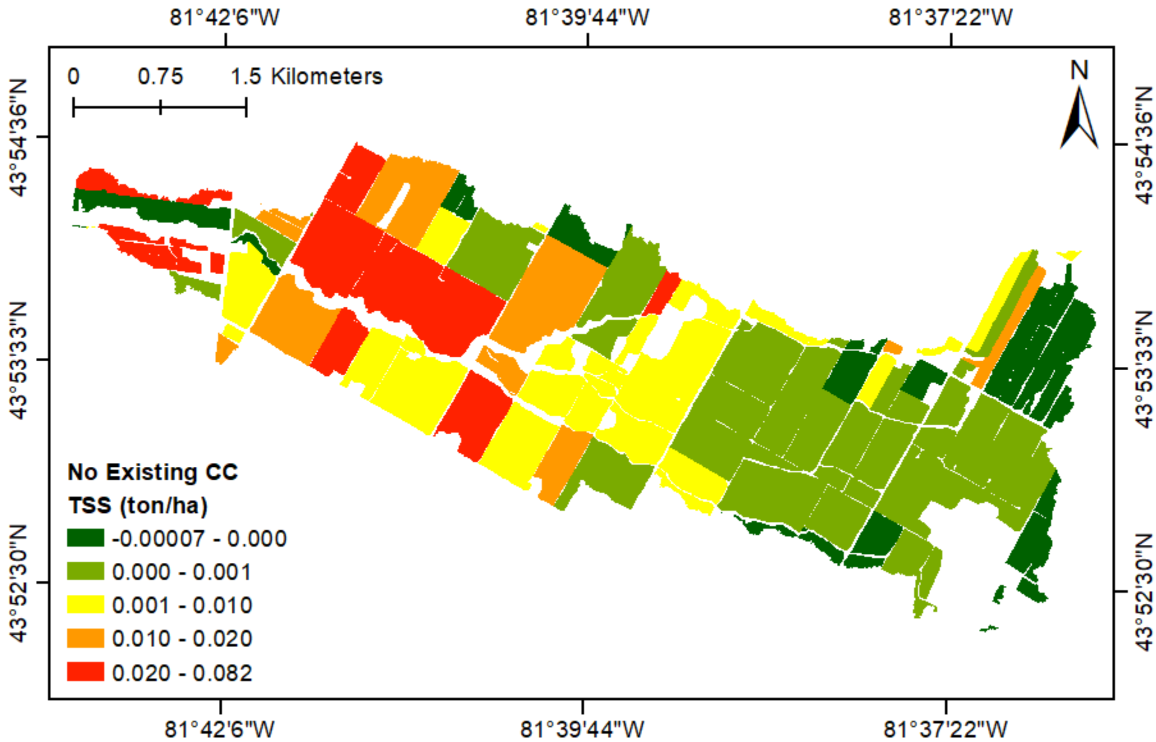

ONFARM

Modelling Report – Garvey Glenn

June 28, 2023

Prepared by:

The Watershed Evaluation Group

University of Guelph

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1.0 INTRODUCTION

The Garvey Glenn subwatershed in the service area of the Maitland Valley Conservation Authority (MVCA) is a representative lakeshore watershed of the southern 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/Beneficial Management Practices" or BMPs that focus on maintaining agricultural activity and farm profitability while protecting the environment.

From 2015 to 2018, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and the Ontario Soil and Crop Improvement Association (OSCIA) jointly implemented the Great Lakes Agricultural Stewardship Initiative (GLASI). In GLASI, the Garvey Glenn subwatershed was selected as one of the six priority subwatersheds for BMP establishment and study. By building upon MVCA's previous BMP initiatives and monitoring program, the GLASI program invested in establishing monitoring systems for evaluating existing and newly-established BMPs in the Garvey Glenn subwatershed, primarily conservation tillage, reducing soil compaction, fertilizer and manure incorporation, precision nutrient management, cover cropping, and construction of agricultural upland erosion control structures such as Water and Sediment Control Basins (WASCoBs), and grassed waterways. As a component of the GLASI, Soil and Water Assessment Tool (SWAT) modelling of the Garvey Glenn subwatershed was conducted to evaluate the water quality effects of various BMP scenarios (Watershed Evaluation Group, 2018).

The On-Farm Applied Research and Monitoring (ONFARM) program, administered by OMAFRA and OSCIA from 2019 to 2023, further developed soil health and water quality research on farms across Ontario. The ONFARM extended previous work under the GLASI priority subwatersheds to evaluate BMP effects on soil health and water quality. In the ONFARM project, MVCA colleagues continued their efforts on BMP experiments and data collection including completing farmer land management surveys and water monitoring. Watershed modelling for BMP assessment was also one of the key components of the ONFARM project.

The purpose of the ONFARM modelling project was to apply the Integrated Modelling for Watershed Evaluation of BMPs (IMWEBs) tool to evaluate the environmental effectiveness and cost effectiveness of three key agricultural BMPs (conservation tillage or no-till, cover cropping, and fertilizer/manure incorporation) in the six priority subwatersheds including the Garvey Glenn subwatershed. Specifically, the modelling project had the following objectives:

1). Collect and prepare IMWEBs modelling input data;

2). Set up and calibrate IMWEBs modelling to simulate the watershed's historical/existing conditions;

3). Apply IMWEBs modelling to evaluate the environmental effectiveness (including P loss reduction efficacies) and cost effectiveness of the three key agricultural BMPs of interest (cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation following application) presently existing or being applied in the study watersheds – referred to in this report as "existing actual BMP" scenario;

4). Apply IMWEBs modelling to evaluate the environmental effectiveness and cost effectiveness of the three key agricultural BMPs of interest (cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation following application) under different implementation levels and placement strategies across the watershed.

2.0 STUDY AREA

2.1 Location

The Garvey Glenn subwatershed is located in southwestern Ontario, about 15 km north of the Town of Goderich (Figure 2-1). The Garvey Glenn subwatershed drains directly into Lake Huron, about 3 km north of Port Albert. The subwatershed has a drainage area of 1,664 ha.

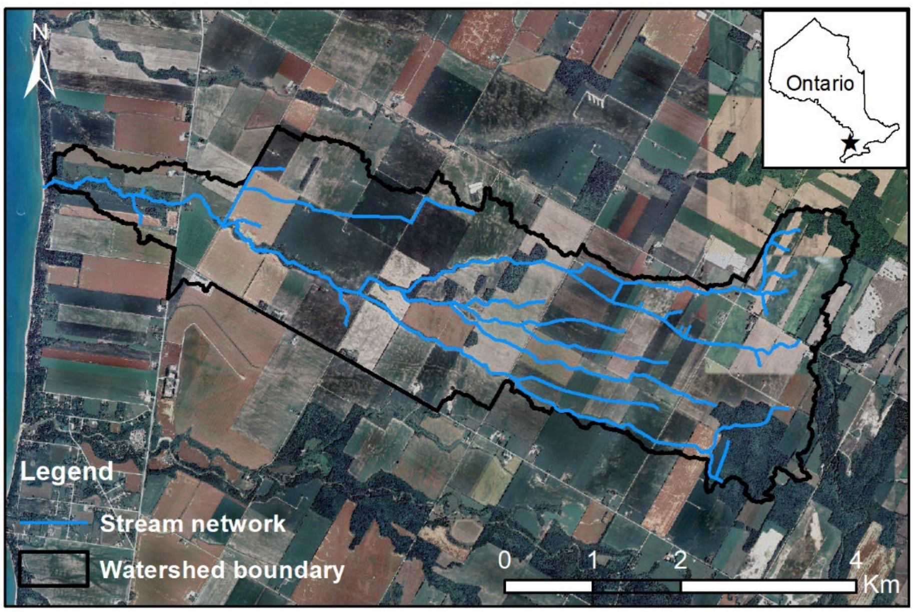

Figure 2-1. The Garvey Glenn subwatershed within southwestern Ontario

2.2 Topography, soil, and landuse

The Garvey Glenn subwatershed has undulating topography sloping from the highest elevation of 265 m in the east, to the lowest elevation of 177 m at the watershed outlet in the northwest (Figure 2-2, Table 2-1). The watershed is characterized by deep incised gullies along the mainstream and at the watershed outlet. The average slope (according to the 1-m pixel resolution LiDAR DEM) is 4.29%, with a minimum of 0.00% in flat areas and up to 211% (65°) at incised gullies (Figure 2-3).

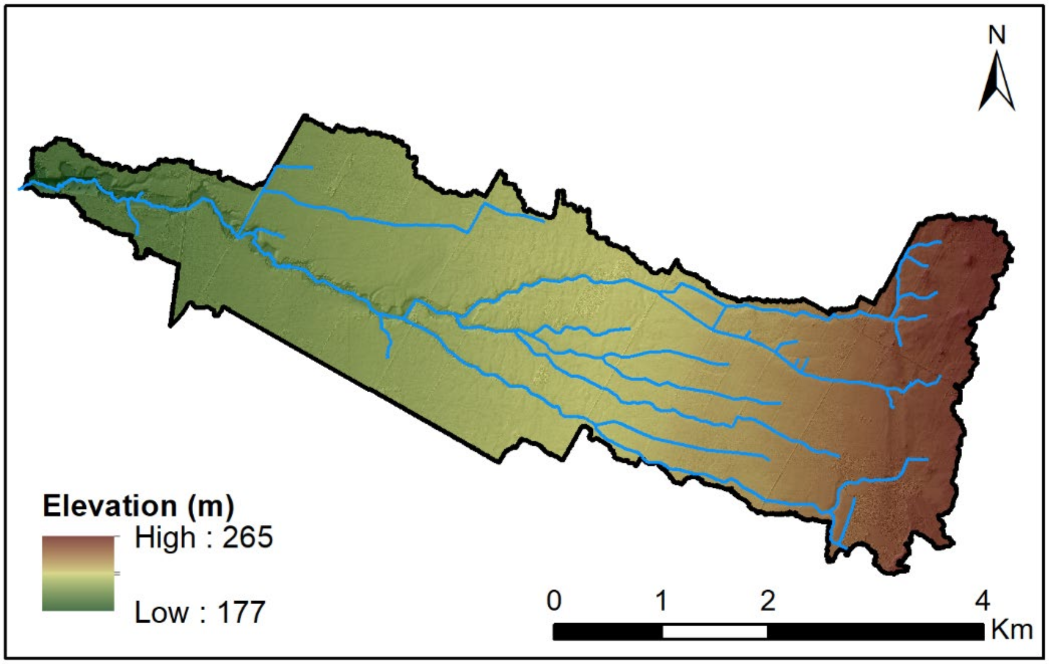

Figure 2-2. Topography of the Garvey Glenn subwatershed

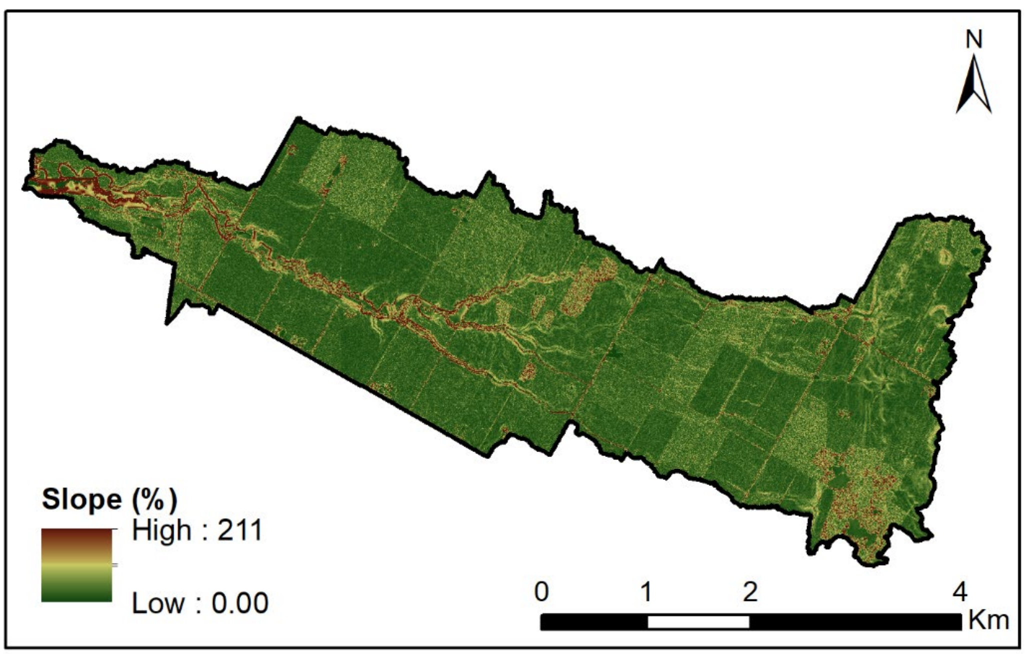

Figure 2-3. Slope of the Garvey Glenn subwatershed

Table 2-1. Elevation and slope areal extent in the Garvey Glenn subwatershed

Class	Elevation (m)	Area extent		Slope (%)	Area extent	
		(km^2)	(%)		(km^2)	(%)
1	177 - 211	1.64	9.85	0.00 - 3.30	9.98	60.0
2	212 - 221	4.21	25.3	3.31 - 10.7	5.53	33.2
3	222 - 231	4.62	27.8	10.8 - 23.9	0.828	4.97
4	232 - 245	2.79	16.8	24.0 - 48.7	0.258	1.55
5	246 - 265	3.38	20.3	48.8 - 211	0.042	0.252
Average/sum	229	16.6		4.29	16.6	100

The map of soil type distribution based on OMAFRA Soil Survey Complex is shown in Figure 2-4. The soil names and areal extents corresponding to each soil type within the Garvey Glenn subwatershed are shown in Table 2-2. The eastern, headwaters region of the watershed has undulating topography where Loam and Silt Loam soil textures dominate. The western, mainstream region is flatter and is dominated by Clay Loam and Sandy Loam soil textures.

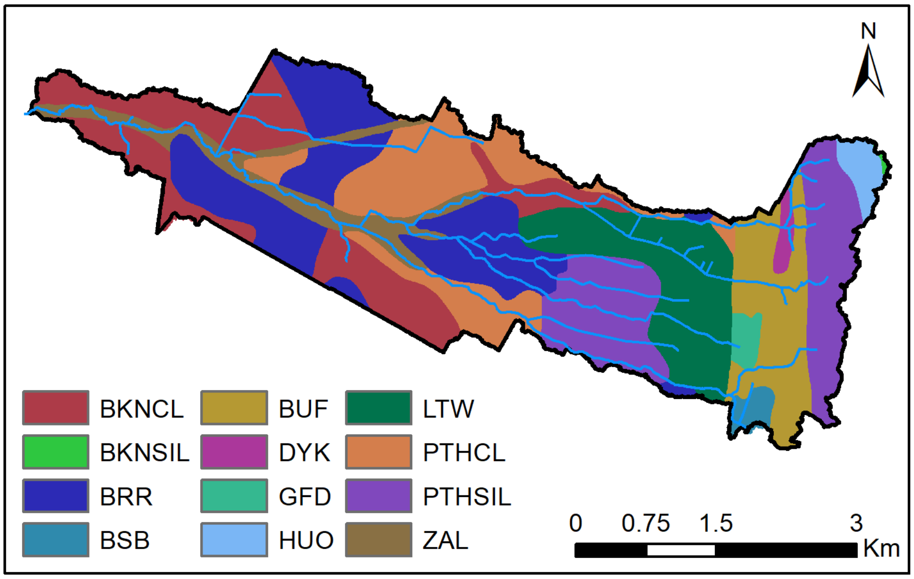

Figure 2-4. Soil types in the Garvey Glenn subwatershed based on OMAFRA soil survey data

Table 2-2. Soil types and areal extent in the Garvey Glenn subwatershed

Soil code	Soil type	Hydrologic group	Soil texture	Area (ha)	Watershed area (%)
BKNCL	Brookston Clay Loam	D	CL	288	17.3
BKNSIL	Brookston Silt Loam	D	SIL	1.74	0.105
BRR	Berrien Sandy Loam	C	SL	322	19.3
BSB	Brisbane Loam	B	L	18.8	1.13
BUF	Burford Loam	A	L	154	9.28
DYK	Donnybrook Sandy Loam	A	SL	13.2	0.790
GFD	Gilford Loam	C	L	16.9	1.01

HUO	Huron Silt Loam	C	SIL	26.4	1.58
LTW	Listowel Loam	B	L	210	12.6
PTHCL	Perth Clay Loam	C	CL	241	14.5
PTHSIL	Perth Silt Loam	C	SIL	261	15.7
ZAL	Bottom Land	C	L	111	6.69
Total				1,664	100.00

Figure 2-5 presents the landuse distribution within the Garvey Glenn subwatershed. The landuse names and associated areas and percentages within the Garvey Glenn subwatershed are listed in Table 2-3. Approximately 83.4% of the land is agricultural, while 11.9% is forest, 3.54% is urban (i.e., residential, industrial, and roads), and less than 2% is grassland.

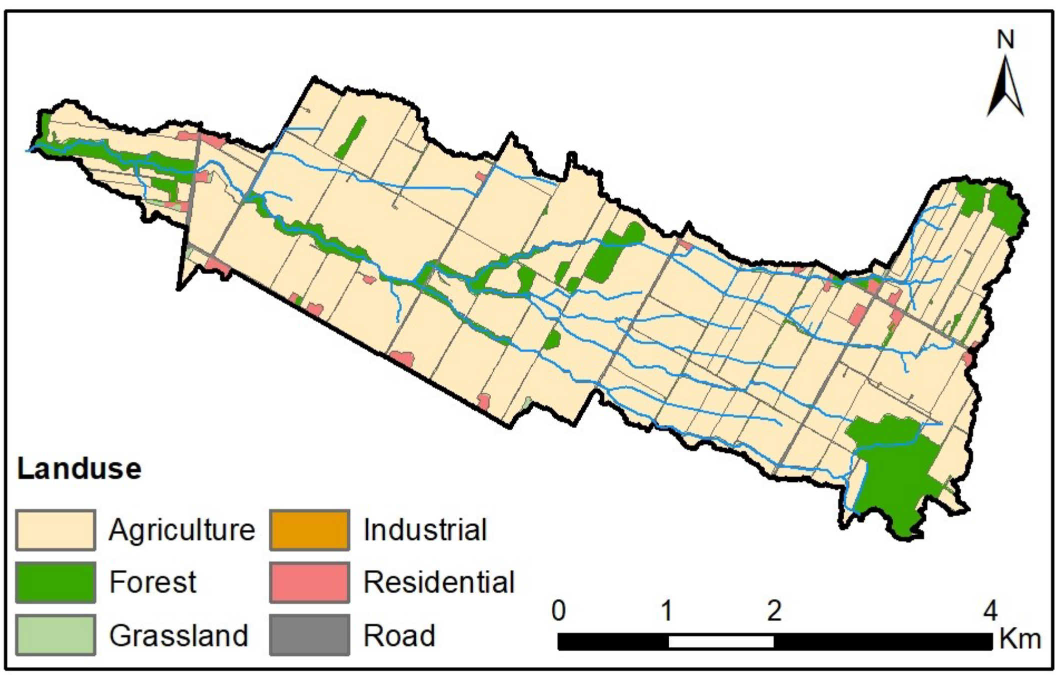

Figure 2-5. Landuse in the Garvey Glenn subwatershed

Table 2-3. Landuse and areal extent of the Garvey Glenn subwatershed

Land use type	Area (ha)	Percent (%)
Agriculture	1,388	83.4
Forest	198	11.9
Grassland	19.3	1.16
Residential	25.2	1.51
Industrial	0.1	0.008
Road	33.474	2.01
Total	1,664	100

2.3 Climate and hydrology

The input climate data (i.e., daily precipitation, maximum and minimum temperature, solar radiation, wind speed, wind direction, and relative humidity) were collected from three Maitland Valley Conservation Authority (MVCA) stations and eight Environment and Climate Change Canada (ECCC) stations (Figure 2-6, Table 2-4). Wind speed, relative humidity, and solar radiation were also downloaded from the website of NASA Prediction of Worldwide Energy Resources based on the latitude and longitude of the ECCC and MVCA climate stations to supplement the available climate data. A synthesized climate dataset from 1970-01-01 to 2022-06-30 was developed for the IMWEBs simulation.

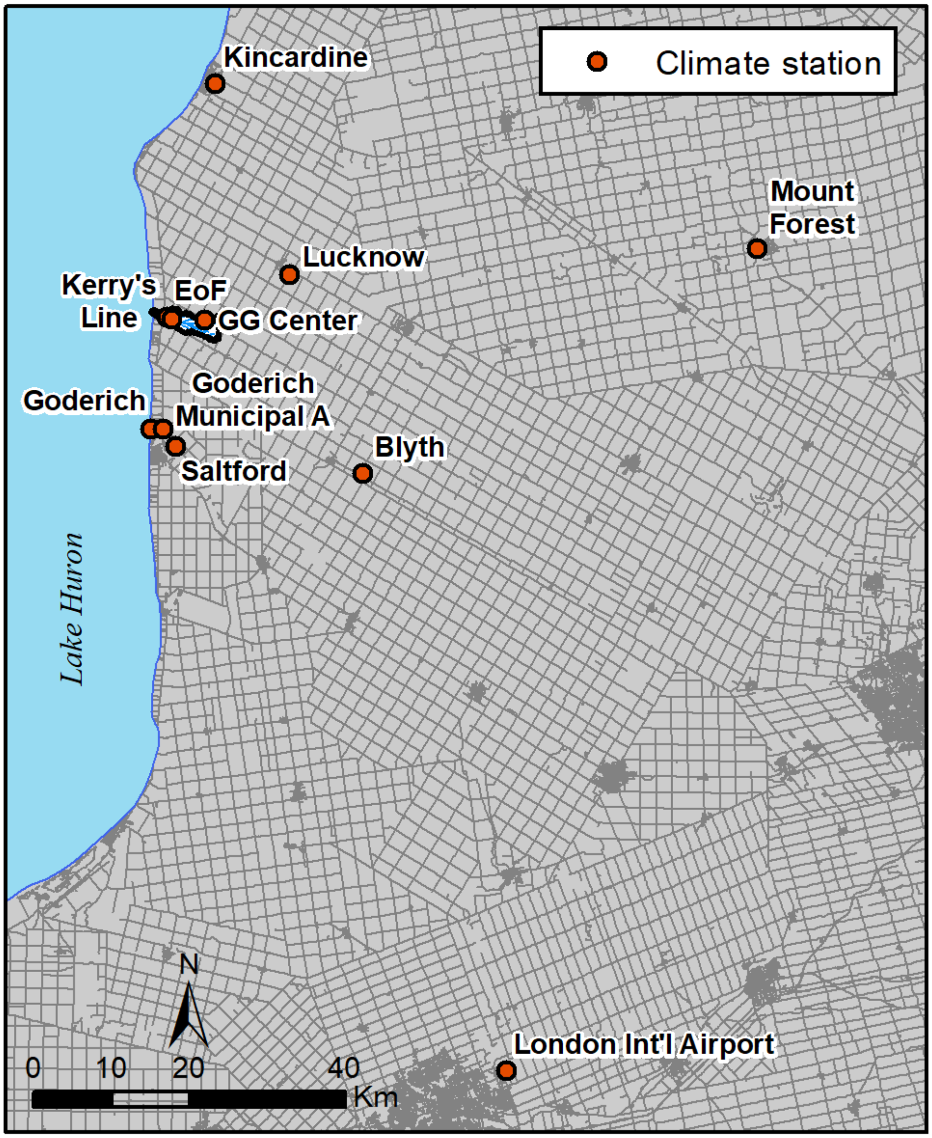

Figure 2-6. Climate monitoring stations for the Garvey Glenn subwatershed IMWEBs modelling. Note that Mount Forest and London Int'l Airport climate stations were only used for wind direction data

Table 2-4. Climate stations for the Garvey Glenn subwatershed IMWEBs modelling

ID	Name	Latitude	Longitude	Elevation	Frequency	Period	Parameters
1	Edge of Field Site (MVCA)	43.898	-81.686	207	5 or 10 minutes	2013-01-08 to 2022-06-30 (TMP & RH 2020-07-02 to 2022-06-30)	PCP, TMP, RH, SLR*, WS*
2	Kerry's Line (MVCA)	43.900	-81.695	217	5 or 10 minutes	2013-01-08 to 2017-07-05	PCP, RH*, SLR*, WS*
3	GG Center (MVCA)	43.896	-81.634	239	5 or 10 minutes	2012-09-24 to 2017-07-05	PCP, TMP, RH, SLR, WD
4	Lucknow (ECCC)	43.95	-81.50	290	Daily	1970-01-01 to 1993-06-30	PCP (Includes snow data), TMP, RH*, SLR*, WS*
5	Goderich Municipal A (ECCC)	43.77	-81.70	213	Hourly and Daily	1970-01-01 to 1980-10-31	PCP (Includes snow data), TMP, RH, WS, WD, SLR*
6	Saltford (ECCC)	43.75	-81.68	229	Daily	1976-01-01 to 1994-09-30	PCP (Includes snow data), TMP, RH*, SLR*, WS*

7	Goderich (ECCC)	43.77	-81.72	214	Hourly and Daily	1994-12-30 to 2022-06-30	PCP (no snow data), TMP, RH, WS, WD, SLR*
8	Blyth (ECCC)	43.72	-81.38	351	Daily	1970-01-01 to 2010-01-31	PCP (Includes snow data), TMP, RH*, SLR*, WS*
9	Kincardine (ECCC)	44.17	-81.62	200	Daily	1994-08-01 to 2022-06-30	PCP (Includes snow data), TMP, RH*, SLR*, WS*
10	Mount Forest (ECCC)	43.98	-80.75	415	Hourly and Daily	1970-01-01 to 2022-06-30	This station was only used for WD
11	London Int'l Airport (ECCC)	43.03	-81.15	278	Hourly and Daily	1970-01-01 to 2022-06-30	This station was only used for WD

Note: PCP means precipitation, TMP means temperature, WD means wind direction, WS means wind speed, RH means relative humidity, SLR means solar radiation. * in 'Parameters' column indicates the data are taken from NASA by specifying the latitude and longitude of the ECCC or MVCA climate station because NASA data are grid based.

