A Research Report Submitted to Ausable Bayfield Conservation Authority, Ontario Soil and Crop Improvement Association, and Ontario Ministry of Agriculture, Food, and Rural Affairs

SWAT Modelling and Assessment of Agricultural BMPs 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 adverse environmental effects of agriculture, farmers, conservation authorities and governments have worked together to promote and implement best management practices (BMPs) - farming practices that focus on maintaining agricultural productivity and profitability while protecting the environment.

From 2010 to 2013, the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) implemented the Watershed Based BMP Evaluation (WBBE) program. The Gully Creek watershed, along with Zurich and Ridgeway watersheds, were selected as study sites for the WBBE program. From 2015 to 2017, OMAFRA and Ontario Soil and Crop Improvement Association (OSCIA) jointed implemented the Great Lakes Agricultural Stewardship Initiative (GLASI). In GLASI, the Gully Creek watershed was selected as one of the six pilot watersheds for BMP establishment and study. By building upon ABCA's previous BMP initiatives and monitoring program, the WBBE and GLASI programs invested in establishing a monitoring system for evaluating existing and newly-established BMPs in the study area. With the 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.

In the WBBE program, the Soil and Water Assessment Tool (SWAT) was adapted and applied to the Gully Creek watershed based on flow and watershed quality monitoring data from 2010 to 2012. In the GLASI program, the purpose of the modelling component of the study was to further adapt the Soil and Water Assessment Tool (SWAT) to examine the water quantity and quality effects of BMP implementation in the Gully Creek watershed based on extended monitoring data. Specifically, the project had three 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). Conduct a preliminary assessment of the cost effectiveness of BMP scenarios.

In GLASI SWAT modelling, snow redistribution, frozen soil, and WASCoB modules were further adapted and parameters were adjusted for characterizing small lakeshore watershed conditions in the Lake Huron basin. The SWAT model setup made use of existing available datasets including a detailed SWOOP-derived DEM, a ten-year (2008-2017) 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 and Climate Change Canada, ABCA and land management surveys through local producer interviews. The BMPs of special interest, due to their level of adoption in the watershed, included conservation tillage, precision nutrient management, cover crop, soil amendment, WASCoB construction, and windbreak planting. The SWAT was calibrated and validated using 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 BMP scenarios. Under current field conditions, Gully Creek watershed has a runoff coefficient 0.585, an average sediment loading 2.8 t/ha/yr, an average total nitrogen (TN) loading 41.6 kg/ha/yr, and an average total phosphorus (TP) loading 2.48 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 applied to examine various BMP scenarios including 1). WASCoB scenarios with five sub-scenarios: WASCoBs under WBBE program, WASCoBs under GLASI program, WASCoBs near or on berm monitoring sites, all existing WASCoBs, and existing and future WASCoBs for the 15-year model simulation period; 2). Land management BMPs during 2013-2014; 3). Land management BMPs during 2014-2015; 4). Land management BMPs during 2015 -2016 (GLASI BMPs); 5). Land management BMPs during 2016 -2017 (GLASI BMPs); 6). Land management BMPs during 2017-2018 (GLASI BMPs); 7). All land management BMPs from 2015 to 2017 (GLASI BMPs); and 8). Windbreak BMPs during GLASI.

Under the baseline scenario with existing land management practices and without WASCoBs, the sediment, TN and TP loadings at watershed outlet are 4,035 t/yr, 73,153 kg/yr, and 3,976 kg/yr respectively. In comparing to the baseline scenario, the 10 WASCoBs in the WBBE program have the potential to reduce sediment, TN, and TP by 224 t/yr, 3,053 kg/yr, and 161 kg/yr, which represent 5.55%, 4.17%, and 4.05% reductions respectively. The 3 WASCoBs in the GLASI program are relatively efficient. They have the potential to reduce sediment, TN, and TP by 140 t/yr, 1,833 kg/yr, and 91 kg/yr, which represent 3.47%, 2.51%, and 2.29% reductions respectively. The 8 WASCoBs in or near the monitoring site are relatively less efficient. They have the potential to reduce sediment, TN, and TP by 89 t/yr, 538 kg/yr, and 34 kg/yr, which represent 2.21%, 0.74%, and 0.86% reductions respectively. However, the construction of WASCoBs over the years has considerably accumulative effects on pollutant reductions. All existing 44 WASCoBs have the potential to reduce sediment, TN, and TP by 1,023 t/yr, 13,472 kg/yr, and 859 kg/yr, which represent 25.35%, 18.42%, and 21.60% reductions respectively. Adding the 3 WASCoBs that will be implemented in the future, the 47 WASCoBs have the potential to reduce sediment, TN, and TP by 1,046 t/yr, 13,933 kg/yr, and 875 kg/yr, which represent 25.92%, 19.05%, and 22.01% reductions respectively.

Under the baseline scenario with existing land management practices and WASCoBs, the sediment, TN and TP loadings at watershed outlet are 3,798 t/yr, 68,352 kg/yr, and 3,635 kg/yr respectively. Under the cover crop BMP scenario (3 fields with cover crop) during 2013-2014, the sediment, TN and TP reductions are 11.0 t/yr, 472.27 kg/yr, and 32.0 kg/yr, which represent 0.29%, 0.69%, and 0.88% reductions respectively in comparing to the baseline scenario. Under the cover crop BMP scenario (3 fields with cover crop) during 2014-2015, the sediment, TN and TP reductions are 56.0 t/yr, 1,569.33 kg/yr, and 9.0 kg/yr, which represent 1.48%, 2.3%, and 0.25%

reductions respectively. Under the precision nutrient BMP scenario (6 fields) during 2015-2016 GLASI program, the sediment, TN and TP reductions are 0.0 t/yr, 1,318.28 kg/yr, and 49.15 kg/yr, which represent 0%, 1.93%, and 1.36% reductions respectively. It is reasonable that precision nutrient management BMPs have no sediment effects. The BMPs in the GLASI program during 2016-2017 included soil amendment with manure application and GPS based precision nutrient management in 3 fields and strip tillage in 3 fields. These BMPs have the potential to reduce sediment, TN and TP by 35.0 t/yr, 884.81 kg/yr, and 33.0 kg/yr, which represent 0.92%, 1.3%, and 0.92% reductions respectively. The GLASI program during 2017-2018 had the implementation of more BMPs, which included GPS based precision nutrient management in 8 fields and zero tillage in 2 fields, and vertical tillage in 3 fields. These BMPs have the potential to reduce sediment, TN and TP by 41.0 t/yr, 116.64 kg/yr, and 53.0 kg/yr, which represent 1.08%, 0.17%, and 1.47% reductions respectively. In total, GLASI program implemented various BMPs in 23 fields during 2015 to 2018. All these BMPs have the potential to reduce sediment, TN and TP by 62.0 t/yr, 547.17 kg/yr, and 75.0 kg/yr, which represent 1.63%, 0.80%, and 2.08% reductions respectively. Note that the effects of these combined GLASI BMPs are less than the sum of GLASI BMPs in individual years because of interactions of different processes within the landscape and marginal decrease of pollutant reduction efficiencies as more BMPs were implemented. While the pollutant reduction effects of these land management BMPs are in relatively small magnitudes due to relatively small scale of BMP implementation in the watershed, the BMP effects at edge-of-field (on-site effects) are more pronounced. Furthermore, SWAT modelling results shows that the two windbreak BMPs as filter strips have reasonable pollutant reduction effects. The two windbreaks have the potential to reduce sediment, TN and TP by 28.7 t/yr, 225.69 kg/yr, and 21.0 kg/yr, which represent 0.76%, 0.33%, and 0.58% reductions respectively.

We conducted a preliminary assessment of cost effectiveness of various BMP scenarios. The GLASI program has a project on estimating the economic costs of GLASI BMPs and the project outcomes are currently not available. In this situation, we used our best knowledge to make assumptions on BMP costs based on the farm-economic modelling of BMPs (conservation tillage, nutrient management planning, cover crop and WASCoBs) conducted in the OMAFRA WBBE program by the Guelph Water Evaluation Group during 2010-2013. For land management BMPs, conservation tillage is the most expensive at $20/ha. Precision nutrient management BMP can reduce fertilizer costs but new equipment such as GPS and yield monitor purchase will add to the cost, with BMP cost at $10/ha. Cover cop and soil amendment BMPs also have benefits to producers in terms of soil built-up, with minimum BMP cost at $5/ha. Windbreak cost is associated with seedling, planting and tree spacing, with an assumption of $25/$100m based on annualization. The WASCoB cost including construction and maintenance costs estimated in WBBE program is at $55/ha of drainage area. Based on the assumptions, the cost effectiveness ratio of all existing WASoBs is $23.4 per kg of phosphorus reduction. The cost effectiveness ratios of other WASCoB scenarios are in the range between $23.6 and $31.2 per kg of P reduction. Cover crop BMPs during 2013-2014 and 2014-2015 periods are relatively efficient, with cost effectiveness ratios $7.5 and $ 21.8 per kg of P reduction. The cost effectiveness ratios for GLASI land management BMPs during 2015-2016, 2016-2017, and 2017-2018 are $20.8, $37.5 and $46.6 per kg of P reduction respectively. The all GLASI land management scenario is most expensive, with cost effectiveness ratio $63.0 per kg of P reduction. However, windbreak BMPs are relatively efficient, with cost effectiveness ratio $13.4 per kg of P reduction. Please note that high uncertainty exists in the cost effectiveness analysis, which is caused by the assumptions on BMP costs. With estimated BMP cost data from the GLASI program, the preliminary cost effectiveness analysis can be updated.

The 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 on examining 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. Furthermore, the effects of some BMPs may need to take several years to be realized. Long-term monitoring data and more detailed input data are very important for reducing model uncertainties. This suggests 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.

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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 this growing concern over the adverse environmental effects of agriculture, farmers, conservation authorities and governments have worked together to promote and implement Best Management Practices (BMPs) that focus on maintaining agricultural activity and farming profitability while protecting the environment.

From 2010 to 2013, Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) established a Watershed Based BMP Evaluation (WBBE) program. The Gully Creek watershed, along with Zurich and Ridgeway watersheds, were selected as the study sites for the WBBE program. From 2015 to 2017, OMAFRA and Ontario Soil and Crop Improvement Association (OSCIA) jointly implemented the Great Lakes Agricultural Stewardship Initiative (GLASI). In GLASI, the Gully Creek watershed was selected as one of the six pilot watersheds for BMP establishment and evaluation. By building upon ABCA's previous BMP initiatives and monitoring program, the WBBE and GLASI programs invested in establishing an enhanced monitoring system for evaluating existing and newly-established BMPs in the study area. A modelling component was also built into this project to simulate watershed hydrologic and nutrient fate processes under a broader range of climate conditions. The calibrated model was then used to examine the water quality effects of various existing or future BMPs in the watershed.

1.2 BMP implementation and monitoring initiatives

In the Gully Creek watershed, ABCA staff contacted producers to discuss their current practices and identify potential opportunities for further BMP implementation. In the WBBE program, four BMPs in common use by producers were conservation tillage, nutrient management planning, red clover cover crop after winter wheat harvest, and WASCoB construction. In the GLASI program, additional BMPs were identified including oat and mixed grain cover crop, GPS and yield monitor based precision nutrient management, soil amendments through manure application, and windbreak. These two projects also set up an intense water monitoring program, both near the watershed outlet at Highway 21 and in-stream upper watershed station locations. Edge-of-Field monitoring at selected locations was also implemented during the project development process.

1.3 Project objectives

In the WBBE program, the Soil and Water Assessment Tool (SWAT) was adapted and applied for the Gully Creek watershed based on flow and watershed quality monitoring data from 2010 to 2012. In the GLASI program, the purpose of the modelling component was to further adapt the SWAT model to examine water quantity and quality effects of BMPs implemented in the Gully Creek watershed based on extended monitoring data. Specifically, the project had four interrelated objectives: 1) Adapt and set up the SWAT model for the Gully Creek watershed; 2) Calibrate and validate the SWAT model based on available monitoring data; 3) Apply the SWAT model to examine water quality benefits of various BMP scenarios in the Gully Creek watershed; 4) Conduct a preliminary assessment of the cost effectiveness of BMP scenarios.

2.0 STUDY AREA

2.1 Location

The Gully Creek watershed is representative of a series of small watersheds in the shoreline areas of Lake Huron (Figure 2-1). The watershed covers 14.5 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, the Gully Creek discharges directly into Lake Huron, thus has 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).

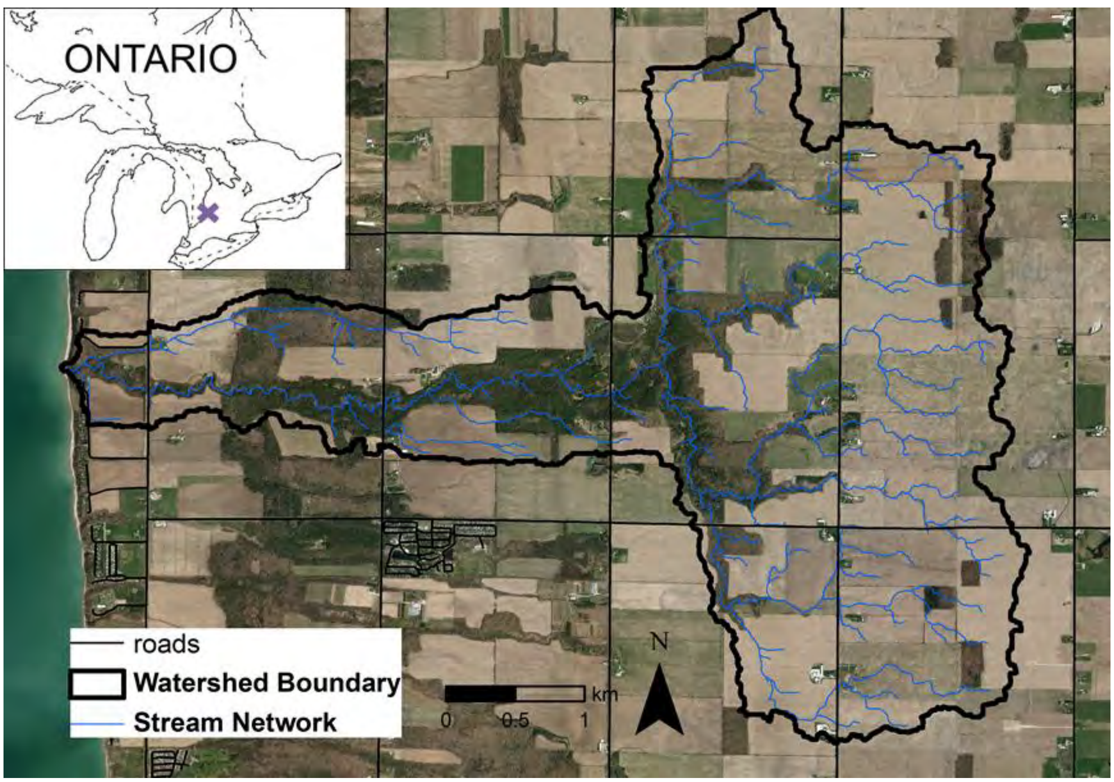

Figure 2-1. Gully Creek watershed located in Ausable Bayfield Conservation Authority

2.2 Topography, soil and landuse

The Gully Creek watershed has an undulating terrain, typical of the small lakeshore watersheds outletting along Lake Huron's eastern shore (Figure 2-2). Land elevations of the watershed range from 176 to 281 m (Figure 2-2). 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).

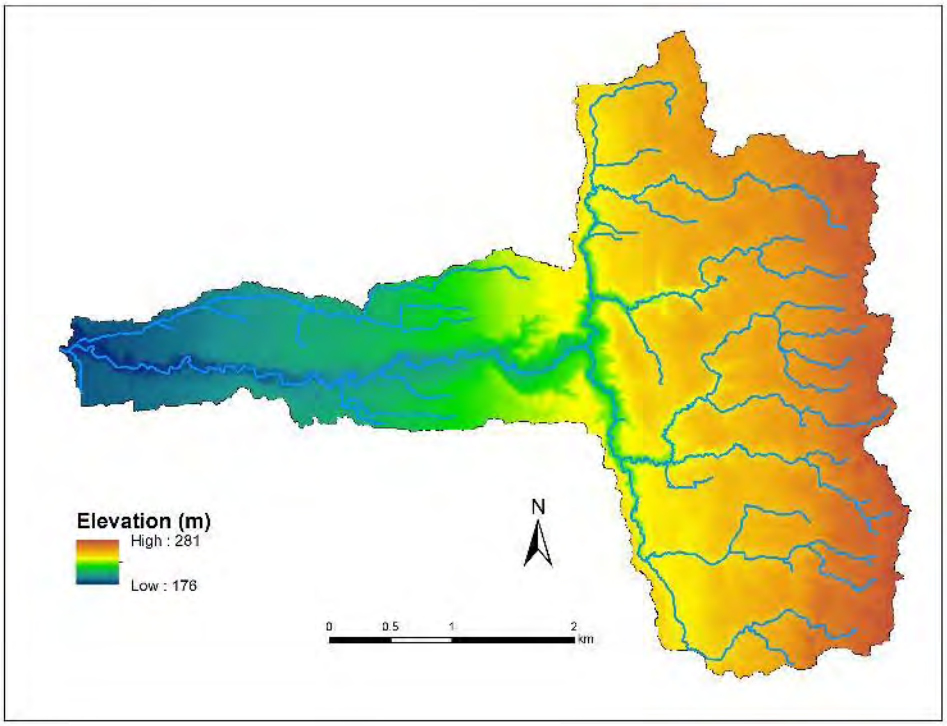

Figure 2-2. Topography of Gully Creek watershed (Source data: OMNRF, 2015)

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. 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	8.23	56.74
BAY	Brady Sandy Loam	1.91	13.19
BKN	Brookston Clay Loam	1.55	10.67
ZAL	Bottom Land	1.39	9.55
PTH1	Perth Clay Loam	1.04	7.15
BUF	Burford Loam	0.39	2.70
Total		14.51	100.00

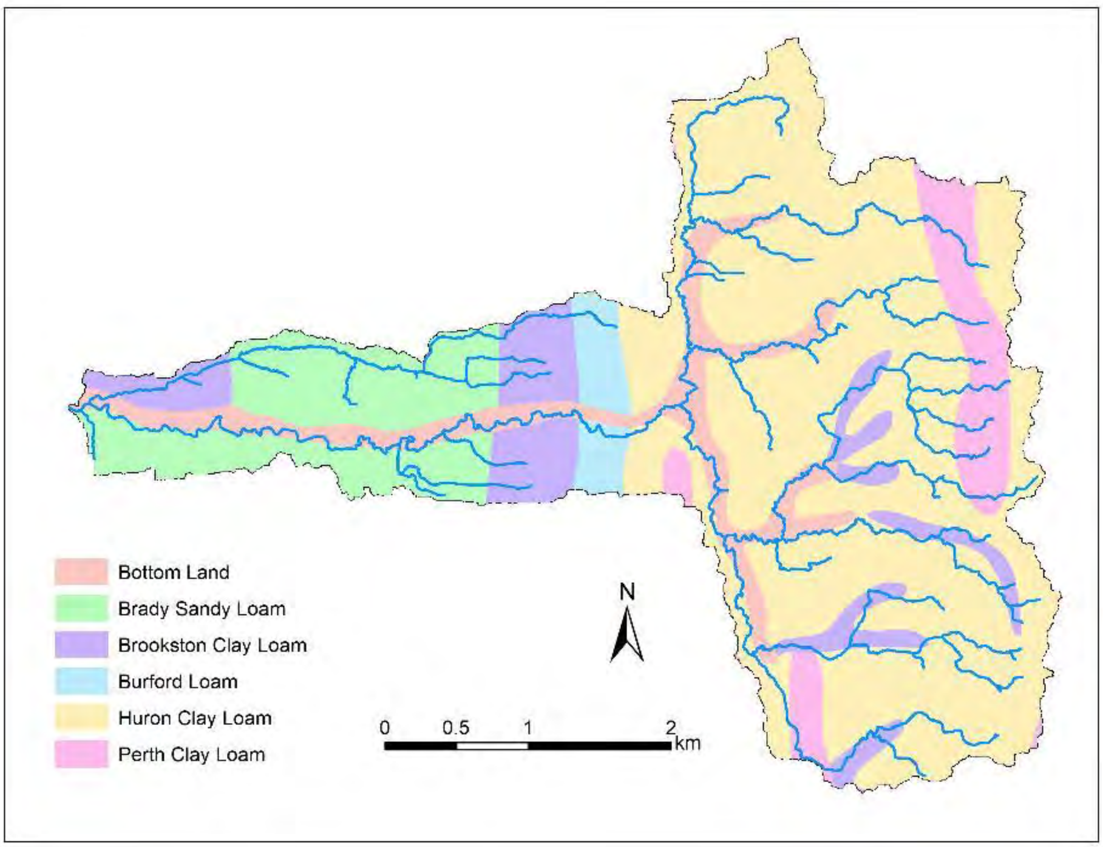

Figure 2-3. Soil types in the Gully Creek watershed (Source data: OMAFRA Soil GIS Database)

Crop and landuse distribution within the Gully Creek watershed for the year of 2017 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. About 67% of the land is agricultural and 28% 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 2017

Category	Name	Area (ha)	Percent (%)	Sub-Total (ha)
Agricultural	Beans	11.46	0.79	969.47
	Corn	312.56	21.55	
	Edible Beans	35.57	2.45	
	Grass Hay	17.11	1.18	
	Soybeans	438.86	30.26	
	Winter Wheat	153.91	10.61	
Forest	Roughland	28.19	1.94	375.87
	Woodland	347.68	23.97	
Grasses	Fencerow	8.14	0.56	28.00
	Forages	2.88	0.20	
	Grass Waterway	0.95	0.07	
	Pasture	16.04	1.11	
Others	Ditch	15.31	1.06	77.11
	Farmstead	30.69	2.12	
	Riparian	16.49	1.14	
	Road	8.86	0.61	
	Urban	5.77	0.40	

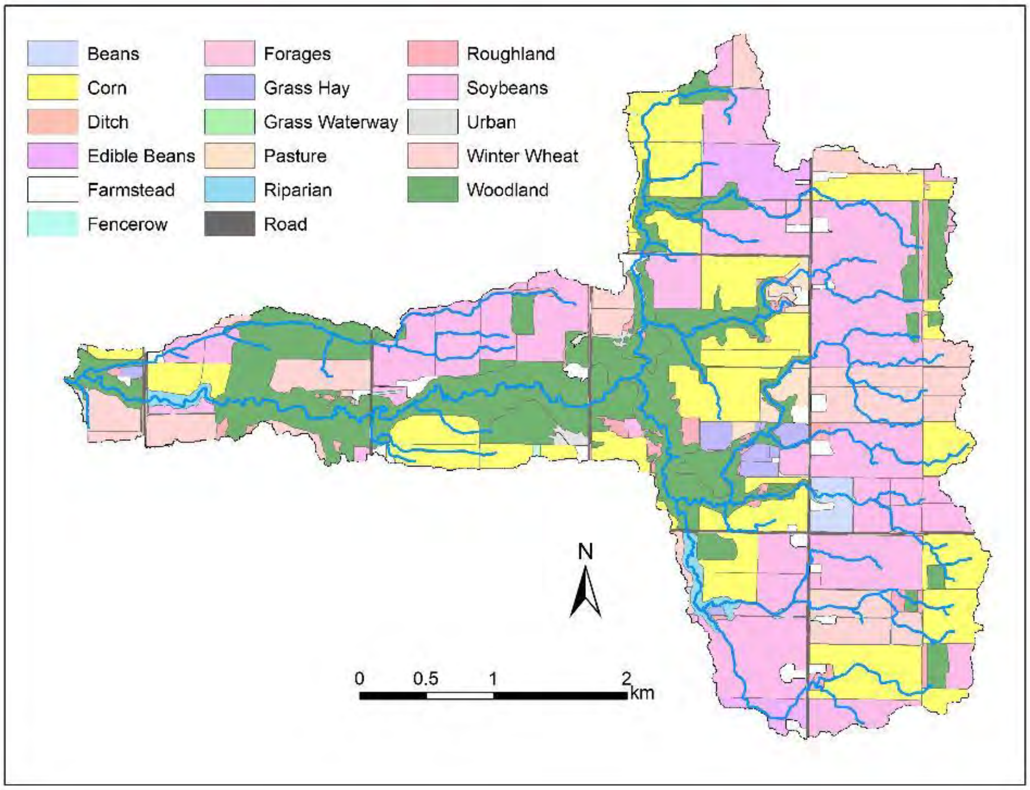

Figure 2-4. Landuse and crop type of 2017 in Gully Creek watershed

2.3 Climate and hydrology

Two weather stations were setup in the Gully Creek watershed since April 2011 and data from these two stations were 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 longer period from January 2001 to May 2017.

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 1,003 mm over 2001 - 2016 with a standard deviation of 169 mm. The maximum annual precipitation of 1,407 mm occurred in 2008, and the minimum was 793 mm, occurring in 2015. The maximum daily precipitation (Pmax) is 86 mm, recorded on September 25, 2005. The average annual temperature (Ty) is 8.1 °C and ranged from 9.7 °C (2016) to 6.4 °C (2014) with a standard deviation of 0.9 °C. From 2010 to 2017, there is a continuous runoff measurement from Jul 12, 2010 to Aug 05, 2013 (with 3 missing days). The total runoff during this period is 1,739 mm in GULGUL2. The total precipitation in the same period is 2,972 mm which makes the average runoff coefficient of 0.585.

A summary of monthly average precipitation (Pm), temperature (Tm), discharge (Qm) and runoff (Rm) for the Gully Creek watershed from July 2010 to May 2017 (based on the period with flow data at GULGUL2 station) is presented in Table 2-3. A graphical presentation of average monthly precipitation, temperature and runoff for the Gully Creek watershed over this period is shown in Figure 2-5.

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

Month	P_m (mm)	T_m (°C)	Q_m (m^3/s)	R_m (mm)	$R_m/\Sigma R_m$ (%)	R_m/P_{mr}[1] (%)	$R_m/\Sigma P_{mr}$[1] (%)
January	74.6	-4.8	0.417	85.1	14.5	98.7	9.7
February	55.4	-5.0	0.593	96.0	16.3	163.2	11.0
March	67.2	0.5	0.761	140.2	23.8	191.7	16.0
April	74.9	6.9	0.297	60.4	10.2	85.2	6.9
May	72.0	13.3	0.094	18.4	3.1	34.8	2.1
June	94.3	17.9	0.207	35.7	6.1	41.4	4.1
July	89.3	20.7	0.056	9.8	1.7	11.5	1.1
August	66.5	19.8	0.110	10.3	1.8	23.8	1.2
September	91.0	16.3	0.069	11.5	2.0	13.5	1.3
October	110.1	9.4	0.153	31.1	5.3	34.2	3.6
November	74.4	3.8	0.201	34.3	5.8	53.7	3.9
December	81.7	-0.6	0.367	56.4	9.6	72.4	6.4
Average	79.3	8.2	0.277	49.1	8.3	68.7	5.6

Note: Pm means monthly precipitation, Tm means average monthly temperature, Qm means average monthly discharge at GULGUL2 station, Rm means monthly runoff at GULGUL2 station, Pmr means monthly precipitation excluded runoff missing days.

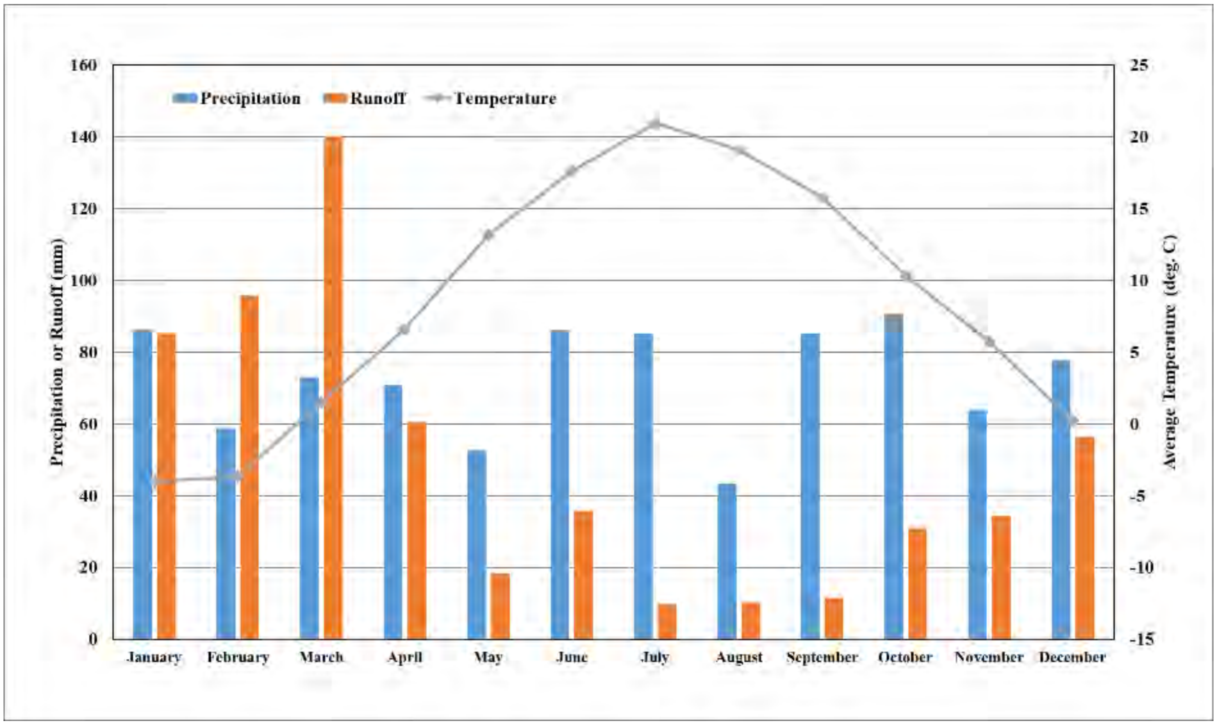

Figure 2-5. Monthly average distribution of measured precipitation, temperature and runoff in Gully Creek watershed from 2010 to 2017

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 (23.8% of the total runoff) because of snowmelt. Low flow happened at Highway 21 station in summer season from July to September (1.7%, 1.8% and 2.0% of the total runoff) 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 34% during the summarization period from 2010 to 2017 based on flow separation analysis using SWAT tool), which provides contribution to the total runoff at the watershed outlet (Figure 2-6).

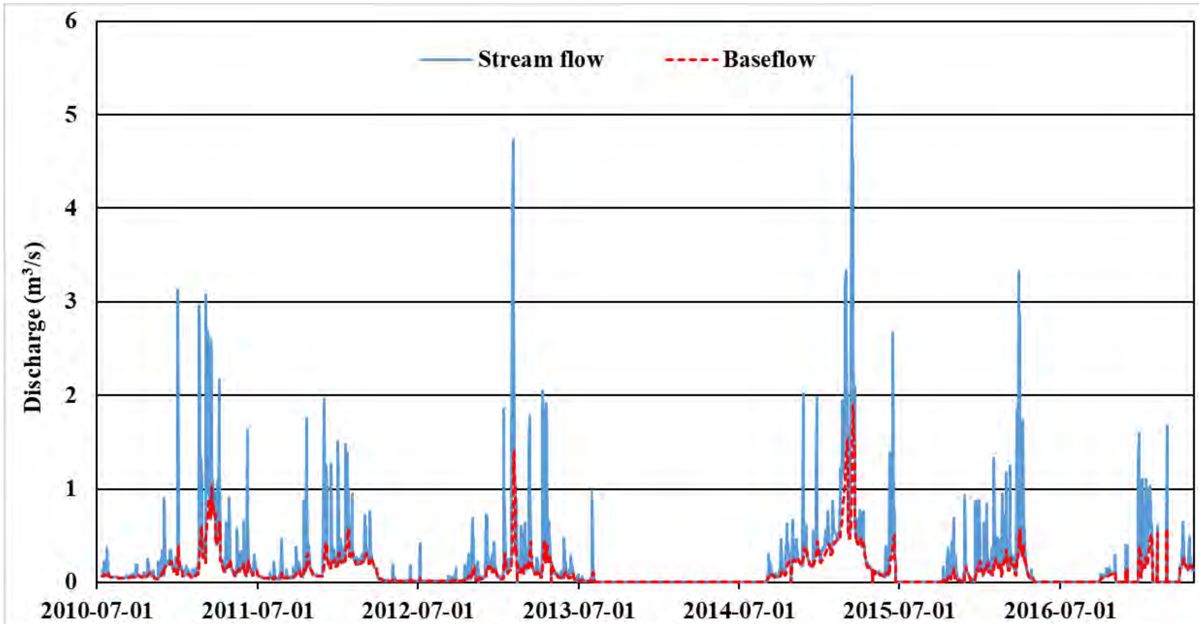

Figure 2-6. Baseflow separation at station GULGUL2 of the Gully Creek watershed from July 2010 to May 2017

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 and Forestry (OMNRF), Environment and Climate Change Canada (ECCC), and ABCA.

