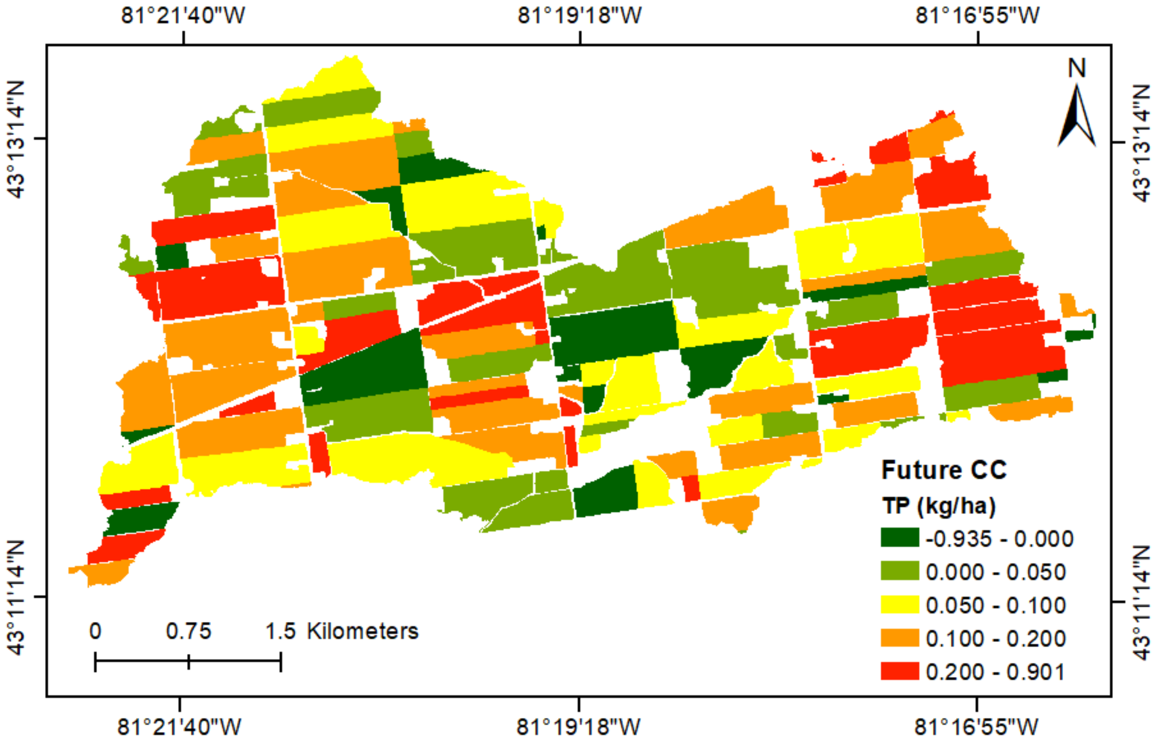

ONFARM

Modelling Report – Upper Medway Creek

June 28, 2023

Prepared by:

The Watershed Evaluation Group

University of Guelph

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1.0 INTRODUCTION

The Upper Medway Creek subwatershed in the service area of the Upper Thames River Conservation Authority (UTRCA) is a representative lakeshore watershed of the Lake St. Clair 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" (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 the Crop Improvement Association (OSCIA) jointly implemented the Great Lakes Agricultural Stewardship Initiative (GLASI). In GLASI, the Upper Medway Creek subwatershed was selected as one of the six priority subwatersheds for BMP establishment and study. By building upon UTRCA's previous BMP initiatives and monitoring program, the GLASI program invested in establishing a monitoring system for evaluating existing and newly-established BMPs in the study area, primarily conservation tillage, fertilizer incorporation, precision nutrient management, cover cropping, Water and Sediment Control Basin (WASCoB), rock chute, grassed waterway, constructed wetland, vegetative buffer strip, and windbreak establishment. Agriculture and Agri-Food Canada (AAFC) has also been conducting experiments on examining the water quantity and quality effects of free and controlled tile drainage since 2014. As a component of the GLASI, Soil and Water Assessment Tool (SWAT) modelling of the Upper Medway Creek 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, UTRCA 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 Upper Medway Creek 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 BMPs of interest (cover cropping, conservation tillage, 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, and fertilizer/manure incorporation following application) under different implementation levels and placement strategies across the watershed.

2.0 STUDY AREA

2.1 Location

The Upper Medway Creek subwatershed is located in southwestern Ontario, about 20 km north of the City of London (Figure 2-1). The Upper Medway Creek flows into the Thames River, which outlets into Lake St. Clair which in turn drains into the Detroit River which empties into the western basin of Lake Erie. The watershed has a drainage area of 2,006 ha.

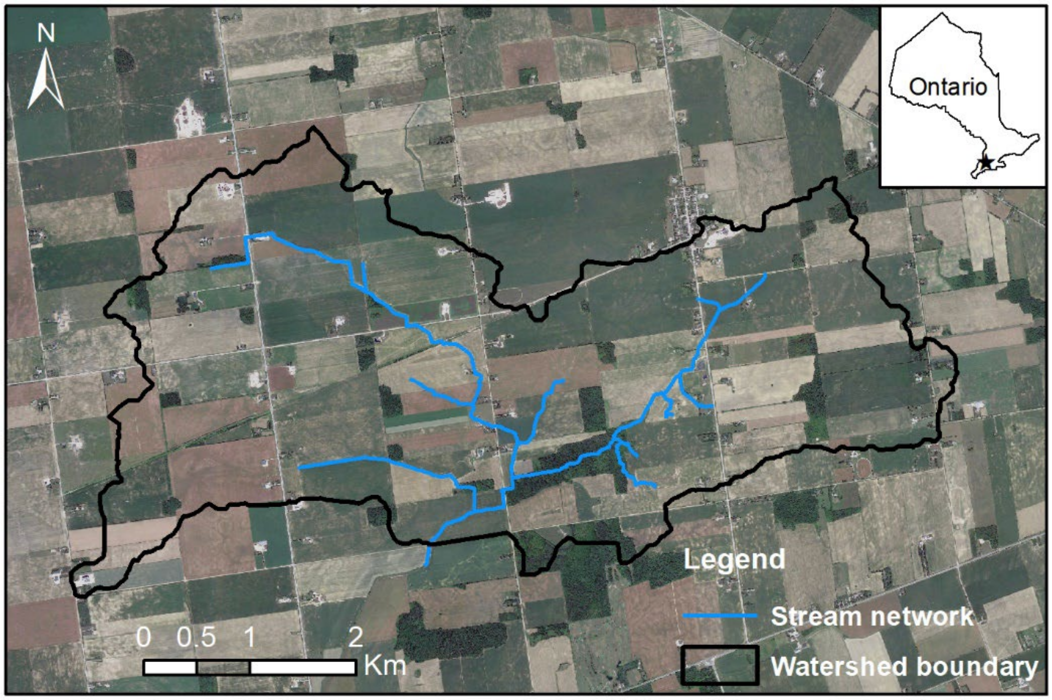

Figure 2-1. The Upper Medway Creek subwatershed within southwestern Ontario

2.2 Topography, soil, and landuse

The Upper Medway Creek subwatershed has an undulating topography ranging from the highest elevation of 336 m in the southeastern portion of the watershed, to the lowest elevation of 295 m at the watershed outlet (Figure 2-2). The average slope (according to the 1-m pixel resolution LiDAR DEM) is 5.72%, with a minimum of 0.00% in flat areas, and up to 184% (62 °) in the vicinity of the open drains, road ditches, and surface water channels (Figure 2-3 and Table 2-1).