Due to a lack of long-term climate data within the Garvey Glenn subwatershed, station 7 (ECCC Goderich) was chosen as a representative climate station for long term climate analysis from 1995 – 2021. Station 1 (MVCA Edge of Field) was also analyzed, but for a shorter time period from 2013 – 2021, based on the available data.

The Garvey Glenn subwatershed has a climate with pronounced seasonal variations. The growing season begins in early May and ends in October with an annual average of about 160 frost free days. At station 7 (ECCC Goderich), the average annual precipitation was 905 mm from 1995 to 2021 with a standard deviation of 173 mm. The maximum annual precipitation of 1,287 mm occurred in 2000, and the minimum was 603 mm, occurring in 2012. The maximum daily precipitation was 83 mm, recorded on May 20, 1996. The average annual temperature was 8.0 °C from 1995 to 2021, ranging from 9.5 °C in 2012 to 6.4 °C in 2014 with a standard deviation of 0.84 °C.

Yearly precipitation and average temperature from 1995 to 2021 at station 7 (ECCC Goderich) and station 1 (MVCA Edge of Field) are presented in Figure 2-7. At station 7 (ECCC Goderich) annual precipitation is on average decreasing, while annual average temperature is increasing from 1995 to 2021 (Figure 2-7). Comparison of annual average temperature between station 7 (ECCC Goderich) and station 1 (MVCA Edge of Field) shows that yearly average temperature is very similar between these two locations (Figure 2-7). Whereas comparison of yearly precipitation totals between station 7 (ECCC Goderich) and station 1 (MVCA Edge of Field) shows more variability in yearly precipitation between these two locations (Figure 2-7).

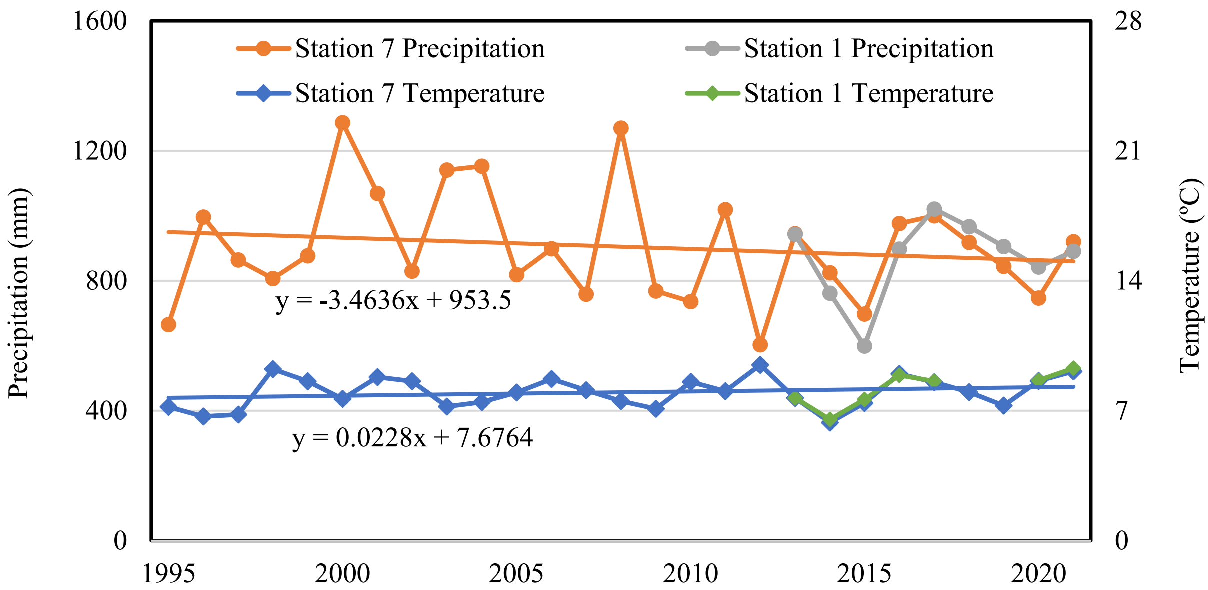

Figure 2-7. Variation of yearly precipitation and average temperature at station 7 (ECCC Goderich) and station 1 (MVCA Edge of Field) from 1995-01-01 to 2021-12-31. Note that station 3 (MVCA GG Center) was used to supplement station 1 (MVCA Edge of Field) average yearly temperature from 2013 – 2017 because station 1 does not measure temperature in those years and these two stations are 4.2 km apart.

Temperature is highest in the summer months from June to September, and lowest in the winter months from December to March in the Garvey Glenn subwatershed (Figure 2-8 and Figure 2-9). Precipitation is distributed somewhat evenly across the seasons, with winter months having lower average precipitation and autumn months having higher average precipitation (Table 2-5, Table 2-6).

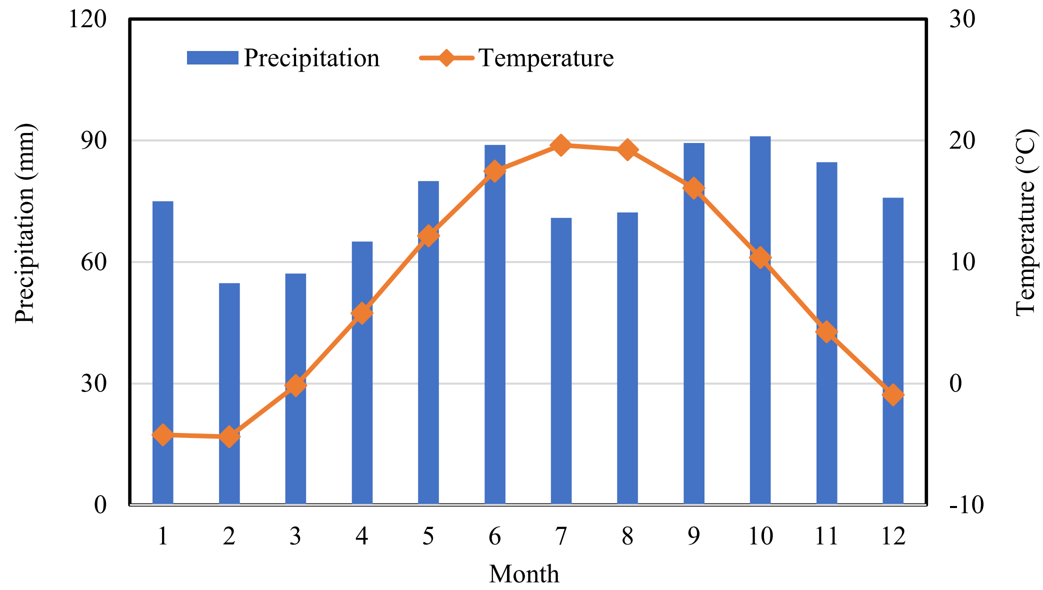

Figure 2-8. Average monthly precipitation and average temperature variation at Station 7 (ECCC Goderich) over the period of 1995 – 2021

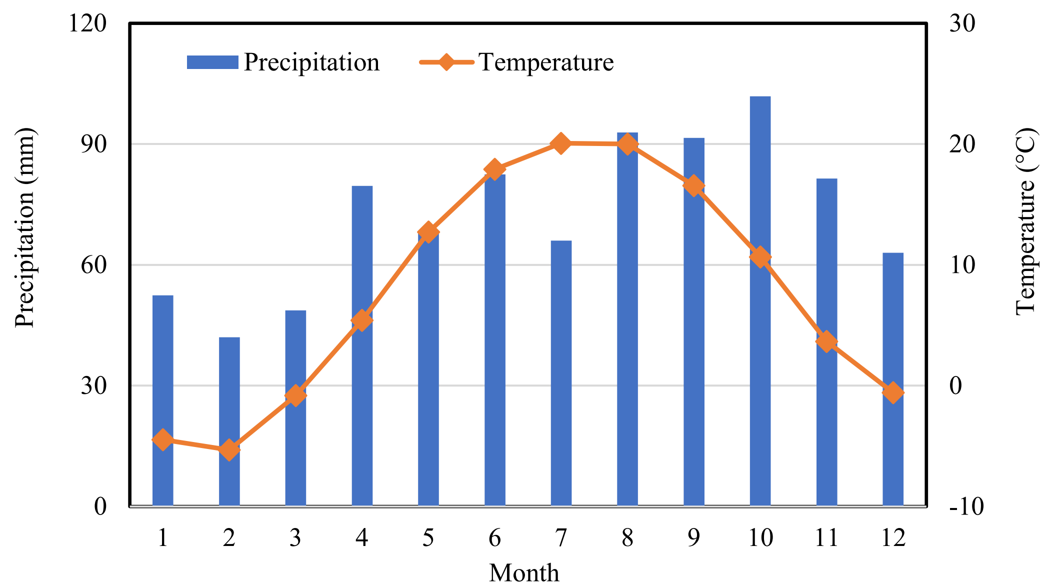

Figure 2-9. Average monthly precipitation and average temperature variation at Station 1 (MVCA Edge of Field) over the period of 2013 – 2021

Table 2-5 and Table 2-6 present average monthly temperature and precipitation at Station 7 (ECCC Goderich) over the period of 1995 – 2021 and Station 1 (MVCA Edge of Field) over the period of 2013 – 2021, respectively. Figure 2-10 presents baseflow separation for the Kerry's Line streamflow monitoring station from 2013-01-01 to 2022-06-30. Based on the SWAT Baseflow Separation tool, baseflow contributed to about 18% of total streamflow at the Garvey Glenn outlet station from 2013-01-01 to 2022-06-30.

Table 2-5. Average monthly precipitation and temperature at Station 7 (ECCC Goderich) over the period of 1995 – 2021

Month	T_max (°C)	T_min (°C)	T_avg (°C)	Precipitation (mm)
1	-1.02	-7.45	-4.23	75.0
2	-0.69	-8.08	-4.39	54.7
3	3.95	-4.27	-0.16	57.2
4	10.6	1.00	5.78	65.1
5	17.3	7.01	12.2	80.0
6	22.4	12.6	17.5	88.9
7	24.4	14.8	19.6	70.9
8	24.0	14.4	19.2	72.2
9	21.0	11.1	16.1	89.4
10	14.5	6.26	10.4	91.0
11	7.49	1.01	4.25	84.7

12	1.82	-3.71	-0.94	75.9
Ave/Sum	12.1	3.73	7.94	905
Max	24.4	14.8	19.6	91.0
Min	-1.02	-8.08	-4.39	54.7
STDV	9.74	8.46	9.08	12.2

Table 2-6. Average monthly precipitation and temperature at Station 1 (MVCA Edge of Field) over the period of 2013 – 2021

Month	T_max (°C)	T_min (°C)	T_avg (°C)	Precipitation (mm)
1	-1.18	-7.73	-4.46	52.4
2	-1.37	-9.27	-5.32	42.0
3	3.38	-4.97	-0.80	48.7
4	10.3	0.58	5.42	79.6
5	18.3	7.15	12.7	68.0
6	23.2	12.6	17.9	82.5
7	25.5	14.6	20.1	66.1

8	24.9	15.1	20.0	92.9
9	21.8	11.4	16.6	91.5
10	14.8	6.53	10.7	101.9
11	6.86	0.47	3.67	81.5
12	2.13	-3.27	-0.57	63.0
Ave/Sum	12.4	3.60	7.99	870
Max	25.5	15.1	20.1	101.9
Min	-1.37	-9.27	-5.32	42.0
STDV	10.32	8.79	9.54	18.9

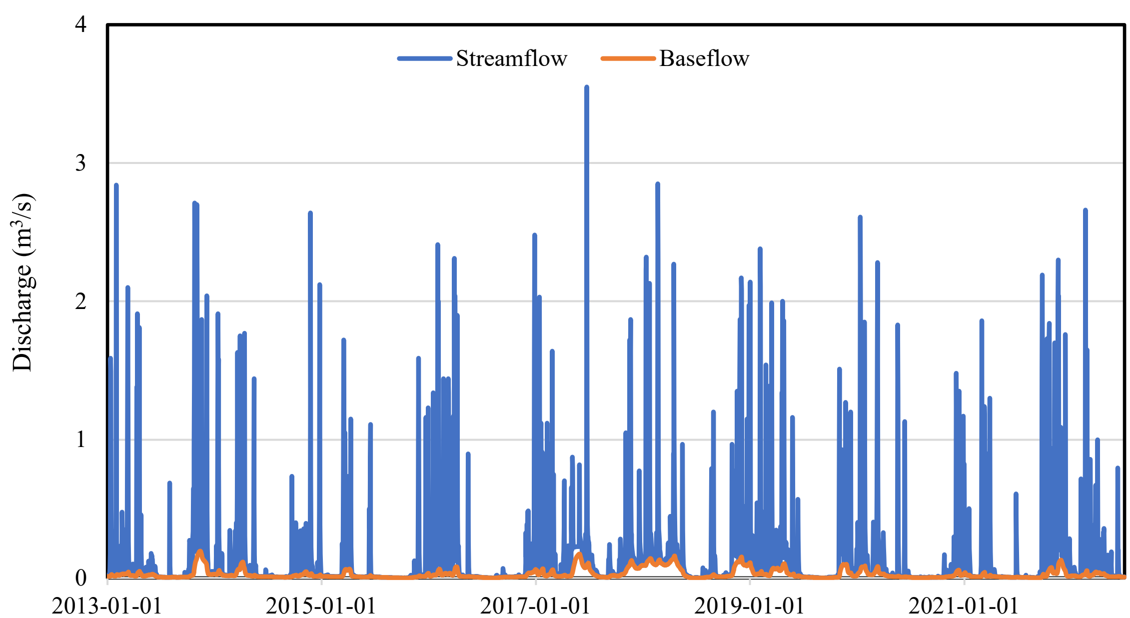

Figure 2-10. Baseflow separation at MVCA Kerry's Line station over the period of 2013-01-01 to 2022-06-30

3.0 DATA COLLECTION AND PREPARATION

3.1 GIS Data

Geospatial data required for IMWEBs model setup include topography, soil, landuse, stream network, and others (Table 3-1). These data were prepared using data from Maitland Valley Conservation Authority (MVCA), Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), and other sources.

Table 3-1. GIS data available for the Garvey Glenn subwatershed

Data	Format	Source	Use
SWOOP DEM (1x1 m)	TIFF	OMNR, MVCA	Model setup
Soil	Shape	OMAFRA	Model setup
Land use	Shape	MVCA	Model setup
Crop inventory 2011-2019	TIFF (30x30 m)	AAFC & MVCA	Crop rotation
Stream network	Shape	MVCA	Watershed delineation
Boundary	Shape	MVCA	Watershed delineation
Existing BMPs	Shape	MVCA	Model setup
Climate, flow, and water quality stations	Shape	MVCA, ECCC, NASA	Model setup
Field boundary	Shape	MVCA	Model setup
Tile drain	Shape	MVCA	Model setup
Transportation	Shape	MNRF	Presentation purpose

3.2 Climate Data

The IMWEBs requires daily precipitation, minimum temperature, maximum temperature, relative humidity, wind speed, wind direction, and solar radiation as input for the model. Climate data were prepared for 1970-01-01 to 2022-06-30 using Environment and Climate Change Canada (ECCC), National Aeronautics and Space Administration (NASA), and Maitland Valley Conservation Authority (MVCA) climate data. See section 2.3 for more details on the climate data.

3.3 Flow and Water Quality Data

Data used in IMWEBs model calibration includes stream flow (discharge), sediment concentration and load, and nutrient (nitrogen and phosphorus) concentration and load at a daily scale. These data were prepared from Maitland Valley Conservation Authority (MVCA) monitoring stations (Table 3-2). The locations of these stations are shown in Figure 3-1. Five stations were used for model calibration due to the availability of flow, sediment, and nutrient data at these five locations. The remaining eight stations were used as reference.

Table 3-2. Water quality and flow monitoring stations within the Garvey Glenn subwatershed

Name	Description	Drainage Area (km2)	Flow	Sediment	Nutrient
Site 10	Grab sample site	16.6	-	2011-2013	2011-2017
Site 19	Grab sample site	2.21	-	2011-2014	2011-2017
Site 20 (Kerry's Line) *	Main branch	13.3	2012-2022	2011-2022	2011-2022
Site 40 (Division Line North)*	Grab sample site	7.03	2012-2022	2011-2017	2011-2017
Site 50 (Division Line South)*	Grab sample site	2.75	2012-2022	2011-2017	2011-2017
Site 60	Grab sample site	2.90	-	2011-2013	2011-2017
Site 70	Grab sample site	1.15	-	2011-2013	2011-2017

Site 80	Grab sample site	2.24	-	2011-2013	2011-2017
Site 90	Grab sample site	1.39	-	2011-2013	2011-2017
Site 100	Grab sample site	0.561	-	2011-2013	2011-2016
Site 110	Grab sample site	0.527	-	2011-2013	2011-2016
EoF Overland*	Edge of field site	0.127	2017-2022	2017-2022	2017-2022
EoF Tile*	Edge of field site	0.127	2017-2022	2016-2022	2016-2022

Note: Stations with asterisks were used for calibration.

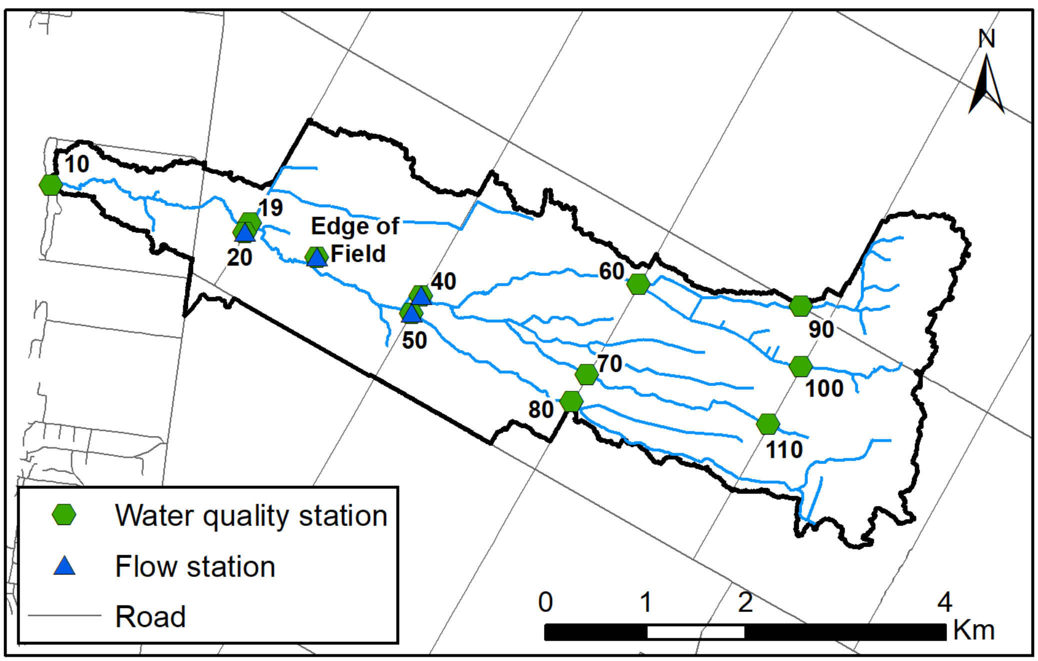

Figure 3-1. Flow and water quality monitoring stations in the Garvey Glenn subwatershed

3.4 Land Management Data

MVCA staff conducted land management surveys in 2017 under the Great Lakes Agricultural Stewardship Initiative (GLASI) program and in 2022 under the ONFARM project. The Garvey Glenn subwatershed IMWEBs modelling utilizes both the 2017 GLASI land management dataset as well as the

2022 ONFARM dataset to establish a land management dataset spanning 2013 – 2022. Windshield survey data and assumptions are used to extend the land management dataset to 2001 which establishes a land management dataset from 2001 to 2022. Table 3-3 describes the key parameters included in the land management dataset. Figure 3-2 shows the field boundary layer used for the collection of land management data for the ONFARM survey.

Table 3-3. Land management parameters surveyed under the GLASI and ONFARM programs in the Garvey Glenn subwatershed

Items	Description
Land features	Land ID, area and physical location
Crop	Crop name
Fall tillage	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, and how applied
Fertilizer, Phosphate	Rate and date applied, and how applied
Manure	Manure type, rate and date applied, and how applied
Tile drainage	Tile drain type, spacing, and depth

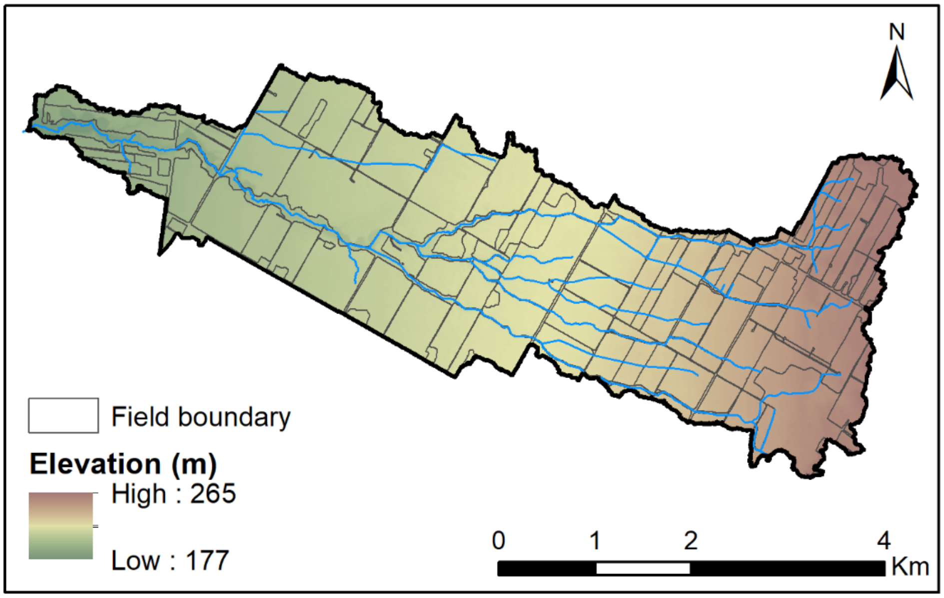

Figure 3-2. Field boundaries for the Garvey Glenn subwatershed IMWEBs modelling

3.5 Existing BMPs

There are 31 berms with associated catch basins (WASCoBs), 13 additional catch basins not associated with berms, 21 existing windbreaks, 16 existing riparian buffers, and 15 existing grassed waterways in the Garvey Glenn subwatershed (Figure 3-3).

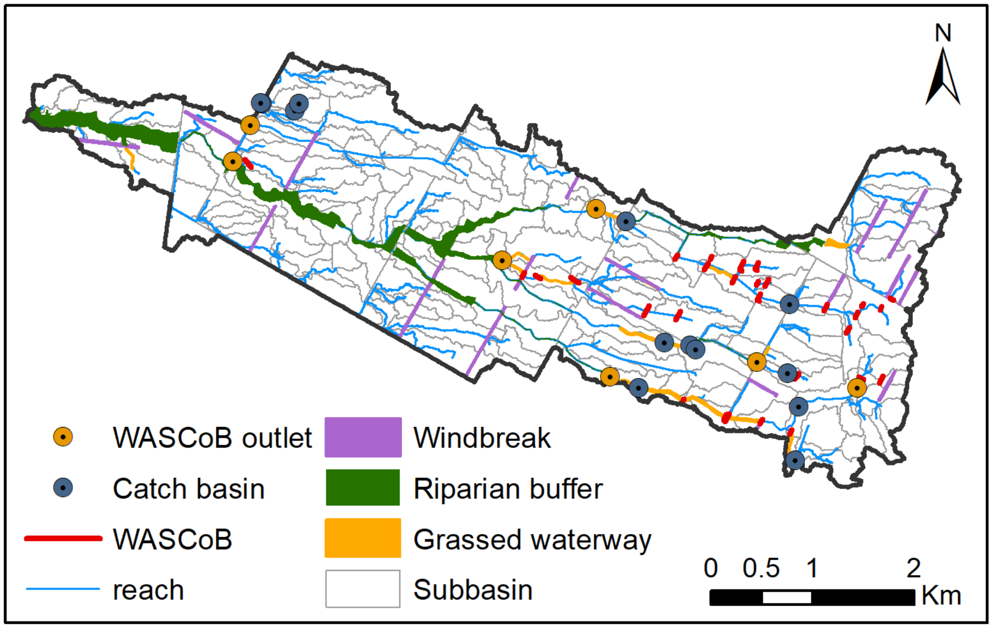

Figure 3-3. Existing Water and Sediment Control Basins (WASCoBs), catch basins, windbreaks, riparian buffers, and grassed waterways in the Garvey Glenn subwatershed

4.0 IMWEBS MODEL SETUP

4.1 Overview of the IMWEBs model

The Integrated Modelling for Watershed Evaluation of BMPs (IMWEBs) tool, developed by the Watershed Evaluation Group (WEG) of the University of Guelph with funding from Agriculture and Agri-Food Canada, Environment and Climate Change Canada, Alberta Agriculture and Forestry, Alberta Environment and Parks, Alberta Innovates, ALUS, and other organizations, is a cell-based hydrologic model specifically designed for conducting location-specific BMP assessment. The IMWEBs spatial units are further aggregated from cells to subareas in order to reduce computational time for model simulation while maintaining detailed characterization of land management practices and BMPs. The subarea layer can be defined by intersecting the farm field boundary layer with the subbasin layer and other layers such as slope class and soil type layers, if necessary. Similar to SWAT/CanSWAT, a relatively coarse resolution can be made of the watershed for the purpose of characterizing BMPs in the context of large watersheds. What is unique about the IMWEBs tool, however, is that it has a cell-based and subarea-based structure, rather than a subbasin/HRU structure, allowing the potential for landscape features including agricultural lands, wetlands, and riparian buffers to be partitioned by fine-resolution grid cells and subareas, enabling location-specific representation within the model. The IMWEBs model is a fully-fledged hydrologic model with characterization of landscape processes including climate, water balance, plant/crop growth, as well as sediment and nutrient fate. The IMWEBs is the only model in Canada that is designed for evaluating water quantity and quality effects of agricultural BMPs over a variety of modelling scales from the site, field, and farm to the watershed scales.