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

Name	Type	Source	Description
Topography	raster	OMNRF, 2015, ABCA, 2017	1×1 m SWOOP 2015 imagery derived DEM
Soil	shape	CANSIS and OMAFRA soils GIS	Soils for Ontario
Landuse	shape	OMAFRA, 2009-11 ABCA, 2012, 2017 MNR, 2007	Agricultural Resources Inventory Producer and Windshield Survey Land Cover Information System (ELC)
Stream network	shape	ABCA	
Berms	shape	OMAFRA, 2012	(unpublished)
Transportation	shape	MNRF, 2006	Ontario Road Network 2005

3.2 Climate data

Weather data required for SWAT setup include precipitation, temperature, relative humidity, solar radiation, and wind speed at a daily scale. Temperature data combining with solar radiation, relative humidity, and wind speed data were used to calculate Potential Evapotranspiration (PET) in SWAT. Two weather stations were setup within in the Gully Creek since 2011, i.e. one (NGmetVB) started from April 2011 and the other (GULGUL5) started from January 2013. A synthesized climate dataset was developed based on similar climate pattern in the various available datasets from Gully Creek NGmetVB, GULGUL5, Varna, and London stations (Table 3-2). In Gully Creek, snowmelt events are significant for stream flow. Therefore, snow data collected at London

ECCC station were referenced in building the precipitation data within the climate dataset. 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 with climate measurements taken at the Gully Greek watershed for the period from April 29, 2011 to May 1, 2017. Relative humidity, solar radiation, and wind speed are only available at Gully Creek NGmetVB station in the period between 2011-04-29 and 2017-05-01. 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 NGmetVB	Apr 29, 2011 May 1, 2017	43°36'53" N	81°40'52" W	5, 10 min, or hourly	PCP (no snow data), TMP, ETP, RHM, WDR, WSP, SLR.
Gully Creek GULGUL5	Jan 11, 2013 May 1, 2017	43°36'51" N	81°39'51" W	Every 5 min	PCP (no snow data)
Varna Enviro. Canada	April 6, 1989 May 1, 2017	43°33'4" N	81°35'22" W	Hourly	PCP (no snow data)
London Enviro. Canada	July 1, 1940 May 1, 2017	43°01'59" N	81°09'04" W	Daily	PCP (Includes snow data), TMP
Exeter Enviro. Canada	Feb 1, 1961 April 15, 2008	43°21'00" N	81°30'00" W	Daily	PCP (Includes snow data), TMP
Goderich Enviro. Canada	Dec. 30, 1994 May 1, 2017	43°45'00" N	81°42'00" W	Daily	PCP (no snow data), TMP

Note: PCP means precipitation, TMP means air temperature, ETP means evapotranspiration, RHM means relative humidity, WDR means wind direction, WSP means wind speed, and SLR means solar radiation.

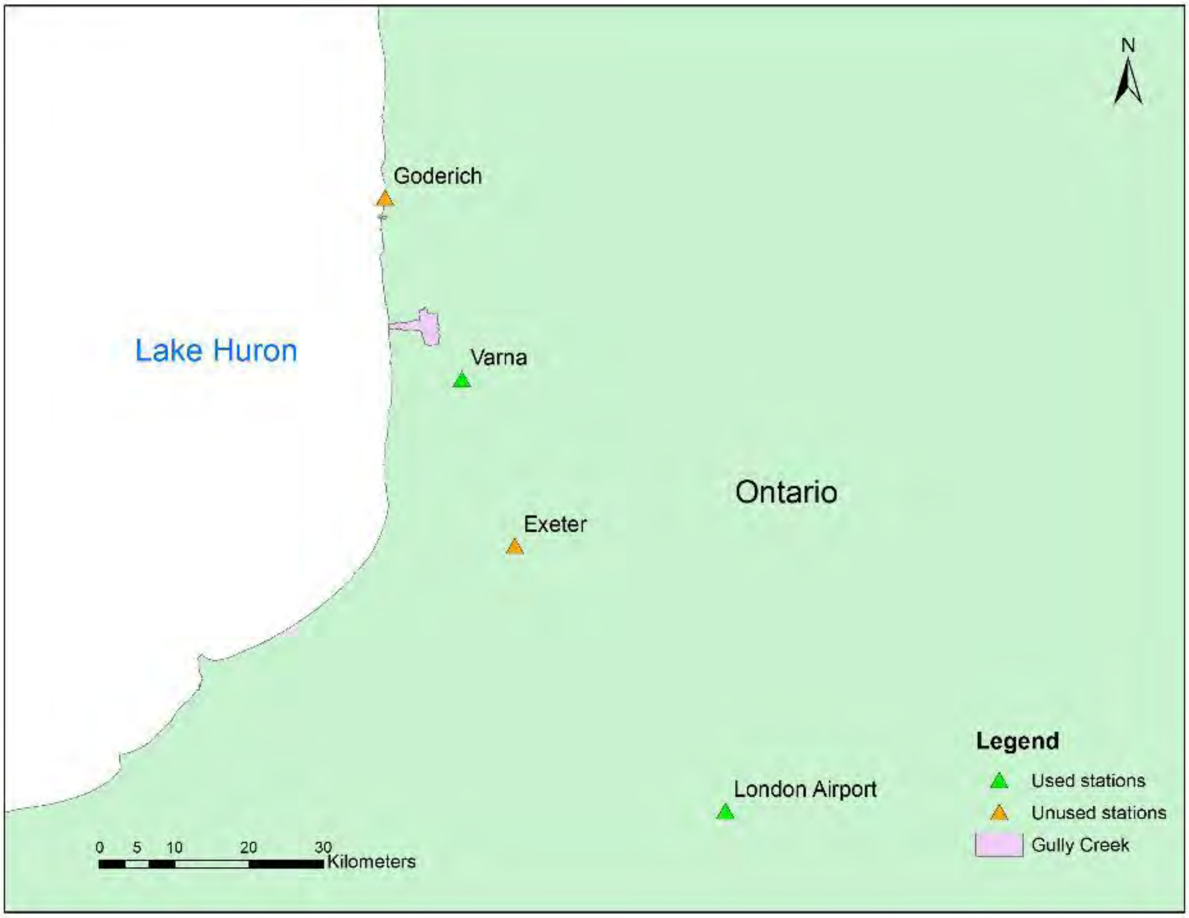

Figure 3-1. Location of Environment Canada climate stations for Gully Creek modelling

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 stations 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

Station	Description	Drainage area (km^2)	Flow (year)	Sediment (year)	Nutrient (year)
GULGUL2*	Main stream	12.62	2010-2017	2007-2014	2007-2014
GULGUL3	Branch	0.86	2011-2017	2009-2013	2009-2013
GULGUL4	Branch	0.48	2011-2016	2011-2013	2011-2013
GULGUL5*	Main stream	10.38	2011-2017	2011-2017	2011-2017
GULGUL6	Main stream	14.51	-	2011-2012	2011-2012
GULGUL7*	Branch	2.38	2012-2017	2012-2014	2012-2014
GULGUL8	Branch	2.74	2012-2017	2013-2014	2013-2014
BBCULV1	Culvert outlet	-	-	2011-2013	2011-2013
BBCULV2	Culvert inlet	-	-	2013	2013
BBFIELD1	Edge of field	-	-	2011-2013	2011-2013
BBTILE1	Tile outlet	-	-	2011-2012	2011-2012
DFCULV1	Edge of field	-	-	2011	2011
DFTELB2-HB*	Field	-	2016-2017	2014	2014
DFTELB2-HBpost	Field	-	-	2015-2017	2015-2017
DFTELB2-HBpre	Field	-	-	2015-2017	2015-2017
DFTELB2-IN	Field	-	-	2014	2014
DFTELB3-HB	Field	-	2016-2017	2014	2014
DFTELB3-HBpost	Field	-	-	2015-2016	2015-2016
DFTELB3-HBpre	Field	-	-	2015-2016	2015-2016
DFTELB4-HB	Field	-	-		
DFTELB5-HBpost	Field	-	-	2015-2016	2015-2016
DFTELB5-HBpre	Field	-	-	2015-2016	2015-2016
DFTILE1	Field Tile	-	2016-2017	2012-2017	2012-2017
ETRUNOFF1	Field	-	-	2011-2012	2011-2012
ETTILE2	Tile outlet	-	-	2011-2012	2011-2012
KV13CCTILL1	Field	-	-	2014	2014
KVBAY-HB	WASCoB Hickenbottom	-	-	2012-2017	2012-2017
KVBAY-IN	WASCoB Inlet	-	-	2012-2015	2012-2015
KVNCTILL1	Field	-	-	2014	2014
KVNCWOOD1	Field	-	-	2014	2014
KVNCWOOD2	Field	-	-	2014	2014
VBTILE1	Drainage tile	-	2013-2017	2013-2015	2013-2015
VBTILE1south	Drainage tile	-	-	2015	2015

Note: Stations with asterisks were used for calibration.

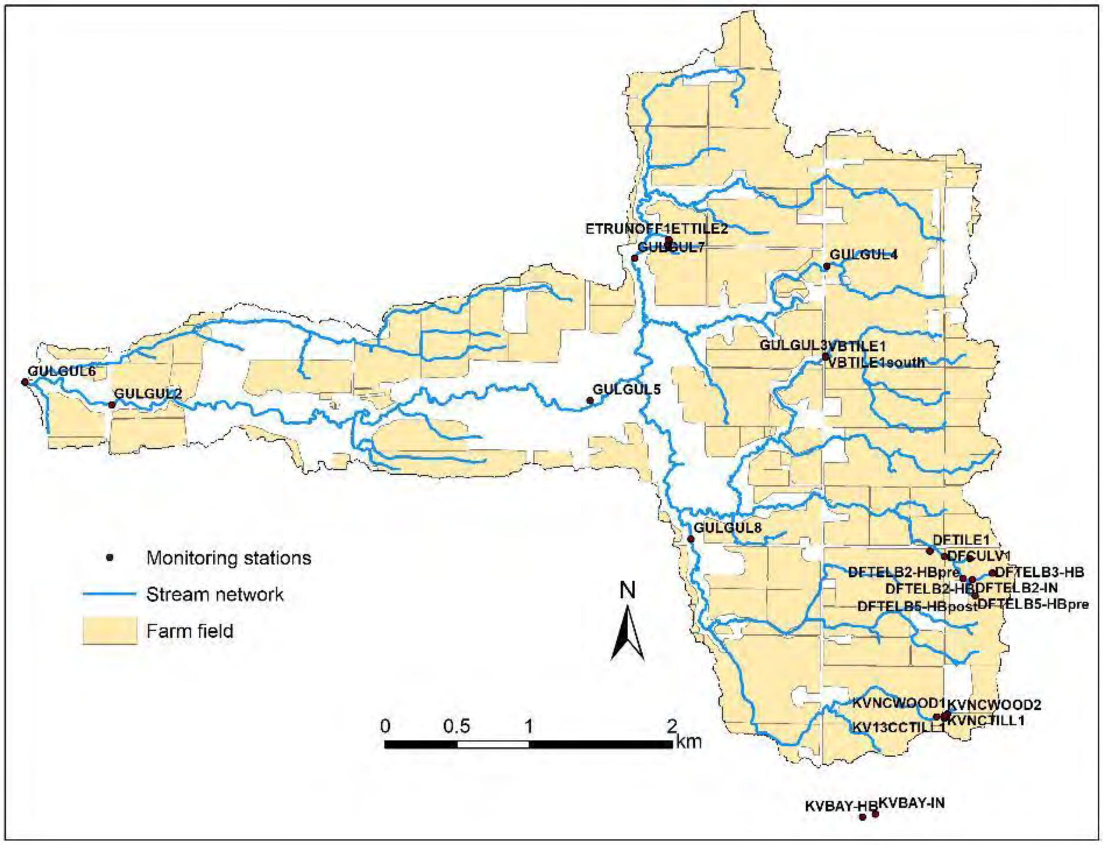

Figure 3-2. Locations of flow and water quality stations

3.4 Land management data

Under the WBBE and GLASI programs, the ABCA conducted two land management surveys in Winter 2011 and 2017 respectively. The WBBE survey included collecting land management data for the 2008 to 2010 historical years and also included a forecasting of the crop production plans for 2011 to 2013 crop years. The GLASI included collecting land management data for the 2013 to 2016 historical years and also included a forecasting of the crop production plans in 2017. The survey data was compared with 2009 to 2016 agricultural inventory (AgRI) field-observed data collected by OMAFRA. AgRI data were collected from field reconnaissance and may be more accurate than survey data, 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 confirmed both of these sources of cropping information to arrive at a final field-verified land management dataset for a 10-year period from 2008 to 2017. 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 model

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, topography, vegetation, and land management practices are the main inputs to the SWAT model for simulating hydrologic and water quality processes in a watershed (Arnold et al., 1998; Neitsch et al., 2011, 2012). SWAT simulates flow, sediment, crop growth, and nutrient cycling, and therefore 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 monitoring and geospatial information.

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. Climate inputs provide the moisture and energy, and determine the relative importance of processes of the hydrologic cycle. The watershed is divided into subbasins, and is further divided into hydrologic response units (HRUs). HRUs are lumped areas within the subbasin comprised of unique land cover, soil, slope range, and management combinations. Daily water balance in each HRU is maintained based on precipitation, surface runoff, infiltration, evapotranspiration, percolation, and return flow from subsurface.

SWAT has been applied widely in various watersheds across the world for long-term simulations of flow, sediment and nutrient transport. The major benefit of the model is its applicability for decision-making in agricultural 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 management scenarios on long term sediment and nutrient loads (e.g. Wu and Johnston, 2007; Zhang et al., 2007). Despite its advantages, the use of SWAT has challenges of extensive data requirements and difficulties in model calibration for a complex watershed. Other drawbacks include its practice of lumping parameters arbitrarily into sub-basins, 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 that SWAT was suitable for predicting yearly flow volumes, sediment and nutrient loads, monthly predictions were generally good except for months having extreme storm events and extreme hydrologic conditions, while daily predictions were 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 considered (Arnold and Fohrer, 2005).

In the 2005-2013 Watershed Evaluation of BMPs (WEBs) program of the Agriculture and Agri-Food Canada (AAFC), the Guelph Watershed Evaluation Group (WEG) had extended SWAT to characterize snow redistribution and frozen soil conditions and also developed/redeveloped BMP modules including small dam/reservoir, manure holding pond, conservation tillage, forage conversion, and grazing management (Yang et al., 2013). These developments had led to the Canadian version of SWAT (CanSWAT) which had 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. 2014; 2015). Due to data and resource limitations, CanSWAT was not applied to the Gully Creek watershed modelling in the 2010-2013 WBBE program. However, in the WBBE program, a BMP module for the water and sediment control basins (WASCoBs) was developed in SWAT to characterize WASCoBs in the Gully Creek watershed. In the modelling component of the GLASI program, the CanSWAT including snow redistribution, frozen soil, and WASCoB modules were further adapted and parameters were adjusted for characterizing small lakeshore watershed conditions in the Lake Huron basin.

4.2 Watershed delineation

Watershed delineation involves delineating stream network and subbasins, and calculating subbasin and reach parameters using available GIS data. The subbasin outlets were defined at outlets of stream tributaries, monitoring sites, and berm and tile drain locations. The GIS data used for watershed delineation were based on 1-m SWOOP 2015 imagery derived DEM along with a watershed boundary layer, a stream network layer, monitoring station locations, berm location, and tile drain outlet location point data. The rationale for setting monitoring stations as subbasin outlets was to define drainage areas for monitoring stations and to calibrate model at both in-stream stations and edge-of-field stations. The reason for setting 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. Watershed delineation involved:

1) Defining stream network based on the 1-m DEM using an area threshold value of 0.5 ha. This ensured that 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 shapefiles 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 96 subbasin outlets were defined including 23 main tributary outlets, 19 monitoring stations (including 4 berm sites), 44 existing berms, 3 future berms, and 11 tile-drain outlets. The total derived reach length in the Gully Creek watershed is 45.7 km, and the derived length weighted averaged slope, bankfull width and depth are 1.44%, 1.86 m, and 0.15 m respectively. The total drainage area derived from the SWOOP DEM was 1,450 ha (14.5 km^2), with an average slope and elevation of 6.18% and 246 m. The subbasin areas ranged from 0.16 ha to 123 ha, with an average of 15.1 ha. Among the 96 subbasins, 54 are under 10 ha, 23 are within 10 to 20 ha, 12 are between 20 and 50 ha, 6 are from 50 to 100 ha, and 1 is above 100 ha. The delineated stream network and subbasin map is shown in Figure 4-1.

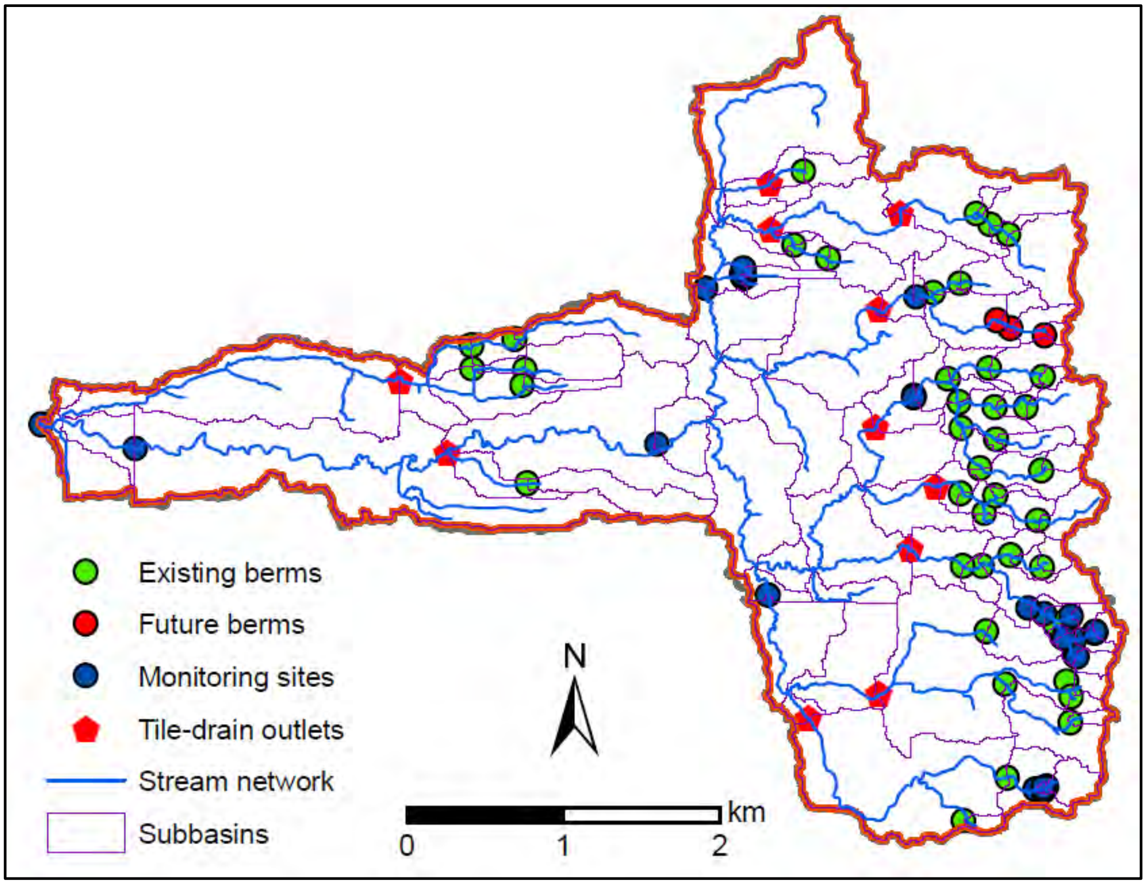

Figure 4-1. SWAT delineated stream network and subbasins in the Gully Creek watershed

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. For the Gully Creek watershed, soil data were obtained from Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). This data combined with soil data from Canadian Soil Information Service (CanSIS) were used to prepare the soil attribute datasets for the study area used in the SWAT model. A summary of soil statistics in the Gully Creek watershed SWAT modelling is provided in Table 4-1.

Table 4-1. Summary of soil statistics in the Gully Creek watershed

Soil code	Number of layers	Hydrology group	Maximum depth (mm)	Soil texture	Area (ha)	Watershed area (%)
ZAL	4	B	1,000	LSa, SaL	145	9.99
BAY	4	B	1,000	SaL, LSa, SaL, LSa	204	14.1
BKN	3	D	1,000	CL, SiCL, SiCL	146	10.1
BUF	5	A	1,000	L, LSa(gr), SaL(gr)	35.9	2.47
HUO	4	C	1,000	CL, SiCL, SiCL, SiCL	826	56.9
PTH1	4	C	1,000	CL, CL, SiC, SiCL	93.9	6.47

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 different management practices such as seeding dates, harvest dates, tillage practices, fertilizer and manure application rates. In addition, SWAT allows users to set up a crop rotation for a specific HRU.

For the Gully Greek SWAT modelling, a total of 29 distinct land cover/use types were identified based on the synthesized landcover/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 producer 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 to group similar crops into one category during model setup. A summary of landuse statistics in the Gully Creek watershed SWAT modelling is provided in Table 4.2.

Table 4-2. Summary of landuse statistics in the Gully Creek watershed (2011)

ID	Landuse	SWAT Code	Area (ha)	Watershed Area (%)
1	Corn	CORN	343	23.7
2	Soybean	SOYB	373	25.7
3	Winter wheat	WWHT	278	19.2
4	Forest-mixed	FRST	342	23.5
5	Tall fescue	FESC	3.15	0.22
6	Meadow brome grass	BROM	0.78	0.05
7	Pasture	PAST	15.9	1.10
8	Forest-deciduous	FRSD	46.9	3.24
9	Spring barley	BARL	7.55	0.52
10	Forest-evergreen	FRSE	17.2	1.18
11	Residential-low density	URLD	8.00	0.55
12	Hay	HAY	14.8	1.02

4.5 Hydrologic response units

SWAT further delineates subbasins into one or more HRUs. Each HRU has a unique landuse, soil and slope combinations, enabling the model to reflect differences in runoff, erosion, nutrient loading and other hydrologic processes for different land covers and soils. 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 classes (10%) in this study. SWAT predicts runoff, sediment and nutrient loading separately for each HRU, aggregates them at subbasin level, and then routes them 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 in slope class > 9% (Table 4-3 and Figure 4-2). In the HRU determination, the threshold value of landuse percentage within a subbasin area was set to 10%, the soil class percentage was set to 20%, and the slope class percentage was set to 10%. This resulted in a total of 687 HRUs within the watershed with a minimum size of 0.02 ha and a maximum size of 29 ha with an average size of 2.1 ha.

The HRU distribution was based on the 2011 crop distribution, and was fixed after model setup. To address land cover changes (i.e. crop rotations) within each HRU, land management data were prepared using a tool developed by the Guelph WEG that allows a detailed scheduling of management operations within a HRU. The scheduled management operations for each HRU were based on land management time-series data that were assembled through the producer interview and roadside survey activities in the Gully Creek watershed.

Table 4-3. Summary of slope classes in the Gully Creek watershed

Slope (%)	Class	Area (ha)	Watershed area (%)	Agricultural Area (%)
0-2	A, B	287	19.8	23
2-5	C	640	44.1	50
5-9	D	295	20.3	22
> 9	E - H	228	15.8	5.0

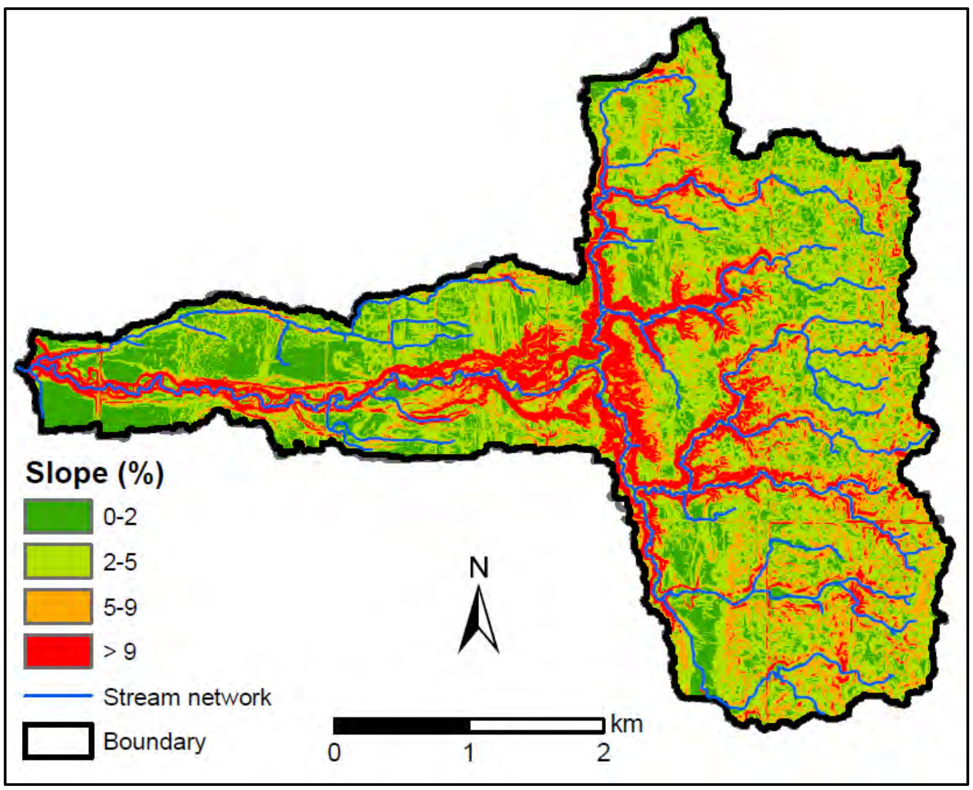

Figure 4-2. Slope classes in the Gully Creek watershed for the SWAT model setup

4.6 Land management

Land management data are important inputs to the SWAT model for simulating runoff, sediment and water quality processes in agricultural watersheds. Land management information includes planting date, harvest date, irrigation, nutrient application dates and rates, pesticide application dates and rates, tillage operations and timing, and others. In this study, two land management surveys were conducted in Winter 2011 and 2017 respectively to collect information on 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 as well as direct windshield surveys completed by ABCA staff to create synthesized land management datasets.

The land management data in the Gully Creek watershed covered the period from 2008 to 2017. The WBBE survey data from 2008 to 2010 were historical (actual) information as provided through the producer surveys and verified using the OMAFRA AgRi mapping for the same period. The predicted data for 2011 – 2012 crop years were based on production plans as provided through the producer interviews conducted in early 2011. The producer's planned practices were verified by the windshield surveys conducted in the 2011 and 2012 growing seasons. The GLASI survey data from 2013 to 2016 were (actual) information as provided through the producer surveys and 2017 data were predicted based on production plans. Four key land management datasets were prepared during the SWAT model setup: (a) planting details for 10 growing seasons from 2008 to 2017, (b) fertilizer application details, (c) harvest and straw management details, and (d) tillage operation details.

Three steps were completed when preparing SWAT management input data for the Gully Creek watershed at the HRU level: (a) cleaning raw land management data at field scale, (b) preparing SWAT management database at field scale on a yearly basis, and (c) converting field management data into SWAT HRU text input files. Step (a) 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 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 GWEG. The variables and preparation processes for the second step are described in more detail in following sections.

4.6.1 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. Parameters associated with planting operation include month of operation, day of operation, land cover identification number (PLANT_ID), and operational SCS runoff curve number (CNOP) for moisture condition II (Neitsch et al., 2012).

Steps for preparing multiple-year planting operation practices in the Gully Creek watershed are: (a) reclassifying the landuse layer for each year using created landuse lookup table, (b) overlaying the reclassified landuse with the HRU distribution based on the 2011 landuse information, (c) reassigning each HRU's landuse type by selecting the landuse having the largest portion within the HRU, (d) defining the seeding date by choosing the date for the area that covers largest part of the HRU, and (e) creating the HRU planting attributes using available data and the lookup table. 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 was reflected by PLANT_ID, operation date and CNOP which are assigned for each year and for each HRU based on the updated landuse information.

4.6.2 Fertilizer application

SWAT's fertilizer operation simulates the process of fertilizer and manure application 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 (FERT_ID), the amount of fertilizer/manure applied (FRT_KG), and the depth distribution of fertilizer application (FRT_SURFACE). Preparing the detailed multi-year datasets of fertilizer application practices entailed completing the following steps: (a) calculating the amount of elemental N, elemental P and manure applied (kg/ha) for each application at field level; (b) estimating the land ID compositions and their area partitions for each HRU from the landuse data; (c) calculating the area-weighted mean N and P application rates for each HRU; (d) calculating average N and P application rates 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) assigning a fertilizer and manure application date by choosing the application date for the area that covers largest part of the HRU, and (f) creating HRU fertilizer application attributes based on data for each application year. The final fertilizer application input data prepared for each HRU and for each year were ultimately stored in the SWAT "mgt2" database.

Manure application in the Gully Creek watershed is a common practice including mainly dried beef manure, dried broiler manure, dried layer manure, liquid layer manure, and liquid swine manure. To match with Ontario condition, manure laboratory and AgriSuite analysis data from OMAFRA (through communication with Kevin McKague) were adopted in the Gully Creek watershed SWAT modelling. Table 4-4 lists the parameters associated with manure application including manure ID, manure code, and fractions of mineral nitrogen (MinN), mineral phosphorous (MinP), organic nitrogen (OrgN), and organic phosphorous (OrgP). These parameters were added to the SWAT fertilized database and were used in the model simulation and BMP assessment in the Gully Creek watershed.

Table 4-4. Manure parameters used in the Gully Creek watershed SWAT modelling

Manure ID	Manure code	Description	MinN	MinP	OrgN	OrgP
100	BEEF-DR	Dried beef manure	0.0018	0.0019	0.0074	0.0014
101	BEEF-LQ	Liquid beef manure	0.0015	0.0005	0.0022	0.0003
110	BROIL-DR	Dried broiler manure	0.0055	0.0026	0.0216	0.0106
120	DAIRYH-DR	Dried dairy manure (young)	0.0011	0.0012	0.0073	0.0009
121	DAIRY-LQ	Liquid dairy manure	0.0016	0.0005	0.0023	0.0004
122	DAIRYM-DR	Dried dairy manure (mature)	0.0016	0.0011	0.0053	0.0008
130	LAYER-DR	Dried layer manure	0.0080	0.0015	0.0084	0.006
131	LAYER-LQ	Liquid layer manure	0.0056	0.0006	0.0027	0.0023
140	SWINE-DR	Dried swine manure	0.0024	0.0020	0.0069	0.0029
141	SWINE-LQ	Liquid swine manure	0.0026	0.0005	0.0013	0.0007
150	TURK-DR	Dried turkey manure	0.0085	0.0041	0.0173	0.0095

4.6.3 Harvest, kill and straw management

The harvest and kill operation in SWAT defines plant harvest and kill in the HRU. The fraction of biomass specified in the land cover 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 or kill operation. Differing from harvest operation, the kill operation stops all plant growth and converts all plant biomass to residual. This operation implies for the cover crop for which the cover crop is killed before seeding and all biomass is converted to residual without harvest. 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 4-5 gives general assumptions on residue cover for different crops in the Gully Creek watershed SWAT modelling. The impact and CNOP changes for different straw management is listed in Table 4-6 for the Gully Creek SWAT modelling.

Table 4-5. 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%

Table 4-6. 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 medium	1.025
8	80R	80%	Low	1.00
9	90R	90%	Low	1.00
10	100R	100%	Low	1.00

Preparing the detailed multi-year datasets of plant harvest, kill and straw management practices involved: (a) classifying the reported straw management practices into categories and assign CNOP/CN2 ratio for each category; (b) estimating land compositions and their area partitions for each HRU for the landuse data; (c) calculating average CNOP/CN2 for each HRU; (d) assigning a harvest date by choosing the date for the area that covers largest part of the HRU; and (e) creating HRU harvest, kill and straw management attributes using available data and lookup tables. The final harvest, kill and straw management input data were prepared for each HRU and for each year and were stored in SWAT's "mgt2" database. The missing data were filled based on general assumptions made in Table 4-5 and Table 4-6.

