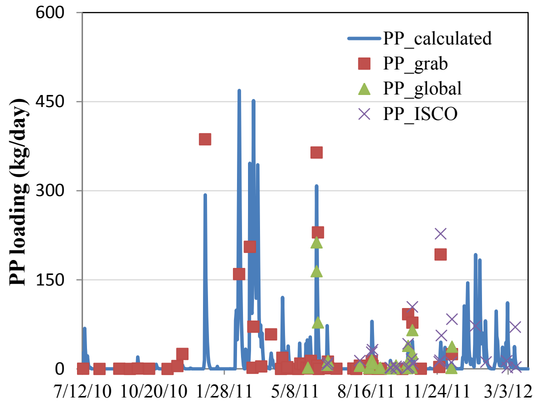
For phosphorus (P), the available water quality data were analyzed for particulate phosphorus (PP), dissolved phosphorus (DP) and total phosphorus (TP), where TP = PP + DP. The SWAT simulates seven forms of P in the soil and water (active mineral P, stable mineral P, solution P, active organic P, stable organic P, fresh organic P, and groundwater soluble P). These seven forms of P are loaded to the stream and are aggregated into mineral P (MINP) and organic P (ORNP) in the model output files. MINP is the sum of active mineral P, solution P and groundwater soluble P, while ORGP is the sum of stable mineral P, active organic P, stable organic P, and fresh organic P. SWAT assumes that all forms of P are attached to sediment particles when entering the stream except for solution P. Because MINP simulated in SWAT includes active mineral P attached to the sediment particles, it is likely to over-estimate the monitored DP and consequently under-estimate monitored PP. Assuming the active mineral P attached to the sediment is a very small portion of the DP, we simply compared the SWAT simulated MINP with monitored DP and the simulated ORGP with monitored PP, and gave more focus on the comparison between simulated TP and monitored TP.

Eight SWAT P parameters were selected in the P manual calibration process as listed in Table 6-7. Among these parameters, the initial soil soluble and organic P concentrations are more sensitive in SWAT P calibration. The parameters of SOL_SOLP and SOL_ORGP were set to 15 and 200 mg/kg respectively in the soil after model calibration. These values are comparable with field measurement of soil P in the study area (personal communication with Kevin McKague, OMAFRA and Ross Wilson, ABCA). The phosphorus available index (PSP) governs the equilibration of soil P between the solution and active pool and also controls the initial mineral P level in the soil. This parameter was set to 0.45 after model calibration which is comparable with the values reported in the literature (Muleta and Nicklow, 2005; Tolson and Shoemaker, 2007). The parameters of PPERCO and PHOSKD were set to 15 and 200 after model calibration. P_UPDIS and GWSOLP were kept to their default parameter values as they are less sensitive to the modelling result. Because in-stream water quality simulation was set to non-active in the model setup, those in-stream P parameters were not adjusted in the model calibration. The final SWAT P parameter values after model calibration are listed in Table 6-7.

Table 6-7: SWAT P parameters assigned for the Gully Creek watershed

Parameter	Definition	File	Value	Sensitivity
SOL_SOLP	Initial soluble P concentration in the soil layer (mg/kg)	chm	15	High
SOL_ORGP	Initial organic P concentration in the soil layer (mg/kg)	chm	200	High
PSP	Phosphorus availability index	bsn	0.45	High
ERORGP	Organic P enrichment ratio	hru	1.3	High
PPERCO	Phosphorus percolation coefficient	bsn	15	High
PHOSKD	Phosphorus soil partitioning coefficient	bsn	200	Moderate
P_UPDIS	Phosphorous uptake distribution parameter	bsn	10	Moderate
GWSOLP	Concentration of soluble phosphorous in ground water contribution to stream flow (ppm)	gw	0.001	Moderate

The calibration of P was conducted by comparing simulated P load with in-situ measurements at monitoring stations. These data included grab, ISCO, and global sampling data at GULGUL2, grab and global sampling data at GULGUL3, grab sampling data at GULGUL4, and grab and ISCO data at GULGUL5. Daily concentrations of PP, DP, and TP were estimated by averaging the samples collected on the monitoring date. Comparisons of observed and simulated daily PP, DP, and TP load at GULGUL2 for the simulation period of July 2010 to March 2012 is shown in Figure 6-10 and Figure 6-11 respectively. Comparisons of observed and simulated daily PP, DP, and TP load at GULGUL3 and GULGUL4 for the simulation period of November 2010 to March 2012 are given in Figure 6-12, Figure 6-13, Figure 6-14, and Figure 6-15, respectively. Comparisons of observed and simulated daily PP, DP, and TP load at GULGUL5 for the simulation period of April 2011 to March 2011 is shown in Figure 6-16 and Figure 6-17 respectively. The results of statistical model performance on PP, DP, and TP (RMSE, CV, and CORR) for the four monitoring stations over the simulation period are provided in Table 6-8.



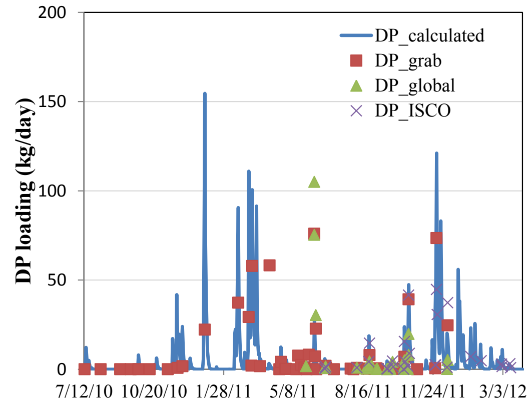


Figure 6-10: PP and DP calibration at GULGUL2

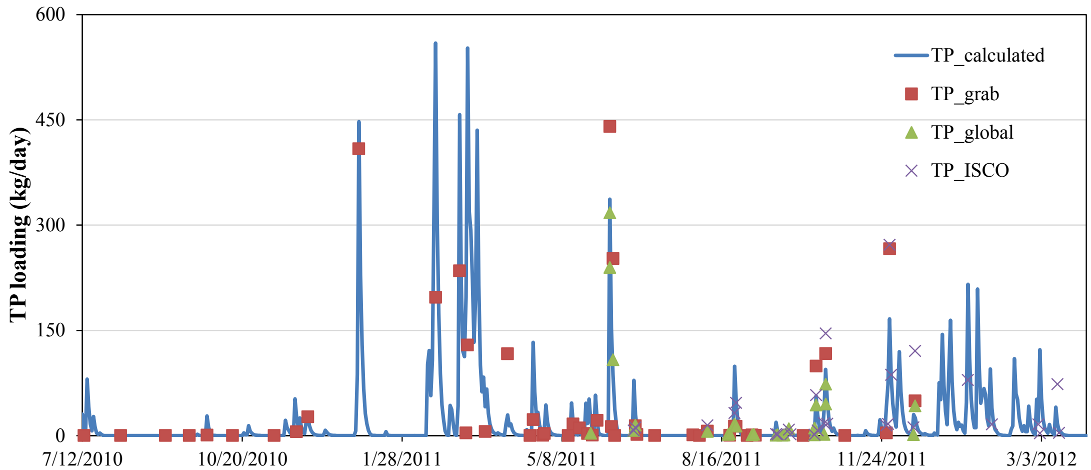
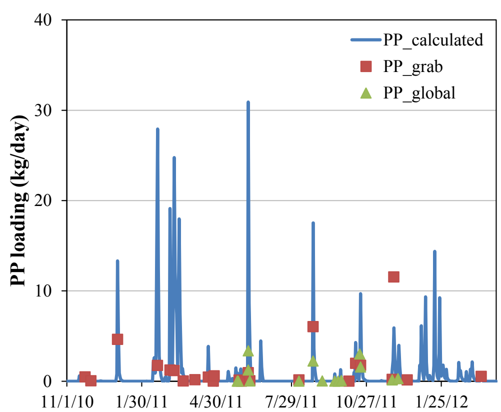


Figure 6-11: TP calibration at GULGUL2



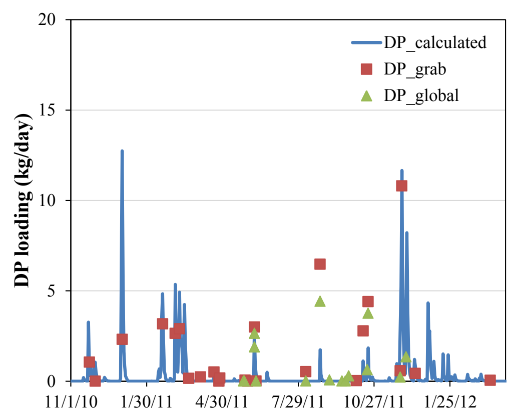


Figure 6-12: PP and DP calibration at GULGUL3

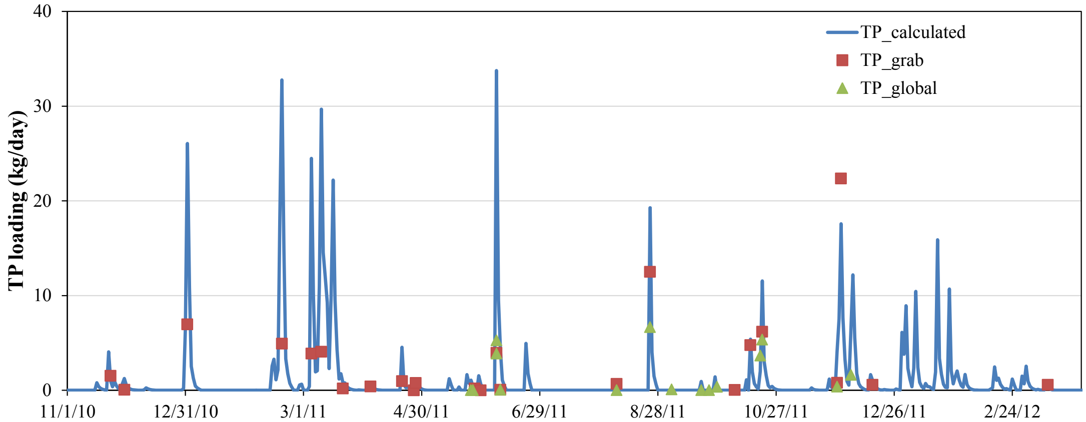
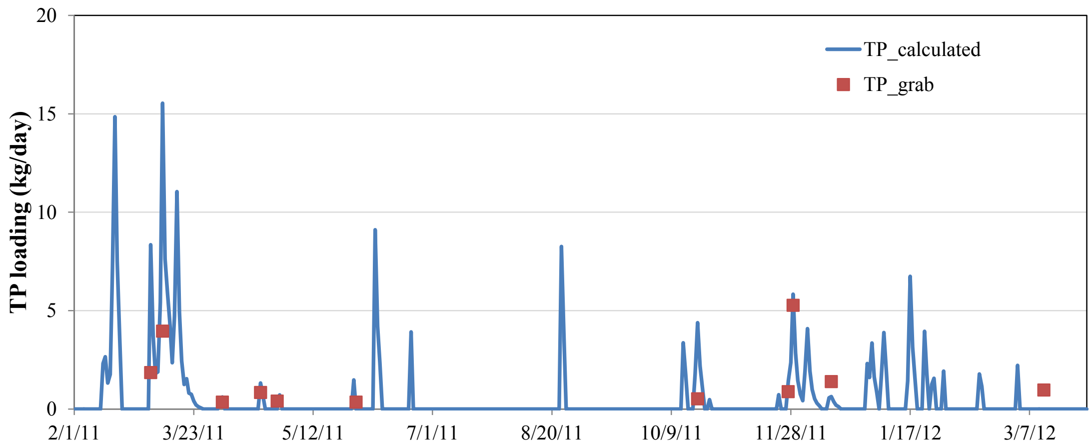


Figure 6-13: TP calibration at GULGUL3



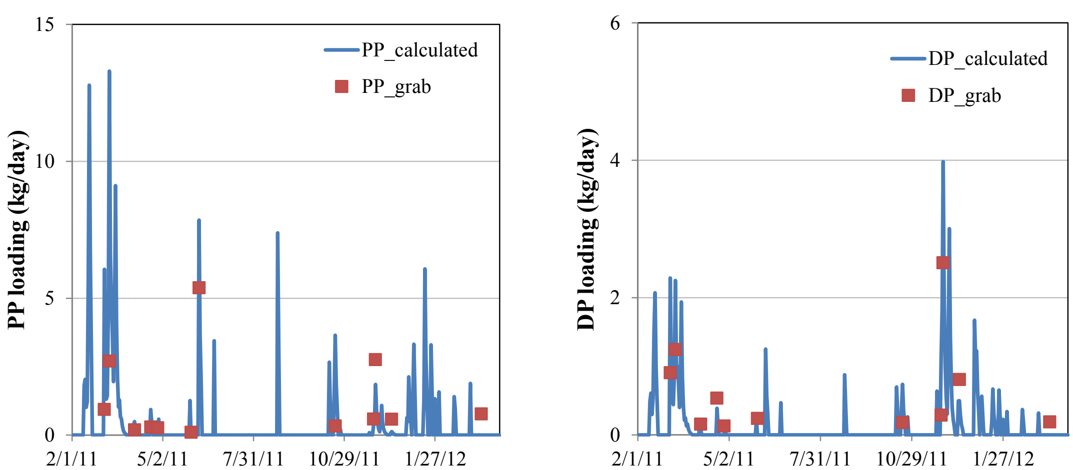


Figure 6-14: TP calibration at GULGUL4

Figure 6-15: PP and DP calibration at GULGUL4

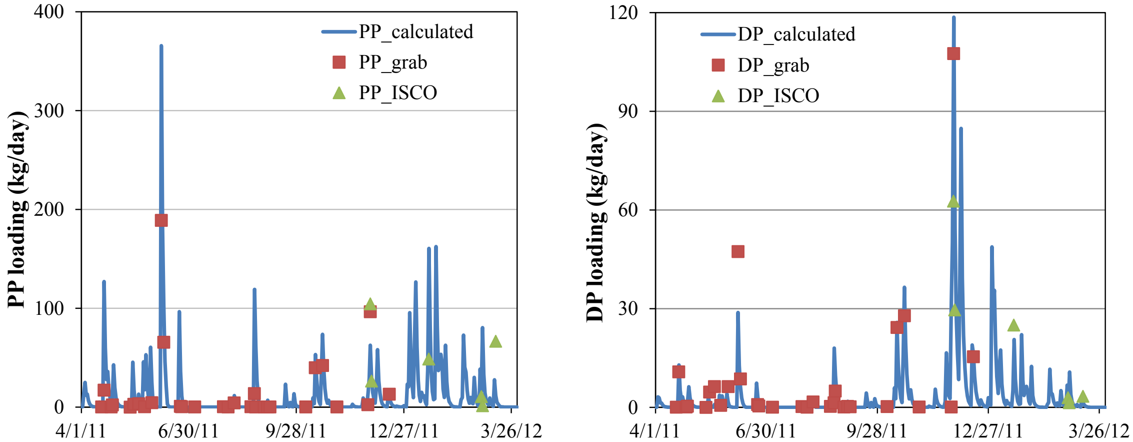


Figure 6-16: PP and DP calibration at GULGUL5

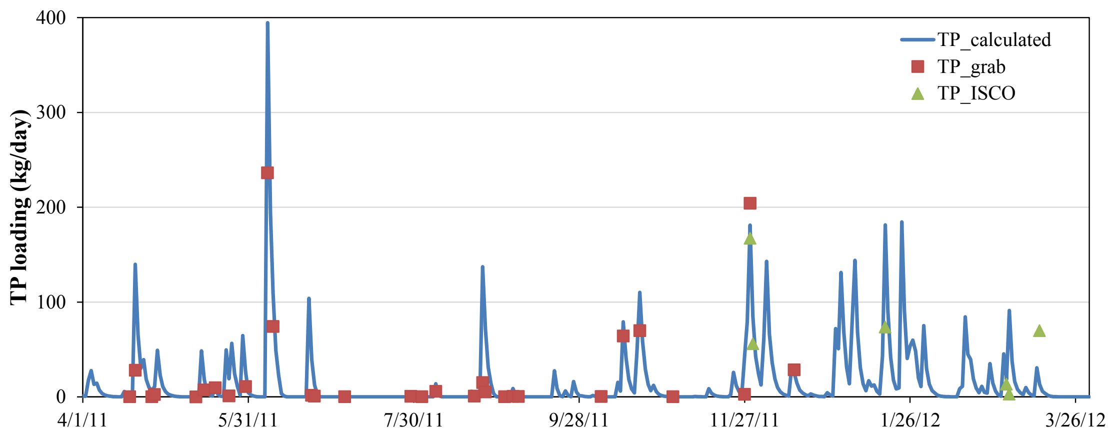


Figure 6-17: TP calibration at GULGUL5

Table 6-8: SWAT performance for PP, DP, and TP in the Gully Creek watershed

Station	Type	Period (month/year)	N	PP RMSE (kg/day)	PP CV	PP CORR	DP RMSE (kg/day)	DP CV	DP CORR	TP RMSE (kg/day)	TP CV	TP CORR
GULGUL2	Grab	7/2010-12/2011	50	3.520	0.088	0.662	2.014	0.202	0.623	3.768	0.075	0.729
GULGUL2	Global	5/2011-12/2011	23	2.649	0.133	0.923	1.906	0.270	0.441	2.532	0.094	0.933
GULGUL2	ISCO	6/2011-3/2012	27	2.895	0.092	0.483	1.998	0.226	0.730	2.708	0.067	0.629
GULGUL3	Grab	11/2010-3/2012	24	1.484	1.048	0.369	0.728	0.412	0.668	1.541	0.484	0.525
GULGUL3	Global	5/2011-12/2011	14	1.553	2.252	0.561	0.609	0.656	0.412	1.542	0.953	0.660
GULGUL4	Grab	3/2011-3/2012	12	1.023	0.823	0.653	1.209	0.562	0.271	1.304	0.384	0.538
GULGUL5	Grab	4/2011-12/2011	30	2.911	0.175	0.879	3.584	0.397	0.455	2.905	0.113	0.778
GULGUL5	ISCO	11/2011-3/2012	6	3.060	0.118	0.360	3.216	0.154	0.967	5.064	0.079	0.618

Similar to sediment load calibration, the predicted daily discharge has a great impact on predicted TP, PP, and DP load. As demonstrated in Table 6-8, the two mainstream stations GULGUL2 and GULGUL5 have higher CORR values compared to the two field-edge stations GULGUL3 and GULGUL4. In addition, The CORR values calculated for global P data are higher than values calculated for grab and ISCO P data at stations GULGUL2 and GULGUL3, and the CORR value calculated for grab P data is higher than the value calculated for ISCO P data at station GULGUL5. This indicates that the grab and ISCO sampling data may over-estimate or under-estimate the daily average P loading compared to global sampling data. Overall, the TP, PP, and DP load predictions appear to agree with the measurements at the four monitoring stations as demonstrated in the above figures and the statistical results. The model gives a better performance at the two mainstream stations compared to the two field-edge stations in simulating PP, DP, and TP. These P parameters are applied to evaluate PP, DP, and TP loads at both field and watershed outlet for various BMP scenarios as discussed in Chapter 7.

6.5.2 Nitrogen Calibration

With respect to N, the available nitrogen data were analyzed for particulate nitrogen (PN), total dissolved nitrogen (TDN) and total nitrogen (TN), where TN = PN + TDN. Similar to P, the SWAT-simulated mineral N (MINN), where MINN = N-NO3 + N-NO2 + N-NH4, was compared with monitored TDN and the simulated organic N (ORGN) was compared with the monitored PN. Equal efforts were given to the comparison of PN, DN, and TN between simulated and monitored values.

Ten SWAT N input parameters were selected in the N manual calibration process as listed in Table 6-9. Among these parameters, the initial soil soluble and organic N concentrations are more sensitive in SWAT N calibration. The parameters of SOL_NO3 and SOL_ORGN were set to 15 and 2,200 mg/kg respectively in the soil after model calibration. These values are comparable with field measurements of soil N in the study area (personal communication with Kevin McKague, OMAFRA and Ross Wilson, ABCA). To allow for more humus mineralization and nitrogen percolation, the parameter CMN was increased to 0.0005 from the default value of 0.0003 and the parameter NPERCO was increased to 0.30 from the default value of 0.20. The residual decomposition coefficient (RSDCO) was decreased to 0.04 from the default value of 0.05 and the biological mixing efficiency (BIOMIX) was increased to 0.30 from the default value of 0.20 (Table 6-2). In addition, the Organic N enrichment ratio (ERORGN), nitrogen uptake distribution parameter (N_UPDIS), denitrification exponential rate coefficient (CDN), and denitrification threshold water content (SDNCO) were set to 2.5, 10, 1.4, and 1.1 respectively as listed in Table 6-9.

Table 6-9: SWAT N parameters assigned for the Gully Creek watershed

Parameter	Definition	File	Value	Sensitivity
SOL_NO3	Initial NO3 concentration in the soil layer (mg/kg)	chm	15	High
SOL_ORGN	Initial organic N concentration in the soil layer (mg/kg)	chm	2200	High
NPERCO	Nitrogen percolation coefficient	bsn	0.30	High
ERORGN	Organic N enrichment ratio	hru	2.5	High
N_UPDIS	Nitrogen uptake distribution parameter	bsn	10	Moderate
CMN	Rate factor for humus mineralization of active organic nitrogen	bsn	0.0005	Moderate
RSDCO	Residue decomposition coefficient	bsn	0.04	Moderate
RCN	Concentration of nitrogen in rainfall (mg/l)	bsn	1.0	Moderate
CDN	Denitrification exponential rate coefficient	bsn	1.4	Moderate
SDNCO	Denitrification threshold water content	bsn	1.1	Moderate

The calibration of N was conducted by comparing the simulated N load with in-situ measurements at monitoring stations. These data included grab, ISCO, and global sampling data at GULGUL2, grab and global sampling data at GULGUL3, grab sampling data at GULGUL4, and grab and ISCO data at GULGUL5. Daily concentration of PN, DN, and TN was estimated by taking an average of the samples collected on the monitoring date. Comparisons of observed and simulated daily PN, DN, and TN load at GULGUL2 for the simulation period of July 2010 to March 2012 is shown in Figure 6-18 and Figure 6-19 respectively. Comparisons of observed and simulated daily PN, DN, and

TN load at GULGUL3 and GULGUL4 for the simulation period of November 2010 to March 2012 are given in Figure 6-20, Figure 6-21, Figure 6-22, and Figure 6-23, respectively. Comparisons of observed and simulated daily PN, DN, and TN load at GULGUL5 for the simulation period of April 2011 to March 2011 are shown in Figure 6-24 and Figure 6-25 respectively. The results of statistical model performance (RMSE, CV, and CORR) on PN, DM, and TN for the four monitoring stations over the simulation period are provided in Table 6-10.

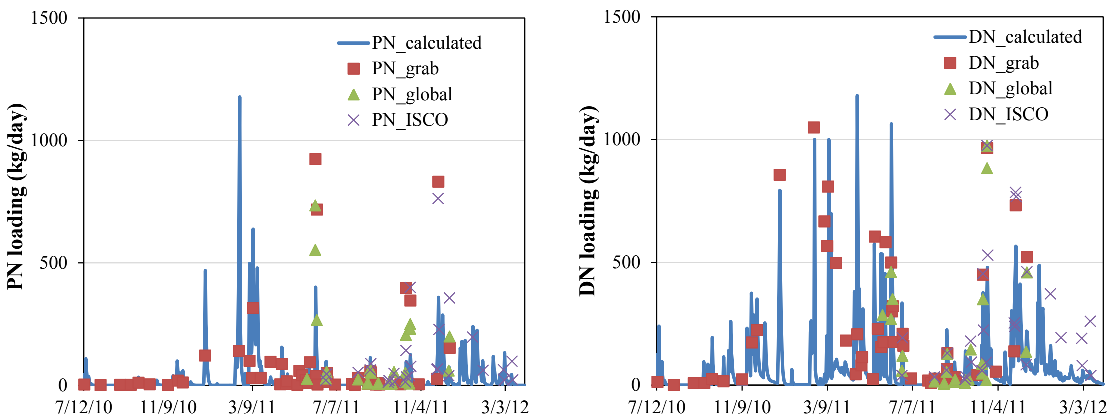


Figure 6-18: PN and DN calibration at GULGUL2

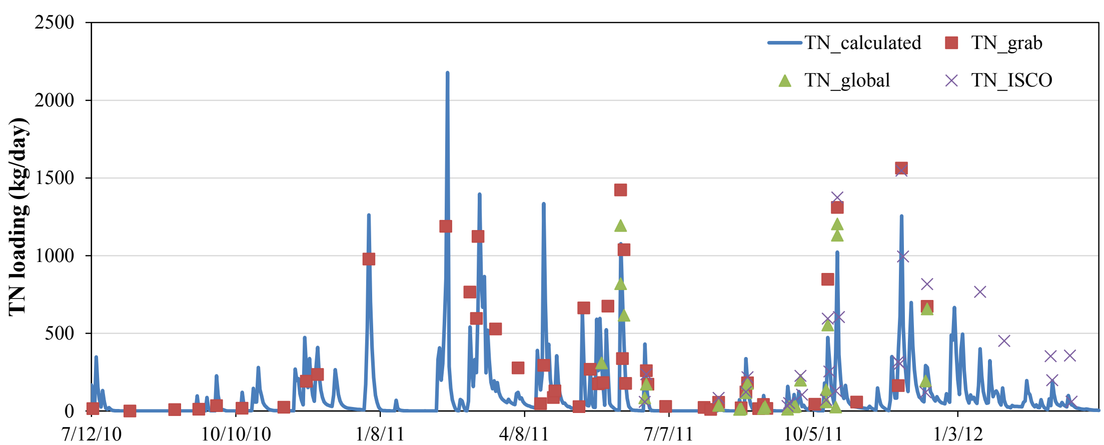
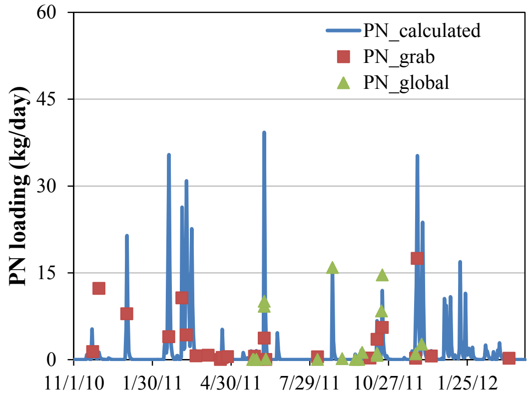


Figure 6-19: TN calibration at GULGUL2



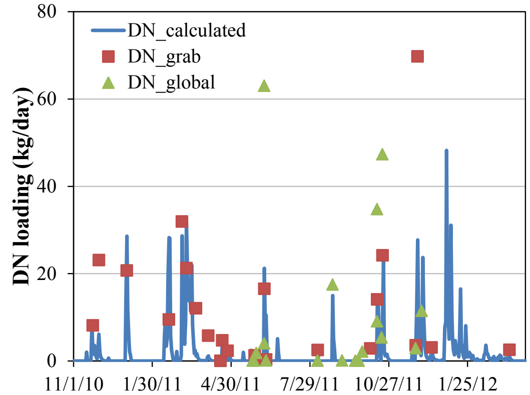


Figure 6-20: PN and DN calibration at GULGUL3

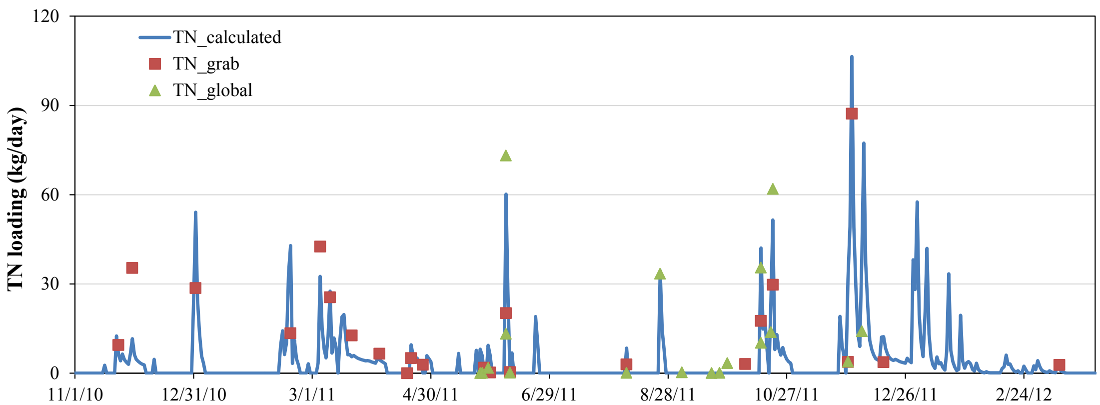
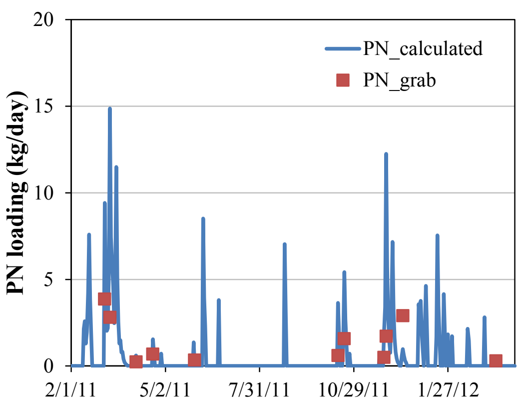