4.2 Watershed delineation

The IMWEBs model uses the Digital Elevation Model (DEM) and stream network to delineate the watershed boundary. The watershed was delineated by burning the stream network into the DEM to ensure accurate flow routing. The flow and water quality monitoring stations as well as the WASCOB outlets were specified as subbasin outlets. The stream initiation threshold was set to 5 ha, in order to delineate subbasins for the monitoring stations with the smallest contributing areas. Figure 4-1 shows the delineated watershed for the Garvey Glenn IMWEBs modelling, which contains 201 subbasins.

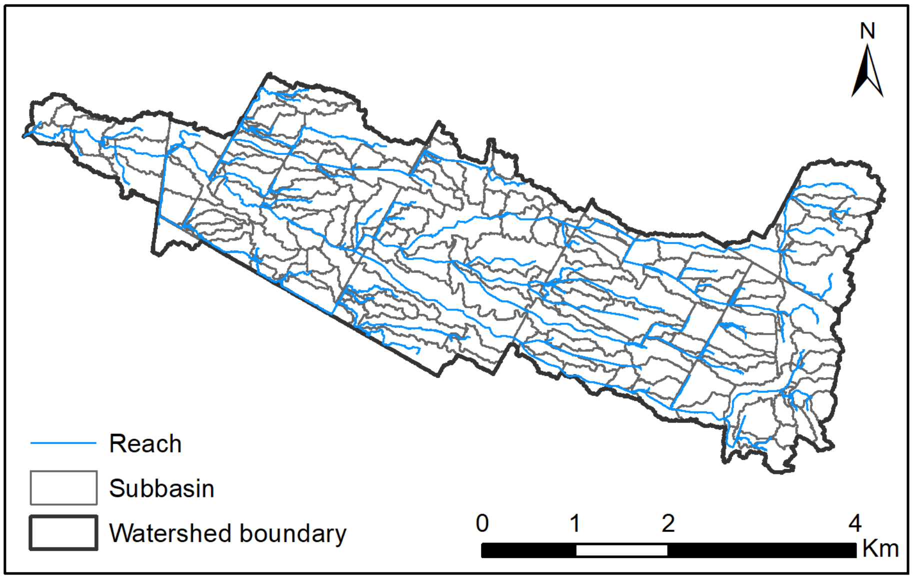

Figure 4-1. Delineated watershed boundary, subbasins, and reaches for the Garvey Glenn IMWEBs modelling

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. The OMAFRA Soil Survey Complex was used to define soil type distribution and key soil parameters for the Garvey Glenn subwatershed IMWEBs modelling. The soil sample data collected at the Edge of Field site for the ONFARM project was also incorporated into the soil database table for the IMWEBs modelling. A summary of soil characterization for the Garvey Glenn subwatershed IMWEBs modelling is provided in Table 2-2.

4.4 Landuse characterization

The IMWEBs model has a detailed land cover classification including 98 plant types and 8 urban landuses. For the Garvey Glenn subwatershed, a total of 6 distinct landuse types were identified based on the landuse data. The landuse types and associated areas and percentages within the Garvey Glenn subwatershed are listed in Table 2-3.

4.5 Subarea definition

The IMWEBs model uses subareas to reduce the computer processing times associated with the cell-based IMWEBs model. Subareas are the smallest management unit for defining land management operations and structural BMPs. The subarea layer was created by intersecting the field boundary layer with the subbasin layer. Figure 4-2 presents the subarea layer for the Garvey Glenn subwatershed modelling, which contains 1,752 subareas.

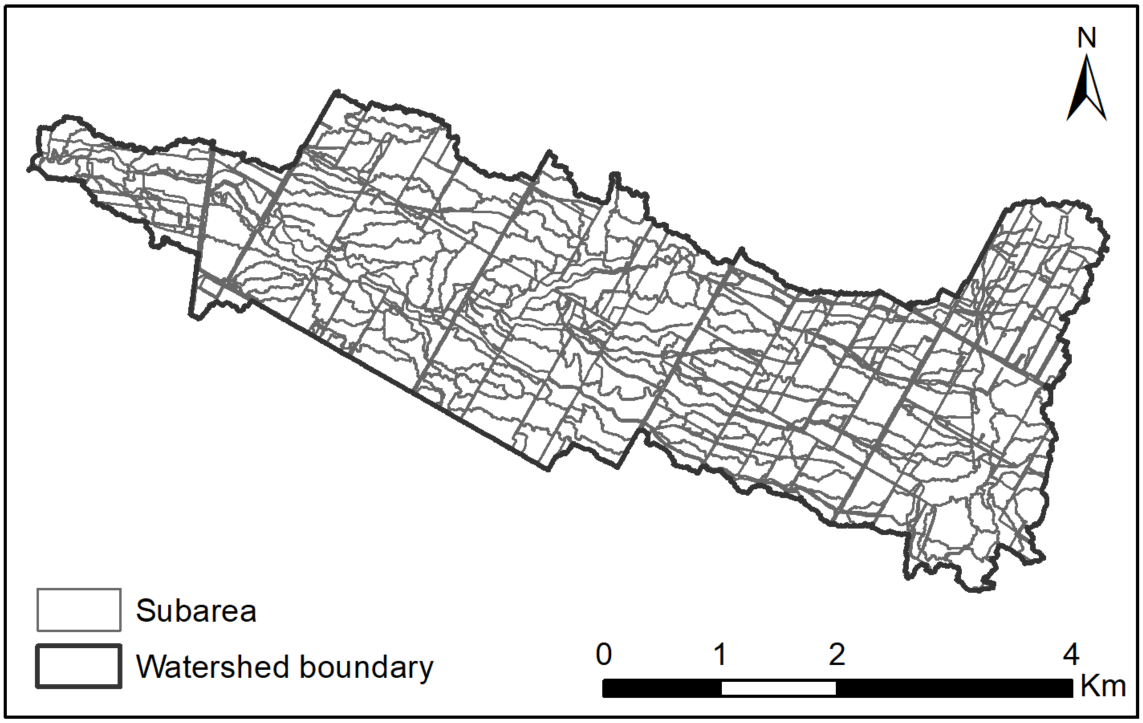

Figure 4-2. Subarea layer for the Garvey Glenn subwatershed IMWEBs modelling

4.6 Land management operations

Land management operations are a critical input for the IMWEBs model. Land management operations affect plant growth, nutrient availability, and nutrient and sediment transport throughout the watershed. MVCA staff conducted GLASI and ONFARM land management surveys in the Garvey Glenn subwatershed in 2017 and 2022 to establish a 10-year land management dataset spanning from 2013 – 2022. Windshield survey data and assumptions were used to extend the land management dataset to 2001 which establishes a land management dataset from 2001 to 2022. Table 3-3 describes the key parameters included in the land management dataset.

4.7 Tile drain characterization

All fields were assumed to be tile drained in the Garvey Glenn subwatershed based on information provided by MVCA. The ONFARM land management survey contained tile drain spacing and tile depth data, which was incorporated into the IMWEBs modelling. For fields that did not have tile drain spacing and depth data listed in the survey, the dominant depth and spacing from the survey was assumed. Table 4-1 presents tile drain parameters for the Garvey Glenn subwatershed, including radius and the dominant tile spacing and tile depth. Note that we also added the parameters for simulating controlled tile drain in IMWEBs setup which include start and end months for controlled tile drain and depth of controlled tile drain.

Table 4-1. Tile drain parameters for the Garvey Glenn subwatershed IMWEBs modelling

Start month for controlled tile drain	End month for controlled tile drain	Radius (mm)	Spacing (mm)	Tile drain depth (mm)	Controlled tile drain depth (mm)
April	October	50	12,192	914	500

4.8 Water and Sediment Control Basin (WASCoB) characterization

There were 31 berms with associated riser or catch basin surface water inlets (WASCoBs), and 13 additional catch basins directing surface water to underground drainage systems not associated with berms setup in the Garvey Glenn IMWEBs model, based on data provided by MVCA. Figure 4-3 shows the locations of these WASCoBs as well as the corresponding cluster outlets (orange color) in the Garvey Glenn subwatershed. The cluster outlets are the points where multiple surface inlets upstream outletting to subsurface tile drainage systems eventually outlet into the surface stream.

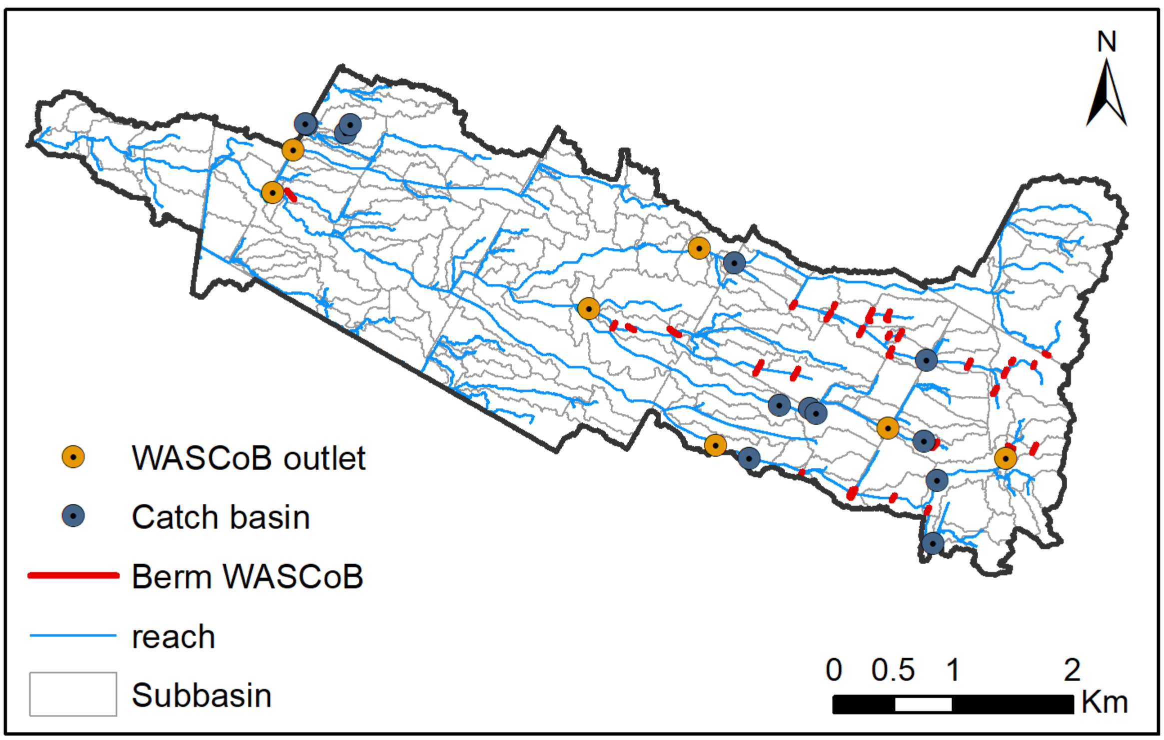

Figure 4-3. Location of WASCoBs and cluster outlets in the Garvey Glenn subwatershed IMWEBs modelling

Parameterization of WASCoBs in the Garvey Glenn IMWEBs model made use of the information available from the GLASI project, as well as new information provided by MVCA. Table 4-2 lists key WASCoB parameters used in the Garvey Glenn subwatershed IMWEBs model. The IMWEBs model requires three WASCoB storage volumes be defined, the normal storage volume, the emergency storage volume, and dead storage. Because no emergency spillways were designed in these WASCOBs, the maximum volume was set to the normal volume, and the maximum surface area was set to the normal surface area. Dead storage was assumed to be zero. Due to a lack of information on the 13 additional catch basins, which were not modelled in the GLASI project, all 13 catch basins were assumed to have a ponding area that covered 0.1 ha surface area and 200 m^3 volume storage capacity. The nearest downstream open reach was assumed to be the outlet location. Some missing WASCoB parameters in the table were estimated by referencing other similar WASCoBs with available data.

Table 4-2. WASCoB characteristics in the Garvey Glenn subwatershed

ID	WASoB ID	Type	Installation Year	Subbasin	Drainage area (ha)	Outlet Reach	Outlet ID	Volume (m^3)	Surface area (ha)	Capacity (m^3/day)
1	KRANE	6"" hickenbottom and french drain	2012	137	9.79	74	GLENN_E_West	965	0.31	20,321
2	KRAT3	6"" hickenbottom and french drain	2012	137	0.09	74	GLENN_E_West	386	0.26	20,321
3	KRAM3	8"" hickenbottom and french drain	2012	137	11.82	74	GLENN_E_West	1,680	1.73	20,321
4	KRAB3	6"" hickenbottom and french drain	2012	147	0.08	74	GLENN_E_West	1,591	0.65	20,321
5	KRANW	600mmx600mm catchbasin and french drain	2012	147	15.52	74	GLENN_E_West	1,053	0.61	20,321
6	KRAWHW	6"" hickenbottom and french drain	2015	181	18.49	187	KRAFT_HW	3,200	1.27	4,000
7	KRAU	10"" dropbox and french drain	2016	182	38.88	173	GLENN_B	6,635	0.23	6,497

8	VVE	10"" dropbox and french drain	2016	193	59.92	173	GLENN_B	9,787	0.66	6,497
9	CULE	10"" dropbox and french drain	2016	188	14.29	173	GLENN_B	5,198	0.89	6,497
10	GN1	900x1200mm and 150mm inlets with french drain	2018	129	26.1	74	GLENN_E_West	4,978	0.64	20,321
11	CC1	900x1200mm and 150mm inlets with french drain	2018	129	0.52	74	GLENN_E_West	3,418	0.44	20,321
12	SC2	900x1200mm and 150mm inlets with french drain	2018	129	0.13	74	GLENN_E_West	4,089	0.53	20,321
13	KRATO	french drain	2014	179	39	174	KRAFT_TO	1,106	3.85	1,382
14	REID	6"" french drain	2015	112	0.2	74	GLENN_E_West	5,426	0.83	20,321
15	GN3	900x1200mm and 150mm inlets with french drain	2018	106	0.15	74	GLENN_E_West	1,909	0.25	20,321
16	MC1	900x1200mm and 150mm inlets with french drain	2018	106	1.56	74	GLENN_E_West	6,827	0.88	20,321

17	CC2	900x1200mm and 150mm inlets with french drain	2018	132	5.44	74	GLENN_E_West	3,061	0.39	20,321
18	SC4	900x1200mm and 150mm inlets with french drain	2018	121	1.06	74	GLENN_E_West	3,804	0.49	20,321
19	SC3	900x1200mm and 150mm inlets with french drain	2018	118	9.14	74	GLENN_E_West	7,903	1.02	20,321
20	SC1	900x1200mm and 150mm inlets with french drain	2018	135	0.02	74	GLENN_E_West	1,375	0.18	20,321
21	KRAEHW	6"" hickenbottom and french drain	2015	181	3.64	187	KRAFT_HW	1,007	0.14	4,000
22	VVET	10"" dropbox and french drain	2016	190	22.72	173	GLENN_B	4,800	0.55	6,497
23	VVWT	Unknown	2016	190	0.11	173	GLENN_B	5,198	1.04	6,497
24	HB1	hickenbottom and french drain	2017	131	45.04	103	GLENN_D_West	1,616	0.21	3,309
25	MC2	hickenbottom and french drain	2017	151	10.99	103	GLENN_D_West	2,647	0.53	3,309
26	MILL	hickenbottom and french drain	2017	141	10.57	103	GLENN_D_West	2,647	2.3	3,309

27	ADA	hickenbottom and french drain	2017	126	1.8	103	GLENN_D_West	1,950	0.25	3,309
28	HB2	hickenbottom and french drain	2017	126	32.02	103	GLENN_D_West	2,647	0.66	3,309
29	KRATOB	french drain	2017	178	8.21	174	KRAFT_TO	1,106	0.99	1,382
30	SNOBE	Unknown	2014	44	28.97	47	SNOBE	2,647	0.66	3,309
31	LH1	6"" hickenbottom	2000	8	6.28	27	LH1	3,061	0.39	20,321

5.0 IMWEBs MODEL CALIBRATION

5.1 Overview of IMWEBs model calibration

Calibrating the IMWEBs model involves adjusting model inputs and parameters to optimize the agreement between measured data and model simulation results for realistically characterizing watershed historical/existing observed conditions. A simulation period of 2012-10-01 to 2021-12-31 was used for model calibration. Streamflow monitoring site 20 (Kerry's Line), 50 (Division Line South) and the Edge of Field overland flow monitoring data were used for model calibration, while sites 40 (Division Line North) and the Edge of Field tile flow monitoring data were used as a reference during model calibration. The water quality data at the other 8 stations were also used as a reference during model calibration. The model was calibrated firstly for flow; followed by sediment, particulate P, and particulate N; and lastly dissolved P and dissolved N.

IMWEBs calibration was evaluated graphically and also statistically based on three indicators, Nash–Sutcliffe coefficient (NSC), Percent bias (PBIAS), and correlation coefficient (CORR). The Nash-Sutcliffe coefficient (Nash and Sutcliffe, 1970) describes how well the model simulates the observed values and is calculated by comparing the variance of the differences between simulated and observed values to the variance of observed values.

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

where NSC is the Nash-Sutcliffe efficiency, *Qoi* and Qs_i and are the observed and simulated values on day i (m^3/s), $\overline{Qo}$ is the mean of observed values, and N is the number of days over the simulation period. 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 stream flow than that predicted by the model. A perfect model prediction has NSC value of 1 with higher positive value indicating better match of simulated flow with observed flow. PBIAS measures the relative mean difference between predicted and observed values.

$$PBIAS = \sum_{i=1}^{N}(Qo_i - Qs_i) * 100 \Big/ \sum_{i=1}^{N} Qo_i$$

The optimal value of PBIAS is 0.0, with lower values indicating more accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. CORR measures the degree of dependence of one variable upon another.

$$CORR = \frac{\sum_{i=1}^{n}\left(Qo_i - \overline{Qo}\right)\left(Qs_i - \overline{Qs}\right)}{\sqrt{\sum_{i=1}^{n}\left(Qo_i - \overline{Qo}\right)^2 \sum_{i=1}^{n}\left(Qs_i - \overline{Qs}\right)^2}}$$

Where $\overline{Qo}$ and $\overline{Qs}$ are means of observed and simulated values. A higher CORR indicates a higher correlation between observed and simulated values. In contrast to continuous flow monitoring data, most Total Suspend Solid (TSS), Nitrogen(N) and Phosphorus (P) monitoring data have limited samples, which are not suitable for calculating NSC. Therefore, only PBIAS and CORR are used for measuring the performance on IMWEBs calibration of TSS, N and P.

5.2 Flow calibration

While we made use of all available flow monitoring data for IMWEBs calibration, we focused on improving modelling performance for flow at a daily time step at site 20 (Kerry's Line). Table 5-1 presents the parameters used for water balance and flow routing calibration and Figure 5-1 shows the graph of measured vs. simulated flow. A reasonable flow calibration was achieved at site 20 (Kerry's Line) resulting in a NSC of 0.41, a model bias of 8.86%, and a CORR of 0.65 based on the criteria outlined in Moriasi et. al (2007).

Table 5-1. Calibrated water balance and flow routing parameters for the Garvey Glenn Subwatershed IMWEBs model

Parameter	Definition	Value
depression	Depression storage capacity	-0.5*
runoff_co	Potential runoff coefficient	0.2*
K_pet	Correction factor for PET	-0.2
rootdepth	Root depth	-0.55*
fieldcap_layer1	Soil field capacity	0*
porosity_layer1	Soil porosity	-0.13*
porosity_layer2	Soil porosity	-0.2*
rv_co	Groundwater revaporation coefficient	0.1
kg	Baseflow recession coefficient	0
base_ex	Baseflow recession exponent	1.3
K_run	Runoff exponent when net rainfall approaches to zero	2.0
P_max	Maximum rainfall intensity	20
soil_ta0	Empirical coefficient for estimating soil temperature	-3.7
K_blow	Fraction of snow into or out of the watershed	-0.05
T0	Snowmelt temperature	-2
swe0	Initial snow water equivalent	25
K_snow	Degree day coefficient mm/ $_{O}$C/day	-1

SHC_crop	Snow holding capacity of cropland	10
s_frozen	Frozen moisture relative to porosity with no	0.1
t_soil	Soil freezing temperature	-1

* Ratio of relative parameter change, e.g. porosity_layer1 modified = porosity_layer1-0.13× porosity_layer1

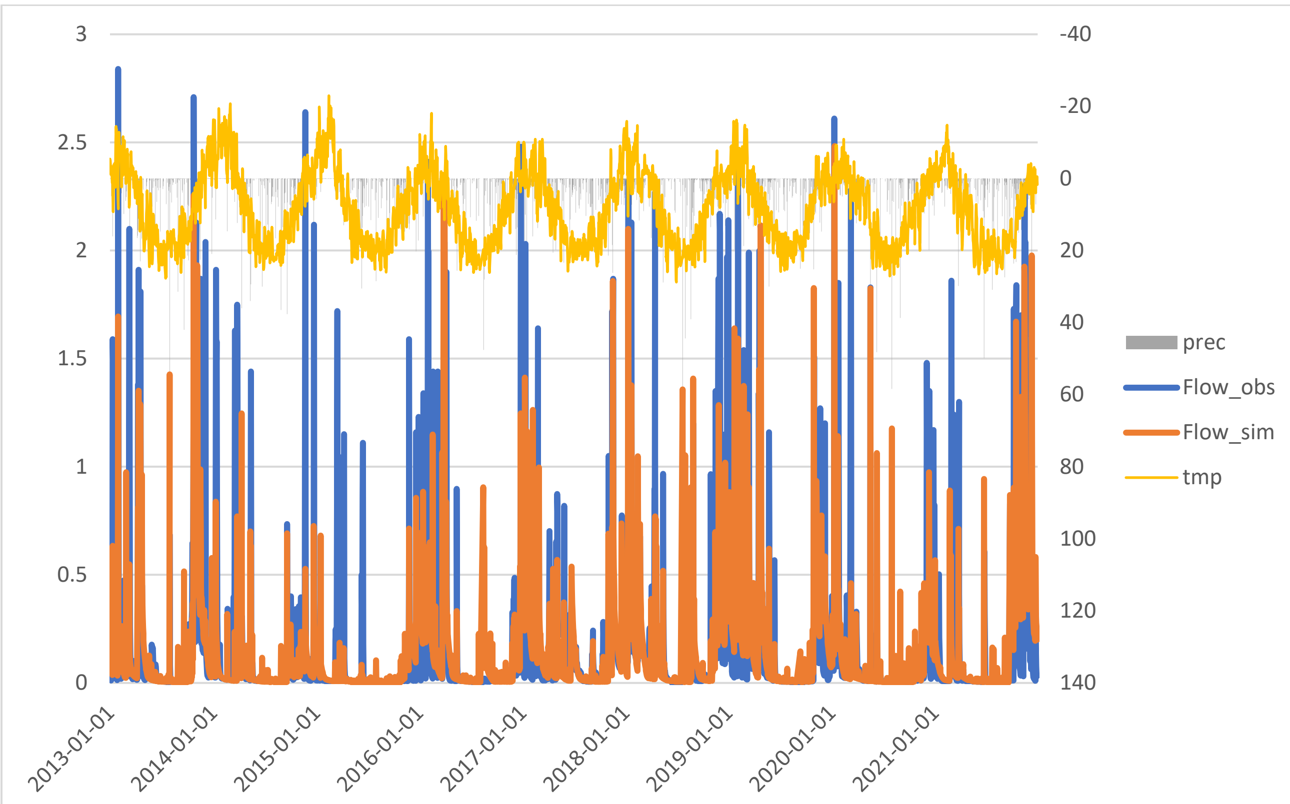

Figure 5-1. Measured vs. simulated flow at site 20 (Kerry's Line)

5.3 Sediment calibration

While we made use of all available sediment concentration monitoring data for IMWEBs calibration, we focused on improving modelling performance for sediment concentration data points at a daily time step at site 20 (Kerry's Line). Table 5-2 presents the parameters used for soil erosion and sediment transport calibration and Figure 5-2 shows the graph of measured vs. simulated sediment concentrations. A reasonable flow calibration was achieved at site 20 (Kerry's Line) resulting in a model bias of -0.67%, and a CORR of 0.68 based on the criteria outlined in Moriasi et. al (2007).