4.6.4 Tillage operation

Tillage operation redistributes residue, nutrients, and pesticides in the soil profile. Information required for SWAT tillage simulation includes timing and type of the tillage operation. The moisture condition II curve number (CNOP) is adjusted by SWAT during model simulation to reflect its effect on runoff generation. Table 4-7 lists parameters (tillage code, tillage ID, tillage depth, mixing efficiency, and CNOP/CN2) associated with tillage operation for the Gully Creek SWAT modelling.

Table 4-7. 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	1.075
Conservation Tillage	CONSTILL	3	100	0.25	Medium to low	1.025
Culti-packer Pulverizer	CULPKPUL	19	40	0.35	Medium	1.05
Disk Plow (DKPLGE23)	DISKPLOW	61	100	0.85	Medium to high	1.075
Field Cultivator	FLDCULT	7	100	0.30	High	1.10
Harrow (HRW10BAR)	HARROW	16	25	0.20	Medium to low	1.025
Moldboard Plow	MLDBOARD	56	150	0.95	High	1.10
No tillage done	NOTILL	108	0	0.00	low	1.00
Deep Ripper-Subsoiler	RIPSUBS	77	350	0.25	High	1.10
Rolling Cultivator	ROLLCULT	11	25	0.50	Medium to low	1.025
Generic Zero Tillage	ZEROTILL	4	25	0.05	Low	1.01

The multi-year tillage practices data were prepared by completing: (a) classifying 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) estimating land compositions and their relative proportions in each HRU from the landuse data; (c) calculating average CNOP/CN2 for the HRUs; (d) defining tillage type by choosing the type that covers the largest part of the HRU; (e) assigning tillage date from the defined tillage type, and (f) creating HRU tillage operation attributes using available data and lookup tables. The scheduled tillage parameters for each crop HRU were and were stored in SWAT’s “mgt2” database.

4.7 Tile drain characterization

Subsurface tile drainage is a common agricultural practice found in the Gully Creek watershed. The tile drainage GIS layer was obtained from OMAFRA for the year 2009. Figure 4-3 shows that majority of the crop fields have tile drainage installed.

To simplify SWAT setup and give an extent of known tile drainage, it was assumed that all agricultural land was tile drained in the Gully Creek watershed SWAT modelling. 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 parameters were estimated based on a combination of soil and field slope. The depth to surface drain was assumed to be 900 mm for all tile drains in the watershed. The time to drain soil to field capacity and lag time were assumed to be 24 hours and 1 hour respectively (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 4-8. Tile drainage parameter values for SWAT setup

Soil type	Depth to surface drain (mm)	Time to drain soil to field capacity (hour)	Tile drain lag time (hour)
Huron Clay Loam	900	24	1
Perth Clay Loam	900	24	1
Brady Sandy Loam	900	24	1
Bottom Land	900	24	1
Brookston Clay Loam	900	24	1
Burford Loam	900	24	1

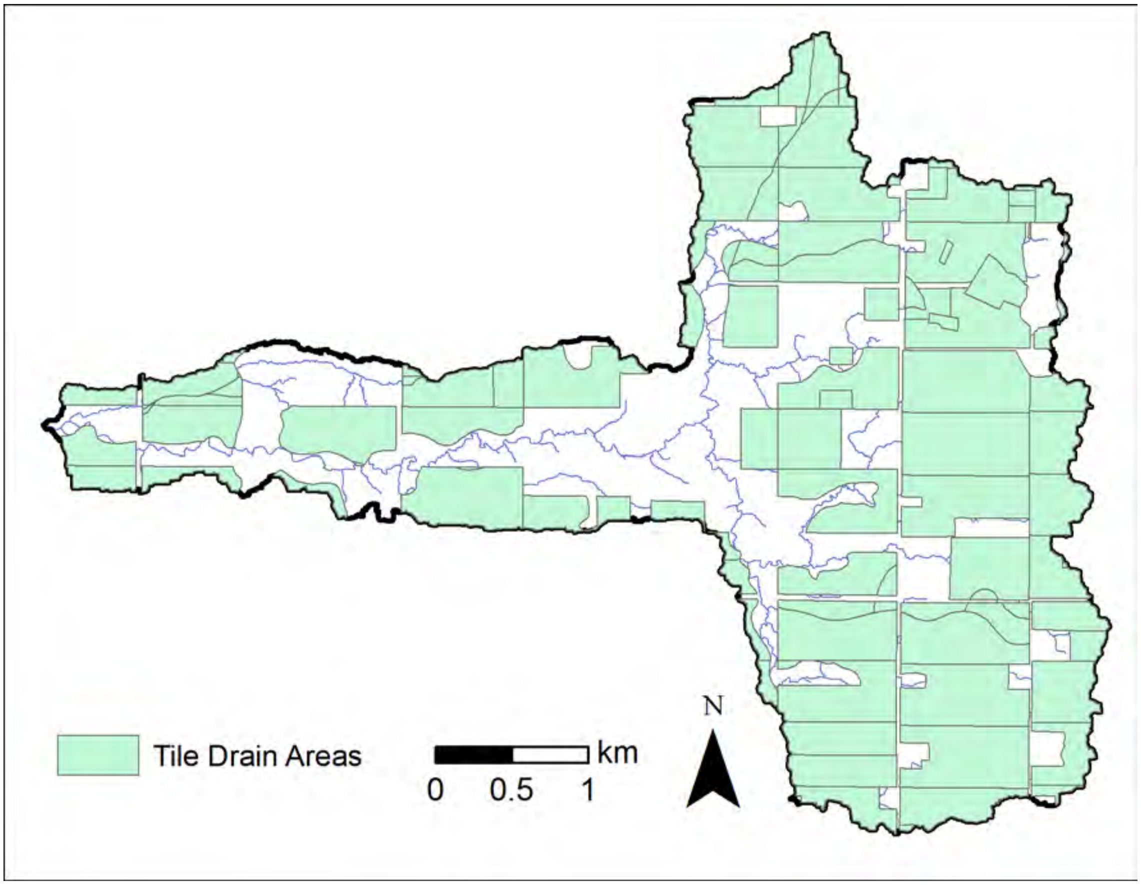

Figure 4-3. Tile-drain distribution in the Gully Creek watershed

5.0 CHARACTERIZATION OF BMPs

In the WBBE program, the SWAT modelling focused on evaluating water quantity and quality effects of four BMPs – conservation tillage, nutrient management planning, fall cover crop establishment, and water and sediment control basins (WASCoBs). In the GLASI program, the SWAT modelling will evaluate these BMPs including conservation tillage, precision nutrient management, cover crop, soil amendments with manure application, windbreak, and WASCoBs.

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 as a conservation tillage method. In the Gully Creek watershed, a mix of conventional and conservation tillage practices were observed. The SWAT modelling for the Gully Creek watershed characterized these existing tillage practices as defined in the SWAT manual including Chisel plow, generic conservation tillage, culti-packer pulverizer, disk plow, field cultivator, harrow, moldboard plow, no tillage done, deep ripper-subsoiler, rolling cultivator, strip tillage, and generic zero tillage (Table 4-7). For conservation tillage, these practices (strip or zero tillage following corn, and no-till following soybeans and wheat) were defined for the cropping system with corresponding tillage parameters (tillage depth, mixing efficiency, and CNOP) in the SWAT model.

5.2 Precision nutrient management

Inputs to the SWAT model for characterizing fertilizer and manure application practices are date of application (month, day, year), fertilizer type (N and P), fertilizer application rate (kg/ha), manure application date, type and rate. Fertilizer and manure data prepared for the 10-year land management dataset in the Gully Creek watershed were used to specify existing nutrient application scenario. The GLASI program implemented precision nutrient management practices including GPS or yield monitor based nutrient applications. In addition to more precisely apply nutrients at specific locations, these practices can ensure no overlapping application swaths and no fertilizer/manure application across field boundaries. In consultation with ABCA and OMAFRA staff, we assumed that the precision nutrient management practices would reduce nutrient application rates by 10%.

5.3 Cover crop

As a BMP, cover crops have the benefit of reducing soil erosion for the period when they are providing vegetative cover, adding organic matter to the soil, reducing nutrient losses, improving soil structure and fertility, and others. There are many different types of cover crops and various opportunities for farmers to establish cover crops depending on their cropping patterns. Crops in the Gully Creek watershed are dominated by a corn, soybean, winter wheat rotation. A red clover, oat or mixed grain cover crop, planted in spring when winter wheat is grown or after wheat harvest, and plowed in late fall or next spring before next crop is the most viable and acceptable cover crop opportunity. To represent cover crop BMP in the SWAT modelling, crop management parameters were modified to characterize the seeding of cover crop after wheat harvest (SWAT does not allow two crops grow in the same field and same period). The cover crop was simulated to remain growing on the field over winter until it was ploughed down in next spring for preparation of next year's crop, and a total of 66 kg/ha of nitrogen (N) was assumed to be reduced from next year's fertilizer application for cover crop scenarios. For the existing scenario, cover crop management data were prepared based on actual information collected from the field.

5.4 Soil amendments with manure application

Manure contains most elements required for plant growth including N, P, potassium, and micronutrients. Soil organic matter is considered nature's signature of a productive soil. Organic carbon from manure provides the energy source for the active, healthy soil microbial environment that both stabilizes nutrient sources and makes those nutrients available to crops. Manure organic matter contributes to improved soil structure, resulting in improved water infiltration and greater water-holding capacity leading to decreased crop water stress, soil erosion, and increased nutrient retention. In addition, organic N is more stable than N applied as commercial fertilizer. A significant fraction of manure N is stored in an organic form that is slowly released as soils warm and as crops require N. Manure N's slow transformation to nitrate is better timed to crop N needs, resulting in less leaching potential (Diacono and Montemurro, 2011; Haynes and Naidu, 1998).

In the GLASI program, soil amendments include livestock manures, approved biosolids and non-agricultural source materials applied under permit. In the Gully Creek watershed, the soil amendments include liquid swine manure and dry dairy manure. In the SWAT model, soil manure amendments can be characterized by manure type, application rate (kg/ha) and application date. To reflect the effect of soil amendment with manure application on increased infiltration and water holding capacity, the CNOP was decreased by 3% after manure application from the current CN2, and the amount of nutrient (OrgN, OrgP, MinN, and MinP) of manure was reduced from next commercial fertilizer application in the soil amendment scenarios.

5.5 Windbreak

Field windbreaks are linear plantings of trees designed to reduce wind speed in open fields at angles to the prevailing wind. Farmstead shelterbelts are windbreaks planted to protect farm buildings and livestock. Windbreaks have benefits on reducing soil wind erosion and increasing crop growth in the farm. In addition, windbreaks can serve as living snow fences that deposit snow on the downwind side, and increasing filed soil moisture in spring (Alemu, 2016).

In the GLASI program, windbreak BMP includes planting of permanent tree windbreaks or seasonal vegetated wind strips. SWAT does not have a function to simulate windbreak effects in terms of wind erosion reduction as SWAT is a hydrologic model for simulating landscape water cycle. However, windbreak can be considered as a vegetative buffer along the field edge and plays a role for water erosion control. This effect is simulated in the Gully Creek SWAT model as a buffer strip. To determine the size and location of these strips, those windbreaks that are located downslope of a field and have flow direction perpendicular to the strip are selected using GIS tools. Parameters (buffer width) associated with a filter strip were then assigned for those crop HRU that are adjacent to the windbreak.

5.6 Water and Sediment Control Basins

Water and Sediment Control Basins (WASCoBs) are commonly implemented in the study area. WASCoBs are intentionally designed to slow down and divert surface storm water to underground tiles, thus reducing ditch, gully, and channel erosion downstream of the structure. They also have effects on increasing groundwater recharge and trapping upstream sediment and nutrients in the ponding area. In the WBBE program, a WASCoB module had been developed in SWAT to simulate water quantity and quality effects of WASCoBs. In the GLASI program, the WASCoB module was further adapted to characterize the complex WASCoB system and drainage network in the Gully Creek watershed. The ABCA monitoring results have demonstrated that for multiple WASCoBs with a common outlet, the WASCoBs at the highest elevation drain first, followed by the WASCoBs at lower elevation, after the higher ones have drained completely.

5.6.1 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. Based on study area's DEM data, a stage-volume (storage) relationship could be developed for the ponding area of each existing or proposed WASCoB berm. SWAT's hydrologic routines can estimate the amount of water draining to the WASCoB pond for a storm event. This volume combined with the stage-volume relationship and data of tile size and gradient can be used to determine the discharge rate out of the WASCoB. Under normal conditions water enters a riser pipe and is conveyed to a downstream channel through the underground tile drain. If the volume of water stored behind the WASCoB's berm exceeds the principal storage volume, water flows overtop of the berm or through an emergency overflow spillway and travels along the original pathway to the downstream main channel. This conceptualization forms a basis for the WASCoB module design in the SWAT model. Modelling of WASCoBs in the Gully Creek watershed consisted of four main steps:

1). Setup each WASCoB as a subbasin outlet during watershed delineation. 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.

2). Develop a stage-storage relationship for the WASCoB's ponding area and a storage-discharge relationship for the tile outlet and the emergency spillway if it exists.

3). Identify the water volume for each WASCoB at which spillway flow or overtopping occurs.

4). Route outflow through the tile-drain and the emergency spillway.

5.6.2 WASCoB Characteristics

Three WASCoB storage volumes are identified in the Gully Creek watershed SWAT modelling including principal storage volume, emergency storage volume, and dead storage. The principal or normal storage volume is the storage volume to the crest of the emergency overflow spillway. The emergency or maximum storage volume is the storage to the top of the WASCoB (berm). The dead storage is the volume of water below the riser inlet slots or holes. These volumes and corresponding surface areas were determined or estimated by ABCA staff using the SWOOP imagery derived DEM. For WASCoBs with no emergency spillway, the maximum volume was set to the normal storage volume. If the dead storage volume was not known, it was assumed to be zero. If the calculated runoff volume from upland field is less than the WASCoB's dead storage, there is no outflow from the structure and all inflow 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 the tile drain pipe. Discharge from WASCoB to the tile-drain is calculated based on the storage-discharge curve of the outlet pipe. If the calculated storage is above the principle storage, pipe outflow is set to its capacity, and spillway flow is estimated using a water balance method, for which 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.

Table 5-1 summarizes the characteristics of all existing and proposed future (*) WASCoBs in the Gully Creek watershed. There are in total 47 berms of which 10 were constructed during the WBBE program, and 3 were constructed during the GLASI program. Berm 45, 46, 47 are proposed future berms while others are existing berms. Four types of berms are differentiated, berm with inlet, berm with tile, berm with Hicken bottom, and berm with drop inlet with different site structures. Volume, Surface area, Discharge, and Capacity in the table denotes the maximum storage, maximum surface area, discharge rate and daily transport capacity of the berm. Because no spillways were specially designed for the berms in the Gully Creek watershed, principle volume and area were set to emergency volume and area, while the dead storage and area was set to zero for all berms in the SWAT modelling. Outlet reach in the table denotes the reach number of tile drain outlet. Berm 32 is a wetland type of berm with no inlet and Hicken bottom installed. Some missing berm parameters in the table were estimated referring to other similar berms with available data. A berm and cluster outlet distribution map in the Gully Creek watershed in shown in Figure 5-1.

Table 5-1. WASCoB characteristics in the Gully Creek watershed

No	Berm ID	Type	Installation year	Subbasin	Drainage area (ha)	Outlet reach	Cluster Outlet ID	Volume (m3)	Surface area (ha)	Discharge (m^3/s)	Capacity (m^3/day)	Program
1	SB2	Berm with inlet	2015	63	3.28	61	OutSD	937	0.331	0.014	1,210	Other
2	AF1	Berm with tile	2012	84	3.09	85	OutVF_M_AF	25.7	0.015	0.020	1,728	Other
3	AF2	Berm with tile	2012	88	2.34	85	OutVF_M_AF	290	0.137	0.020	1,728	Other
4	AF3	Berm with tile	2012	90	2.18	85	OutVF_M_AF	76.4	0.050	0.020	1,728	Other
5	DFTELB3	Berm with Hicken bottom	2012	78	2.85	68	OutVW_DFTEL	488	0.141	0.017	1,469	Other
6	DFTELB5	Berm with Hicken bottom	2012	83	3.49	68	OutVW_DFTEL	1,139	0.333	0.014	1,210	Other
7	DFTELB2	Berm with Hicken bottom	2012	82	2.12	68	OutVW_DFTEL	1,904	0.437	0.017	1,469	Other
8	DFTELB4	Berm with Hicken bottom	2012	76	2.35	68	OutVW_DFTEL	103	0.044	0.017	1,469	Other
9	DFTELB1	Berm with Hicken bottom	2012	79	0.88	68	OutVW_DFTEL	375	0.112	0.014	1,210	Other
10	R2	Berm with Hicken bottom	2003	13	10.70	9	OutR	2,375	0.522	0.016	1,382	Other
11	R1	Berm with Hicken bottom	2003	12	4.18	9	OutR	2,215	0.449	0.016	1,382	Other
12	VBSM2	Berms with tile	2014	55	11.70	58	OutVBSM	4,486	0.862	0.028	2,419	WBBE
13	VBSM1-a	Berms with tile	2014	50	5.97	58	OutVBSM	231	0.129	0.038	3,283	WBBE
14	VBSM3	Berms with tile	2014	48	5.33	58	OutVBSM	2,500	0.637	0.057	4,925	WBBE
15	VBSM2-b	Berms with tile	2014	41	3.39	58	OutVBSM	1,047	0.287	0.062	5,357	WBBE
16	VBSM4	Berms with tile	2014	40	11.90	58	OutVBSM	2,916	0.825	0.095	8,208	WBBE
17	VBSM1-b	Berms with tile	2014	39	14.10	58	OutVBSM	219	0.093	0.059	5,098	WBBE
18	VBSM2-c	Berms with tile	2014	27	10.70	58	OutVBSM	479	0.178	0.045	3,888	WBBE
19	VBSM5	Berms with tile	2014	33	6.64	58	OutVBSM	7,682	1.104	0.300	25,920	WBBE
20	VBSM1	Berms with tile	2014	56	11.70	58	OutVBSM	373	0.133	0.028	2,419	WBBE
21	VBH1	Berm with Hicken bottom	pre-2010	25	5.47	43	OutVBH	708	0.305	0.007	605	Other
22	VBH3	Berm with Hicken bottom	pre-2010	24	25.50	43	OutVBH	909	0.224	0.007	605	Other

23	VBH4	Berm with Hicken bottom	pre-2010	28	15.70	43	OutVBH	229	0.108	0.007	605	Other
24	VBH2	Berm with Hicken bottom	pre-2010	29	2.57	43	OutVBH	3,910	1.110	0.007	605	Other
25	VW3	Berm with Hicken bottom	pre-2010	70	3.06	68	OutVW_DFTEL	192	0.072	0.014	1,210	Other
26	VW2	Berm with Hicken bottom	pre-2010	66	21.00	68	OutVW_DFTEL	220	0.114	0.014	1,210	Other
27	VW1	Berm with Hicken bottom	pre-2010	69	4.37	68	OutVW_DFTEL	91.7	0.064	0.014	1,210	Other
28	VW4	Berm with Hicken bottom	pre-2010	67	3.64	68	OutVW_DFTEL	101	0.099	0.014	1,210	Other
29	VF1	Berm with drop inlet	2009	80	29.20	85	OutVF_M_AF	5,071	1.014	0.060	5,184	Other
30	V2	Berm with Hicken bottom	2005	96	2.29	89	OutV	573	0.188	0.008	691	Other
31	VBSM1-c	Berm with tile	2014	32	1.90	58	OutVBSM	50.0	0.030	0.035	3,024	WBBE
32	P1	Berm with wetland	2010	57	17.70	51	OutP	30.0	0.028	0.000	0	Other
33	V1	Berm with Hicken bottom	2003	92	19.70	89	OutV	13,423	1.361	0.047	4,061	Other
34	VBNB30-1	Berm with Hicken bottom	2015	11	21.00	8	OutVBNB	53.7	0.024	0.016	1,382	GLASI
35	VBNB30-2	Berm with Hicken bottom	2015	10	2.71	8	OutVBNB	225	0.090	0.016	1,382	GLASI
36	VBNB30-3	Berm with Hicken bottom	2012	6	1.52	8	OutVBNB	29.6	0.017	0.016	1,382	Other
37	M1	Berm with Hicken bottom	2016	87	19.80	85	OutVF_M_AF	458	0.080	0.040	3,456	GLASI
38	VBH5	Berm with Hicken bottom	pre-2010	37	4.41	43	OutVBH	247	0.101	0.007	605	Other
39	C1	Berm with Hicken bottom	2015	1	7.20	4	OutC	123	0.047	0.017	1,469	Other
40	VBSB1	Berm with Hicken bottom	2012	18	9.28	31	OutVBSB	791	0.201	0.017	1,469	Other
41	VBSB2	Berm with Hicken bottom	2014	16	7.38	31	OutVBSB	74.5	0.043	0.017	1,469	Other
42	SB1	Berm with inlet	2015	62	10.10	61	OutSD	1,498	0.355	0.014	1,210	Other
43	SB4	Berm with inlet	2016	60	1.59	61	OutSD	24.6	0.018	0.014	1,210	Other
44	SB3	Berm with inlet	2015	64	8.95	61	OutSD	98.0	0.043	0.014	1,210	Other
45*	F1	Berm	2017	22	1.51	31	OutVBSB	40.0	0.031	0.016	1,382	GLASI
46*	F2	Berm	2017	23	5.68	31	OutVBSB	4,280	0.907	0.016	1,382	GLASI
47*	F3	Berm	2017	21	4.04	31	OutVBSB	176	0.107	0.016	1,382	GLASI

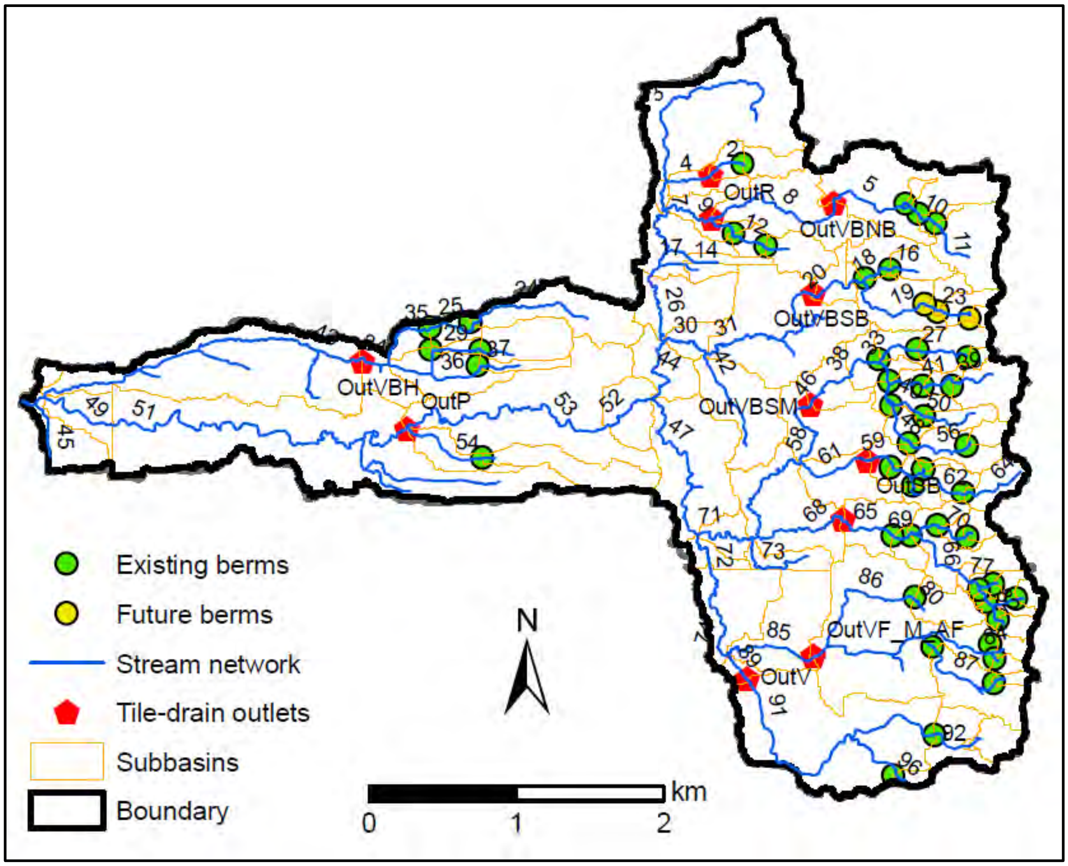

Figure 5-1. Location of WASCoBs and cluster outlets in the Gully Creek Watershed

5.6.3 Area-Storage-Discharge Curves

The stage-storage relationship for each WASCoB in the study area was determined by ABCA staff using a 1-m DEM derived from the 2015 SWOOP imagery. The extent of ponding surface area behind the berm was estimated from contour maps with 15-cm contour interval, beginning with the lowest point in the ponding area and extending to top of the berm. This area-depth information was then used to estimate the volume of pond storage at each elevation increment using the contour stage storage method. Figure 5-2(a) shows the stage-storage relationships for berm B2RT, B3RT and B5RT, and Figure 5-2(b) shows the stage-area relationships for berm B2RT, B3RT and B5RT.

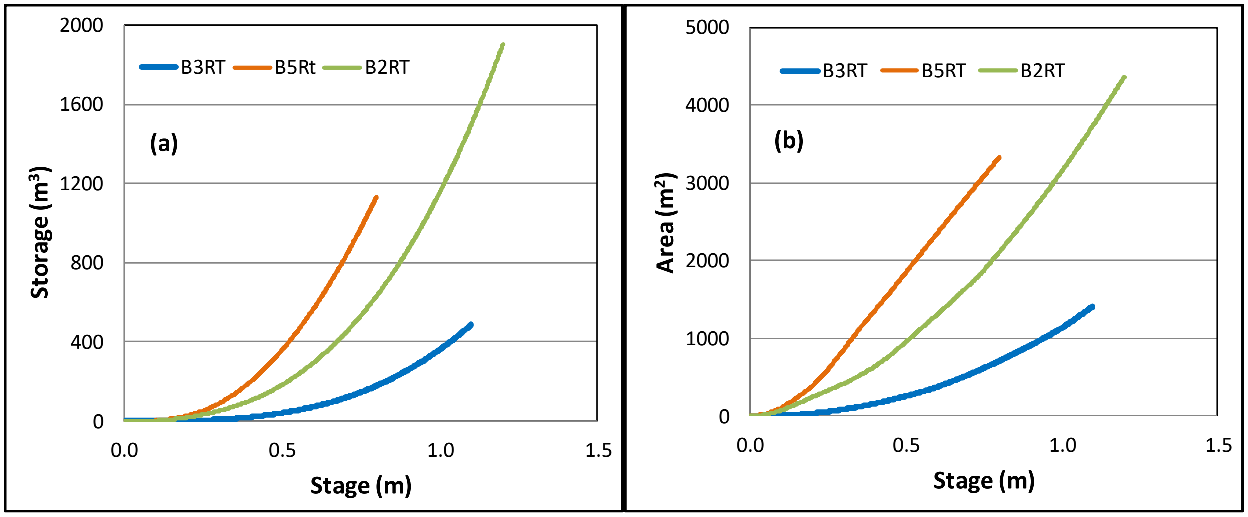

Figure 5-2. (a) Stage-storage relationships for berm B2RT, B3RT and B5RT, and (b) Stage-area relationships for berm B2RT, B3RT and B5RT

Ideally the capacity of tile drain would be greater than the intake capacity of the perforated riser and berm discharge would be a function of the intake capacity of the riser governed by the intake size and pipe gradient. In the WBBE program, berm discharge was estimated following the specifications included in the OMAFRA Publication. 832: Agricultural Erosion Control Structures - A Design and Construction Manual (OMAFA, 2008). This method, however, may likely overestimate outflow from the WASCoB during wet periods when tile drain achieves its capacity before berm intake. Field measurements during the GLASI program showed that for a large snowmelt or a large storm event, discharge of downstream berms in the tile network were typically delayed after emptying upstream berms. The discharge rate measured at the berm monitoring site was nearly a constant close to the berm outlet capacity with discharge time less than one day. The backwater effects of tile drain could be accounted for in subsequent model setups by modifying the discharge curves of each WASCoB based on available information. Because SWAT runs at a daily time step, this process was simplified in the Gully Creek watershed modelling by replacing the stage-discharge curve with the berm discharge capacity (Table 5-1). Combining the stage-area-volume and stage-discharge curves, the volume-area and volume-discharge curves were created for each berm, providing input to the WASCoB module in SWAT. The inflow volume to the WASCoB was obtained from the SWAT reach output upstream of the WASCoB, and average surface area and average discharge of the WASCoB were estimated with the WASCoB module using a mass balance approach.

5.6.4 Flow 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 is broken down into two pathways. The first pathway involves routing the flow from the riser pipe to the main channel through the subsurface tile drain. The second pathway entails routing flow from the emergency spillway or overtop along the SWAT delineated surface flow pathway to the downstream reach. Discharge out of the WASCoB through the tile-drain is routed using the small dam module developed by the Guelph WEG. The small dam module calculates equivalent storage and equivalent discharge based on the storage-discharge rating curve at a daily time step. The transfer function in the SWAT is then used to route this outflow from the WASCoB to the tile-drain outlet (Table 5-2). The tile drain outlet for each WASCoB was determined from field survey and air photo interpretation by ABCA staff. Typically, multiple berms would transfer flow through a same main tile and discharge at a reach in the mainstream. In the SWAT routing configuration, this can be processed by setting a same destination reach (DEST_NUM) in the transport function. The overtop flow is routed along the SWAT delineated overland channel using the SWAT channel routing algorithm.

Table 5-2. Parameters in the SWAT transfer function for WASCoB flow routing

Parameter	Value	Definition
Command	4	Water transfer command
DEP_TYPE	2	Water source type, 2 - reservoir
DEP_NUM	-	Water source number, Berm ID obtained from Table 5-1
DEST_TYPE	1	Destination type, 1 - reach
DEST_NUM	-	Destination number, Reach ID obtained from Table 5-1
TRANS_AMT	-	Daily pipe discharge capacity, obtained from Table 5-1
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 MODEL CALIBRATION AND RESULTS UNDER EXISTING CONDITION

6.1 Calibration and validation strategy

Model calibration is the procedure that adjusts model inputs and parameters to optimize the agreement between measured data and model simulation results, while model validation is the process that demonstrates a given hydrologic model capable of making accurate predictions for periods outside of the calibration period. However, because of the relatively short monitoring period in the Gully Creek watershed, model calibration was conducted at selected stations for the entire monitoring period, while a spatial model validation was conducted at other monitoring stations for the same period (Table 6-1). As management data were from 2008 to 2017, the calibration and validation period was from to 2010 to 2017, which is 5 years longer than that of the SWAT modelling in the WBBE project.

Table 6-1. Flow calibration and validation stations in the Gully Creek watershed

Station	Contribution area (km^2)	Monitoring period	Calibration/ Validation	Description
GULGUL2	12.62	2010-2017	Calibration	Down mainstream close to watershed outlet
GULGUL3	0.86	2011-2017	Validation	Upper tributary
GULGUL4	0.48	2011-2016	Validation	Upper tributary
GULGUL5	10.38	2011-2017	Calibration	Middle mainstream
GULGUL7	2.38	2012-2017	Calibration	Upper tributary
GULGUL8	2.74	2012-2017	Validation	Upper tributary
DFTELB2-HB	-	2016-2017	Calibration	Field, berm site
DFTELB3-HB	-	2016-2017	Validation	Field, berm site
DFTILE1	-	2016-2017	Validation	Field, tile-drain

To make the best use of all available data for improving model performance, a multi-site and multi-objective calibration strategy was conducted in this study. There are in total nine flow monitoring stations including two main stream stations, 4 tributary stations, and 3 field stations (Table 6-1). Model calibration was performed for station GULGUL2, GULGUL5, GULGUL7, and DFTELB2-HB1, while validation for other five stations for the same period. A simulation period of 2001-2017 was used for model calibration while the first nigh years (2001-2009) were used for model warming-up to eliminate the effect of initial parameter values on model outputs. This simulation period was also used for evaluating BMP scenarios after model calibration and validation. Flow calibration focused on daily predictions. There are a total of 26 water quality sampling stations in the Gully Creek watershed. Calibration of sediment and nutrient loadings focused on point predictions rather than continuous predictions because of limited water quality samples at the sampling sites. The Gully Creek SWAT model was manually calibrated using the iSWAT interface (Yang et al., 2006) and the SWAT-CUP software (Abbaspour, 2013). The iSWAT and SWAT-CUP have a generic format that allows parameter aggregation based on HRU, soil, land use, 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 with SWAT-CUP and SWAT user manual recommendations. Other parameters were set to their default values and were not adjusted during the process of model calibration.