Figure 6-21: TN calibration at GULGUL3



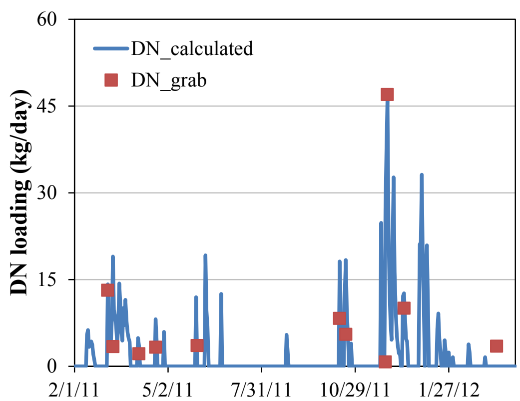


Figure 6-22: PN and DN calibration at GULGUL4

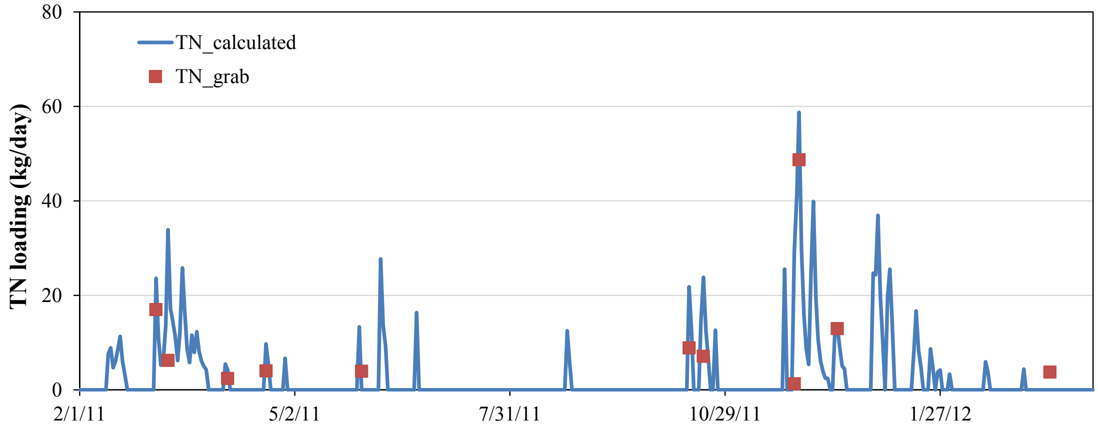


Figure 6-23: TN calibration at GULGUL4

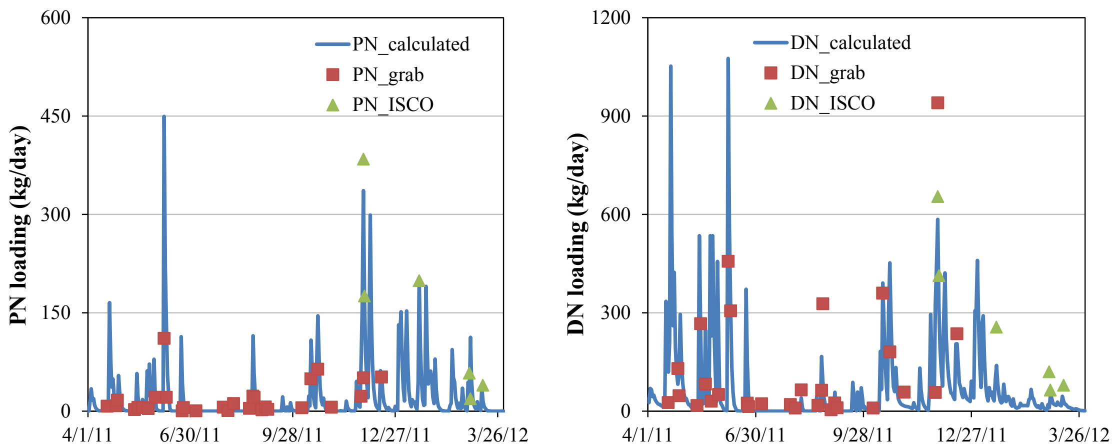


Figure 6-24: PN and DN calibration at GULGUL5

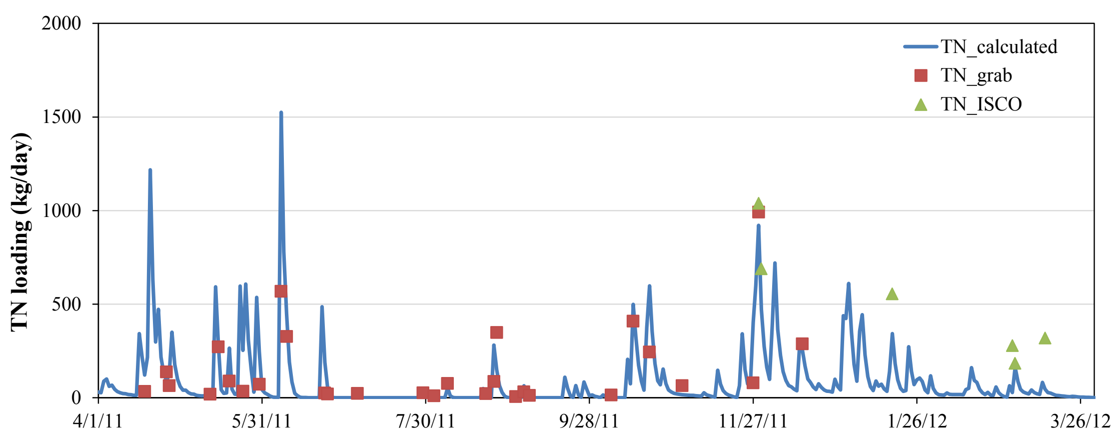


Figure 6-25: TN calibration at GULGUL5

Table 6-10: SWAT performance for PN, DN, and TN in the Gully Creek watershed

Station	Type	Period (month/year)	N	PN RMSE (kg/day)	PN CV	PN CORR	DN RMSE (kg/day)	DN CV	DN CORR	TN RMSE (kg/day)	TN CV	TN CORR
GULGUL2	Grab	7/2010-12/2011	50	5.164	0.053	0.493	6.449	0.026	0.425	6.121	0.018	0.792
GULGUL2	Global	5/2011-12/2011	23	4.026	0.047	0.926	6.587	0.042	0.575	5.700	0.024	0.881
GULGUL2	ISCO	6/2011-3/2012	27	4.689	0.042	0.743	6.024	0.024	0.632	6.724	0.017	0.762
GULGUL3	Grab	11/2010-3/2012	23	1.690	0.517	0.559	1.713	0.141	0.510	2.061	0.133	0.746
GULGUL3	Global	5/2011-12/2011	15	1.479	0.406	0.622	1.672	0.223	0.518	2.092	0.188	0.721
GULGUL4	Grab	3/2011-3/2012	11	1.274	0.903	0.650	1.796	0.196	0.759	2.064	0.196	0.765
GULGUL5	Grab	4/2011-12/2011	29	4.079	0.221	0.881	5.641	0.042	0.706	6.399	0.042	0.790
GULGUL5	ISCO	11/2011-3/2012	6	4.402	0.030	0.929	5.897	0.022	0.985	9.064	0.018	0.960

Similar to P load calibration, the predicted daily discharge has a great impact on predicted PN, DN, and TN load. As demonstrated in Table 6-10, the two mainstream stations GULGUL2 and GULGUL5 have higher CORR values compared to the two field-edge stations GULGUL3 and GULGUL4. In addition, The CORR values calculated for global N data are higher than values calculated for grab and ISCO N data at stations GULGUL2 and GULGUL3. This indicates that the grab and ISCO sampling data may over-estimate or under-estimate the daily average N loading compared to global sampling data. Overall, the PN, DN, and TN load predictions appear to agree with the measurements at the four monitoring stations as demonstrated in the above figures and the statistical results. The model gives a better performance at the two mainstream stations compared to the two field-edge stations in simulating PN, DN, and TN. These N parameters are applied to evaluate PN, DN, and TN loads at both field and watershed outlet for various BMP scenarios as discussed in Chapter 7.

7.0 HYDROLOGIC EVALUATION OF BMP SCENARIOS

7.1 Definition of base scenarios

The purpose of the SWAT modelling was to evaluate the water quantity and quality effects of selected BMP practices – both those in place (existing) in the watershed today, as well as possible future implemented BMPs. In the evaluation, a baseline scenario had to be defined and run in order to establish a reference condition against which the other BMP scenario options could be evaluated against. The following defines the control or "baseline" scenario and the other BMP scenario runs that were completed to compare against the baseline run.

Baseline Scenario – Existing Conditions (Scenario III)

This scenario was a simulation of current (existing) Gully Creek watershed conditions including existing WASCoBs and land management practices. This scenario is essentially the calibrated SWAT model and accounted for the BMP practices currently in use in the watershed. All other scenarios were compared against this reference condition.

Scenario I: No WASCoB + 1978 Land Management Practices

This scenario was an approximation of the watershed conditions in 1978 – prior to the advent of conservation programming in Ontario. No WASCoBs were present at that time. Hickenbottom inlets had yet to be introduced into the Ontario market. No-till was in its infancy. The crops grown and represented by this mode scenario mimic those interpreted from summer 1978 aerial photography available for the area. Only conventional tillage (fall moldboard ploughing) was assumed to be used on all tilled land.

The 1978 aerial photography clearly showed smaller field units and a greater proportion of the cropland was growing hay or pasture crops at that time. There was very little soybean production in the watershed. A proper representation of the 1978 conditions would have required the modellers to re-build the baseline model dataset using a new landuse layer. This, however, would be time-consuming. As a compromise, it was decided to look at the relative proportion of crops in 1978 and compare them to the proportion of crops in the current (baseline) scenario and substitute crops having a similar proportion in order to “simulate” the 1978 land management condition. For example, it was found that there was roughly the same amount of land in soybeans and edible beans in 2001 as was in hay in 1978. So, for the 1978 run, lands in beans in the 2001 landuse layer were changed to hay for the 1978 landuse layer. Similarly, winter wheat fields identified in the 2011 landuse layer were changed to barley or mixed grain for the 1978 land layer. As for tillage practices, it was assumed the 1978 tilled cropland saw extensive use of fall moldboard ploughing. In the spring the fields were then assumed to have one disk or cultivator pass and a second cultivator pass applied. For corn, 120 kg/ha of N and 45 kg/ha of P were assumed broadcasted before spring tillage and 15 kg/ha of P was assumed to be applied during seeding (with planter) in the 1978 scenario. For barley, 45 kg/ha of N and 5 kg/ha of P were assumed broadcasted before seeding and 15 kg/ha of P was assumed applied during seeding (with drill). For grass hay and forage, 45 kg/ha of P was broadcasted before spring tillage in the first year of hay establishment.

Scenario II: No WASCoB + Existing Land Management Practices

This scenario simulates the existing Gully Creek watershed land management conditions (such as some fields with conservation tillage) but without WASCoB implementation. A comparison of scenarios I and II can reveal the implications of changes in crop pattern and management practice changes since 1978.

7.2 Definition of BMP scenarios

The following describes the set of BMP scenarios that were set-up for the Gully Creek watershed using the SWAT model. The output from these scenario runs could then be compared against the baseline scenario output to assess the effectiveness of the various BMPs considered. A summary of the various SWAT model run scenarios completed and the relative input differences between these runs are given in Table 7.1.

Scenario IV: Existing WASCoBs + Enhanced Use of Conservation Tillage

In this scenario, the existing WASCoBs were modelled, and all row crops (corn, soybeans, and winter wheat) were assumed to be under a conservation tillage system which for this study entailed fall chisel ploughing/vertical tillage following corn harvest and no till following soybean and wheat harvest. Fertilizer rates were the same as under the existing (baseline) scenario. Scenario IV was developed to help assess the environmental benefits of extensive no-till adoption in the watershed.

Scenario V: Existing WASCoBs + Nutrient Management

In this scenario, the existing WASCoBs were modeled and the fertilization practices simulated on all agricultural fields ensured that N and P application rates matched crop yield goals and that no BMP or legislative "red flags" with respect to N and P application were present. This analysis was completed for each field in the watershed using Ontario's NMAN3 software. The NMAN3-based fertilization recommendations resulted in only a few fields within the Gully Creek watershed seeing a reduction in fertilizer application rates compared to existing (baseline) practices. Tillage practices in this scenario were left the same as with the existing scenario. Scenario V was developed to assess the impact of strict implementation of nutrient management practices on outlet water quality.

Scenario VI: Existing WASCoBs + Red Clover Cover Crop following Winter Wheat

In this scenario the existing WASCoBs were modeled and a red clover cover crop was assumed to be under-seeded with the winter wheat. Following wheat harvest, the red clover was allowed to continue to grow as a cover until it was plowed down in late October using moldboard plow. In the following year, two secondary cultivation passes were assumed for preparing the following crop's seeding bed. This BMP only affected the fields growing winter wheat in the years modeled. All practices on the remaining fields were assumed to be the same as those in the existing (baseline) scenario. In the year following the red clover cover crop, the N rate was reduced by 60 kg/ha (due to N supply from red clover) from existing N rate for the follow-up crop (typically corn). The fertilizer rates assigned to the other fields in the follow-up year remained the same as with the existing scenario. Scenario VI was developed to assess the impact of increased use of a common cover crop practice on outlet water quality.

Scenario VII: Existing WASCoBs + All Agronomic BMPs

In this scenario the existing WASCoBs were modeled and all of the BMPs described in Scenarios IV to VI were applied simultaneously (conservation tillage, nutrient management, red clover cover crop). Note, however, that to implement the red clover cover crop BMP, conservation tillage following winter wheat could not be implemented as it was assumed that the red clover would need to be ploughed in the fall in order to obtain a proper kill and capture the fixed nitrogen benefit. Scenario VII was developed to assess the cumulative impact on water quality of all agronomic and existing structural BMPs. This scenario could be considered as pushing agronomic BMP implementation in the watershed to the limit.

Scenario VIII: Future WASCoBs + Existing Land Management Practices

In this scenario 14 potential (future) WASCoBs were added to the existing (baseline) model set-up in locations it was believed landowners were interested in implementing WASCoBs. The 18 existing WASCoBs were also represented. Scenario VIII was developed to help assess the environmental benefits of implementing these additional WASCoBs.

Scenario IX: Future WASCoBs + Enhanced Use of Conservation Tillage

In this scenario, 14 potential (future) WASCoBs were added to the model set-up described for Scenario IV (see above). The 14 existing WASCoBs were also represented. Scenario IX was established to help assess the environmental benefits of combining structural and agronomic BMPs (WASCoBs and conservation tillage).

Scenario X: Future WASCoBs + Nutrient Management

In this scenario, 14 potential (future) WASCoBs were added to the model set-up described for Scenario V (see above). The 14 existing WASCoBs were also represented.

Scenario X was established to help assess the environmental benefits of combining structural and agronomic BMPs (WASCoBs and nutrient management).

Scenario XI: Future WASCoBs + Red Clover Cover Crop following Winter Wheat

In this scenario, 14 potential (future) WASCoBs were added to the model set-up described for Scenario VI (see above). The 14 existing WASCoBs were also represented. Scenario XI was established to help assess the environmental benefits of combining structural and agronomic BMPs (WASCoBs and red clover cover crop following winter wheat).

Scenario XII: Future WASCoBs + All Agronomic BMPs

In this scenario 14 potential (future) WASCoBs were added to the model set-up described for Scenario VII (see above). The 14 existing WASCoBs were also represented. Scenario XII was established to help assess the environmental benefits of combining all of the structural and agronomic BMPs assessed in this study within the context of the Gully Creek watershed.

Table 7-1: Model Run Scenarios Developed for the Gully Creek Watershed

Scenario ID	WASCoB	Tillage	Fertilizer	Cover crop
Historical Run Scenarios				
I	No	1978 Conditions	1978 Conditions	1978 Conditions
II	No	Existing (2011)	Existing	Existing
Calibrated (Baseline) Run				
III	Existing	Existing	Existing	Existing
BMP Run Scenarios				
IV	Existing	Conservation Tillage	Existing	Existing
V	Existing	Existing	NMAN3 Recommended	Existing
VI	Existing	Modified	Modified	Cover crop
VII	Existing	Conservation Tillage	NMAN3 Recommended	Cover crop
VIII	Existing + Future	Existing	Existing	Existing
IX	Existing + Future	Conservation Tillage	Existing	Existing
X	Existing + Future	Existing	NMAN3 Recommended	Existing
XI	Existing + Future	Modified	Modified	Cover crop
XII	Existing + Future	Conservation Tillage	NMAN3 Recommended	Cover crop

7.3 Watershed Scale SWAT Results under Existing (Baseline) Conditions

With the model parameters calibrated against available measurement data, SWAT was then run for the period 2002-2011 under existing climate and land management conditions. The average monthly precipitation (P), snow (SN), and simulated potential evapotranspiration (PET), actual evapotranspiration (ET), surface runoff (SR), subsurface runoff including tile flow and groundwater flow (SUBSR), total runoff (TR), and sediment yield before entering streams (from fields, not including in-channel erosion and sedimentation) are listed in Table 7-2. A graphical presentation of the simulated average monthly variation in precipitation, actual evapotranspiration, and runoff in the Gully Creek watershed over the period 2002-2011, under existing land management conditions, is given in Figure 7-1. A graphical presentation of the simulated average monthly surface runoff, subsurface runoff, total runoff, and sediment yield at the Gully Creek watershed outlet over the period 2002-2011 under the same existing land management conditions is shown in Figure 7-2.

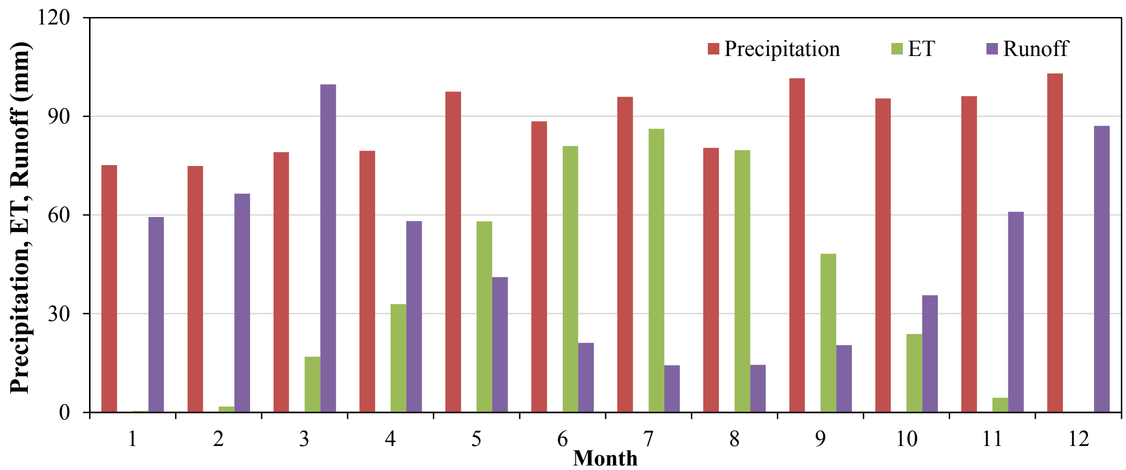


Figure 7-1: Simulated average monthly precipitation, ET, and runoff in the Gully Creek watershed over the period 2002-2011 under existing conditions

Table 7-2: Simulated average monthly and yearly water balance and sediment yield before entering streams over the period 2002-2011under existing condition

Month	P (mm)	SNOW (mm)	PET (mm)	ET (mm)	SR (mm)	SUBSR (mm)	TR (mm)	SED (t/ha)
1	75.2	53.72	0.51	0.47	32.03	27.38	59.41	0.16
2	74.87	52.86	1.96	1.77	53.45	13.05	66.5	0.26
3	79.1	40.25	23.48	16.95	69.12	30.61	99.73	0.35
4	79.5	12.04	54.48	32.93	16.88	41.25	58.13	0.11
5	97.5	0	100.4	58.08	19.08	22.03	41.11	0.14
6	88.5	0	131.62	80.98	15.5	5.65	21.15	0.11
7	95.9	0	142.8	86.18	13.04	1.25	14.29	0.06
8	80.4	0	121.15	79.73	13.89	0.54	14.43	0.05
9	101.6	0	70.68	48.24	18.54	1.94	20.48	0.06
10	95.4	1.22	30.97	23.84	18.28	17.34	35.62	0.06
11	96.1	17.72	5.46	4.46	27.66	33.33	60.99	0.11
12	103	65.03	0.08	0.08	47.64	39.47	87.11	0.18
Year	1,067	242.8	683.6	433.7	345.1	233.8	579.0	1.65
%	100	22.8	64.1	40.6	32.3	21.9	54.3	

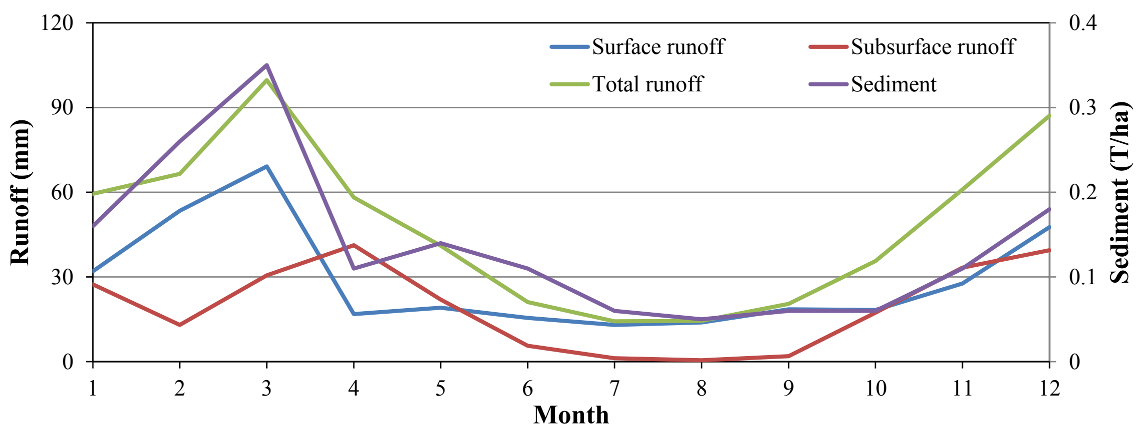


Figure 7-2: Simulated average monthly surface runoff, subsurface runoff, total runoff, and sediment yield at the Gully Creek watershed outlet over the period 2002-2011 under existing conditions

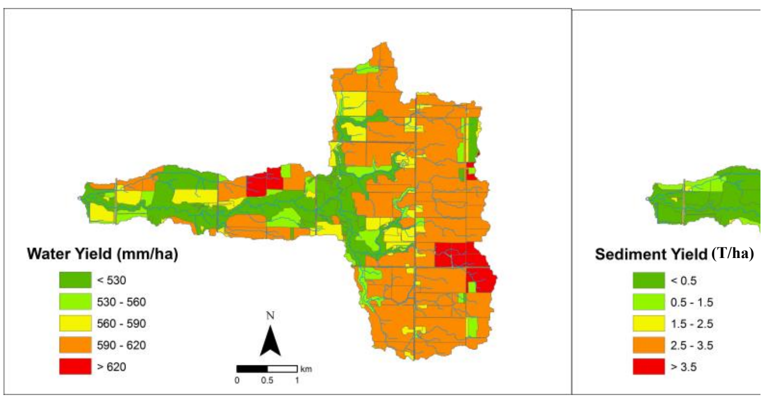
The calculated average annual precipitation in the watershed was 1,067 mm, of which 242.8 mm (22.8%) fell as snow occurring from late October to early April. The total calculated average annual PET was 683.6 mm for the watershed using the Hargreaves method, while the actual average annual evapotranspiration was 433.7 mm. This is 40.6% of the annual precipitation. The calculated total average annual runoff was 579.0 mm (54.3%) of which 345.1 mm (32.3%) is from the land surface and 233.8 mm (21.9%) is from subsurface discharge including tile flow and groundwater flow. Monthly precipitation is relatively uniform throughout the year. High evapotranspiration occurs in the summer period from June to August because of the high temperature, while high flow occurred in the winter and spring due to the winter rainfall and snowmelt. Peak monthly surface runoff and total runoff occurred in March because of winter rainfall and snowmelt, while peak monthly subsurface runoff occurred in April because of the high groundwater recharge in spring. Both surface runoff and subsurface runoff are lower in the summer period because of the high evapotranspiration (Figure 7-2) and low soil moisture. The yearly water yield exhibits considerable spatial variation, with the higher than average water yields occurring in most of the crop fields in upper watershed (max 657 mm) and the lower than average water yields occurring in the middle to lower reach areas (min 515 mm) (Figure 7-3a).

The calculated sediment yield before entering streams (excluding in-channel erosion and sedimentation) is 1.65 T/ha for the watershed, of which high erosion occurs in March and February because of winter flooding. Sediment yield from overland is relatively small from April to November because of the low rate of surface runoff. This is specifically demonstrated in April in which the total runoff is high but the sediment yield is small because the majority of the runoff is from subsurface sources having a much lower sediment concentration than was estimated to be associated with surface runoff. The majority of the cropland area has annual sediment yield above 1.60 t/ha in the upper section of the watershed (Figure 7-3b). The lower sediment yield in the middle to lower reach area is associated with the gentle slope and increased vegetation cover characteristic of this area. The higher sediment yield in upper watershed is closely associated with higher slope and increased level of crop production.

The simulated average annual total sediment load at the watershed outlet is 5,131 T (3.60 T/ha), of which 2,354 T (1.65 T/ha) is from overland erosion and 2,777 T (40.5 T/km) is from channel erosion. Note that the channel erosion portion includes the soil loss from concentrated flow pathways and gullied areas that can be present in farm fields. The average overland (rill and inter-rill) erosion rate is calculated by using the estimated sediment yield before flows enter the modeled stream or channelized flow network divided by the watershed area. The average channel erosion rate is calculated by taking the estimated channel sediment load and dividing it by the total channel and ditch length (68.57 km) used in the model. Because the watershed is divided into 62 small subbasins for evaluation of WASCoBs, a very dense stream network was delineated, including mainstreams, tributaries, and ditches. Therefore, a little over half of the total sediment loading was estimated to originate from concentrated flow paths, i.e. channels and ditches (54.3%), and a slightly lower sediment loading was estimated to originate from upland fields (45.7%). The average channel and ditch erosion has significant variation. In most locations the annual channel erosion rate was estimated to be less than 3 T/km. A small percentage of channels and ditches have annual sediment delivery rates of over 50 T/km. These reaches tend to be located in the lower downstream main channels. Three reaches have annual sediment delivery rates over 100 T/km as shown in Figure 7-4. They tend to be associated with reaches having high channel slopes. The simulated average annual sediment and nutrient yield at watershed outlet over the period 2002-2011 under existing condition is presented in Table 7-3. The modelling results for each subbasin under 1978 conditions are presented in Appendix D-2.

Table 7-3: Simulated average yearly sediment and nutrient yield at watershed outlet over the period 2002-2011 under existing condition

Overland sediment	2,354 T	1.65 T/ha	45.7 %
Channel sediment	2,777 T	40.5 T/km	54.3 %
Total Sediment	5,131 T	3.60 T/ha	100 %
PP	3,914 kg	2.74 kg/ha	69.2 %
DP	1,742 kg	1.22 kg/ha	30.8 %
TP	5,656 kg	3.96 kg/ha	100 %
PN	11,800 kg	8.27 kg/ha	28.9 %
DN	29,080 kg	20.4 kg/ha	71.1 %
TN	40,880 kg	28.7 kg/ha	100 %



(a) (b)

Figure 7-3: Simulated average yearly water yield (a) and sediment yield (b) at field scale under existing (baseline) land management conditions in the Gully Creek watershed

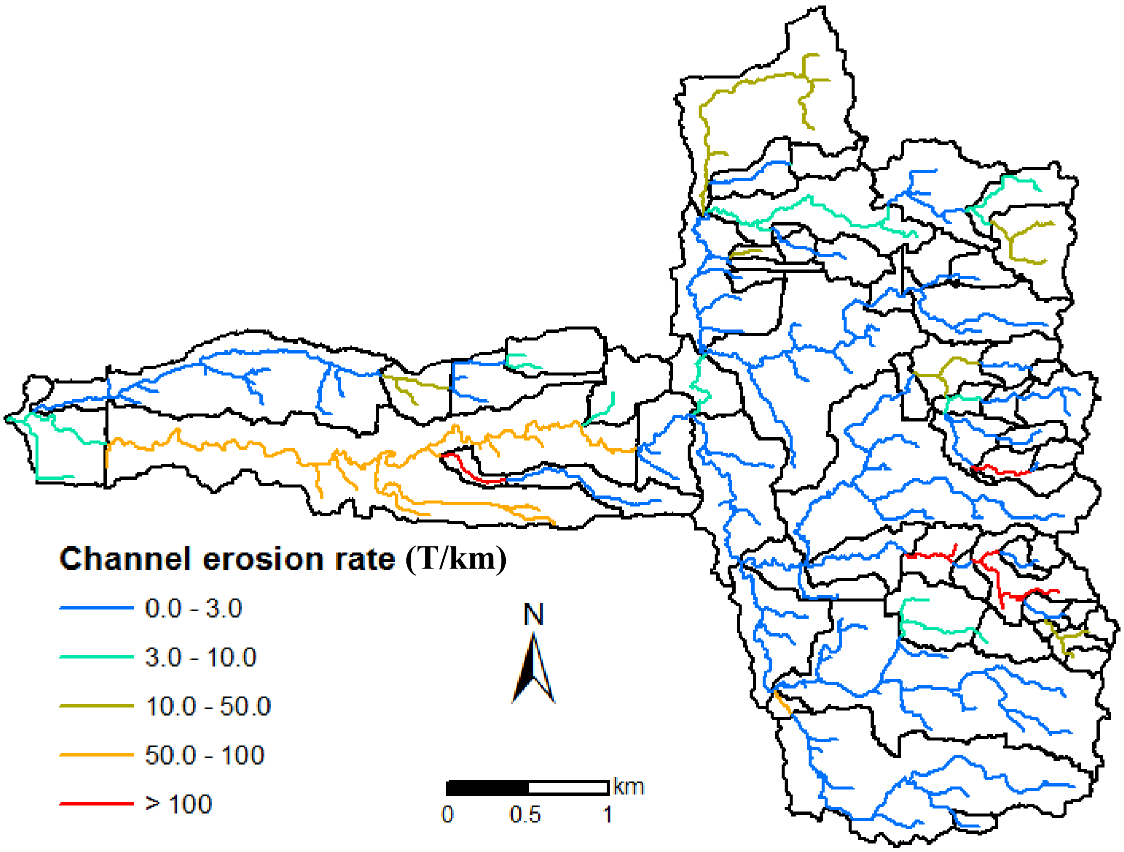
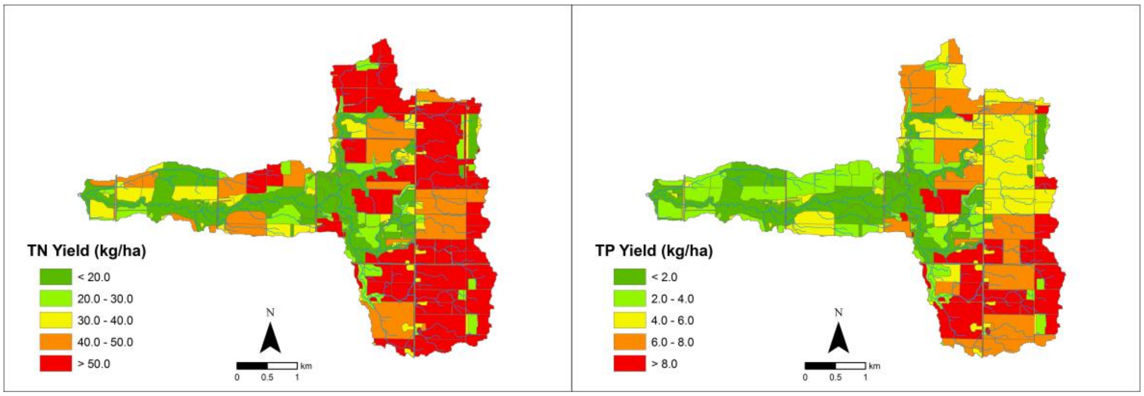


Figure 7-4: Simulated average yearly channel and ditch erosion under existing (baseline) land management conditions (2002 - 2011)

The estimated average annual TN load at the watershed outlet for the 10 year SWAT simulation period was 40,880 kg (28.7 kg/ha), of which 11,800 kg (8.27 kg/ha) arrived in particulate form (28.9%) and 29,080 kg (20.4 kg/ha) arrived in dissolved form (71.1%). The majority of the nitrogen load is DN with a PN/DN ratio of 0.40. As shown in Figure 7-5a, the spatial distribution of TN indicates that most of the middle to lower reach areas have TN below average and TN loading in the upper watershed cropland is above average.

The estimated average annual TP load at the watershed outlet for the 10 year simulation was 5,656 kg (3.96 kg/ha), of which 3,914 kg (2.74 kg/ha) was in particulate form (69.2%) and 1,742 kg (1.22 kg/ha) was in dissolved form (30.8%). The majority of the phosphorous load is PP with a PP/DP ratio of 2.25. As shown in Figure 7-5b, the spatial distribution of TP indicates that most of the middle to lower reach areas have TP below average and TP loading in the upper watershed cropland is above average. The estimated ratio of average annual sediment load, TN load, and TP load at the watershed outlet is about 907:7:1.



(a) (b)

Figure 7-5: Simulated average yearly TN yield (a) and TP yield (b) at field scale under existing (baseline) land management conditions in the Gully Creek Watershed

7.4 Watershed Scale SWAT results comparing existing land management conditions with 1978 land management conditions

SWAT output following simulation of the estimated 1978 land management conditions (Scenario I) are summarized in Table 7.4. Sediment, TN, and TP loadings were 5,596 tonnes, 28,430 kg, and 6,596 kg respectively. Similarly, a SWAT output summary for Scenario II (existing (baseline) conditions, except no WASCoBs) can be found in Table 7.5. Sediment, TN, and TP loadings are 5,697 tonnes, 43,720 kg, and 6,024 kg respectively. A comparison of Scenario II to I suggests that the pollution pattern has changed since 1978 due to the natural evolution in crop type and land management practice changes alone. Compared to Scenario I, sediment loading in Scenario II increased just slightly (107 tons or 6.1%), but TN loading increased significantly due to the cropping changes (15,290 kg or 53.8%). The majority of the TN increase was estimated to be in the dissolved form.