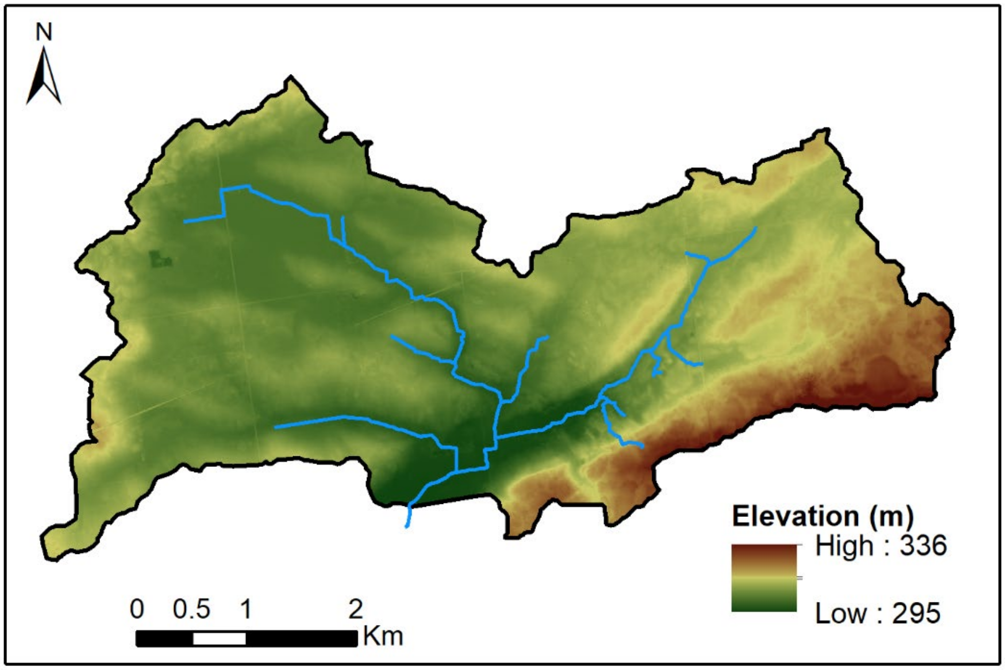

Figure 2-2. Topography of the Upper Medway Creek subwatershed

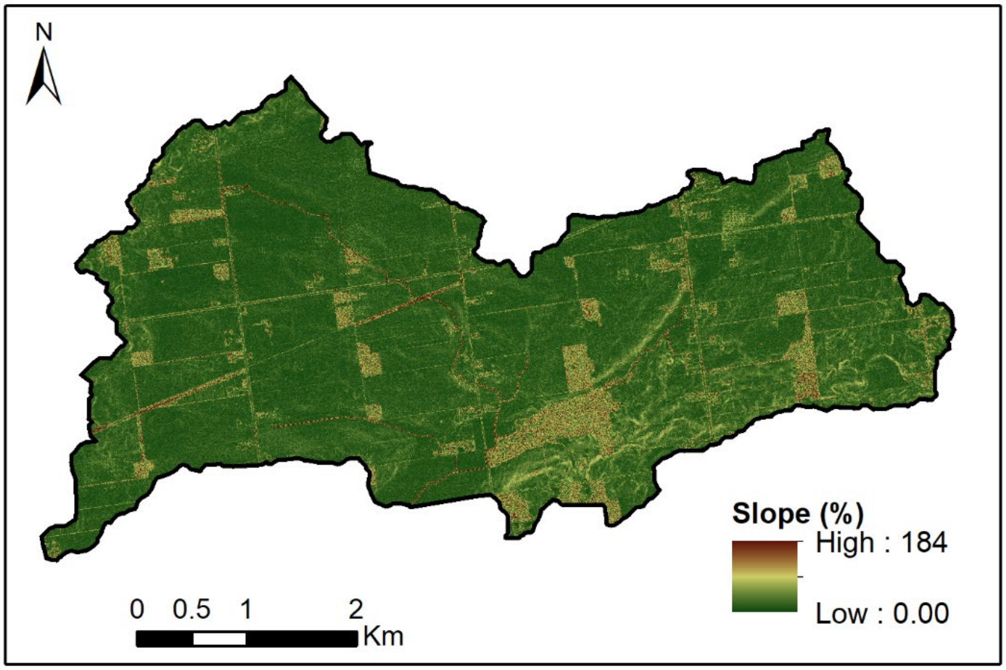

Figure 2-3. Slope of the Upper Medway Creek subwatershed

Table 2-1. Elevation and slope areal extent in the Upper Medway Creek subwatershed.

Class	Elevation (m)	Areal extent		Slope (%)	Areal extent	
		(km^2)	(%)		(km^2)	(%)
1	295 - 303	1.62	8.08	0.00 - 4.31	11.2	56.0
2	304 - 308	7.47	37.2	4.32 - 10.7	6.75	33.6
3	309 - 313	6.12	30.5	10.8 - 22.2	1.40	6.97
4	314 - 321	3.20	16.0	22.3 - 40.2	0.528	2.64
5	322 - 336	1.65	8.23	40.3 - 184	0.149	0.745
Average/sum	310	20.1	100	5.72	20.1	100.0

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 Upper Medway Creek subwatershed are shown in Table 2-2**.** In the upper reach area, the landscape is more rolling and is dominated by clay loam soil texture. The lower reach area is flatter and has a greater proportion of silt and loam soils.

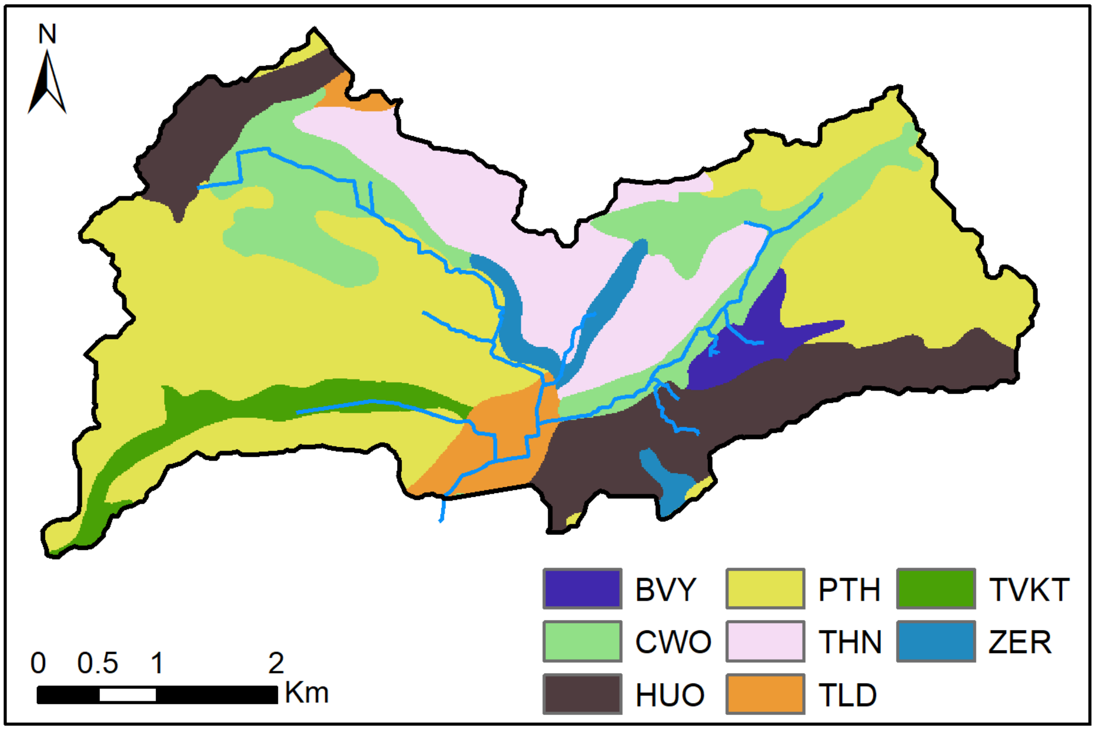

Figure 2-4. Soil types in the Upper Medway Creek subwatershed based on OMAFRA soil survey.

Table 2-2. Soil types and areal extent in the Upper Medway Creek subwatershed

Soil code	Soil type	Hydrologic group	Soil texture	Area (km^2)	Area (%)
PTH	Perth Silty Clay Loam	C	SiCL	8.59	42.9
HUO	Huron Silt Loam	C	SiL	3.08	15.4
CWO	Colwood Loam	C	L	2.94	14.7
THN	Thorndale Silt Loam	B	SiL	2.76	13.7
TVK	Tavistock Loam	C	L	0.870	4.34
TLD	Toledo Silty Clay Loam	D	SiCL	0.824	4.11
ZER	Eroded Channel Sandy Loam	B	SL	0.537	2.68
BVY	Beverly Silty Clay Loam	C	SiCL	0.449	2.24
Total				20.1	100

Figure 2-5 presents the landuse distribution within the Upper Medway Creek subwatershed. The landuse names and associated areas and percentages within the Upper Medway Creek subwatershed are listed in Table 2-3**.** Approximately, 83% of the land is agricultural, while 10% is grassland, 5% is built-up (i.e., urban, residential, and transportation), and less than 2% is forest.

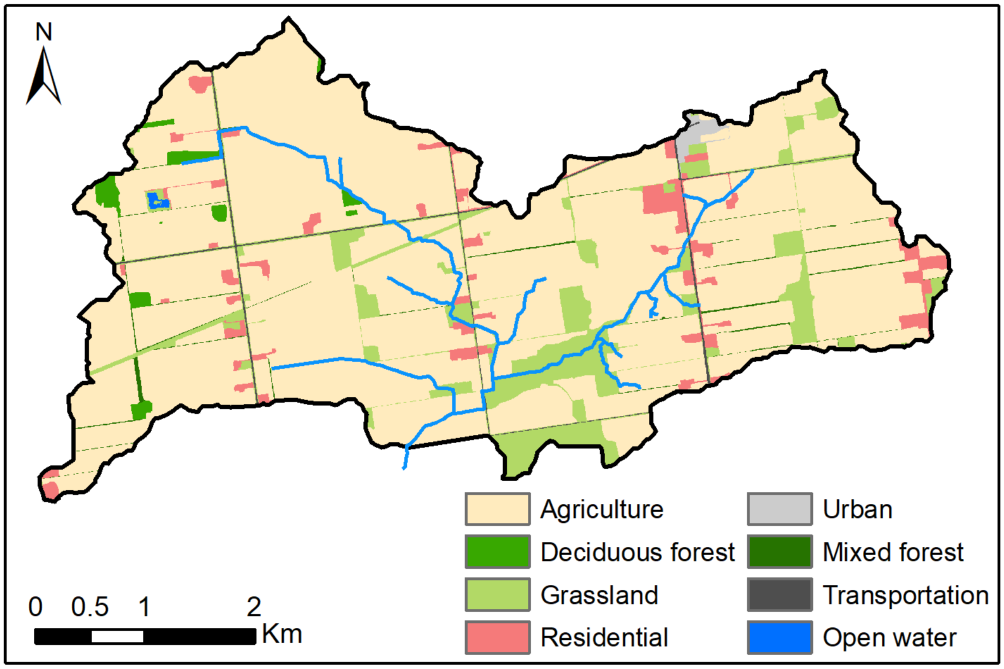

Figure 2-5. Landuse in the Upper Medway Creek subwatershed

Table 2-3. Landuse and areal extent of the Upper Medway Creek subwatershed

Landuse type	Area (ha)	Percent (%)
Agriculture	1,656	82.6
Grassland	207	10.3
Residential	78.0	3.89
Deciduous forest	22.2	1.11
Transportation	17.8	0.887
Mixed forest	14.3	0.714
Urban	9.03	0.450
Open water	1.80	0.090
Total	2,006	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 two UTRCA stations and six 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 UTRCA 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.