Table 6-2. General SWAT setup for the Gully Creek watershed

Rainfall distribution for MUSLE	Skewed normal
PET method	Priestley-Taylor method
Rainfall/Runoff/Routing	Daily Rain/SCS CN Method/Daily
Crack flow	Not active
Surface runoff	SCS CN
Soil erosion	MYSLE
Algae/CBOD/Dissolved Oxygen	Active
Channel routing method	Variable storage
Channel dimensions	Active
In-stream water quality	Active
Elevation bands	Active
Snow redistribution	Active
Frozen soil	Active
Rain-on-snow	Active

The general SWAT setup for the Gully Creek watershed is provided in Table 6-2. 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 Priestley-Taylor method. Surface runoff is simulated using the SCS CN method and the flow is routed in the channel using the variable storage method. Four elevation bands were created in each subbasin to account for uneven distribution of rainfall and snowfall with elevations. In particular, modules of snow redistribution, frozen soil, and rain-on-snow developed for CanSWAT (Liu et al., 2016) were updated to the SWAT2012 for the Gully Creek watershed SWAT modelling.

For flow calibration and validation, model performance was evaluated graphically and statistically based on model bias, Nash–Suttcliffe coefficient (NSC), and correlation coefficient (CORR). 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.

$$Bias = \sum_{i=1}^{N} Qs_i \Big/ \sum_{i=1}^{N} Qo_i - 1 \tag{6-1}$$

where Bias is the 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. 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 (Nash and Sutcliffe, 1970) describes how well the stream flows are simulated by the model which is commonly used for model evaluation.

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

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 that predicted by the model. A perfect model prediction has NSC value of 1. The correlation coefficient is defined as the mean product of the paired standardized scores and can be expressed as Equation (6-3), where CORR is the correlation coefficient, $\overline{LS}$ is the mean of simulated values. A higher CORR indicates a higher correlation between observed and simulated values.

$$CORR = \frac{\sum_{i-1}^{n}\left(LS_i - \overline{LS}\right)\left(LO_i - \overline{LO}\right)}{\sqrt{\sum_{i-1}^{n}\left(LS_i - \overline{LS}\right)^2 \sum_{i-1}^{n}\left(LO_i - \overline{LO}\right)^2}} \tag{6-3}$$

The calibration objective for flow was to maximize NSC and CORR coefficient while simultaneously attempting to reduce model bias. Calibration of sediment, total phosphorous (TP), and total nitrogen (TN) were conducted for their loadings on sampling days and at different stations. Measured sediment loading was calculated by multiplying observed sediment concentration by observed flow of the day. Measured TP and TN loadings were calculated by multiplying sampled TP and TN concentrations by observed flow of the day. In the SWAT modelling output, TP was calculated by summing mineral phosphorous (MinP) and organic phosphorous (OrgP), and TN was calculated by summing mineral nitrogen (MinN) and organic nitrogen (OrgN), both with a unit of kg/day. The model was calibrated firstly for stream flow, then sediment, and finally TP and TN at different monitoring stations.

6.2 Flow Calibration

Flow calibration in this study focused on improving model performance at nigh flow monitoring stations. 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. 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 different monitoring stations 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 comparison of observed and simulated daily stream flow at GULGUL2 for the simulation years of July 12, 2010 – April 30, 2017 is shown in Figure 6-1. The comparisons of observed and simulated daily stream flow at GULGUL5 and GULGUL7 for the simulation years of July 15, 2010 – April 30, 2012 are shown in Figure 6-2 and Figure 6-3. The evaluation results summarized in Table 6-4 show that SWAT reproduced flow at the nigh flow monitoring stations reasonably very for the simulation period.

Table 6-3. Calibrated water balance and flow routing parameters for the Gully Creek watershed SWAT modelling

Parameter	Definition	File	Value	Sensitivity
SFTMP	Snowfall temperature (°C)	bsn	2.50	Moderate
SMTMP	Snowmelt base temperature (°C)	bsn	-1.50	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	4.50	High
TIMP	Snow pack temperature lag factor	bsn	1.00	Moderate
CN2	Initial SCS curve number for moisture condition II	mgt	0.0*	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	0.0*	High
CANMX	Maximum canopy storage (mm)	hru	3.00	Moderate
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	gw	0.0	Moderate
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	0.00	Moderate
SOL_ALB	Moist soil albedo	sol	0.0*	Moderate
CH_K2	Channel hydraulic conductivity (mm/hr)	rte	0.0	High
BIO_MIX	Biological mixing efficiency	mgt	0.20	Moderate
EPCO	Plant uptake compensation factor	hru	0.05	Moderate
SURLAG	Surface runoff lag time (days)	bsn	0.35	High

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

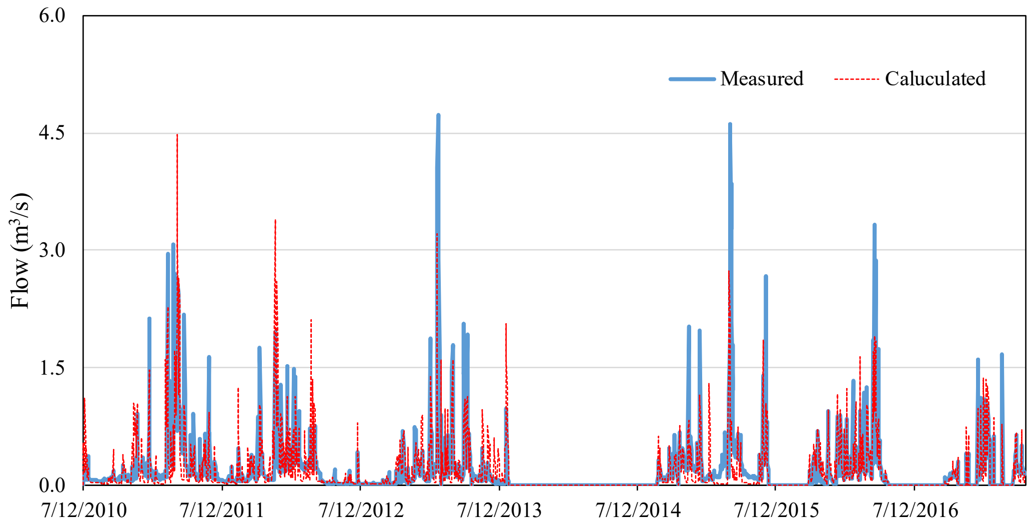

Figure 6-1. Daily flow calibration at GULGUL2

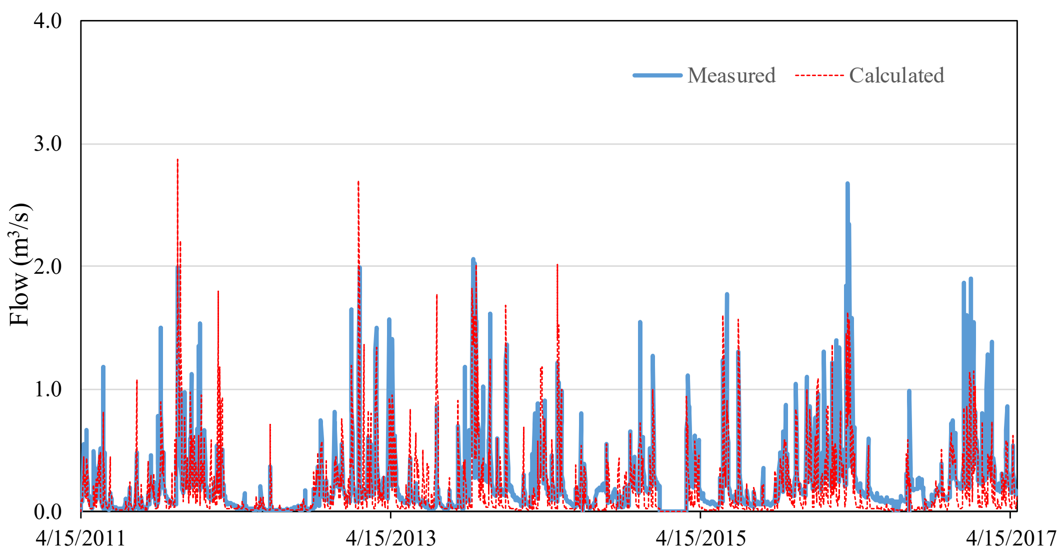

Figure 6-2. Daily flow calibration at GULGUL5

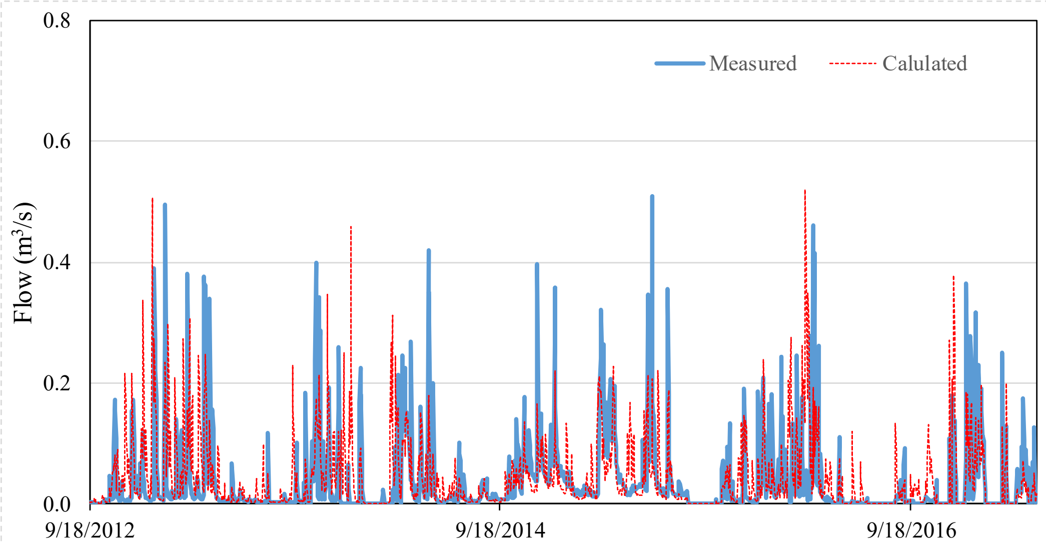

Figure 6-3. Daily flow calibration at GULGUL7

Table 6-4. Model performance for flow simulation at the nigh monitoring stations

Station	Period	Bias	R^2	Daily NSC	Monthly NSC
GULGUL2	2010-2017	0.03	0.88	0.42	0.76
GULGUL3	2011-2017	0.18	0.97	0.16	0.58
GULGUL4	2011-2016	-0.19	0.96	0.33	0.62
GULGUL5	2011-2017	-0.14	0.62	0.52	0.71
GULGUL7	2012-2017	-0.13	0.56	0.36	0.67
GULGUL8	2012-2017	0.26	0.85	0.29	0.74
DFTELB2-HB	2016-2017	0.15	0.51	0.17	0.60
DFTELB3-HB	2016-2017	0.32	0.42	0.22	0.51
DFTILE1	2016-2017	-0.23	0.47	0.08	0.42

Flow data from August 2013 to August 2014 was missing at GULGUL2. This period was not included in flow calibration for GULGUL2. Model biases at GULGUL2 for the period 7/12/2010-4/30/2017 are 0.03, R^2 (correlation coefficient) is 0.88, Daily NSC is 0.42, and monthly NSC is 0.76. In general, model performances at main stream stations were higher than field stations, and monthly NSCs were higher than daily NSCs. Given the uncertainties of stream flows at monitoring stations, SWAT performed reasonably well over the simulation period. The model captured the rising and recessing patterns exhibited by the computed stream flows. The model underestimated peak flows for three extreme floods, 1/31/2013, 3/14/2015, and 3/31/2016 at GULGUL2 indicating an improvement of the model for simulating extreme floods under winter and spring conditions is required. Overall, the SWAT-simulated stream flows at the nigh flow monitoring stations matched the measured flows reasonably well in term of magnitude, peak time, and flow volume.

6.3 Sediment Calibration

Grab samples were available at 26 sampling stations in the Gully Creek watershed (Table 3-3). These data were used to calibrate the SWAT sediment loading and transport parameters. Among these stations, nigh of them have flow monitoring data, which can be used for comparing sediment loadings over the simulation period. Concentration data at other non-flow monitoring station were also used in the model calibration for comparing measured and simulated sediment concentrations. The calibration was done manually by comparing the simulated sediment load/concentration to the measured load/concentration. 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 (Table 6-5). Special attention was given to the calibration for high flow periods during which large sediment load was produced. The final SWAT sediment parameter values after model calibration are listed in Table 6-5. The comparison of observed and simulated daily sediment loads at GULGUL2 for the simulation period of July 2010 to April 2017 is shown in Figure 6-4. Comparisons of observed and simulated daily sediment loads at GULGUL5 and GULGUL7 are given in Figure 6-5 and Figure 6-6 respectively. The results of statistical model performance for the nigh sediment sampling stations with flow measurements over the simulation period are provided in Table 6-6. A comparison between measured and simulated sediment concentrations at other field stations is provided in Figure 6-7.

Table 6-5. Sediment parameters for the Gully Creek watershed SWAT modelling

Parameter	Definition	File	Value	Sensitivity
SLSSUBBSN	Average slope length	hru	-0.10*	Moderate
SLOPE	Average slope steepness	hru	-0.10*	Moderate
USLE_K	USLE soil erodibility factor	sol	-0.20*	High
USLE_C	Minimum USLE crop factor	crp	0.00*	Moderate
USLE_P	USLE support practice factor	mgt	-0.60*	High
SPCON	Linear parameter for sediment channel routing	bsn	0.005	High
SPEXP	Exponent parameter for sediment channel routing	rte	1.8	High
PRF	Mainstream peak rate adjustment factor	bsn	2.00	High
CH_EROD	Channel erodibility factor	rte	0.15	High
CH_COV	Channel cover factor	rte	1.0	Moderate
CH_N2	Channel roughness coefficient	rte	0.024	Moderate
CH_W2	Bankful channel width	rte	-0.20*	Moderate
CH_S2	Channel slope	rte	0.00*	High
VCRIT	Critical flow velocity	rte	1.5	High

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

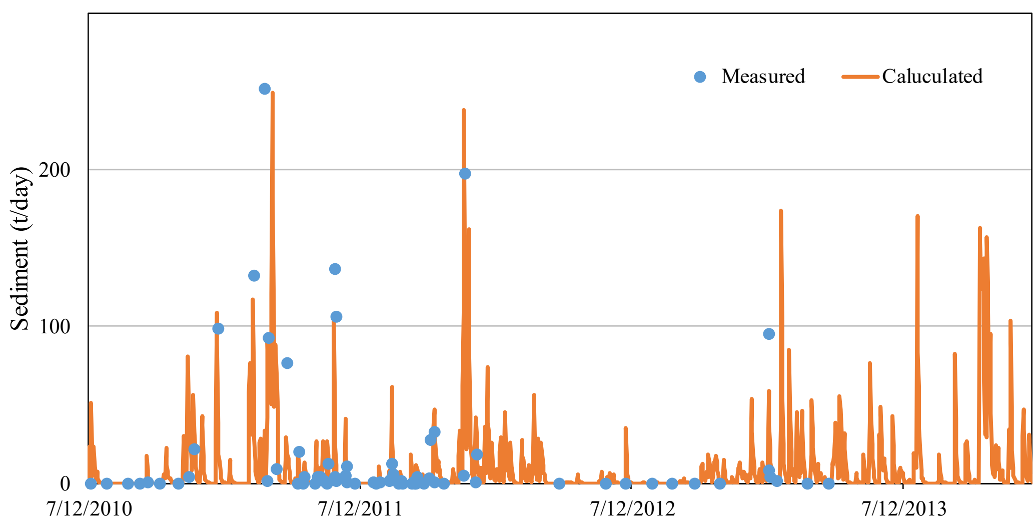

Figure 6-4. Measured and simulated sediment loadings at the GULGUL2 station

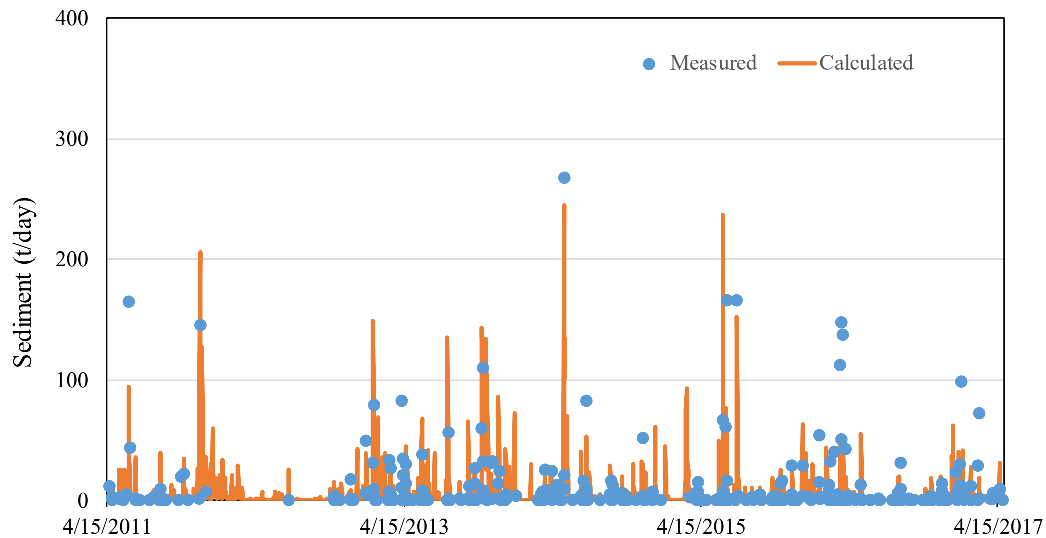

Figure 6-5. Measured and simulated sediment loadings at the GULGUL5 station

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

Station	Period	Samples	Bias	NSC	R^2
GULGUL2	2010-2017	119	0.15	0.54	0.98
GULGUL3	2011-2017	46	-0.24	0.42	0.67
GULGUL4	2011-2016	21	0.31	0.11	0.73
GULGUL5	2011-2017	377	0.19	0.27	0.91
GULGUL7	2012-2017	63	-0.23	-1.60	0.32
GULGUL8	2012-2017	19	0.48	-0.46	0.57
DFTELB2-HB	2016-2017	40	0.08	0.18	0.64
DFTELB3-HB	2016-2017	23	0.30	-2.50	0.55
DFTILE1	2016-2017	147	-0.11	0.34	0.36

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 R^2 values compared to other tributary and field stations. In addition, the NSC values calculated for global sediment data at stations GULGUL2 and GULGUL3 were higher than values calculated for grab sediment data at other stations. This indicates that the grab sampling data may over-estimate or under-estimate the daily average sediment loading compared to a global sampling methodology. NSC values at station

GULGUL7, GULGUL8, and DFTELB3-HB were negative indication sediment loadings were not well simulated at these stations. Overall, the sediment load predictions appear to agree with the measurements at the two mainstream and other four tributary and field stations. The model gives a better performance at the two mainstream stations compared to other tributary and field stations. These sediment parameters were applied to evaluate sediment loadings for various BMP scenarios.

6.4 Nutrients Calibration

Phosphorus and nitrogen are two major nutrients that are essential for plant growth and crop production, and are therefore selected for model simulation in the Gully Creek GLASI program. 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.

6.4.1 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 model 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 outputs. MINP is the sum of active mineral P and solution P, while ORGP is the sum of stable mineral P, active organic P, stable organic P, and fresh organic P. SWAT assumes that all these forms of P are attached to sediment particles when entering the stream except for solution P. 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. SOL_SOLP was set to 30 mg/kg referring to soil-P test data in the Gully Creek watershed. The phosphorus available index (PSP) governs the equilibration of soil P between the solution and active pool and controls the initial mineral P level in the soil. This parameter was set to 0.45 after model calibration. The parameters of PPERCO and PHOSKD were set to 12 and 140 after model calibration. P_UPDIS and GWSOLP were kept to their default parameter values as they are less sensitive to the modelling result. The final SWAT P parameter values after model calibration are listed in Table 6-7.

Table 6-7. Phosphorus parameters for the Gully Creek watershed SWAT modelling

Parameter	Definition	File	Value	Sensitivity
SOL_SOLP	Initial soluble P concentration in the soil layer (mg/kg)	chm	30	High
SOL_ORGP	Initial organic P concentration in the soil layer (mg/kg)	chm	30	High
PSP	Phosphorus availability index	bsn	0.45	High
ERORGP	Organic P enrichment ratio	hru	2.0	High
PPERCO	Phosphorus percolation coefficient	bsn	15	High
PHOSKD	Phosphorus soil partitioning coefficient	bsn	140	Moderate
P_UPDIS	Phosphorous uptake distribution parameter	bsn	10	Moderate
GWSOLP	Concentration of soluble P in groundwater (ppm)	gw	0.003	Moderate

The calibration of P was conducted by comparing simulated P loading with in-site measurements at monitoring stations. These data included grab, ISCO, and global sampling data at different monitoring stations. 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 loads at GULGUL2 for the simulation period of July 2010 to January 2013 is shown in Figure 6-6. Comparisons of observed and simulated daily TP loads at GULGUL5 for the simulation period of April 2011 to April 2017 are given in Figure 6-7, The results of statistical model performance on PP, DP, and TP for the nigh monitoring stations with flow measurement over the simulation period are provided in Table 6-8.

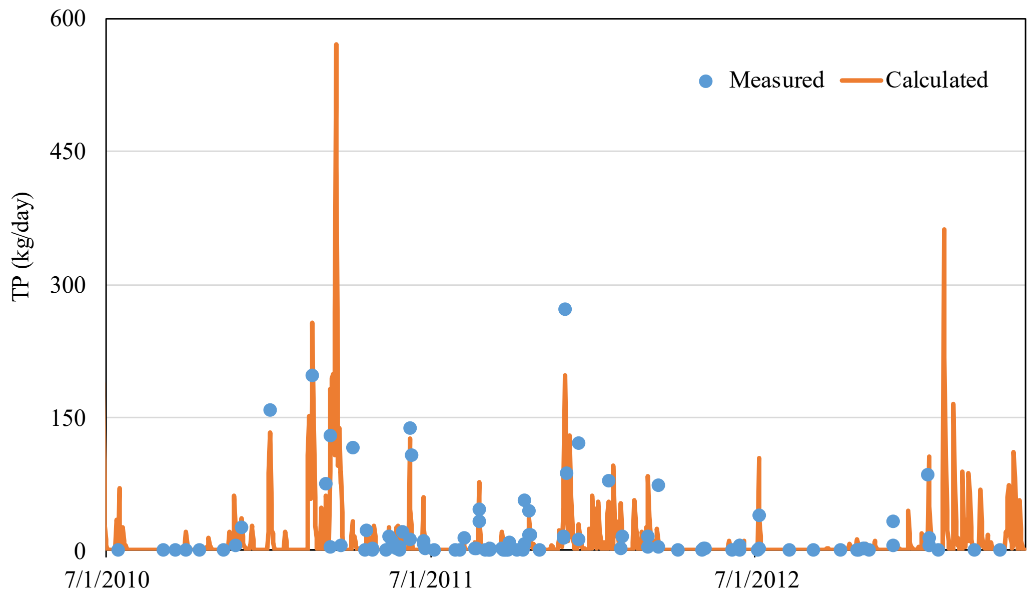

Figure 6-6. Measured and simulated TP loadings at the GULGUL2 station

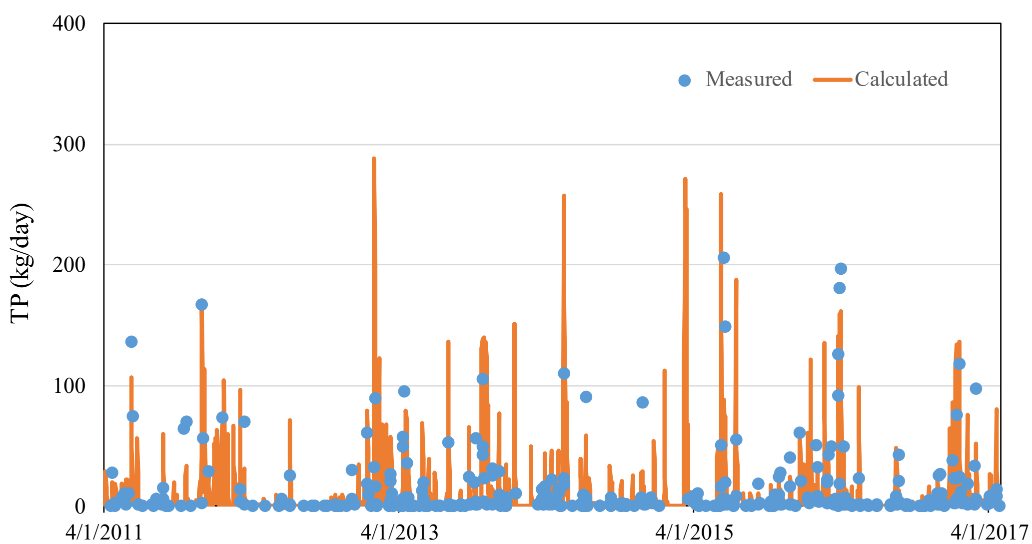

Figure 6-7. Measured and simulated TP loadings at the GULGUL5 station

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

			PP			DP			TP		
Station	Period	N	Bias	NSC	R^2	Bias	NSC	R^2	Bias	NSC	R^2
GULGUL2	2010-2017	142	0.02	0.54	0.72	0.03	0.38	0.85	0.12	0.62	0.45
GULGUL3	2011-2017	45	-0.18	0.45	0.87	-0.10	0.62	0.66	-0.14	0.60	0.84
GULGUL4	2011-2016	21	-0.24	0.36	0.75	-0.33	-0.68	0.41	-0.28	0.21	0.78
GULGUL5	2011-2017	391	0.25	0.52	0.88	-0.13	0.39	0.82	0.18	0.51	0.86
GULGUL7	2012-2017	62	-0.22	-2.37	0.44	-0.18	0.07	0.15	-0.23	-2.54	0.40
GULGUL8	2012-2017	20	0.45	-1.38	0.31	0.33	0.12	0.33	0.39	-1.59	0.81
DFTELB2-HB	2016-2017	41	0.10	0.21	0.52	-0.02	0.35	0.69	0.05	0.26	0.50
DFTELB3-HB	2016-2017	23	0.26	0.32	0.65	0.17	0.27	0.44	0.21	0.31	0.56
DFTILE1	2016-2017	148	-0.44	-1.39	0.25	-0.53	-2.63	0.14	-0.51	-2.65	0.26

Similar to the result of sediment calibration, the predicted daily discharge has a greater impact on predicted TP, PP, and DP loadings. As demonstrated in Table 6-8, the two mainstream stations GULGUL2 and GULGUL5 have higher R^2 values compared to other tributary and field stations. In addition, The NSC values calculated with global P data at GULGUL2 and GULGUL3 were higher than values calculated for grab and ISCO P data at other stations. This indicates that the grab and ISCO sampling data might over or under estimate the daily average P loading compared to global sampling data. Negative TP NSC values were calculated at station GULGUL7, GULGUL8, DFTILE1 indicating TP loadings were poorly simulated at these stations. Overall, the TP, PP, and DP load predictions appear to agree with the measurements at the nigh monitoring stations with flow data as demonstrated in the above figures and the statistical results. The model performed better at the two mainstream stations compared to other tributary and field stations. These P parameters were applied to evaluate PP, DP, and TP loadings for various BMP scenarios.

6.4.2 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.

Ten SWAT N 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 55 and 75 mg/kg respectively in the soil after model calibration. 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 0.35 from the default value of 0.20. 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 3.0, 10, 1.4, and 1.0 respectively as listed in Table 6-9.

Table 6-9. Nitrogen parameters for the Gully Creek watershed SWAT modelling

Parameter	Definition	File	Value	Sensitivity
SOL_NO3	Initial NO3 concentration in the soil layer (mg/kg)	chm	55	High
SOL_ORGN	Initial organic N concentration in the soil layer (mg/kg)	chm	75	High
NPERCO	Nitrogen percolation coefficient	bsn	0.35	High
ERORGN	Organic N enrichment ratio	hru	3.0	High
N_UPDIS	Nitrogen uptake distribution parameter	bsn	20	Moderate
CMN	Rate factor for humus mineralization	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	1.0	Moderate

The calibration of N was conducted by comparing the simulated N load with in-situ measurements at sampling stations. 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 loadings at GULGUL2 for the simulation period of July 2010 to April 2013 is shown in Figure 6-8. Comparison of observed and simulated daily TN loads at GULGUL5 for the simulation period of April 2011to April 2017 is given in Figure 6-9, The results of statistical model performance on PN, DM, and TN for the nigh monitoring stations with measured flow data over the simulation period are provided in Table 6-10.

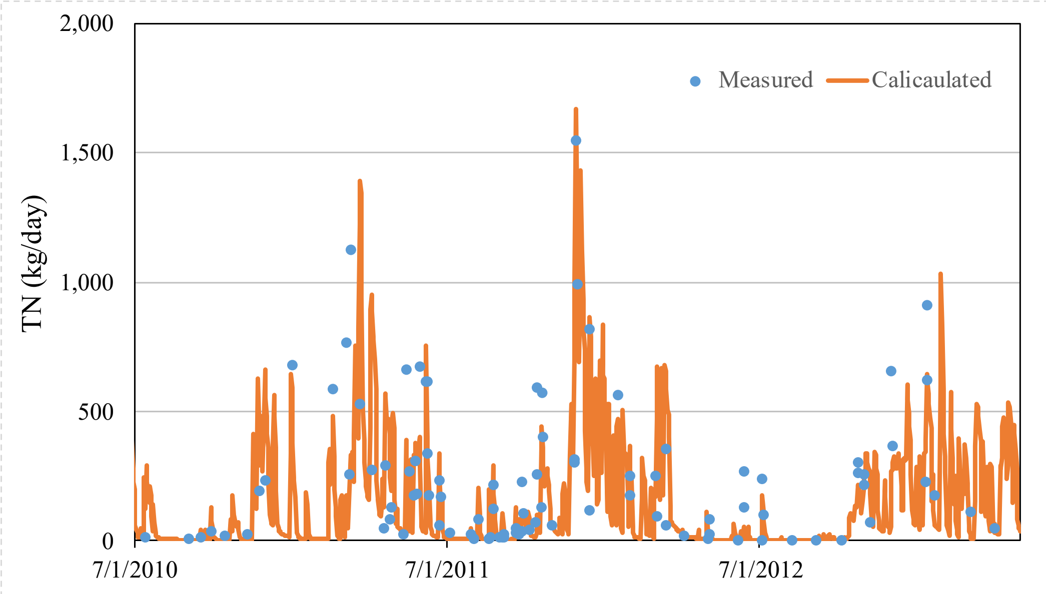

Figure 6-8. Measured and simulated TN loadings at the GULGUL2 station

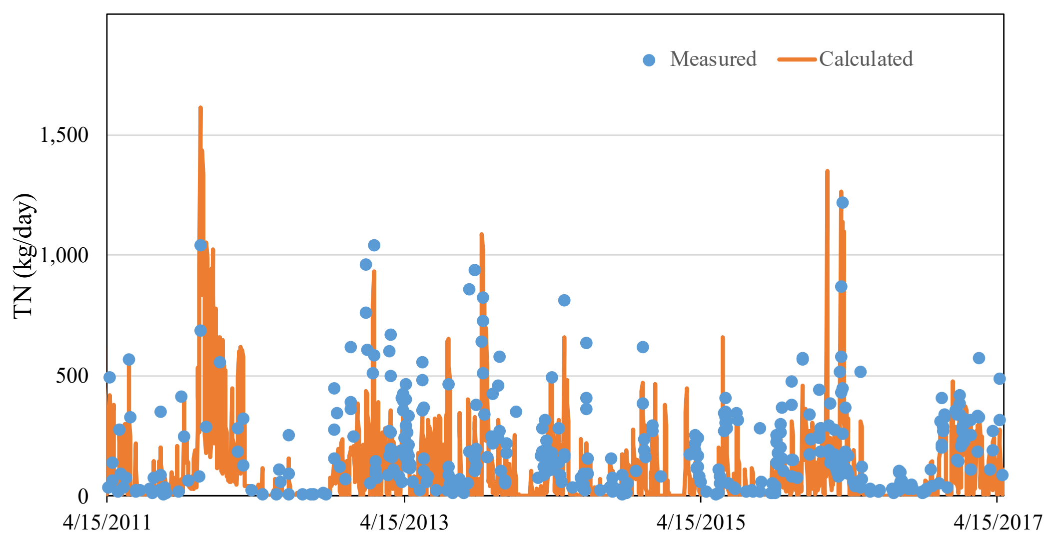

Figure 6-9. Measured and simulated TN loadings at the GULGUL5 station

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

			PN			DN			TN		
Station	Period	N	Bias	NSC	R^2	Bias	NSC	R^2	Bias	NSC	R^2
GULGUL2	2010-2017	142	0.03	0.43	0.58	0.02	0.36	0.68	0.12	0.42	0.88
GULGUL3	2011-2017	39	0.25	0.42	0.64	0.16	0.34	0.56	0.23	0.39	0.87
GULGUL4	2011-2016	51	0.19	0.09	0.36	0.34	-1.51	0.44	0.26	-1.06	0.69
GULGUL5	2011-2017	390	-0.14	0.35	0.46	0.18	0.38	0.97	0.05	0.37	0.92
GULGUL7	2012-2017	62	-0.13	0.26	0.65	-0.06	0.43	0.78	-0.07	0.35	0.79
GULGUL8	2012-2017	20	-0.11	0.41	0.72	-0.22	0.52	0.68	-0.16	0.49	0.79
DFTELB2-HB	2016-2017	41	0.41	-2.35	0.29	0.33	-3.21	0.25	0.36	-1.56	0.31
DFTELB3-HB	2016-2017	23	0.26	-1.31	0.43	0.21	0.12	0.38	0.25	0.15	0.45
DFTILE1	2016-2017	147	-0.22	-3.65	0.21	-0.33	0.17	0.41	-0.28	-2.35	0.34

Similar to the result of P calibration, the predicted daily discharge has a greater impact on predicted PN, DN, and TN loadings. As demonstrated in Table 6-10, the two mainstream stations GULGUL2 and GULGUL5 have higher R^2 values compared to other tributary and field stations. In addition, the NSC values calculated for global N data at station GULGUL2 and GULGUL3 were higher than those of other stations with grab and ISCO sampling data. This indicates that the grab and ISCO sampling data might over or under estimated the daily average N loadings compared to global sampling data. Negative TN NSC values were calculated at station GULGUL4, DFTELB2-HB, and DFTILE1O indicating TN loadings were not well simulated at these stations. Overall, the PN, DN, and TN load predictions appeared to agree with the measurements at the nigh monitoring stations with measured flow data as demonstrated in the above figures and the statistical results. The model performed better at the two mainstream stations compared to other tributary and field stations. These N parameters were applied to evaluate PN, DN, and TN loadings for various BMP scenarios.