Table 5-2. Calibrated soil erosion and sediment transport parameters for the Garvey Glenn Subwatershed IMWEBs model

Parameter	Definition	Value
USLE_K_layer1	K-factor for MUSLE	-0.08*
USLE_C	C-factor for MUSLE	-0.08*
spexp	Exponent in sediment transport equation	0
spcon	Coefficient in sediment transport equation	0.019

Note: * ratio of relative parameter change, e.g. USLE_C modified = USLE_C-0.08×USLE_C

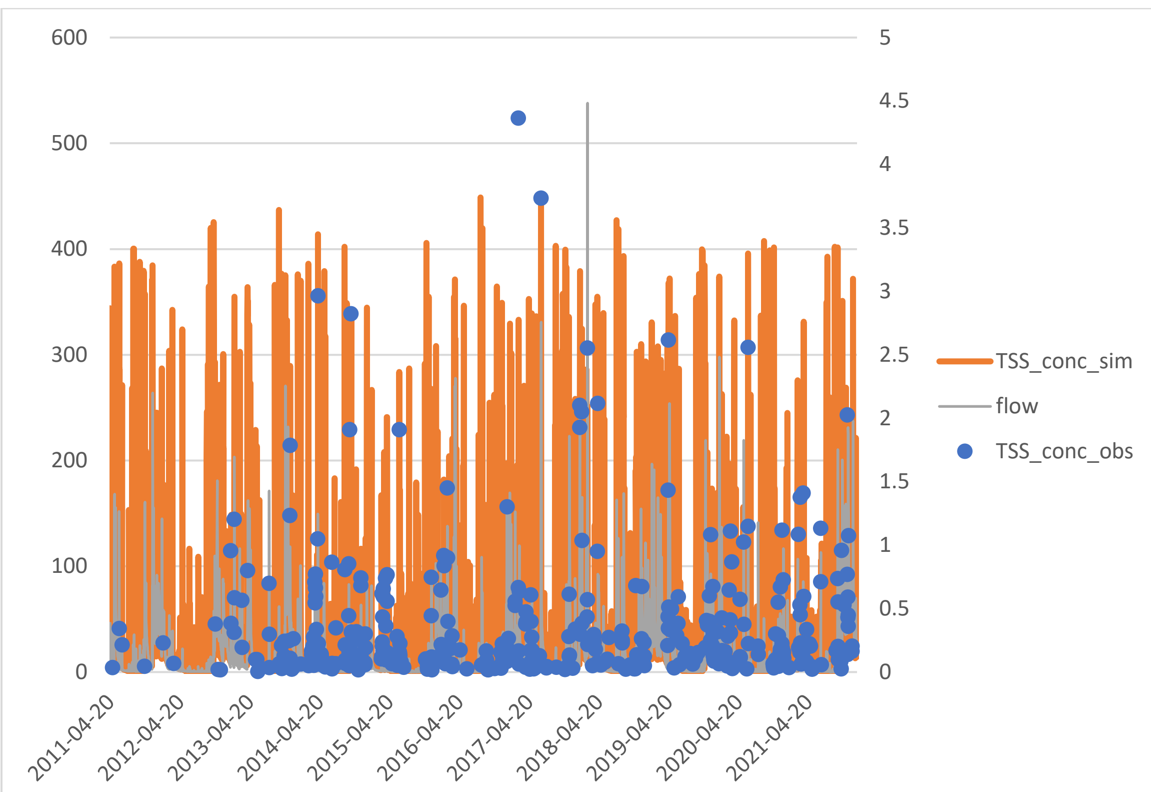

Figure 5-2. Measured vs. simulated sediment concentration at site 20 (Kerry's Line)

5.4 Nutrient calibration

While we made use of all available nutrient concentration monitoring data for IMWEBs calibration, we focused on improving modelling performance for nutrient concentration data points at a daily time step at site 20 (Kerry's Line). Table 5-3 presents the parameters used for dissolved and particulate phosphorus calibration and Figure 5-3 shows the graph of measured vs. simulated total phosphorus concentrations. A reasonable total phosphorus concentration calibration was achieved at site 20 (Kerry's Line) resulting in a model bias of 18.78% and a CORR of 0.68 based on the criteria outlined in Moriasi et. al (2007). Table 5-4 presents the parameters used for dissolved and particulate nitrogen calibration and Figure 5-4 shows the graph of measured vs. simulated total nitrogen concentrations. A reasonable total nitrogen concentration calibration was achieved at site 20 (Kerry's Line) resulting in a model bias of 37.66% and a CORR of 0.46 based on the criteria outlined in Moriasi et. al (2007).

Table 5-3. Calibrated phosphorus parameters for the Garvey Glenn Subwatershed IMWEBs model

Parameter	Definition	Value
phosphrusPartiCo	Phosphorus partitioning coefficient	12
phosphrusPercoCo	Phosphorus percolation coefficient	-7.5
gwOrganicP	Organic P concentration in groundwater loading to reach	0.05
P_enrich	Phosphorus enrichment ratio	1.0

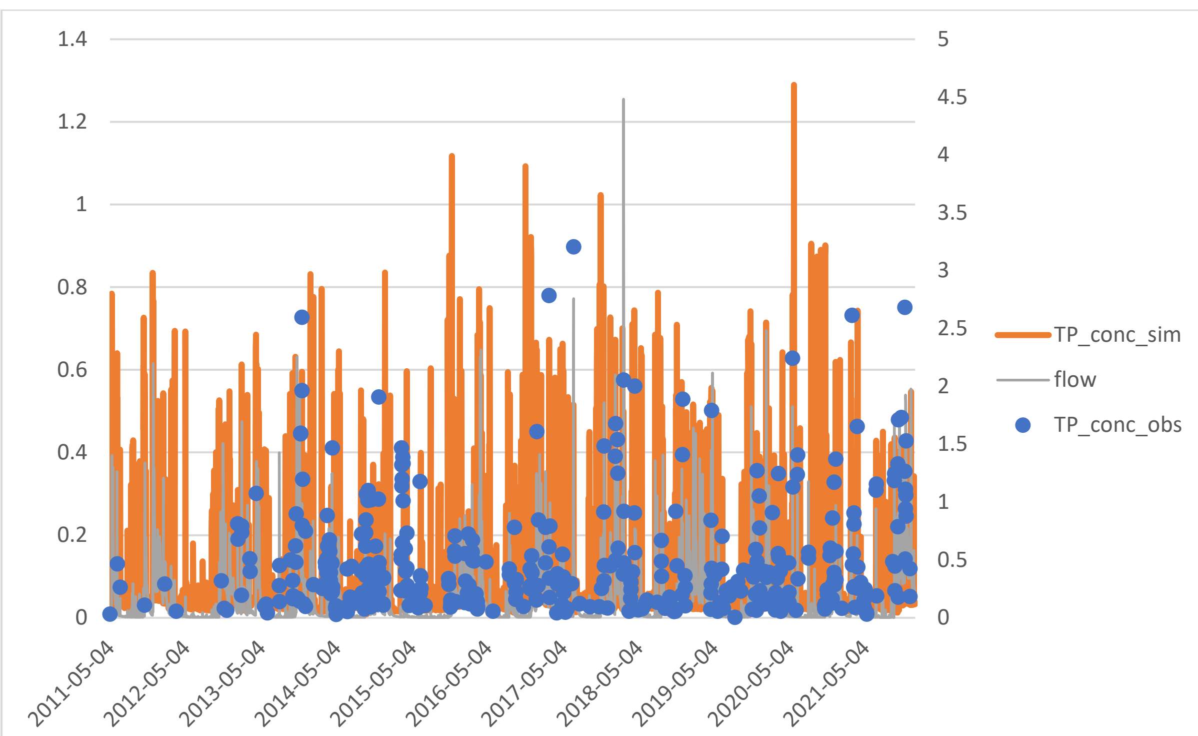

Figure 5-3. Measured vs. simulated total phosphorus concentration at site 20 (Kerry's Line)

Table 5-4. Calibrated nitrogen parameters for the Garvey Glenn Subwatershed IMWEBs model

Parameter	Definition	Value
organicN_coefficient	Organic nitrogen adjustment coefficient	1.5
nitratePercoCo	Nitrate percolation coefficient	0.75
gwNO3	NO_3 concentration in groundwater loading to reach	0.4
organicN_enrich	Organic nitrogen enrichment ratio	1.5

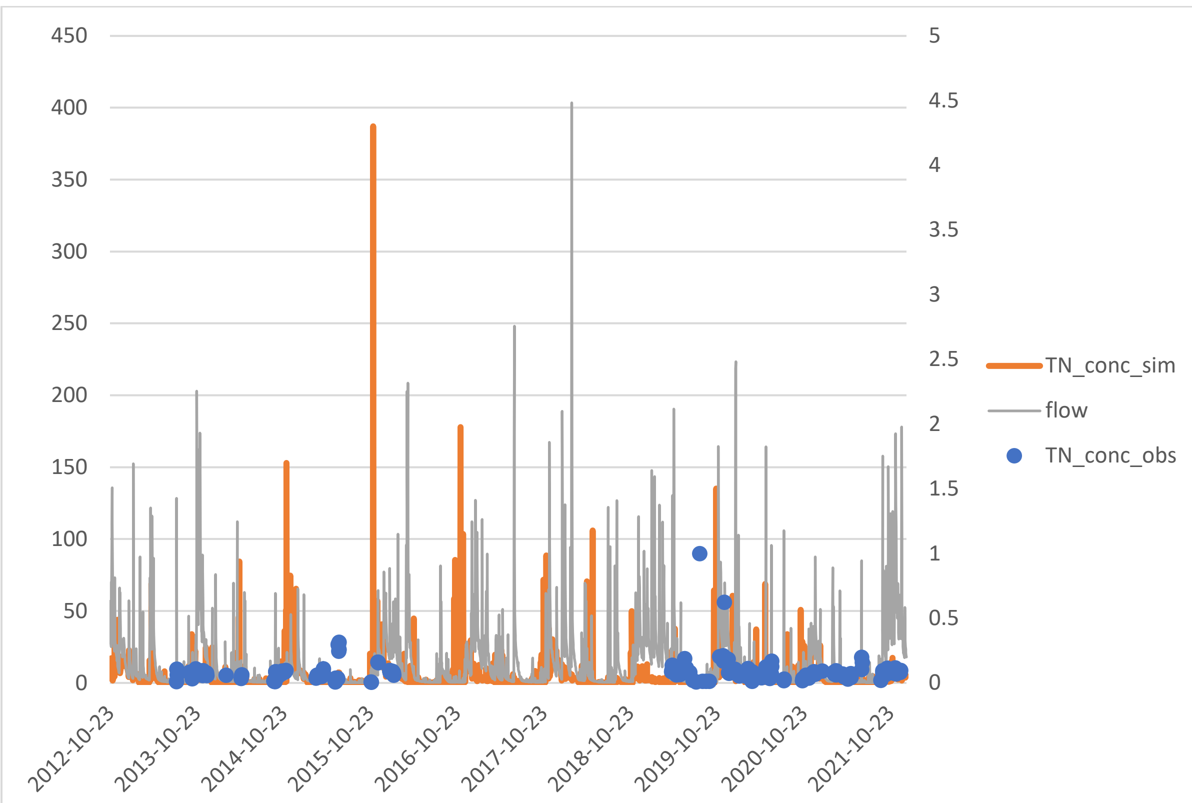

Figure 5-4 Measured vs. simulated total nitrogen concentration at site 20 (Kerry's Line)

6.0 DEFINITION OF BMP SCENARIOS AND BMP ASSESSMENT APPROACHES

In IMWEBs modelling, the crop management, tillage management, and fertilizer/manure management input tables, prepared using the information collected through the landowner interviews and roadside observations represented the actual land management conditions occurring in the landscape including established BMPs. These conditions represented the actual field conditions that produced the streamflow and water quality observations made at the various watershed monitoring stations. The model run that utilized this input dataset was defined as the "existing actual BMP" scenario.

In addition to this “existing actual BMP” scenario, land management input files were constructed to represent two additional theoretical scenarios, namely the “no existing BMP” scenario and the “potential future BMP” scenario. Within each of these scenarios there were three sub-scenarios that focused on the three soil health-related BMPs (cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation following application). Model outputs were then compared between these various model runs, in order to arrive at an estimate of the potential efficacy of these key BMPs with respect to water quality improvement under varying levels of adoption of these practices across the watershed. A comparison of model outputs between the “existing actual BMP” scenario and the “no existing BMP” scenario provided an estimate of the efficacy of historical/existing BMP adoption. A comparison of model outputs between the “existing actual BMP” scenario and the “potential future BMP” scenario provided an estimate of the efficacy of additional potential BMP adoption. Furthermore, a comparison of model outputs between the “no existing BMP” scenario and the “potential future BMP” scenario provided an estimate of the efficacy of full adoption of these practices across the watershed. The specific scenario runs compared to achieve this were as follows: no existing cover cropping scenario vs. potential future cover cropping scenario, no existing conservation tillage scenario vs. potential future conservation tillage scenario, and no existing fertilizer/manure incorporation scenario vs. potential future fertilizer/manure incorporation scenario.

6.1 Existing Actual BMP scenario

The “existing actual BMP” scenario characterizes all of the historical/existing BMPs or established BMPs in the Garvey Glenn subwatershed. This includes the key soil health-related BMPs of interest in this study as well as a good number of other soil conservation structural and agronomic bet practices. These all needed to be represented in the model as they are present and influence the water flow and quality observations. There are 31 existing Water and Sediment Control Basins (WASCoBs), 13 additional catch basins acting as surface inlets to subsurface drainage systems, 21 windbreaks, 16 riparian buffers, and 15 grassed waterways in the Garvey Glenn subwatershed. The locations of these existing structural BMPs are shown in Figure 3-3. The land management data for the historical/existing scenario include all land management BMPs collected through the ONFARM, GLASI, and windshield surveys, including the key practices of interest, namely cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation for the period from 2001 to 2022.

6.2 No existing BMP scenarios

The “no existing BMP” scenarios are built by removing all of the BMPs of interest from the Garvey Glenn model land management input files. Three no existing BMP scenarios were developed including: no existing cover cropping scenario (i.e. removal of existing cover crops), no existing conservation tillage scenario (i.e. converting existing conservation tillage and no-till operations to conventional tillage), and no existing fertilizer/manure incorporation scenario (i.e. converting existing fertilizer and manure incorporation into no incorporation or surface application), respectively.

6.3 Potential future BMPs scenarios

The “potential future BMP” scenarios are built by adding the BMPs of interest to the model’s land management input file. If a field is already utilizing the BMP, as observed from the land management operations or windshield surveys, then they were left in the model input file. If there were fields however that had the opportunity to implement the BMPs, but they had not been adopted yet, then the model input file was adjusted to assume its adoption. In this way the full adoption potential of the BMPs of interest was represented in the “potential future BMP” model runs. The potential future BMP scenarios in the Garvey Glenn subwatershed include potential future cover cropping scenario (i.e. implementing cover crop in all potential fields beyond existing cover crop fields), potential future conservation tillage scenario (i.e. implementing conservation tillage and no-till in all potential fields beyond existing conservation tillage and no-till fields), and potential future fertilizer/manure incorporation scenario (i.e. implementing fertilizer/manure incorporation in all potential fields beyond existing fertilizer/manure incorporation fields), respectively.

6.3.1 Assumptions used in developing potential future BMP scenarios

This section describes the methods that were used in developing the land management input file that was used to represent a potential of theoretical situation where the three key BMPs were adopted to their fullest potential across the watershed landscape. The potential future cover cropping scenario was defined by adding either oats or rye as a cover crop to the all crop fields and all years that did not already have an existing cover crop in the “existing actual scenario”. In the potential future cover cropping scenario, an oats cover crop was planted after winter wheat and terminated by year end. A rye cover crop was simulated as being planted after either corn or soybean (when the next crop was not winter wheat or a cover crop) and terminated when the following crop was seeded, simulating cover crops growing over winter. Nitrogen fertilizer application rates were reduced for the crops following future cover crops in consultation with experts from the OMAFRA and the University of Guelph, as shown in Table 6-1.

Table 6-1. Nitrogen credit amounts to reduce N fertilizer rates by for the crop that follows a future cover crop

Cover Crop	Nitrogen credit (kg/ha/yr)
Red Clover	66
Oats	45
Rye	45

The potential conservation tillage scenario was defined by changing all historical/existing conventional tillage in the existing actual BMP scenario into conservation tillage.

The potential future fertilizer/manure incorporation scenario was defined by changing all historical/existing manure and fertilizer applications with no or partial incorporation in the existing BMP scenario into full incorporation.

6.4 BMP assessment approaches

6.4.1 Assessing the effectiveness of existing actual BMPs

The land activities survey conducted across the watershed identified that a good number of Best/Beneficial Management Practices (BMPs) including cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation were currently being applied on some fields and in some years across the watershed. To assess the effectiveness or water quality benefits of these BMPs currently being applied in the watershed, a hypothetical modelling scenario (which was called the conventional “No existing BMP” scenario) was constructed for the watershed in which all existing BMPs were removed and replaced with more conventional practices. Specifically, for this no existing BMP scenario all fields that had been cover cropped under actual conditions were set to not being cover cropped (i.e. the “no existing cover cropping scenario). Conservation tillage/no-till was converted to conventional tillage (i.e. “no existing conservation tillage” scenario), and any fertilizer/manure incorporation that occurred under actual conditions was altered in the model’s land management input file to have been surface applied in the “no existing fertilizer/manure incorporation’ scenario. The differences between the IMWEBs modelling results using the land management input files defining the more conventional “no existing BMP” scenario model runs and the “existing actual BMP” model run (i.e. no existing cover cropping scenario vs. existing actual BMP scenario, no existing conservation tillage scenario vs. existing actual BMP scenario, and no existing fertilizer/manure incorporation scenario vs. existing actual BMP scenario) were used to estimate the water quality benefits of the three key BMPs of interest currently being employed in the watershed. Note that during the 21-year period of IMWEBs simulation, from 2001 to 2021, a BMP may be only applied on a farm field in selected years due to crop rotation patterns, farmer choice, and other factors. The BMP effectiveness values generated, however, represented the yearly average of water quality benefits in a farm field despite the mixed presence and absence of a BMP during the entire simulation period, and therefore does not necessarily represent the yearly average of water quality benefits for a particular BMP in each year.

6.4.2 Assessing the effectiveness of increased adoption of the selected soil health-related BMPs

Under the existing actual BMP scenario model run, BMPs including cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation exist in some fields and in some years. Those fields/years without such BMPs but which have the potential to implement these BMPs in the future were also identified. To assess the water quality benefits of more extensive BMP adoption, new BMP scenarios were constructed in which cover crops were added to those fields which could potentially implement the key soil health-related BMPs considered in this study. For example, fields that were currently not cover cropped but which would have the potential to be cover cropped were identified and a model input dataset was prepared defining this situation for use in a theoretical model run (i.e. the “potential future cover cropping” scenario). Similarly for the tillage BMP, any existing conventionally tilled fields were converted to conservation tillage or no-till (i.e. the “potential future conservation tillage” scenario), and finally full fertilizer /manure incorporation was applied to all fields receiving fertilizer or manure in the watershed over the period of model simulation (i.e. the “potential future fertilizer/manure incorporation" scenario). The IMWEBs modelling was setup for both the actual (historical/existing) BMP implementation conditions (i.e. the "existing actual BMP" scenarios) and these theoretical full adoption "potential future BMP" scenarios (i.e. "potential future cover cropping" scenario, "potential future conservation tillage" scenario, and "potential future fertilizer/manure incorporation" scenario). The differences between the IMWEBs modelling results generated by the "existing actual BMP" scenario model runs and the results returned from the various theoretical "potential future BMP" scenario model runs represented the water quality benefits of the additional potential future BMPs. In the scenario comparison, the differences were those fields without existing BMPs vs. potential future BMPs added to those fields. Note that during the 21 years of IMWEBs simulation period from 2001 to 2021, the selected BMPs will not necessarily be applied every year, perhaps due to the existence of the BMP in some years but not others due to various factors. For example, crop rotation may have restricted the ability to implement the BMP in some years. The BMP effectiveness estimate represented the yearly average of water quality benefits in a farm field during the entire simulation period and does not necessarily represent the yearly average of water quality benefits of the various BMPs studied in the actual year of implementation.

6.4.3 Assessing the overall effectiveness of the selected soil health-related BMPs

When estimating the full water quality benefits for the Garvey Glen watershed of the three key soil health-related land management BMPs including cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation, a comparison was conducted between the model output from the "no existing BMP" scenarios (i.e. no existing cover cropping scenario, no existing conservation tillage scenario, and no existing fertilizer/manure incorporation scenario) and the "potential future BMP" scenarios (i.e. potential future cover cropping scenario, potential future conservation tillage scenario, and potential future fertilizer/manure incorporation scenario). Specifically, model run comparisons were made between three pairs of conventional "no existing BMP" scenarios and the corresponding "potential future BMP" scenarios, namely: 1). No existing cover cropping scenario and potential future cover cropping scenario, 2). No existing conservation tillage scenario and potential future conservation tillage scenario, and 3). No existing fertilizer/manure incorporation scenario and potential future fertilizer/manure incorporation scenario. Note that the potential future BMP scenarios included those fields and years where the BMP of interest was already being applied as well as the fields and years where the BMP could potentially be applied. This then resulted in an estimation of the full water quality benefits that could be achieved in going from no adoption of the BMP of interest in the watershed to full adoption of the best practice. The overall effectiveness of the BMP of interest was therefore estimated.

7.0 IMWEBS MODELLING RESULTS UNDER HISTORICAL/EXISTING CONDITIONS/SCENARIOS

With the IMWEBs model input variables calibrated against available streamflow and water quality measurement data, the model was run for the Garvey Glenn subwatershed for the period of 2001-2021 using assembled weather datasets for that same period (see Section 2.3). The simulated average yearly stream flow along with the sediment and nutrient yields/loads at the watershed outlet and at a field scale for this IMWEBs modelling simulation period (2001-2021) were documented and presented in either a tabular or graphical format.

For Garvey Glenn subwatershed, the average annual precipitation for the period of 2001 to 2021 was 885.5 mm and the simulated annual total runoff/flow was 414.1 mm, with a runoff/flow coefficient of 0.47. The simulated average annual total sediment yield/load at the watershed outlet was 1,440.6 tonnes (0.86 t/ha), of which 1,006.2 tonnes (0.60 t/ha) were from overland sediment yield and 434.4 tonnes (0.26 t/ha) were from channel sediment load. The average overland sediment delivery rate was calculated using the estimated sediment yield associated with the surface runoff and tile flow before it entered into the defined streams/channels divided by the watershed area, while the average channel/stream sediment delivery rate was calculated by dividing the total channel sediment load by the watershed area. The estimated average annual TN load at the watershed outlet was 56,207.8 kg (33.71 kg/ha), of which 9,252.0 kg was in particulate form (16.5%) and 46,955.8 kg was in dissolved form (83.5%). The estimated average annual TP load at the watershed outlet was 1,758.5 kg (1.06 kg/ha), of which 846.9 kg was in particulate form (48.2%) and 911.6 kg was in dissolved form (51.8%) (Table 7-1).

Figures 7-1, 7-2, and 7-3 show the spatial distribution of simulated average yearly sediment, TN and TP yields/loads at a field scale under historical/existing land management conditions from 2001 to 2021. Note that the maps focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 7-2, the majority of the cropland area (83.8%) had sediment yield/load under 1.0 ton/ha and about 48.0% of the cropland area had sediment yield/load under 0.5 ton/ha. About 16.2% of the cropland area had sediment yield/load above 1.0 ton/ha and as high as 6.2 ton/ha. About 43.4% of the cropland area had TN yield/load under 10 kg/ha. About 19.4% of the cropland area had TN yield/load above 50.0 kg/ha and as high as 88.6 kg/ha, which was likely related to TN load from tile drain in the field and transported from other fields. About 28.0% of the cropland area had TP yield/load under 0.5 kg/ha. About 14.7% of the cropland area had TP yield/load above 3.0 kg/ha and as high as 5.3 kg/ha, which was also likely related to TP load from tile drain in the field and transported from other fields.

Table 7-1. Simulated average yearly sediment and nutrient yield/load at the watershed outlet over the period 2001-2021 under historical/existing land management conditions for the Garvey Glenn subwatershed

Overland sediment yield	1,006.2	t	0.60	t/ha	69.8	%
Channel sediment load	434.4	t	0.26	t/ha	30.2	%
Total sediment	1,440.6	t	0.86	t/ha	100	%
Particulate P	846.9	kg	0.51	kg/ha	48.2	%
Dissolved P	911.6	kg	0.55	kg/ha	51.8	%
TP	1,758.5	kg	1.06	kg/ha	100	%
Particulate N	9,252.0	kg	5.55	kg/ha	16.5	%
Dissolved N	46,955.8	kg	28.16	kg/ha	83.5	%
TN	56,207.8	kg	33.71	kg/ha	100	%

Table 7-2. Simulated average yearly sediment, TN, and TP yields/loads at a field scale under historical/existing land management conditions from 2001 to 2021 in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<=0.1 (21.2%)	0.1-0.5 (26.8%)	0.5-0.75 (23.2%)	0.75-1.0 (12.5%)	>1.0 (16.2%)	0.645
TN (kg/ha)	<=5 (23.7%)	5-10 (19.7%)	10-20 (18.0%)	20-50 (19.3%)	>50 (19.4%)	28.198
TP (kg/ha)	<=0.25 (17.3%)	0.25-0.5 (10.7%)	0.5-1.0 (27.3%)	1.0-2.0 (26.3%)	>3.0 (14.7%)	1.099

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area.