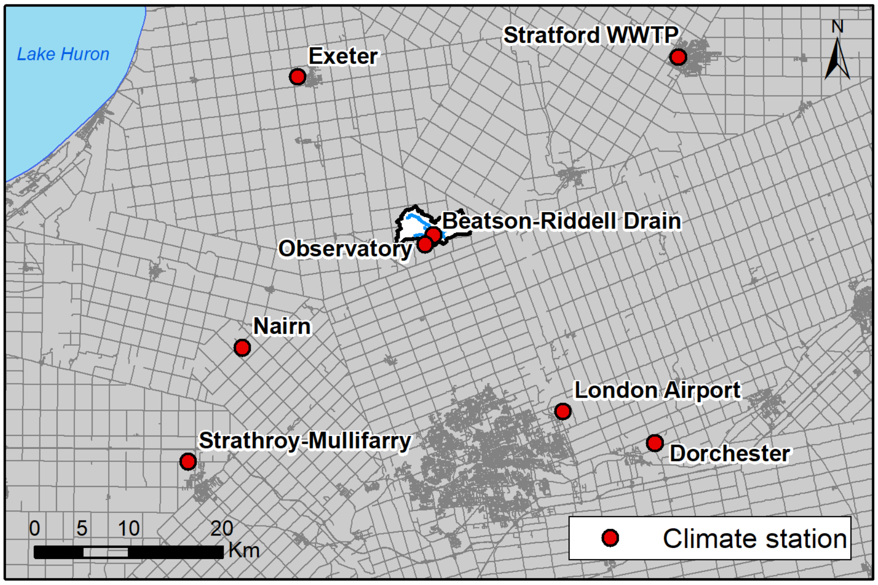

Figure 2-6. Climate monitoring stations for the Upper Medway Creek subwatershed IMWEBs modelling.

Table 2-4. Climate stations for the Upper Medway Creek subwatershed IMWEBs modelling

ID	Name	Latitude	Longitude	Elevation	Frequency	Period	Parameters
1	London Airport (ECCC)	43.03	-81.15	278	Hourly and Daily	1970-01-01 to 2022-06-30	PCP, TMP, RH*, SLR*, WS*, WD
2	Nairn (ECCC)	43.09	-81.57	233	Daily	1994-05-01 to 2011-06-17	PCP, TMP, RH*, SLR*, WS*
3	Exeter (ECCC)	43.35	-81.5	262	Daily	1970-01-01 to 2008-04-15	PCP, TMP, RH*, SLR*, WS*
4	Dorchester (ECCC)	43	-81.03	271	Daily	1976-04-14 to 2017-09-08	PCP, RH*, SLR*, WS*
5	Strathroy-Mullifarry (ECCC)	42.98	-81.64	243	Daily	1997-10-01 to 2022-06-30	PCP, TMP, RH*, SLR*, WS*
6	Stratford WWTP (ECCC)	43.37	-81	345	Daily	1970-01-01 to 2016-09-29	PCP, TMP, RH*, SLR*, WS*
7	Beatson-Riddell Drain (UTRCA)	43.2	-81.32	300	5 Minutes	2018-10-13 to 2022-06-30	PCP
8	Observatory (UTRCA)	43.19	-81.33	298	5 Minutes	2015-05-01 to 2022-04-26	TMP

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 UTRCA climate station because NASA data are grid based.

The Upper Medway Creek subwatershed has a climate with pronounced seasonal variations. The growing season begins in the middle of April and ends in late October with an annual average of about 160 frost free days. At station 1 (ECCC London Airport), the average annual precipitation was 1,023 from 1995 – 2021 with a standard deviation of 142 mm. The maximum annual precipitation of 1,302 mm occurred in 2006, and the minimum was 750 mm, occurring in 1998. The maximum daily precipitation was 89 mm, recorded on September 9, 1996. The average annual temperature was 8.4 °C from 1995 – 2021, ranging from 9.9 °C in 2012 to 6.8 °C in 2014 with a standard deviation of 0.84 °C. Yearly precipitation and average temperature from 1995 – 2021 at station 1 (ECCC London Airport) is presented in Figure 2-7. Annual precipitation and temperature are on average increasing from 1995 – 2021.

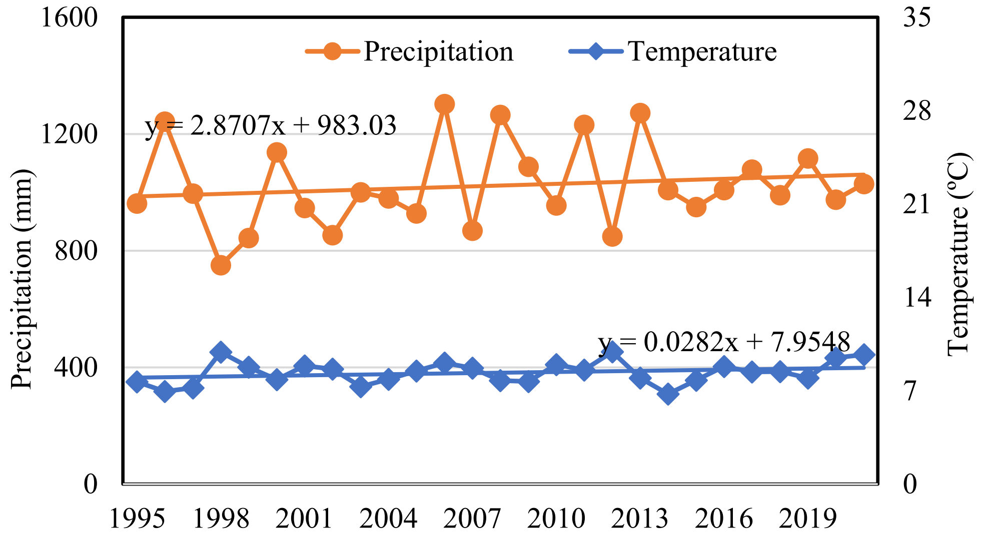

Figure 2-7. Variation of yearly precipitation and average temperature at station 1 (ECCC London Airport) from 1995-01-01 to 2021-12-31.

Temperature is highest in the summer months from June to September, and lowest in the winter months from December to March in the Upper Medway Creek subwatershed (Figure 2-8). Precipitation is distributed somewhat evenly across the seasons, with February and March having the lowest monthly average precipitation and September having the highest monthly average precipitation (Table 2-5).

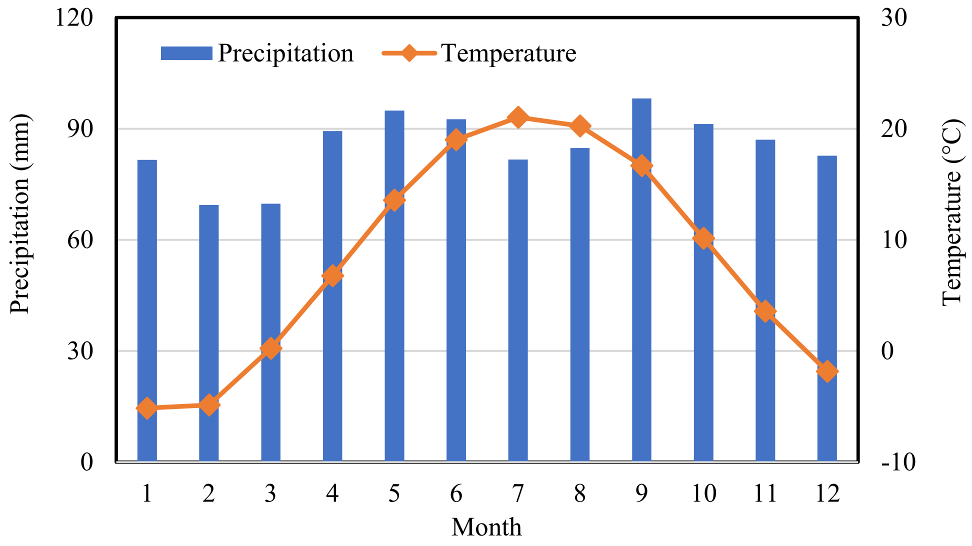

Figure 2-8. Average monthly precipitation and temperature at station 1 (ECCC London Airport) from 1995-01-01 to 2021-12-31.

Table 2-5. Average monthly precipitation and temperature at station 1 (ECCC London Airport) over the period of 1995 – 2021.

Month	T_max (°C)	T_min (°C)	T_avg (°C)	Precipitation (mm)
1	-1.57	-8.69	-5.13	81.6
2	-0.731	-8.96	-4.84	69.4
3	4.81	-4.33	0.240	69.8
4	12.1	1.40	6.77	89.4
5	19.3	7.78	13.6	94.9
6	24.5	13.5	19.0	92.6
7	26.7	15.4	21.0	81.6
8	25.8	14.6	20.2	84.8
9	22.3	11.0	16.7	98.2
10	14.9	5.45	10.2	91.3
11	7.38	-0.218	3.58	87.0
12	1.32	-4.99	-1.84	82.7
Ave/Sum	13.1	3.50	8.29	1,023
Max	26.7	15.4	21.0	98.2
Min	-1.57	-8.96	-5.13	69.4
STDV	10.7	9.04	9.84	9.01

Figure 2-9 presents baseflow separation at the Observatory streamflow monitoring station from 2016-03-07 to 2022-06-30. Based on the SWAT Baseflow Separation tool, baseflow contributes to about 37% of total streamflow at the Upper Medway outlet station from 2016-03-07 to 2022-06-30. Table 2-6 presents average monthly precipitation, runoff, and baseflow at the Observatory station from 2017-01-01 to 2021-12-31. Runoff is highest in the winter months due to frozen soils and snowmelt. Runoff is lowest from June to August due to higher temperatures and evapotranspiration (Figure 2-10).