Table 7-4: Average Annual SWAT output at the watershed outlet under 1978 and existing (2011) land management practices

Scenarios	Flow (cms)	Sed. (tonne	PP (kg)	DP (kg)	TP (kg)	PN (kg)	DN (kg)	TN (kg)
I 1978 Land Management	0.258	5,590	4,848	1,748	6,596	12,630	15,800	28,430
II Existing minus WASCoBs	0.260	5,697	4,169	1,855	6,024	12,610	31,110	43,720
III Existing (Baseline)	0.242	5,131	3,914	1,742	5,656	11,800	29,080	40,880

Table 7-5: Difference in Average Annual SWAT output at the watershed outlet under different land management scenarios

Scenarios	Sed (tonne)	PP (kg)	DP (kg)	TP (kg)	PN (kg)	DN (kg)	TN (kg)
II minus I Crop effects	107 (-1.9%)	-679 (14.0%)	107 (-6.1%)	-572 (8.7%)	-20 (0.2%)	15,310 (-96.9%)	15,290 (-53.8%)
III minus I Mgmt effects	-459 (8.2%)	-934 (19.3%)	-6.0 (0.3%)	-940 (14.3%)	-830 (6.6%)	13,280 (-84.1%)	12,450 (-43.8%)
III minus II WASCoB effects	-566 (9.9%)	-255 (6.1%)	-113 (6.1%)	-368 (6.1%)	-810 (6.4%)	-2,030 (6.5%)	-2,840 (6.5%)

Phosphorus loading in Scenario II (Existing land management but no WASCoBs) was estimated to be 679 kg/year or 14% less than the loading under estimated 1978 loadings (Table 7-5). For nitrogen, however, a negative water quality impact of existing agriculture, compared to 1978 practices is evident. While the slight P loading reduction was estimated by SWAT to have been achieved with the aid of agronomic-based BMPs in place today (existing), despite an increasing intensity of agriculture, the same could not be said for nitrogen, where estimated N loads increased by over 15,000 kg/yr under today's management compared to the 1978 practices. Detailed modelling results for each subbasin under the 1978 condition are presented in Table D-1 of Appendix D. Similarly, detailed modelling output for each subbasin under existing (baseline) conditions is provided in Table D-2 of Appendix D. Detailed documentation of the SWAT model's output differences for this comparison can be found in Table D-3 of Appendix D.

A comparison of Scenario III (existing WASCoB and existing land management) to Scenario II estimates the relative environmental effectiveness of installing the existing WASCoBs. Compared to Scenario II, Scenario III had reductions in sediment loading 566 tons or 9.9%, a TN loading of 2,840 kg or 6.5%, and a TP loading reduction of 368 kg or 6.1% (see Table 7-5). These differences suggest that WASCoBs are effective in reducing pollution loadings in the Gully Creek watershed.

A comparison of Scenario III existing (baseline) conditions to Scenario I (1978 land management practices) shows the aggregated pollution pattern changes due to the combination of land management evolution and the implementation of the existing BMPS in the watershed. Compared to Scenario I, Scenario III had a reduction of sediment loading by 459 tons or 8.2% and a reduction of TP loading of 940 kg or 14.3% between 1978 and 2011 land management practices. However, TN loading increased by 12,450 kg or 43.8% (Table 7-5). This pattern suggests that, despite the adoption of some BMPs such as WASCoBs and conservation tillage over the years, the shift in cropping pattern, leading to higher N application and N fixation under the existing agricultural practices, has caused increased N loadings. The sediment and P loadings, however, were estimated by the model to have decreased slightly between the two time periods which contribute to water quality improvement in the Gully Creek watershed.

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 kg/ha) than were assumed under the historical (1978) run (120 kg/ha). Phosphorous application and tillage practices remained similar between the two simulations. 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. This however, may not necessarily be the case and the crop growth model embedded in SWAT then may not be properly representing this genetic change, affecting the estimate of nitrogen available for environmental loss under one of the two scenarios. Another possibility is that the effects of soybean atmospheric fixation on environmental losses of N are not fully understood and therefore not effectively modelled in SWAT. A third possibility is that the SWAT model may not be fully capturing the extent of subsurface tile drainage differences between the two time periods. Even with these shortcomings, however, 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.

7.5 Watershed Scale SWAT results of BMP effectiveness

SWAT was run for each of the 9 BMP scenarios as defined in Section 7.2 of this report. A comparison of the BMP scenarios with Scenario III (existing (baseline) land management practices) in most situations shows reductions after adopting BMPs (see Table 7-6). Nitrogen loading is often the exception. The following paragraphs, discuss each comparison in more detail.

For Scenario IV, which looked at the impact of enhanced use of no-till in the watershed, SWAT estimated that an average annual sediment loading reduction of 759 tonnes or 14.8% could be expected. Similarly it estimated a TP reduction of 2,250 kg or 39.8% with the majority of this reduction associated with particulate P due to reduced erosion from conservation tillage. Total N (TN) was estimated to be reduced by only 1,014 kg or 2.5% with no-till implementation. While particulate N was estimated to be reduced by 4,444 kg or 37.7%, dissolved N as predicted to increase by 3,430 kg or 11.8% (see Figures 7-6, 7-7 and 7-8).

Table 7-6: Yearly Average Annual SWAT output of various pollutants at the watershed outlet under BMP scenarios in relation to the existing (baseline) scenario

Scenarios		Sed. (tonne)	PP (kg)	DP (kg)	TP (kg)	PN (kg)	DN (kg)	TN (kg)
	Yield	4,372	1,695	1,711	3,406	7,356	32,510	39,866
IV	Change	-759	-2,219	-31	-2,250	-4,444	+3,430	-1,014
	%	-14.8	-56.7	-1.8	-39.8	-37.7	+11.8	- 2.5
	Yield	5,125	3,911	1,741	5,652	11,750	28,320	40,070
V	Change	-6.0	-3.0	-1.0	-4.0	-50	-760	-810
	%	-0.1	-0.1	-0.1	-0.1	-0.4	-2.6	-2
	Yield	4,705	3,338	1,654	4,992	10,240	26,330	36,570
VI	Change	-426	-576	-88	-664	-1,560	-2,750	-4,310
	%	-8.3	-14.7	-5.1	-11.7	-13.2	-9.5	-10.5
	Yield	4,362	2,489	1,639	4,128	8,288	28,380	36,668
VII	Change	-769	-1,425	-103	-1,528	-3,512	-700	-4,212
	%	-15.0	-36.4	-5.9	-27	-29.8	-2.4	-10.3
	Yield	4,572	3,675	1,647	5,322	11,000	27,180	38,180
VIII	Change	-559	-239	-95	-334	-800	-1,900	-2,700
	%	-10.9	-6.1	-5.5	-5.9	-6.8	-6.5	-6.6
	Yield	3,888	1,573	1,618	3,191	6,817	30,440	37,257
IX	Change	-1,243	-2,341	-124	-2,465	-4,983	+1,360	-3,623
	%	-24.2	-59.8	-7.1	-43.6	-42.2	+ 4.7	-8.9
	Yield	4,569	3,678	1,646	5,324	10,970	26,630	37,600
X	Change	-562	-236	-96	-332	-830	-2,450	-3,280
	%	-11.0	-6.0	-5.5	-5.9	-7.0	-8.4	-8.0
	Yield	4,183	3,105	1,565	4,670	9,504	24,630	34,134
XI	Change	-948	-809	-177	-986	-2,296	-4,450	-6,746
	%	-18.5	-20.7	-10.2	-17.4	-19.5	-15.3	-16.5
	Yield	3,882	2,320	1,552	3,872	7,706	26,740	34,446
XII	Change	-1,249	-1,594	-190	-1,784	-4,094	-2,340	-6,434
	%	-24.3	-40.7	-10.9	-31.5	-34.7	-8.0	-15.7

This model scenario, suggests that conservation tillage across the watershed has pronounced effects on erosion reduction and leads to considerable reductions of sediment and TP loadings. While particulate N is also reduced, increased residue under conservation tillage likely causes more leaching or loss of dissolved N to both surface and subsurface flow. Overall, this BMP scenario had the highest reduction rates in sediment and TP among the individual agronomic and structural BMPs evaluated in this study. The calculated differences for each subbasin between existing condition and conservation tillage scenario are presented in Table D-4 of Appendix D.

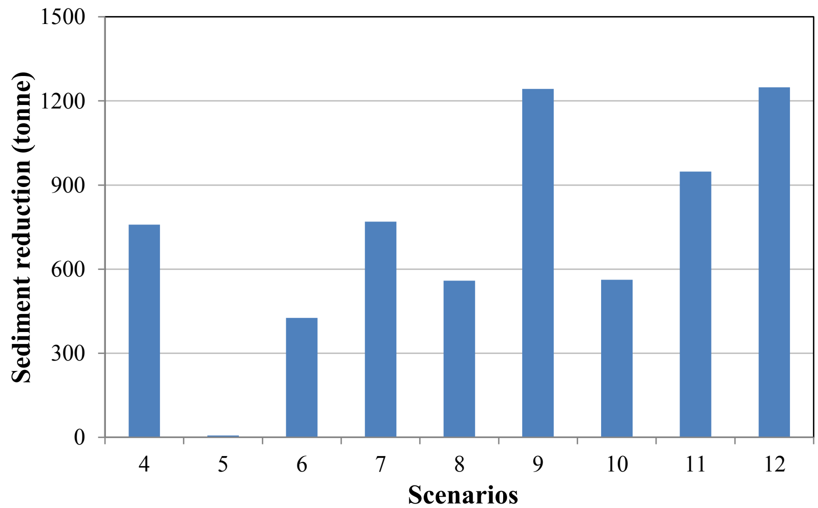


Figure 7-6: Average annual sediment load reductions at the watershed outlet under selected BMP scenarios relative to the existing (baseline) scenario

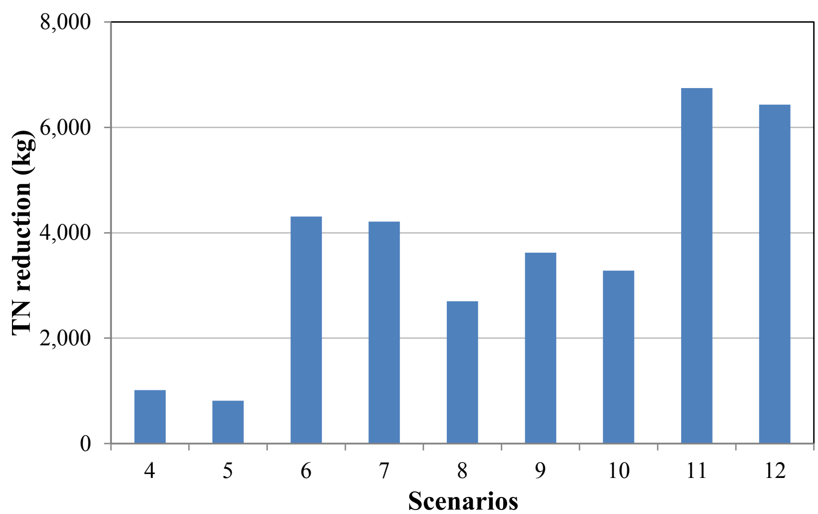


Figure 7-7: Average annual TN load reductions at the watershed outlet under selected BMP scenarios relative to the existing (baseline) scenario

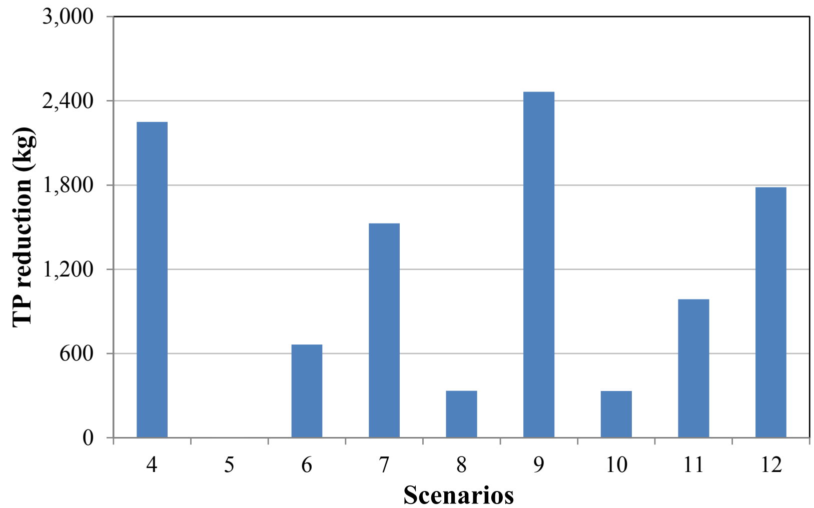


Figure 7-8: Average annual TP load reductions at the watershed outlet under selected BMP scenarios relative to the existing (baseline) scenario

For Scenario V, which looked at the impact of nutrient management planning in the watershed, SWAT estimated a minimal average annual sediment load reduction 6.0 tonnes or 0.1% as one might expect because nutrient management does little towards soil conservation. TP loading at the outlet from improved nutrient management practices in the watershed was estimated to decline annually by 4.0 kg or 0.1%, and TN reduction was also predicted to decline by 810 kg or 2.0% (Figures 7-6, 7-7 and 7-8). These results suggest that enhancing the focus on nutrient management in the watershed would have minimal effects on reducing pollution loadings in the Gully Creek watershed. The reason for this is likely that the fertilizer rates as estimated by NMAN3 are very close to actual fertilizer application rates on average. Some producers applied more than recommended, but on the other hand, some landowners applied less than recommended, given their yield goal. Therefore the room for nutrient reduction is small. This scenario has the smallest pollution reduction rates among all of the BMPs considered. The calculated differences for each subbasin between the existing condition and this nutrient management scenario are presented in Table D-5 of Appendix D.

For Scenario VI, which looked at the impact of enhanced use of red clover cover crops following winter wheat in the watershed, SWAT estimated that an average annual sediment load reduction of 426 tonnes or 8.3% could be achieved. TP reduction was estimated to decline annually by 664 kg or 11.7%, with majority of this decline associated with particulate P due to reduced soil erosion. The annual average TN reduction was estimated at 4,310 kg or 10.5% with particulate N declining by 1,560 kg/yr or 13.2% and dissolved N increasing by 2,750 kg/year or 9.5% (Figures 7-6, 7-7 and 7-8). Cover cropping as part of wheat production across the watershed therefore would appear to have positive effects on reducing sediment, as well as both dissolved and particulate N and P. The cover crop scenario ranked second among the three agronomic BMP practices evaluated in this study in terms of sediment and TP reductions. It ranked first on TN reduction which may in part be due to the assumption that producers would account for the additional 66 kg/ha of N made available from the red clover ploughdown to the subsequent year's crop, reducing their fertilizer application. The calculated differences for each subbasin between existing (baseline) condition and this cover crop scenario are presented in table D6 of Appendix D.

Scenario VII, which saw a SWAT simulation of all three agronomic BMPS (conservation tillage, nutrient management, and cover crops), average annual sediment loading was reduced by 769 tonnes or 15.0% compared to the existing (baseline) scenario. TP loadings were predicted to decline by 1,528 kg or 27.0% annually, with the majority of this reduction being realized again from particulate P due to reduced erosion from conservation tillage and cover cropping. Annual loading of TN was estimated to be reduced by 4,212 kg or 10.3% with majority of this reduction also from particulate N (Figures 7-6, 7-7 and 7-8).

The results from this run indicate that the aggregate effects of the three BMPs are actually smaller than the sum of the effects from individual BMPs. The reasons are twofold: On one hand, the pollution reduction of one BMP may limit the potential of other BMPs to further reduce pollution. On the other hand, some aspects of the BMPs may have contradicting effects. For example, the conservation tillage could not be implemented on the winter wheat fields under red clover if a requirement of the cover crop BMP was to plow down the cover crop in the fall to kill it and capture the fixed nitrogen. The calculated differences for each subbasin between existing (baseline) condition and this three BMP scenario are provided in Table D of Appendix D.

Comparing Scenario VIII (14 additional WASCoBs installed under existing land management) with Scenario III (existing or baseline land management practices) evaluated the pollution reduction potential possible from constructing additional WASCoBs in the Gully Creek watershed. SWAT estimated that the average annual sediment loading could be reduced by 559 tons or 10.9% through installing all 14 proposed new WASCoBs. Similarly, the installations would reduce annual TP by 334 kg or 5.9%, and TN by a net amount of 4,310 kg or 10.5%, with particulate N decreasing by 1,560 kg or 13.2% and dissolved N decreasing 2,700 kg or 6.6% (Figures 7-6, 7-7 and 7-8). This pattern indicates that WASCoBs as a structural BMP have pronounced positive effects on reducing pollution in the Gully Creek watershed.

Scenario IX, which evaluated the water quality impacts of combining future WASCoBs with the agronomic BMP of enhanced conservation tillage, was predicted by SWAT to reduce average annual sediment loads by 1,243 tons or 24.2%. TP was also predicted to decline by 2,465 kg or 43.6%, with majority of this reduction from particulate P due to reduced erosion from conservation tillage. Average annual TN loading was estimated to drop by a net amount of 3,623 kg or 8.9%, with particulate N reducing by 4,983 kg or 42.2% and dissolved N increasing 1,360 kg or 4.7% (Figures 7-6, 7-7 and 7-8). Similar to Scenario IV, conservation tillage across the watershed has significant effects on erosion reduction and leads to considerable reductions of sediment and TP loadings. In combination with additional WASCoBs, Scenario IX gave the highest reduction rates in sediment and TP among the BMP scenarios considered in this study.

Scenario X, which looked at combining future WASCoBs with improved nutrient management planning saw average annual sediment load reduce by 562 tons or 11.0%. Similarly the average annual TP loading was also predicted to drop by 332 kg or 5.9%, and TN was estimated to fall by 3,280 kg or 8.0% (Figures 7-6, 7-7 and 7-8). Taking the effects of additional WASCoBs into account, the reduction rates show that nutrient management has minimal effects on pollution reduction in the Gully Creek watershed, similar to what was estimated with Scenario V. This scenario had one of the smallest pollution reduction potentials among the BMP scenarios considered.

For Scenario XI, which involved combining future WASCoBs with the cover crop BMP, the average annual sediment reduction was estimated by SWAT to be 948 tons or 18.5%. The TP reduction was 986 kg or 17.4%, with the majority of this reduction coming from particulate P due to reduced erosion from WASCoBs and cover crops. The TN annual average reduction under this scenario was estimated to be 6,746 kg or 16.5%, with particulate N being reduced by 2,296 kg or 19.5% and dissolved N being reduced by 4,450 kg or 15.3% (Figures 7-6, 7-7 and 7-8). WASCoBs and cover crop under wheat production across the watershed have positive effects on reducing sediment, and both dissolved and particulate N and P. Similar to Scenario VI, this WASCoB and cover crop combination scenario ranks second in terms of sediment and TP reductions, and ranks first with respect to TN reduction.

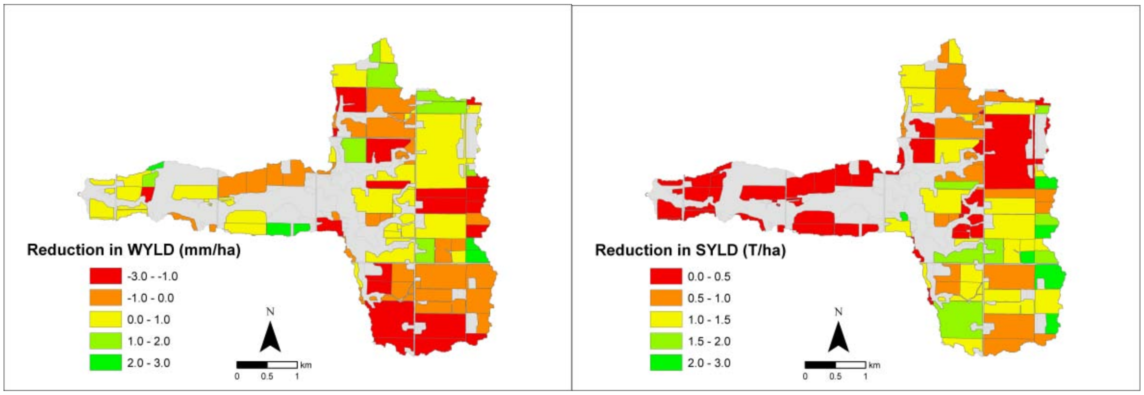
For Scenario XII which looked at combining the effects of all structural and agronomic BMPs evaluated in this study, SWAT estimated that the average annual sediment load could be reduced by 1,249 tons or 24.3%. Similarly, TP was estimated to decline by 1,784 kg or 31.5%, with the majority of this due to estimated declines in particulate P loadings due to reduced erosion achieved through the installation of WASCoBs and implementation of conservation tillage and cover cropping. Average annual TN was estimated to drop by 6,434 kg or 10.3%, with the majority of the reduction coming from particulate N (Figures 7-6, 7-7 and 7-8). Similar to Scenario VII, the results indicate that the aggregate effects of future WASCoBs and three land management BMPs are smaller than the sum of the effects from WASCoBs with individual land management BMPs. These results indicate that BMP combinations need to be carefully designed to maximize pollution reduction benefits and that BMP effects are not necessarily additive.

7.6 Field Scale SWAT results of BMP effectiveness

The previous section described the watershed scale impacts of BMP implementation (i.e. the effects of BMP implementation on water quality at the outlet of Gully Creek). This section reports on the field level and farm-level BMP effects. Only the runs that consider the existing WASCoBs (Scenarios IV, V, VI, and VII) were used in this analysis and, as before, compared against output from the existing (baseline) land management practice scenario (Scenario III). It is interesting to note that the output from scenarios that include the future WASCoBs gave very similar results to the comparisons above because the WASCoBs, as this modelling suggests have a greater impact on water quality downstream of the fields they are installed in than on the field area above the WASCoB. Please note that on the field distribution maps positive numbers denotes reductions and negative numbers indicate increases.

7.6.1 Scenario IV: Existing WASCoBs + Enhanced Use of Conservation Tillage

Compared to the existing (baseline) conditions in the watershed, the SWAT modelling output for the conservation tillage scenario, summarized and presented at a field scale, showed contrasting changes in spatial patterns for the average yearly water yield (surface and subsurface runoff). There was an estimated increase in water yields in 54% of cropland area (a maximum of 2.8 mm) and decrease in water yields in the remaining 46% of the cropland area (a maximum of 3.2 mm). Most of the areas showing an increase in water yields occur in flat areas in the upper watershed and appears to be due to increased subsurface runoff with conservation tillage, while surface runoff does not change significantly (Figure 7-9a). The decreasing water yields occur mostly in sloped areas and are distributed across the watershed. The decrease is likely due to the reduction of surface runoff with the implementation of conservation tillage. The average yearly sediment yield reductions ranged from 0 to 2.8 T/ha due to reduced surface runoff associated with the conservation tillage, with 57% of cropland area seeing a sediment reduction of under 1.0 T/ha and 43% of the cropland area having sediment reductions over 1.0 T/ha. The higher sediment reductions mostly occurred in sloped areas in the upper watershed (Figure 7-9b).

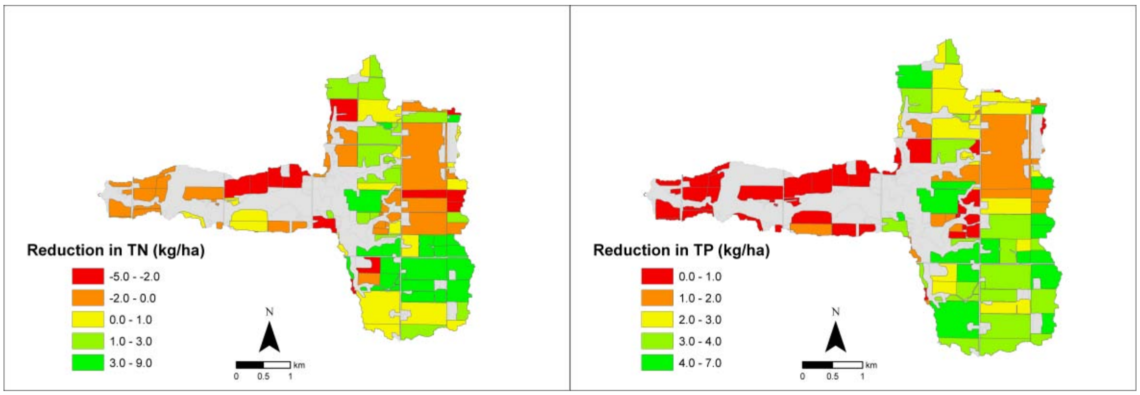


(a) (b)

Figure 7-9: Simulated average annual reduction of water yield (a) and sediment yield (b) at field scale with enhanced use of conservation tillage compared to existing (baseline) land management practices.

Because the majority of nitrogen lost was estimated to be in a dissolved form in the watershed, the spatial pattern of N loss was similar to the spatial pattern of water yield changes. SWAT estimated that 42% of the cropland area increased its TN loss (a maximum of 5.1 kg/ha) and 58% of cropland area reduced its TN loss (a maximum of 8.8 kg/ha) with the implementation of enhanced conservation tillage. The increased in dissolved N load is possibly because conservation tillage leaves more residues on the soil surface, slowing runoff but at the same time increasing infiltration and thus leaching effects. On the other hand, the reduction of particulate N from surface runoff is smaller with conservation tillage. If, however, the increase in dissolved N from both surface and subsurface runoff exceeds the reduction in particulate N losses due to reduced erosion, then the TN can show a net increase. On the other hand, if the particulate N reduction from surface runoff outweighs the increase in dissolved N loading from both surface and subsurface runoff, then the TN can show a net decrease. Most of the areas with increasing TN following the implementation of conservation tillage were located in the flatter areas in the upper watershed while the decreasing TN areas were distributed mostly in the more sloped areas across the watershed (Figure 7-10a).

Because the majority of phosphorous is in a particulate form in the watershed and leaves the watershed attached to sediment in the surface runoff there is a predicted decline in TP across the watershed with the implementation of enhanced conservation tillage. The maximum average annual TP reduction was estimated by SWAT to be 6.7 kg/ha, with 54% of the cropland area seeing reductions of less than 3 kg/ha and 45% of the cropland area seeing reductions exceeding 3 kg/ha. The higher TP reduction tended to occur on the more sloped areas in the upper portion of the watershed (Figure 7-10b).

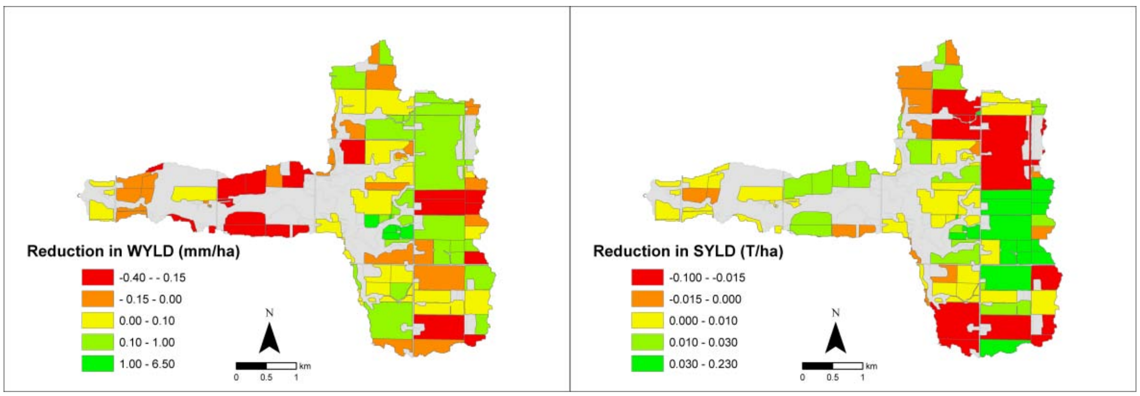


(a) (b)

Figure 7-10: Simulated average annual reduction of TN yield (a) and TP yield (b) at field scale with enhanced use of conservation tillage compared to existing (baseline) land management practices

7.6.2 Scenario V: Existing WASCoBs + Nutrient Management

As expected, focusing on improved nutrient management within the watershed was estimated by SWAT to likely have limited effects on water yield and sediment loading. In comparing the nutrient management run output to output from the existing (baseline) conditions model, 40% of the cropland area has minimal water yield increase with a maximum of 0.38 mm and 58% of the cropland area has slight water yield reduction. These minor differences are likely the result of the model accounting for slight changes in crop growth and cover under different fertilization practices that in-turn were perhaps affecting the partitioning of surface runoff, infiltration, and other hydrologic processes. Most of the increasing water yields happened in flat areas in upper watershed while the decreasing water yields were distributed in the more sloping topography areas across the watershed (Figure 7-11a). With the focused implementation of nutrient management in the watershed, 37% of the cropland area was estimated to give a minimal decrease in sediment loading (to a maximum of 0.1 kg/ha) and 63% of the cropland area was estimated to generate a slight increase in sediment loading (to a maximum of 0.22 kg/ha). The reductions in sediment loading mostly happened in the upper watershed area (Figure 7-11b).

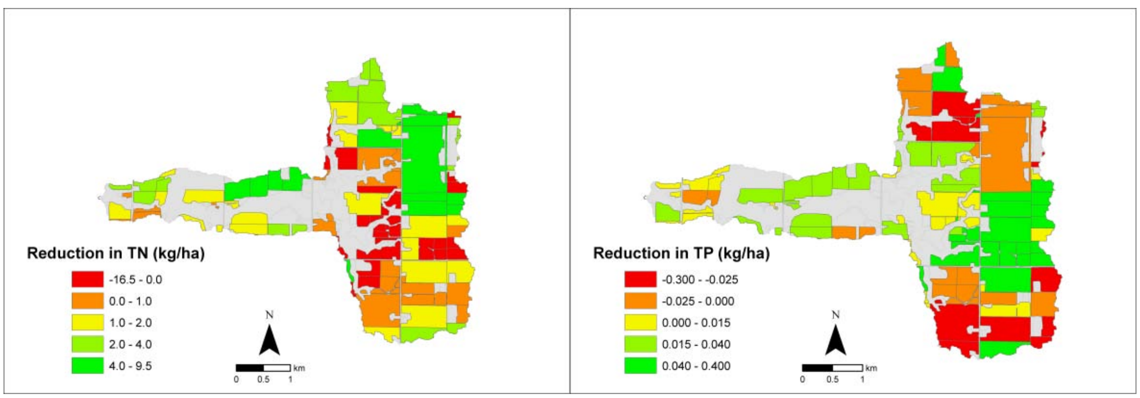


(a) (b)

Figure 7-11: Simulated average annual reduction of water yield (a) and sediment yield (b) at field scale with enhanced implementation of Nutrient Management compared to existing (baseline) land management practices

The effect of the nutrient management BMP was more pronounced on TN loss patterns. In the Gully Creek watershed, 14% of the cropland area was estimated to experience an increase in TN loading (to maximum of 16.5 kg/ha) under the nutrient management scenario compared to the existing (baseline) condition. While this seems counter-intuitive, this increase TN loading is likely a result of the higher fertilizer N rates applied under nutrient management on some fields than was used under the existing scenario. In some instances, NMAN3 recommended higher nitrogen application than what the producers were applying in order to meet their stated yield goal. This would result in some cases where nutrient management planning N fertilization rate were greater than the existing rates. A slight TN reduction (0 – 2 kg/ha) was estimated to happen on 47% of the cropland area, while 14% of the cropland area had a TN reduction from 2 to 4 kg/ha and 25% of the cropland area was estimated to experience a 4 to 9.1 kg/ha TN loading reduction (Figure 7-12a). These fields were likely assigned a lower recommended N fertilization rate by NMAN3 under nutrient management than was historically being applied by the producer. In general, the increase or decrease in TN loading from the fields was closely related to fertilizer N application rates simulated in the model.

The nutrient management BMP simulation had minimal effect on TP reduction. While 35% of the cropland in the watershed saw the SWAT model simulate a net increase in TP loading, to maximum of 0.26 kg/ha, 65% of the cropland simulated a reduction in TP loading, the drop being as high as 0.37 kg/ha (Figure 7-12b). Similar to TN, the reason for TP loading increasing or decreasing from the various fields was closely related to fertilizer P application rates recommended for the field through the nutrient management planning (NMAN3) process.