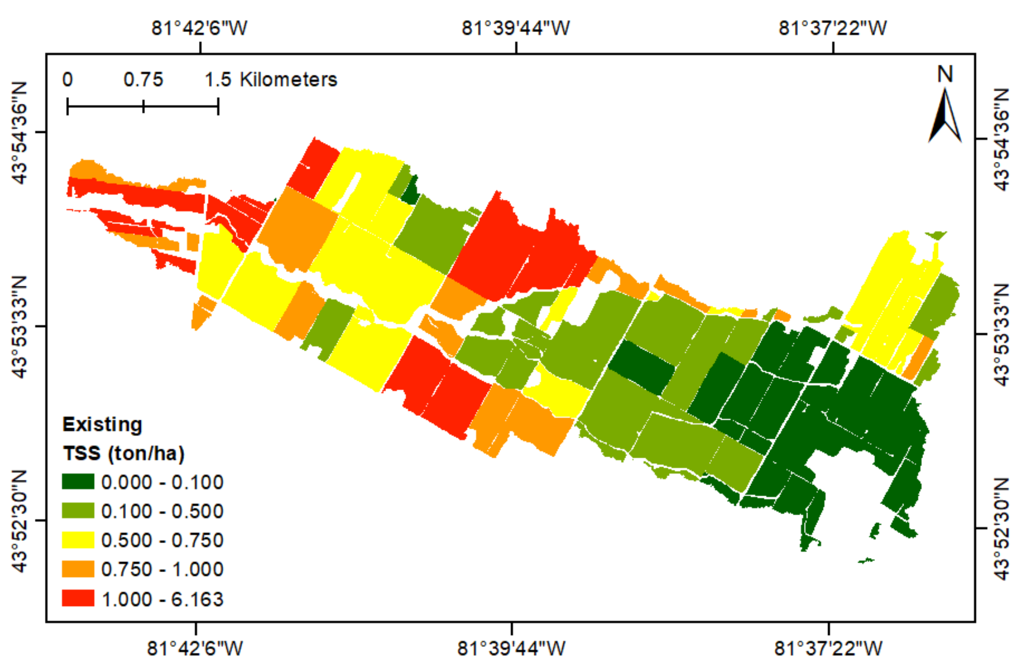

Figure 7-1. Simulated average yearly sediment yield/load at a field scale under historical/existing land management conditions in the Garvey Glenn subwatershed

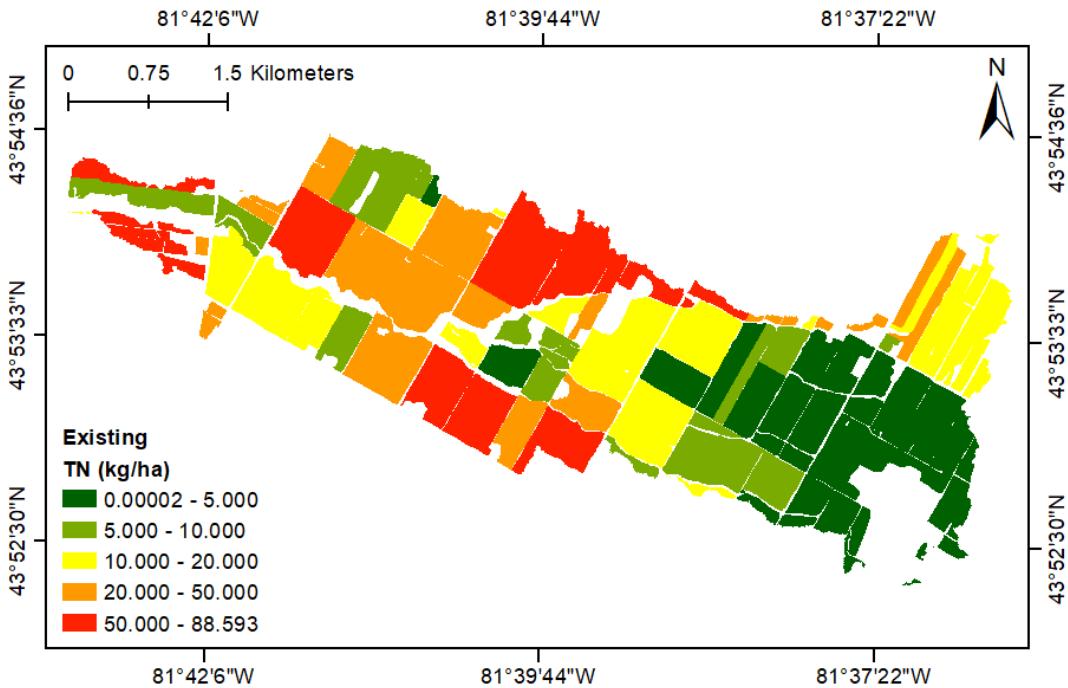

Figure 7-2. Simulated average yearly TN yield/load at a field scale under historical/existing land management conditions in the Garvey Glenn subwatershed

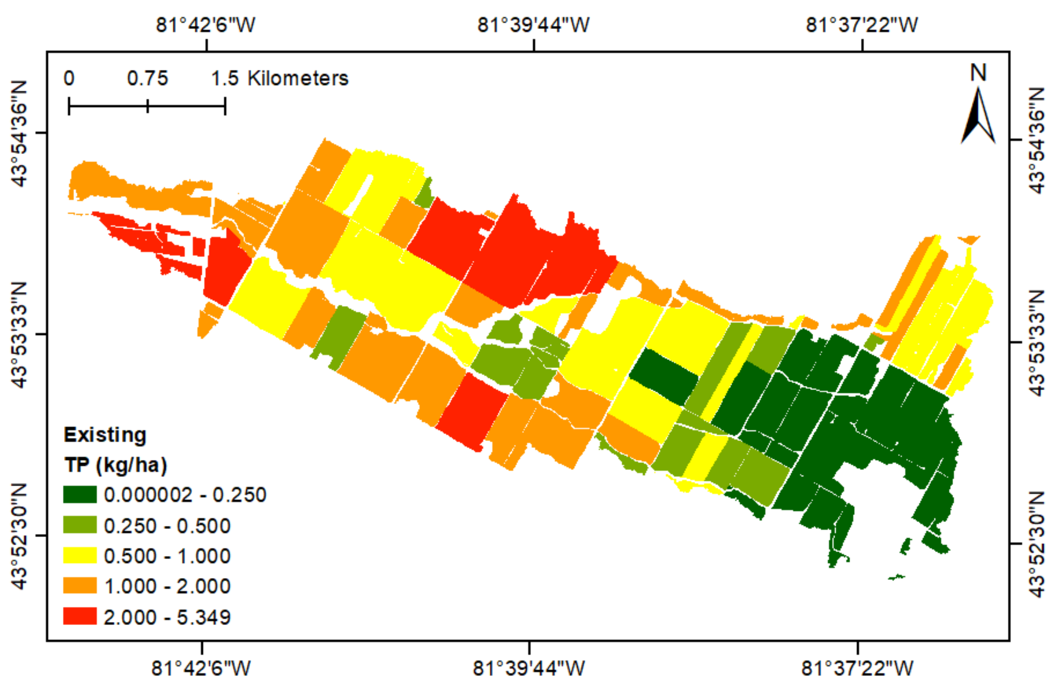

Figure 7-3. Simulated average yearly TP yield/load at a field scale under historical/existing land management conditions in the Garvey Glenn subwatershed

8.0 IMWEBS MODELLING RESULTS FOR ASSESSING THE EFFECTIVENESS OF EXISTING ACTUAL BMPS

The calibrated Garvey Glenn IMWEBs model was applied to estimate the water quality benefits of the three key soil health-related BMPs including cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation under the current level of adoption by land managers in relation to no adoption of these measures, referred to as the "no existing BMP" scenarios. The sections which follow provide a more detailed discussion of the results of this model output comparison for each of the three key BMPs of interest.

8.1 IMWEBs results for assessing the effectiveness of existing cover crop BMP adoption

The differences between the IMWEBs modelling results under the "existing actual cover cropping" scenario (based on existing/historical conditions) and the "no existing cover cropping" scenario represents the effects of cover cropping on sediment, nitrogen and phosphorus dynamics in those existing cover cropping fields and related fields on the hydrological pathways. BMP effects were more pronounced in the fields cover crops were applied. The magnitudes of BMP effects were also related to field characteristics such as crop rotation, topography, soil, and others. Figures 8-1, 8-2, and 8-3 show the spatial distribution of simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario from 2001 to 2021. Note that the maps focused on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 8-1, about 58.8% of the cropland area had TSS yield/load reduction between 0 and 0.01 ton/ha and about 16.2% of the cropland area had TSS yield/load reduction above 0.02 and as high as 0.08 ton/ha. About 62.8% of the cropland area had TN yield/load reduction between 0 and 0.1 kg/ha and about 13.0% of the cropland area had TN yield/load reduction above 1.0 and as high as 7.2 kg/ha. About 49.2% of the cropland area had TP yield/load reduction between 0 and 0.05 kg/ha and about 14.2% of the cropland area had TP yield/load reduction above 0.1 and as high as 0.4 kg/ha. On average, existing cover crop planting led to TSS, TN and TP yield/load reductions of 1.4%, 2.6% and 4.7% respectively in relation to corresponding TSS, TN and TP yields/loads under the no existing cover cropping scenario. The pattern shows the net benefits of existing actual cover crop planting to the watershed's water quality. Note that 12.7%, 18.2% and 20.2% of the cropland area had TSS, TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to cover crop planting. However, the magnitudes of the increases were very small. This pattern may be due to the assumption that the cover crops would be ploughed down in late fall or early spring, possibly making the soil in some places more susceptible to erosion and nutrient loss if storm events occurred.

Table 8-1. Simulated average yearly reductions of TSS, TN and TP yields/loads at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (12.7%)	0-0.001 (37.6%)	0.001-0.01 (21.2%)	0.01-0.02 (12.2%)	>0.02 (16.2%)	0.009 (0.645, 1.4%)
TN (kg/ha)	<= 0 (18.2%)	0-0.01 (49.6%)	0.01-0.1 (13.2%)	0.1-1.0 (9.8%)	>1.0 (13.0%)	0.734 (28.198, 2.6%)
TP (kg/ha)	<= 0 (20.2%)	0-0.025 (34.4%)	0.025-0.05 (14.8%)	0.05-0.1 (16.4%)	>0.1 (14.2%)	0.051 (1.099, 4.7%)

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area. In parathesis, TSS, TN, and TP yield/load under the existing actual cover cropping scenario and percentage increase if historical/existing cover crop is removed under the conventional no existing cover cropping scenario.

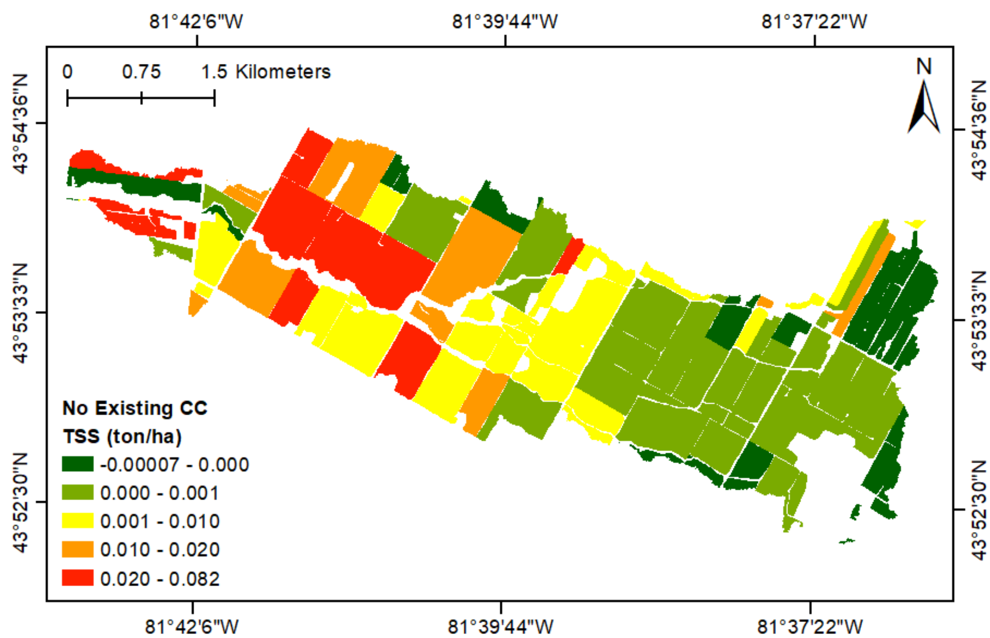

Figure 8-1. Simulated average yearly reduction of TSS yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

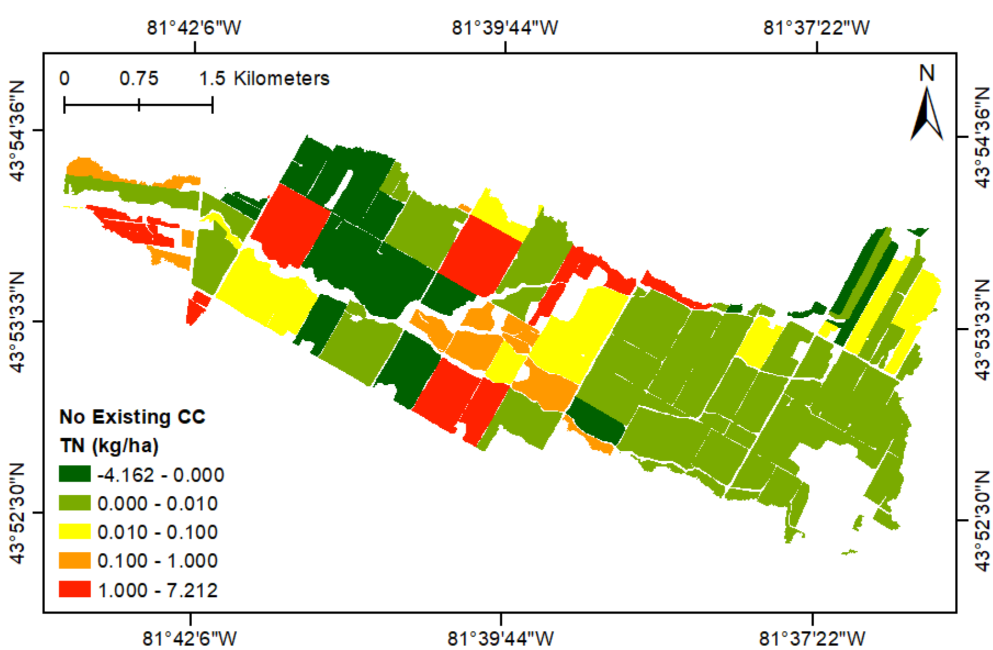

Figure 8-2. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

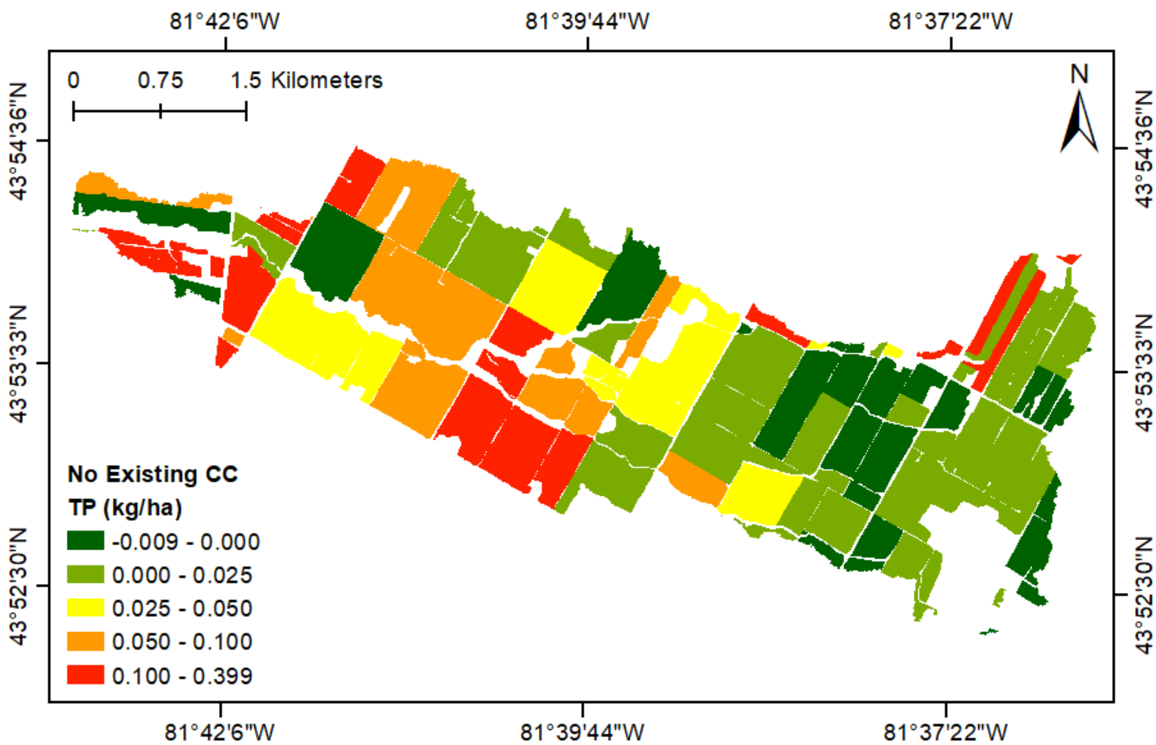

Figure 8-3. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

8.2 IMWEBs results for assessing the effectiveness of existing conservation tillage adoption

The differences between the IMWEBs modelling results under the existing actual conservation tillage scenario (based on existing/historical conditions) and the no existing conservation tillage scenario represented the effects of existing levels of conservation tillage adoption on sediment, nitrogen and phosphorus dynamics in those existing conservation tillage fields and related fields on the hydrological pathways. BMP effects were more pronounced in those existing conservation tillage fields and the magnitudes of BMP effects were also related to field characteristics such as crop rotation, topography, soil, and others. Figures 8-4, 8-5, and 8-6 show the spatial distribution of simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario from 2001 to 2021. Note that the maps focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 8-2, about 56.6% of the cropland area had TSS yield/load reduction between 0 and 0.05 ton/ha and about 14.1% of the cropland area has TSS yield/load reduction above 0.1 and as high as 0.3 ton/ha. About 44.9% of the cropland area had TN yield/load reduction between 0 and 1.0 kg/ha and about 14.9% of the cropland area had TN yield/load reduction above 3.0 kg/ha and as high as 12.4 kg/ha. About 48.9% of the cropland area had TP yield/load reduction between 0 and 0.05 kg/ha and about 15.0% of the cropland area had TP yield/load reduction above 0.1 kg/ha and as high as 0.5 kg/ha. On average, existing conservation tillage application led to TSS, TN and TP yield/load reductions of 8.7%, 5.2% and 4.0% respectively in relation to corresponding TSS, TN and TP yields/loads under the no existing conservation tillage scenario. The pattern shows the net benefits of existing actual conservation tillage and no-till application in the watershed. Note that some portion of the cropland area (4.5%, 18.9% and 21.0%) had TSS, TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to conservation tillage or no-till practices. These areas mostly overlapped with fields with slightly lower TSS yield/load reduction where more nutrient leaching may outweigh soil-associated nutrient retention.

Table 8-2. Simulated average yearly reductions of TSS, TN and TP yields/loads at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (4.5%)	0-0.025 (27.2%)	0.025-0.05 (29.4%)	0.05-0.1 (24.8%)	>0.1 (14.1%)	0.056 (0.645, 8.7%)
TN (kg/ha)	<= 0 (18.9%)	0-0.5 (30.4%)	0.5-1.0 (14.5%)	1.0-3.0 (21.3%)	>3.0 (14.9%)	1.480 (28.198, 5.2%)
TP (kg/ha)	<= 0 (21.0%)	0-0.02 (30.5%)	0.02-0.05 (18.4%)	0.05-0.1 (15.1%)	>0.1 (15.0%)	0.044 (1.099, 4.0%)

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area. In parathesis, TSS, TN and TP yield/load under the existing actual conservation tillage scenario and percentage increase under the no existing conservation tillage scenario.

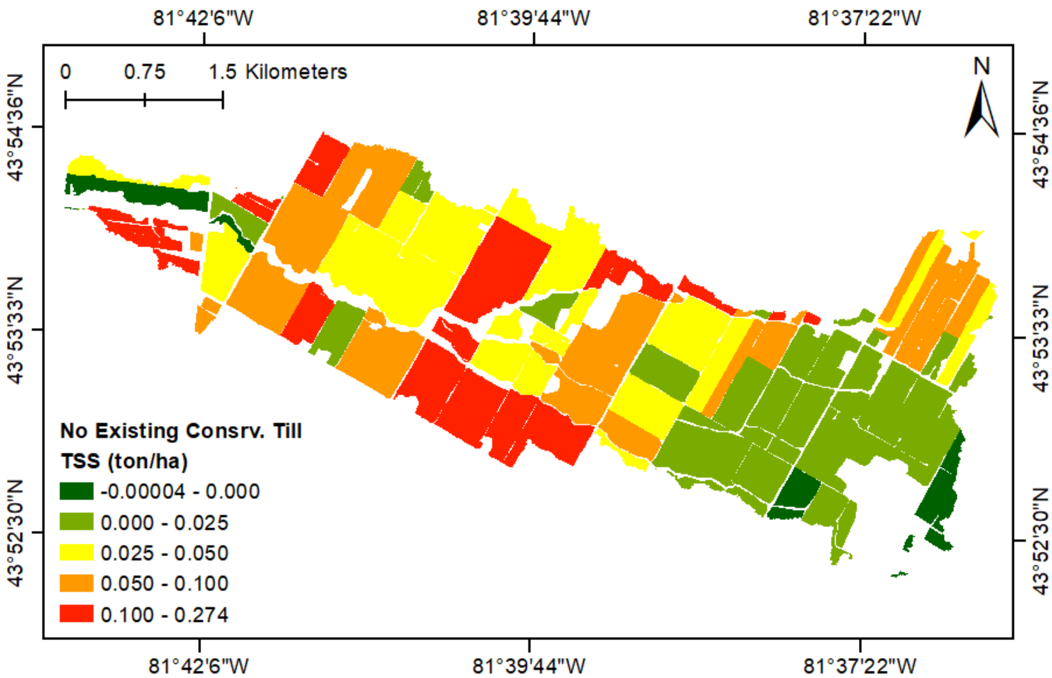

Figure 8-4. Simulated average yearly reduction of TSS yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

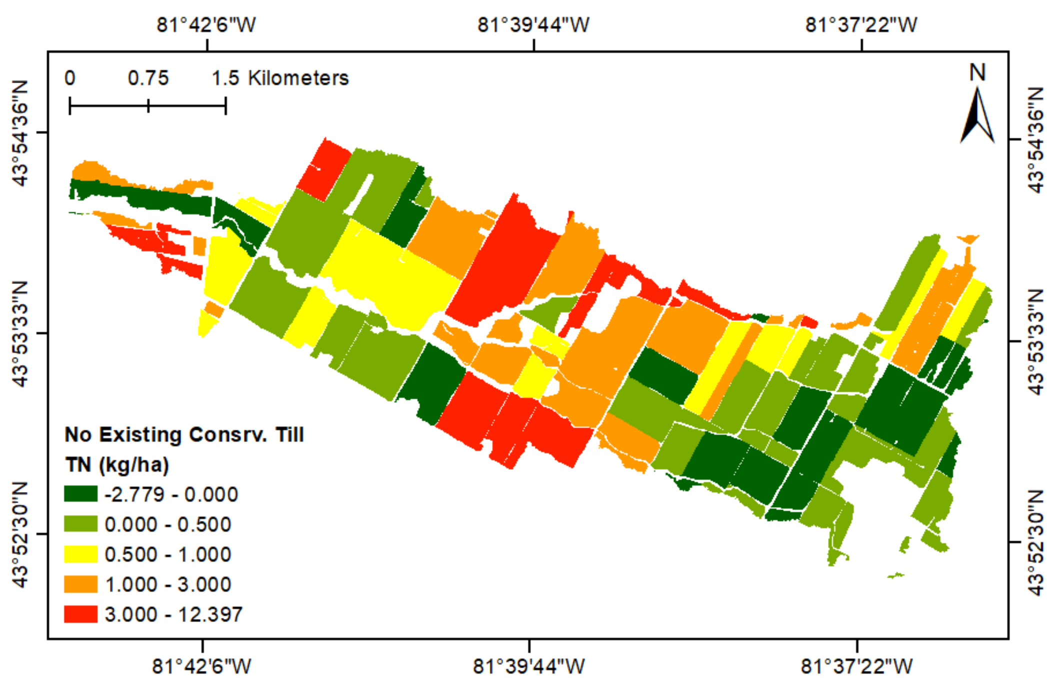

Figure 8-5. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

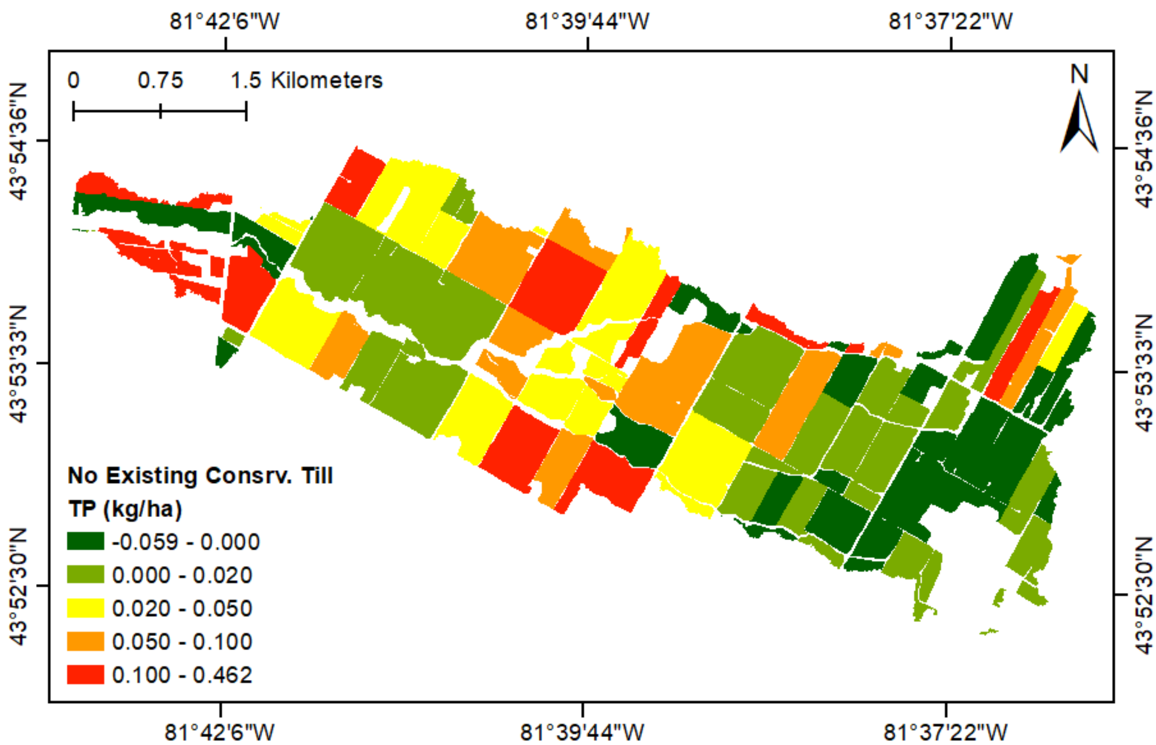

Figure 8-6. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

8.3 IMWEBs results for assessing the effectiveness of existing fertilizer/manure incorporation BMP adoption

The differences between the IMWEBs modelling results under the existing actual fertilizer/manure incorporation scenario (based on existing/historical conditions) and the no existing fertilizer/manure incorporation scenario represented the effects of fertilizer/manure incorporation on sediment, nitrogen and phosphorus dynamics in those existing fertilizer/manure incorporation fields and related fields on the hydrological pathways. BMP effects were more pronounced in those existing fertilizer/manure incorporation fields and the magnitudes of BMP effects were also related to field characteristics such as crop rotation, topography, soil, and others. Figures 8-7 and 8-8 show the spatial distribution of simulated average yearly reductions of TN and TP yields/loads at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the no existing fertilizer/manure incorporation scenario from 2001 to 2021. Fertilizer/manure incorporation had almost no effect on erosion, so TSS yield/load reductions were not reported in the study. Note that the maps focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 8-

3, about 64.7% of the cropland area had TN yield/load reduction between 0 and 3 kg/ha and about 15.8% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 18.6 kg/ha. About 42.7% of the cropland area had TP yield/load reduction between 0 and 0.2 kg/ha and about 22.0% of the cropland area had TP yield/load reduction above 0.5 kg/ha and as high as 2.5 kg/ha. On average, existing actual fertilizer/manure incorporation led to TN and TP yield/load reductions of 8.2% and 30.4% respectively in relation to corresponding TN and TP yields/loads under the conventional no existing fertilizer/manure incorporation scenario. The pattern shows the net benefits of existing actual fertilizer/manure incorporation in the watershed. Note that 5.6% and 9.5% of the cropland areas had TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to fertilizer/manure incorporation. In these areas fertilizer/manure incorporation caused more nutrient leaching.