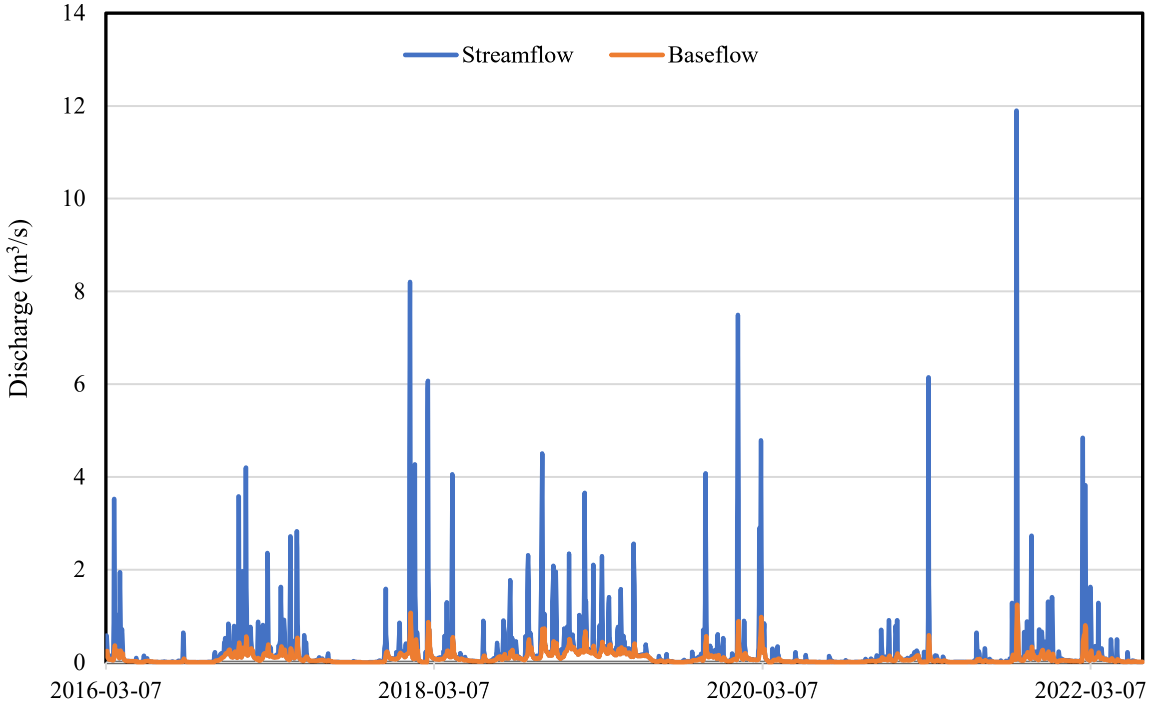

Figure 2-9. Baseflow separation at UTRCA Observatory station over the period of 2016-03-07 to 2022-06-30.

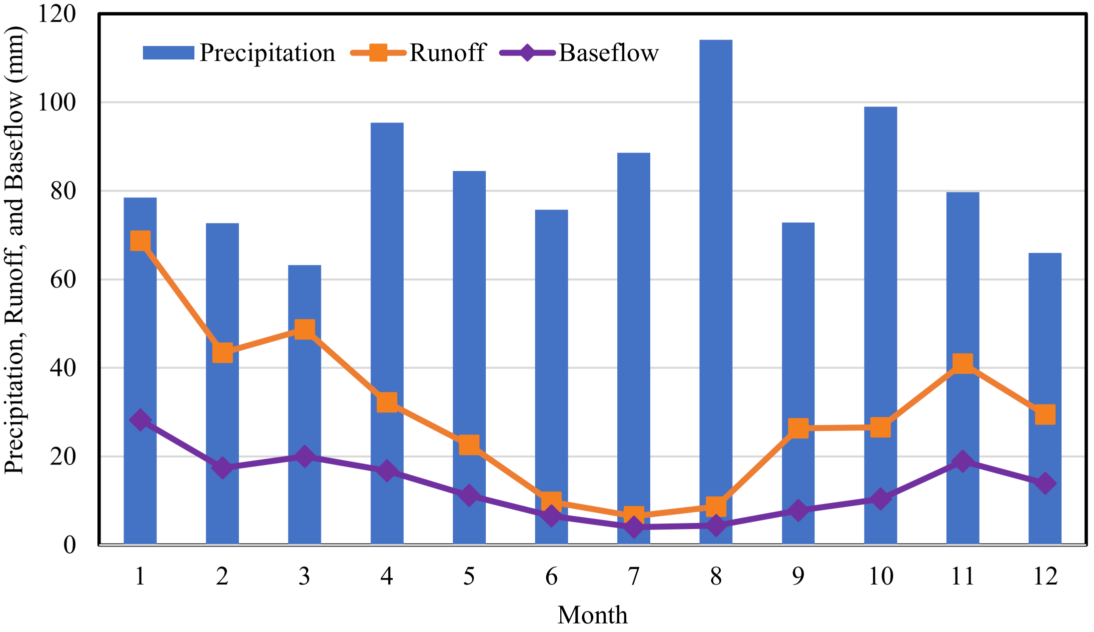

Figure 2-10. Average monthly precipitation, runoff, and baseflow at the Observatory station over the period of 2017-01-01 to 2021-12-31

Table 2-6. Average monthly precipitation, runoff, and baseflow at the Observatory station over the period of 2017-01-01 to 2021-12-31.

Month	Precipitation	Runoff			Baseflow		
	(mm)	(m^3/s)	(mm)	(% of Precipitation)	(m^3/s)	(mm)	(% of Runoff)
1	78.4	0.501	68.8	87.6	0.206	28.3	41.1
2	72.7	0.349	43.4	59.7	0.140	17.4	40.2
3	63.2	0.355	48.7	77.0	0.146	20.0	41.1
4	95.4	0.243	32.2	33.8	0.126	16.7	51.9
5	84.5	0.165	22.6	26.7	0.081	11.2	49.4
6	75.7	0.073	9.76	12.9	0.050	6.58	67.4
7	88.6	0.047	6.51	7.34	0.029	4.04	62.0
8	114	0.067	8.67	7.60	0.034	4.43	51.1
9	72.8	0.198	26.3	36.2	0.059	7.80	29.6
10	99.0	0.194	26.6	26.8	0.076	10.4	39.2
11	79.7	0.313	40.9	51.3	0.144	18.9	46.2
12	66.0	0.215	29.5	44.7	0.102	13.9	47.2
Sum/Ave	990	0.227	364	39.3	0.099	160	47.2
Max	114	0.501	68.8	87.6	0.206	28.3	67.4
Min	63.2	0.047	6.51	7.34	0.029	4.04	29.6
STDV	14.7	0.135	18.2	26.0	0.054	7.27	10.3

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 UTRCA, OMAFRA, and other sources.

Table 3-1. GIS data available for the Upper Medway Creek subwatershed

Data	Format	Source	Use
LiDAR DEM (1x1 m)	TIFF	UTRCA	Model setup
Soil	Shape	OMAFRA	Model setup
Land use	Shape	UTRCA	Model setup
Crop inventory 2011-2021	TIFF (30x30 m)	AAFC	Crop rotation
Stream network	Shape	UTRCA	Watershed delineation
Boundary	Shape	UTRCA	Watershed delineation
Existing BMPs	Shape	UTRCA	Model setup
Climate, flow, and water quality stations	Shape	UTRCA, ECCC, NASA	Model setup
Field boundary	Shape	UTRCA	Model setup
Tile drain	Shape	OMAFRA	Model setup
Transportation	Shape	MNRF	Presentation purpose

Note: UTRCA stands for Upper Thames River Conservation Authority, OMAFRA stands for Ontario Ministry of Agriculture, Food and Rural Affairs, AAFC stands for Agriculture and Agri-Food Canada, ECCC stands for Environment and Climate Change Canada, NASA stands for National Aeronautics and Space Administration, MNRF stands for Ministry of Natural Resources and Forestry.

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 ECCC, National Aeronautics and Space Administration (NASA), and UTRCA 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 UTRCA monitoring stations (Table 3-2). The locations of these stations are shown in Figure 3-1. The Observatory, Beatson Riddle Drain, and Cook Drainage Works monitoring stations were used for model calibration due to the availability of flow, sediment, and nutrient data at these three locations. The remaining sites were used as reference.

Table 3-2. Water quality and flow monitoring stations within the Upper Medway Creek subwatershed

Name	Description	Drainage Area (km^2)	Flow	Sediment	Nutrient
Observatory	Continuous flow and automatic sampling	19.5	2016-2022	2017-2021	2015-2022
Cook Drainage Works	Grab sample site	6.74	2018-2022	2016-2022	2016-2022
Beatson Riddle Drain	Grab sample site	1.40	2018-2022	2016-2022	2016-2022
Granton Wastewater Treatment Plant	Wastewater treatment plant site	2.22	2008-2020	2016-2021	2016-2021
Controlled Tile Drain Station 1	Edge of field site	0.018	2015-2017	-	2015-2017
Controlled Tile Drain Station 2	Edge of field site	0.026	2015-2017	-	2015-2017
Free Tile Drain Station	Edge of field site	0.085	2014-2017	-	2014-2017

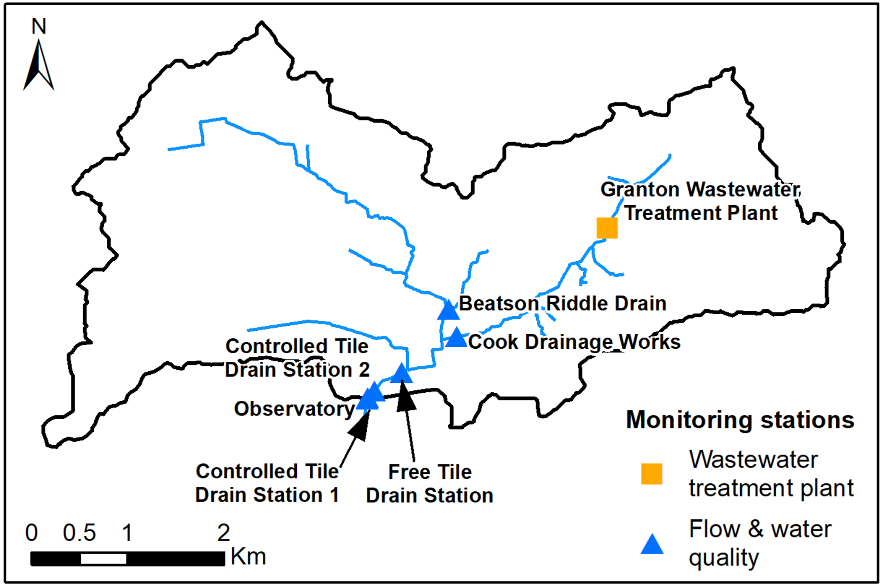

Figure 3-1. Flow and water quality monitoring stations in the Upper Medway Creek subwatershed