6.5 SWAT modelling results under existing conditions

With model parameters calibrated against available measurement data, the SWAT was run for the period 2002-2016 under existing climate and land management conditions. The average monthly precipitation (P), snow (SNOW), and simulated potential evapotranspiration (PET), actual evapotranspiration (ET), surface runoff (SR), subsurface runoff including tile flow (SUBSR), total runoff (TR), and sediment yield (SED) before streams are listed in Table 6-11. A graphic presentation of the simulated average monthly variation of precipitation, actual evapotranspiration, and runoff in the Gully Creek watershed over the period 2002-2016 under existing condition is given in Figure 6-10. A graphic presentation of the simulated average monthly surface runoff, subsurface runoff, total runoff, and sediment yield at the Gully Creek watershed outlet over the period 2002-2016 under existing condition is shown in Figure 6-11.

Table 6-11. Simulated average monthly and yearly water balance and sediment yield before streams over the period 2002-2016 under existing condition

Month	P (mm)	SNOW (mm)	PET (mm)	ET (mm)	SR (mm)	SUBSR (mm)	TR (mm)	SED (t/ha)
1	76.3	58.2	0.76	0.65	34.2	20.41	54.6	0.14
2	68.2	63.1	3.13	2.68	57.1	9.02	66.1	0.29
3	74.7	44.5	26.4	19.5	58.8	47.82	106.6	0.25
4	75.1	15.0	57.5	35.5	18.5	37.68	56.1	0.10
5	88.5	0.0	84.7	48.2	22.2	21.86	44.0	0.27
6	85.3	0.0	106.0	58.6	19.1	14.33	33.4	0.21
7	94.2	0.2	111.2	64.7	18.8	11.44	30.2	0.14
8	76.4	0.0	100.2	61.6	17.1	9.09	26.2	0.09
9	90.6	0.0	70.1	46.1	16.1	8.99	25.1	0.08
10	99.5	15.4	29.8	20.5	21.0	26.30	47.3	0.13
11	82.9	22.4	4.84	3.73	30.6	39.63	70.2	0.21
12	90.9	67.7	0.08	0.07	50.2	30.38	80.6	0.34
Year	1,002	286	595	362	363	277	640	2.25
%	100	28.6	59.3	36.1	36.3	27.6	63.9	

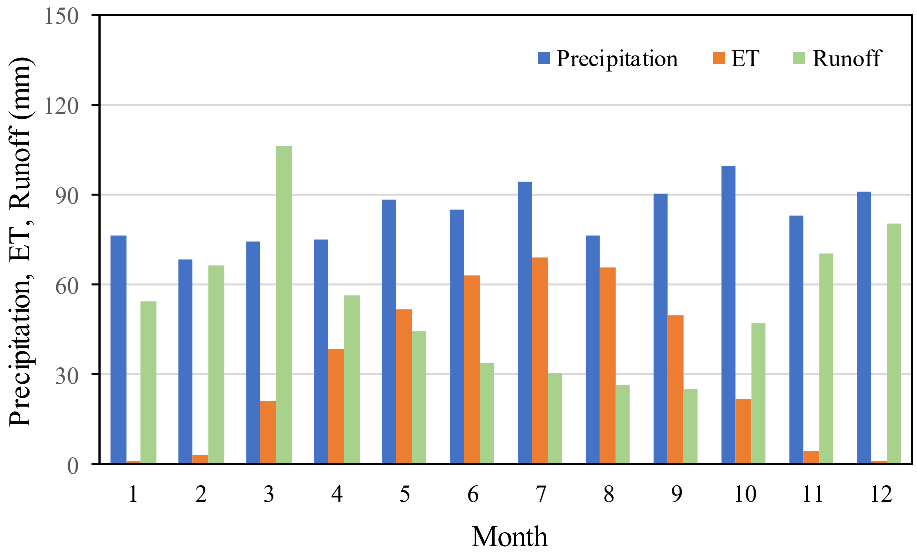

Figure 6-10. Simulated average monthly precipitation, ET, and runoff in the Gully Creek watershed over the period 2002-2016 under existing condition

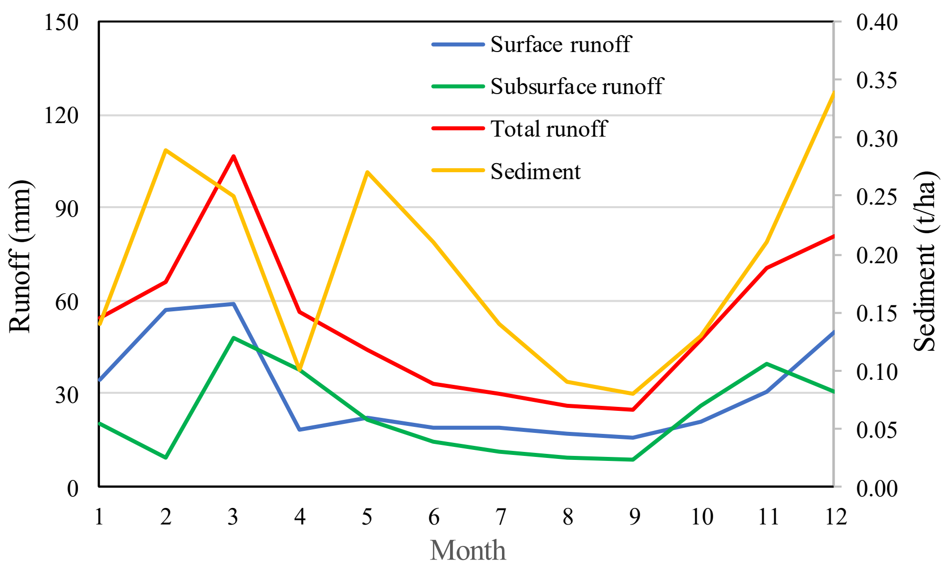

Figure 6-11. Simulated average monthly surface runoff, subsurface runoff, total runoff, and sediment yield at the Gully Creek watershed outlet over the period 2002-2016 under existing condition

The calculated average annual precipitation in the watershed is 1,002 mm, of which 286 mm (28.6%) is snow occurring from late October to early April. The total calculated average annual

PET is 595 mm, while the actual average annual evapotranspiration is 362 mm and is 36.1% of the annual precipitation. The calculated total average annual runoff is 640 mm (63.9%) of which 363 mm (36.3%) is from land surface and 277 mm (27.6%) is from subsurface including tile flow (188 mm), interflow (45 mm) and groundwater flow (44 mm). 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 occurs in winter and spring due to the winter rainfall and snowmelt. Peak monthly surface runoff, subsurface runoff, and total runoff occur in March because of winter rainfall and snowmelt. Both surface runoff and subsurface runoff are lower in summer period because of the high evapotranspiration (Figure 6-12) and low soil moisture. The yearly water yield exhibits considerable spatial variations, with higher water yield above average in most of the crop fields in upper watershed and lower than average in the middle to lower reach forest areas (Figure 6-12).

The calculated sediment yield before streams is 2.25 t/ha for the watershed, of which high erosion occurs in March and February because of winter flooding and in May because of extreme storm event. Sediment yield from overland is relatively small from June to November because of low rate of surface runoff. Majority of cropland area has annual sediment yield above 1.75 t/ha in upper area of the watershed (Figure 6-13). The lower sediment yield in the middle to lower reach area is associated with gentle slope and more vegetation cover, while the higher sediment yield in upper part of the watershed is closely related with higher slope and crop production. The simulated average annual total sediment load at the watershed outlet is 4,059 tons (2.80 t/ha), of which 3,262 tons (2.25 t/ha) are from overland erosion and 797 tons are from channel erosion. The average overland erosion rate is calculated by the estimated sediment yield before streams divided by the watershed area, while the average channel erosion rate is calculated by the total sediment load minus overland sediment load. The average channel and ditch erosion has significant variations ranging from 3.0 t/km to 120 t/km for some segments with high slopes (Figure 6-14). The simulated average annual sediment and nutrient yield at watershed outlet over the period 2002-2016 under existing condition is presented in Table 6-12.

Table 6-12. Simulated average yearly sediment and nutrient yield at watershed outlet over the period 2002-2016 under existing condition

Overland erosion	3,262 t	2.25 t/ha	80.0 %
Channel erosion	797 t	17.4 t/km	20.0 %
Sediment	4,059 t	2.80 t/ha	100 %
OrgP	2,397 kg	1.65 kg/ha	66.4 %
MinP	1,211 kg	0.83 kg/ha	33.6 %
TP	3,608 kg	2.48 kg/ha	100 %
OrgN	8,770 kg	6.10 kg/ha	14.7 %
MinN	51,562 kg	35.5 kg/ha	85.3 %
TN	60,333 kg	41.6 kg/ha	100 %

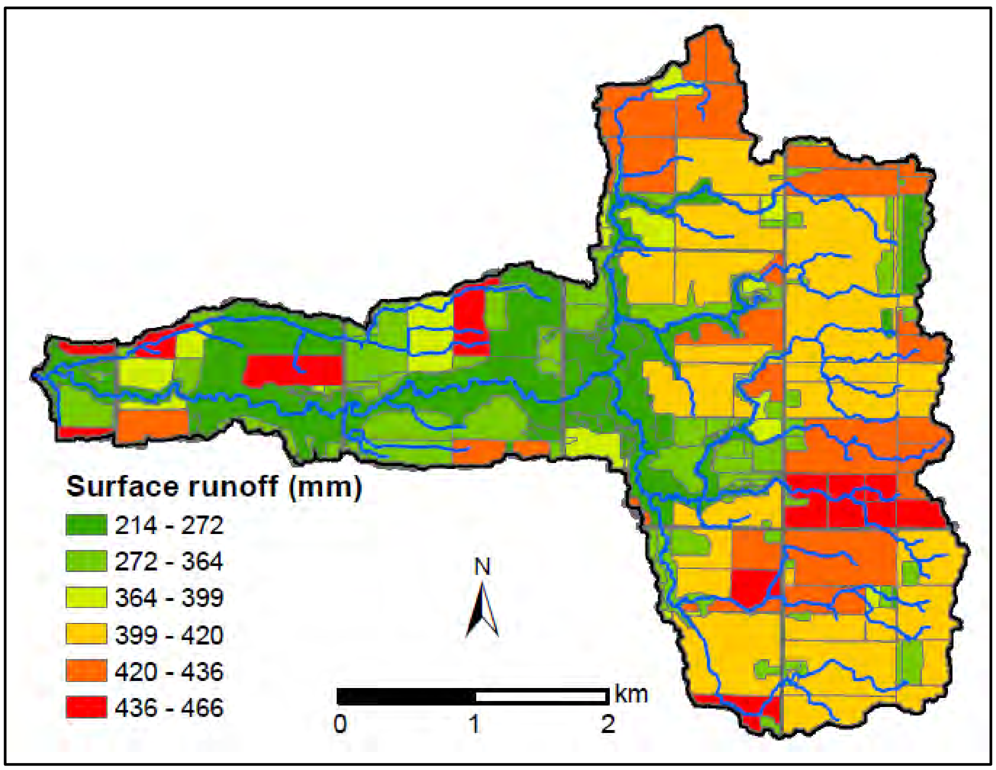

Figure 6-12. Simulated average yearly surface runoff distribution in the Gully Creek watershed under existing condition

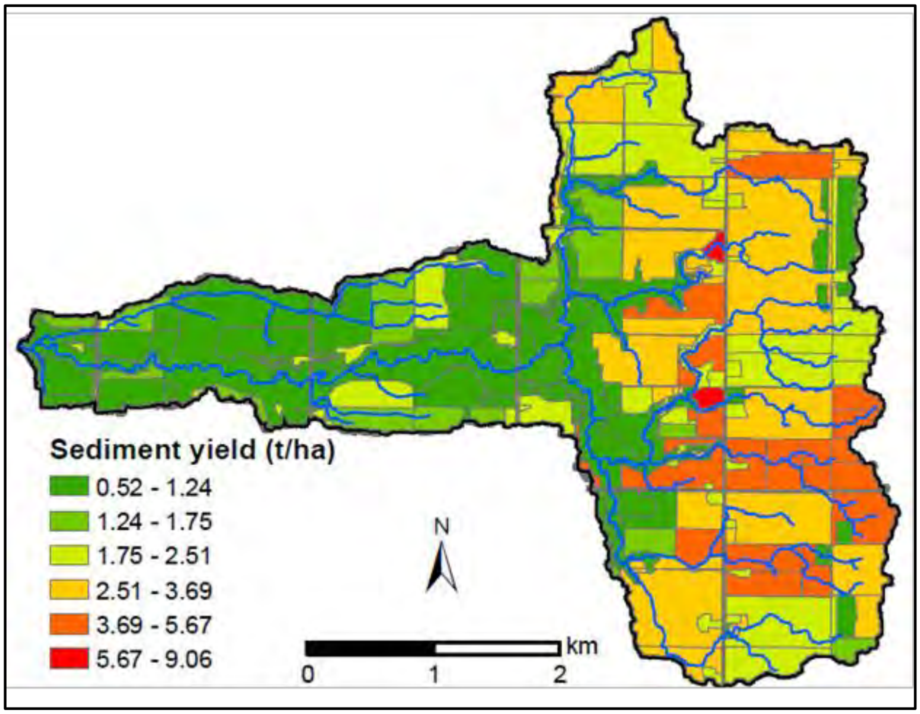

Figure 6-13. Simulated average yearly sediment yield distribution in the Gully Creek watershed under existing condition

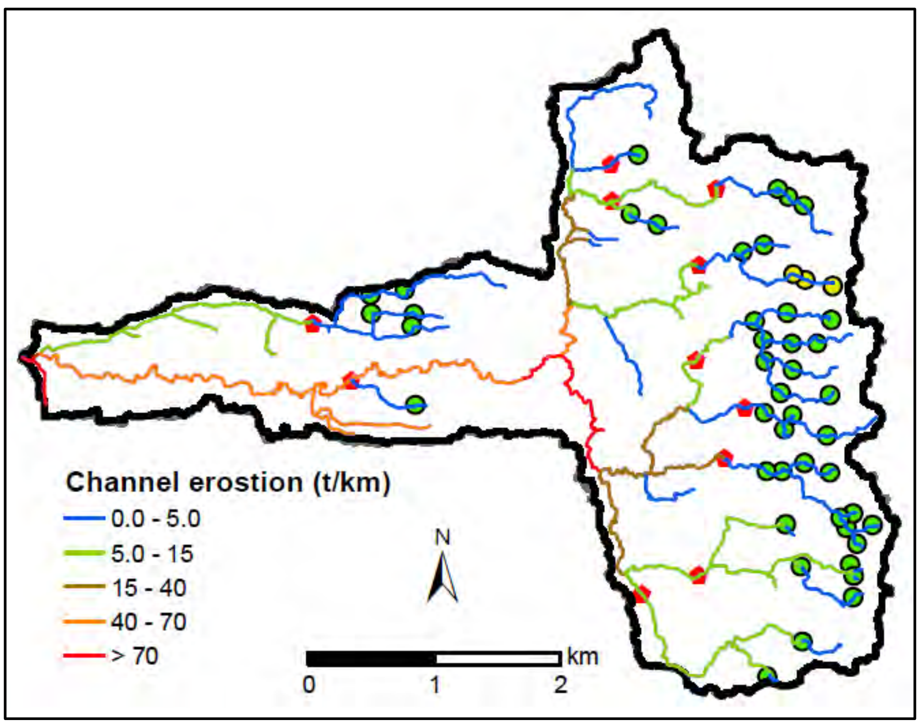

Figure 6-14. Simulated average yearly channel erosion in the Gully Creek watershed under existing condition

The estimated average annual TN load at the watershed outlet is 60,333 kg (41.6 kg/ha), of which 8,771 kg (6.10 kg/ha) is in particulate (OrgN in the SWAT output) form (14.7%) and 51,562 kg (35.5 kg/ha) is in dissolved form (85.3%). Majority nitrogen load is MinN with a MinN/OrgN ratio of 0.17. As shown in Figure 6-15, spatial distribution of TN indicates that most of middle to lower reach areas has TN below average and TN loading from upper part of the watershed is above average. The estimated average annual TP load at the watershed outlet is 3,608 kg (2.48 kg/ha), of which 2,397 kg (1.65 kg/ha) is in particulate (OrgP in the SWAT output) form (66.4%) and 1,211 kg (0.83 kg/ha) is in dissolved form (33.6%). Majority phosphorous load is particulate P with an OrgP/MinP ratio of 1.99. As shown in Figure 6-16, spatial distribution of TP indicates that most of middle to lower reach areas has TP below average and TP loading from upper part of the watershed is above average. The estimated ratio of average annual sediment load, TN load, and TP load at the watershed outlet is about 1,135:16:1.

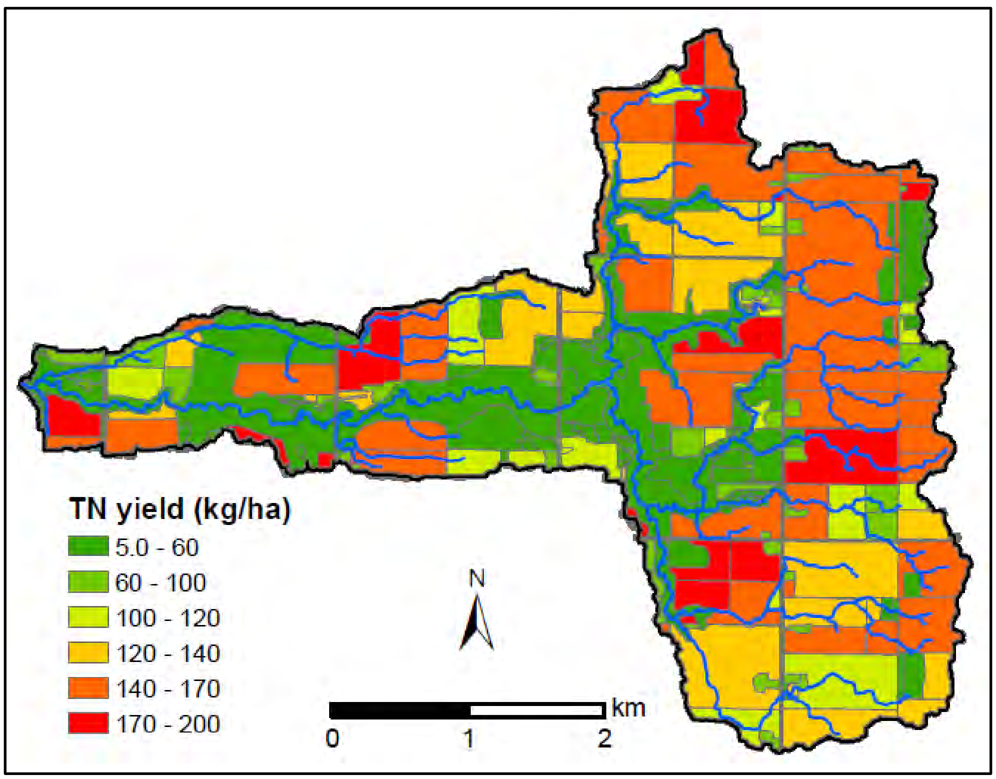

Figure 6-15. Simulated average yearly TN yield at field scale under existing condition

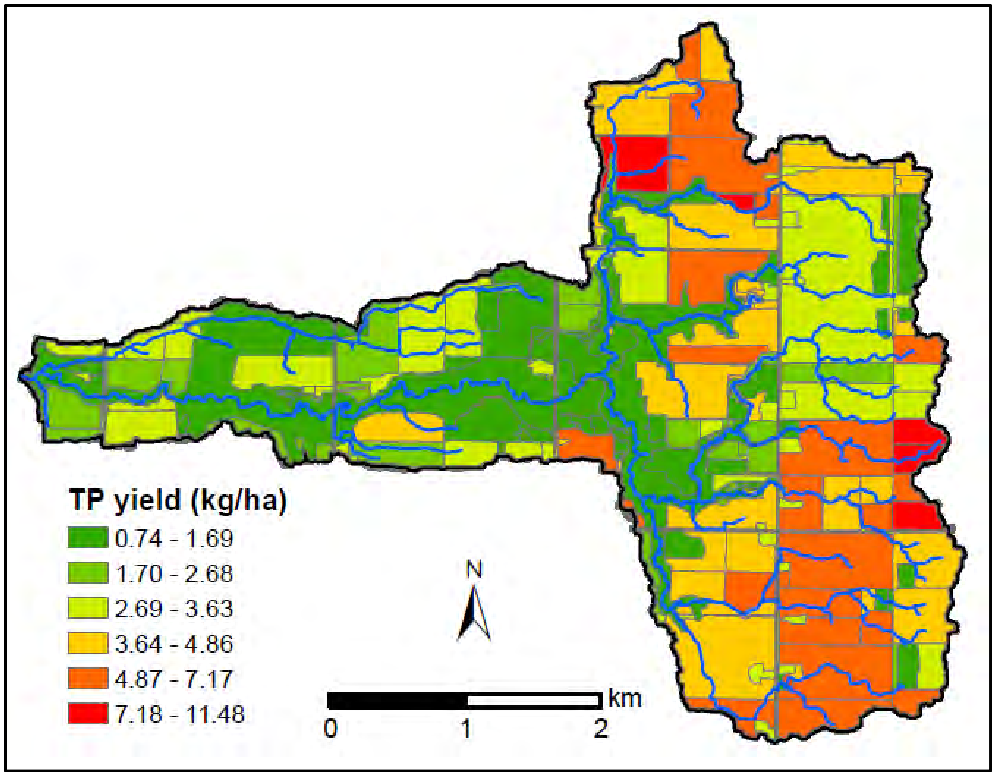

Figure 6-16. Simulated average yearly TP yield at field scale under existing condition

7.0 DEFINITION OF BMP SCENARIOS

A suite of BMPs including WASCoBs, conservation tillage, cover crop, precision nutrient management, soil amendment, and windbreak have been implemented in the Gully Creek watershed, including those implemented in the GLASI program from 2015 to 2017. Some of the BMPs such as WASCoBs have been planned for future implementation. The calibrated and validated SWAT will be applied to evaluate the water quantity and quality effects of these existing and future BMPs.

7.1 WASCoB scenarios

The WASCoBs in the Gully Creek watershed have been constructed in different time or project periods. Five WASCoB scenarios have been developed in this study.

7.1.1 WASCoBs in the WBBE program

The WBBE program supported the construction of 10 WASCoBs in Van Beets farm (Figure 7-1). In SWAT modelling, the baseline scenario includes all historical land management practices without WASCoB. Then the 10 WASCoBs in the WBBE program are added to the model, which is the BMP scenario. The differences in SWAT simulation results between the baseline scenario and the BMP scenario represent the water quantity and quality effects of the 10 WASCoBs.

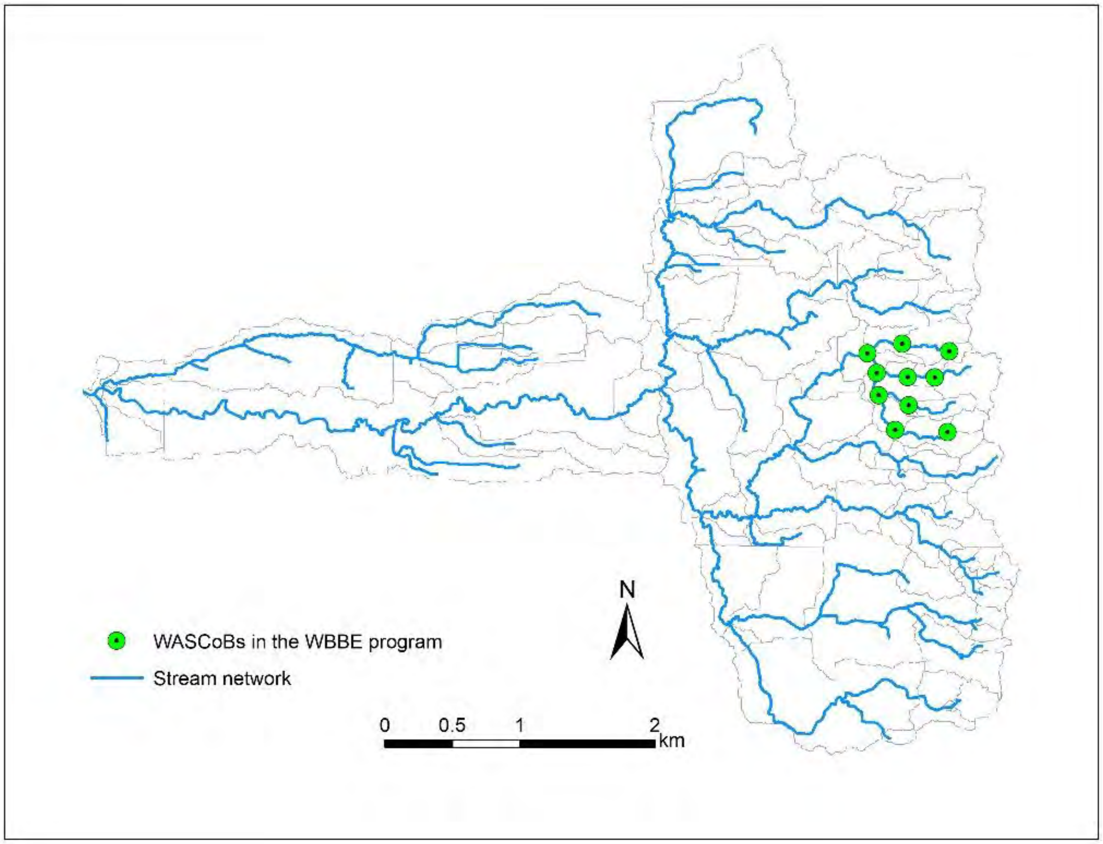

Figure 7-1. WASCoBs in the WBBE Program

7.1.2 WASCoBs in the GLASI program

The GLASI program supported the construction of 3 WASCoBs (Figure 7-2). In SWAT modelling, the baseline BMP scenario includes all historical land management practices without WASCoBs. Then the 3 WASCoBs in the GLASI program are added to build the BMP scenario. The differences in SWAT simulation results between the baseline scenario and the BMP scenario represent the water quantity and quality effects of the 3 GLASI WASCoBs.

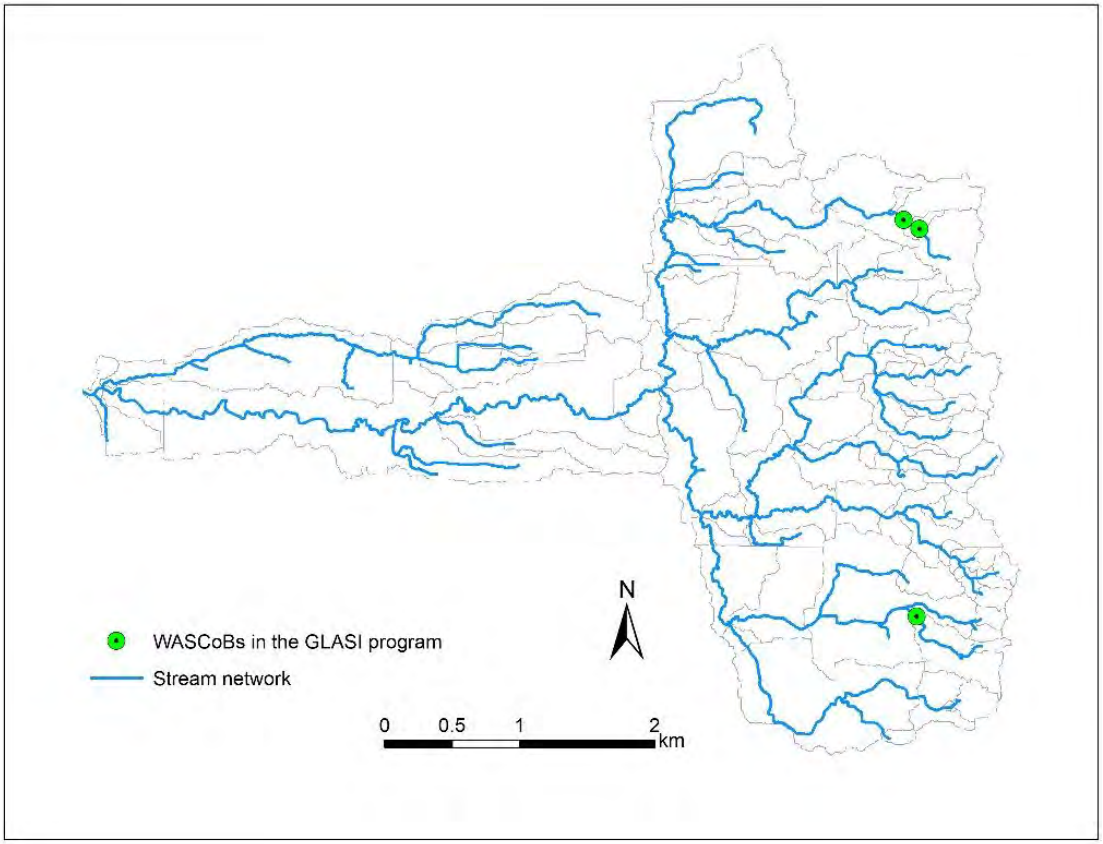

Figure 7-2. WASCoBs in the GLASI Program

7.1.3 WASCoB in or near berm monitoring sites

In 2012, 8 WASCoBs were constructed in the DFTELB site and intensive monitoring has been conducted since 2014 (Figure 7-3). In SWAT modelling, the baseline scenario includes all historical land management practices without WASCoBs. Then the 8 WASCoBs in or near berm monitoring sites are added to the system forming the BMP scenario. The differences in SWAT simulation results between the baseline scenario and the BMP scenario represent the water quantity and quality effects of the 8 WASCoBs in or near berm monitoring sites.