Table 8-3. Simulated average yearly reductions of TN and TP yields/loads at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
TN (kg/ha)	<= 0 (5.6%)	0-1 (40.5%)	1-3 (24.2%)	3-5 (14.0%)	>5 (15.8%)	2.321 (28.198, 8.2%)
TP (kg/ha)	<= 0 (9.5%)	0-0.1 (28.3%)	0.1-0.2 (14.4%)	0.2-0.5 (25.9%)	>0.5 (22.0%)	0.335 (1.099, 30.4%)

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area. In parathesis, TN and TP yield/load under the existing actual fertilizer/manure incorporation scenario and percentage increase under the conventional no existing fertilizer/manure incorporation scenario.

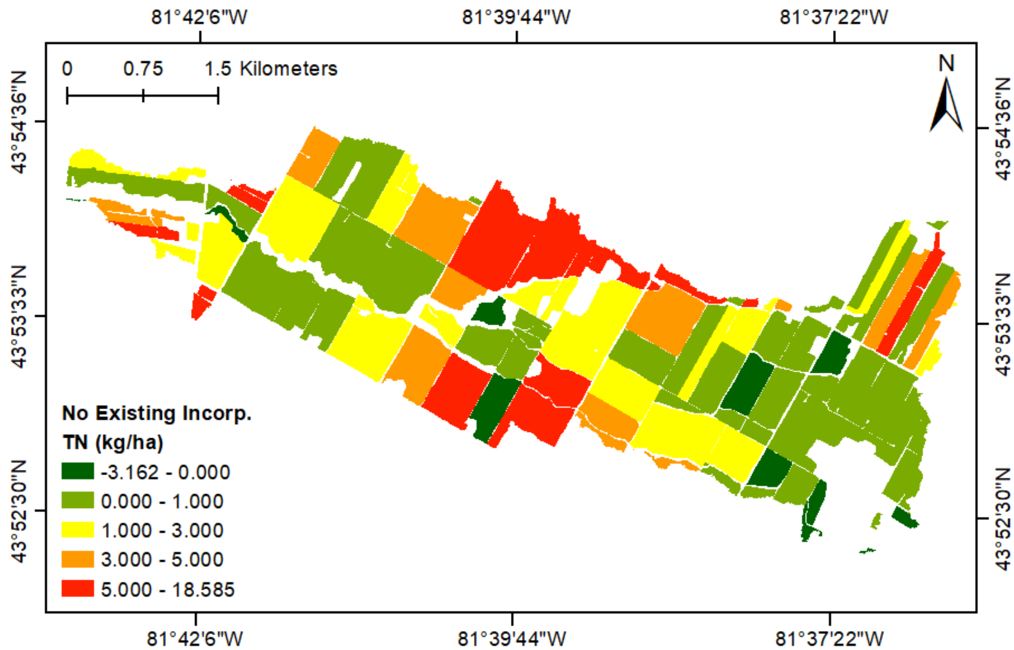

Figure 8-7. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

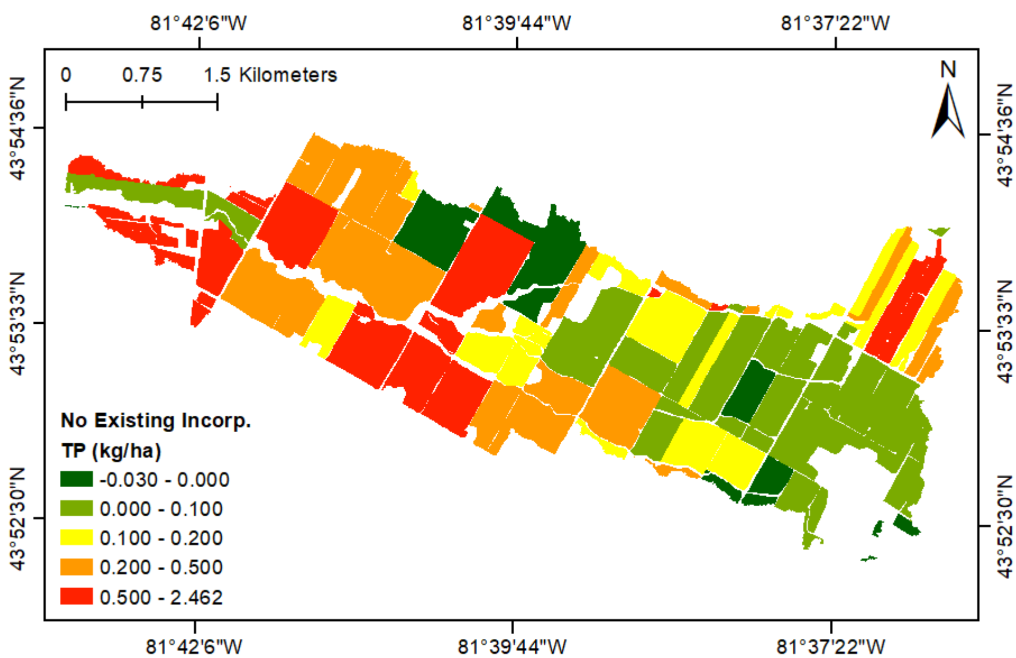

Figure 8-8. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

9.0 IMWEBS MODELLING RESULTS FOR ASSESSING THE EFFECTVENESS OF ADDITIONAL POTENTIAL COVER CROP BMP ADOPTION

The calibrated Garvey Glenn IMWEBs model was applied to estimate the water quality benefits of additional adoption of the three key soil health-related BMPs including cover cropping, conservation tillage/no-till and fertilizer/manure incorporation in relation to the current level of adoption of these same BMPs in the watershed. The sections which follow provide a more detailed discussion of the results of this model output comparison for each of the three key BMPs of interest.

9.1 IMWEBs results for assessing the effectiveness of additional potential cover crop BMP adoption.

The differences between the IMWEBs modelling results under the existing actual cover cropping scenario (based on existing/historical conditions) and the potential future cover cropping scenario represented the effects of cover cropping on sediment, nitrogen and phosphorus dynamics in those potential future cover cropping fields and related fields on the hydrological pathways. BMP effects were more pronounced in those potential future cover cropping fields and the magnitudes of BMP effects were also related to field characteristics such as crop rotation, topography, soil, and others. Figures 9-1, 9-2, and 9-3 show the spatial distribution of simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario from 2001 to 2021. Note that the maps focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 9-1, about 44.8% of the cropland area had TSS yield/load reduction between 0 and 0.05 ton/ha and about 19.6% of the cropland has TSS yield/load reduction above 0.1 and as high as 0.3 ton/ha. About 49.6% of the cropland area had TN yield/load reduction from 0 to 3.0 kg/ha and about 17.1% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 37.9 kg/ha. About 43.6% of the cropland area had TP yield/load reduction from 0 to 0.1 kg/ha and about 13.1% of the cropland area had TP yield/load reduction above 0.2 kg/ha and as high as 1.8 kg/ha. On average, future cover crop planting led to TSS, TN and TP yield/load reductions of 10.6%, 14.4% and 12.9% respectively in relation to corresponding TSS, TN and TP yields/loads under the existing actual cover cropping scenario (or historical/existing conditions). The pattern shows the net benefits of potential future cover crop planting in the watershed. Note that 5.6%, 18.4% and 17.3% of the cropland area had TSS, TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to future cover crop planting. This pattern maybe due to the assumption that the cover crops would be ploughed down in late fall or early spring, possibly making the soil in some places more susceptible to erosion and nutrient loss if storm events occurred.

Table 9-1. Simulated average yearly reductions of TSS, TN and TP yields/loads at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (5.6%)	0-0.025 (23.4%)	0.025-0.05 (21.4%)	0.05-0.1 (30.1%)	>0.1 (19.6%)	0.068 (0.645, 10.6%)
TN (kg/ha)	<= 0 (18.4%)	0-1.0 (33.4%)	1-3.0 (16.2%)	3.0-5.0 (14.9%)	>5.0 (17.1%)	4.063 (28.198, 14.4%)
TP (kg/ha)	<= 0 (17.3%)	0-0.05 (25.3%)	0.05-0.1 (18.3%)	0.1-0.2 (26.0%)	>0.2 (13.1%)	0.142 (1.099, 12.9%)

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area. In parathesis, TSS, TN, and TP yield/load under the existing actual cover cropping scenario and percentage decrease under the potential future cover cropping scenario.

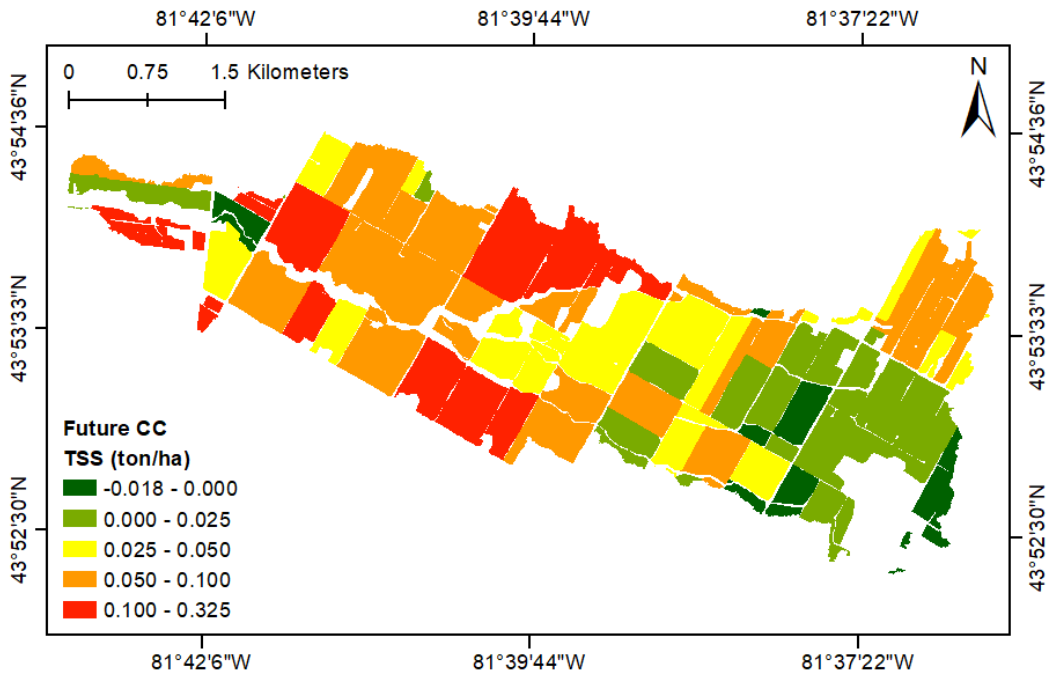

Figure 9-1. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Garvey Glenn subwatershed

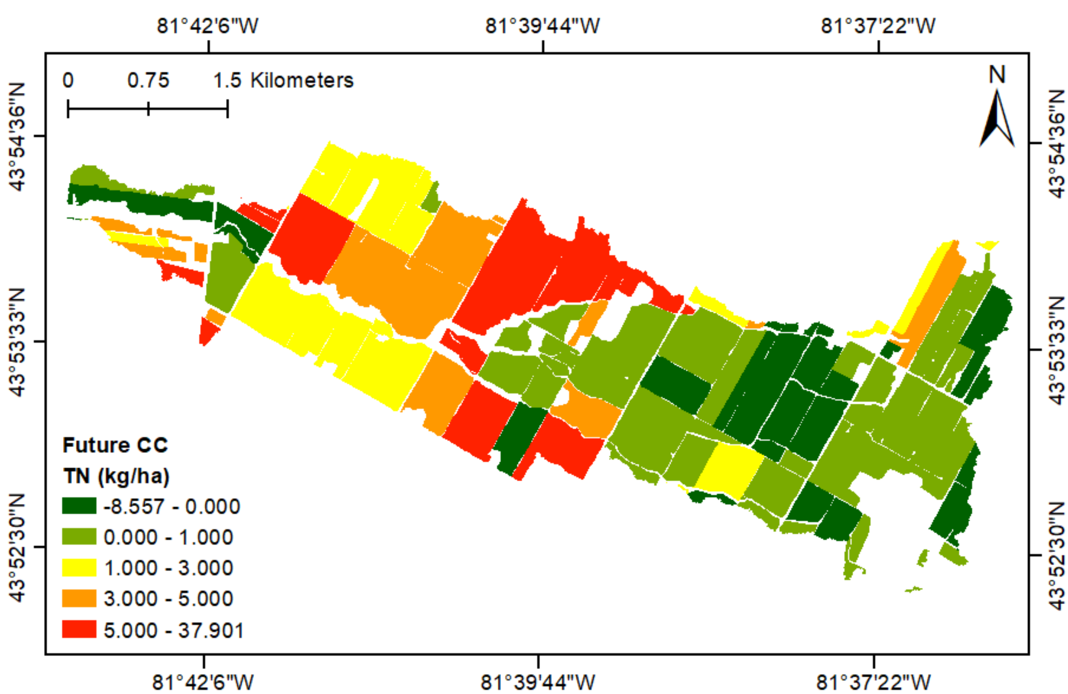

Figure 9-2. Simulated average yearly reduction of TN yield/load at a field under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Garvey Glenn subwatershed

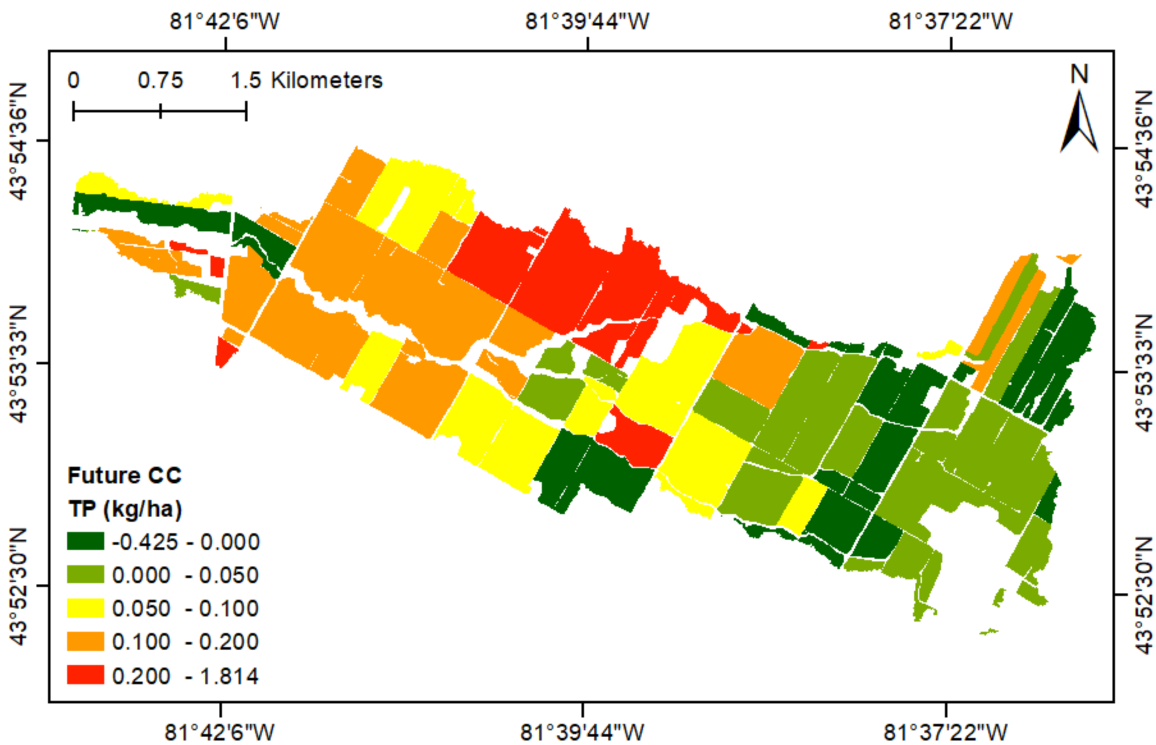

Figure 9-3. Simulated average yearly reduction of TP yield/load at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Garvey Glenn subwatershed

9.2 IMWEBs results for assessing the effectiveness of additional potential conservation tillage BMP adoption

The differences between the IMWEBs modelling results under the existing actual conservation tillage scenario (based on existing/historical conditions) and the potential future conservation tillage scenario represented the effects of conservation tillage on sediment, nitrogen and phosphorus dynamics in those potential future conservation tillage fields and related fields on the hydrological pathways. BMP effects were more pronounced in those potential conservation tillage fields and the magnitudes of BMP effects were also related to field characteristics such as crop rotation, topography, soil, and others. Figures 9-4, 9-5, and 9-6 show the spatial distribution of simulated average yearly reduction of TSS, TN, and TP yields/loads at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario from 2001 to 2021. Note that the maps focused on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 9-2, about 59.8% of the cropland area had TSS yield/load reduction between 0 and 0.03 ton/ha and 16.7% of the cropland area had TSS yield/load reduction above 0.05 and as high as 0.28

ton/ha. About 36.4% of the cropland area had TN yield/load reduction between 0 and 0.5 kg/ha and 16.8% of the cropland area had TN yield/load reduction above 3.0 kg/ha and as high as 33.2 kg/ha. About 36.9% of the cropland area had TP yield/load reduction between 0 and 0.05 kg/ha and 20.1% of the cropland area had TP yield/load reduction above 0.1 kg/ha and as high as 0.9 kg/ha. On average, potential future conservation tillage/no-till application led to TSS, TN and TP yield/load reductions of 4.7%, 8.5% and 8.3% respectively in relation to corresponding TSS, TN and TP yields/loads under the existing actual conservation tillage scenario (or historical/existing conditions). The pattern shows the net benefits of potential future conservation tillage/no-till application in the watershed. Note that 6.0%, 25.0%, and 27.6% of the cropland area had TSS, TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to conservation tillage/no-till practices. These areas mostly overlapped with fields with slightly lower TSS yield/load reduction where more nutrient leaching may outweigh soil-associated nutrient retention.

Table 9-2. Simulated average yearly reductions of TSS, TN and TP yields/loads at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (6.0%)	0-0.01 (28.3%)	0.01-0.03 (31.5%)	0.03-0.05 (17.5%)	>0.05 (16.7%)	0.030 (0.645, 4.7%)
TN (kg/ha)	<= 0 (25.0%)	0-0.5 (24.2%)	0.5-1.0 (12.2%)	1.0-3.0 (21.9%)	>3.0 (16.8%)	2.409 (28.198, 8.5%)
TP (kg/ha)	<= 0 (27.6%)	0-0.025 (24.3%)	0.025-0.05 (12.6%)	0.05-0.1 (15.4%)	>0.1 (20.1%)	0.091 (1.099, 8.3%)

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area. In parathesis, TSS, TN and TP yield/load under the existing actual conservation tillage scenario and percentage decrease under the potential future conservation tillage scenario.

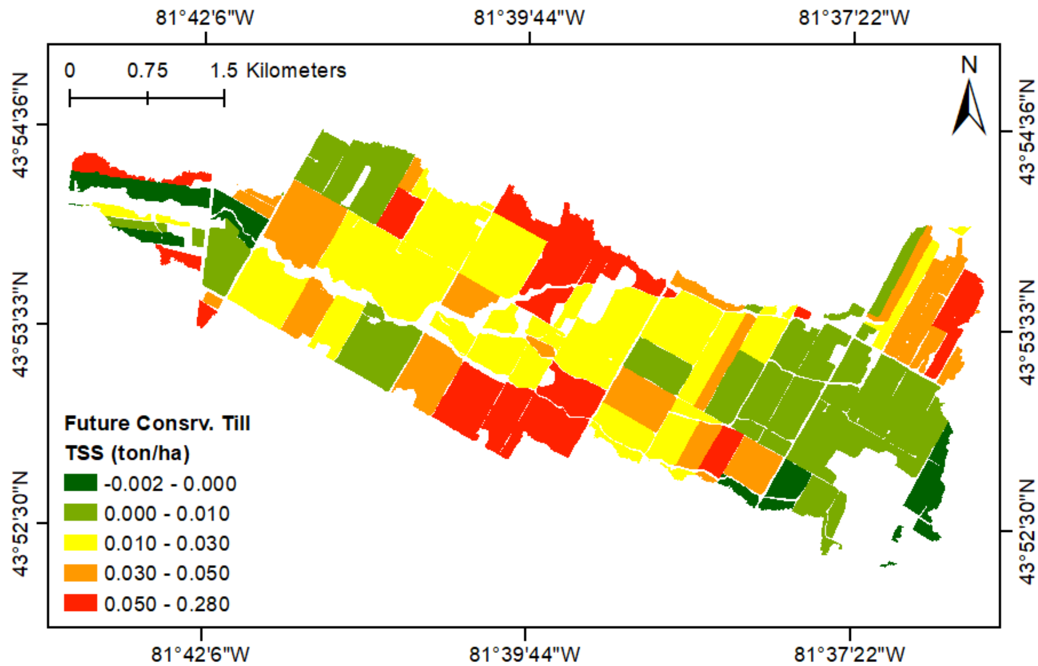

Figure 9-4. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Garvey Glenn subwatershed

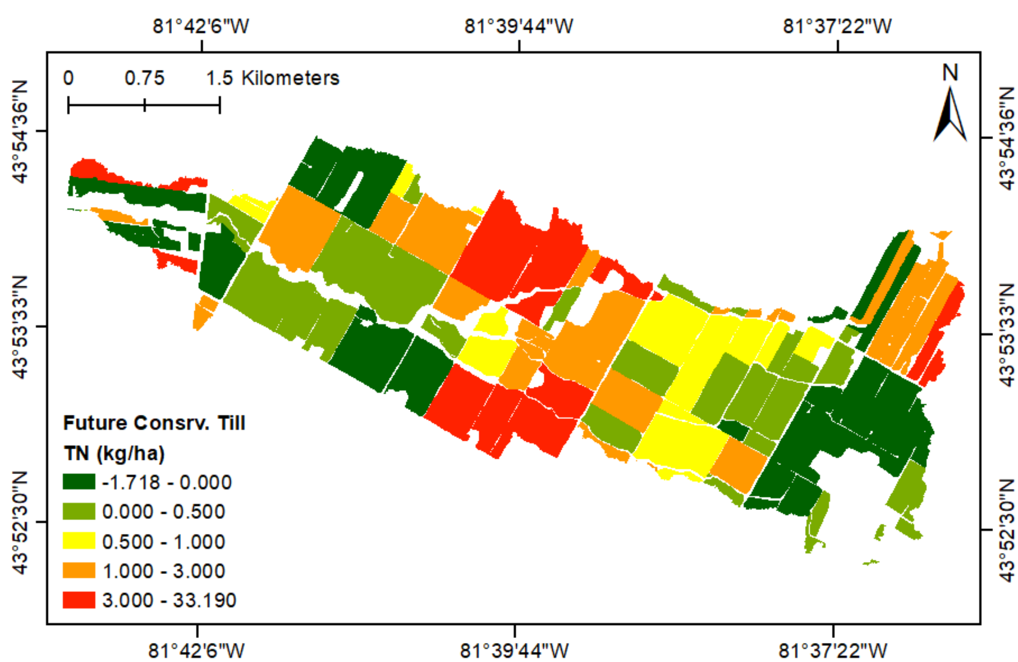

Figure 9-5. Simulated average yearly reduction of TN yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Garvey Glenn subwatershed

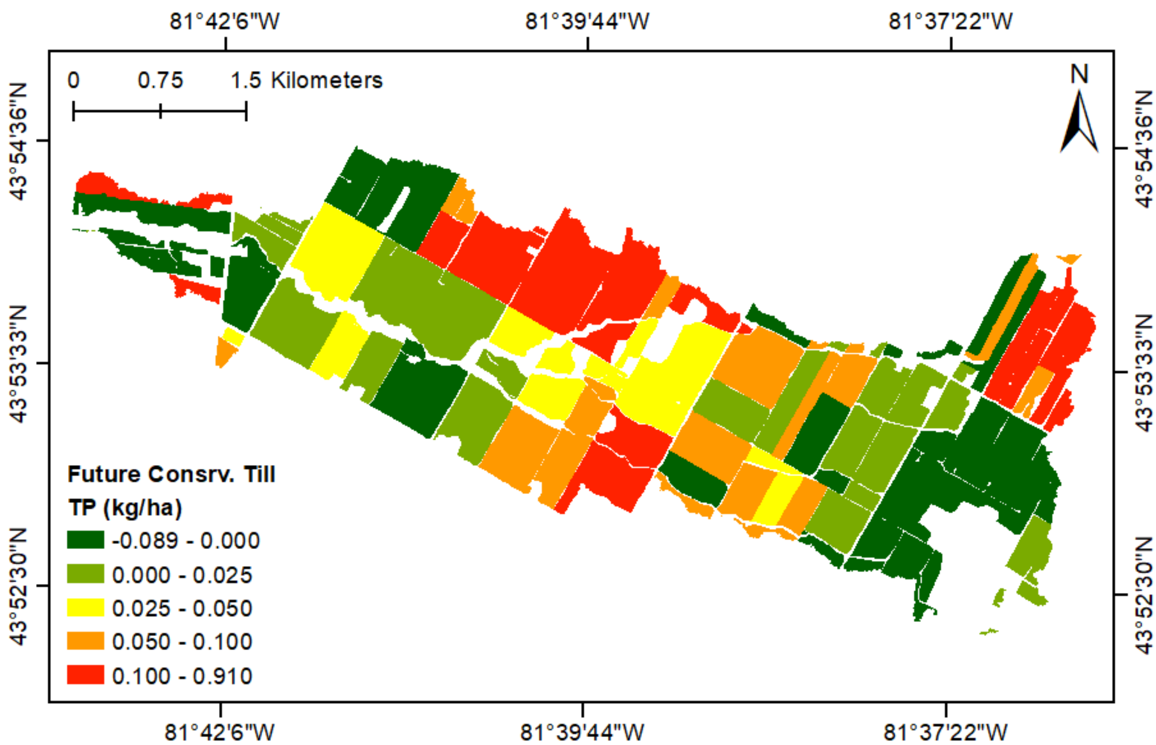

Figure 9-6. Simulated average yearly reduction of TP yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Garvey Glenn subwatershed

9.3 IMWEBs results for assessing the effectiveness of additional potential fertilizer/manure incorporation BMP adoption

The differences between the IMWEBs modelling results under the existing actual fertilizer/manure incorporation scenario (based on existing/historical conditions) and the potential future fertilizer/manure incorporation scenario represented the effects of fertilizer/manure incorporation on sediment, nitrogen and phosphorus dynamics in those potential fertilizer/manure incorporation fields and related fields on the hydrological pathways. BMP effects were more pronounced in those potential future fertilizer/manure incorporation fields and the magnitudes of BMP effects were also related to field characteristics such as crop rotation, topography, soil, and others. Figures 9-7 and 9-8 show the spatial distribution of simulated average yearly reduction of TN and TP yields/loads at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario from 2001 to 2021. Fertilizer/manure incorporation had almost no effect on erosion, so TSS yield/load reductions are not reported in the study. Note that the maps focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation.