3.4 Land Management Data

UTRCA staff conducted land management surveys in 2017 under the GLASI program and in 2022 under the ONFARM project. The Upper Medway Creek 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 back to 2001 which establishes a land management dataset from 2001 – 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 Upper Medway Creek 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

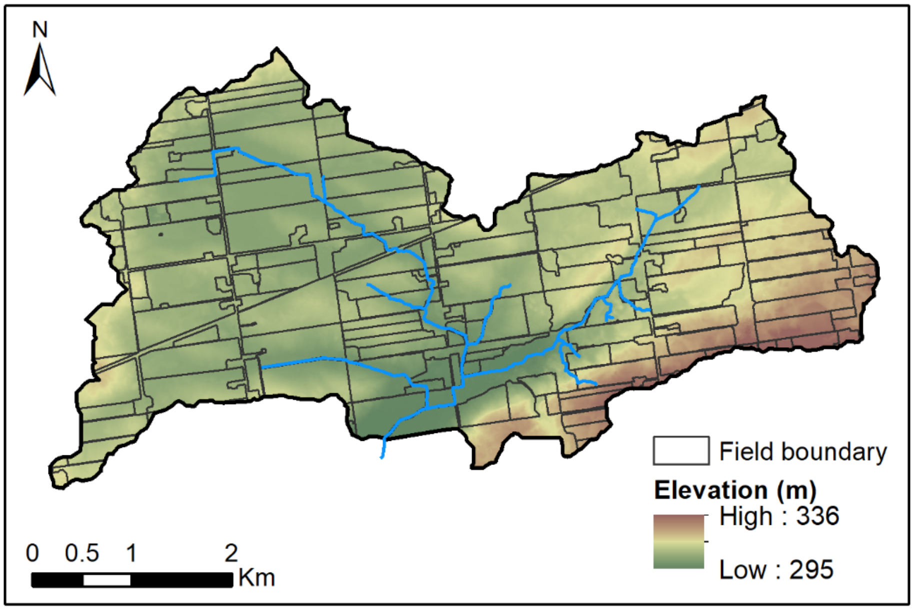

Figure 3-2. Field boundaries for the Upper Medway Creek subwatershed IMWEBs modelling

3.5 Existing Structural BMPs

There are 27 existing Water and Sediment Control Basins (WASCoBs), 33 existing surface inlet/depression features, three existing grassed waterways, seven existing riparian buffers, 22 existing windbreaks, and three existing wetlands in the Upper Medway Creek subwatershed (Figure 3-3). These features were represented in the IMWEBs model because their presence in the watershed affect the water flow and quality observations made at the various monitoring locations.

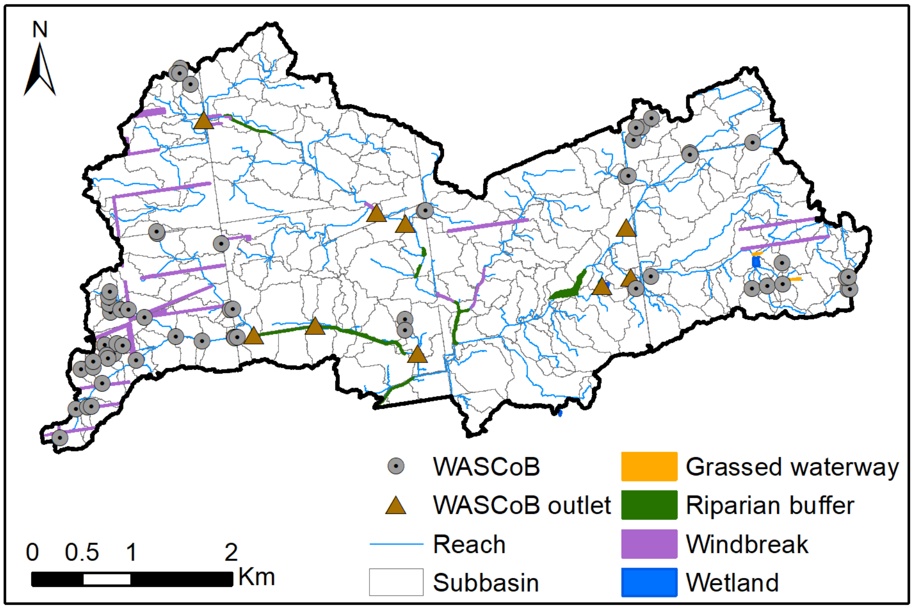

Figure 3-3. Existing Water and Sediment Control Basins (WASCoBs), grassed waterways, riparian buffers, windbreaks, and wetlands in the Upper Medway Creek subwatershed. Note that surface inlet/depression features are shown as WASCoBs on the map.

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 site, field, farm to 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 Upper Medway IMWEBs modelling, which contains 325 subbasins.

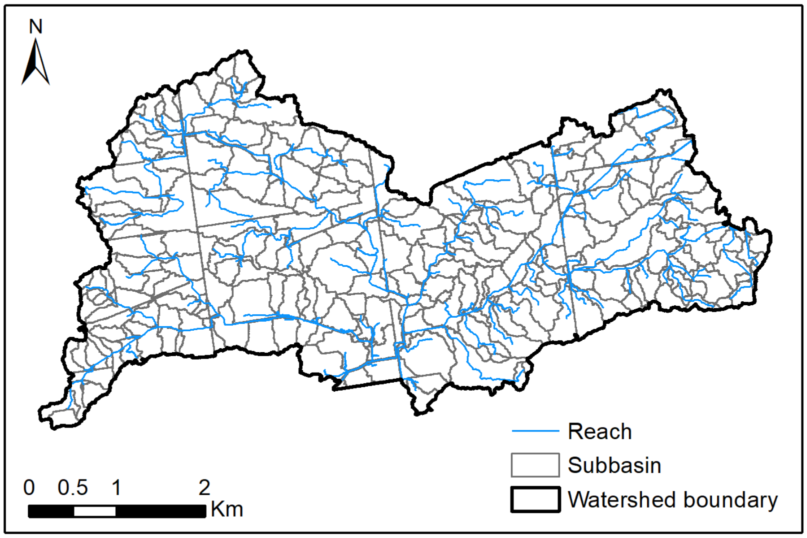

Figure 4-1. Delineated watershed boundary, subbasins, and reaches for the Upper Medway IMWEBs model.

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 Upper Medway IMWEBs model. A summary of soil characterization for the Upper Medway Creek subwatershed IMWEBs model is provided in Table 2-2.

4.4 Landuse characterization

The IMWEBs model has a detailed land cover classification including 98 plant types and eight urban landuses. For the Upper Medway Creek subwatershed, a total of eight distinct landuse types were identified based on the landuse data. The landuse types and associated areas and percentages within the Upper Medway Creek 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 Upper Medway Creek subwatershed IMWEBs model, which contains 2,141 subareas.

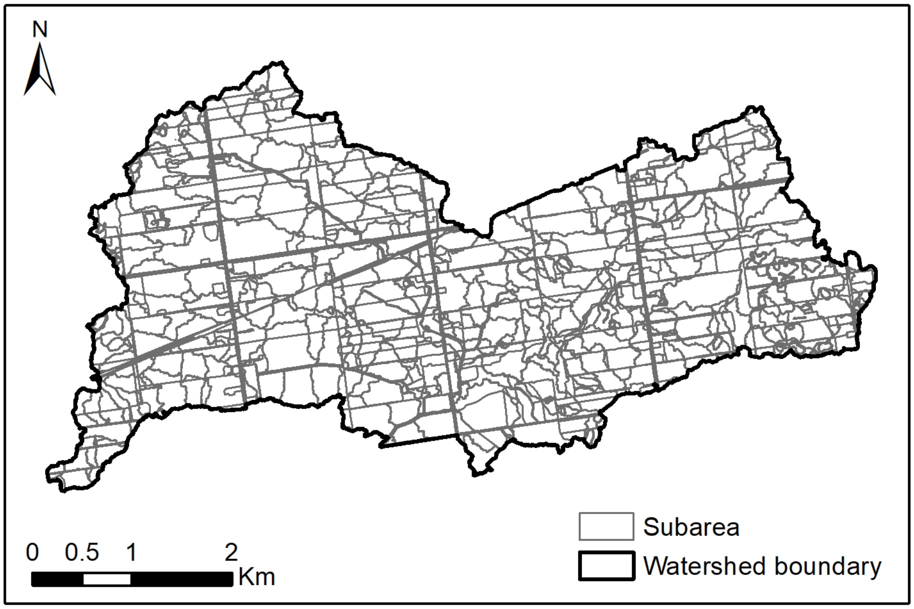

Figure 4-2. Subarea layer for the Upper Medway Creek subwatershed IMWEBs model.

4.6 Land management operations

Land management operations are a critical input for the IMWEBs model. Land management operations effect plant growth, nutrient availability, and nutrient and sediment transport throughout the watershed. UTRCA staff conducted GLASI and ONFARM land management surveys in the Upper Medway Creek 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 back to 2001 which establishes a land management dataset from 2001 – 2022. Table 3-3 describes the key parameters included in the land management dataset.