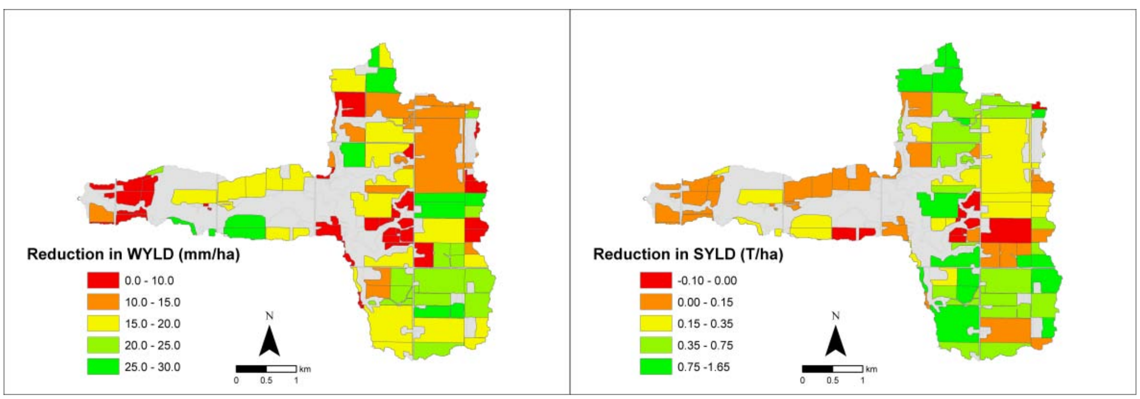


(a) (b)

Figure 7-12: Simulated average annual reduction of TN yield (a) and TP yield (b) at field scale with enhanced implementation of Nutrient Management compared to existing (baseline) land management practices

7.6.3 Scenario VI - Existing WASCoBs + Red Clover Cover Crop following Winter Wheat

Cover crop BMP was found through the SWAT model to affect hydrologic processes in autumn, winter, and snowmelt season, and therefore had a significant effect on reducing water yield. Compared to the existing (baseline) conditions, 35% of the cropland area saw a modelled water yield reduction of less than 15 mm, 35% of the cropland area saw a water yield reduction of 15 mm and 20 mm, and 30% of the watershed's crop area had a water yield reduction in the range of 20 to 30 mm annually. This all occurred with the simulation of a red clover cover crop following winter wheat (Figure 7-13a). The magnitude of sediment reduction under the cover crop scenario was approaching, but still less than that simulated for the conservation tillage (no till). For the cover crop option, SWAT estimated that 6% of the cropland area would experience a slight increase sediment loading (to a maximum of 0.09 T/ha), 49% of the cropland area would experience a reduction in sediment loading reduction from 0 to 0.35 T/ha, and 45% of the cropland area would see a sediment load reduction of 0.35 to 1.63 T/ha (Figure 7-13b). The reason for some fields possibly seeing a slight increase may be due to the fact that it was assumed that the red clover cover crop would be ploughed down in late fall, possibly making the soil more susceptible to early spring erosion if the storm events occurred.

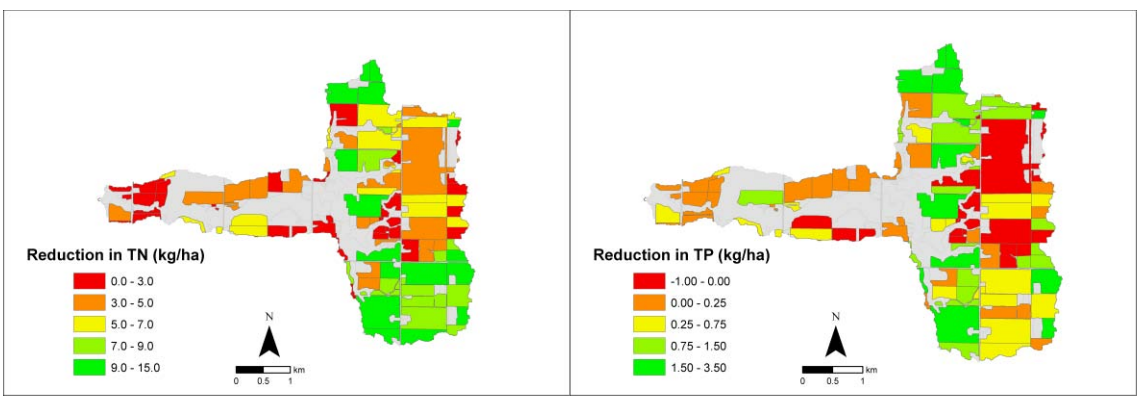


(a) (b)

Figure 7-13: Simulated average annual reduction of water yield (a) and sediment yield (b) at field scale with use of a red clover cover crop following winter wheat compared to existing (baseline) land management practices

The cover crop BMP modeled here was found to have a pronounced effect on TN reduction due in large part to the assumed condition that red clover would biologically fix and store 66 kg/ha of N which would then be available for the next year's crop nutrient needs. The model also assumed that the producer would account for this N credit and reduce their fertilizer application rates proportionately. In the Gully Creek watershed, 44% of the cropland area was estimated to experience a TN load reduction of under 5 kg/ha, 30% of the cropland area would see a TN reduction of between 5 and 9 kg/ha, and 26% of the cropland area would see TN reductions from 9 to 14.7 kg/ha (Figure 7-14a) as a result of this BMP.

With phosphorus loading under the cover crop BMP scenario, there were circumstances where the cover crop implementation resulted in an increase in TP. For cropland which did show a decline in TP loading, the magnitude of this reduction was generally lower than the reductions estimated for TN. This may be due to the combined effect of surface retention over the period and the fact that the fields in cover crops were assumed to be fall ploughed and spring cultivated in order to kill the cover crop. Overall, the Gully Creek watershed had 22% of the cropland area experience an increase in TP (to a maximum of 1.1 kg/ha), 42% of the cropland area see a reduction in TP under 0.75 kg/ha, and 36% of the cropland area see a TP reduction from 0.75 to 3.4 kg/ha as a consequence of simulating the implementation of a cover crop BMP (Figure 7-14b).



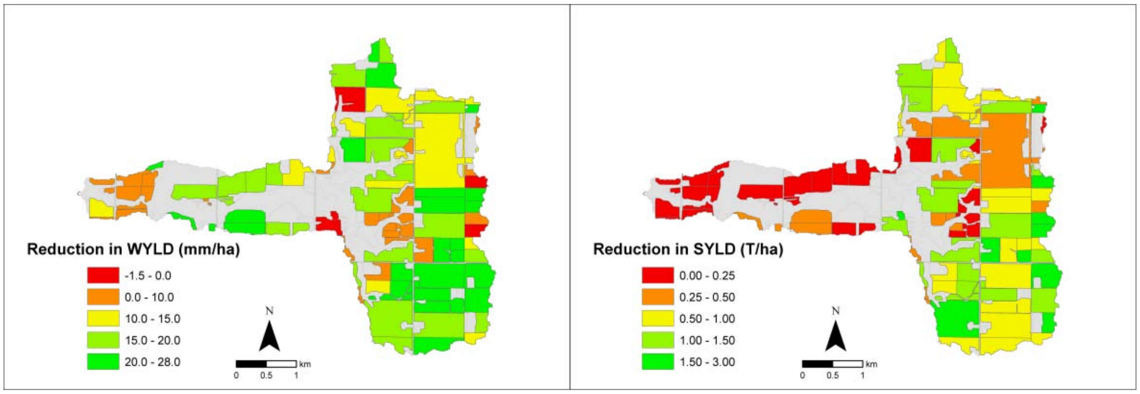
(a) (b)

Figure 7-14: Simulated average annual reduction of TN yield (a) and TP yield (b) at field scale with use of a red clover cover crop following winter wheat compared to existing (baseline) land management practices

7.6.4 Scenario VII - Existing WASCoBs + All Agronomic BMPs

The aggregate effects of three land management BMPs (conservation tillage, nutrient management, and red clover cover crop after winter wheat) are not simply the additive effects of these individual BMPs as described in the previous sections due to interactions among these BMPs. In this combined agronomic BMP scenario, 4% of the cropland area was estimated to experience a small (up to 1.3 mm) increase in average annual water yield. The remaining cropland was predicted to experience an average annual decline in water yield, with 32% of the watershed's cropland seeing a reduction in water yield under 15 mm, 35% having a reduction between 15 and 20 mm, and the remaining 29% of cropland experiencing a decline in water yield in the range of 20 mm to 27.7 mm. Most of the cropland showing an estimated increase in water yields occurred in the more sloping topography within the upper watershed (Figure 7-15a).

The average yearly sediment yield reductions with the simulated implementation of all agronomic BMPs ranged from 0 to 2.8 T/ha. Of the total cropland area in the watershed, 38% had a predicted sediment reduction less than 0.5 T/ha, 27% saw reductions of between 0.5 and 1.0 T/ha, and the remaining 35% had sediment reductions of between 1.0 to 3.0 T/ha. The higher sediment reductions mostly occurred in the more sloping topography areas within the upper watershed (Figure 7-15b).

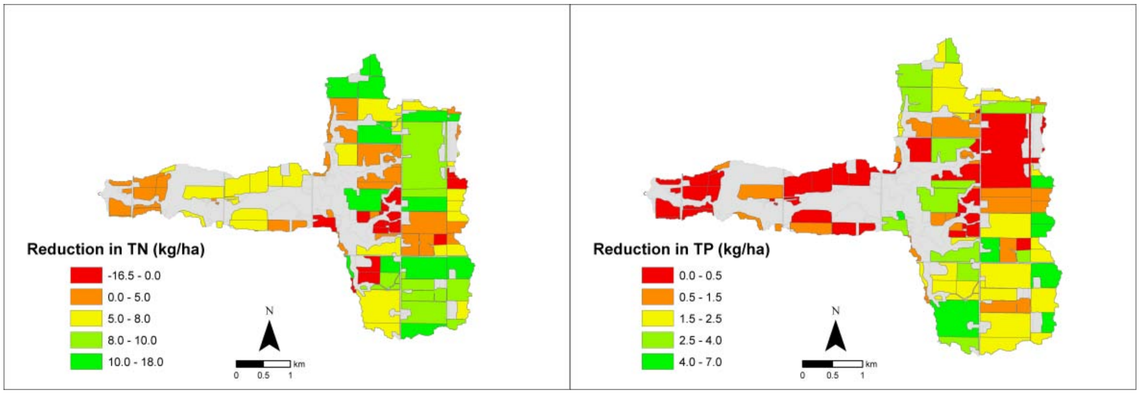


(a) (b)

Figure 7-15: Simulated average annual reduction of water yield (a) and sediment yield (b) at field scale with use of all agronomic BMPs compared to existing (baseline) land management practices

Because the majority of nitrogen lost from the watershed is in a dissolved form, the spatial pattern of N loss is similar to the spatial pattern of water yield changes. About 7% (3.3 ha) of the cropland area showed an increase in TN loading (to a maximum of 16.5 kg/ha) with the modeled implementation of all three agronomic BMPs. The cropland area was estimated to experience a reduction TN loss, with 49% seeing a reduction amount under 8 kg/ha, 21% seeing the average annual TN loss reduced between 8 and 10 kg/ha, and 23% seeing TN reductions from 10 to 17.2 kg/ha. It tended to be the relatively flat areas in upper watershed that yielded the higher TN losses while the TN reduction tended to occur on the more sloping areas all across the watershed (Figure 7-16a).

Because majority of phosphorous is in a particulate form in the watershed, the change in TP loadings with this BMP scenario followed a similar pattern to the sediment yield and approached but did not exceed the reductions that were possible with the implementation of conservation (no till) alone. Overall, 29% of the cropland area experienced a TP average annual load reduction of less than 0.5 kg/ha, 43% of the cropland area saw a TP load reduction between 0.5 and 2.5 kg/ha, and 28% of the cropland area had a TP load reduction of between 2.5 to 6.7 kg/ha. The higher TP reduction was distribute across the more sloped areas in the upper portion of the watershed (Figure 7-16b).

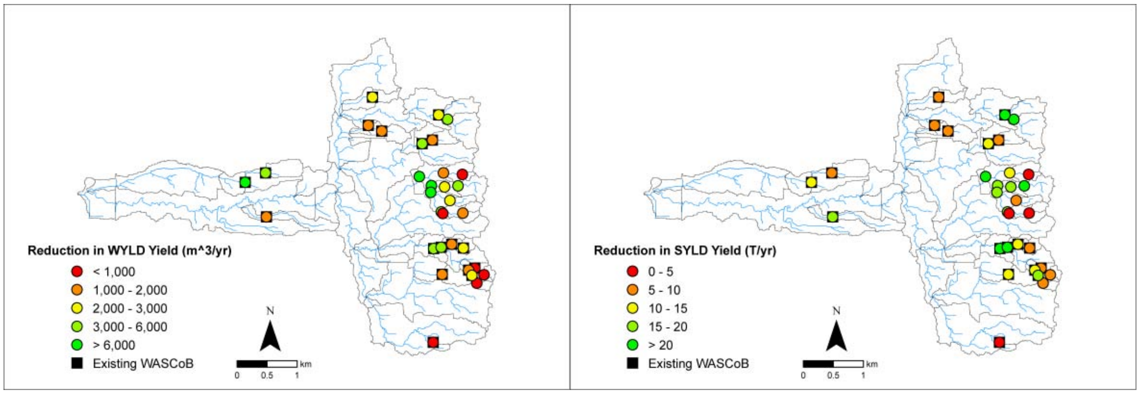


(a) (b)

Figure 7-16: Simulated average annual reduction of TN yield (a) and TP yield (b) at field scale with use of all agronomic BMPs compared to existing (baseline) land management practices

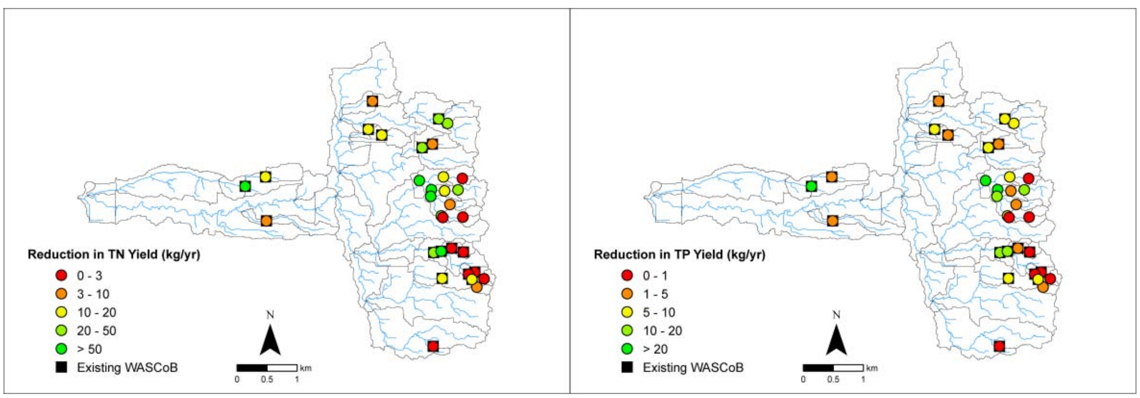
7.7 Site-specific SWAT results for WASCoBs (Scenario VIII)

SWAT modelling was applied to simulate the water quantity and quality effects of WASCoBs under Scenario VIII (Future WASCoB + existing land management practices). The SWAT-estimated water yield, sediment loading, and TN and TP loadings before entering into and after leaving the WASCoBs, as well as the resulting load reductions are shown in Table D-8 and Table D-9 of Appendix D. The spatial patterns of the WASCoB effects are shown in Figures 7-17 and 7-18.



(a) (b)

Figure 7-17: Reduction Estimates in water yield (a) and sediment loading (b) for the WASCoB BMP within Gully Creek Watershed



(a) (b)

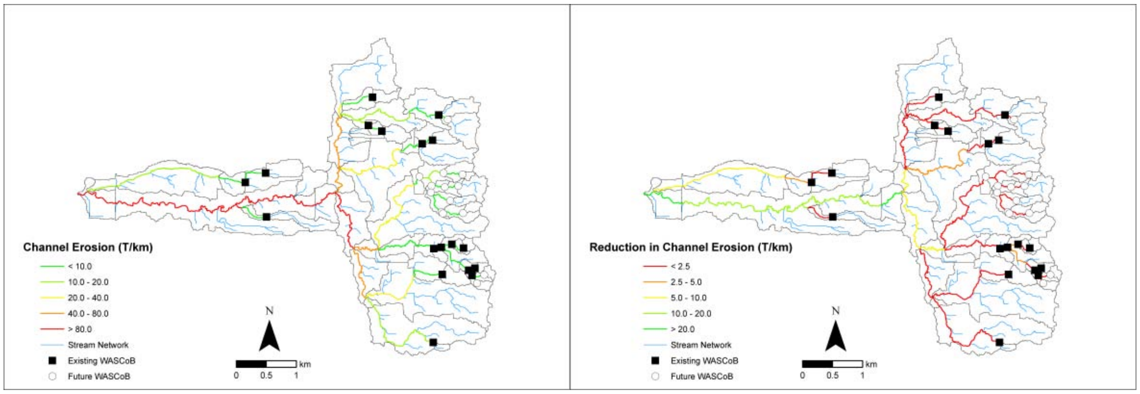
Figure 7-18: Reduction Estimates of TN loading (a) and TP loading (b) for the WASCoB BMP within Gully Creek Watershed

The SWAT model's output suggests that significant spatial variations of water quantity and quality effects can exist for individual WASCoBs established within the watershed. Typically WASCoBs downstream in the channel network gave higher reductions in water yield, sediment, TN, and TP loadings due to the larger drainage area associated with the WASCoBs at those point. Furthermore, loading reductions from WASCoBs also seem to depend on the drainage area conditions, with the higher reductions possible at sites where there is a potential for a higher supply of water and pollutants.

7.8 Location-specific SWAT results for channel erosion associated with WASCoBs (Scenarios II, III, and VIII)

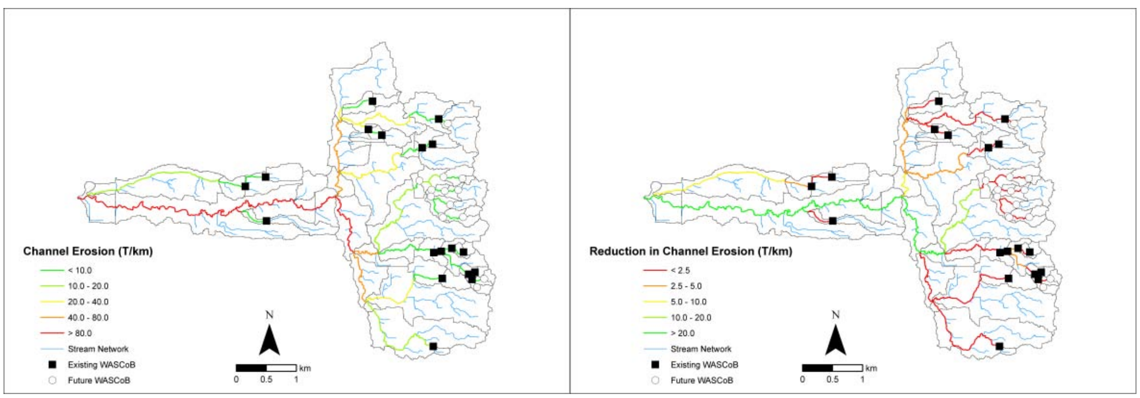
The construction of WASCoBs have positive effects on reducing channel erosion just downstream of the after WASCoB sites due to their ability to retain runoff water and subsequently divert this runoff flow underground. The aggregate effects of peak reduction can also reduce erosion in the downstream main channels. The difference in channel erosion rates between the existing WASCoBs being present (i.e. existing or baseline conditions), and existing WASCoBs being removed (i.e. Scenario II), is summarized in detail in Table D-10 of Appendix D. As well, the difference between no WASCoBs being present (Scenario II) and all existing and future WASCoBs in place (Scenario VIII) is summarized in Table D-11 in Appendix D.

By running SWAT without the existing WASCoBs simulated, it was estimated that the existing WASCoBs could reduce the average annual watershed channel erosion about 206.86 T/year with the reduction magnitude being the highest along the main channel reach at 5.46 T/km. With the addition of the 14 future WASCoBs to complement the 18 existing WASCoBs, SWAT estimated that the average annual channel erosion could be reduced by about 530.46 T/yr. Again the magnitude of channel erosion reduction was highest along the lower (main) channel reach at 13.99 T/km. A more complete overview of the spatial distribution of channel erosion reductions along the various channel reaches are shown in Figure 7-19 (a+b), which compares the existing WASCoB effect against the “no WASCoB” condition, and Figure 7-20 (a+b) which compared the existing + future WASCoB effect against the “no WASCoB” condition..



(a) (b)

Figure 7-19: Channel erosion with existing WASCoBs (a) and without Existing WASCoBs (b)



(a) (b)

Figure 7-20: Channel erosion with existing and future WASCoBs (a) and without existing and future WASCoBs (b)

Figures 7-19 and 7-20 show channel erosion levels increase from upstream to downstream. With the construction of WASCoBs, channel erosion immediately downstream of the WASCoB is reduced significantly. In addition, the accumulated effects of WASCoBs have pronounced effects on reducing erosion much further downstream in the main stream channels. A comparison of Figure 7-19b and Figure 7-20b indicates that as more WASCoBs are constructed, the ability to reduce downstream channel erosion also increases.

8.0 COST EFFECTIVENESS ANALYSIS OF BMP SCENARIOS

8.1 A definition of field–level cost effectiveness under existing WASCoBs and land management BMP scenarios

In Section 7.6, the SWAT-estimated field-specific water quantity and quality effects of implementing three land management BMPs (conservation tillage, nutrient management, and a red clover cover crop after winter wheat) in combination with the existing WASCoBs in the watershed are presented. Also, a companion report to this document, entitled: "Economic evaluation of the selected BMPs in the Gully Creek watershed (Huron County, Ontario)", presents estimates of field-specific annual costs for the three land management BMPs described above. This section reports on the field-specific cost effectiveness results for the three land management BMPs, calculated by dividing the BMP water quantity/quality effects by their economic cost, and then multiplying the results by $1,000. This converts the units for BMP cost effectiveness into mm of water/$1,000 for water yield, tonnes of sediment reduced/$1,000 for sediment yield, and kg of pollutant load reduced/$1,000 for TN and TP yields, which indicate the water quantity/quality effects per $1,000 BMP costs. For water quantity/quality effects, positive values indicate constituent reductions (environmental benefits) and negative values indicate constituent increases (environmental harms) compared to the existing condition (i.e. Existing (baseline) scenario – BMP scenario). For BMP costs, positive values indicate net return increases (economic gain) and negative values indicate net return reduction (economic loss) when compared against the existing condition (BMP scenario – Existing (baseline) scenario). As a result, cost effectiveness results have negative or positive signs due to various combinations of water quantity/quality effects and BMP costs (Table 8-1). In most instances, it was found that environmental benefits could be achieved through BMPs but with economic costs, which lead to a negative cost effectiveness. The higher absolute value of cost effectiveness indicates more cost effectiveness. However, in some cases of negative cost effectiveness, implementing BMPs may have economic gains but cause environmental harm. In contrast, positive cost effectiveness may be related to both economic gain and environmental benefit, or both economic loss and environmental harm from BMP implementation. Please also note that in the cost effectiveness estimation, water quantity effects were based on yearly average results from SWAT simulations during 2002–2011 but the yearly BMP costs for the three agronomic BMPs were based on actual crop production data collected for 2008–2010 as obtained from the synthesized land management database prepared through the WBBE study. The rationale was that both datasets were representative of long-term average water quantity and quality effects and agronomic BMP costs. These different time periods, however, make it necessary to interpret with caution the pattern of cost effectiveness shown here. An alternative approach was to just look at a single crop year. This approach had a disadvantage in that it did not give an overall picture. Fields for example, not growing the crop for which the analysis was completed could not be assessed. A one-year study of cost effectiveness of implementing conservation tillage in corn (2009) is shown in Appendix E.

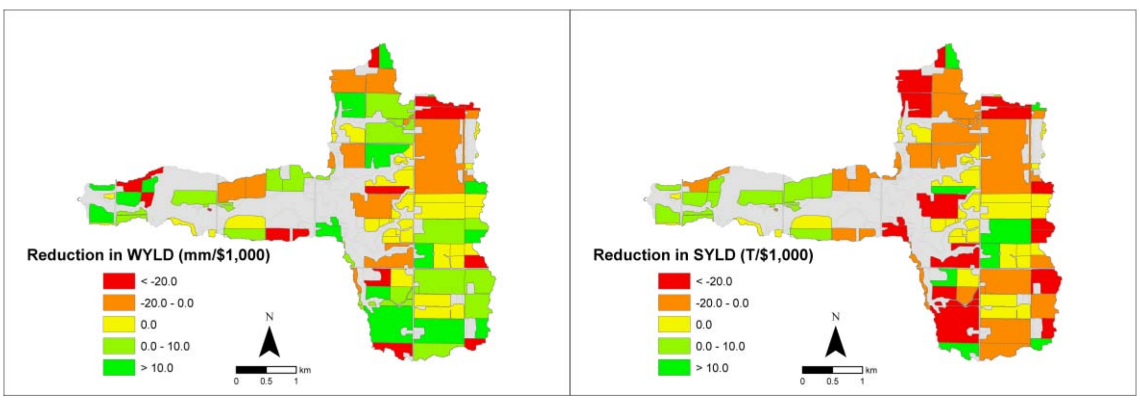
Table 8-1: Various combinations of water quantity/quality effects and BMP costs

Water/pollutant reduction – environmental benefits (+) Net return reduction – Economic loss(–)	Water/pollutant reduction – environmental benefit (+) Net return increase – Economic gain (+)
Water/pollutant increase – environmental harm (–) Net return reduction – Economic loss(–)	Water/pollutant increase – environmental harm (–) Net return increase – Economic gain (+)

8.2 Existing WASCoB + Conservation tillage (Scenario IV)

In the Gully Creek watershed, 20% of cropland area is already under conservation tillage. The cost effectiveness for these areas is therefore 0, as no tillage change is necessary. In areas with a negative cost effectiveness for water yields of less than -20 mm/$1,000, 6% of the crop fields have a water yield reduction and net return loss while 4% of the crop fields have a water yield increase and net return gain due to conservation tillage. In areas with negative cost effectiveness for water yields between -20 mm/$1,000 and 0 mm/$1000, 20% of the crop fields have a water yield reduction and net return loss while 3% of the crop fields have a water yield increase and net return gain due to conservation tillage. In areas with a positive cost effectiveness for water yield of greater than 10 mm/$1,000, 17% of the crop fields have a water yield increase and net return loss while 4% of the crop fields have a water yield decrease and net return gain due to conservation tillage. In areas with a positive cost effectiveness for water yields between 0 and 10 mm/$1,000, 22% of the crop fields have a water yield reduction and net return loss while 4% of the crop fields have a water yield increase and net return gain due to conservation tillage (Figure 8-1a).

A negative cost effectiveness for sediment yield has a clean pattern of positive environmental benefit and negative economic cost, with 23% and 38% of the crop fields in the ranges of less than -20 tons/$1,000 and between -20 tons/$1,000 and 0 tons/$1000 respectively, while positive cost effectiveness for sediment yields has a clean pattern of positive environmental benefit and economic gain, with 9% lying in the range of greater than 10 tons/$1,000 and 10% of the crop fields lying between 0 and 10 tons/$1,000 (Figure 8-1b).

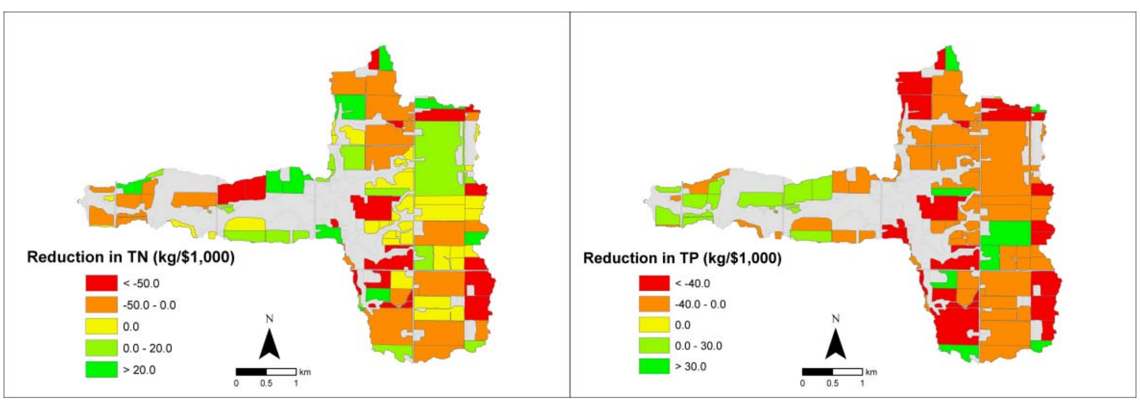


(a) (b)

Figure 8-1: Simulated average cost effectiveness based on water yield (a) and sediment yield (b) at field scale under existing WASCoBs and conservation tillage

Similar to the pattern of cost effectiveness for water yields, in areas with a negative cost effectiveness for TN yields less than -50 kg/$1,000, 13% of the crop fields have a TN reduction and net return loss while 4% of the crop fields have a TN yield increase and net return gain due to conservation tillage. In areas with a negative cost effectiveness for TN yields between -50 kg/$1,000 and 0 kg/$1000, 27% of the crop fields have a TN yield reduction and net return loss while 9% of the crop fields have a water yield increase and net return gain due to conservation tillage. In areas with a positive cost effectiveness for TN yields greater than 20 kg/$1,000, 8% of the crop fields have a TN yield increase and net return loss while 1% of the crop fields have water yield decrease and net return gain due to conservation tillage. In areas with a positive cost effectiveness for water yields between 0 and 20 kg/$1,000, 14% of the crop fields have a water yield reduction and net return loss while 5% of the crop fields have a water yield increase and net return gain due to conservation tillage (Figure 8-2a).

Similar to the cost effectiveness pattern for sediment yields, a negative cost effectiveness for TP yields has a clean pattern of positive environmental benefit and negative economic cost, with 25% and 36% of the crop fields in ranges of less than -40 kg/$1,000 and 36% of the crop fields lying in the range of between -40 kg/$1,000 and 0 kg/$1000 respectively, while positive cost effectiveness for TP yields has a clean pattern of positive environmental benefit and economic gain, with 10% of the crop fields in ranges of greater than 30 kg/$1,000 and 9% of the crop fields in ranges between 0 and 30 kg/$1,000 respectively (Figure 8-2b).