Based on the analysis in Table 9-3, about 52.8% of the cropland area had TN yield/load reduction between 0 and 2.5 kg/ha and about 21.5% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 16.8 kg/ha. Also, about 63.1% of the cropland area had TP yield/load reduction between 0 and 0.25 kg/ha and about 14.9% of the cropland had TP yield/load reduction above 1.0 kg/ha and as high as 3.3 kg/ha. On average, potential future fertilizer/manure incorporation led to TN and TP yield/load reductions of 12.6% and 37.9% respectively in relation to corresponding TSS, TN and TP yields/loads under the existing actual fertilizer/manure incorporation scenario (or historical/existing conditions). The pattern shows the net benefits of potential future fertilizer/manure incorporation in the watershed. Note that about 4.5% and 5.5% of the cropland areas had TN and TP yield/load no change or increases in estimates of these water quality parameters in response to fertilizer/manure incorporation. In these areas fertilizer/manure incorporation caused more nutrient leaching.

Table 9-3. Simulated average yearly reductions of TN and TP yields/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
TN (kg/ha)	<= 0 (4.5%)	0-1.0 (32.7%)	1.0-2.5 (20.1%)	2.5-5.0 (21.2%)	>5.0 (21.5%)	3.565 (28.198, 12.6%)
TP (kg/ha)	<= 0 (5.5%)	0-0.1 (34.6%)	0.1-0.25 (28.5%)	0.25-1.0 (16.5%)	>1.0 (14.9%)	0.417 (1.099, 37.9%)

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area. In parathesis, TN and TP yield/load under the existing actual fertilizer/manure incorporation scenario and percentage decrease under the potential future fertilizer/manure incorporation scenario.

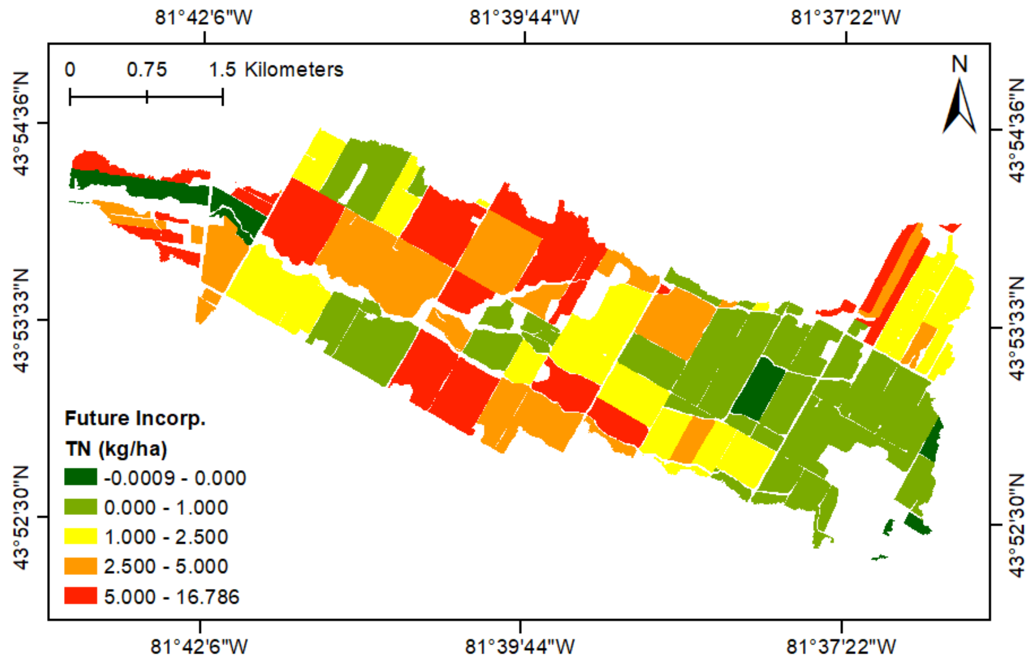

Figure 9-7. Simulated average yearly reduction of TN yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

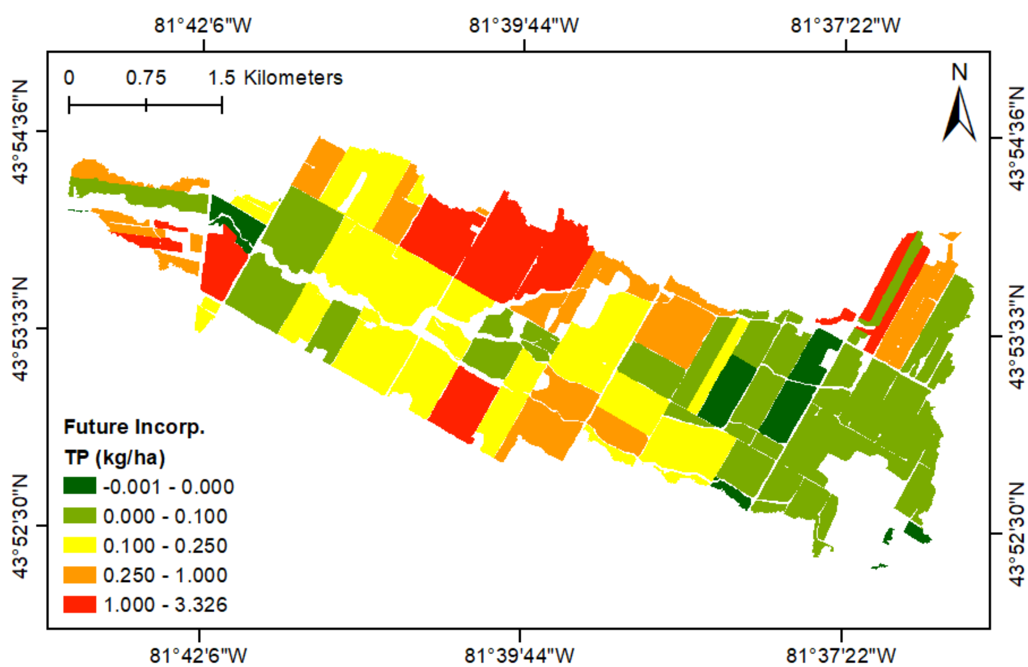

Figure 9-8. Simulated average yearly reduction of TP yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

10.0 IMWEBS MODELLING RESULTS FOR ASESSING THE EFFECTIVENESS OF FULL ADOPTION OF SELECTED BMPS

The calibrated Garvey Glen IMWEBs model was applied to estimate the water quality benefits of full adoption of the three key BMPs of interest, including cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation in relation to the entire absence of implementation of these BMPs in the watershed. The sections which follow provide a more detailed discussion of the results of this model output comparison for each of the three key BMPs of interest.

10.1 IMWEBs results for assessing the effectiveness of full adoption of the cover crop BMP

The differences between the IMWEBs modelling results under the conventional no existing cover cropping scenario and the potential future cover cropping scenario represented the effects of cover cropping on sediment, nitrogen, and phosphorus dynamics in all fields and in all years. The magnitudes of BMP effects were related to field characteristics such as crop rotation, topography, soil, and others. Figures 10-1, 10-2, and 10-3 show the spatial distribution of simulated average yearly reduction of TSS, TN, and TP yields/loads at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario from 2001 to 2021. Note that the maps focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 10-1, about 37.6% of the cropland area had TSS yield/load reduction between 0 and 0.05 ton/ha and 22.4% of the cropland had TSS yield/load reduction above 0.1 ton/ha and as high as 0.4 ton/ha. About 43.1% of the cropland area had TN yield/load reduction from 0 to 1 kg/ha and about 19.3% of the cropland area had TN yield/load reduction above 5 kg/ha and as high as 39.1 kg/ha. About 37.7% of the cropland area had TP yield/load reduction from 0 to 0.1 kg/ha and about 19.6% of the cropland area had TP yield/load reduction above 0.3 kg/ha and as high as 1.9 kg/ha. On average, potential future cover crop planting led to TSS, TN and TP yield/load reductions of 11.8%, 16.6% and 16.8% respectively in relation to corresponding TSS, TN and TP yields/loads under the conventional no existing cover cropping scenario. The pattern showed the full benefits of both existing actual and potential future cover crop planting in the watershed. Note that about 5.3%, 19.2% and 14.6% of the cropland areas had TSS, TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to full watershed adoption of cover cropping practices. This pattern maybe due to the assumption that the cover crops would be ploughed down in late fall or early spring, possibly making the soil in some places more susceptible to erosion and nutrient loss if storm events occurred.

Table 10-1. Simulated average yearly reductions of TSS, TN and TP yields/loads at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (5.3%)	0-0.025 (19.7%)	0.025-0.05 (17.9%)	0.05-0.1 (34.8%)	>0.1 (22.4%)	0.077 (0.654, 11.8%)
TN (kg/ha)	<= 0 (19.2%)	0-0.5 (22.7%)	0.5-1.0 (20.4%)	1.0-5.0 (18.4%)	>5.0 (19.3%)	4.797 (28.932, 16.6%)
TP (kg/ha)	<= 0 (14.6%)	0-0.05 (22.4%)	0.05-0.1 (15.3%)	0.1-0.3 (28.1%)	>0.3 (19.6%)	0.193 (1.150, 16.8%)

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area. In parathesis, TSS, TN, and TP yield/load under the conventional no existing cover cropping scenario and percentage decrease under the potential future cover cropping scenario.

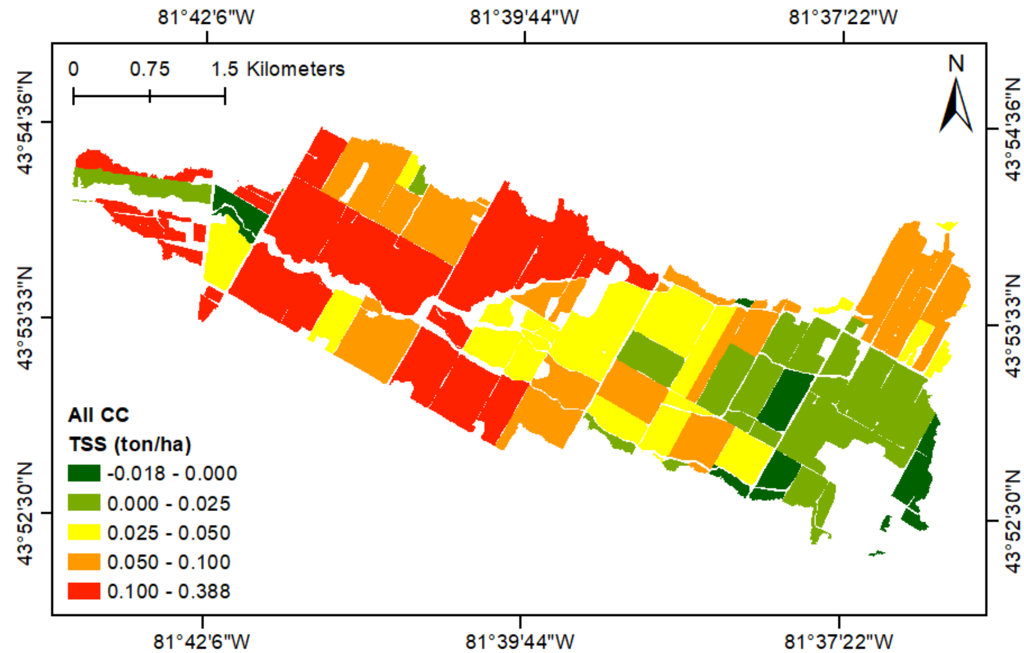

Figure 10-1. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

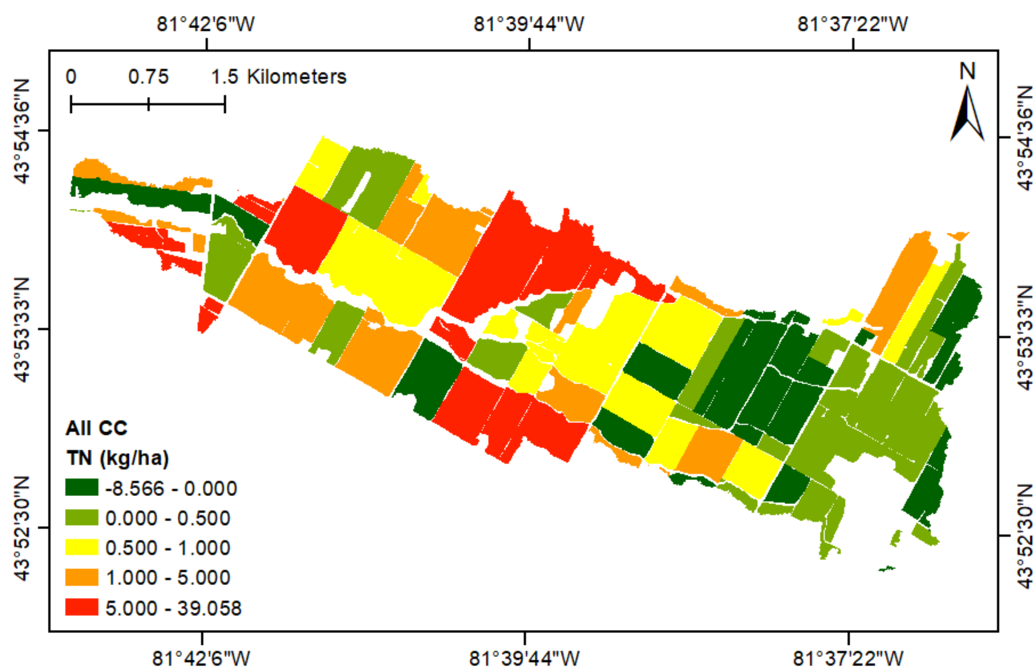

Figure 10-2. Simulated average yearly reduction of TN yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

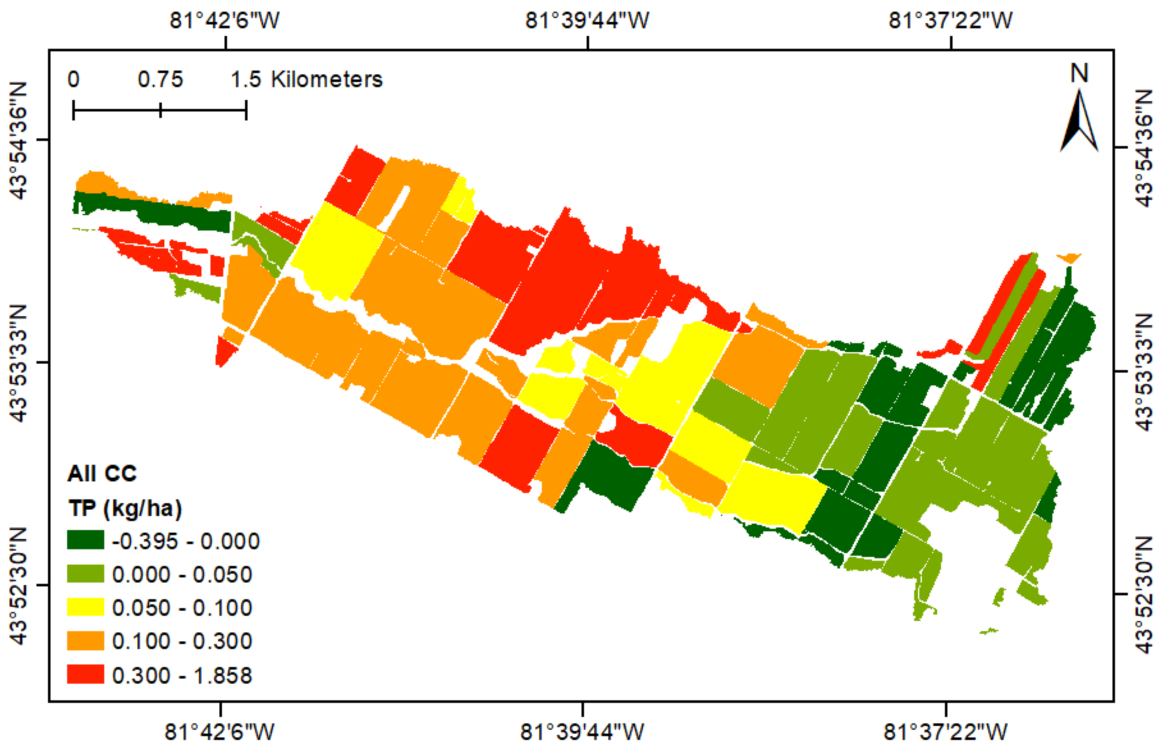

Figure 10-3. Simulated average yearly reduction of TP yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

10.2 IMWEBs results for assessing the effectiveness of full adoption of the conservation tillage BMP

The differences between the IMWEBs modelling results under the conventional no existing conservation tillage scenario and the potential future conservation tillage scenario represented the effects of conservation tillage on sediment, nitrogen and phosphorus dynamics in all fields and in all years. The magnitudes of BMP effects were related to field characteristics such as crop rotation, topography, soil, and others. Figures 10-4, 10-5, and 10-6 show the spatial distribution of simulated average yearly reduction of TSS, TN, and TP yields/loads at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario from 2001 to 2021. Note that the maps focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 10-2, about 63.0% of the cropland area had TSS yield/load reduction between 0 and 0.1 ton/ha and 11.0% of the cropland area had TSS yield/load reduction above 0.2 and as high as 0.4 ton/ha. About 45.5% of the cropland area had TN yield/load reduction between 0 and 2.0 kg/ha and 16.7% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 36.7 kg/ha. About 53.4% of the cropland area had TP yield/load reduction between 0 and 0.1 kg/ha and 19.2% of the cropland area had TP yield/load reduction above 0.2 kg/ha and as high as 1.0 kg/ha. On average, existing actual and potential future conservation tillage/no-till application led to TSS, TN and TP yield/load reductions of 12.3%, 13.1% and 11.8% respectively in relation to corresponding TSS, TN and TP yields/loads under the no existing conservation tillage scenario. The pattern showed the full benefits of both existing actual and potential future conservation tillage and no-till application in the watershed. Note that 4.8%, 13.7%, and 12.7% of the cropland area had TSS, TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to full watershed adoption of conservation tillage or no-till practices. These areas mostly overlapped with fields with slightly lower TSS yield/load reduction where more nutrient leaching may outweigh soil-associated nutrient retention.

Table 10-2. Simulated average yearly reductions of TSS, TN and TP yields/loads at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (4.8%)	0-0.05 (26.1%)	0.05-0.1 (36.9%)	0.1-0.2 (21.1%)	>0.2 (11.0%)	0.086 (0.701, 12.3%)
TN (kg/ha)	<= 0 (13.7%)	0-1.0 (32.2%)	1.0-2.0 (13.3%)	2.0-5.0 (24.2%)	>5.0 (16.7%)	3.889 (29.678, 13.1%)
TP (kg/ha)	<= 0 (12.7%)	0-0.05 (34.7%)	0.05-0.1 (18.7%)	0.1-0.2 (14.8%)	>0.2 (19.2%)	0.135 (1.143, 11.8%)

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area. In parathesis, TSS, TN and TP yield/load under the no existing conservation tillage scenario and percentage decrease under the potential future conservation tillage scenario.