4.7 Tile drain characterization

The OMAFRA Tile Drainage Area dataset was used to define the spatial distribution of tile drainage in the Upper Medway Creek subwatershed. The ONFARM land management survey contained tile drain spacing and tile depth data, which was incorporated into the IMWEBs model. 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 Upper Medway Creek subwatershed, including radius and the dominant tile spacing and tile depth from the ONFARM survey. 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 Upper Medway Creek subwatershed IMWEBs model.

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	12,200	900	500

4.8 Water and Sediment Control Basin (WASCoB) characterization

There were 27 WASCoBs setup in the Upper Medway IMWEBs model, based on information from the GLASI modelling report and field verification by UTRCA field staff. Note that there were also numerous tile drain surface inlets installed in depressional areas of this watershed’s landscape. Table 4-2 lists these features as either “HB with depression” or “CB with depression”. Given the inlet’s placement in the landscape, these features also can store a certain amount of runoff water and therefore can function in much the same way as a true WASCoB system, and redirect a good portion of overland flow into underground tile drainage systems. Figure 4-3 shows the location of the WASCoBs in the Upper Medway Creek subwatershed as well as the corresponding cluster outlets for their associated riser pipe or French drain inlets. The cluster outlets are the points where multiple surface inlets upstream outletting to subsurface tile drainage systems eventually outlet into the surface stream. Note that in Figure 4-3, the surface inlet/depression locations represented on the map as WASCoBs.

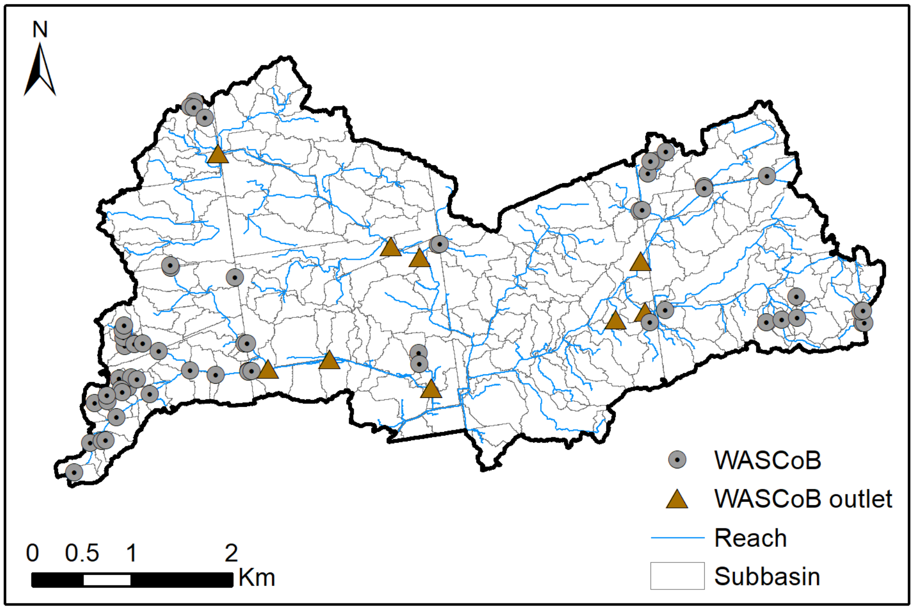

Figure 4-3. Location of WASCoBs and cluster outlets in the Upper Medway Creek subwatershed IMWEBs model.

Parameterization of WASCoBs as well as the surface inlet/depression features in the Upper Medway IMWEBs model made use of the information available from the GLASI project. Table 4-3 lists key WASCoB parameters used in characterizing each WASCoB and inlet/depression feature present within the Upper Medway 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 or depression storage features, 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.

Table 4-2. WASCoB and Drained Depression Storage characteristics in the Upper Medway Creek subwatershed

Type	Installation year	Subbasin	Drainage area (ha)	Outlet reach	Volume (m3)	Surface area (ha)	Capacity (m^3/day
HB with depression	1980	215	9.99	177	3,456	1.00	4,320
HB with depression	1980	194	1.71	179	1,037	0.48	1,296
CB with depression	1950	139	1.11	267	909	0.31	1,296
CB with depression	1950	128	3.93	267	1,037	1.00	1,296
CB with depression	1950	269	15.7	251	5,530	1.00	6,912
CB with depression	1950	280	15.7	251	5,530	1.00	6,912
CB with depression	1950	266	2.37	251	1,037	0.67	1,296

CB with depression	1950	248	81.7	267	8,294	1.00	10,368
CB with depression	1950	248	0.053	267	43.0	0.01	432
CB with depression	1950	102	39.0	118	8,294	1.00	10,368
CB with depression	1950	117	39.0	118	8,294	1.00	10,368
CB with depression	1950	83	29.1	96	8,294	1.00	10,368
CB with depression	1950	83	13.3	96	5,530	1.00	6,912
CB with depression	1950	61	57.9	96	8,294	1.00	10,368
CB with depression	1950	62	57.9	96	8,294	1.00	10,368
CB with depression	1950	217	7.06	96	2,074	1.00	2,592
CB with depression	1950	209	0.643	96	484	0.18	605
CB with depression	1950	202	1.64	96	1,037	0.46	1,296
CB with depression	1950	141	0.643	96	484	0.18	605
CB with depression	2016	249	11.4	251	5,530	1.00	6,912
CB with depression	2000	273	34.2	251	8,294	1.00	10,368
CB with depression	2000	284	12.8	251	5,530	1.00	6,912
CB with depression	2016	294	18.6	251	5,530	1.00	6,912
CB with depression	1950	39	8.33	96	3,456	1.00	4,320
CB with depression	2017	134	1.39	103	1,037	0.39	1,296
CB with depression	2005	8	1.46	35	1,037	0.41	1,296
CB with depression	2005	11	1.03	35	844	0.29	1,296
HB with narrow-based berm	1990	237	2.54	297	1,037	0.72	1,296
CB with depression	1950	20	1.68	96	1,037	0.48	1,296
CB with depression	1950	42	7.23	96	2,074	1.00	2,592
CB with depression	1950	20	0.343	96	207	0.10	259
CB with depression	1950	20	0.515	96	424	0.15	605
CB with depression	2010	325	0.593	251	484	0.17	605
CB with depression	2005	8	1.03	35	844	0.29	1,296

HB with narrow-based berm	2005	8	1.03	35	844	0.29	1,296
CB with narrow-based berm	1995	222	4.28	179	1,037	1.00	1,296
CB with narrow-based berm	1995	186	7.94	179	3,456	1.00	4,320
CB with narrow-based berm	1995	182	2.46	179	1,521	0.69	1,901
HB with narrow-based berm	1995	155	0.705	179	484	0.20	605
HB with narrow-based berm	2016	235	4.33	251	1,900	0.48	2,160
HB with narrow-based berm	2016	236	0.533	251	1,350	0.48	1,642
HB with narrow-based berm	2016	185	1.42	251	130	0.05	432
FD with broad-based berm	2016	184	3.94	251	1,037	1.00	1,296
FD with broad-based berm	2016	235	5.97	251	1,350	0.52	3,888
HB with narrow-based berm	2016	226	2.97	251	1,037	0.84	1,296
CB with broad-based berm	2016	324	8.92	251	3,456	1.00	4,320
CB with broad-based berm	2016	320	1.83	251	1,037	0.52	1,296
CB with broad-based berm	2016	323	2.78	251	1,037	0.79	1,296
CB with broad-based berm	2016	310	11.9	251	5,530	1.00	6,912
FD with broad-based berm	2017	294	0.540	251	444	0.15	605
FD with broad-based berm	2017	294	0.540	251	444	0.15	605

FD with broad-based berm	2017	277	0.513	251	422	0.14	605
FD with broad-based berm	2017	296	0.505	251	416	0.14	605
FD with broad-based berm	2017	277	0.668	251	484	0.19	605
FD with broad-based berm	2017	277	0.290	251	207	0.08	259
FD with broad-based berm	2017	286	1.13	251	932	0.32	1,296
FD with broad-based berm	2017	286	0.113	251	93	0.03	259
FD with broad-based berm	2017	296	0.240	251	198	0.07	259
FD with broad-based berm	2017	296	0.920	251	484	0.26	605
HB with narrow-based berm	1990	268	3.72	297	1,037	1.00	1,296

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 2016-01-01 to 2022-06-30 was used for model calibration. Monitoring sites Observatory, Beatson Riddle Drain, and Cook Drainage Works were used for model calibration. The water quality data at the other stations were used as reference during model calibration. The model was calibrated firstly for flow (Observatory streamflow monitoring station only); followed by sediment, particulate P, and particulate N; and lastly dissolved P and dissolved N (all calibration stations).

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 the watershed outlet Observatory site. 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 Observatory site resulting in a NSC of 0.46, a model bias of 1.15%, and a CORR of 0.69 based on the criteria outlined in Moriasi et. al (2007).