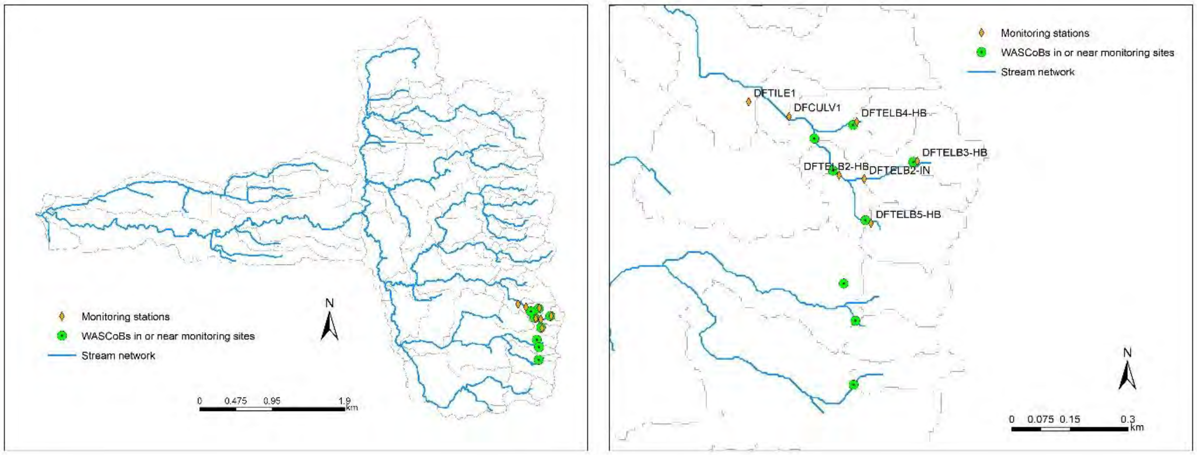

Figure 7-3. WASCoB in or near berm monitoring sites (watershed view on the left, zoom in view on the right)

7.1.4 All existing WASCoBs

The Gully Creek watershed has a total of 44 WASCoBs (Figure 7-4). In SWAT modelling, the baseline scenario includes all historical land management practices without WASCoBs. Then the 44 existing WASCoBs are added to the model to build the BMP scenario. The differences in SWAT simulation results between the baseline scenario and the BMP scenario represent the water quantity and quality effects of the 44 WASCoBs.

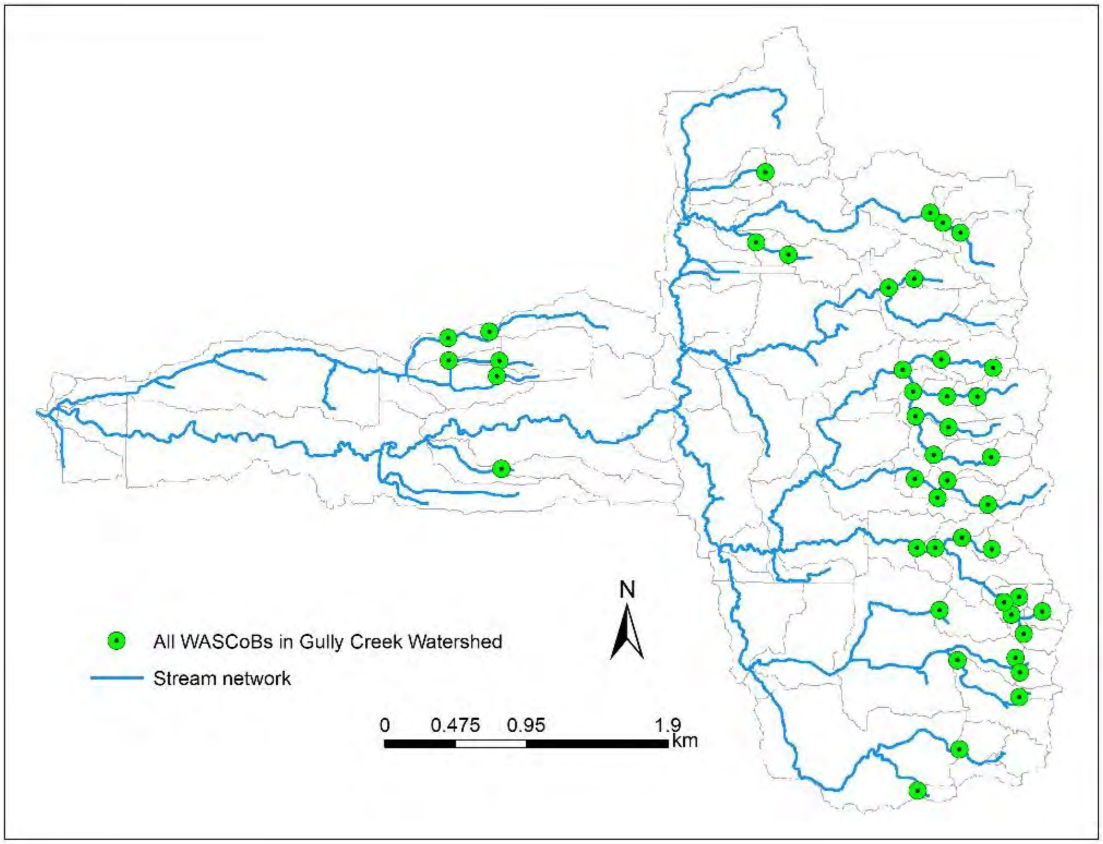

Figure 7-4. All WASCoB in the Gully Creek watershed

7.1.5 Existing + Future WASCoBs

ABCA is planning to work with producers to construct 3 WASCoBs in the future (Figure 7-5). In SWAT modelling, the baseline scenario includes all historical land management practices without WASCoBs. Then the 44 existing and 3 future WASCoBs are added to the baseline scenario, which is the existing + future WASCoB scenario. The differences in SWAT simulation results between the existing and future BMP scenarios represent the water quantity and quality effects of the 44 existing and 3 future WASCoBs.

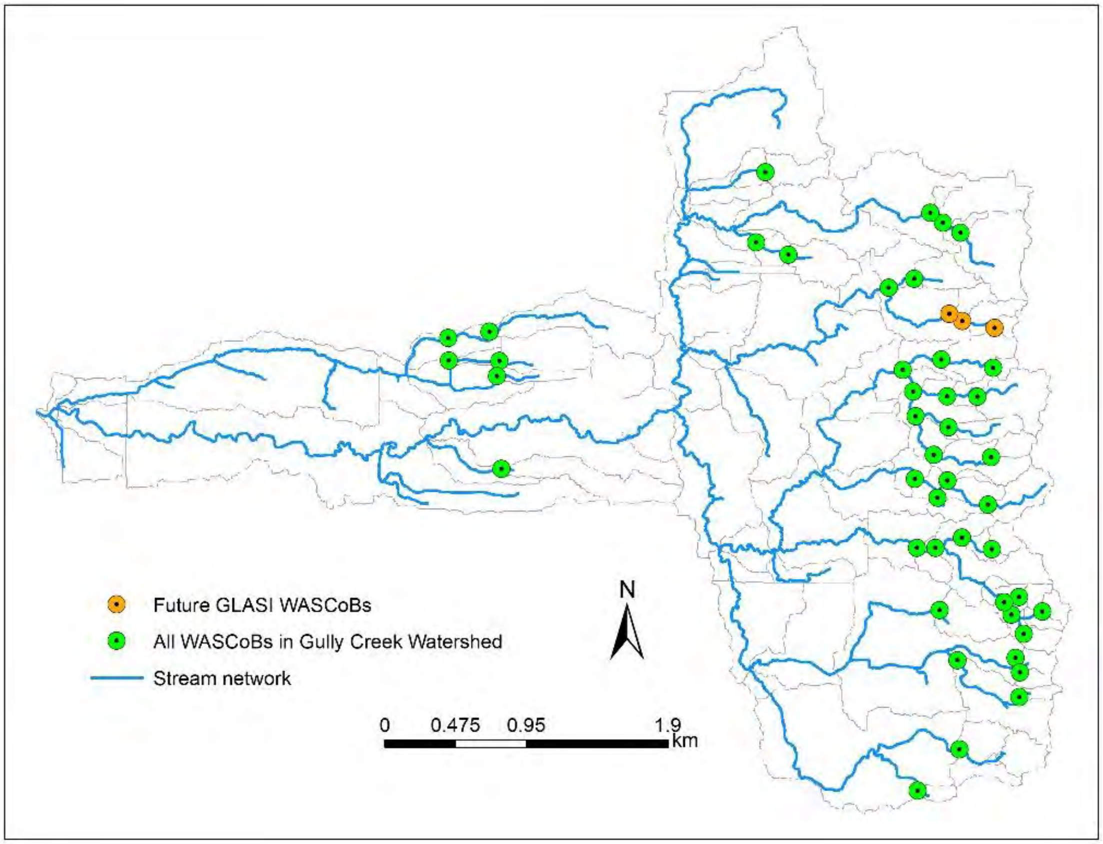

Figure 7-5. Future WASCoB in the Gully Creek watershed

7.2 Land Management BMPs during 2013-2014

ABCA supported the implementation of cover crop BMP in 3 fields (20 – Mixed grain cover crop, 63- Red clover cover crop, 78- Oat cover crop) during 2013-2014 (Figure 7-6). In SWAT modelling, 3 scenarios were constructed for these BMPs, i.e. conventional scenario, existing BMP scenario, and future BMP scenario. The existing BMP scenario includes all historical land management practices and WASCoBs. Three cover crop BMPs are added to the existing BMP scenario at their implementation year. Comparing to the existing BMP scenario, the conventional scenario removes the 3 cover crop BMPs. The future BMP scenario sets the implementation year of the 3 cover crop BMPs at the beginning of simulation which represents the long-term effects of these BMPs. The differences in SWAT simulation results between the conventional scenario and the existing (or future) BMP scenario represent the water quantity and quality effects of the 3 cover crop BMPs.

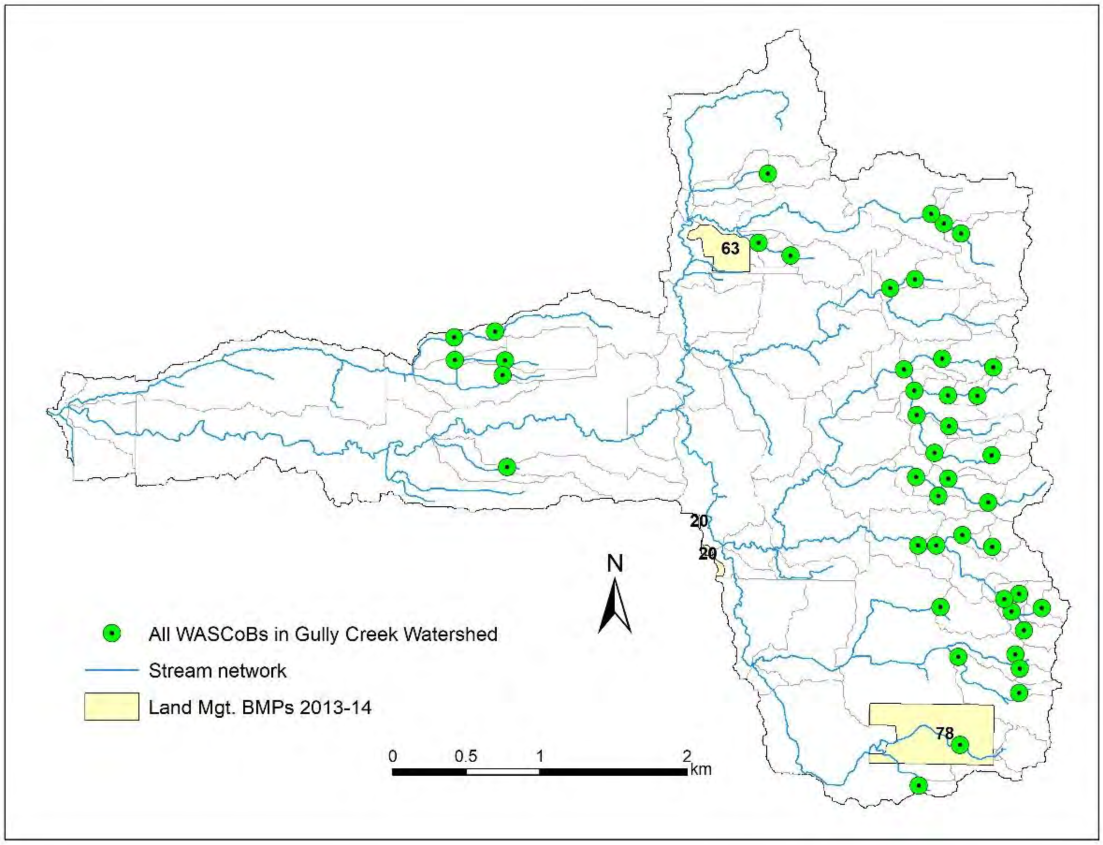

Figure 7-6. Cover Crop BMPs during 2013-2014

7.3 Land Management BMPs during 2014-2015

ABCA supported the implementation of cover crop BMP in 3 fields (36 – Oat cover crop, 79 and 80 – Mixed grain cover crop) during 2014-2015 (Figure 7-7). Similar to the 2013-14 scenario design in SWAT modelling, 3 scenarios are constructed for these BMPs, i.e. conventional scenario, existing BMP scenario, and future BMP scenario. The existing BMP scenario includes all historical land management practices and WASCoBs. The cover crop BMPs in 2014-2015 are added to the existing BMP scenario at their implementation year. Comparing to the existing BMP scenario, conventional scenario removes the 3 cover crop BMPs. The future BMP scenario set the implementation year of the 3 cover crop BMPs at the beginning of simulation which represents the long-term effects of these BMPs. The differences in SWAT simulation results between the conventional scenario and the existing (or future) BMP scenario represent the water quantity and quality effects of the 3 cover crop BMPs.

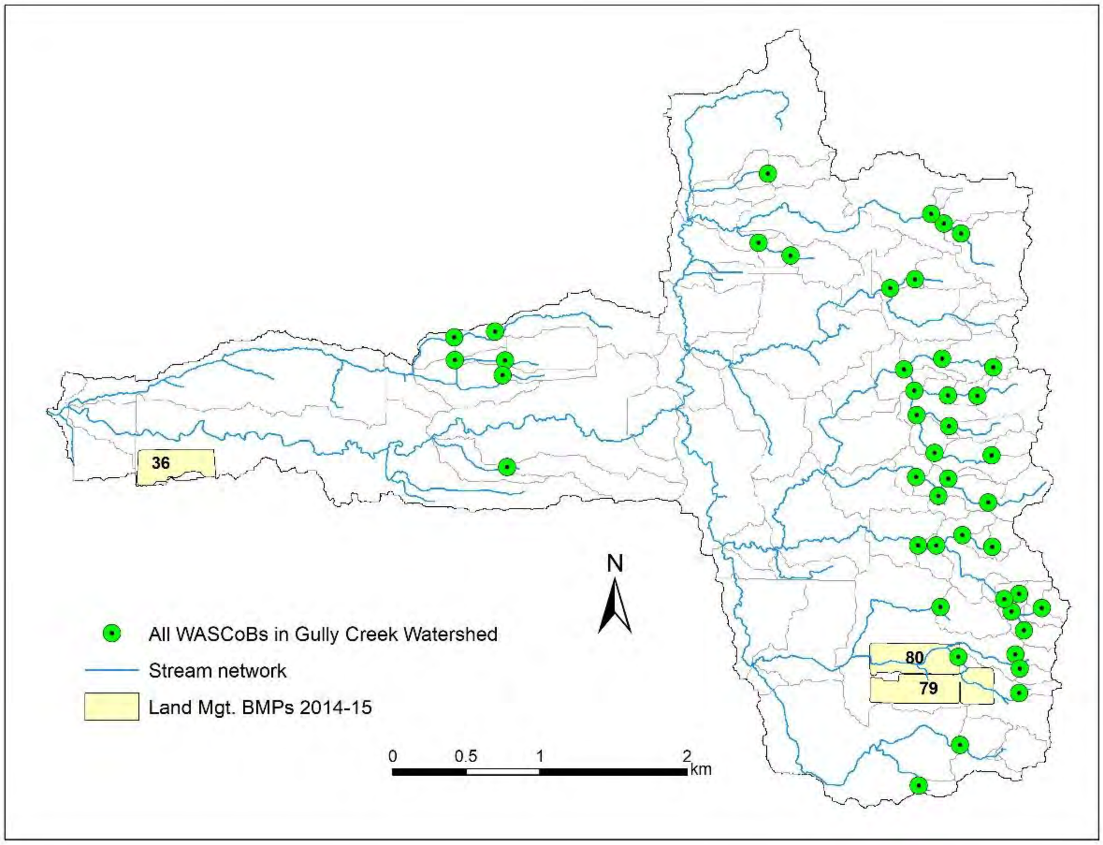

Figure 7-7. Cover Crop BMPs during 2014-2015

7.4 GLASI Land Management BMPs during 2015-2016

The GLASI program supported the implementation of multiple BMPs during 2015-2016, which included yield monitor based precision nutrient management in 6 fields (Field 1, 77, 78, 83, 84, 132) and windbreak on the north border of 1 field (Field 92) (windbreak is setup and simulated separately in section 7.8 GLASI windbreak BMPs) (Figure 7-8). In SWAT modelling, 3 scenarios are constructed for these BMPs, i.e. conventional scenario, existing BMP scenario, and future BMP scenario. The existing BMP scenario includes all historical land management practices and WASCoBs. The GLASI BMPs during 2015-2016 are added to the existing BMP scenario at their implementation year. Comparing to the existing BMP scenario, conventional scenario removes these GLASI BMPs. The future BMP scenario sets the implementation year of the GLASI BMPs at the beginning of simulation which represents the long-term effects of these BMPs. The differences in SWAT simulation results between the conventional scenario and the existing (or future) BMP scenario represent the water quantity and quality effects of the GLASI BMPs during 2015-2016.

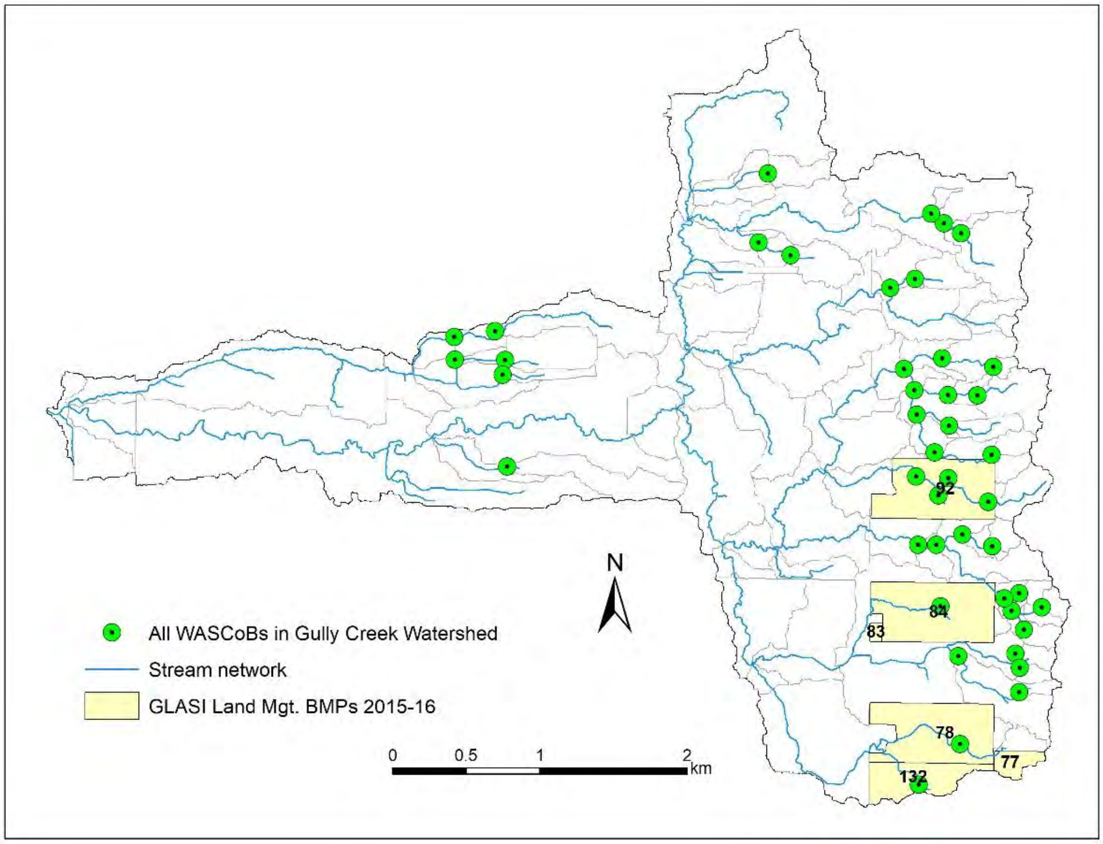

Figure 7-8. GLASI BMPs during 2015-2016

7.5 GLASI Land Management BMPs during 2016-2017

The GLASI program supported the implementation of multiple BMPs during 2016-2017, which include soil amendment with manure application and GIS based precision nutrient management in 3 fields (Field 81, 85, 142) and strip tillage in 3 fields (Field 44, 50, 137) (Figure 7-9). In SWAT modelling, 3 scenarios are constructed for these BMPs, i.e. conventional scenario, existing BMP scenario, and future BMP scenario. The existing BMP scenario includes all historical land management practices and WASCoBs. The GLASI BMPs during 2016-2017 are added to the existing BMP scenario at their implementation year. Comparing to the existing BMP scenario, conventional scenario removes these GLASI BMPs. The future BMP scenario sets the implementation year of the GLASI BMPs at the beginning of simulation which represents the long-term effects of these BMPs. The differences in SWAT simulation results between the conventional scenario and the existing (or future) BMP scenario represent the water quantity and quality effects of the GLASI BMPs during 2016-2017.

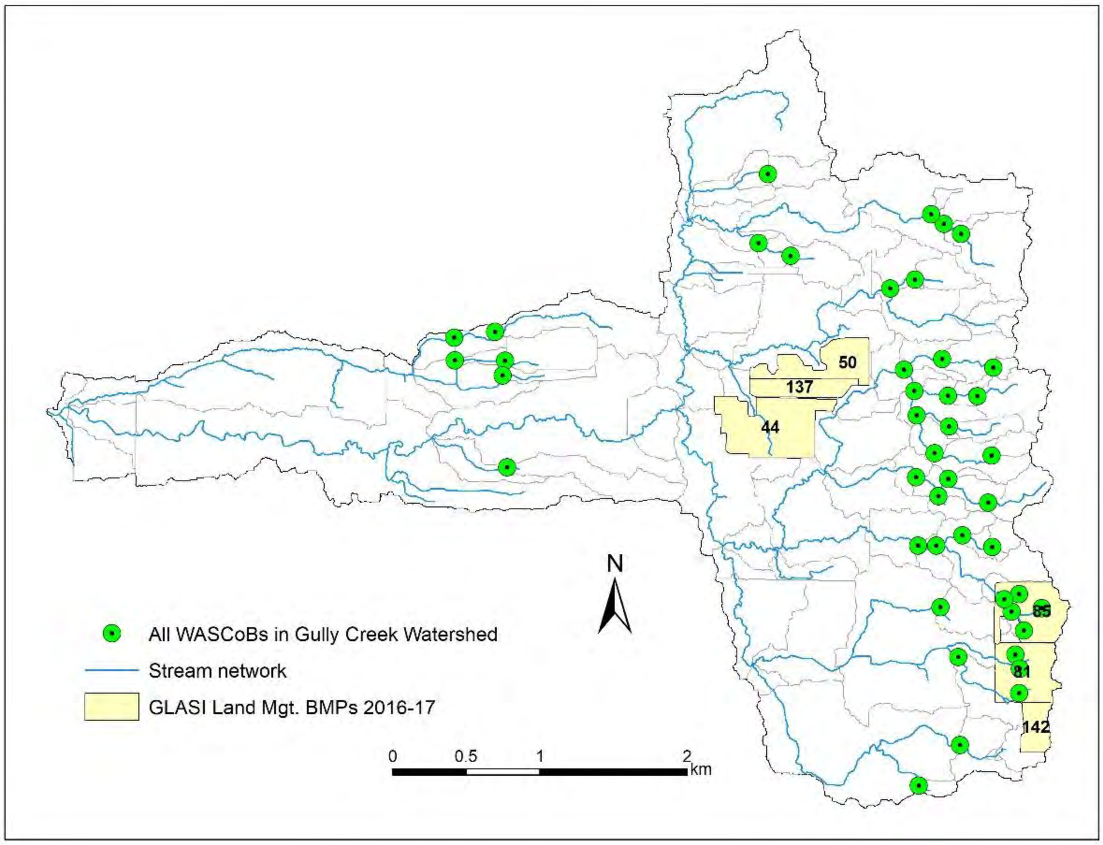

Figure 7-9. GLASI BMPs during 2016-2017

7.6 GLASI Land Management BMPs during 2017-2018

The GLASI program supported the implementation of multiple BMPs during 2017-2018, which included GIS based precision nutrient management in 8 fields (Field 71, 72, 89, 93, 128, 129, 133, 134), zero tillage in 2 fields (Field 91, 92), vertical tillage in 3 fields (Field 81, 85, 142) (Figure 7-10), and windbreak in the west border of 1 field (Field 86) (windbreak is setup and simulated separately in section 7.8 GLASI windbreak BMPs). In SWAT modelling, 3 scenarios are constructed for these BMPs, i.e. conventional scenario, existing BMP scenario, and future BMP scenario. The existing BMP scenario includes all historical land management practices and WASCoBs. The GLASI BMPs during 2017-2018 are added to the existing BMP scenario at their implementation year. Comparing to the existing BMP scenario, conventional scenario removes these GLASI BMPs. The future BMP scenario sets the

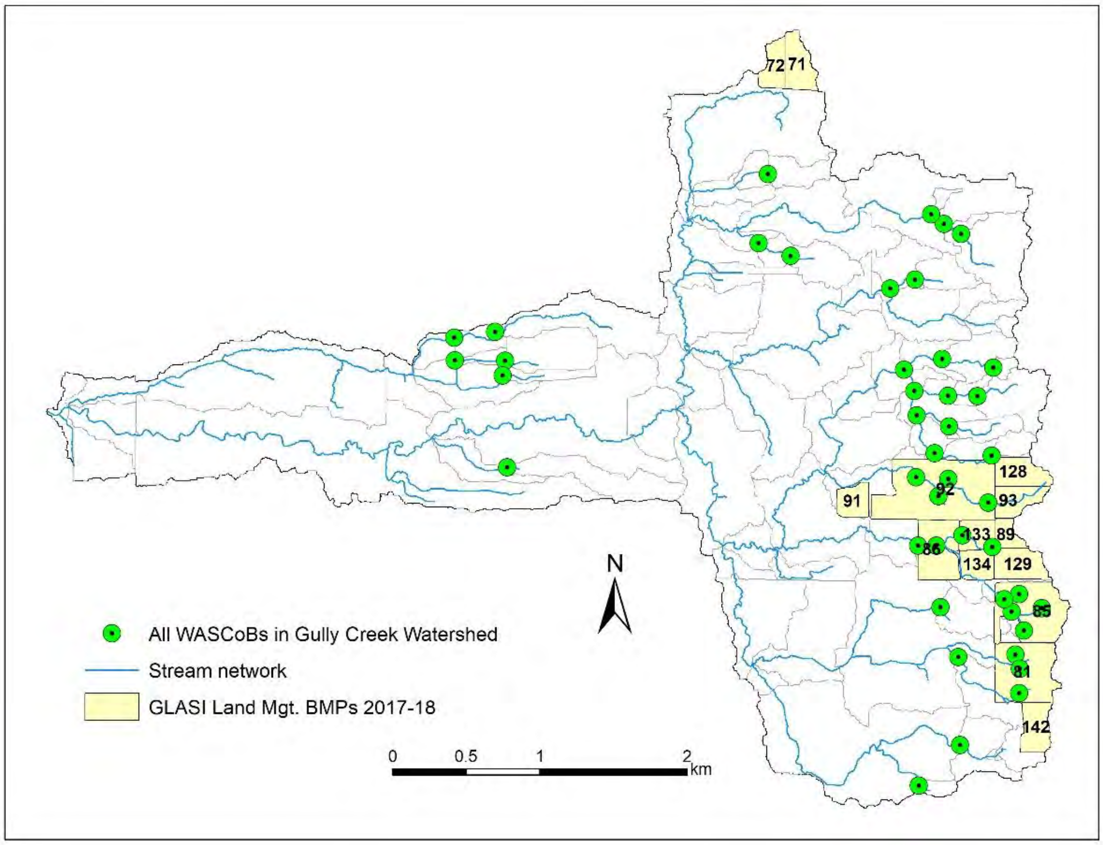

Figure 7-10. GLASI BMPs during 2017-2018

implementation year of the GLASI BMPs at the beginning of simulation which represents the long-term effects of these BMPs. The differences in SWAT simulation results between the conventional scenario and the existing (or future) BMP scenario represent the water quantity and quality effects of the GLASI BMPs during 2017-2018.

7.7 GLASI Land Management BMPs during 2015-2018

This scenario represents the combination of GLASI land management BMPs from 2015 to 2018. In total, land management BMPs in 27 fields are included in the existing and future BMP scenarios (Figure 7-11). The conventional scenario includes all historical land management practices and WASCoBs without the GLASI BMPs. Existing BMP scenario sets up the BMPs at their implementation year, and the future BMP scenario sets up the BMPs at the beginning of simulation. The differences in SWAT simulation results between the conventional scenario and the existing (or future) BMP scenario represent the water quantity and quality effects of the GLASI BMPs during 2015-2018.

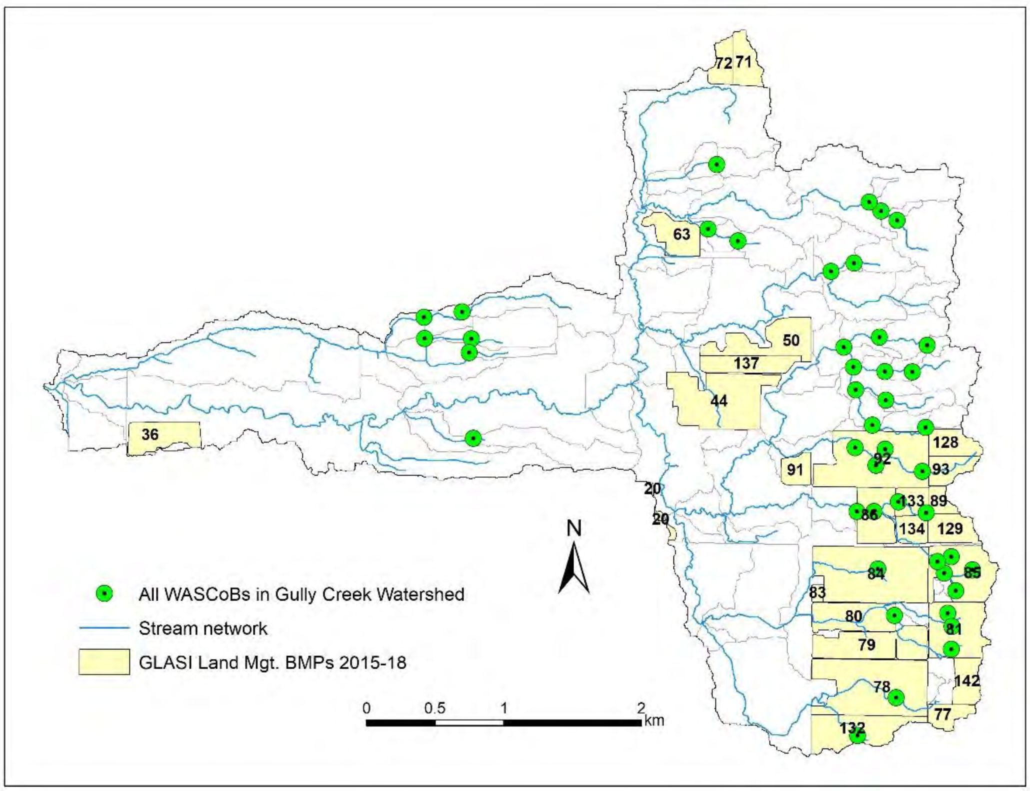

Figure 7-11. GLASI BMPs during 2015-2018

7.8 GLASI windbreak BMPs

The windbreak BMP was simulated separately in the SWAT modelling. The GLASI program supported the windbreak implementation in the two fields, i.e. on the north border of field 92 in

2015-2016, and on the west border of field 86 in 2017-2018 (Figure 7-12). SWAT only simulates hydrologic processes which doesn't include wind erosion. However, windbreak can serve as a filter strip in filtering sediment and nutrients loadings from fields. Therefore, we built the windbreak BMP scenario by assigning filter strips to the HRUs that are overlapping with the windbreak. The conventional scenario includes all historical land management practices and WASCoBs without the windbreaks. The differences in SWAT simulation results between the conventional scenario and the windbreak BMP scenario represent the water quantity and quality effects of the windbreaks in these two fields.