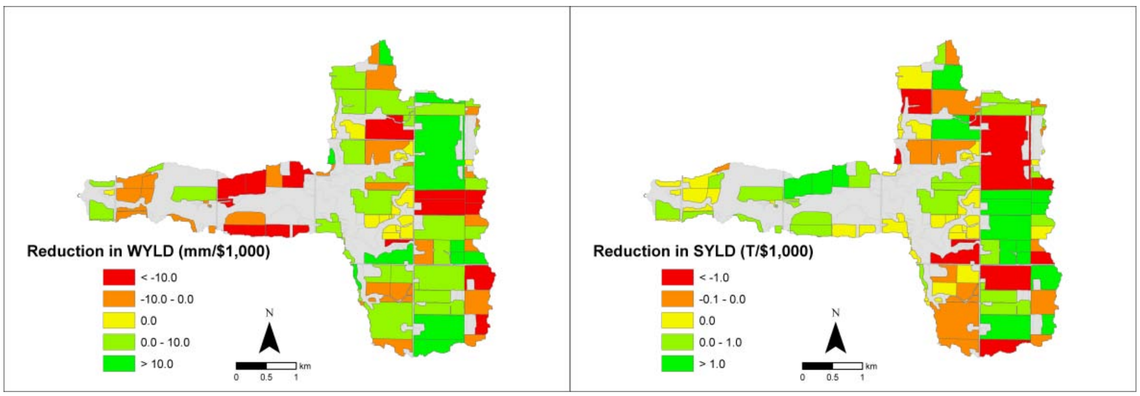
(a) (b)

Figure 8-2: Simulated average cost effectiveness based on TN yield (a) and TP yield (b) at field scale under existing WASCoBs and conservation tillage

8.3 Existing WASCoB + Fertilizer NMAN (Scenario V)

In the Gully Creek watershed, 5% of the cropland area is already under nutrient management (i.e. in the ranges of NMAN3 software recommended rates), the cost effectiveness is 0 as no change in fertilization practices is necessary. As discussed previously, nutrient management has limited effects on water yield and sediment loading. The magnitudes of the cost effectiveness are also lower than those of the conservation tillage and cover crop BMPs. In areas with a negative cost effectiveness for water yields less than -0 mm/$1,000, 7% of the crop fields have a water yield reduction and net return loss while 10% of the crop fields have a water yield increase and net return gain due to nutrient management. In areas with a negative cost effectiveness for water yields between -10 mm/$1,000 and 0 mm/$1000, 8% of the crop fields have a water yield reduction and net return loss while 12% of the crop fields have a water yield increase and net return gain due to nutrient management. In areas with a positive cost effectiveness for water yields greater than 10 mm/$1,000, 8% of the crop fields have a water yield increase and net return loss while 12% of the crop fields have a water yield decrease and net return gain due to nutrient management. In areas with a positive cost effectiveness for water yields between 0 and 10 mm/$1,000, 6% of the crop fields have a water yield reduction and net return loss while 32% of the crop fields have a water yield increase and net return gain due to nutrient management (Figure 8-3a).

In areas with a negative cost effectiveness for sediment yields less than -1.0 T/$1,000, 11% of the crop fields have a sediment yield reduction and net return loss while 10% of the crop fields have a sediment yield increase and net return gain due to nutrient management. In areas with a negative cost effectiveness for sediment yields between -1.0 T/$1,000 and 0 T/$1000, 6% of the crop fields have a sediment yield reduction and net return loss while 11% of the crop fields have a sediment yield increase and net return gain due to nutrient management. In addition to the 5% of the crop area in existing nutrient management, 7% of the crop fields have 0 cost effectiveness. In areas with positive cost effectiveness for sediment yields greater than 1.0 T/$1,000, 0.2% of the crop fields have a sediment yield increase and net return loss while 25.8% of the crop fields have a sediment yield decrease and net return gain due to nutrient management. In areas with positive cost effectiveness for sediment yields between 0 T/$1000 and 1.0 T/$1,000, 8% of the crop fields have a sediment yield reduction and net return loss while 16% of the crop fields have a sediment yield increase and net return gain due to nutrient management (Figure 8-3b).

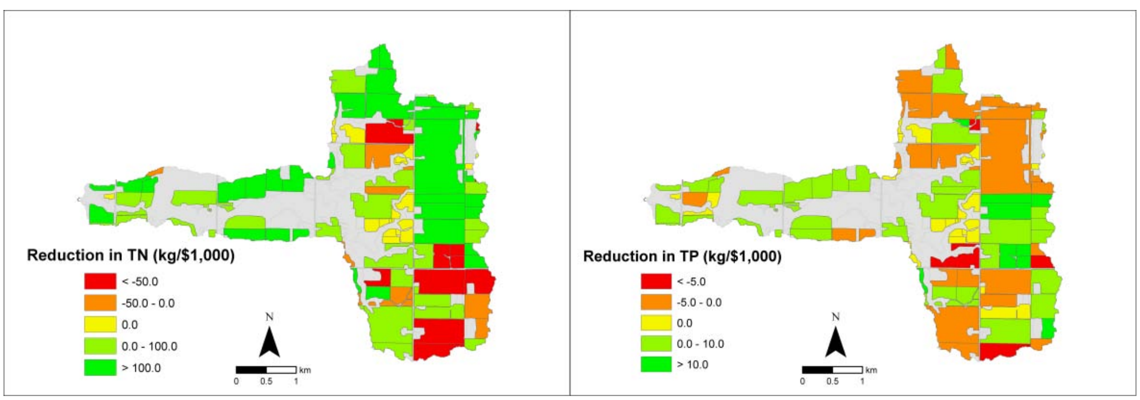


(a) (b)

Figure 8-3: Simulated average cost effectiveness based on water yield (a) and sediment yield (b) at field scale under existing WASCoBs and nutrient management

In areas with a negative cost effectiveness for TN yields less than -50 kg/$1,000, 13% of the crop fields have a TN yield reduction and net return loss while 3% of the crop fields have a TN yield increase and net return gain due to nutrient management. In areas with negative cost effectiveness for TN yields between -50 kg/$1,000 and 0 kg/$1000, 6% of the crop fields have a TN yield reduction and net return loss while 1% of the crop fields have a TN yield increase and net return gain due to nutrient management. In areas with positive cost effectiveness for TN yields greater than 100 kg/$1,000, 2% of the crop fields have a TN yield increase and net return loss while 39% of the crop fields have a TN yield decrease and net return gain due to nutrient management. In areas with a positive cost effectiveness for TN yields between 0 kg/$1000 and 100 kg/$1,000, 4.5% of the crop fields have a TN yield reduction and net return loss while 26.5% of the crop fields have a TN yield increase and net return gain due to nutrient management (Figure 8-4a).

In areas with a negative cost effectiveness for TP yields less than -5.0 kg/$1,000, 4% of the crop fields have a TP yield reduction and net return loss while 10% of the crop fields have a TP yield increase and net return gain due to nutrient management. In areas with a negative cost effectiveness for TP yields between -5.0 kg/$1,000 and 0 kg/$1000, 13% of the crop fields have a TP yield reduction and net return loss while 18% of the crop fields have a TP increase and net return gain due to nutrient management. In areas with a positive cost effectiveness for TP yields greater than 10.0 kg/$1,000, 1% of the crop fields have a TP yield increase and net return loss while 7% of the crop fields have a TP yield decrease and net return gain due to nutrient management. In areas with a positive cost effectiveness for TP yields between 0 kg/$1000 and 10.0 kg/$1,000, 11% of the crop fields have a TP yield reduction and net return loss while 31% of the crop fields have a TP yield increase and net return gain due to nutrient management (Figure 8-4b).

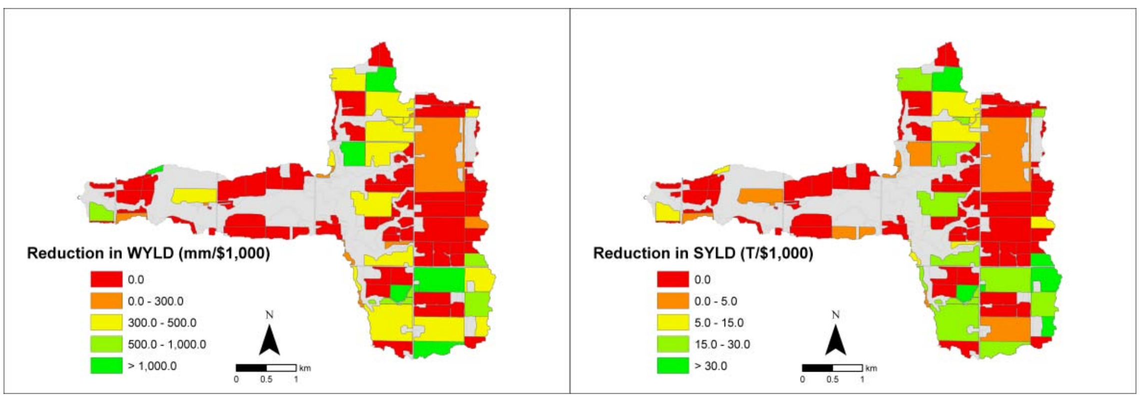


(a) (b)

Figure 8-4: Simulated average cost effectiveness based on TN yield (a) and TP yield (b) at field scale under existing WASCoBs and nutrient management

8.4 Existing WASCoB + Cover Crop (Scenario VI)

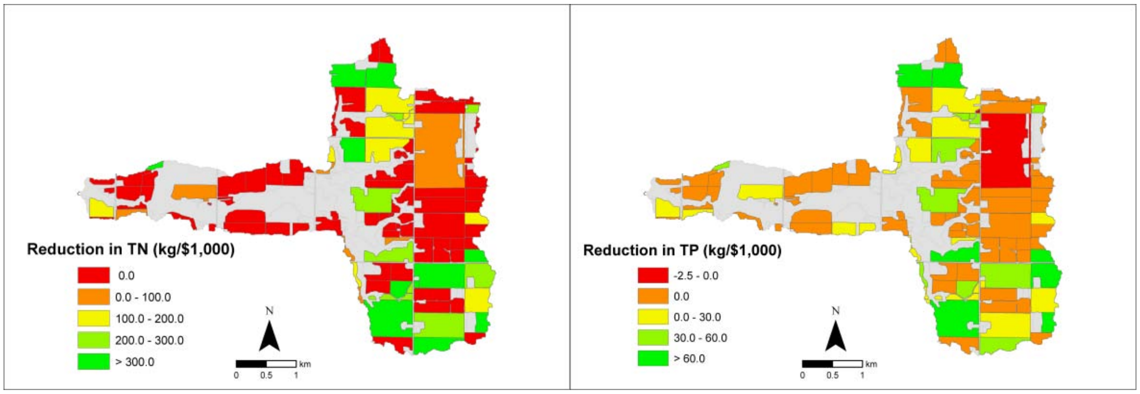
As cover crops were modeled as only being planted under winter wheat, 47% of the cropland area in the Gully Creek watershed is not eligible for the cover crop and cost effectiveness is 0 as no cover crop BMP is necessary. Most of the crop fields with cover crop have an economic gain, except for field 30 which had an economic loss due to the fact that fertilizer rates used were lower than the nitrogen credits received from the cover crop and the cover crop production cost ($66.7/ha) was not offset by the fertilizer cost savings ($44.2). Cover crop reduces water and sediment yields. The cost effectiveness for water yields has a clear positive pattern of a water yield reduction and economic gain, with 12%, 26%, 5%, and 10% of the crop fields in ranges of 0 – 300, 300 – 500, 500 – 1000, and > 1,000 mm/$1,000 respectively (Figure 8-5a). Similarly, the cost effectiveness for sediment yields has a clear positive pattern of a sediment yield reduction and economic gain, with 18%, 8%, 21%, and 6% of the crop fields in ranges of 0 – 5, 5 – 15, 15 – 30, and > 30 tons/$1,000 respectively (Figure 8-5b).



(a) (b)

Figure 8-5: Simulated average cost effectiveness based on water yield (a) and sediment yield (b) at field scale under existing WASCoBs and cover crop

Cover crop reduces TN yields. The cost effectiveness for TN yields has a clear positive pattern of TN yield reduction and economic gain, with 14%, 11%, 10%, and 18% of the crop fields in ranges of 0 – 100, 100 – 200, 200 – 300, and > 300 kg/$1,000 respectively (Figure 8-6a). Cover crop has mixed effects on TP, with 10% of crop area has phosphorus yield increase and cost effectiveness between – 2.5 and 0 kg/$1,000. Majority of crop fields with cover crop have a positive pattern of TP yield reduction and economic gain, with 19%, 12%, and 13% of the crop fields in ranges of 0 – 30, 30 – 60, and > 60 kg/$1,000 respectively (Figure 8-6b).

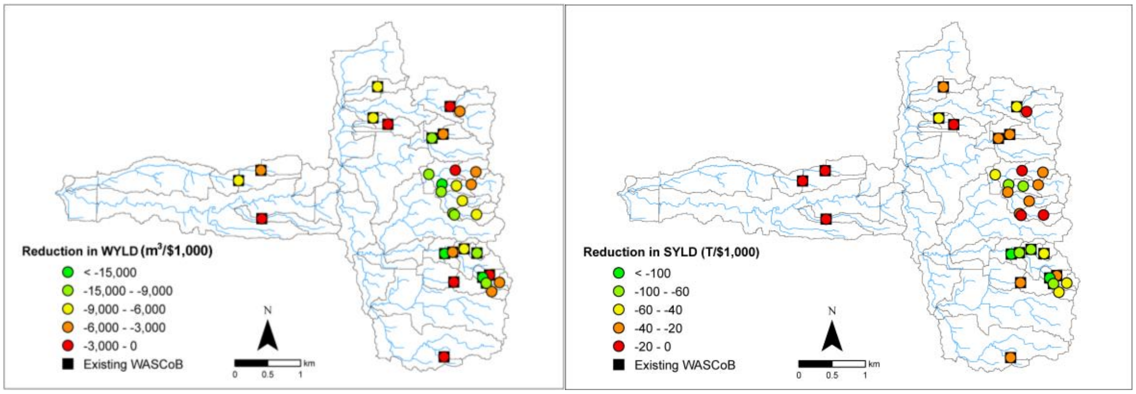


(a) (b)

Figure 8-6: Simulated average cost effectiveness based on TN yield (a) and TP yield (b) at field scale under existing WASCoBs and cover crop

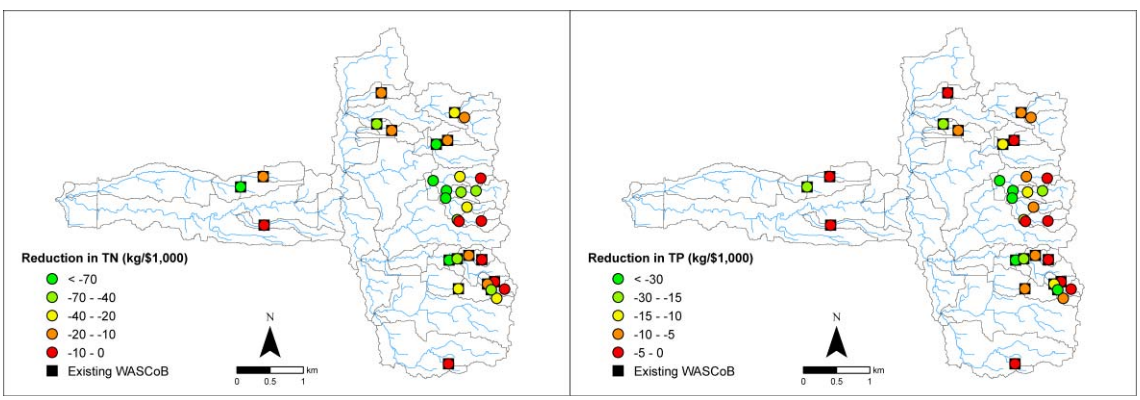
8.5 Site-specific cost effectiveness results for WASCoBs (Scenario VIII)

As described in Section 7.7, SWAT modelling was applied to simulate the water quantity and quality effects of WASCoBs under Scenario VIII (Future WASCoB + existing (baseline) conditions). Comparing this run with the baseline conditions, the on-site reductions of water yield, sediment loading, and TN and TP loadings before entering into and after leaving the future (proposed) WASCoBs were estimated. In the research report "Economic evaluation of the selected BMPs in the Gully Creek watershed (Huron County, Ontario)", the yearly costs for the WASCoBs were also estimated. This subsection reports on the site-specific cost effectiveness results for the WASCoBs obtained through dividing the on-site water quantity/quality reductions by the economic costs, and then multiplying by $1,000. The units for WASCoB cost effectiveness are mm/$1,000 for water yield, T/$1,000 for sediment yield, and kg/$1,000 for TN and TP yields, which indicate the water quantity/quality effects per $1,000 of WASCoB implementation cost. WASCoBs have positive environmental benefits in terms of reductions in water yield, and sediment, TN, and TP loadings achieved through economic costs invested in their construction (i.e. negative). As a result, cost effectiveness results for WASCoBs have negative signs. The higher absolute value of cost effectiveness means the measure at that point in the landscape is more cost effective (Table 8-2).



(a) (b)

Figure 8-7: Simulated average cost effectiveness for WASCoBs based on on-site reductions of water yield (a) and sediment loading (b) (Scenario VIII)



(a) (b)

Figure 8-8: Simulated average cost effectiveness for WASCoBs based on on-site reductions of TN loading (a) and TP loading (b) (Scenario VIII)

Table 8-2: Simulated average cost effectiveness for WASCoBs based on on-site reductions of water yield, and sediment, TN and TP loadings (Scenario VIII)

Reservoir No.	Subbasin No.	Subbasin Area (ha)	Yearly economic cost ($/yr)	Cost effectiveness - Water Yield (m^3/$1,000)	Cost effectiveness - Sediment (ton/$1,000)	Cost effectiveness - Total P (kg/$1,000)	Cost effectiveness - Total N (kg/$1,000)
1*	1	7.33	-395	-6,135	-23	-3	-10
2	7	23.29	-1,255	-3,902	-16	-6	-17
3*	4	14.6	-787	-2,725	-40	-7	-33
4*	10	10.66	-575	-2,616	-13	-7	-19
5*	9	4.2	-226	-8,791	-43	-23	-63
6*	14	7.38	-398	-5,009	-22	-2	-13
7*	15	9.3	-501	-11,444	-27	-13	-70
8*	21	15.69	-845	-4,941	-8	-3	-18
9*	25	18.42	-993	-7,711	-12	-21	-128
10	22	2.06	-111	-3,747	-32	-3	-5
11	20	10.73	-578	-2,717	-18	-9	-23
12	27	14.72	-793	-4,494	-39	-19	-51
13	29	5.12	-276	-7,724	-69	-11	-45
14	36	5.38	-290	-7,826	-28	-6	-20
15	41	4.18	-225	-8,152	-19	-2	-6
16	42	0.55	-30	-12,060	-11	-3	-5
17	40	10.57	-570	-9,826	-28	-10	-40
18	32	11.51	-620	-12,436	-30	-30	-122
19	28	5.02	-270	-51,462	-71	-104	-463
20	23	14.28	-769	-13,164	-40	-36	-169
21*	43	18.19	-980	-1,175	-16	-1	-3
22*	48	3.69	-199	-11,795	-48	-4	-9
23*	44	3.98	-215	-7,354	-65	-5	-11
24*	53	2.36	-367	-2,121	-20	-1	-2
25	56	3.14	-169	-3,236	-42	-2	-6
26*	57	10.68	-576	-2,206	-26	-9	-22
27	60	3.61	-194	-3,409	-48	-7	-20
28*	59	4.64	-167	-12,331	-95	-38	-65
29*	55	1.23	-66	-18,109	-190	-10	-16
30*	46	20.41	-1,100	-4,203	-93	-17	-59
31*	50	4.48	-241	-17,548	-160	-60	-200
32*	64	2.8	-151	-2,725	-27	-1	-5

Note: * indicates existing WASCoBs

As shown in Figures 8-7 a&b and Figures 8-8 a&b, there exist significant spatial variations of cost effectiveness for existing and future WASCoBs. For cost effectiveness based on water yields, 3, 7, 7, 8, and 7 WASCoBs are in the categories of > -15,000, -15,000 to -9,000, -9,000 to -6,000, -6,000 to -3,000, and -3,000 to 0 mm/$1,000, respectively. For cost effectiveness based on sediment loading, 2, 5, 6, 11, and 8 WASCoBs are in the categories of > -100, -100 to-60, -60 to -40, -40 to -20, and -20 to 0 tons/$1,000, respectively. For cost effectiveness based on TN loading, 5, 7, 5, 7, and 8 WASCoBs are in the categories of >-70, -70 to -40, -40 to -20, -20 to -10, and -10 to 0 kg/$1,000, respectively. For cost effectiveness based on TP loading, 4, 5, 4, 8, and 11 WASCoBs are in the categories of > -30, -30 to -15, -15 to -10, -10 to-5, and -5 to 0 kg/$1,000, respectively. Overall, the cost effectiveness pattern is consistent for water yield, sediment, TN, and TP loadings. The WASCoB cost effectiveness is associated with drainage area and berm structure. Typically WASCoBs located in the headwater areas were more cost-effective than WASCoBs located in downstream areas in the WASCoB network.

9.0 CONCLUSIONS

9.1 Project summary

This project modified, built and ran the SWAT model for the purposes of BMP assessment in the Gully Creek watershed. Innovations were developed at every stage to improve the quality of the modelling. For data preparation, climate input data was prepared using both available inside (within watershed) weather station data and long-term available nearby outside watershed station data. A statistical analysis of various climate series was conducted to ensure consistency of the synthesized climate data for SWAT modelling. A high resolution LiDAR DEM was used for watershed delineation and derivation of spatial model parameters. Existing culvert data and field verification data were used to modify LiDAR data to ensure a correct flow pattern for the watershed. In soil data preparation, the OMAFRA soil database, the CANSIS database, parameter inference, and data transfer functions were utilized to populate the soils dataset with reasonable values for the required SWAT input. Generalized land cover data, ecological land classification data, agricultural inventory (AgRI) data, landowner interviews, and windshield survey data were all used and combined to develop a synthesized landuse/land cover data layer. Furthermore, landowner interview data, NMAN3 fertilization recommendations, and county and provincial crop budget templates were all used to help prepare existing and BMP specific land management data including seeding and harvesting dates, tillage events and times, chemical fertilizer and manure rates and timing, and residue management practices.

For SWAT setup, significant outlets including confluences of major tributaries, existing and future WASCoB sites, field monitoring station locations at field-edge, in-stream, and the watershed outlet, and tile drain outlets were all used to delineate the watershed into subbasins. This approach allowed modellers to make better use of the monitoring data for model calibration and validation and also enabled the simulation of some BMPs such as WASCoBs because drainage areas of monitoring sites and WASCoBs were defined in advance as part of the model set-up. A total of 64 subbasins were delineated for the

Gully Creek watershed, with outlets located at 15 main tributaries, 7 monitoring stations, 18 existing WASCoBs, 14 future WASCoBs, and 10 tile drain outlets.

By combining slope classes with soil and landuse layers, a total of 518 HRUs were defined belonging to 4 slope classes, 0-2%, 2%-5%, 5%-9%, and >9% across the watershed. These HRUs were sufficient to represent the spatial distribution of hydrologic processes for different combinations of slope, soil, and landuse in the Gully Creek watershed.

In order to characterize the subsurface drain system in the watershed, tile drain data obtained from OMAFRA and field survey were used to setup tile drain features in the SWAT.

Because no field measurement data for the specific BMPs within the Gully Creek watershed were available, various literature values and BMP parameters were referenced and applied in this study. The conservation tillage BMP was characterized by adjusting tillage management parameters including tillage type, depth, mixing efficiency, and operational curve number. The nutrient management BMP was characterized in the model by adjusting fertilizer and manure application rates based on the calculated NMAN3 recommendations for each field in the watershed. The cover crop BMP was characterized in the model by planting red clover after wheat harvest and plowing it down in late fall before the next year's crop. To enhance SWAT capacity, a WASCoB module was developed specifically for the project to simulate water quantity and quality effects of WASCoBs.

SWAT calibration was conducted to improve model predictions at the Gully Creek outlet (GULGUL2) and at three inside stations GULGUL3, GULGUL4, and GULGUL5 using available flow and water quality data. Both graphical comparisons and statistical measures indicated that the SWAT modelling was doing a very good job of simulating watershed processes under the existing conditions in the Gully Creek watershed.

The goal of the SWAT modelling was to use it to examine the water quantity and quality effects of four selected BMPs for investigation: Conservation tillage, nutrient management, red clover cover crop after winter wheat and WASCoBs. A 1978 land management condition was also constructed to represent agricultural land management practices as they existed in the watershed at that point in time. Based on the options of without WASCoBs, existing WASCoBs, and future WASCoBs, historical (1978) land management, and three land management BMPs, a total of 12 model scenarios were developed for SWAT simulations. The calibrated SWAT model was then applied to evaluate these 12 BMP scenarios in the Gully Creek watershed. Combined with BMP economic modelling results, a cost effectiveness analyses was conducted at both a field level and at a site specific level for the BMP scenarios developed for the Gully Creek watershed.

9.2 Key findings and lessons learned

A calibrated SWAT model of the existing watershed conditions, estimates that the Gully Creek watershed generates an average annual runoff amount of 579 mm, with a flow coefficient of 0.54. The average annual sediment loading is 5,131 T/yr, which translates to an average annual sediment delivery rate of 3.6 T/ha/yr. Overland erosion contributes 45.7% of this sediment load and channel, ditch and in-field concentrated flow path erosion contributes 54.3% of this total sediment load. The total nitrogen (TN) loading was estimated using the calibrated SWAT model to be 40,880 kg/year which translates to an average unit loading of of 28.7 kg/ha/yr. Most of the nitrogen loadings are dissolved (71.1%) with an average unit loading of 20.4 kg/ha/yr. Particulate N contributes 28.9% of the TN with an average unit loading rate of 8.27 kg/ha/yr. The total TP loading is 5,656 kg/yr with an average unit loading rate of 3.96 kg/ha/yr. In contrast to nitrogen loadings, most of the phosphorus loadings are in particulate form (69.2%), with an average PP unit loading rate of 2.74 kg/ha/yr, while dissolved P contributes 30.8% of the TP with an average DP unit loading rate of 1.22 kg/ha/yr. These results do correspond to field observations from typical small lakeshore watershed conditions in the Lake Huron Basin.

Comparing the SWAT simulations of the historical (1978) and existing (2011) crop type and land management conditions (assuming no WASCoBs had been implemented) showed a slight increase in sediment loading and a significant increase in TN loading between the 1978 conditions and the 2011 conditions. This pattern indicates that existing agriculture may cause more water degradation compared to 1978 conditions. Note, however, when the 1978 condition was compared with the 2011 (baseline) conditions that accounted for the WASCoBs that had been installed in the watershed since 1978, there was actually a small decrease in sediment loading under the 2011 conditions. Nitrogen loading, however, remained significantly elevated under the 2011 (baseline) conditions.

For the three land management BMPs, enhanced conservation tillage ranked the highest in ability to reduce sediment and TP due to its effectiveness at controlling rill and inter-rill erosion. However, SWAT modelling estimated that enhanced use of conservation tillage could cause a small increase in dissolved N loss due to more leaching associated with residue cover and increased contributions from lateral subsurface flow. Overall, however, no till, because of its influence on reducing overland sediment and nutrient losses, did show a net small reduction effect for TN.

The red clover cover crop after winter wheat ranked second in terms of sediment and TP reductions, and ranked first in terms of reducing TN loads due to the assumed cover crop's ability to biologically fix nitrogen and make it available for the next year's crop. This result assumes producers would account for this additional N contribution from the red clover ploughdown and adjust their fertilization rates accordingly as part of their nutrient management planning.

The nutrient management BMP had the lowest effect on pollution reduction. The reason is that the fertilizer rates recommended for the targeted yield goals in the watershed by NMAN3 was very close to, and in some cases was higher than actual fertilizer application rates reported by the landowners in the on-farm interviews. Therefore, while there may be room for individual improvement, the average potential to further optimize nutrient application rates across the watershed is small.

The aggregated effects of all three agronomic BMPs are smaller than the sum of the effects of these individual BMPs due to the fact that one BMP may limit the overall implementation potential of another BMP. For example, modelling no-till practices after winter wheat harvest was not possible at the same time the fall ploughdown of the red clover cover crop BMP was modeled. Overall, however, the land management BMPs exhibited clear spatial patterns in terms of sediment and nutrient reductions. Typically, the implementation of conservation tillage and cover crops in the more sloping areas of the watershed seemed more effective in reducing sediment and TP than in the same practices in flatter areas of the watershed.

WASCoBs as a structural BMP have pronounced positive effects on reducing sediment, TN, and TP loadings. Their efficacy is comparable to conservation tillage and cover cropping, and they are effective in reducing both particulate and dissolved nutrients. The WASCoBs also have positive effects in reducing channel erosion immediately downstream and further downstream of WASCoB sites. Compared to the "no WASCoB" condition, the existing WASCoBs were estimated to be reducing channel erosion about 206.86 T/yr with the magnitude being as high as 5.46 T/km on the downstream main channel. Adding 14 additional (Future) WASCoBs to the existing 18 WASCoBs already present (existing) was estimated to have the potential to reduce channel erosion to about 530.46 t/yr relative the "no WASCoB" scenario. The magnitude of sediment load reduction was estimated to be as high as 13.99 T/km on the main channel with all potential WASCoBs in place. Similar to the land management BMPs, the effects of WASCoBs also have spatial variations. The WASCoBs downstream of the channel network are more effective in sediment and nutrient reduction due to cumulative (larger) drainage areas. Placement of WASCoBs in high sediment and nutrient generation areas is also more effective.

Combining BMP cost data from on-farm economic modelling with BMP water quantity/quality effects data from SWAT modelling leads to an estimate of the cost effectiveness of the BMP measures. In the Gully Creek watershed, the cost effectiveness of conservation tillage/no-till, nutrient management, and cover crop BMPs exhibited considerable spatial variation across farm fields. Similarly, the cost effectiveness for WASCoBs also had clear spatial variation across sites. These patterns indicate the importance of spatial targeting of BMPs. Identifying these differences, however, is difficult outside of detailed modelling of the system.

From the modelling study of BMPs effects on water quantity and water quality in the Gully Creek watershed, the following lessons have been learned for improving model performance in similar projects in the region:

(1) The soil data including soil test N and P concentration as well as associated soil parameters are crucial in determining nutrient lost from crop fields particularly for a short calibration period as for the case in this study. Therefore, these parameters need to be assigned appropriately in the model to reflect actual situations in the fields.

(2) Because of the short monitoring period at the four stations (Table 6-4), considerable uncertainties exist in the model calibration and therefore the BMP assessment results in this study. Continuing measurement of climate, land management, and water quantity and quality is required to improve the modelling reliability of the Gully Creek watershed.

(3) Snowmelt related runoff, sediment, and nutrient yields are important components in the annual hydrologic cycle in the Gully Creek watershed. However, because no specific snow measurement data (e.g. snow distribution, density, temperature) are available, the algorithm of snow redistribution we developed for the SWAT in the WEBs project was not implemented in this study and the model assumed a uniform snow distribution among different HRUs as is normally done by SWAT. This may affect the modelling result of spatial distribution of snowmelt runoff, and associated sediment and nutrient yields in the Gully Creek watershed. To improve the model performance, a snow survey to characterize snow redistribution under various landcover/landuse and topographic conditions is required.

(4) Tile drains are placed in most of cropland areas in the Gully Creek watershed and play an important role in the water and nutrient cycle. However, no detailed tile train data such as spatial distribution, design parameters, and field water quantity and water quality measurements are available in this project. This could affect the setup and calibration of the model in characterizing tile drain flow and water quality dynamics at different scale. Further detailed tile drain data particularly field flow and water quality data need to be collected in order to improve the model's reliability and predictability for the watershed.

(5) Because there is field flow and local water quality data are not available for the three land management BMPs (conservation tillage, nutrient management, and cover crop) in the Gully Creek watershed, modelling evaluation of these BMPs was conducted by referring to various literature values and by communication with field specialists. This could bring uncertainties to the BMP evaluation and cost-effectiveness analysis results. In order to improve the BMP assessment reliability, the model needs to be revalidated once the flow and water quality data for the specific BMPs at site and at field scale are available.

9.3 Recommendations for future research

Based on the hydrologic modelling and BMP assessment studies in the Gully Creek watershed, following recommendations and issues for consideration are provided for future research and development:

(1) Develop a long-term monitoring program

The performance of hydrologic modelling and the assessment of BMP effects on flow and water quality are strongly dependent upon the quality of the data (length, accuracy, and spatial distribution) that are used to train and validate the model. These data include climate, flow, water quality, and land management variables. In particular, field flow and water quality data, measured at representative BMP sites, are essential to calibrate the model for a proper assessment of BMPs at both field and watershed scale. Therefore, a long-term monitoring program, that serves watershed management needs and addresses different types of BMPs, needs to be developed.

(2) Develop parallel semi-distributed modelling and fully-distributed modelling

SWAT is a semi-distributed model that simulates hydrologic processes at subbasin and HRU scales. In comparison to other commonly used watershed models, SWAT has an important advantage of explicit incorporation of land management practices, and therefore, is suitable for a long-term assessment of BMPs at a watershed scale. However, because HRUs are not hydrologically connected, the processes within the HRU and interactions among HRUs are not simulated in the model. This limits the use of the model to study more detailed hydrologic processes, to assess the effect of place-based BMPs (e.g. structural BMPs), and to design a spatial BMP management system in a watershed. To overcome this problem, a fully distributed modelling approach, parallel to SWAT, is recommended for adequately characterizing the spatial and temporal variations of hydrologic processes in the watershed.