Table 5-1. Calibrated water balance and flow routing parameters for the Upper Medway Creek Subwatershed IMWEBs model

Parameter	Definition	Value
depression	Depression storage capacity	-0.3*
runoff_co	Potential runoff coefficient	0.22*
K_pet	Correction factor for PET	0.0
Surface_lag	Surface lag coefficient	-0.5
rootdepth	Root depth	-0.4*
interflow_scale_factor	Interflow scale factor	-0.5
porosity_layer2	Soil porosity for layer 2	-0.25*
rv_co	Groundwater revaporation coefficient	0.1
Kg	Baseflow recession coefficient	0.059
base_ex	Baseflow recession exponent	1.4
K_run	Runoff exponent when net rainfall approaches to zero	2.0
P_max	Maximum rainfall intensity	50
soil_ta0	Empirical coefficient for estimating soil temperature	-2.7
T_Snow	Snowfall temperature, SFTMP	0.0
T0	Snowmelt temperature	-0.5
swe0	Initial snow water equivalent	25
K_snow	Degree day coefficient mm/ $_{O}$C/day	1.0
K_rain	Rainfall impact factor	0.05
SHC_crop	Snow holding capacity of cropland	10.0
s_frozen	Frozen moisture relative to porosity with no infiltration	0.3
t_soil	Soil freezing temperature	-5.0

[*] Ratio of relative parameter change, e.g. porosity_layer2 = porosity_layer2-0.25×Soil porosity for layer 2

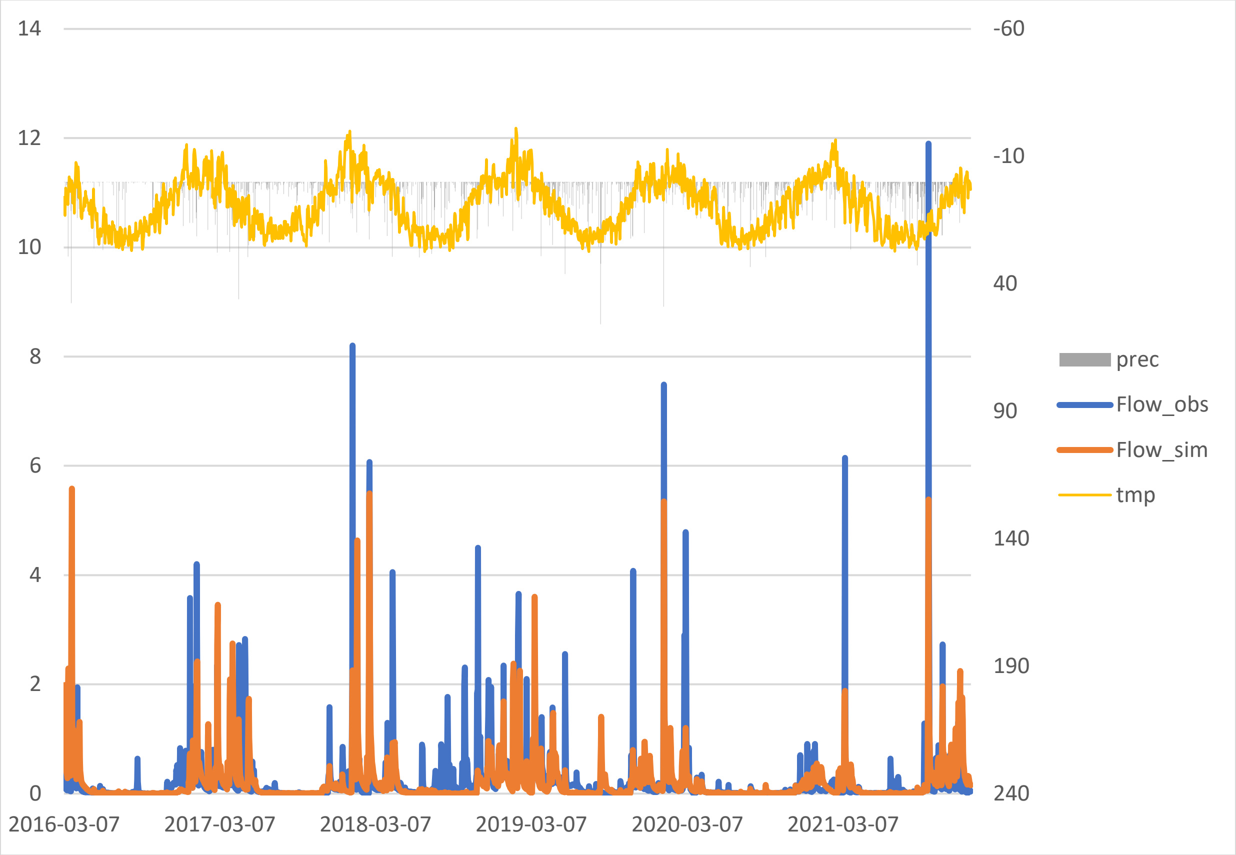

Figure 5-1. Measured vs. simulated flow at the Observatory site

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 Observatory site. 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 sediment calibration was achieved at Observatory site resulting in model bias of -4.13%, and CORR of 0.72 based on the criteria outlined in Moriasi et. al (2007).

Table 5-2. Calibrated soil erosion and sediment transport parameters for the Upper Medway Creek Subwatershed IMWEBs model

Parameter	Definition	Value
USLE_K_layer1	K-factor for MUSLE	-0.1*
USLE_C	C-factor for MUSLE	-0.1*
USLE_P	The erosion control practice factor	-0.07*
vcrit	Critical velocity for sediment deposition	0.2
spcon	Coefficient in sediment transport equation	0.079

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

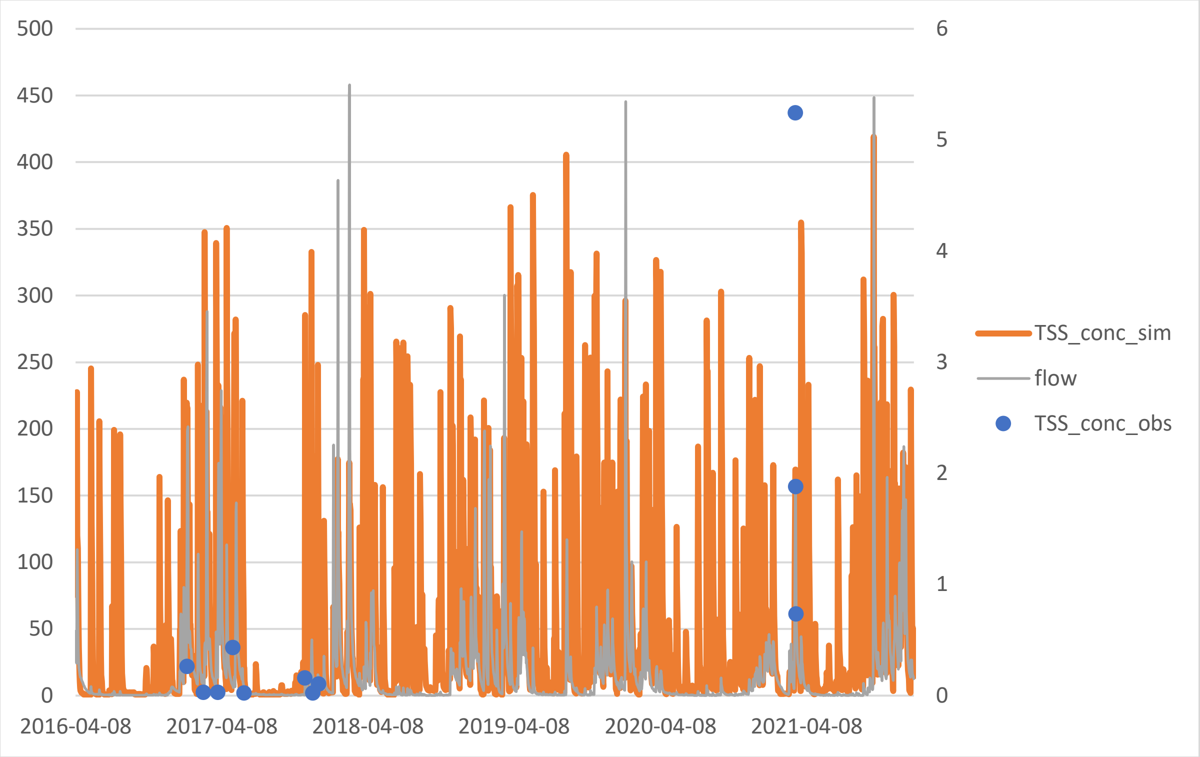

Figure 5-2. Measured vs. simulated sediment concentration at the Observatory site

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 the Observatory site. 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 the Observatory site resulting in a model bias of 13.07%, and a CORR of 0.59 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. An acceptable total nitrogen concentration calibration was achieved at the Observatory site resulting in a model bias of -18.46%, and a CORR of 0.23 based on the criteria outlined in Moriasi et. al (2007).

Table 5-3. Calibrated phosphorus parameters for the Upper Medway Creek Subwatershed IMWEBs model

Parameter	Definition	Value
phosphrusPartiCo	Phosphorus partitioning coefficient	105
phosphrusPercoCo	Phosphorus percolation coefficient	-12
OrganicP_coefficient	Organic phosphorus adjustment coefficient	5.0