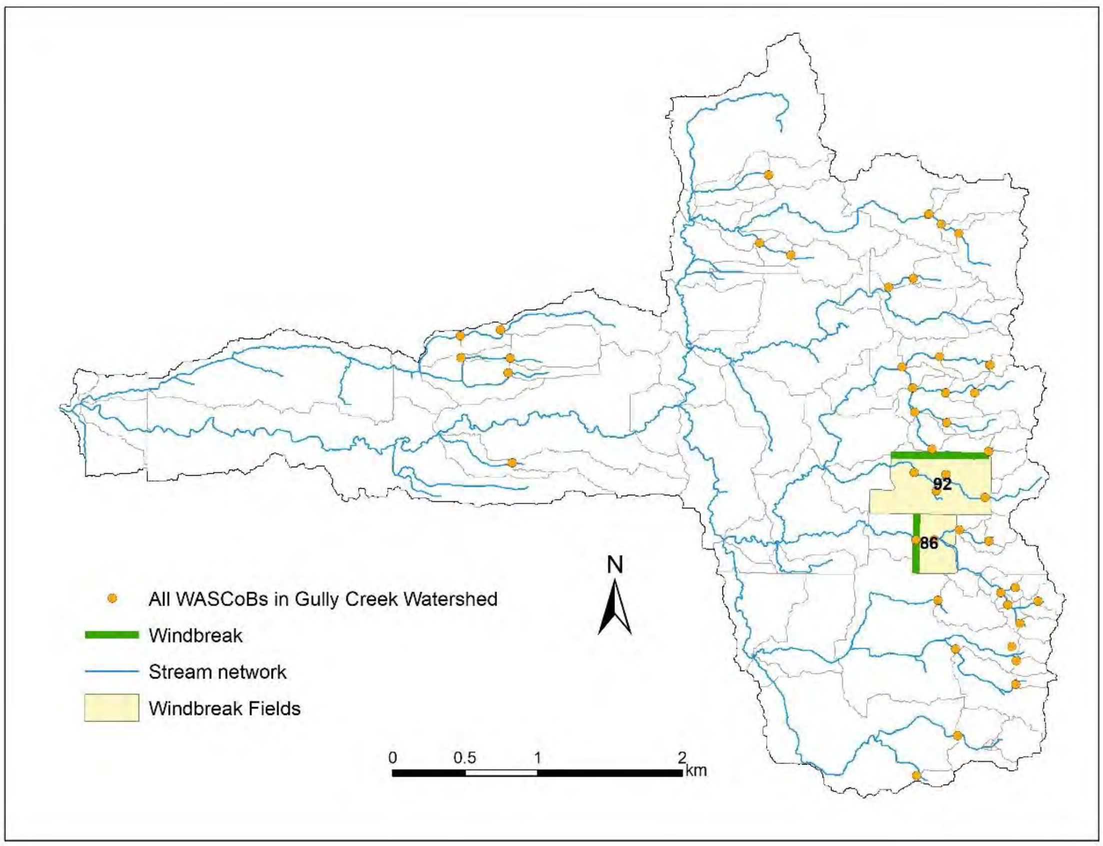

Figure 7-12. GLASI windbreak BMPs during 2015-2018

8.0 MODELLING RESULTS OF BMP SCENARIOS

A total of eight scenarios were assessed using the calibrated SWAT model for the Gully Creek watershed. In each scenario, several sub-scenarios were further developed and evaluated to reflect pre-, during, and post BMP conditions. The baseline scenario is the conventional scenario without the specific BMPs to be evaluated. Other BMP scenarios are analyzed by comparing against the baseline scenario with respect to flow, sediment, and nutrient yield. Modelling results were compared at both watershed outlet and fields to account for on-site and off-site impacts of the BMPs on water quantity and water quality. The simulation period was from January 2001 to April 2017, while the year 2001 was used for model warming-up. Because BMP evaluation results are presented on a yearly basis, all results in this chapter are 15-year (2002 – 2016) average obtained from the SWAT output. For future BMP scenarios, because no future predicted daily climate data is available for the study area, we assumed that the climate would repeat for the next 15 years, and the BMP evaluation results were based on climate and existing land management data for the period 2002-2016.

8.1 WASCoB scenarios

8.1.1 Modelling results at watershed outlet

Seven WASCoB sub-scenarios were evaluated using the calibrated SWAT model as presented in Table 8-1. Scenario 1.1 is the baseline scenario assuming no WASCoBs exited in the watershed. Scenario 1.2 is an existing scenario for which WASCoBs are simulated starting from their construction years. Scenario 1.3 is a hypothetical scenario for which only WASCoBs constructed during the WBBE program are simulated from the beginning to the end of the modelling period. Scenario 1.4 simulates only WASCoBs constructed during the GLASI program. Scenario 1.5 simulates only WASCoBs in or near berm monitoring sites. Scenario 1.6 simulates all existing WASCoBs from the beginning to the end of the modelling period. Scenario 1.7 is a hypothetical scenario that simulates both existing and future WASCoBs from the beginning to the end of the modelling period.

Table 8-1. Modelling results at watershed outlet for different WASCoB scenarios

Scenario	Flow	Sediment	OrgN	MinN	TN	OrgP	MinP	TP
	(m^3/s)	(t/yr)	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)
1.1	0.310	4,035	9,191	43,918	53,109	2,709	1,267	3,976
1.2	0.301	3,738	8,538	41,639	50,177	2,446	1,196	3,642
1.3	0.304	3,811	8,556	42,336	50,892	2,606	1,209	3,815
1.4	0.308	3,895	8,853	42,925	51,778	2,653	1,232	3,885
1.5	0.309	3,946	9,104	43,614	52,718	2,684	1,258	3,942
1.6	0.283	3,012	6,774	36,554	43,328	2,094	1,023	3,117
1.7	0.282	2,989	6,693	36,300	42,993	2,085	1,016	3,101
Absolute Reduction								
1.2	0.0092	297	653	2,279	2,932	263	71.0	334
1.3	0.0058	224	635	1,582	2,217	103	58.0	161
1.4	0.0024	140	338	992	1,330	56.0	35.0	91.0
1.5	0.0015	89.0	87.0	304	391	25.0	9.0	34.0
1.6	0.0274	1,023	2,417	7,364	9,781	615	244	859
1.7	0.0285	1,046	2,498	7,618	10,116	624	251	875
Relative Reduction (%)								
1.2	2.97	7.36	7.10	5.29	5.52	9.71	5.60	8.40
1.3	1.87	5.55	6.91	3.78	4.17	3.80	4.58	4.05
1.4	0.77	3.47	3.68	2.34	2.51	2.07	2.76	2.29
1.5	0.48	2.21	0.95	0.71	0.74	0.92	0.71	0.86
1.6	8.84	25.35	26.30	17.28	18.42	22.70	19.26	21.60
1.7	9.19	25.92	27.18	17.88	19.05	23.03	19.81	22.01

For Scenario 1.1 without WASCoBs and with existing land management condition, sediment, TN, and TP loadings are 4,035 ton/yr, 53,109 kg/yr, and 3,976 kg/yr respectively. For Scenario 1.2 with only constructed WASCoBs in their respective years and existing land management conditions, sediment, TN, and TP loadings are 3,738 ton/yr, 50,177 kg/yr, and 3,642 kg/yr respectively. For Scenario 1.6 with all existing WASCoB and existing land management conditions from the beginning to the end of the model simulation period, sediment, TN, and TP loadings are 3,012 ton/yr, 43,328 kg/yr, and 3,117 kg/yr respectively. For Scenario 1.7 with existing and future WASCoB and existing land management conditions from the beginning to the end over the model simulation period, sediment, TN, and TP loadings are 2,989 ton/yr, 42,993 kg/yr, and 3,101 kg/yr respectively. A comparison between Scenario 1.7 and Scenario 1.1 shows that with all existing and future WASCoBs, sediment, TN, and TP loadings can be reduced by 1,046 ton/yr, 10,116 kg/yr, and 875 kg/yr respectively, corresponding to relative reductions of

25.92%, 19.05%, and 22.01% respectively. These results demonstrate that WASCoBs are effective measures in reducing sediment, TN, and TP loads at the Gully Creek watershed outlet. A graphical presentation of relative reductions for different WASCoB scenarios are shown in Figure 8-1.

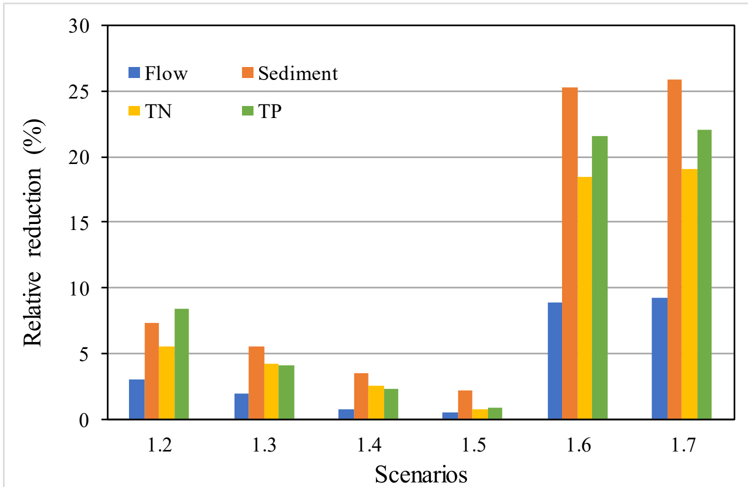

Figure 8-1. Relative reductions of flow, sediment, TN, and TP at watershed outlet for different WASCoB scenarios in the Gully Creek watershed

8.1.2 Modelling results of channel erosion

A direct consequence of WASCoB construction is to reduce channel erosion after WASCoB site due to water diversion to the underground tile-drain. Sediment reduction may also come from the deposition in and up of the ponding area because of decreased flow velocity. The aggregate effects of peak reduction can also reduce erosion in the main stream channels. This has been demonstrated in the sediment modelling results at different reaches (Table 8-2). Comparing Scenario 1.7 (with all existing and future WASCoBs) to Scenario 1.1 (without berms), it was found that high channel sediment reductions occurred in channels right after berms. The highest sediment reductions were in reach 35 (94.2%) and reach 69 (91.2%) indicating almost 100% of channel erosions in these reaches were reduced due to berm construction. Moderate reductions of channel erosion (10% - 30%) were also found in downstream main channels because of reduced peak discharge (Figure 8-2). A comparison of the seven WASCoB scenarios indicated that the more WASCoBs constructed, the more channel erosion reductions were achieved but with different orders.

Table 8-2. Reduction of sediment yield at reach outlet for different WASCoB scenarios

Reach	Scenario2		Scenario3		Scenario4		Scenario5		Scenario6		Scenario7	
	(t/yr)	(%)	(t/yr)	(%)	(t/yr)	(%)	(t/yr)	(%)	(t/yr)	(%)	(t/yr)	(%)
2	0.7	2.4	0.0	0.0	0.0	0.0	0.0	0.0	14	49.9	14	49.9
4	0.7	1.6	0.0	0.0	0.0	0.0	0.0	0.0	14	33.8	14	33.8
5	3.9	2.0	0.0	0.0	44	22.6	0.0	0.0	48	24.5	48	24.5
7	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	15	6.7	15	6.7
8	4.0	1.4	0.0	0.0	45	16.1	0.0	0.0	49	17.4	49	17.4
9	42	12.2	0.0	0.0	45	13.1	0.0	0.0	88	25.3	88	25.3
10	1.9	4.4	0.0	0.0	33	76.3	0.0	0.0	33	76.3	33	76.3
12	23	56.8	0.0	0.0	0.0	0.0	0.0	0.0	23	58.4	23	58.4
17	43	6.8	0.0	0.0	46	7.4	0.0	0.0	102	16.3	102	16.3
18	7	15.2	0.0	0.0	0.0	0.0	0.0	0.0	19	43.7	19	43.7
19	16	13.3	0.0	0.0	0.0	0.0	0.0	0.0	45	38.0	64	54.4
20	16	10.1	0.0	0.0	0.0	0.0	0.0	0.0	46	29.0	65	41.6
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11	59.8
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	16.0
25	10	33.4	0.0	0.0	0.0	0.0	0.0	0.0	26	83.1	26	83.1
26	43	6.3	0.0	0.0	47	6.8	0.0	0.0	102	15.0	102	15.0
27	0.5	1.7	3.5	12.4	0.0	0.0	0.0	0.0	4	12.4	3.5	12.4
29	7	29.0	0.0	0.0	0.0	0.0	0.0	0.0	21	82.9	21	82.9
30	16	3.9	0.0	0.0	0.0	0.0	0.0	0.0	47	11.2	68	16.1
31	16	4.9	0.0	0.0	0.0	0.0	0.0	0.0	47	13.9	67	20.1
33	3.7	7.9	29	60.9	0.0	0.0	0.0	0.0	29	60.9	29	60.9
34	26	26.1	0.0	0.0	0.0	0.0	0.0	0.0	67	68.2	67	68.2
35	13	37.7	0.0	0.0	0.0	0.0	0.0	0.0	32	94.2	32	94.2
36	13	22.2	0.0	0.0	0.0	0.0	0.0	0.0	35	61.0	35	61.0
38	20	8.6	192	83.6	0.0	0.0	0.0	0.0	192	83.6	192	83.6
40	11	7.9	114	79.9	0.0	0.0	0.0	0.0	114	79.9	114	79.9
41	3.4	7.3	35	74.2	0.0	0.0	0.0	0.0	35	74.2	35	74.2
43	31	17.6	29.2	1.1	0.0	0.0	0.0	0.0	79	44.1	79	44.1
44	59	5.1	0.0	0.0	47	4.1	0.0	0.0	150	13.0	171	14.9
45	297	7.4	224	5.6	140	3.5	89	2.2	1023	25.4	1047	25.9
46	20.2	7.9	195	75.5	0.0	0.0	0.0	0.0	195	75.5	195	75.5
47	194	9.4	212	10.2	89	4.3	86	4.1	731	35.3	731	35.3
48	3.9	7.9	40	80.0	0.0	0.0	0.0	0.0	40	80.0	40	80.0
49	265	6.9	226	5.9	140	3.7	89	2.3	943	24.6	966	25.2
51	264	7.0	224	5.9	139	3.7	88	2.3	939	24.8	962	25.4
52	255	7.7	214	6.5	136	4.1	86	2.6	887	26.9	908	27.6
53	256	7.5	218	6.3	137	4.0	87	2.5	895	26.1	918	26.7
54	2.8	5.7	0.0	0.0	0.0	0.0	0.0	0.0	23	47.2	23	47.2
56	0.9	2.2	10	23.7	0.0	0.0	0.0	0.0	10	23.7	10	23.7
58	21	6.2	197	59.0	0.0	0.0	0.0	0.0	197	59.0	197	59.0
59	5.7	5.4	0.0	0.0	0.0	0.0	0.0	0.0	82	77.4	82	77.4
61	5.7	3.2	0.0	0.0	0.0	0.0	0.0	0.0	83	46.3	83	46.3
62	4.1	5.0	0.0	0.0	0.0	0.0	0.0	0.0	50	61.1	50	61.1
65	108	34.2	0.0	0.0	0.0	0.0	56	17.8	251	79.5	251	79.5
66	28	12.2	0.0	0.0	0.0	0.0	56	24.3	89	39.0	89	39.0
68	137	14.1	202	20.8	0.0	0.0	57	5.9	539	55.8	539	55.8
69	97	39.0	0.0	0.0	0.0	0.0	56	22.4	227	91.2	227	91.2
70	8	22.7	0.0	0.0	0.0	0.0	0.0	0.0	18	52.6	18	52.6
71	138	13.6	204	20.2	0.0	0.0	57	5.6	544	53.8	544	53.8
72	52	6.0	0.0	0.0	87	10.1	27	3.1	169	19.6	169	19.6
74	51	6.1	0.0	0.0	87	10.3	27	3.2	169	19.9	169	19.9
75	13	16.7	0.0	0.0	0.0	0.0	55	69.8	55	69.8	55	69.8
77	13	18.0	0.0	0.0	0.0	0.0	55	75.0	55	75.0	55	75.0
79	10	21.5	0.0	0.0	0.0	0.0	41	89.8	41	89.8	41	89.8
81	2.4	11.7	0.0	0.0	0.0	0.0	10	48.1	10	48.1	10	48.1
82	5.8	14.1	0.0	0.0	0.0	0.0	24	58.5	24	58.5	24	58.5
85	19	3.6	0.0	0.0	87	16.3	27	5.0	130	24.5	130	24.5
86	19	4.4	0.0	0.0	86	20.0	26	6.1	129	30.1	129	30.1
89	32	11.9	0.0	0.0	0.0	0.0	0.0	0.0	37	13.9	37	13.9
91	32	12.4	0.0	0.0	0.0	0.0	0.0	0.0	37	14.5	37	14.5

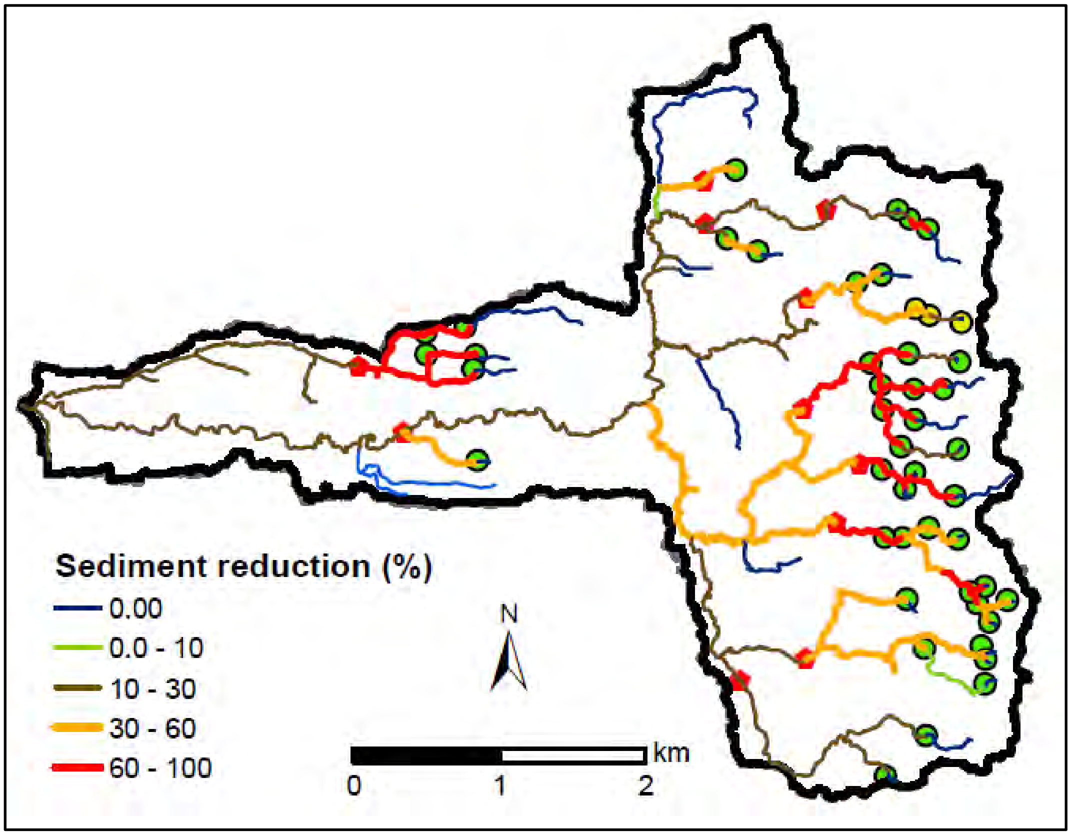

Figure 8-2. Relative reduction of sediment yield for WASCoB scenario 7 (Existing+future)

8.2 Land management BMPs during 2013-2014

Land management BMPs during 2013-2014 were cover crops in field 20, 63, and 78. A conventional scenario was built by assuming no cover crops in these fields and with all other existing land management and WASCoB conditions. The existing scenario simulates these BMPs starting from their implementation year, while the future scenario simulates these BMPs from the beginning to the end over the simulation period with all other land management and WASCoB conditions the same as in the conventional scenario. The modelling results (15-year average) are presented in Table 8-3. Water yield (WYLD), sediment yield (SYLD), mineral N (MinN), organic N (OrgN), total N (TN), mineral P (MinP), organic P (OrgP), and total P (TP) were compared at the watershed outlet and at the three fields to analyze the off-site and on-site effects of these BMPs.

Table 8-3. Modelling results for land management BMPs during 2013-2014

Scenario	Location	WYLD	SYLD	MinN	OrgN	TN	MinP	OrgP	TP
		(mm)	(t/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	
Conventional	Outlet	621	2.61	5.98	41.09	47.06	1.65	0.84	2.49
	Field 20	654	5.33	157.27	16.72	173.99	1.22	5.33	6.55
	Field 63	628	1.89	141.98	7.75	149.73	1.19	2.76	3.94
	Field 78	634	2.35	107.22	8.06	115.28	1.21	5.06	6.27
Existing	Outlet	621	2.61	5.96	40.99	46.96	1.65	0.83	2.49
	Field 20	647	5.11	159.10	14.06	173.16	1.20	5.01	6.21
	Field 63	623	1.77	143.09	7.42	150.51	1.16	2.41	3.56
	Field 78	630	2.23	108.41	7.74	116.15	1.19	4.43	5.62
Future	Outlet	621	2.61	5.95	40.86	46.81	1.65	0.83	2.48
	Field 20	641	4.98	148.20	13.13	161.33	1.20	4.87	6.07
	Field 63	618	1.69	129.98	7.55	137.53	1.15	2.34	3.49
	Field 78	629	2.12	99.17	7.14	106.31	1.19	4.42	5.61
				Reduction					
Existing	Outlet	0.22	0.00	0.01	0.10	0.11	0.00	0.00	0.00
	Field 20	7.19	0.22	-1.83	2.66	0.83	0.02	0.32	0.34
	Field 63	4.97	0.12	-1.11	0.32	-0.79	0.03	0.35	0.38
	Field 78	3.91	0.12	-1.19	0.31	-0.88	0.02	0.63	0.65
Future	Outlet	0.22	0.00	0.02	0.23	0.25	0.00	0.00	0.00
	Field 20	13.43	0.35	9.07	3.59	12.66	0.02	0.46	0.48
	Field 63	9.54	0.20	12.0	0.20	12.20	0.04	0.42	0.45
	Field 78	4.77	0.23	8.05	0.91	8.96	0.02	0.63	0.66
				Relative reduction (%)					
Existing	Outlet	0.04	0.05	0.20	0.24	0.23	-0.04	0.08	0.00
	Field 20	1.10	4.13	-1.16	15.91	0.48	1.31	6.00	5.13
	Field 63	0.79	6.39	-0.78	4.15	-0.53	2.59	12.65	9.62
	Field 78	0.62	5.23	-1.11	3.89	-0.76	1.86	12.43	10.39
Future	Outlet	0.04	0.05	0.38	0.55	0.53	0.04	0.08	0.06
	Field 20	2.05	6.57	5.77	21.47	7.27	1.64	8.63	7.33
	Field 63	1.52	10.62	8.45	2.58	8.15	3.01	15.10	11.46
	Field 78	0.75	9.91	7.51	11.32	7.77	1.99	12.50	10.47

Because of the limited BMP application area, reductions of pollutant at the watershed outlet were not obvious. Comparing the future scenario with the conventional scenario, relative reductions of SYLD, TN, and TP at the watershed outlet were 0.04%, 0.53%, 0.06% respectively. However, considerable reductions of pollutant were obtained at the edge-of-field. The relative reductions of SYLD at Field 20, 63, and 78 were 6.57%, 10.62%, 9.91%; TN 7.27%, 8.15%, 7.77%; and TP 7.33%, 11.46%, and 10.47% respectively. The relative reductions of MinN were much less than

OrgN because cover crop would increase infiltration resulting in more MinN loss from subsurface (tile) flow and less OrgN loss from surface runoff. An increase of MinN and TN was found at the three fields for the existing scenario. This is because the N application rate was not reduced in the following year after cover crop based on actual field investigation data, while for future scenarios, the N credit of cover crop was considered and the N application rate was reduced by 60 kg/ha resulting in a decrease of TN loss in the modelling results.

8.3 Land management BMPs during 2014-2015

Land management BMPs during 2014-2015 were cover crops in field 36, 79, and 80. A conventional scenario was built by assuming no cover crops in these fields and with all other existing land management and WASCoB conditions. The existing scenario simulates these BMPs starting from their implementation year, while the future scenario simulates these BMPs from the beginning to the end over the simulation period with all other land management and WASCoB conditions the same as in the conventional scenario. The modelling results (15-year average) are presented in Table 8-4. WYLD, SYLD, MinN, OrgN, TN, MinP, OrgP, and TP were compared at the watershed outlet and at the three fields to analyze the off-site and on-site effects of these BMPs.

Similar as the 2013-2014 scenario, because of the limited BMP application area, reductions of pollutant at the watershed outlet were not obvious. Comparing the future scenario with the conventional scenario, relative reductions of SYLD, TN, and TP at the watershed outlet were 0.24%, 0.48%, 0.01% respectively. However, considerable reductions of pollutant were obtained at the edge-of-field. The relative reductions of SYLD at Field 36, 79, and 80 were 13.7%, 15.8%, 13.9%; TN 6.42%, 3.76%, 3.66%; TP 30.7%, 14.4%, and 16.8% respectively. The relative reductions of MinN were much less than OrgN because cover crop would increase infiltration resulting in more MinN loss from subsurface (tile) flow and less OrgN loss from surface runoff. An increase of MinN was found at the Field 36 and Field 79 for the existing scenario. This is because the N application rate was not reduced in the following year after cover crop based on actual field investigation data, while for future scenarios, the N credit of cover crop was considered and N application rate was reduced by 60 kg/ha resulting in a decrease of TN loss in the modelling results.

Table 8-4. Modelling results for land management BMPs during 2014-2015

Scenario	Location	WYLD	SYLD	MinN	OrgN	TN	MinP	OrgP	TP
		(mm)	(t/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	
Conventional	Outlet	621	2.61	41.09	5.98	47.06	0.84	1.65	2.49
	Field 36	635	1.03	134.40	5.13	139.53	1.42	1.42	2.84
	Field 79	637	4.31	144.84	17.19	162.03	1.18	4.93	6.11
	Field 80	642	4.28	127.25	15.82	143.07	1.23	4.81	6.04
Existing	Outlet	621	2.61	40.89	5.95	46.84	0.84	1.65	2.49
	Field 36	634	1.02	135.09	5.01	140.10	1.41	1.30	2.71
	Field 79	635	4.25	145.05	16.47	161.52	1.15	4.33	5.48
	Field 80	639	4.07	125.21	15.13	140.34	1.23	4.37	5.60
Future	Outlet	621	2.57	40.09	5.90	45.98	0.83	1.65	2.48
	Field 36	629	0.72	125.83	4.74	130.57	1.40	1.05	2.45
	Field 79	625	3.69	140.16	15.78	155.94	1.11	4.03	5.14
	Field 80	634	3.56	123.40	14.43	137.83	1.19	4.02	5.21
				Reduction					
Existing	Outlet	0.00	0.01	0.20	0.02	0.22	0.00	0.00	0.00
	Field 36	1.18	0.02	-0.69	0.12	-0.57	0.01	0.12	0.13
	Field 79	2.04	0.06	-0.21	0.72	0.51	0.03	0.60	0.63
	Field 80	3.46	0.21	2.04	0.68	2.72	0.01	0.44	0.45
Future	Outlet	0.65	0.04	1.00	0.08	1.08	0.00	0.00	0.01
	Field 36	6.73	0.32	8.57	0.39	8.96	0.02	0.37	0.39
	Field 79	12.3	0.62	4.68	1.41	6.09	0.07	0.90	0.97
	Field 80	8.18	0.72	3.85	1.39	5.24	0.05	0.79	0.84
				Relative reduction (%)					
Existing	Outlet	0.00	0.24	0.49	0.39	0.48	0.00	0.01	0.01
	Field 36	0.19	1.65	-0.51	2.36	-0.41	0.45	8.69	4.58
	Field 79	0.32	1.33	-0.14	4.20	0.32	2.48	12.2	10.3
	Field 80	0.54	4.80	1.60	4.32	1.90	0.57	9.15	7.40
Future	Outlet	0.11	1.48	2.44	1.36	2.30	0.25	0.18	0.20
	Field 36	1.06	30.7	6.38	7.65	6.42	1.16	26.2	13.7
	Field 79	1.92	14.4	3.23	8.20	3.76	5.68	18.3	15.8
	Field 80	1.27	16.8	3.03	8.76	3.66	3.89	16.4	13.9

8.4 GLASI land management BMPs during 2015-2016

GLASI land management BMPs during 2015-2016 were GPS based precision nutrient management in six fields (1, 77, 78, 83, 84, 132) and windbreak in Field 92. The windbreak is evaluated in a separate scenario (Section 8.8) and is not included in this scenario. A conventional scenario is built by assuming no this BMP in these six fields and with all other existing land management and WASCoB conditions. The existing scenario simulates these BMPs starting from their implementation year by reducing chemical fertilizer and manure by 10%, while the future scenario simulates these BMPs from the beginning to the end over the simulation period with all other land management and WASCoB conditions the same as in the conventional scenario. The modelling results (15-year average) are presented in Table 8-5 including comparisons at the watershed outlet and three representative fields (77, 78, 83). WYLD, SYLD, MinN, OrgN, TN, MinP, OrgP, and TP were compared at the watershed outlet and at the three fields to analyze the off-site and on-site effects of these BMPs.

Table 8-5. Modelling results for land management BMPs during 2015-2016

Scenario	Location	WYLD	SYLD	MinN	OrgN	TN	MinP	OrgP	TP
		(mm)	(t/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	
Conventional	Outlet	621	2.61	41.09	5.98	47.06	0.84	1.65	2.49
	Field 77	634	1.59	122.78	6.95	129.73	1.20	4.33	5.52
	Field 78	633	2.11	111.92	8.12	120.04	1.22	4.23	5.45
	Field 83	637	3.56	131.93	14.87	146.79	1.21	3.92	5.13
Existing	Outlet	621	2.61	40.96	5.96	46.92	0.83	1.65	2.48
	Field 77	634	1.59	121.05	6.91	127.96	1.19	4.32	5.51
	Field 78	633	2.11	111.83	8.12	119.95	1.21	4.22	5.42
	Field 83	637	3.56	131.87	14.86	146.74	1.20	3.91	5.11
Future	Outlet	621	2.61	40.27	5.88	46.15	0.83	1.65	2.49
	Field 77	634	1.59	113.81	6.82	120.63	1.18	4.31	5.49
	Field 78	633	2.11	107.02	8.02	115.03	1.20	4.21	5.41
	Field 83	637	3.56	127.84	14.84	142.69	1.20	3.91	5.11
				Reduction					
Existing	Outlet	0.00	0.00	0.13	0.02	0.15	0.00	0.01	0.01
	Field 77	0.00	0.00	1.73	0.04	1.77	0.01	0.00	0.01
	Field 78	0.00	0.00	0.09	0.00	0.09	0.01	0.01	0.02
	Field 83	0.00	0.00	0.05	0.00	0.05	0.01	0.02	0.02
Future	Outlet	0.00	0.00	0.81	0.10	0.91	0.00	0.00	0.00
	Field 77	0.00	0.00	8.97	0.13	9.10	0.02	0.01	0.03
	Field 78	0.02	0.00	4.91	0.10	5.01	0.02	0.02	0.03
	Field 83	0.04	0.00	4.08	0.03	4.11	0.01	0.01	0.03
				Relative reduction (%)					
Existing	Outlet	0.00	0.00	0.32	0.30	0.32	0.30	0.48	0.42
	Field 77	0.00	0.00	1.41	0.57	1.36	0.85	0.08	0.25
	Field 78	0.00	0.00	0.08	0.00	0.07	0.66	0.30	0.38
	Field 83	0.00	0.00	0.04	0.03	0.04	0.50	0.41	0.43
Future	Outlet	0.00	0.00	1.98	1.60	1.93	0.06	0.08	0.08
	Field 77	0.00	0.00	7.31	1.89	7.02	1.52	0.28	0.55
	Field 78	0.00	0.00	4.38	1.27	4.17	1.38	0.43	0.64
	Field 83	0.01	0.00	3.09	0.18	2.80	1.06	0.33	0.50

Similar as 2013-2014 and 2014-2015 scenarios, because of the limited BMP application area, reduction of pollutants at the watershed outlet was not obvious. Comparing the future scenario with the conventional scenario, relative reductions of SYLD, TN, and TP at the watershed outlet were 0.0%, 1.93%, 0.08% respectively. Considerable reductions of N were obtained at the edge-of-field. However, reductions of P at edge-of-field were not significant. No sediment reductions were obtained for Field 77, 78, and 83 in the modelling results. TN relative reductions at Field 77, 78, and 83 were 7.02%, 4.17%, 2.80%, while relative TP reductions were 0.55%, 0.64%, and 0.50% respectively. The small relative reductions of TP maybe because that the existing P application rate was close to the recommended rate, while after addition 10% reduction, majority of soil P would be used for plant growth and left less for loss with runoff.