(3) Develop modelling transfers to other similar lakeshore watersheds

The modelling approach has an advantage in that it is transferable to watersheds with similar geographical features. A lot has been learned from the modelling and BMP studies in the Gully Creek watershed. This modelling knowledge and experience can be transferred to similar lakeshore watersheds in the region. In addition to the modelling technique, the knowledge obtained from data analysis such as crop, tillage, fertilizer, and WASCoBs can also be transferred to scale-up the model and to evaluate BMP effects on water quantity and water quality in other similar watersheds.

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APPENDICES

Appendix A: Additional Tables for SWAT setup (Chapter 4)

Table A-1: Classification of landuses, soils, and slopes in the model setup

LANDUSE	Code	Area (ha)	Percentage (%)
Corn	CORN	336.58	23.58
Soybean	SOYB	320.45	22.45
Winter Wheat	WWHT	262.07	18.36
Spring Barley	BARL	7.22	0.51
Hay	HAY	19.32	1.35
Pasture	PAST	19.36	1.36
Orchard	ORCD	2.21	0.16
Field Peas	FPEA	1.31	0.09
Meadow	BROM	27.37	1.92
Tall Fescue	FESC	8.01	0.56
Forest-Evergreen	FRSE	18.29	1.28
Forest-Deciduous	FRSD	57.69	4.04
Forest-Mixed	FRST	299.15	20.96
Range-Brush	RNGB	0.87	0.06
Wetlands-Non-Forested	WETN	0.78	0.05
Water	WATR	0.58	0.04
Residential-Low Density	URLD	37.03	2.59
Transportation	UTRN	9.06	0.63
SOILS	Code	Area (ha)	Percentage (%)
Brady Sandy Loam	BAY	178.61	12.51
Brookston Clay Loam	BKN	151.12	10.59
Burford Loam	BUF	36.13	2.53
Huron Clay Loam	HUO	819.60	57.42
Perth Clay Loam	PTH1	104.63	7.33
Bottom Land	ZAL	137.25	9.62
SLOPE	Code	Area (ha)	Percentage (%)
0-2	A	295.76	20.72
2-5	B	601.22	42.12
5-9	C	294.25	20.62
>9	D	236.11	16.54
TOTAL		1427.35	100.00

Table A-2: SWAT generated reach parameters for the Gully Creek watershed

Reach	Subbasin	Length (m)	Slope (%)	Bankfull width (m)	Bankfull depth (m)	Shape length (m)	Contribution area (ha)
1	1	17.07	1.93	0.27	0.05	17.07	7.33
2	2	589.20	2.07	0.48	0.07	589.20	19.25
3	3	658.55	0.78	1.05	0.11	1253.97	70.64
4	4	217.63	4.47	0.72	0.09	872.90	37.89
5	5	1492.31	1.78	1.49	0.14	2163.80	126.74
6	6	271.07	8.60	1.21	0.12	2626.22	90.26
7	7	561.63	1.34	0.54	0.07	945.83	23.29
8	8	94.50	3.19	0.43	0.06	94.50	16.20
9	9	284.35	1.25	0.41	0.06	284.35	14.86
10	10	221.92	1.04	0.34	0.05	221.92	10.66
11	11	216.57	3.22	0.15	0.03	216.57	2.78
12	12	19.14	13.53	0.17	0.03	19.14	3.55
13	13	102.43	0.98	0.16	0.03	102.43	3.08
14	14	217.78	1.53	0.27	0.05	217.78	7.38
15	15	223.14	1.65	0.44	0.06	223.14	16.67
16	16	133.64	12.06	0.82	0.10	1561.60	46.96
17	17	357.99	1.64	0.88	0.10	357.99	53.34
18	18	1361.57	1.75	2.31	0.19	2421.73	263.49
19	19	1808.09	1.55	1.60	0.15	3873.60	142.46
20	20	378.49	1.93	0.38	0.06	378.49	12.78
21	21	256.92	1.37	0.42	0.06	430.21	15.69
22	22	20.00	0.90	0.13	0.03	20.00	2.06
23	23	356.76	1.66	1.16	0.12	671.63	84.10
24	24	469.35	1.29	0.82	0.10	718.70	47.43
25	25	523.99	1.41	0.68	0.08	871.27	34.11
26	26	193.14	0.26	1.21	0.12	193.14	89.95
27	27	535.27	1.57	0.41	0.06	675.98	14.72
28	28	182.92	1.26	0.92	0.10	374.71	57.04
29	29	285.56	1.75	0.49	0.07	285.56	19.84
30	30	2703.86	1.33	1.51	0.14	4669.16	129.35
31	31	668.91	1.06	3.05	0.23	668.91	420.13
32	32	430.37	1.18	0.65	0.08	825.83	32.19
33	33	858.15	2.64	6.36	0.38	1505.79	1427.35
34	34	1449.39	2.12	3.84	0.27	2291.93	616.41
35	35	205.21	5.37	0.44	0.06	205.21	16.78
36	36	361.42	2.08	0.22	0.04	361.42	5.38
37	37	5266.66	0.86	5.93	0.36	8701.78	1271.79
38	38	509.56	3.86	5.31	0.33	1006.54	1056.88
39	39	527.49	1.96	0.53	0.07	527.49	22.98
40	40	389.24	1.45	0.42	0.06	447.13	15.30
41	41	74.50	2.48	0.19	0.04	74.50	4.18
42	42	7.50	3.73	0.06	0.02	7.50	0.55
43	43	1177.90	1.70	0.46	0.07	1177.90	18.19
44	44	280.21	2.52	0.28	0.05	280.21	7.67
45	45	372.13	1.45	0.98	0.11	372.13	63.60
46	46	459.19	2.91	0.83	0.10	1114.12	47.58
47	47	2032.58	1.73	1.90	0.17	5089.43	190.81
48	48	51.21	1.00	0.18	0.03	51.21	3.69
49	49	675.12	3.03	2.43	0.20	1161.90	287.17
50	50	145.71	1.32	0.87	0.10	167.78	52.06
51	51	881.19	1.61	1.13	0.12	907.40	80.54
52	52	1192.61	1.46	2.42	0.20	1863.59	285.03
53	53	22.07	2.04	0.14	0.03	22.07	2.36
54	54	230.17	2.90	0.48	0.07	324.71	19.50
55	55	109.50	1.54	0.37	0.06	109.50	12.61
56	56	27.07	4.10	0.16	0.03	27.07	3.14
57	57	128.14	0.81	0.34	0.05	128.14	10.68
58	58	642.84	1.02	0.65	0.08	948.91	31.72
59	59	209.41	1.64	0.35	0.05	364.35	11.38
60	60	46.21	0.71	0.18	0.03	46.21	3.61
61	61	1219.68	2.72	1.62	0.15	5788.78	146.17
62	62	213.14	1.95	1.35	0.13	213.14	108.41
63	63	1891.31	1.61	1.33	0.13	4544.75	105.52
64	64	243.57	2.05	0.15	0.03	243.57	2.80
Sum/Ave		37754.22	1.76	2.16	0.17	68923.51	122.62

Table A-3: SWAT generated subbasin parameters for the Gully Creek watershed

Subbasin	Area (ha)	Length (m)	Slope (%)	Slope length (m)	Elevation (m)	Type
1	7.33	636.45	3.42	91.44	261.89	BE
2	11.93	706.81	4.34	91.44	253.96	T
3	32.75	1101.37	3.23	91.44	265.14	T
4	14.60	963.58	3.98	91.44	274.10	BE
5	39.90	2026.19	6.92	60.96	257.24	C
6	71.01	2460.37	3.87	91.44	255.72	C
7	23.29	950.83	4.49	91.44	274.10	BF
8	1.34	236.24	6.48	60.96	254.65	T
9	4.20	325.56	4.97	91.44	256.37	BE
10	10.66	621.63	2.99	91.44	260.32	BE
11	2.78	416.60	3.13	91.44	252.51	G
12	3.55	638.31	2.87	91.44	254.39	G
13	3.08	407.46	2.53	91.44	252.21	G
14	7.38	523.85	3.38	91.44	268.32	BE
15	9.30	660.95	3.25	91.44	263.92	BE
16	30.29	1487.14	3.68	91.44	266.46	G
17	6.38	566.13	6.91	60.96	259.71	T
18	37.08	1447.31	10.42	60.96	245.75	C
19	89.12	2065.87	8.99	60.96	252.85	C
20	10.73	628.02	4.09	91.44	269.04	BF
21	15.69	833.52	2.78	91.44	232.95	BE
22	2.06	254.85	4.22	91.44	273.21	BF
23	14.28	734.41	3.86	91.44	261.33	BF
24	13.32	572.67	2.45	91.44	216.01	T
25	18.42	1102.87	2.71	91.44	224.70	BE
26	5.86	354.17	4.45	91.44	259.37	G
27	14.72	773.23	4.53	91.44	273.87	BF
28	5.02	410.24	3.77	91.44	261.94	BF
29	5.12	460.24	4.82	91.44	266.87	BF
30	81.92	3194.10	2.99	91.44	206.10	C
31	14.19	799.62	15.80	24.38	237.28	C
32	11.51	563.67	2.87	91.44	263.46	BF
33	26.22	1050.83	10.30	60.96	194.00	M
34	44.21	1640.45	13.02	24.38	240.96	C
35	16.78	874.62	11.54	60.96	237.31	C
36	5.38	566.27	3.96	91.44	271.72	BF
37	175.15	5610.85	8.08	60.96	213.05	G
38	20.35	725.83	13.61	24.38	231.20	G
39	4.79	551.63	6.03	60.96	216.24	T
40	10.57	778.38	3.95	91.44	269.84	BF
41	4.18	397.13	3.87	91.44	274.98	BF
42	0.55	173.82	2.65	91.44	265.02	BF
43	18.19	1463.97	4.45	91.44	236.35	BE
44	3.98	447.13	7.07	60.96	268.09	BE
45	11.54	650.80	6.04	60.96	257.89	T
46	20.41	1092.90	6.25	60.96	268.13	BE
47	100.85	3119.48	7.22	60.96	258.27	C
48	3.69	266.75	6.24	60.96	272.94	BE
49	15.82	1487.11	9.11	60.96	246.52	C
50	4.48	372.81	5.98	60.96	260.98	BE
51	16.94	1144.83	11.29	60.96	251.37	C
52	30.45	1299.68	9.02	60.96	245.19	C
53	2.36	264.35	5.32	60.96	274.74	BE
54	4.53	435.42	6.79	60.96	269.56	T
55	1.23	181.07	6.08	60.96	270.81	BE
56	3.14	259.17	4.02	91.44	277.38	BF
57	10.68	613.20	4.44	91.44	266.98	BE
58	21.04	823.05	3.82	91.44	257.99	T
59	4.64	413.85	4.95	91.44	273.23	BE
60	3.61	299.17	4.47	91.44	275.37	BF
61	114.46	2885.10	4.83	91.44	260.29	C
62	2.89	332.81	7.62	60.96	246.56	C
63	102.72	3031.46	4.21	91.44	258.11	T
64	2.80	367.46	4.64	91.44	266.14	BE
Sum/Ave	1427.35	2288.48	6.33	74.58	246.33	

Notes: B – Berms, G – Gauging station, C – Stream confluence, M – Main stream, T – Tile drain outlet

Table A-4: Attributes of the user soil table of layer 1 for the Gully Creek watershed

CODE	ZAL	BAY	BKN	BUF	HUO	PTH
NAME	Bottom Land	Brady Sandy Loam	Brookston Clay Loam	Burford Loam	Huron Clay Loam	Perth Clay Loam
ZMX	1000	1000	1000	1000	1000	1000
AN-EX	0.5	0.5	0.5	0.5	0.5	0.5
TEXTURE	LSa, SaL	SaL, LSa, SaL, LSa	CL, SiCL, SiCL	L, LSa(gr), SaL(gr)	CL, SiCL, SiCL, SiCL	CL, CL, SiC, SiCL
NLS	4	4	3	5	4	4
Z1	190	180	250	220	200	250
BD1	1.08	1.06	1.27	1.26	1.25	1.32
AWC1	0.32	0.26	0.2	0.26	0.25	0.16
K1	4.94	31.43	3.36	11.57	3.79	4.4
CBN1	3.9	3.1	2	2.1	2.2	2.55
CLAY1	25	12	37	12	27	31
SILT1	60	27	47	53	55	48
SAND1	15	61	16	35	18	21
ROCK1	0	0	0	0	0	2
ALB1	0.03	0.05	0.1	0.09	0.09	0.07
USLE_K1	0.1	0.17	0.24	0.21	0.25	0.25

CODE – Soil code in the user soil lookup table
NAME – Soil name
ZMX – Maximum rooting depth of soil profile (mm)
AN-EX – Fraction of void space from which anions are excluded
TEXTURE – Texture of the soil layer
NLS – Number of soil layers
Z1 – Depth of the first soil layer (mm)
BD1 – Moist bulk density of the first soil layer (g/cm3)
AWC1 – Available water capacity of the first soil layer (mm/mm)
K1 – Saturated hydraulic conductivity of the first soil layer (mm/hr)
CBN1 – Organic carbon content in the first soil layer in percent of soil weight (%)
CLAY1 – Clay content in the first soil layer in percent of soil weight (%)
SILT1 – Silt content in the first soil layer in percent of soil weight (%)
SAND1 – Sand content in the first soil layer in percent of soil weight (%)
ROCK1 – Rock fragment content in the first soil layer in percent of total weight (%)
ALB1 – Moist soil albedo of the first soil layer
USLE_K1 – USLE equation soil erodibility factor

Appendix B: Additional Tables for BMP Characterization (Chapter 5)

Table B-1: Sample seeding and harvest management table for the Gully Creek watershed

Land ID	Producer ID	Year	Crop Code	Crop Name	Crop Group	SWAT Code	Seed Date	Seed Month	Straw_mgt Code	Straw_mgt_ Type	Residue Cover	Harvest Date	Harvest month
1	4	2008	3	Winter Wheat	Cereals	WWHT	20	4	12	100R	1.00	1	8
1	4	2009	1	Corn	Grain	CORN	5	5	4	25R	0.25	30	10
1	4	2010	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	30	9
1	4	2011	3	Winter Wheat	Cereals	WWHT	20	4	12	100R	1.00	1	8
1	4	2012	1	Corn	Grain	CORN	5	5	4	25R	0.25	30	10
1	4	2013	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	30	9
2	100	2008	3	Winter Wheat	Cereals	WWHT	20	4	6	50R	0.50	25	7
2	100	2009	1	Corn	Grain	CORN	5	5	2	10R	0.10	5	11
2	100	2010	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	5	10
2	100	2011	3	Winter Wheat	Cereals	WWHT	20	4	6	50R	0.50	25	7
2	100	2012	1	Corn	Grain	CORN	5	5	2	10R	0.10	5	11
2	100	2013	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	5	10
3	100	2008	1	Corn	Grain	CORN	5	5	2	10R	0.10	5	11
3	100	2009	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	5	10
3	100	2010	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	5	10
3	100	2011	1	Corn	Grain	CORN	5	5	2	10R	0.10	5	11
3	100	2012	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	5	10
3	100	2013	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	5	10
4	100	2008	1	Corn	Grain	CORN	5	5	2	10R	0.10	5	11
4	100	2009	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	5	10
4	100	2010	3	Winter Wheat	Cereals	WWHT	20	4	6	50R	0.50	25	7
4	100	2011	1	Corn	Grain	CORN	5	5	2	10R	0.10	5	11
4	100	2012	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	5	10
4	100	2013	3	Winter Wheat	Cereals	WWHT	20	4	6	50R	0.50	25	7
5	100	2008	1	Corn	Grain	CORN	5	5	2	10R	0.10	5	11
5	100	2009	2	Soybeans	Soybeans	SOYB	8	5	9	75R	0.75	5	10
5	100	2010	3	Winter Wheat	Cereals	WWHT	20	4	6	50R	0.50	25	7

Table B-2: Sample fertilizer management table for the Gully Creek watershed

Land ID	Year	Fert Sed Da	Fert Sed Mo	Fertw Sedn (kg/ha)	Fert Wsedp (kgP/ha)	Fert Bro Da	Fert Bro Mo	Fert Bro N	Fert Bro P	Fert Bans Da	Fert Bans Mo	Fert Bansn (kg/ha)	Fert Bansp (kgP/ha)	Fert Banf Da	Fert Banf Mo	Fert Banfn (kg/ha)	Fert Banfp (kgP/ha)	Man Da	Man Mo	Man Code	Manrat (kg/ha)	Man SWAT Code
1	2008	28	9	0	0	7	4	116	0	15	4	0	0	11	9	0	0	1	10	11	9000	61
2	2008	5	10	30	30	15	4	110	30	16	4	0	0	11	9	0	0	1	10	1	27000	45
3	2008	5	5	0	0	3	5	150	45	15	6	0	0	11	9	0	0	1	10	0	0	0
4	2008	5	5	0	0	3	5	150	45	15	6	0	0	11	9	0	0	1	10	0	0	0
5	2008	5	5	0	0	3	5	150	45	15	6	0	0	11	9	0	0	1	10	0	0	0
6	2008	5	10	0	0	15	4	112	0	16	4	0	0	11	9	0	0	30	9	14	44901	64
7	2008	5	5	10	17	3	5	0	0	15	6	112	0	11	9	0	0	1	10	0	0	0
8	2008	5	5	0	0	3	5	186	21	15	6	0	0	11	9	0	0	1	10	0	0	0
9	2008	7	5	0	0	5	5	0	0	15	6	0	0	11	9	0	0	1	10	0	0	0
10	2008	5	5	0	0	3	5	186	21	15	6	0	0	11	9	0	0	1	10	0	0	0
11	2008	5	5	0	0	3	5	186	21	15	6	0	0	11	9	0	0	1	10	0	0	0
12	2008	15	5	0	0	13	5	0	0	15	6	0	0	11	9	0	0	1	10	0	0	0
13	2008	1	10	10	15	15	4	123	10	16	4	0	0	11	9	0	0	1	10	0	0	0
14	2008	5	10	0	0	15	4	112	0	16	4	0	0	11	9	0	0	1	10	0	0	0
15	2008	1	5	0	0	14	6	0	0	15	6	0	0	11	9	0	0	1	10	0	0	0
16	2008	1	5	0	0	14	6	0	0	15	6	0	0	11	9	0	0	1	10	0	0	0
17	2008	5	10	0	0	15	4	112	0	16	4	0	0	11	9	0	0	1	10	0	0	0
18	2008	30	4	0	0	14	6	0	0	15	6	0	0	11	9	0	0	1	10	0	0	0
19	2008	30	4	0	0	14	6	0	0	15	6	0	0	11	9	0	0	1	10	0	0	0
20	2008	5	5	0	0	3	5	150	45	15	6	0	0	11	9	0	0	1	10	0	0	0
21	2008	5	5	0	0	3	5	150	45	15	6	0	0	11	9	0	0	1	10	0	0	0

Fertsedda: The date for fertilizer application with seeding; Fertsedmo: The month for fertilizer application with seeding; Fertwsedn (kg/ha): The amount of nitrogen applied to the field with seeding; Fertwsedp (kgP/ha): The amount of phosphate applied to the field with seeding; Fertbroda: The date for fertilizer application in a broadcast operation; Fertbromo: The month for fertilizer application in a broadcast operation; Fertbron: The amount of nitrogen applied to the field in a broadcast operation; Fertbrop: The amount of phosphate applied to the field in a broadcast operation; Fertbansda: The date for fertilizer application with cultivation in the spring; Fertbansmo: The month for fertilizer application with cultivation in the spring; Fertbansn (kg/ha): The amount of nitrogen applied to the field with cultivation in the spring; Fertbansp (kgP/ha): The amount of phosphate applied to the field with cultivation in the spring; Fertbanfda: The date for fertilizer application with cultivation in the fall; Fertbanfmo: The month for fertilizer application with cultivation in the fall; Fertbanfn (kg/ha): The amount of nitrogen applied to the field with cultivation in the fall; Fertbanfp (kgP/ha): The amount of phosphate applied to the field with cultivation in the fall; Manda: The date that manure is applied; Manmo: The month that manure is applied; Mancode: The code for different types of manure; 3. Chicken manure; Manrat (kg/ha): The rate at which manure is applied; ManSWATcode: The SWAT code for different types of manure.

Table B-3: Sample tillage management table for the Gully Creek watershed

Land ID	Year	Stilim1	Stilim1 Type	Stilim1 SWAT	Stilim1 Date	Stilim1 Month	Stilim2	Stilim2 Type	Stilim2 SWAT	Stilim2 Date	Stilim2 Month	Ftilim1	Ftilim1 Type	Ftilim1 SWAT	Ftilim1 Date	Ftilim1 Month	Ftilim2	Ftilim2 Type	Ftilim2 SWAT	Ftilim2 Date	Ftilim2 Month
1	2008	8	NOTILL	108	5	10	8	NOTILL	108	10	10	1	CHISPLOW	59	20	10	8	NOTILL	108	1	11
1	2009	5	FLDCULT	7	3	5	8	NOTILL	108	8	5	8	NOTILL	108	20	10	4	DISKPLOW	61	1	11
1	2010	4	DISKPLOW	61	28	4	8	NOTILL	108	11	5	11	ZEROTILL	4	5	10	8	NOTILL	108	10	10
1	2011	8	NOTILL	108	5	10	8	NOTILL	108	10	10	1	CHISPLOW	59	20	10	8	NOTILL	108	1	11
1	2012	5	FLDCULT	7	3	5	8	NOTILL	108	8	5	8	NOTILL	108	7	11	4	DISKPLOW	61	11	11
1	2013	4	DISKPLOW	61	28	4	8	NOTILL	108	11	5	11	ZEROTILL	4	5	10	8	NOTILL	108	10	10
2	2008	8	NOTILL	108	5	10	8	NOTILL	108	10	10	7	MLDBOARD	56	20	10	8	NOTILL	108	1	11
2	2009	5	FLDCULT	7	3	5	8	NOTILL	108	8	5	8	NOTILL	108	7	11	8	NOTILL	108	11	11
2	2010	11	ZEROTILL	4	6	5	8	NOTILL	108	11	5	11	ZEROTILL	4	5	10	8	NOTILL	108	10	10
2	2011	8	NOTILL	108	5	10	8	NOTILL	108	10	10	7	MLDBOARD	56	20	10	8	NOTILL	108	1	11
2	2012	5	FLDCULT	7	3	5	8	NOTILL	108	8	5	8	NOTILL	108	7	11	8	NOTILL	108	11	11
2	2013	11	ZEROTILL	4	6	5	8	NOTILL	108	11	5	11	ZEROTILL	4	5	10	8	NOTILL	108	10	10
3	2008	5	FLDCULT	7	3	5	8	NOTILL	108	8	5	8	NOTILL	108	7	11	8	NOTILL	108	11	11
3	2009	11	ZEROTILL	4	6	5	8	NOTILL	108	11	5	8	NOTILL	108	5	10	8	NOTILL	108	10	10
3	2010	11	ZEROTILL	4	6	5	8	NOTILL	108	11	5	7	MLDBOARD	56	5	10	8	NOTILL	108	10	10
3	2011	5	FLDCULT	7	3	5	8	NOTILL	108	8	5	8	NOTILL	108	7	11	8	NOTILL	108	11	11
3	2012	11	ZEROTILL	4	6	5	8	NOTILL	108	11	5	8	NOTILL	108	5	10	8	NOTILL	108	10	10
3	2013	11	ZEROTILL	4	6	5	8	NOTILL	108	11	5	7	MLDBOARD	56	5	10	8	NOTILL	108	10	10
4	2008	5	FLDCULT	7	3	5	8	NOTILL	108	8	5	8	NOTILL	108	7	11	8	NOTILL	108	11	11
4	2009	11	ZEROTILL	4	6	5	8	NOTILL	108	11	5	11	ZEROTILL	4	5	10	8	NOTILL	108	10	10
4	2010	8	NOTILL	108	5	10	8	NOTILL	108	10	10	7	MLDBOARD	56	20	10	8	NOTILL	108	1	11
4	2011	5	FLDCULT	7	3	5	8	NOTILL	108	8	5	8	NOTILL	108	7	11	8	NOTILL	108	11	11
4	2012	11	ZEROTILL	4	6	5	8	NOTILL	108	11	5	11	ZEROTILL	4	5	10	8	NOTILL	108	10	10
4	2013	8	NOTILL	108	5	10	8	NOTILL	108	10	10	7	MLDBOARD	56	20	10	8	NOTILL	108	1	11

Stilim1: The first spring tillage ID; Stilim1_Type: The first spring tillage type ; Stilim1_SWAT: The first spring tillage SWAT code; Stilim1_Date: The first spring tillage date; Stilim1_Month: The first spring tillage month; Stilim2: The second spring tillage ID ; Stilim2_Type: The second spring tillage type; Stilim2_SWAT: The second spring tillage SWAT code; Stilim2_Date: The second spring tillage date; Stilim2_Month: The second spring tillage month; Ftilim1: The first fall tillage ID; Ftilim1_Type: The first fall tillage type; Ftilim1_SWAT: The first fall tillage SWAT code; Ftilim1_Date: The first fall tillage date; Ftilim1_Month: The first fall tillage month; Ftilim2: The second fall tillage ID; Ftilim2_Type: The second fall tillage type; Ftilim2_SWAT: The second fall tillage SWAT code; Ftilim2_Date: The second fall tillage date; Ftilim2_Month: The second fall tillage month.

Table B-4: Sample HRU- land lookup table for the Gully Creek watershed

SubID	HruID	LandID	PercArea (%)	Area (m^2)	SubID	HruID	LandID	PercArea (%)	Area (m^2)
1	1	68	100.00	14808.85	3	3	118	1.03	345.07
1	2	68	100.00	23724.90	3	3	119	0.39	131.15
1	3	68	100.00	34716.25	3	3	121	5.73	1925.41
2	1	68	37.35	26610.46	3	3	131	0.46	155.27
2	1	69	56.80	40468.63	3	3	905	1.44	483.37
2	1	70	0.04	27.42	3	3	910	7.86	2638.63
2	1	915	2.34	1664.70	3	3	915	0.86	289.48
2	1	975	3.47	2474.45	3	3	920	0.39	130.06
2	2	68	42.85	6508.94	3	3	955	0.00	0.64
2	2	69	51.36	7801.01	3	3	960	0.85	286.59
2	2	70	0.05	7.54	3	4	68	0.60	233.39
2	2	915	2.34	354.90	3	4	113	6.42	2496.40
2	2	975	3.41	517.46	3	4	114	0.00	0.08
2	3	68	33.79	11087.34	3	4	115	0.29	112.67
2	3	69	59.86	19641.66	3	4	116	0.04	14.62
2	3	70	0.06	18.86	3	4	118	0.06	25.07
2	3	915	2.57	844.92	3	4	119	29.41	11439.43
2	3	975	3.72	1221.72	3	4	121	0.21	80.34
3	1	68	23.47	3613.65	3	4	131	51.55	20052.55
3	1	113	53.69	8268.14	3	4	905	1.33	516.14
3	1	114	0.00	0.03	3	4	910	7.99	3108.31
3	1	115	0.29	44.60	3	4	915	0.94	366.62
3	1	116	0.04	5.79	3	4	920	0.31	119.87
3	1	118	10.19	1568.45	3	4	955	0.00	0.74
3	1	119	0.39	60.14	3	4	960	0.85	331.98
3	1	121	0.21	31.80	3	5	68	0.60	94.62
3	1	131	0.33	51.05	3	5	113	6.42	1012.05
3	1	905	1.30	200.31	3	5	114	0.00	0.03
3	1	910	7.83	1206.38	3	5	115	0.29	45.68
3	1	915	0.93	142.57	3	5	116	0.04	5.93
3	1	920	0.48	73.85	3	5	118	0.06	10.16
3	1	955	0.00	0.29	3	5	119	69.26	10922.66
3	1	960	0.85	131.42	3	5	121	0.21	32.57
3	2	68	31.35	21481.48	3	5	131	10.45	1648.24
3	2	113	52.76	36149.96	3	5	905	2.14	337.25
3	2	114	0.00	0.15	3	5	910	8.30	1308.93
3	2	115	0.29	198.47	3	5	915	1.06	167.94
3	2	116	0.04	25.76	3	5	920	0.31	48.60
3	2	118	2.24	1536.78	3	5	955	0.00	0.30
3	2	119	0.39	267.61	3	5	960	0.85	134.59
3	2	121	1.02	699.08	3	6	68	0.60	465.11
3	2	131	0.35	240.41	3	6	113	6.42	4974.94
3	2	905	1.37	939.28	3	6	114	0.00	0.17
3	2	910	7.93	5430.77	3	6	115	0.29	224.54
3	2	915	1.04	709.33	3	6	116	0.04	29.14
3	2	920	0.37	255.03	3	6	118	0.06	49.96
3	2	955	0.00	1.30	3	6	119	44.33	34360.21
3	2	960	0.85	584.80	3	6	121	0.21	160.57
3	3	68	29.09	9768.66	3	6	131	36.26	28109.50
3	3	113	51.57	17315.56	3	6	905	1.42	1104.50
3	3	114	0.00	0.07	3	6	910	7.96	6170.03
3	3	115	0.29	97.27	3	6	915	1.25	967.53
3	3	116	0.04	12.62	3	6	920	0.31	238.89

SubID: subbasin ID; HruID: HRU ID; LandID: Field ID; PercArea: Percent of the field within the HRU, Area: Field area.

Appendix C: Mathematical and Statistical Tools Used in Assessing Model Calibration and Performance (Chapter 6)

Table C-1: Equations used in the model performance evaluation

Criteria	Equation	Explanation
Bias	$\sum_{i=1}^{N} Qs_i \Big/ \sum_{i=1}^{N} Qo_i - 1$	Bias is model bias, Qs_i and Qo_i are the simulated and observed stream flows on day i (m^3/s), and N is the number of days over the simulation period.
NSC	$1 - \sum_{i=1}^{N} (Qs_i - Qo_i)^2 \Big/ \sum_{i=1}^{N} (Qo_i - \overline{Qo})^2$	NSC is the Nash-Sutcliffe efficiency score, Qs_i and Qo_i are the simulated and observed stream flows on day i (m^3/s), and N is the number of days over the simulation period.
RMSE	$\sqrt{\left[\sqrt{\sum_{i=1}^{n} (LS_i - LO_i)^2}\right] \Big/ n}$	RMSE is root mean square error, LS is the predicted value, LO is the observed value, and n is the number of samples.
CV(RMSE)	$\frac{RMSE}{\overline{LO}}$	CV (RMSE) is the RMSE normalized to the mean of the observed values, and $\overline{LO}$ is the mean of observed values.
CORR	$\frac{\sum_{i-1}^{n} (LS_i - \overline{LS})(LO_i - \overline{LO})}{\sqrt{\sum_{i-1}^{n} (LS_i - \overline{LS})^2 \sum_{i-1}^{n} (LO_i - \overline{LO})^2}}$	CORR is the correlation coefficient, LS is the predicted value, LO is the observed value, $\overline{LS}$ is the mean of simulated values, $\overline{LO}$ is the mean of observed values, and n is the number of samples.