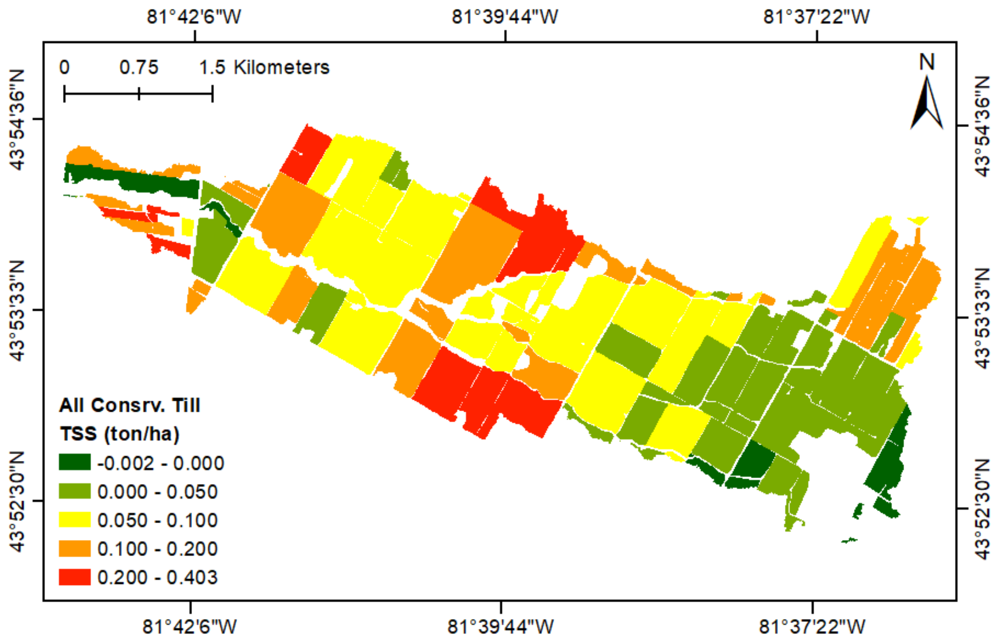

Figure 10-4. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

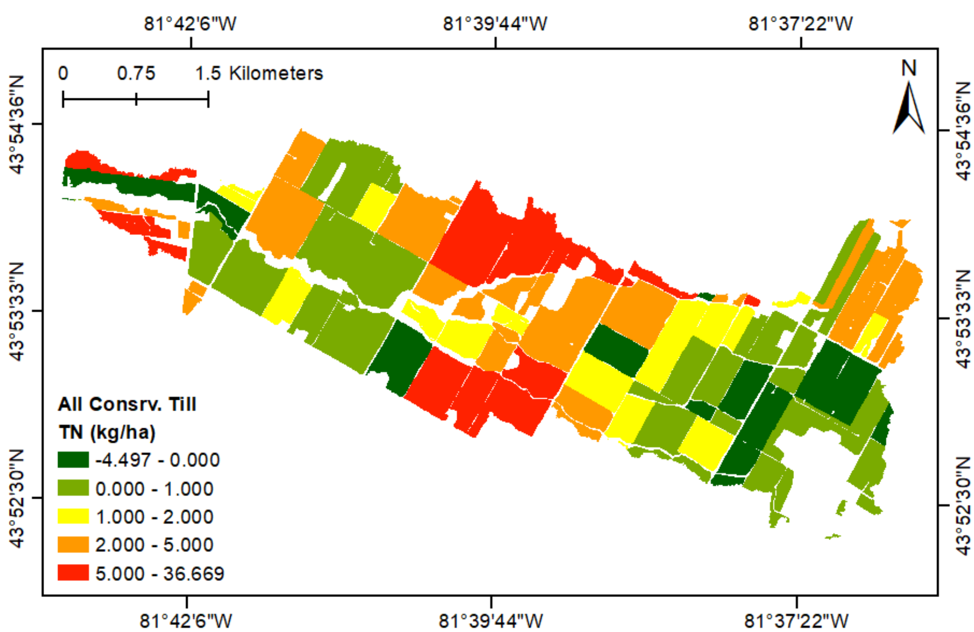

Figure 10-5. Simulated average yearly reduction of TN yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

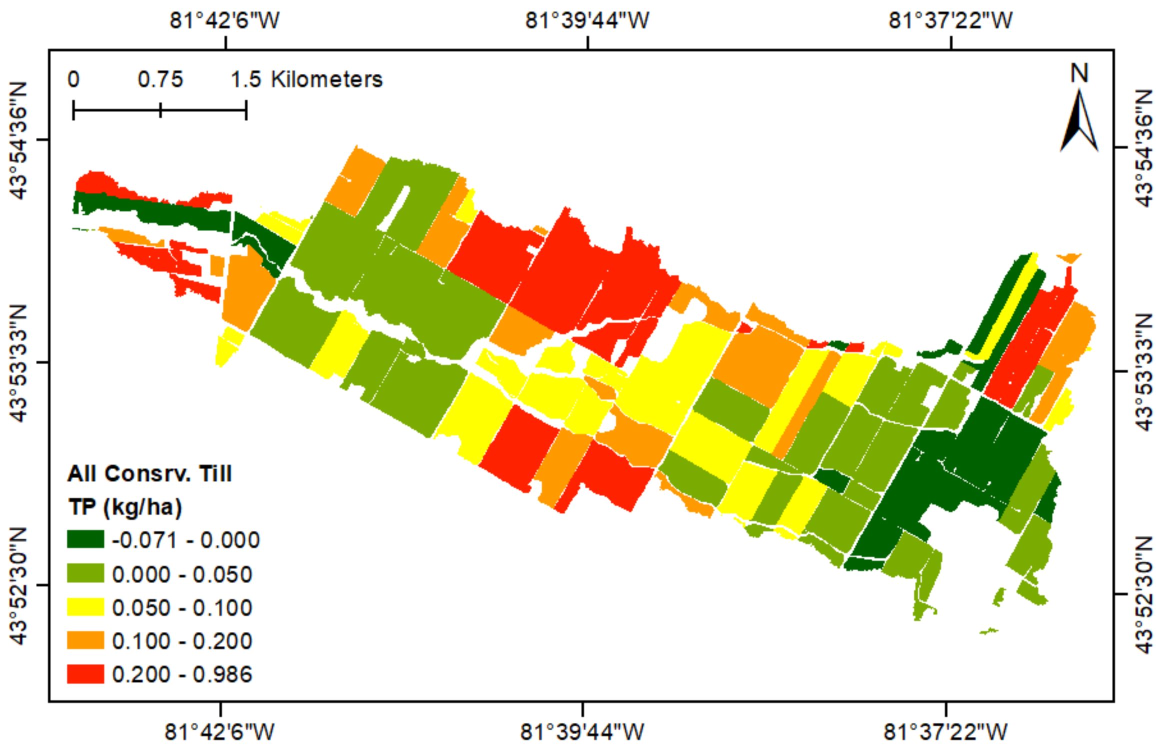

Figure 10-6. Simulated average yearly reduction of TP yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

10.3 IMWEBs results for assessing the effectiveness of full adoption of the fertilizer/manure incorporation BMP

The differences between the IMWEBs modelling results under the conventional no existing fertilizer/manure incorporation scenario and the potential future fertilizer/manure incorporation scenario represented the effects of fertilizer/manure incorporation on sediment, nitrogen and phosphorus dynamics in all fields and in all years. The magnitudes of BMP effects were related to field characteristics such as crop rotation, topography, soil, and others. Figures 10-7 and 10-8 show the spatial distribution of simulated average yearly reduction of TN and TP yields/loads at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario from 2001 to 2021. Fertilizer/manure incorporation had almost no effect on erosion, so TSS yield/load reductions were not reported in the study. Note that the maps focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 10-3, about 54.6% of the cropland area had TN yield/load reduction between 0 and 5.0 kg/ha and about 21.2% of the cropland area had TN yield/load reduction above 10.0 kg/ha and as high as 33.0 kg/ha. Also, about 44.8% of the cropland area had TP yield/load reduction between 0 and 0.5 kg/ha and about 24.6% of the cropland had TP yield/load reduction above 1.0 kg/ha and as high as 3.9 kg/ha. On average, existing actual and potential future fertilizer/manure incorporation led to TN and TP yield/load reductions of 19.3% and 52.4% respectively in relation to corresponding TSS, TN and TP yields/loads under the conventional no existing fertilizer/manure incorporation scenario. The pattern showed the full benefits of both existing actual and potential future fertilizer/manure incorporation in the watershed. Note that 3.8% and 1.9% of the cropland areas had TN and TP yield/load no change or increases in estimates of these water quality parameters in response to fertilizer/manure incorporation. In these areas fertilizer/manure incorporation caused more nutrient leaching.

Table 10-3. Simulated average yearly reductions of TN and TP yields/loads at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
TN (kg/ha)	<= 0 (3.8%)	0-1.0 (23.5%)	1.0-5.0 (31.1%)	5.0-10.0 (20.3%)	>10.0 (21.2%)	5.886 (30.519, 19.3%)
TP (kg/ha)	<= 0 (1.9%)	0-0.25 (34.6%)	0.25-0.5 (10.2%)	0.5-1.0 (28.7%)	>1.0 (24.6%)	0.751 (1.433, 52.4%)

Note: [1]. Percentages of watershed cropland area in parathesis; [2]. Average for watershed cropland area. In parathesis, TN and TP yield/load under the conventional no existing fertilizer/manure incorporation scenario and percentage decrease under the potential future fertilizer/manure incorporation scenario.

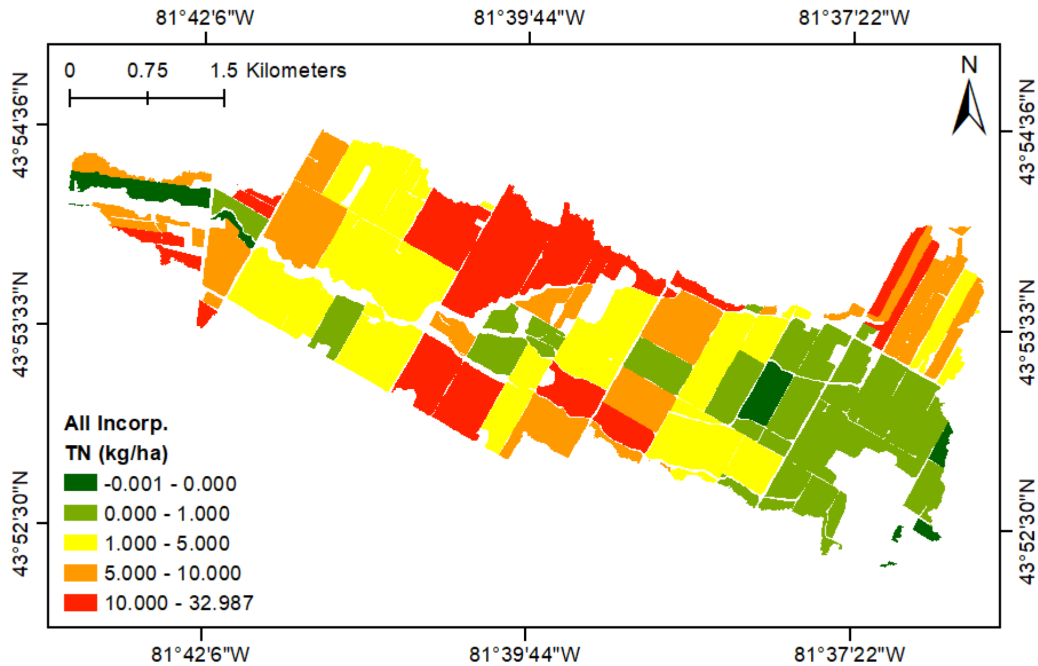

Figure 10-7. Simulated average yearly reduction of TN yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

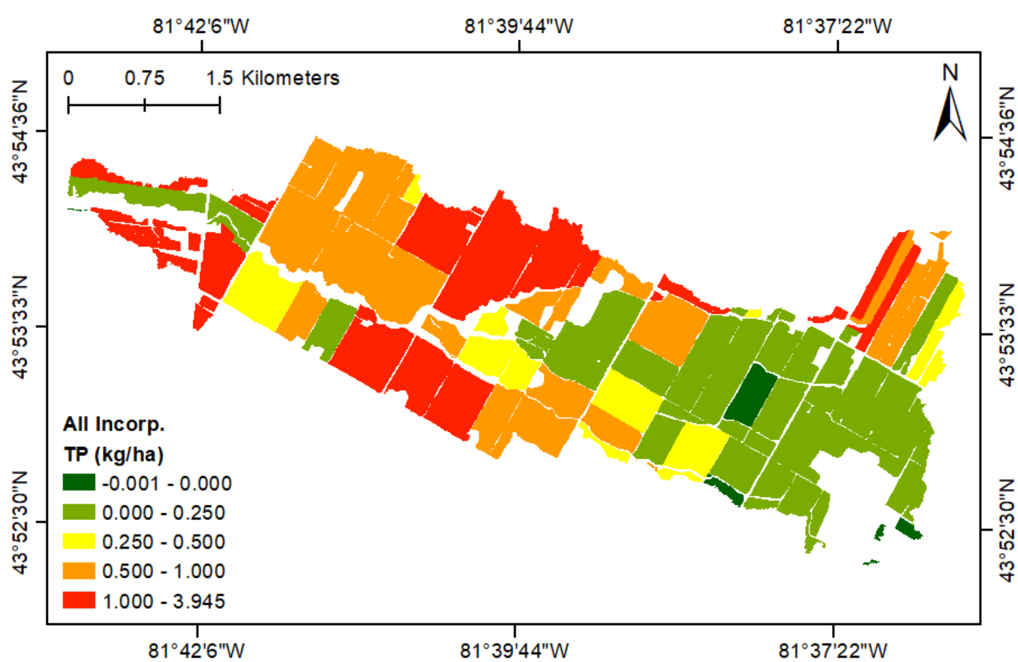

Figure 10-8. Simulated average yearly reduction of TP yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

11.0 BMP COST-BENEFIT ANALYSIS

BMP cost-benefit analysis (CBA) was another important component of the ONFARM project. Modellers worked with staff at MVCA to conduct a CBA for BMPs in the Garvey Glenn subwatershed. Four farmers provided data for cover crop only. One farmer provided data for cover crop and Tillage and Nutrient Application Equipment (No-till Drill). Note that in the components of the CBA, positive and negative numbers indicate costs and benefits respectively based on the fact that in most cases BMP costs outweigh benefits and positive numbers are used to represent positive net costs minus benefits. For the net cost-benefit, positive numbers indicate costs are over benefits while negative numbers indicate benefits are over costs.

Table 11-1. Cover Crop CBA for the Garvey Glenn Subwatershed

Farmer (acres in the subwatershed)	Seed cost ($/ac)	Pesticide cost ($/ac)	Operating/ maintenance cost ($/ac)	Labour cost ($/ac)	Nitrogen credit or yield increase benefit ($/ac)	Net cost-benefit ($/ac)
MV-3 (95 acres)	20		20	8		48
MV-5 (80 acres)	30	10	20	4		64
MV-4 (100 acres)	35	10	15	4	-32	32
MV-2 (250 acres)	20		30	3	-15	38
MV-6 (50 acres)	20		30	5		55

Note: 1. There is inconsistency in pesticide cost. MV-5, MV-2, and MV-6 have no pesticide cost. 2. There is inconsistency in nitrogen credit (MV02) or yield increase (MV-4). MV-3, MV-5, and MV-6 have no nitrogen credit or yield increase benefit data, which makes their values of net cost minus benefit inflated in comparing to those of the M-2 and MV-4.

Farmer MV-3 acquired new Tillage and Nutrient Application Equipment (No-till Drill) to implement the BMP. A 30-year life span and yearly interest rate of 5%, to amortize the initial investment cost of $120,000 over a 30-year period was assumed to arrive at a yearly cost of $7,806/yr, plus a 2.5% yearly repair cost ($3,000/yr) and a 1% insurance cost ($1,200/yr). This gave a total yearly cost of $12,006/yr. With 1,000 acres in the entire farm, the cost of $12/acre/yr for the no-drill equipment was arrived at. Labour cost was assumed to be $12/acre/yr. Reduction in input costs (fertilizer and fuel) was assumed to be $10/acre /yr. The net cost-benefit for Tillage and Nutrient Application Equipment (No-Till Drill) was $12 + $12 - $10 = $14/acre/yr, which means costs are over benefits. Note that this was a conservative or high-end estimate of the BMP cost. If the farmer didn't purchase the No-Till Drill, an existing or a new conventional drill would still need to be used and the opportunity cost of the NO-Till Drill would be lower. In addition, the labour cost would be lower in comparing to the use of conventional drill. Therefore, the BMP cost of No-till Drill would be lower than $14/acre/yr.

12.0 BMP COST-EFFECTIVENESS ANALYSIS

The cost-benefit analysis of cover cropping for the Garvey Glenn subwatershed had five sample values ranging from a net cost to production of $32/acre/yr to $64/acre/yr. We assumed an average of the five sample values as the cover cropping cost, which was $47.4/acre/yr or $117.1/ha/yr. Based on IMWEBs modelling, the average TP yield/load reduction of cover cropping was 0.193 kg/ha/yr. For cover cropping then, the BMP cost effectiveness of applying this practice for TP yield/load reduction was $606.9/kg of TP in the Garvey Glenn subwatershed.

There was no cost-benefit analysis for conservation tillage/no-till specifically for the Garvey Glenn subwatershed. Instead, based on the cost-benefit analysis for conservation tillage/no-till for the Gully Creek subwatershed (reduced cost of -$23/acre/yr or increased cost of $67/acre/yr), we assumed the cost of conservation tillage/no-till BMP at $22/acre or $54.4/ha. Based on IMWEBs modelling, the average TP yield/load reduction associated with conservation tillage practices was 0.135 kg/ha/yr. Therefore, for conservation tillage/no-till, the BMP cost effectiveness for TP yield/load reduction was $402.7/kg of TP in the Garvey Glenn subwatershed.

The cost-benefit analysis of Tillage & Nutrient Application Equipment Modifications for the Garvey Glenn subwatershed has a value of $14/acre/yr or $34.6/ha/yr. Based on IMWEBs modelling, the average TP yield/load reduction of fertilizer/manure incorporation was 0.752 kg/ha/yr. Therefore, for fertilizer/manure incorporation, the BMP cost effectiveness for TP yield/load reduction was $46.0/kg of TP in the Garvey Glenn subwatershed.

In the Garvey Glenn subwatershed, the BMP cost effectiveness for cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation was $606.9, $402.7, and $46.0 for per kg of TP yield/load reduction, respectively. Therefore, fertilizer/manure incorporation was the most cost-effective BMP and cover cropping was the least cost-effective BMP for TP yield/load reduction.

13.0 GENERAL SUMMARY AND CONCLUSION

In the ONFARM project we developed IMWEBs modelling for evaluating the water quality benefits of three key BMPs, namely cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation BMPs in the six priority subwatersheds. The IMWEBs modelling was setup based on watershed boundary, stream network, climate, topography/DEM, soil, landuse, and historical/existing land management and BMPs. It was then calibrated based on observed flow and water quality monitoring data. We made efforts to calibrate IMWEBs modelling for all six priority subwatersheds with various levels of success. In the end, only the calibrated IMWEBs modelling for the Garvey Glenn and Upper Medway Creek subwatersheds was applied for BMP assessment. For these two subwatersheds, the calibrated IMWEBs modelling was re-setup and subsequently run to simulate an absence of each of the three evaluated BMPs in the study watersheds. This was achieved by removing from the model's land management input datasets each of the three existing key BMPs in those fields and years where they were present. Other model set-ups went to the other extreme, and assumed full adoption of the three key BMPs in the study watersheds. This was achieved by adding each of the three BMPs to potential fields and years where they were not currently being applied but where they could be used within the study watersheds. The differences between the IMWEBs results under various combinations for these model set-ups were used as the basis for arriving at estimates of the benefits of the three key BMPs studied as currently adopted across the watershed as well as what might potentially be achieved in terms of water quality improvements if they were fully adopted, and what could be the water quality consequences if no adoption of these practices occurred in the watersheds. The differences between the IMWEBs results under the conventional no existing BMP scenarios and the existing actual BMP scenario (characterized by the calibrated IMWEBs model) represented the water quality benefits of historical/existing BMPs. These historical/existing BMP effectiveness results were then used to estimate an understanding of what had been achieved by the current level of BMP implementation in the subwatershed. The differences between the IMWEBs results under the existing actual BMP scenario and the potential future BMP scenarios represented the water quality benefits of what additional adoption BMPs in the watershed could potentially achieve. These potential future BMP effectiveness results were then used to understand what full adoption of these BMPs in the entire subwatershed would mean in terms of water quality improvements. This was accomplished by calculating the differences in the IMWEBs modelling results between the conventional "no existing BMP" scenarios and the "potential future BMP" scenarios

In addition, we worked with Conservation Authority colleagues to conduct BMP cost-benefit analyses (for the Garvey Glenn, Gully Creek, Upper Medway Creek, and North Kettle Creek subwatersheds) and cost effectiveness analyses (for the Garvey Glenn and Upper Medway Creek subwatersheds). The cost effectiveness analysis has shown a dollar cost for removing 1 kg of TP using the three key BMPs studied under the ONFARM project.

Table 13-1 provides a summary of the TP yield/load reductions for cover cropping, conservation tillage, and fertilizer/manure incorporation BMPs in the Garvey Glenn subwatershed. The results showed that the magnitudes of TP yield/load reductions for the historical/existing cover crop and conservation tillage/no-till adoption were relatively smaller, which reflected the relatively lower numbers of field/years with historical/existing BMP adoption. However, historical/existing fertilizer/manure incorporation BMP adoption had the relatively larger TP yield/load reduction resulting from greater implementation of this BMP. On the other hand, the results showed that there is still considerable potential for reducing TP loads with additional future BMP adoptions.

Overall, full adoption of the three agronomic BMPs can make significant contributions to TP yield/load reductions in the Garvey Glenn subwatershed. As we constructed three paired scenarios for BMP assessment (no existing BMP scenario vs. full BMP adoption scenario for each of the cover cropping, conservation tillage, and fertilizer/manure incorporation BMPs) to focus on individual BMP assessment, the baseline TP yield/load values were somewhat different for each pair. This led to somewhat different percentage reductions of TP yield/load for the full BMP adoption across the three agronomic BMPs and also in relation to existing actual BMP adoption and potential future BMP adoption. However, the absolute values of TP yield/load reductions of existing actual BMP adoption and potential future BMP adoption added up to those of the full BMP adoption for each of the three agronomic BMPs. If we assume an average TP yield/load under the no existing BMP scenarios, which is 1.242 kg/ha/yr for the Garvey Glenn subwatershed, full adoption of the three agronomic BMPs will contribute to a TP yield/load reduction of 1.080 kg/ha/yr if TP yield/load reductions of individual BMPs were added together, which represented 87.0% of TP yield/load reductions. While the total TP yield/load reductions of jointly implementing the three agronomic BMPs would likely protect the same nutrient sources or loss pathways, are therefore likely more effective combined than any of the individual BMPs was as modelled, we can still expect that full adoption of the three agronomic BMPs will mitigate or reduce the majority of the TP loss in the Garvey Glenn subwatershed.

Table 13-1. TP yield/load reductions for cover cropping, conservation tillage, and fertilizer/manure incorporation BMPs in the Garvey Glenn subwatershed

Cover cropping	Existing actual BMP adoption[1]	Potential future BMP adoption[2]	Full BMP adoption[3]
Avg TP load reduction (kg/ha)	0.051	0.142	0.193
Avg TP load without BMP scenario (kg/ha)[4]	1.099	1.099	1.150
Percent reduction in load from BMP scenario	4.7%	12.9%	16.8%

Conservation Tillage	Existing actual BMP adoption[1]	Potential future BMP adoption[2]	Full BMP adoption[3]
Avg TP load reduction (kg/ha)	0.044	0.091	0.135
Avg TP load without BMP scenario (kg/ha)[4]	1.099	1.099	1.143
Percent reduction in load from BMP scenario	4%	8.3%	11.8%
Fertilizer/manure incorporation	Existing actual BMP adoption[1]	Potential future BMP adoption[2]	Full BMP adoption[3]
Avg TP load reduction (kg/ha)	0.335	0.417	0.752
Avg TP load without BMP scenario (kg/ha)[4]	1.099	1.099	1.433
Percent reduction in load from BMP scenario	30.4%	37.9%	52.4%

[1.] A comparison between the existing actual BMP scenario and the no existing BMP scenario; [2.] A comparison between the existing actual BMP scenario and potential future BMP scenario; [3.] A comparison between the potential future BMP scenario and the no existing BMP scenario; [4]. The baseline for comparison with a BMP scenario. For existing actual BMP adoption, the baseline is the no existing BMP scenario. For potential future BMP adoption, the baseline is the existing actual BMP adoption (with potential future BMPs). For full BMP adoption, the baseline is the no existing BMP scenario.

Table 13-2 provided a summary of TP yield/load reduction, cost, and cost effectiveness for cover cropping, conservation tillage, and fertilizer/manure incorporation BMPs in the Garvey Glenn subwatershed. The rankings of BMP effectiveness in terms of per ha TP yield/load reduction from high to low were fertilizer/manure incorporation, cover cropping, and conservation tillage. The rankings of BMP cost from low to high had a slightly different pattern, fertilizer/manure incorporation, conservation tillage, and cover cropping. As a result, the rankings of BMP cost effectiveness in terms of a dollar cost for removing 1 kg of TP from low to high were fertilizer/manure incorporation, conservation tillage, and cover cropping. The pattern showed that both BMP effectiveness and cost play a role in determining the rankings and magnitudes of final BMP cost effectiveness. As the estimates of both BMP effectiveness and cost had uncertainties, further research needs to be conducted to further improve the accuracy in estimating BMP effectiveness, cost, and cost effectiveness.

Table 13-2. TP yield/load reduction, cost, and cost effectiveness for cover cropping, conservation tillage, and fertilizer/manure incorporation BMPs in the Garvey Glenn subwatershed

	TP yield/load reduction (kg/ha)	BMP cost ($/ha)	Cost effectiveness ($/kg of P reduction)
Cover cropping	0.193	117.1	606.9
Conservation Tillage	0.135	54.4	402.7
Fertilizer/ manure incorporation	0.752	34.6	46.0

14.0 Recommendations for Future Efforts

The ONFARM modelling, by necessity, is a collaborative initiative. Conservation Authority colleagues in collaboration with the landowners and farm operators, worked very hard to provide land management survey data, climate data, flow and water quality monitoring data, soil data and other data to us. We also asked for inputs from CA, OSCIA and OMAFRA colleagues on various modelling parameterization questions. Moving forward, we would like to make the following suggestions:

1). Support the development of a long-term watershed-based monitoring and data collection program

In Ontario, the WBBE, GLASI and ONFARM programs have invested on establishing the monitoring and data collection program for BMP assessment in several representative subwatersheds since 2014. These data are highly valuable for understanding watershed hydrology and other watershed characteristics and for setting up and calibrating watershed BMP modelling. We hope that the investment on the monitoring and data collection program can be sustained in order to support future BMP assessment initiatives.

We would like to provide several suggestions on improving quality control for climate and water monitoring data:

a). Ensure that the climate monitoring equipment setup is in good working order (such as free from obstruction), comparing climate data with nearby stations quickly after its initial collection to help identify inconsistencies, and make data corrections, if necessary;

b). Check climate, flow, TSS and nutrient data regularly to detect abnormal outliners or errors and make data corrections, if necessary;

c). Conduct consistency analysis between precipitation and flow observations, identify possible reasons for mismatches between precipitation and flow during a time window (such as periods where no precipitation was observed but flow occurred and conversely periods with precipitation but no flow), making data corrections promptly, if necessary.

2). Develop paired experimental sites for BMP assessment

In BMP assessment, it would be important to develop paired experimental sites, one with BMPs and one without BMPs, for monitoring flow and water quality differences. These monitoring data would be very helpful for setting up and calibrating watershed BMP modelling to evaluate on-site or edge-of-field and off-site or watershed outlet BMP effectiveness. We understand the challenges in setting up the paired experimental sites and conducting water monitoring (no two watersheds are exactly the same), but hope resources can be provided for this important component of the BMP assessment initiatives.

3). Transfer or scale up IMWEBs modelling to other representative subwatersheds or larger watersheds

The IMWEBs modelling was able to utilize valuable data collected by the WBBE, GLASI, and ONFARM programs to evaluate BMP effectiveness. While IMWEBs modelling can be further developed as more data from ONFARM subwatersheds are available, we would like to propose transferring or scaling up IMWEBs modelling to other representative subwatersheds or larger watersheds in future BMP assessment initiatives. Transferring IMWEBs modelling will extend BMP modelling to other representative subwatersheds with different landscape characteristics. Scaling up IMWEBs modelling from the existing subwatersheds can support the BMP assessment in larger areas. Both transferring and scaling up can broaden the scope of BMP assessment in the future.

15.0 REFERENCES

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