8.5 GLASI land management BMPs during 2016-2017

GLASI land management BMPs during 2016-2017 included soil amendments (manure application) and GPS based precision nutrient applications in Field 81, 85, and 142, and conservation tillage (strip tillage) in Field 44, 50, 137. A conventional scenario was built by assuming no these BMPs in these six fields and with all other existing land management and WASCoB conditions. The existing scenario simulates these BMPs starting from their implementation year, while the future scenario simulates these BMPs from the beginning to the end over the simulation period with all other land management and WASCoB conditions the same as in the conventional scenario. The modelling results (15-year average) are presented in Table 8-6 including comparisons at the watershed outlet and three representative fields (81, 85, 142). WYLD, SYLD, MinN, OrgN, TN, MinP, OrgP, and TP were compared at the watershed outlet and at the three fields to analyze the off-site and on-site effects of these BMPs.

Similar as the 2013-2014 and 2014-2015 scenarios, because of the limited BMP application area, reductions of pollutant at the watershed outlet were not obvious. Comparing the future scenario with the conventional scenario, relative reductions of SYLD, TN, and TP at the watershed outlet were 0.43%, 3.97%, 0.91% respectively. However, considerable reductions of pollutant were obtained at the edge-of-field. The relative reductions of SYLD at Field 81, 85, and 142 were 0.5%, 5.02%, 6.27%; TN 1.28%, 15.49%, 22.91%; TP 1.03%, 3.69%, and 5.39% respectively. The relative reductions of N were higher than P reduction maybe because the existing P application rate was close to the recommended rate.

Table 8-6. Modelling results for land management BMPs during 2016-2017

Scenario	Location	WYLD	SYLD	MinN	OrgN	TN	MinP	OrgP	TP
		(mm)	(t/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	
Conventional	Outlet	621	2.61	41.09	5.98	47.06	0.84	1.65	2.49
	Field 81	636	3.71	152.32	13.39	165.72	1.16	3.45	4.61
	Field 85	638	4.44	146.27	12.34	158.61	1.18	2.73	3.91
	Field 142	635	3.64	135.64	11.21	146.84	1.16	2.10	3.26
Existing	Outlet	621	2.61	40.81	5.92	46.73	0.83	1.64	2.48
	Field 81	636	3.66	145.35	13.26	158.61	1.16	3.39	4.55
	Field 85	637	4.36	145.46	12.11	157.57	1.18	2.69	3.87
	Field 142	635	3.63	130.09	10.92	141.02	1.16	2.07	3.23
Future	Outlet	620	2.60	40.58	5.88	46.46	0.83	1.64	2.46
	Field 81	635	3.52	128.44	11.61	140.04	1.15	3.29	4.44
	Field 85	635	4.16	113.49	8.78	122.27	1.18	2.52	3.70
	Field 142	634	3.49	117.20	8.48	125.67	1.15	2.00	3.15
Reduction									
Existing	Outlet	0.43	0.01	0.28	0.05	0.33	0.00	0.01	0.01
	Field 81	0.08	0.05	6.97	0.13	7.11	0.00	0.06	0.06
	Field 85	1.24	0.08	0.81	0.23	1.05	0.00	0.04	0.04
	Field 142	0.00	0.02	5.54	0.28	5.82	0.00	0.03	0.03
Future	Outlet	1.09	0.01	0.51	0.09	0.60	0.01	0.02	0.03
	Field 81	1.56	0.19	23.89	1.79	25.67	0.01	0.16	0.17
	Field 85	3.35	0.28	32.78	3.56	36.34	0.00	0.21	0.21
	Field 142	0.10	0.15	18.44	2.73	21.17	0.01	0.10	0.11
Relative reduction (%)									
Existing	Outlet	0.00	0.00	0.32	0.30	0.32	0.30	0.48	0.42
	Field 81	0.07	0.21	0.67	0.91	0.70	0.50	0.60	0.56
	Field 85	0.01	1.23	4.58	1.01	4.29	0.36	1.74	1.39
	Field 142	0.19	1.80	0.56	1.87	0.66	0.19	1.49	1.10
Future	Outlet	0.00	0.43	4.09	2.53	3.97	0.03	1.39	0.91
	Field 81	0.18	0.50	1.24	1.57	1.28	0.91	1.10	1.03
	Field 85	0.25	5.02	15.68	13.35	15.49	0.53	4.75	3.69
	Field 142	0.53	6.27	22.41	28.85	22.91	0.20	7.64	5.39

8.6 GLASI Land Management BMPs during 2017-2018

GLASI land management BMPs during 2017-2018 included GPS based nutrient applications in nigh fields (71, 72, 86, 89, 93, 128, 129, 133, 134), zero tillage in two fields (91, 92), vertical tillage in three fields (81, 85, 142), and windbreak in Field 86. The windbreak is evaluated in a separate scenario (Section 8.8) and is not included in this scenario. A conventional scenario was

Table 8-7. Modelling results for land management BMPs during 2017-2018

Scenario	Location	WYLD	SYLD	MinN	OrgN	TN	MinP	OrgP	TP
		(mm)	(t/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	
Conventional	Outlet	621	2.61	41.09	5.98	47.06	0.84	1.65	2.49
	Field 89	640	4.57	103.45	15.58	119.03	1.23	4.85	6.08
	Field 93	628	4.15	147.02	14.30	161.32	1.22	10.35	11.57
	Field 128	638	4.37	150.30	15.89	166.19	1.23	7.89	9.11
Existing	Outlet	621	2.60	41.08	5.93	47.01	0.83	1.63	2.46
	Field 89	640	4.39	101.98	15.08	117.06	1.21	4.80	6.01
	Field 93	628	4.10	143.02	14.15	157.17	1.22	10.25	11.47
	Field 128	638	4.37	150.30	15.89	166.19	1.22	7.79	9.01
Future	Outlet	621	2.58	41.07	5.92	46.98	0.83	1.62	2.45
	Field 89	640	4.24	100.45	14.50	114.95	1.20	4.67	5.86
	Field 93	628	4.02	137.98	14.10	152.08	1.20	10.04	11.24
	Field 128	638	4.37	140.87	15.44	156.31	1.21	7.71	8.92
				Reduction					
Existing	Outlet	0.00	0.01	0.01	0.05	0.06	0.00	0.03	0.03
	Field 89	0.00	0.18	1.47	0.50	1.97	0.02	0.05	0.08
	Field 93	0.14	0.05	4.00	0.15	4.15	0.01	0.10	0.10
	Field 128	0.00	0.00	0.00	0.00	0.00	0.01	0.10	0.10
Future	Outlet	0.00	0.03	0.02	0.06	0.08	0.00	0.04	0.04
	Field 89	0.01	0.33	3.00	1.08	4.08	0.04	0.19	0.22
	Field 93	0.01	0.13	9.04	0.20	9.24	0.02	0.31	0.33
	Field 128	0.00	0.00	9.43	0.45	9.88	0.02	0.17	0.19
				Relative reduction (%)					
Existing	Outlet	0.00	0.55	0.02	0.81	0.12	0.05	1.52	1.02
	Field 89	0.00	4.01	1.42	3.23	1.66	1.79	1.11	1.25
	Field 93	0.02	1.29	2.72	1.03	2.57	0.58	0.93	0.89
	Field 128	0.00	0.00	0.00	0.00	0.00	0.65	1.23	1.15
Future	Outlet	0.00	1.08	0.05	1.02	0.17	0.08	2.35	1.59
	Field 89	0.00	7.16	2.90	6.95	3.43	2.93	3.85	3.67
	Field 93	0.00	3.22	6.15	1.38	5.73	1.72	2.97	2.84
	Field 128	0.00	0.00	6.27	2.83	5.95	1.22	2.22	2.08

built by assuming no these BMPs in these fields and with all other existing land management and WASCoB conditions. The existing scenario simulates these BMPs starting from their implementation year, while the future scenario simulates these BMPs from the beginning to the end over the simulation period with all other land management and WASCoB conditions the same as in the conventional scenario. The modelling results (15-year average) are presented in Table 8-7 including comparisons at the watershed outlet and three representative fields (89, 93, 128). WYLD, SYLD, MinN, OrgN, TN, MinP, OrgP, and TP were compared at the watershed outlet and at the three fields to analyze the off-site and on-site effects of these BMPs.

Similar as the 2013-2014, 2014-2015, and 2015-2016 scenarios, because of the limited BMP application area, reductions of pollutant at the watershed outlet were not obvious. Comparing the future scenario with the conventional scenario, relative reductions of SYLD, TN, and TP at the watershed outlet were 1.08%, 0.17%, 1.59% respectively. However, considerable reductions of pollutants were obtained at the edge-of-field. The relative reductions of SYLD at Field 89, 93, and 128 were 7.16%, 3.12%, 0.0%; TN 3.43%, 5.73%, 5.95%; TP 3.67%, 2.84%, and 2.08% respectively. The relative reductions of P were comparable with N reduction because zero tile and vertical till would highly reduce surface erosion compared with conventional tillage resulting in a reduction of P loss with sediment reduction.

8.7 GLASI Land Management BMPs during 2015-2018

GLASI land management BMPs during 2015-2018 were combined BMPs from 2015 to 2018, excluding WASCoB BMPs which were assessed separately in Section 8.1 and windbreak BMPs which were assessed separately in Section 8.8. A conventional scenario was built by assuming no these BMPs and with all other existing land management and WASCoB conditions. The existing scenario simulates these BMPs starting from their implementation year, while the future scenario simulates these BMPs from the beginning to the end over the simulation period with all other land management and WASCoB conditions the same as in the conventional scenario. The modelling results (15-year average) are presented in Table 8-8 including comparisons at the watershed outlet and three representative fields (81, 85, 142). WYLD, SYLD, MinN, OrgN, TN, MinP, OrgP, and TP were compared at the watershed outlet and at the three fields to analyze the off-site and on-site effects of these BMPs.

Table 8-8. Modelling results for GLASI Land Management BMPs during 2015-2018

Scenario	Location	WYLD	SYLD	MinN	OrgN	TN	MinP	OrgP	TP
		(mm)	(t/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	
Conventional	Outlet	621	2.61	41.09	5.98	47.06	0.84	1.65	2.49
	Field 81	636	3.71	152.32	13.39	165.72	1.16	3.44	4.60
	Field 85	638	4.42	146.27	12.34	158.61	1.18	2.73	3.91
	Field 142	635	3.63	130.10	10.94	141.05	1.16	2.29	3.44
Existing	Outlet	621	2.61	40.94	5.94	46.88	0.83	1.63	2.46
	Field 81	636	3.66	152.34	13.26	165.59	1.16	3.31	4.47
	Field 85	637	4.30	141.40	11.51	150.91	1.18	2.66	3.88
	Field 142	634	3.43	130.06	10.92	140.98	1.16	2.24	3.40
Future	Outlet	621	2.58	40.78	5.85	46.69	0.83	1.60	2.43
	Field 81	635	3.64	129.48	12.52	142.00	1.16	3.29	4.45
	Field 85	636	3.87	115.04	10.46	125.49	1.17	2.59	3.76
	Field 142	631	3.02	119.88	9.87	129.75	1.15	2.17	3.31
				Reduction					
Existing	Outlet	0.00	0.00	0.15	0.04	0.19	0.00	0.02	0.03
	Field 81	0.08	0.05	-0.01	0.14	0.12	0.00	0.13	0.13
	Field 85	1.24	0.12	4.87	0.83	7.70	0.00	0.07	0.03
	Field 142	1.72	0.20	0.04	0.02	0.06	0.00	0.04	0.04
Future	Outlet	0.00	0.03	0.31	0.12	0.37	0.00	0.05	0.05
	Field 81	1.19	0.07	22.84	0.88	23.72	0.00	0.15	0.15
	Field 85	2.69	0.55	31.23	1.89	33.12	0.01	0.14	0.15
	Field 142	3.91	0.61	10.23	1.07	11.29	0.01	0.12	0.13
				Relative reduction (%)					
Existing	Outlet	0.00	0.00	0.37	0.59	0.40	0.25	1.43	1.03
	Field 81	0.01	1.23	-0.01	1.01	0.08	0.00	3.78	2.83
	Field 85	0.19	2.62	3.33	6.75	4.86	0.37	2.70	0.87
	Field 142	0.27	5.51	0.03	0.16	0.04	0.03	1.79	1.20
Future	Outlet	0.00	1.21	0.75	2.04	0.79	0.50	3.06	2.20
	Field 81	0.19	1.87	15.00	6.54	14.31	0.31	4.31	3.30
	Field 85	0.42	12.40	21.35	15.29	20.88	0.90	5.19	3.89
	Field 128	0.62	16.89	7.86	9.76	8.01	1.01	5.08	3.71

Because of the limited BMP application area, reductions of pollutant at the watershed outlet were not obvious. Comparing the future scenario with the conventional scenario, relative reductions of SYLD, TN, and TP at the watershed outlet were 1.21%, 2.04%, 2.20% respectively. However, considerable reductions of pollutant were obtained at the edge-of-field. The relative reductions of SYLD at Field 81, 85, and 142 were 1.87%, 12.4%, 16.89%; TN 14.31%, 20.88%, 8.01%; TP 3.30%, 3.89%, and 3.71% respectively. These results indicate that TP reductions from these BMPs were less effective than reductions of TN at edge-of-field, but were comparable at watershed outlet because of in-stream processes. The effects of these combined BMPs were less than the sum of individual BMPs given in above sections because of interactions of different processes on the landscape and marginal decrease of pollutant reduction efficiencies as more BMPs were implemented.

8.8 GLASI windbreak BMPs

Windbreak is a structural BMP designed primarily for reduction of wind erosion. SWAT is a hydrologic process model and does not have functions to simulate wind erosion processes. However, windbreak located at downslope of a field also serves as a filter strip to reduce sediment and nutrient load out of the field. A separate scenario was created for windbreaks in the Gully Creek watershed because windbreak BMP is different from other BMPs and only water quality effects from runoff were assessed using the SWAT model in this study. A conventional scenario was built by assuming no windbreaks and with all other existing land management and WASCoB conditions. The future scenario simulates windbreaks in Field 86 (2017-2018) and 92 (2015-2016) from the beginning to the end over the simulation period with all other land management and WASCoB conditions the same as in the conventional scenario. The modelling results (15-year average) are presented in Table 8-9 including comparisons at the watershed outlet and the two windbreak fields (81, 85, 142). The filter strip length and width were estimated based on DEM and land cover information as described in Chapter 7. WYLD, SYLD, MinN, OrgN, TN, MinP, OrgP, and TP were compared at the watershed outlet and at the two implementation fields to analyze both off-site and on-site effects of windbreaks.

Table 8-9. Modelling results of windbreak scenarios

Scenario	Location	WYLD	SYLD	MinN	OrgN	TN	MinP	OrgP	TP
		(mm)	(t/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	
No windbreak	Outlet	621	2.61	41.09	5.98	47.06	0.84	1.65	2.49
	Field 86	654	5.09	102.08	16.42	118.50	1.24	3.46	4.70
	Field 92	645	2.94	178.41	9.59	188.00	1.19	3.90	5.09
Windbreak	Outlet	621	2.59	40.99	5.92	46.91	0.83	1.64	2.47
	Field 86	654	4.22	99.54	13.24	112.78	0.97	2.88	3.85
	Field 92	645	2.42	174.19	7.90	182.09	1.03	3.23	4.26
Reduction									
Windbreak	Outlet	0.15	0.02	0.10	0.06	0.16	0.00	0.02	0.02
	Field 86	0.00	0.87	2.54	3.18	5.72	0.27	0.58	0.85
	Field 92	0.00	0.53	4.22	1.69	5.91	0.16	0.67	0.83
Relative reduction (%)									
Windbreak	Outlet	0.02	0.76	0.24	0.98	0.33	0.06	1.03	0.70
	Field 86	0.00	17.11	2.49	19.39	4.83	21.55	16.81	18.06
	Field 92	0.00	17.87	2.37	17.62	3.14	13.44	17.27	16.37

Because of the limited BMP application area, reductions of pollutant at the watershed outlet were not obvious. Comparing the future scenario with the conventional scenario, relative reductions of SYLD, TN, and TP at the watershed outlet were 0.76%, 0.33%, and 0.70%. However, relative pollutant reductions at edge-of-field were significant. The relative reductions of SYLD at Field 86 and 92 were 17.11% and 17.87%; TN 19.39%, 17.62%; and TP 18.06%, 16.73% respectively. This demonstrated that windbreaks located on downslopes are also effective in water pollution control in the watershed.

9.0 COST EFFECTIVENESS ANALYSIS OF BMP SCENARIOS

This section makes assumptions on BMP costs and combines BMP cost data with total phosphors reduction at watershed outlet estimated by SWAT to conduct cost effectiveness analysis of BMP scenarios in the Gully Creek watershed.

9.1 Assumptions on BMP costs

GLASI program has a project on estimating the economic costs of GLASI BMPs and the project outcomes are currently not available. In this situation, we would like to use our best knowledge to make assumptions on BMP costs. In WBBE program from 2010 to 2013, the Guelph WEG conducted farm economic modelling to estimate economic costs of conservation tillage, nutrient management (conventional vs. NMAN fertilizer rates), cover crop and WASCoBs. The farm economic modelling considered changes in production inputs (such as nitrogen credit for cover crop) and outputs (such as yield effects for conservation tillage) associated with land management BMPs. The modelling also considered annualization of structural BMPs such as WASCoBs (20-years of life span). The WBBE study will be used as a basis for making BMP cost assumptions in the GLASI program. However, some BMPs in the GLASI program were implemented on top of existing equipment such as purchasing no-till drill for conservation tillage. Some of the BMPs such as precision nutrient management involve new equipment purchase. Therefore, some adjustments were made based on the BMP costs in the WBBE program. Note that the BMP cost assumptions in GLASI program may have high uncertainties. These data need to be updated for further BMP cost effectiveness analysis when the estimated GLASI BMP cost data become available.

The BMP cost assumptions and justifications are listed in Table 9.1. For land management BMPs, conservation tillage is the most expensive at \$20/ha. Precision nutrient management BMP can reduce fertilizer costs but new equipment such as GPS and yield monitor purchase will add to the cost, with BMP cost at \$10/ha. Cover cop and soil amendment BMPs also have benefits to producers in terms of soil built-up, with minimum BMP cost at \$5/ha. Windbreak cost is associated with seedling, planting and tree spacing, with an assumption of \$25/\$100m based on annualization.

The WASCoB cost including construction and maintenance costs estimated in the WBBE program at $55/ha of drainage area.

Table 9-1. Assumptions on BMP costs

BMP Type	BMP cost assumption	Justifications
Conservation tillage	$20/ha	The estimated conservation tillage cost is $35/ha in the WBBE program. The cost is reduced based on partial purchase of equipment.
Precision nutrient management	$10/ha	Nutrient management is estimated to have a positive benefit of $23/ha in the WBBE program. The cost is increased based on purchase of new equipment.
Cover crop	$5/ha	Cover crop is estimated to have a positive benefit of $36/ha in the WBBE program. The cost is increased based on purchase of new equipment.
Soil amendment	$5/ha	Soil amendment cost is assumed to be similar to that of the cover crop.
Windbreak	$25/100m	The cost is based on 4-m spacing of windbreak, seedling and planting cost $20 per seedling, and annualized by 20 years.
WASCoB	$55/ha of drainage area	The WASCoB cost is based on that in the WBBE program without change.

9.2 Cost effectiveness of WASCoB scenarios

The cost effectiveness of WASCoB scenarios is listed in Table 9.2. On average, the cost effectiveness ratio of all existing WASoBs is $23.4 per kg of phosphorus reduction. Adding 3 future WASCoBs, the cost effectiveness ratio is 23.6 kg per kg of P reduction. However, some small variations exist. The cost effectiveness rations for the GLASI and WBBE scenarios are $26.3 and $28.5 per kg of P reduction respectively. The highest cost effectiveness ratio is for those WASCoBs at monitoring site, at $31.2 per kg of P reduction, which is the most expensive scenario.

Table 9-2. Cost effectiveness of various WASCoB scenarios

	Number of WASCoBs	Drainage area (ha)	Economic cost ($/yr)	Phosphorus reduction (kg/yr)	Cost effectiveness ($/kg of P)
WBBE	10	83.3	4,583.2	161.0	28.5
GLASI	3	43.5	2,393.1	91.0	26.3
Monitoring site	8	19.3	1,061.5	34.0	31.2
All existing	44	364.9	20,071.2	859.0	23.4
All existing and future	47	376.2	20,688.8	875.0	23.6

9.3 Cost effectiveness of land management BMP scenarios

The cost effectiveness of various land management scenarios is listed in Table 9.3. The scenario is developed based on SWAT simulated BMP effects for 15-year period. Windbreak BMP as a field-edge BMP is separated from those in-field BMPs. The cost effectiveness of land management BMPs has considerable variations. The cover crop BMP in 3 fields during 2013-2014 has a cost effectiveness ratio of $7.5 for per kg of P reduction. Windbreak BMP is also less expensive, with a cost effectiveness ratio of $13.4 per kg of P reduction. The next in the order are precision nutrient BMP in 6 fields during 2015-2016 and cover crop BMP in 3 fields during 2014-2015, with a cost effectiveness ratio of $20.8 and $21.8 per kg of P reduction respectively. However, other land management BMPs are relatively expensive, which is driven by relatively higher conservation tillage BMP cost. The cost effectiveness ratios for 2016-2017 and 2017-2018 periods are $37.5 and $46.6 per kg of P

Table 9-3. Cost effectiveness of various land management BMP scenarios

	Number of fields and BMPs	Area or length (ha or m)	Economic cost ($/yr)	Phosphorus reduction (kg/yr)	Cost effectiveness ($/kg of P)
2013-2014	3 cover crop fields	47.9	239.3	32.0	7.5
2014-2015	3 cover crop fields	39.2	196.0	9.0	21.8
2015-2016	6 precision nutrient management fields	58.7	1,020.0	49.2	20.8
2016-2017	3 soil amendment fields and 3 strip tillage fields	102.7	1,237.1	33.0	37.5
2017-2018	2 zero tillage field, 3 vertical tillage fields, and 8 precision nutrient management fields	157.9	2,471.5	53.0	46.6
Windbreak	2 fields of windbreak	1,125 m	281.3	21.0	13.4
2015-2018	All BMP fields during 2015-2018	319.1	4,728.6	75.0	63.0

reduction respectively. Another fact is that the cost effectiveness ratio for all land management BMPs (excluding windbreak) during 2015 to 2018 periods is $63.0 per kg of P reduction, which is the highest among all BMP scenarios. The reason is that these BMPs are implemented in multiple years and in some of the same fields, the joint effects of multiple BMPs have marginally decreasing trend but increasing BMP costs, which leading to the higher cost effectiveness ratio.

10.0 CONCLUSIONS

10.1 Project summary

This GLASI modelling further adapted SWAT modelling developed in the WBBE program during 2010-2013 to evaluate water quantity and quality effects of various BMPs in the Gully Creek watershed, particularly those BMPs implemented during the GLASI program from 2015 to 2017. For data preparation, climate input data were 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 2015 SWOOP imagery derived DEM was used for watershed delineation and derivation of spatial model parameters. Existing culvert data and field verification data were used to modify DEM 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, producer interviews, and windshield survey data were all used and combined to develop a synthesized landuse/land cover data layer. Furthermore, land management survey data from 2008 to 2010 were used to 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 sub-basins. This approach allowed modelers 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 96 subbasins were delineated for the Gully Creek watershed, which include 23 main tributary outlets, 19 monitoring stations (including 4 berm sites), 44 existing berms, 3 future berms, and 11 tile-drain outlets.

By combining slope classes with soil and landuse layers, a total of 689 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 ABCA staff were used to setup tile drain features in the SWAT.

SWAT calibration and validation were conducted to improve model predictions at the Gully Creek outlet (GULGUL2) and other inlet stations using available flow and water quality data. Both graphical comparisons and statistical measures indicated that the SWAT modelling had reasonable performances in simulating watershed processes under the existing conditions in the Gully Creek watershed.

The calibrated and validated SWAT model was applied to examine various BMP scenarios including 1). WASCoB scenarios with five sub-scenarios: WASCoBs under WBBE program, WASCoBs under GLASI program, WASCoBs near or on berm monitoring sites, all existing WASCoBs, and existing and future WASCoBs for the 15-year model simulation period; 2). Land management BMPs during 2013-2014; 3). Land management BMPs during 2014-2015; 4). Land management BMPs during 2015 -2016 (GLASI BMPs); 5). Land management BMPs during 2016 -2017 (GLASI BMPs); 6). Land management BMPs during 2017-2018 (GLASI BMPs); 7). All land management BMPs from 2015 to 2017 (GLASI BMPs); and 8). Windbreak BMPs during GLASI.

10.2 Key findings

Under the baseline scenario with existing land management practices and without WASCoBs, the sediment, TN and TP loadings at watershed outlet are 4,035 t/yr, 73,153 kg/yr, and 3,976 kg/yr respectively. In comparing to the baseline scenario, the 10 WASCoBs in the WBBE program have the potential to reduce sediment, TN, and TP by 224 t/yr, 3,053 kg/yr, and 161 kg/yr, which represent 5.55%, 4.17%, and 4.05% reductions respectively. The 3 WASCoBs in the GLASI program are relatively efficient. They have the potential to reduce sediment, TN, and TP by 140 t/yr, 1,833 kg/yr, and 91 kg/yr, which represent 3.47%, 2.51%, and 2.29% reductions respectively. The 8 WASCoBs in or near the monitoring site are relatively less efficient. They have the potential to reduce sediment, TN, and TP by 89 t/yr, 538 kg/yr, and 34 kg/yr, which represent 2.21%, 0.74%, and 0.86% reductions respectively. However, the construction of WASCoBs over the years has considerably accumulative effects on pollutant reductions. All existing 44 WASCoBs have the potential to reduce sediment, TN, and TP by 1,023 t/yr, 13,472 kg/yr, and 859 kg/yr, which represent 25.35%, 18.42%, and 21.60% reductions respectively. Adding the 3 WASCoBs that will be implemented in the future, the 47 WASCoBs have the potential to reduce sediment, TN, and TP by 1,046 t/yr, 13,933 kg/yr, and 875 kg/yr, which represent 25.92%, 19.05%, and 22.01% reductions respectively.

Under the baseline scenario with existing land management practices and WASCoBs, the sediment, TN and TP loadings at watershed outlet are 3,798 t/yr, 68,352 kg/yr, and 3,635 kg/yr respectively. Under the cover crop BMP scenario (3 fields with cover crop) during 2013-2014, the sediment, TN and TP reductions are 11.0 t/yr, 472.27 kg/yr, and 32.0 kg/yr, which represent 0.29%, 0.69%, and 0.88% reductions respectively in comparing to the baseline scenario. Under the cover crop BMP scenario (3 fields with cover crop) during 2014-2015, the sediment, TN and TP reductions are 56.0 t/yr, 1,569.33 kg/yr, and 9.0 kg/yr, which represent 1.48%, 2.3%, and 0.25% reductions respectively. Under the precision nutrient BMP scenario (6 fields) during 2015-2016 GLASI program, the sediment, TN and TP reductions are 0.0 t/yr, 1,318.28 kg/yr, and 49.15 kg/yr, which represent 0%, 1.93%, and 1.36% reductions respectively. It is reasonable that precision nutrient management BMPs have no sediment effects. The BMPs in the GLASI program during 2016-2017 included soil amendment with manure application and GIS based precision nutrient management in 3 fields and strip tillage in 3 fields. These BMPs have the potential to reduce sediment, TN and TP by 35.0 t/yr, 884.81 kg/yr, and 33.0 kg/yr, which represent 0.92%, 1.3%, and 0.92% reductions respectively. The GLASI program during 2017-2018 had the implementation of more BMPs, which included GPS based precision nutrient management in 8 fields, zero tillage in 2 fields, and vertical tillage in 3 fields. These BMPs have the potential to reduce sediment, TN and TP by 41.0 t/yr, 116.64 kg/yr, and 53.0 kg/yr, which represent 1.08%, 0.17%, and 1.47% reductions respectively. In total, GLASI program implemented various BMPs in 23 fields during 2015 to 2018. All these BMPs have the potential to reduce sediment, TN and TP by 62.0 t/yr, 547.17 kg/yr, and 75.0 kg/yr, which represent 1.63%, 0.80%, and 2.08% reductions respectively. Note that the effects of these combined GLASI BMPs are less than the sum of GLASI BMPs in individual years because of interactions of different processes within the landscape and marginal decrease of pollutant reduction efficiencies as more BMPs were implemented. While the pollutant reduction effects of these land management BMPs are in relatively small magnitudes due to relatively small scale of BMP implementation in the watershed, the BMP effects at edge-of-field (on-site effects) are more pronounced. Furthermore, SWAT modelling shows that the two windbreak BMPs as filter strips have reasonable pollutant reduction effects. The two windbreaks have the potential to reduce sediment, TN and TP by 28.7 t/yr, 225.69 kg/yr, and 21.0 kg/yr, which represent 0.76%, 0.33%, and 0.58% reductions respectively.

We conducted a preliminary assessment of cost effectiveness of various BMP scenarios. The GLASI program has a project on estimating the economic costs of GLASI BMPs and the project outcomes are currently not available. In this situation, we used our best knowledge to make assumptions on BMP costs based on the farm-economic modelling of BMPs (conservation tillage, nutrient management planning, cover crop and WASCoBs) conducted in the OMAFRA WBBE program by the Guelph WEG during 2010-2013. For land management BMPs, conservation tillage is the most expensive at \$20/ha. Precision nutrient management BMP can reduce fertilizer costs but new equipment such as GPS and yield monitoring purchase will add to the cost, with BMP cost at \$10/ha. Cover cop and soil amendment BMPs also have benefits to producers in terms of soil built-up, with minimum BMP cost at \$5/ha. Windbreak cost is associated with seedling, planting and tree spacing, with an assumption of \$25/\$100m based on annualization. The WASCoB cost including construction and maintenance costs estimated in WBBE program is at \$55/ha of drainage area. Based on the assumptions, the cost effectiveness ratio of all existing WASoBs is \$23.4 per kg of phosphorus reduction. The cost effectiveness ratios of other BMP scenarios are in the range between \$23.6 and \$31.2 per kg of P reduction. Cover crop BMPs during 2013-2014 and 2014-2015 periods are relatively efficient, with cost effectiveness ratios \$7.5 and \$ 21.8 per kg of P reduction. The cost effectiveness ratios for GLASI land management BMPs during 2015-2016, 2016-2017, and 2017-2018 are \$20.8, \$37.5 and \$46.6 per kg of P reduction respectively. The all GLASI land management scenario is most expensive, with cost effectiveness ratio \$63.0 per kg of P reduction. However, windbreak BMPs are relatively efficient, with cost effectiveness ratio $13.4 per kg of P reduction. Please note that high uncertainty exists in the cost effectiveness analysis, which is caused by the assumptions on BMP costs. With estimated BMP cost data from the GLASI, the preliminary cost effectiveness analysis can be updated.

The 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 on examining 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. Furthermore, the effects of some BMPs may need to take several years to be realized. Long-term monitoring data and more detailed input data are very important for reducing model uncertainties. This suggests 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.

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