Appendix D: Additional Tables for Hydrologic Evaluation of BMPs (Chapter 7)

Table D-1: Modelling results for each subbasin under 1978 conditions

Subbasin	WYLD (mm)	SYLD (t/ha)	PP (kg/ha)	DP (kg/ha)	TP (kg/ha)	PN (kg/ha)	DN (kg/ha)	TN (kg/ha)
1	572.12	2.33	5.51	1.71	7.22	14.79	26.34	41.13
2	572.35	3.32	7.83	1.71	9.54	20.65	24.60	45.25
3	599.12	2.35	5.33	1.66	6.99	14.91	20.64	35.55
4	613.59	2.77	5.78	1.63	7.41	17.43	22.68	40.11
5	553.08	2.49	5.81	1.67	7.49	15.22	16.79	32.02
6	587.05	1.57	3.60	1.46	5.06	9.68	17.36	27.05
7	586.09	2.00	3.57	1.73	5.30	11.30	15.02	26.31
8	571.36	4.79	11.37	1.60	12.97	28.77	25.93	54.70
9	572.10	3.70	8.87	1.60	10.47	22.98	26.29	49.26
10	571.64	1.88	4.58	1.60	6.18	12.36	24.53	36.89
11	575.52	0.08	0.12	0.98	1.10	0.58	14.55	15.14
12	578.41	1.38	2.96	1.44	4.39	8.68	13.08	21.75
13	582.41	0.24	0.49	1.15	1.64	1.67	8.53	10.20
14	636.87	2.55	5.57	1.55	7.11	16.03	16.48	32.50
15	622.17	2.73	6.57	1.58	8.15	16.66	16.55	33.21
16	619.38	2.81	6.41	1.62	8.02	17.04	13.97	31.01
17	588.56	1.58	3.16	1.05	4.21	9.64	10.94	20.58
18	553.05	0.44	0.97	1.27	2.23	2.84	9.12	11.96
19	570.31	2.90	6.56	1.67	8.23	16.66	13.65	30.31
20	608.06	2.16	4.78	1.64	6.41	13.31	16.59	29.90
21	576.98	1.45	2.93	1.73	4.66	9.40	31.97	41.37
22	598.77	2.66	5.10	1.66	6.76	17.27	24.65	41.92
23	622.31	3.29	7.84	1.58	9.42	19.54	16.71	36.25
24	561.27	1.00	3.05	1.67	4.73	6.75	27.96	34.70
25	591.66	1.95	4.49	1.78	6.27	12.61	38.91	51.51
26	609.02	2.85	6.13	1.37	7.50	15.80	13.66	29.46
27	586.79	1.96	4.25	1.32	5.57	12.22	16.99	29.20
28	608.15	1.96	4.63	1.37	6.01	11.90	13.15	25.06
29	614.44	2.00	4.39	1.26	5.66	12.05	11.50	23.55
30	550.45	0.53	1.25	1.35	2.60	3.40	16.70	20.11
31	506.12	0.02	0.00	1.43	1.43	0.10	14.92	15.02
32	585.38	0.14	0.20	1.03	1.23	0.99	7.42	8.41
33	545.70	0.01	0.01	0.95	0.96	0.09	8.27	8.36
34	529.50	1.22	2.66	1.60	4.26	6.40	15.30	21.70
35	515.30	0.16	0.31	0.91	1.22	0.96	14.26	15.22
36	610.22	0.21	0.26	0.95	1.21	1.40	6.54	7.94
37	528.09	0.52	1.28	1.32	2.60	3.32	12.51	15.83
38	526.39	0.62	1.19	1.63	2.82	3.76	16.83	20.60
39	564.15	0.25	0.33	0.98	1.31	1.42	8.62	10.04
40	598.63	1.15	2.31	1.25	3.55	7.38	15.30	22.68
41	599.56	0.19	0.24	0.98	1.22	1.27	6.97	8.25
42	618.02	1.51	3.59	1.62	5.21	9.69	16.52	26.21
43	545.08	1.10	2.43	1.50	3.93	6.86	21.07	27.93
44	593.28	0.50	0.65	1.16	1.81	2.98	7.62	10.61
45	600.73	0.99	1.91	1.27	3.17	6.00	8.56	14.56
46	587.55	0.44	0.58	1.09	1.67	2.63	8.00	10.63
47	589.64	2.66	5.81	1.44	7.25	15.16	12.89	28.05
48	585.95	0.36	0.48	1.06	1.54	2.23	7.29	9.51
49	572.53	1.52	3.65	1.55	5.20	9.28	14.32	23.60
50	586.11	0.40	0.53	1.06	1.59	2.42	7.27	9.69
51	584.59	4.44	10.23	1.57	11.80	23.51	13.30	36.81
52	546.65	0.98	2.27	1.76	4.03	6.05	17.17	23.22
53	621.64	4.27	10.16	1.58	11.75	25.02	15.85	40.87
54	622.77	4.49	9.56	1.54	11.11	25.66	12.61	38.26
55	621.16	5.40	12.62	1.58	14.20	29.86	16.47	46.33
56	621.35	3.24	7.76	1.58	9.34	19.52	16.67	36.19
57	584.26	0.25	0.34	1.04	1.38	1.61	7.91	9.52
58	588.93	0.22	0.30	1.09	1.39	1.44	7.63	9.07
59	608.51	3.32	7.47	1.72	9.19	19.58	17.75	37.33
60	621.46	3.80	9.04	1.58	10.63	22.34	16.39	38.73
61	601.92	2.42	5.69	1.34	7.03	14.41	12.23	26.64
62	591.68	1.92	4.40	1.78	6.18	10.58	15.17	25.75
63	596.29	3.26	7.56	1.53	9.09	19.51	19.02	38.53
64	585.79	0.25	0.35	1.04	1.39	1.65	7.29	8.94
Average	572.72	1.73	3.93	1.44	5.37	10.36	15.20	25.56

Table D-2: Modelling results for each subbasin under existing (2011) conditions

Subbasin	WYLD (mm)	SYLD (t/ha)	PP (kg/ha)	DP (kg/ha)	TP (kg/ha)	PN (kg/ha)	DN (kg/ha)	TN (kg/ha)
1	603.14	1.87	3.99	1.63	5.62	11.97	47.24	59.20
2	585.44	3.19	6.73	1.69	8.42	19.78	35.86	55.64
3	608.49	1.94	3.72	1.54	5.26	12.56	39.83	52.39
4	617.67	2.68	5.05	1.61	6.66	16.54	41.71	58.25
5	573.81	1.75	3.71	1.62	5.32	10.80	27.64	38.44
6	590.49	2.06	4.40	1.65	6.05	12.76	38.48	51.24
7	578.69	1.37	1.75	1.70	3.45	7.71	28.72	36.44
8	605.57	3.28	6.63	1.61	8.24	19.88	33.97	53.85
9	621.15	2.55	5.21	1.60	6.82	16.16	34.35	50.52
10	624.26	1.27	2.66	1.60	4.26	8.79	34.43	43.22
11	589.86	0.89	1.94	1.36	3.30	5.87	26.18	32.05
12	601.33	0.98	1.72	1.58	3.30	6.48	26.15	32.63
13	608.33	0.87	1.58	1.69	3.27	6.11	45.21	51.32
14	640.94	1.70	2.89	1.49	4.38	11.37	51.64	63.01
15	651.16	1.75	3.29	1.52	4.81	11.53	51.28	62.80
16	603.37	1.71	3.06	1.57	4.62	11.07	41.70	52.78
17	601.99	1.28	2.17	1.05	3.22	7.86	18.51	26.37
18	568.63	0.86	1.63	1.56	3.19	5.67	28.87	34.54
19	571.28	2.18	4.23	1.64	5.88	12.56	27.07	39.64
20	595.57	1.42	2.46	1.60	4.05	9.23	38.30	47.53
21	612.56	0.58	0.95	1.61	2.56	4.43	41.72	46.14
22	619.94	2.92	5.28	1.60	6.88	18.75	29.64	48.39
23	603.69	2.12	3.93	1.52	5.44	13.35	51.76	65.12
24	589.50	0.51	1.16	1.51	2.67	4.13	43.86	47.99
25	653.16	0.83	1.52	1.67	3.19	6.29	50.70	56.99
26	607.71	2.30	4.02	1.58	5.60	13.59	41.88	55.47
27	604.92	3.18	6.11	1.58	7.69	19.64	31.75	51.39
28	600.71	1.81	3.40	1.53	4.93	11.92	46.73	58.65
29	613.28	2.31	3.99	1.51	5.50	14.73	45.35	60.07
30	548.00	0.26	0.59	1.38	1.98	1.95	24.80	26.75
31	506.12	0.02	0.00	1.43	1.43	0.10	14.92	15.02
32	601.44	1.57	2.93	1.54	4.47	10.32	34.86	45.18
33	551.98	0.15	0.36	1.40	1.76	1.15	21.16	22.31
34	524.85	1.00	2.15	1.59	3.74	4.98	18.49	23.46
35	520.08	0.10	0.13	0.89	1.02	0.60	17.23	17.82
36	630.05	2.25	3.52	1.50	5.02	14.49	37.02	51.51
37	538.68	0.34	0.65	1.39	2.04	2.37	22.58	24.96
38	528.47	0.61	1.01	1.63	2.64	3.61	18.76	22.37
39	583.89	2.15	2.82	1.50	4.32	10.82	37.35	48.16
40	621.40	2.05	3.56	1.55	5.10	13.19	37.46	50.65
41	615.56	1.49	2.54	1.50	4.04	10.31	41.32	51.63
42	592.03	1.16	2.21	1.59	3.80	7.71	31.79	39.50
43	555.32	1.13	2.20	1.50	3.70	7.05	27.16	34.21
44	642.20	4.06	6.04	1.75	7.79	21.88	32.66	54.55
45	602.72	4.43	8.06	1.71	9.77	23.21	35.28	58.50
46	626.92	4.94	8.25	1.69	9.94	25.65	35.41	61.06
47	580.90	2.10	3.76	1.43	5.19	11.95	22.26	34.21
48	649.44	3.79	6.61	1.73	8.34	21.31	33.71	55.01
49	557.26	1.20	2.74	1.57	4.31	7.45	28.92	36.37
50	649.66	3.30	5.12	1.73	6.85	18.57	29.99	48.57
51	566.68	3.43	7.37	1.59	8.96	17.86	29.58	47.44
52	552.93	0.78	1.65	1.73	3.39	5.00	29.09	34.09
53	638.17	4.73	9.72	1.71	11.42	26.56	33.98	60.54
54	619.00	5.89	11.01	1.77	12.78	31.29	35.34	66.64
55	606.78	6.03	12.01	1.71	13.71	31.06	35.18	66.23
56	626.53	3.62	7.56	1.71	9.26	21.30	35.36	56.66
57	621.57	2.53	5.05	1.57	6.62	15.71	41.29	56.99
58	605.43	2.19	4.39	1.62	6.01	13.89	39.64	53.53
59	636.56	3.64	7.10	1.84	8.95	20.67	32.53	53.20
60	607.26	4.24	8.72	1.71	10.42	23.93	34.93	58.86
61	610.25	3.64	6.96	1.64	8.60	20.79	37.39	58.18
62	576.37	1.98	4.35	1.79	6.14	10.49	22.51	33.00
63	602.17	2.94	6.56	1.58	8.14	18.02	33.46	51.49
64	624.40	2.42	4.82	1.54	6.36	15.31	43.60	58.91
Average	580.10	1.79	3.49	1.54	5.03	10.70	30.75	41.45

Table D-3: Difference between existing conditions and 1978 conditions

Subbasin	WYLD (mm)	SYLD (t/ha)	PP (kg/ha)	DP (kg/ha)	TP (kg/ha)	PN (kg/ha)	DN (kg/ha)	TN (kg/ha)
1	31.024	-0.462	-1.522	-0.077	-1.599	-2.822	20.897	18.075
2	13.087	-0.134	-1.100	-0.012	-1.112	-0.869	11.260	10.391
3	9.371	-0.408	-1.606	-0.116	-1.722	-2.346	19.186	16.840
4	4.087	-0.090	-0.733	-0.023	-0.756	-0.892	19.032	18.140
5	20.733	-0.739	-2.108	-0.054	-2.162	-4.420	10.848	6.428
6	3.444	0.486	0.797	0.193	0.990	3.083	21.115	24.197
7	-7.402	-0.639	-1.823	-0.023	-1.846	-3.583	13.706	10.123
8	34.208	-1.508	-4.738	0.005	-4.734	-8.891	8.037	-0.854
9	49.053	-1.158	-3.655	0.004	-3.651	-6.811	8.064	1.253
10	52.615	-0.614	-1.921	0.004	-1.917	-3.564	9.897	6.333
11	14.341	0.809	1.823	0.378	2.201	5.283	11.625	16.908
12	22.917	-0.395	-1.234	0.138	-1.096	-2.196	13.077	10.880
13	25.929	0.625	1.086	0.544	1.630	4.436	36.686	41.122
14	4.061	-0.854	-2.677	-0.054	-2.732	-4.653	35.164	30.511
15	28.993	-0.982	-3.278	-0.063	-3.341	-5.128	34.727	29.599
16	-16.009	-1.097	-3.349	-0.053	-3.402	-5.963	27.730	21.767
17	13.436	-0.295	-0.992	-0.003	-0.996	-1.774	7.566	5.791
18	15.586	0.417	0.662	0.298	0.961	2.830	19.749	22.579
19	0.969	-0.720	-2.326	-0.024	-2.350	-4.090	13.417	9.327
20	-12.486	-0.737	-2.318	-0.040	-2.359	-4.075	21.708	17.633
21	35.585	-0.866	-1.984	-0.116	-2.100	-4.975	9.752	4.777
22	21.168	0.261	0.180	-0.057	0.123	1.480	4.987	6.467
23	-18.616	-1.170	-3.909	-0.063	-3.972	-6.190	35.051	28.861
24	28.231	-0.490	-1.889	-0.163	-2.051	-2.618	15.902	13.285
25	61.505	-1.121	-2.965	-0.117	-3.081	-6.311	11.788	5.476
26	-1.311	-0.549	-2.108	0.207	-1.900	-2.213	28.221	26.008
27	18.126	1.224	1.861	0.256	2.117	7.422	14.765	22.187
28	-7.441	-0.147	-1.234	0.155	-1.080	0.014	33.573	33.587
29	-1.159	0.310	-0.408	0.248	-0.160	2.678	33.850	36.528
30	-2.453	-0.265	-0.656	0.031	-0.625	-1.449	8.093	6.644
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	16.058	1.430	2.727	0.514	3.241	9.335	27.434	36.769
33	6.288	0.141	0.353	0.452	0.805	1.060	12.889	13.949
34	-4.648	-0.214	-0.509	-0.006	-0.515	-1.425	3.189	1.765
35	4.787	-0.067	-0.176	-0.022	-0.198	-0.363	2.963	2.600
36	19.831	2.044	3.262	0.548	3.810	13.088	30.486	43.573
37	10.584	-0.178	-0.623	0.070	-0.554	-0.945	10.072	9.127
38	2.077	-0.016	-0.177	0.001	-0.176	-0.151	1.927	1.776
39	19.732	1.901	2.488	0.520	3.008	9.398	28.725	38.123
40	22.768	0.903	1.252	0.299	1.551	5.816	22.159	27.974
41	15.999	1.303	2.300	0.519	2.818	9.038	34.346	43.384
42	-25.996	-0.352	-1.375	-0.028	-1.403	-1.982	15.266	13.284
43	10.242	0.030	-0.228	0.001	-0.227	0.190	6.090	6.280
44	48.922	3.554	5.394	0.586	5.980	18.899	25.040	43.939
45	1.987	3.437	6.154	0.440	6.594	17.210	26.723	43.933
46	39.364	4.495	7.665	0.602	8.267	23.016	27.414	50.430
47	-8.746	-0.567	-2.053	-0.012	-2.065	-3.211	9.372	6.160
48	63.481	3.437	6.130	0.671	6.801	19.080	26.419	45.500
49	-15.273	-0.320	-0.906	0.016	-0.891	-1.827	14.600	12.773
50	63.551	2.900	4.585	0.675	5.260	16.154	22.719	38.873
51	-17.911	-1.012	-2.863	0.019	-2.844	-5.642	16.276	10.634
52	6.285	-0.197	-0.618	-0.026	-0.644	-1.056	11.923	10.867
53	16.526	0.454	-0.445	0.124	-0.321	1.537	18.137	19.674
54	-3.773	1.398	1.444	0.228	1.672	5.635	22.738	28.372
55	-14.382	0.632	-0.613	0.124	-0.489	1.194	18.708	19.902
56	5.185	0.388	-0.203	0.124	-0.079	1.779	18.685	20.464
57	37.311	2.286	4.713	0.529	5.242	14.098	33.375	47.473
58	16.498	1.976	4.095	0.530	4.625	12.447	32.019	44.466
59	28.046	0.319	-0.363	0.120	-0.243	1.095	14.780	15.875
60	-14.208	0.436	-0.326	0.124	-0.202	1.585	18.546	20.131
61	8.324	1.220	1.261	0.307	1.568	6.377	25.161	31.539
62	-15.310	0.057	-0.053	0.011	-0.042	-0.086	7.341	7.255
63	5.877	-0.320	-1.004	0.048	-0.956	-1.488	14.445	12.957
64	38.608	2.169	4.471	0.497	4.968	13.660	36.313	49.974
Average	7.373	0.056	-0.441	0.100	-0.341	0.333	15.557	15.890

Table D-4: Difference between existing (baseline) condition and scenario IV (conservation tillage)

Subbasin	WYLD (mm)	SYLD (t/ha)	PP (kg/ha)	DP (kg/ha)	TP (kg/ha)	PN (kg/ha)	DN (kg/ha)	TN (kg/ha)
1	0.123	0.735	2.320	0.042	2.363	4.337	-3.730	0.607
2	-1.808	1.555	4.400	0.065	4.465	9.321	-10.952	-1.630
3	1.352	0.653	1.799	0.039	1.838	3.946	-4.578	-0.632
4	0.564	1.102	2.905	0.053	2.958	6.437	-4.813	1.624
5	-0.072	0.688	2.153	0.032	2.185	4.053	-1.552	2.501
6	0.319	0.988	2.896	0.042	2.938	5.699	-5.087	0.612
7	0.283	0.105	0.425	0.009	0.435	0.813	-0.751	0.062
8	-0.693	0.972	3.328	0.038	3.366	6.079	-1.222	4.857
9	-0.407	0.760	2.617	0.038	2.655	4.732	-1.239	3.492
10	-0.359	0.378	1.327	0.037	1.364	2.312	-1.572	0.740
11	-0.048	0.281	0.994	0.022	1.016	1.675	-3.015	-1.341
12	-0.136	0.241	0.848	0.028	0.876	1.472	-2.073	-0.601
13	0.918	0.174	0.626	0.046	0.672	1.085	-2.838	-1.753
14	0.589	0.170	0.712	0.022	0.734	1.212	-1.843	-0.631
15	0.499	0.184	0.850	0.025	0.875	1.282	-1.990	-0.707
16	0.607	0.173	0.764	0.021	0.785	1.248	-1.619	-0.371
17	-0.316	0.388	1.093	0.021	1.114	2.257	-1.371	0.885
18	0.284	0.239	0.769	0.030	0.799	1.506	-2.295	-0.788
19	-0.466	0.837	2.380	0.031	2.411	4.798	-2.986	1.811
20	0.456	0.151	0.631	0.016	0.647	1.092	-1.251	-0.159
21	-0.434	0.032	0.201	0.010	0.211	0.171	-2.235	-2.064
22	0.092	1.846	3.931	0.108	4.039	11.441	-12.187	-0.746
23	0.686	0.222	1.021	0.025	1.046	1.604	-1.986	-0.383
24	-0.719	0.025	0.241	0.005	0.246	0.073	-3.076	-3.003
25	-0.380	0.058	0.350	0.019	0.369	0.360	-2.762	-2.402
26	-0.263	0.421	1.364	0.038	1.401	2.842	-4.438	-1.596
27	-2.527	1.863	4.395	0.053	4.447	10.926	-13.290	-2.365
28	-0.189	0.359	1.189	0.035	1.224	2.314	-4.715	-2.401
29	-0.559	0.541	1.513	0.037	1.551	3.515	-5.330	-1.815
30	0.275	0.058	0.275	0.012	0.287	0.337	-1.048	-0.711
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	-3.568	0.888	2.024	0.047	2.071	5.545	-8.357	-2.812
33	0.237	0.052	0.192	0.004	0.196	0.315	-1.140	-0.825
34	0.070	0.480	1.473	0.004	1.477	2.335	-0.607	1.728
35	-0.140	0.003	0.026	0.001	0.028	0.010	-0.445	-0.434
36	-3.057	1.207	2.336	0.045	2.382	7.712	-7.883	-0.171
37	0.308	0.080	0.251	0.017	0.268	0.479	-0.569	-0.090
38	-0.143	0.305	0.660	0.010	0.670	1.845	-1.794	0.051
39	0.022	-0.033	-0.060	-0.004	-0.064	-0.107	0.236	0.129
40	-1.880	1.007	2.265	0.046	2.311	6.301	-6.764	-0.463
41	-1.714	0.354	1.110	0.020	1.130	2.531	-6.791	-4.260
42	0.016	0.493	1.242	0.033	1.276	2.918	-8.902	-5.984
43	-0.583	0.577	1.453	0.030	1.483	3.469	-5.685	-2.216
44	-0.020	1.063	2.560	0.059	2.619	6.828	-2.870	3.958
45	1.904	1.699	4.613	0.054	4.668	9.223	-8.465	0.757
46	1.776	1.909	4.513	0.046	4.559	10.339	-3.139	7.200
47	0.089	0.919	2.201	0.025	2.225	5.165	-5.595	-0.431
48	2.078	1.013	2.944	0.050	2.994	5.885	-2.516	3.370
49	0.083	0.574	1.864	0.022	1.885	3.321	-1.699	1.622
50	-2.453	0.699	2.005	0.041	2.045	4.750	-3.864	0.886
51	0.134	1.617	4.955	0.026	4.981	8.507	-1.929	6.578
52	-0.643	0.294	0.934	0.018	0.952	1.635	-4.078	-2.443
53	-0.622	2.279	6.184	0.037	6.221	12.522	-5.171	7.351
54	-0.050	2.737	6.925	0.043	6.968	15.414	-4.634	10.780
55	-0.234	2.868	7.582	0.037	7.619	14.961	-5.163	9.798
56	-0.437	1.718	4.765	0.037	4.802	9.704	-5.240	4.464
57	-1.232	0.748	2.667	0.053	2.720	5.139	-2.892	2.247
58	-0.238	0.705	2.385	0.060	2.445	4.628	-4.272	0.357
59	0.001	1.717	4.431	0.031	4.462	9.572	-4.224	5.348
60	-0.087	2.016	5.506	0.037	5.543	11.138	-5.200	5.939
61	-0.217	1.296	3.655	0.040	3.695	7.387	-3.414	3.973
62	-0.650	1.126	3.194	0.031	3.225	5.877	-5.916	-0.039
63	-1.990	1.230	4.151	0.048	4.199	7.703	-7.043	0.660
64	-1.261	0.699	2.502	0.031	2.533	4.739	-3.140	1.599
Average	-0.158	0.666	1.929	0.029	1.958	3.898	-3.299	0.599

Table D-5: Difference between existing (baseline) conditions and scenario V (nutrient management)

Subbasin	WYLD (mm)	SYLD (t/ha)	PP (kg/ha)	DP (kg/ha)	TP (kg/ha)	PN (kg/ha)	DN (kg/ha)	TN (kg/ha)
1	-0.061	0.023	0.047	0.007	0.054	0.126	1.920	2.047
2	0.018	-0.013	-0.015	0.003	-0.012	-0.042	1.844	1.802
3	0.210	0.011	0.008	-0.002	0.006	0.128	4.807	4.935
4	0.160	0.011	0.007	0.001	0.008	0.104	4.092	4.196
5	0.152	-0.046	-0.134	0.002	-0.132	-0.158	1.388	1.229
6	0.024	0.008	0.016	0.000	0.016	0.061	2.490	2.551
7	0.150	-0.016	-0.030	0.000	-0.029	-0.036	2.236	2.200
8	0.639	-0.081	0.055	0.000	0.054	0.307	7.038	7.345
9	0.860	-0.069	0.028	-0.001	0.027	0.192	7.203	7.395
10	0.764	-0.030	0.007	-0.001	0.006	0.036	5.217	5.253
11	-0.652	0.008	-0.001	0.001	0.000	0.057	2.460	2.517
12	0.229	-0.005	0.026	0.001	0.028	0.048	2.940	2.988
13	-0.463	0.010	0.012	0.000	0.012	0.037	-2.692	-2.654
14	0.317	-0.009	-0.007	0.001	-0.006	0.032	6.744	6.776
15	0.338	-0.007	-0.002	0.001	-0.001	0.071	6.485	6.557
16	0.297	-0.033	-0.066	0.000	-0.066	-0.100	4.050	3.950
17	0.044	0.002	0.030	0.000	0.030	0.040	1.127	1.167
18	-0.156	0.009	0.019	0.001	0.020	0.040	-1.143	-1.103
19	0.012	0.005	0.010	0.000	0.010	0.017	0.073	0.090
20	0.225	-0.014	-0.014	0.001	-0.013	-0.009	3.134	3.125
21	-0.173	0.010	0.018	0.001	0.019	0.080	5.019	5.099
22	-0.144	0.019	0.047	0.001	0.048	0.091	-4.567	-4.476
23	0.256	-0.008	-0.001	0.001	0.000	0.088	6.568	6.656
24	-0.289	0.015	0.017	0.000	0.017	0.140	6.003	6.143
25	-0.204	0.024	0.039	0.001	0.040	0.186	6.689	6.875
26	0.178	-0.005	-0.007	0.001	-0.006	0.079	5.305	5.384
27	-0.153	0.049	0.143	0.001	0.144	0.289	1.062	1.351
28	0.167	-0.002	0.014	0.000	0.014	0.084	6.597	6.681
29	0.042	0.003	0.027	0.000	0.028	0.111	6.948	7.058
30	-0.001	0.002	0.005	0.000	0.005	0.016	0.960	0.977
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	-0.424	0.147	0.390	-0.003	0.387	0.941	7.967	8.909
33	0.012	0.004	0.013	0.000	0.013	0.025	0.580	0.605
34	0.022	-0.001	-0.002	0.000	-0.002	0.000	0.212	0.212
35	-0.046	0.001	0.002	0.000	0.002	0.006	0.657	0.664
36	-0.402	0.083	0.201	0.005	0.207	0.565	8.555	9.119
37	-0.079	0.002	0.004	0.001	0.005	0.012	0.691	0.703
38	0.006	0.000	0.001	0.001	0.002	0.003	0.142	0.145
39	-0.099	0.030	0.049	0.004	0.053	0.129	0.479	0.608
40	-0.208	0.059	0.132	0.004	0.137	0.380	4.808	5.188
41	-0.256	0.065	0.133	0.000	0.133	0.433	6.760	7.193
42	-0.043	0.003	0.004	0.000	0.003	0.029	2.173	2.203
43	0.005	0.001	0.005	0.003	0.008	0.010	0.448	0.458
44	0.242	0.211	0.346	0.001	0.348	0.868	-9.344	-8.476
45	-0.008	0.030	0.093	0.007	0.100	0.140	-0.194	-0.054
46	-0.030	0.122	0.184	0.001	0.185	0.426	-5.905	-5.479
47	0.905	0.026	0.047	0.002	0.050	0.141	-1.252	-1.111
48	0.235	0.061	0.216	0.002	0.218	0.081	-9.333	-9.252
49	-0.106	0.006	0.034	0.000	0.034	0.029	-0.915	-0.886
50	0.059	0.128	0.136	0.001	0.137	0.514	-8.536	-8.022
51	-0.085	0.010	0.059	0.001	0.060	0.046	-0.757	-0.710
52	0.091	0.000	0.007	0.001	0.008	0.025	-0.171	-0.147
53	0.476	-0.042	-0.161	0.000	-0.161	-0.162	1.213	1.051
54	0.259	-0.041	0.047	0.000	0.047	-0.152	0.229	0.077
55	0.326	-0.070	-0.202	0.000	-0.202	-0.275	1.306	1.032
56	0.501	-0.041	-0.123	0.000	-0.123	-0.186	1.310	1.124
57	-0.201	0.049	0.074	-0.004	0.070	0.260	2.316	2.576
58	-0.110	0.029	0.047	0.002	0.049	0.154	1.517	1.672
59	0.351	-0.030	-0.090	0.000	-0.090	-0.110	1.163	1.053
60	0.439	-0.049	-0.146	0.000	-0.146	-0.217	1.276	1.060
61	0.097	0.003	-0.019	0.000	-0.019	0.022	0.509	0.531
62	0.103	-0.026	-0.106	0.000	-0.106	-0.094	0.172	0.077
63	-0.071	-0.017	-0.083	0.001	-0.083	-0.067	1.800	1.733
64	0.051	0.041	0.051	-0.007	0.044	0.245	4.136	4.380
Average	0.078	0.007	0.008	0.001	0.009	0.053	1.239	1.292

Table D-6: Difference between existing (baseline) conditions and scenario VI (red clover cover crop after winter wheat)

Subbasin	WYLD (mm)	SYLD (t/ha)	PP (kg/ha)	DP (kg/ha)	TP (kg/ha)	PN (kg/ha)	DN (kg/ha)	TN (kg/ha)
1	17.935	0.594	1.281	0.137	1.418	3.042	8.289	11.331
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	11.752	0.337	0.373	0.076	0.450	1.782	2.755	4.537
4	16.232	0.682	1.059	0.119	1.178	3.414	3.910	7.323
5	12.580	0.520	1.122	0.091	1.213	2.583	2.802	5.385
6	16.063	0.750	1.673	0.110	1.783	3.944	5.999	9.943
7	5.271	0.077	-0.120	0.040	-0.080	0.074	1.288	1.362
8	17.874	0.605	1.057	0.118	1.175	2.680	2.117	4.796
9	18.447	0.479	0.863	0.117	0.980	2.350	2.147	4.498
10	18.355	0.245	0.469	0.117	0.586	1.435	2.931	4.366
11	5.648	0.000	-0.063	0.022	-0.041	-0.019	1.250	1.231
12	11.332	0.134	0.253	0.070	0.323	0.780	2.735	3.515
13	26.974	0.100	0.069	0.145	0.214	0.598	9.594	10.191
14	11.727	0.175	-0.111	0.091	-0.020	0.743	3.634	4.377
15	10.707	0.163	-0.186	0.087	-0.099	0.601	3.968	4.569
16	9.978	0.129	-0.213	0.078	-0.136	0.367	2.954	3.322
17	7.493	0.214	0.422	0.048	0.470	1.109	1.320	2.430
18	14.788	0.123	0.157	0.083	0.239	0.651	4.562	5.213
19	12.087	0.497	0.746	0.072	0.818	2.069	3.266	5.335
20	8.262	0.126	-0.123	0.064	-0.059	0.420	2.443	2.863
21	11.623	0.028	-0.026	0.056	0.030	0.224	2.271	2.495
22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	10.953	0.198	-0.231	0.087	-0.145	0.518	4.022	4.540
24	14.996	0.067	-0.016	0.124	0.108	0.532	3.328	3.860
25	15.569	0.079	0.047	0.101	0.148	0.583	2.726	3.309
26	17.188	0.148	-0.245	0.110	-0.135	0.089	3.579	3.668
27	12.224	0.111	0.085	0.067	0.152	0.601	1.896	2.497
28	16.009	0.172	-0.111	0.112	0.001	0.701	4.321	5.022
29	17.495	0.231	-0.085	0.121	0.036	0.850	4.187	5.037
30	4.416	0.056	0.176	0.050	0.225	0.368	0.898	1.266
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	35.529	0.466	0.623	0.206	0.829	2.807	5.740	8.547
33	5.340	0.056	0.154	0.056	0.210	0.381	1.493	1.874
34	3.075	0.447	1.022	0.019	1.041	1.677	1.118	2.794
35	2.177	0.011	0.006	0.015	0.021	0.081	0.497	0.578
36	30.904	0.533	0.607	0.193	0.799	3.055	5.067	8.122
37	8.007	0.052	0.023	0.066	0.089	0.317	1.463	1.780
38	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	18.716	-0.030	-1.169	0.132	-1.037	-1.831	4.054	2.223
40	26.815	0.562	0.836	0.174	1.010	3.095	5.849	8.944
41	23.121	0.110	-0.107	0.121	0.015	0.631	0.273	0.905
42	18.756	-0.088	-0.455	0.084	-0.371	-0.600	4.821	4.221
43	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44	23.708	-0.082	-1.248	0.122	-1.126	-2.256	6.299	4.043
45	7.367	-0.087	-0.354	0.029	-0.325	-0.717	2.193	1.476
46	20.753	0.900	1.035	0.090	1.125	2.256	5.996	8.252
47	7.528	-0.111	-0.532	0.034	-0.497	-0.938	2.377	1.439
48	14.862	0.623	1.076	0.086	1.162	2.332	4.866	7.198
49	10.338	0.464	1.170	0.060	1.230	2.530	2.031	4.561
50	23.191	-0.360	-1.662	0.099	-1.564	-3.426	6.517	3.091
51	11.958	1.277	2.877	0.069	2.946	5.161	2.204	7.365
52	3.796	0.102	0.193	0.023	0.216	0.437	1.017	1.453
53	21.466	1.807	3.329	0.146	3.475	8.223	5.930	14.153
54	22.678	1.739	2.830	0.128	2.959	6.900	5.559	12.459
55	21.717	2.354	4.295	0.146	4.441	9.277	6.165	15.442
56	21.971	1.412	2.767	0.146	2.913	6.951	6.189	13.140
57	24.312	0.336	0.334	0.131	0.465	1.366	8.845	10.212
58	18.256	0.216	0.224	0.095	0.319	0.925	6.486	7.411
59	17.514	1.357	2.472	0.109	2.581	6.287	4.957	11.244
60	21.600	1.649	3.165	0.146	3.311	7.593	6.131	13.725
61	24.045	0.750	0.836	0.154	0.989	2.563	6.342	8.905
62	9.249	0.760	1.760	0.055	1.815	3.161	4.318	7.479
63	18.428	0.554	1.227	0.099	1.326	2.544	7.777	10.321
64	25.325	0.319	0.295	0.129	0.424	1.382	9.572	10.954
Average	12.197	0.315	0.470	0.078	0.549	1.327	3.405	4.732

Table D-7: Difference between existing (baseline) conditions and scenario VII (all agronomic BMPs)

Subbasin	WYLD (mm)	SYLD (t/ha)	PP (kg/ha)	DP (kg/ha)	TP (kg/ha)	PN (kg/ha)	DN (kg/ha)	TN (kg/ha)
1	17.911	0.600	1.321	0.135	1.456	3.174	9.799	12.973
2	-1.803	1.553	4.399	0.067	4.466	9.342	-8.822	0.520
3	13.003	0.722	1.389	0.109	1.498	4.152	3.918	8.070
4	16.286	1.193	2.372	0.146	2.518	6.490	4.153	10.644
5	12.703	0.517	1.141	0.090	1.230	2.717	4.109	6.826
6	15.787	0.965	2.288	0.121	2.409	5.272	6.262	11.534
7	5.488	0.130	0.063	0.048	0.111	0.474	3.173	3.647
8	18.825	0.624	1.122	0.120	1.242	3.508	9.547	13.055
9	19.280	0.490	0.909	0.119	1.028	2.970	9.745	12.715
10	19.227	0.262	0.522	0.119	0.642	1.761	8.527	10.287
11	4.844	0.299	0.883	0.046	0.930	1.802	0.788	2.590
12	11.489	0.166	0.371	0.080	0.451	1.064	4.825	5.888
13	26.316	0.170	0.268	0.167	0.435	0.973	5.256	6.229
14	12.101	0.259	0.188	0.109	0.297	1.382	9.669	11.051
15	11.253	0.245	0.147	0.108	0.254	1.232	9.731	10.964
16	10.425	0.210	0.099	0.095	0.194	0.977	6.343	7.320
17	7.371	0.329	0.662	0.054	0.717	1.812	1.632	3.444
18	14.329	0.227	0.436	0.099	0.535	1.248	1.709	2.957
19	11.628	0.697	1.135	0.085	1.220	3.237	1.026	4.264
20	8.599	0.193	0.128	0.078	0.205	0.925	5.050	5.976
21	11.029	0.070	0.139	0.068	0.206	0.496	4.981	5.477
22	-0.067	1.820	3.916	0.110	4.027	11.268	-17.106	-5.838
23	11.380	0.296	0.170	0.108	0.278	1.284	9.885	11.169
24	14.151	0.096	0.184	0.131	0.315	0.699	5.862	6.561
25	15.065	0.122	0.260	0.117	0.377	0.886	6.939	7.825
26	17.281	0.364	0.373	0.125	0.498	1.550	5.431	6.982
27	9.863	1.799	3.999	0.112	4.111	10.383	-9.437	0.946
28	15.903	0.366	0.436	0.129	0.565	2.000	7.288	9.289
29	17.117	0.515	0.595	0.137	0.732	2.695	6.596	9.292
30	4.572	0.060	0.231	0.052	0.283	0.401	1.405	1.806
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	34.017	0.723	1.172	0.207	1.379	4.388	9.381	13.770
33	5.433	0.057	0.160	0.056	0.216	0.381	1.807	2.188
34	3.113	0.447	1.021	0.019	1.040	1.681	1.266	2.947
35	1.976	0.014	0.027	0.016	0.043	0.100	0.678	0.779
36	29.551	0.886	1.145	0.201	1.346	5.217	9.109	14.326
37	7.994	0.087	0.125	0.072	0.197	0.528	1.613	2.141
38	-0.143	0.305	0.660	0.010	0.670	1.846	-1.646	0.200
39	18.698	-0.038	-1.182	0.134	-1.048	-1.855	4.535	2.680
40	26.079	0.782	1.222	0.180	1.402	4.496	7.340	11.836
41	21.960	0.166	0.192	0.129	0.321	1.145	5.041	6.186
42	18.461	0.417	0.564	0.118	0.683	2.473	-3.338	-0.865
43	-0.571	0.577	1.454	0.031	1.485	3.476	-5.215	-1.739
44	23.493	0.572	-0.049	0.152	0.103	0.966	-2.594	-1.629
45	9.305	1.613	4.138	0.090	4.228	8.408	-6.286	2.122
46	20.590	1.464	2.058	0.118	2.176	5.027	0.120	5.147
47	8.494	0.828	1.446	0.061	1.508	4.187	-5.107	-0.920
48	14.293	0.751	1.389	0.093	1.482	2.912	-2.857	0.054
49	10.229	0.485	1.188	0.070	1.257	2.657	-0.009	2.648
50	21.078	0.337	-0.241	0.143	-0.099	0.198	-3.330	-3.132
51	11.847	1.345	2.975	0.081	3.056	5.564	0.117	5.680
52	3.211	0.282	0.665	0.040	0.705	1.475	-3.010	-1.535
53	20.720	2.370	4.994	0.154	5.148	11.556	2.793	14.348
54	21.883	2.608	5.215	0.141	5.357	11.783	2.289	14.073
55	20.921	3.018	6.107	0.154	6.261	13.105	3.172	16.277
56	21.550	1.816	3.896	0.154	4.050	9.406	3.163	12.570
57	21.724	0.822	1.853	0.166	2.019	4.298	9.013	13.311
58	16.949	0.742	1.851	0.139	1.990	4.085	4.142	8.227
59	16.969	1.766	3.571	0.116	3.687	8.752	2.615	11.367
60	20.895	2.122	4.478	0.154	4.632	10.420	3.074	13.494
61	23.800	1.167	2.119	0.167	2.286	5.029	3.920	8.949
62	8.683	1.074	2.430	0.075	2.505	4.956	-1.855	3.101
63	16.028	1.092	2.749	0.124	2.873	6.010	2.098	8.108
64	22.716	0.774	1.722	0.139	1.861	4.142	10.914	15.056
Average	11.929	0.610	1.228	0.093	1.321	3.072	1.976	5.047

Table D-8: Average yearly water yield, sediment loading, and TN and TP loadings in and out of WASCoBs (Scenario VIII – Existing and Future WASCoBs)

WASCoB No.	Subbasin No.	Subbasin area (ha)	Daily Capacity (m^3/d)	WYLD In (1,000 m^3/yr)	WYLD Out (1,000 m^3/yr)	SED In (t/yr)	SED Out (t/yr)	TP In (kg/y)	TP out (kg/y)	TN In (kg/y)	TN Out (kg/y)
1*	1	7.33	2,938	46.10	43.68	13.70	4.62	7.62	6.57	42.26	38.41
2	7	23.29	2,333	136.62	131.72	31.82	11.30	52.81	45.14	274.26	252.51
3*	4	14.6	2,592	228.09	225.95	41.75	10.36	114.21	108.88	700.90	675.16
4*	10	10.66	6,134	66.45	64.95	13.54	6.13	17.72	13.75	85.72	75.03
5*	9	4.20	6,826	92.10	90.11	17.03	7.27	23.29	18.14	111.94	97.63
6*	14	7.38	1,642	47.20	45.21	12.51	3.89	7.83	6.99	49.09	43.98
7*	15	9.30	4,838	105.62	99.89	20.45	7.14	31.31	24.64	212.61	177.33
8*	21	15.69	2,851	95.95	91.77	9.17	2.74	20.58	17.84	153.96	138.80
9*	25	18.42	5,357	211.79	204.13	19.98	8.29	62.23	41.86	679.24	551.74
10	22	2.06	2,938	13.23	12.82	5.99	2.43	0.92	0.61	2.47	1.88
11	20	10.73	8,813	78.52	76.95	17.95	7.34	21.98	16.98	111.95	98.51
12	27	14.72	9,677	92.29	88.72	46.87	16.04	59.03	43.96	254.74	214.03
13	29	5.12	3,283	121.62	119.49	28.30	9.22	47.98	44.99	243.22	230.83
14	36	5.38	4,234	35.78	33.51	12.11	4.13	5.21	3.60	23.12	17.24
15	41	4.18	3,197	27.34	25.50	6.22	2.02	1.62	1.16	5.91	4.47
16	42	0.55	1,728	3.54	3.18	0.64	0.32	0.24	0.16	0.66	0.50
17	40	10.57	2,419	98.70	93.09	24.39	8.50	28.67	22.94	162.86	139.78
18	32	11.51	5,270	200.90	193.19	31.96	13.55	61.63	43.06	421.35	345.71
19	28	5.02	5,875	345.29	331.40	33.16	13.93	106.95	78.92	764.59	639.67
20	23	14.28	14,947	501.42	491.30	56.37	25.26	167.71	140.34	1492.14	1361.95
21*	43	18.19	691	100.62	99.47	20.58	4.85	30.75	29.50	108.73	105.41
22*	48	3.69	2,678	23.91	21.56	13.98	4.35	2.68	1.98	9.24	7.44
23*	44	3.98	2,074	47.05	45.47	20.56	6.64	10.34	9.32	36.83	34.54
24*	53	2.36	3,715	15.05	14.27	11.16	3.94	1.20	0.84	2.76	2.17
25	56	3.14	5,443	19.63	19.08	11.36	4.26	1.25	0.84	3.85	2.75
26*	57	10.68	8,813	66.30	65.03	27.04	12.04	32.07	26.83	131.49	119.05
27	60	3.61	3,456	22.72	22.06	15.28	5.98	2.77	1.40	9.67	5.83
28*	59	4.64	5,357	70.65	68.59	27.15	11.28	20.66	14.39	56.06	45.25
29*	55	1.23	950	76.63	75.43	18.74	6.20	17.09	16.44	44.60	43.55
30*	46	20.41	2,333	290.81	286.18	147.79	45.11	238.80	220.07	1154.85	1089.75
31*	50	4.48	1,901	315.19	310.96	60.71	22.21	221.73	207.16	1078.11	1029.94
32*	64	2.80	4,320	17.44	17.03	6.77	2.67	0.35	0.19	2.03	1.34
Total		274.20	139623.0	3614.53	3511.69	825.01	294.02	1419.22	1209.52	8431.21	7592.15

Note: * indicates existing WASCoBs

Table D-9: On-site reductions of average yearly water yield, sediment loading, and TN and TP for WASCoBs (Scenario VIII – Existing and Future WASCoBs)

WASCoB No.	Subbasin No.	Subbasin area (ha)	Daily capacity (m^3/d)	Water Yield (m^3/yr)	Sediment (ton/yr)	Total P (kg/yr)	Total N (kg/yr)
1*	1	7.33	2,938	2423.23	9.08	1.04	3.84
2	7	23.29	2,333	4897.11	20.52	7.67	21.75
3*	4	14.6	2,592	2144.45	31.39	5.33	25.74
4*	10	10.66	6,134	1504.27	7.41	3.97	10.70
5*	9	4.2	6,826	1986.77	9.76	5.15	14.31
6*	14	7.38	1,642	1993.39	8.62	0.84	5.11
7*	15	9.3	4,838	5733.24	13.30	6.67	35.28
8*	21	15.69	2,851	4175.37	6.43	2.74	15.16
9*	25	18.42	5,357	7656.94	11.70	20.36	127.51
10	22	2.06	2,938	415.96	3.56	0.31	0.59
11	20	10.73	8,813	1570.49	10.61	5.00	13.44
12	27	14.72	9,677	3563.57	30.83	15.07	40.71
13	29	5.12	3,283	2131.83	19.08	2.99	12.39
14	36	5.38	4,234	2269.65	7.98	1.61	5.88
15	41	4.18	3,197	1834.13	4.20	0.46	1.44
16	42	0.55	1,728	361.81	0.32	0.08	0.16
17	40	10.57	2,419	5600.79	15.89	5.72	23.08
18	32	11.51	5,270	7710.55	18.41	18.57	75.64
19	28	5.02	5,875	13894.76	19.22	28.03	124.92
20	23	14.28	14,947	10123.06	31.10	27.37	130.19
21*	43	18.19	691	1151.06	15.73	1.25	3.32
22*	48	3.69	2,678	2347.22	9.63	0.70	1.80
23*	44	3.98	2,074	1581.22	13.92	1.02	2.29
24*	53	2.36	3,715	778.31	7.22	0.36	0.59
25	56	3.14	5,443	546.83	7.10	0.41	1.10
26*	57	10.68	8,813	1270.90	15.00	5.24	12.44
27	60	3.61	3,456	661.31	9.30	1.36	3.85
28*	59	4.64	5,357	2059.30	15.87	6.27	10.81
29*	55	1.23	950	1195.21	12.53	0.65	1.06
30*	46	20.41	2,333	4623.18	102.68	18.72	65.10
31*	50	4.48	1,901	4228.98	38.49	14.58	48.17
32*	64	2.8	4,320	411.54	4.10	0.15	0.69
Total		274.20	139623.00	102846.44	530.99	209.70	839.06

Note: * indicates existing WASCoBs

Table D-10: Change of channel sediment loading rate between Scenario II (no WASCoBs) and Scenario III (existing WASCoBs)

Reach	Main channel Length (km)	Total length (km)	Scenario II (t/yr)	Scenario II (t/km/yr)	Scenario III (t/yr)	Scenario III (t/km/yr)	Change on main channel (t/yr)	Change on main channel (t/km/yr)
1	0.017	0.017	0.00	0.00	0.00	0.00	0.00	0.00
2	0.589	0.589	0.64	1.09	0.92	1.56	-0.28	-0.48
3	0.659	1.254	3.70	2.95	3.70	2.95	0.00	0.00
4	0.218	0.873	1.50	1.72	1.50	1.72	0.00	0.00
5	1.492	2.164	32.90	15.20	29.60	13.68	3.30	2.21
6	0.271	2.626	8.30	3.16	8.40	3.20	-0.10	-0.37
7	0.562	0.946	0.00	0.00	0.00	0.00	0.00	0.00
8	0.094	0.094	0.16	1.70	0.04	0.46	0.12	1.24
9	0.284	0.284	0.18	0.63	-0.04	-0.14	0.22	0.77
10	0.222	0.222	0.00	0.00	0.00	0.00	0.00	0.00
11	0.217	0.217	0.00	0.00	0.00	0.00	0.00	0.00
12	0.019	0.019	0.00	0.00	0.00	0.00	0.00	0.00
13	0.102	0.102	0.00	0.00	0.00	0.00	0.00	0.00
14	0.218	0.218	0.00	0.00	0.00	0.00	0.00	0.00
15	0.223	0.223	0.22	0.99	0.28	1.26	-0.06	-0.27
16	0.134	1.448	0.51	0.35	0.29	0.20	0.22	1.64
17	0.358	0.358	2.35	6.56	1.51	4.22	0.84	2.35
18	1.362	2.346	77.90	33.21	74.80	31.88	3.10	2.28
19	1.808	3.685	42.90	11.64	36.50	9.91	6.40	3.54
20	0.378	0.378	0.27	0.71	0.27	0.71	0.00	0.00
21	0.257	0.430	0.00	0.00	0.00	0.00	0.00	0.00
22	0.020	0.020	0.00	0.00	0.00	0.00	0.00	0.00
23	0.357	0.672	4.40	6.55	4.50	6.70	-0.10	-0.28
24	0.469	0.719	2.58	3.59	0.59	0.82	1.99	4.24
25	0.524	0.871	1.84	2.11	1.97	2.26	-0.13	-0.25
26	0.193	0.193	0.20	1.04	0.30	1.55	-0.10	-0.52
27	0.535	0.676	0.00	0.00	0.00	0.00	0.00	0.00
28	0.183	0.375	1.10	2.93	1.10	2.93	0.00	0.00
29	0.286	0.286	0.26	0.91	0.26	0.91	0.00	0.00
30	2.704	4.803	56.80	11.83	39.53	8.23	17.27	6.39
31	0.669	0.669	53.80	80.42	49.80	74.44	4.00	5.98
32	0.430	0.826	1.00	1.21	1.18	1.43	-0.18	-0.42
33	0.858	1.506	473.00	314.08	427.00	283.53	46.00	53.61
34	1.449	2.292	267.00	116.49	257.00	112.13	10.00	6.90
35	0.357	0.357	0.00	0.00	0.00	0.00	0.00	0.00
36	0.361	0.361	0.00	0.00	0.00	0.00	0.00	0.00
37	5.267	8.690	1586.00	182.51	1492.00	171.69	94.00	17.85
38	0.510	1.007	235.00	233.37	223.00	221.45	12.00	23.53
39	0.527	0.527	1.02	1.94	0.12	0.23	0.90	1.71
40	0.389	0.447	0.29	0.65	0.29	0.65	0.00	0.00
41	0.074	0.074	0.00	0.00	0.00	0.00	0.00	0.00
42	0.008	0.008	0.00	0.00	0.00	0.00	0.00	0.00
43	1.178	1.178	0.00	0.00	0.00	0.00	0.00	0.00
44	0.280	0.280	-0.03	-0.11	-0.08	-0.29	0.05	0.18
45	0.372	0.485	3.30	6.80	2.64	5.44	0.66	1.77
46	0.459	1.114	2.70	2.42	1.30	1.17	1.40	3.05
47	2.033	5.089	76.10	14.95	76.80	15.09	-0.70	-0.34
48	0.051	0.051	0.00	0.00	0.00	0.00	0.00	0.00
49	0.675	1.162	55.80	48.02	52.10	44.84	3.70	5.48
50	0.146	0.168	0.40	2.38	0.44	2.62	-0.04	-0.27
51	0.881	0.907	7.30	8.05	6.50	7.17	0.80	0.91
52	1.193	1.864	67.90	36.43	67.50	36.21	0.40	0.34
53	0.022	0.022	0.00	0.00	0.00	0.00	0.00	0.00
54	0.230	0.325	0.25	0.77	0.06	0.18	0.19	0.83
55	0.109	0.109	-0.04	-0.37	-0.04	-0.38	0.00	0.01
56	0.027	0.027	0.00	0.00	0.00	0.00	0.00	0.00
57	0.128	0.128	0.00	0.00	0.00	0.00	0.00	0.00
58	0.643	0.949	1.03	1.09	1.17	1.23	-0.14	-0.22
59	0.209	0.364	-0.06	-0.16	-0.09	-0.25	0.03	0.14
60	0.046	0.046	0.00	0.00	0.00	0.00	0.00	0.00
61	1.220	5.763	39.10	6.78	39.10	6.78	0.00	0.00
62	0.213	0.213	3.80	17.84	3.60	16.90	0.20	0.94
63	1.891	4.545	29.00	6.38	28.10	6.18	0.90	0.48
64	0.244	0.244	0.00	0.00	0.00	0.00	0.00	0.00
Sum/Ave	37.91	68.90	3142.52	45.61	2935.52	42.61	206.86	5.46

Table D-11: Change of channel sediment loading rates between Scenario II (no WASCoBs) and Scenario VIII (Existing and Future WASCoBs)

Reach	Main channel Length (km)	Total length (km)	Scenario II (t/yr)	Scenario II (t/km/yr)	Scenario VIII (t/yr)	Scenario VIII (t/km/yr)	Change on main channel (t/yr)	Change on main channel (t/km/yr)
1	0.017	0.017	0.00	0.00	0.00	0.00	0.00	0.00
2	0.589	0.589	0.64	1.09	0.22	0.37	0.42	0.71
3	0.659	1.254	3.70	2.95	4.54	3.62	-0.84	-1.27
4	0.218	0.873	1.50	1.72	1.61	1.84	-0.11	-0.50
5	1.492	2.164	32.90	15.20	30.80	14.23	2.10	1.41
6	0.271	2.626	8.30	3.16	7.50	2.86	0.80	2.95
7	0.562	0.946	0.00	0.00	0.00	0.00	0.00	0.00
8	0.094	0.094	0.16	1.70	0.04	0.46	0.12	1.24
9	0.284	0.284	0.18	0.63	-0.04	-0.14	0.22	0.77
10	0.222	0.222	0.00	0.00	0.00	0.00	0.00	0.00
11	0.217	0.217	0.00	0.00	0.00	0.00	0.00	0.00
12	0.019	0.019	0.00	0.00	0.00	0.00	0.00	0.00
13	0.102	0.102	0.00	0.00	0.00	0.00	0.00	0.00
14	0.218	0.218	0.00	0.00	0.00	0.00	0.00	0.00
15	0.223	0.223	0.22	0.99	0.28	1.26	-0.06	-0.27
16	0.134	1.448	0.51	0.35	0.29	0.20	0.22	1.64
17	0.358	0.358	2.35	6.56	1.51	4.22	0.84	2.35
18	1.362	2.346	77.90	33.21	72.20	30.78	5.70	4.19
19	1.808	3.685	42.90	11.64	36.50	9.91	6.40	3.54
20	0.378	0.378	0.27	0.71	0.24	0.63	0.03	0.08
21	0.257	0.430	0.00	0.00	0.00	0.00	0.00	0.00
22	0.020	0.020	0.00	0.00	0.00	0.00	0.00	0.00
23	0.357	0.672	4.40	6.55	4.13	6.15	0.27	0.76
24	0.469	0.719	2.58	3.59	0.59	0.82	1.99	4.24
25	0.524	0.871	1.84	2.11	1.97	2.26	-0.13	-0.25
26	0.193	0.193	0.20	1.04	-0.12	-0.62	0.32	1.66
27	0.535	0.676	0.00	0.00	0.00	0.00	0.00	0.00
28	0.183	0.375	1.10	2.93	1.05	2.80	0.05	0.27
29	0.286	0.286	0.26	0.91	0.44	1.54	-0.18	-0.63
30	2.704	4.803	56.80	11.83	39.53	8.23	17.27	6.39
31	0.669	0.669	53.80	80.42	48.90	73.09	4.90	7.32
32	0.430	0.826	1.00	1.21	0.80	0.97	0.20	0.47
33	0.858	1.506	473.00	314.08	389.00	258.30	84.00	97.90
34	1.449	2.292	267.00	116.49	208.00	90.75	59.00	40.72
35	0.357	0.357	0.00	0.00	0.00	0.00	0.00	0.00
36	0.361	0.361	0.00	0.00	0.00	0.00	0.00	0.00
37	5.267	8.690	1586.00	182.51	1347.00	155.01	239.00	45.38
38	0.510	1.007	235.00	233.37	196.00	194.64	39.00	76.47
39	0.527	0.527	1.02	1.94	0.12	0.23	0.90	1.71
40	0.389	0.447	0.29	0.65	0.19	0.43	0.10	0.26
41	0.074	0.074	0.00	0.00	0.00	0.00	0.00	0.00
42	0.008	0.008	0.00	0.00	0.00	0.00	0.00	0.00
43	1.178	1.178	0.00	0.00	0.00	0.00	0.00	0.00
44	0.280	0.280	-0.03	-0.11	-0.08	-0.29	0.05	0.18
45	0.372	0.485	3.30	6.80	2.55	5.26	0.75	2.02
46	0.459	1.114	2.70	2.42	1.30	1.17	1.40	3.05
47	2.033	5.089	76.10	14.95	36.60	7.19	39.50	19.43
48	0.051	0.051	0.00	0.00	0.00	0.00	0.00	0.00
49	0.675	1.162	55.80	48.02	32.00	27.54	23.80	35.26
50	0.146	0.168	0.40	2.38	0.43	2.56	-0.03	-0.21
51	0.881	0.907	7.30	8.05	6.40	7.06	0.90	1.02
52	1.193	1.864	67.90	36.43	67.50	36.21	0.40	0.34
53	0.022	0.022	0.00	0.00	0.00	0.00	0.00	0.00
54	0.230	0.325	0.25	0.77	0.05	0.15	0.20	0.87
55	0.109	0.109	-0.04	-0.37	-0.04	-0.34	0.00	-0.03
56	0.027	0.027	0.00	0.00	0.00	0.00	0.00	0.00
57	0.128	0.128	0.00	0.00	0.00	0.00	0.00	0.00
58	0.643	0.949	1.03	1.09	1.17	1.23	-0.14	-0.22
59	0.209	0.364	-0.06	-0.16	-0.07	-0.19	0.01	0.05
60	0.046	0.046	0.00	0.00	0.00	0.00	0.00	0.00
61	1.220	5.763	39.10	6.78	39.10	6.78	0.00	0.00
62	0.213	0.213	3.80	17.84	3.60	16.90	0.20	0.94
63	1.891	4.545	29.00	6.38	28.10	6.18	0.90	0.48
64	0.244	0.244	0.00	0.00	0.00	0.00	0.00	0.00
Sum/Ave	37.91	68.90	3142.52	45.61	2611.91	37.91	530.46	13.99

Appendix E: Further Analysis of Cost Effectiveness for Three Agronomic BMPs (Chapter 8)

1. Background and methods

Combining the analyses undertaken for the WBBE of the environmental and economic effectiveness of BMPs was complicated. The SWAT modelling was run on a ten-year cycle to evaluate the environmental effectiveness of the BMPs. In contrast, a model developed to evaluate the economic effectiveness of the BMPs was run on a three-year cycle. In order to combine the environmental and economic model results, the models would have to be rerun on the same time scale. Furthermore, the effectiveness of multiple BMPs, or even a single BMP applied over multiple years, can be variable, depending on factors such as the previous crop, existing crop, and amount of precipitation in a given year. Therefore, another approach was taken that combined the environmental and economic effectiveness of one BMP on one crop during one year. This approach to a preliminary economic and environmental analysis reduced variability in the results. In the Gully Creek watershed, conservation tillage applied to corn was evaluated on a field-by-field basis for the year 2009 to determine if it had environmental benefits, economic benefits, 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.

Results

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 E-1). 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 E-2). The effectiveness of a BMP typically depends on the soil type, slope, landuse, 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.

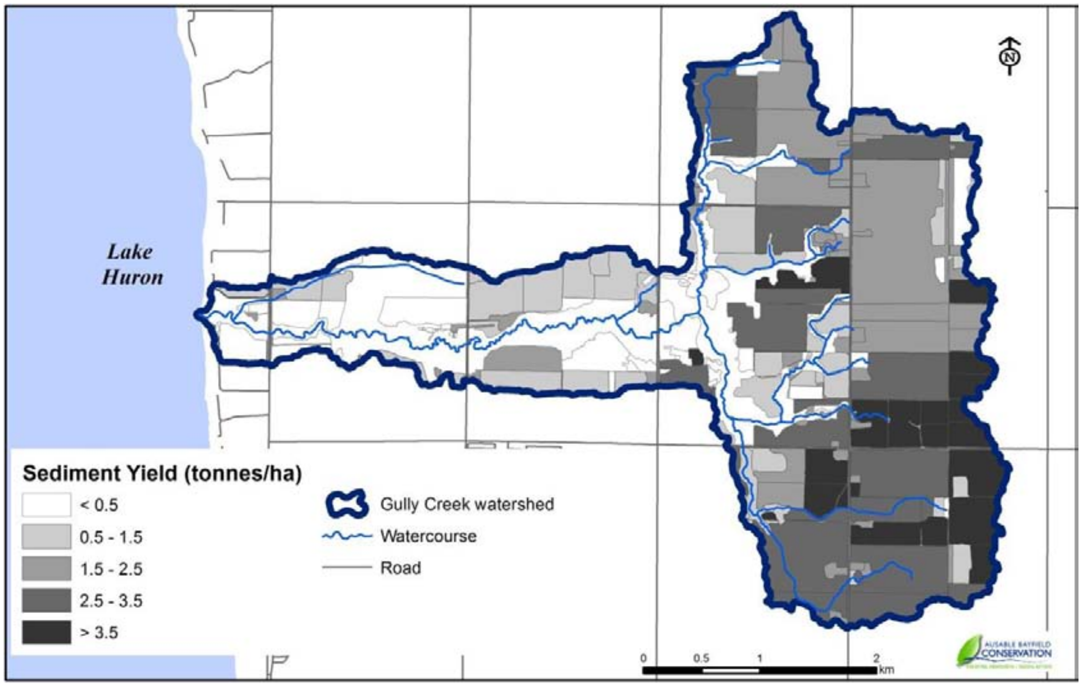

Figure E-1: Simulated sediment yield in the Gully Creek watershed at the field scale, average 2002 – 2011.

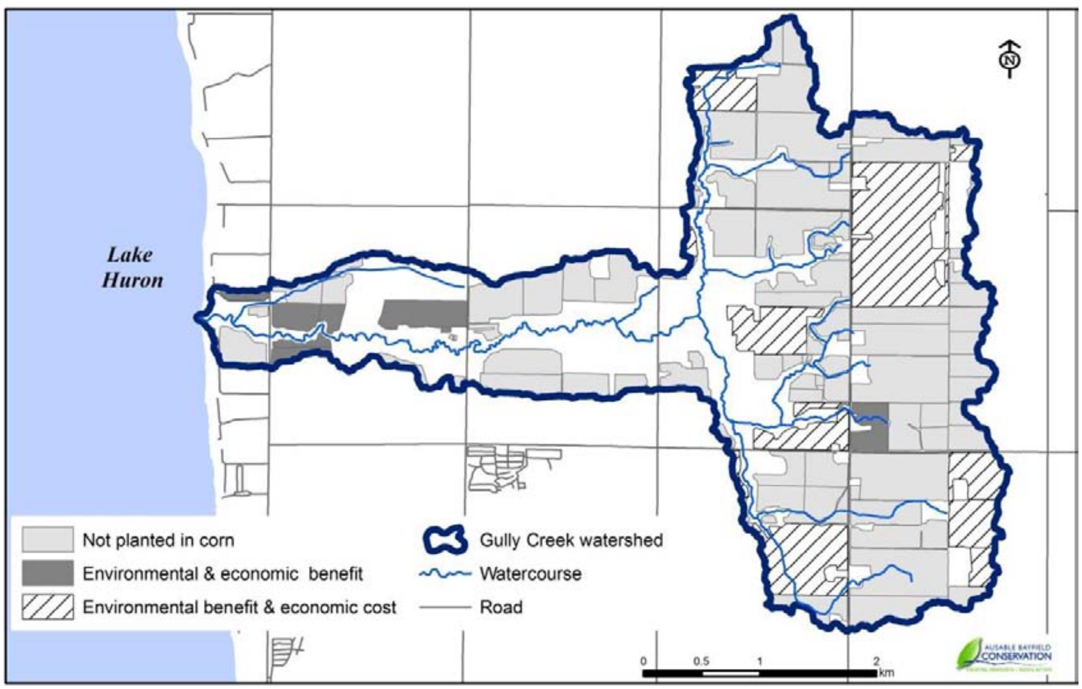

Figure E-2: Environmental and economic impacts of implementing a conservation tillage best management practice on corn fields in Gully Creek Watershed – 2009 crop year