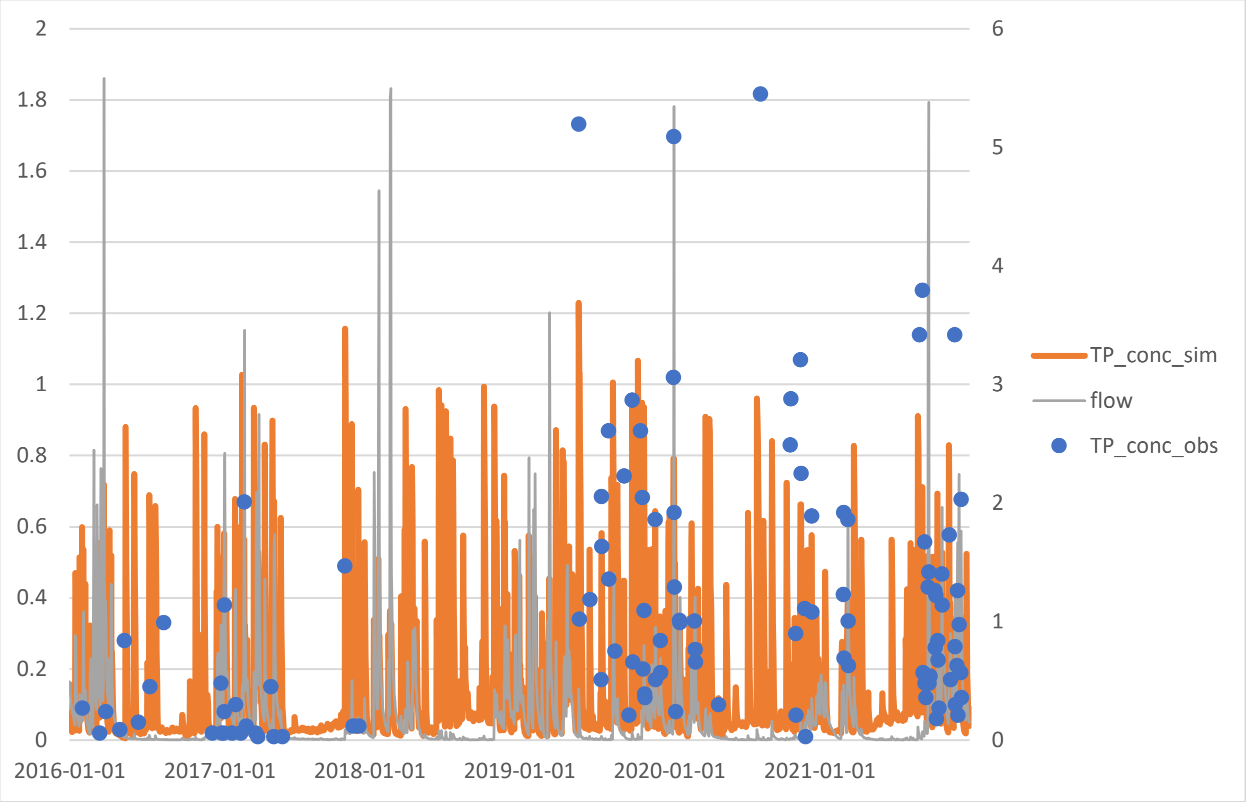

Figure 5-3. Measured vs. simulated total phosphorus concentration at the Observatory site

Table 5-4. Calibrated nitrogen parameters for the Upper Medway Creek Subwatershed IMWEBs model

Parameter	**Definition**	**Value**
organicN_coefficient	Organic nitrogen adjustment coefficient	5.0
nitratePercoCo	Nitrate percolation coefficient	0.25

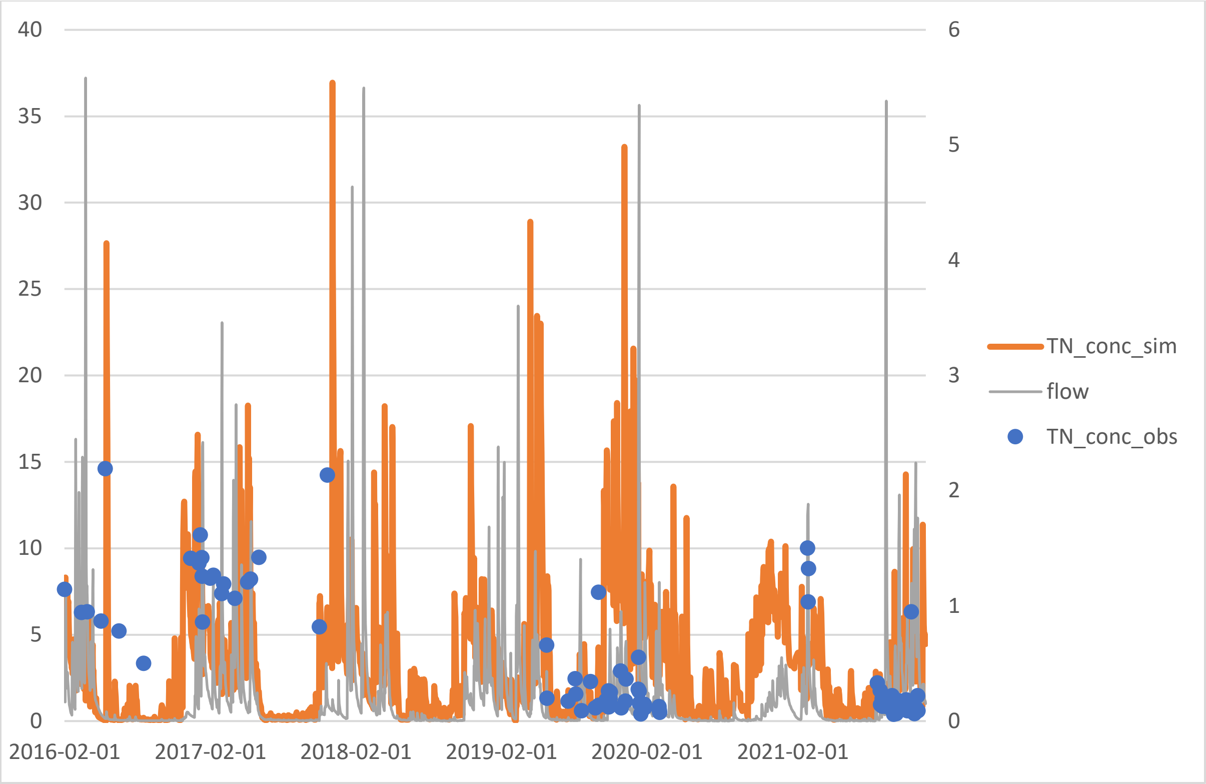

Figure 5-4. Measured vs. simulated total nitrogen concentration at the Observatory site

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 land management conditions present in the watershed landscape, including established BMPs. This input represented the actual field conditions that produced the streamflow and water quality observations made at the Observatory monitoring station. The model runs that utilized this input dataset were defined as the “existing actual BMP” scenarios.

In addition to this “existing actual BMP” condition, land management input files were constructed to represent two additional theoretical field conditions, namely the “no existing BMP” condition and the “potential future BMP” condition. Within each of these main field conditions, there were three model scenarios run 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 Upper Medway Creek 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 best practices. These all needed to be represented in the model as they are present and influence the water flow and quality observations. There are 27 existing WASCoBs, 33 existing surface inlet/depression features, three existing grassed waterways, seven existing riparian buffers, 22 existing windbreaks, and three existing wetlands in the Upper Medway Creek subwatershed. The location of these existing structural BMPs are shown in Figure 3-3.The land management data for the historical/existing scenario includes all land management BMPs collected through the ONFARM, GLASI and windshield surveys, including 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 Upper Medway 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 Upper Medway Creek 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 files that was used to represent a potential 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 all crop fields and all years that did not already have an existing cover crop in the existing actual BMP 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 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. the “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 maybe only applied on a farm field in selected years due to crop rotation, farmer choice, and other factors. The BMP effectiveness values generated, however, represent 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” scenario) 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 run and the results returned from the various theoretical “potential future BMP” scenario model runs represented the water quality benefits of full adoption of the three key BMPs assessed within the watershed. 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 represents the overall yearly average of water quality benefits in a farm field during the entire simulation period, and does not necessarily represent the annual 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 Upper Medway 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 Upper Medway Creek 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 the Upper Medway subwatershed, the average annual precipitation for the period of 2001 to 2021 was 948.0 mm and the simulated annual total runoff/flow was 394.6 mm, with a runoff/flow coefficient of 0.42. The simulated average annual total sediment yield/load at the watershed outlet was 810.1 tonnes (0.41 t/ha), of which 650.7 tonnes (0.33 t/ha) originated from overland sediment yield and 159.4 tonnes (0.08 t/ha) was sourced 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 sediment delivery rate was calculated by dividing the total channel/stream sediment load by the watershed area. The estimated average annual TN load at the watershed outlet was 38,130.9 kg (19.51 kg/ha), of which 6,980.3 kg were in particulate form (18.1%) and 31,222.6 kg was in dissolved form (81.9%). The estimated average annual TP load at the watershed outlet was 2,011.7 kg (1.03 kg/ha), of which 1,200.1 kg was in particulate form (59.7%) and 811.6 kg was in dissolved form (40.3%) (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 (93.8%) had sediment yield/load under 1.0 ton/ha and about 55.3% of the cropland area had sediment yield/load under 0.25 ton/ha. About 6.2% of the cropland area had sediment yield/load above 1.0 ton/ha and as high as 7.4 ton/ha. Close to half (47.7%) of the cropland area had TN yield/load under 10 kg/ha. About 13.5% of the cropland area had TN yield/load above 25.0 kg/ha and as high as 63.8 kg/ha, which was likely related to TN load from tile drain in the field and transported from other fields. More than half (60.8%) of the cropland area had TP yield/load under 1.0 kg/ha. About 5.5% of the cropland area had TP yield/load above 3 kg/ha and as high as 13.6 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 Upper Medway Creek subwatershed

Overland sediment yield	650.7	t	0.33	t/ha	80.3	%
Channel sediment load	159.4	t	0.08	t/ha	19.7	%
Total Sediment	810.1	t	0.41	t/ha	100	%
Particulate P	1,200.1	kg	0.61	kg/ha	59.7	%
Dissolved P	811.6	kg	0.42	kg/ha	40.3	%
TP	2,011.7	kg	1.03	kg/ha	100	%
Particulate N	6,908.3	kg	3.54	kg/ha	18.1	%
Dissolved N	31,222.6	kg	15.91	kg/ha	81.9	%
TN	38,130.9	kg	19.51	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 Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<=0.1 (28.9%)	0.1-0.25 (26.4%)	0.25-0.5 (27.0%)	0.5-1.0 (11.6%)	>1.0 (6.2%)	0.394
TN (kg/ha)	<=5 (21.9%)	5-10 (25.8%)	10-15 (19.9%)	15-25 (18.8%)	>25 (13.5%)	13.861
TP (kg/ha)	<=0.5 (27.0%)	0.5-1 (33.8%)	1-2 (23.5%)	2-3 (10.2%)	>3 (5.5%)	1.190

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

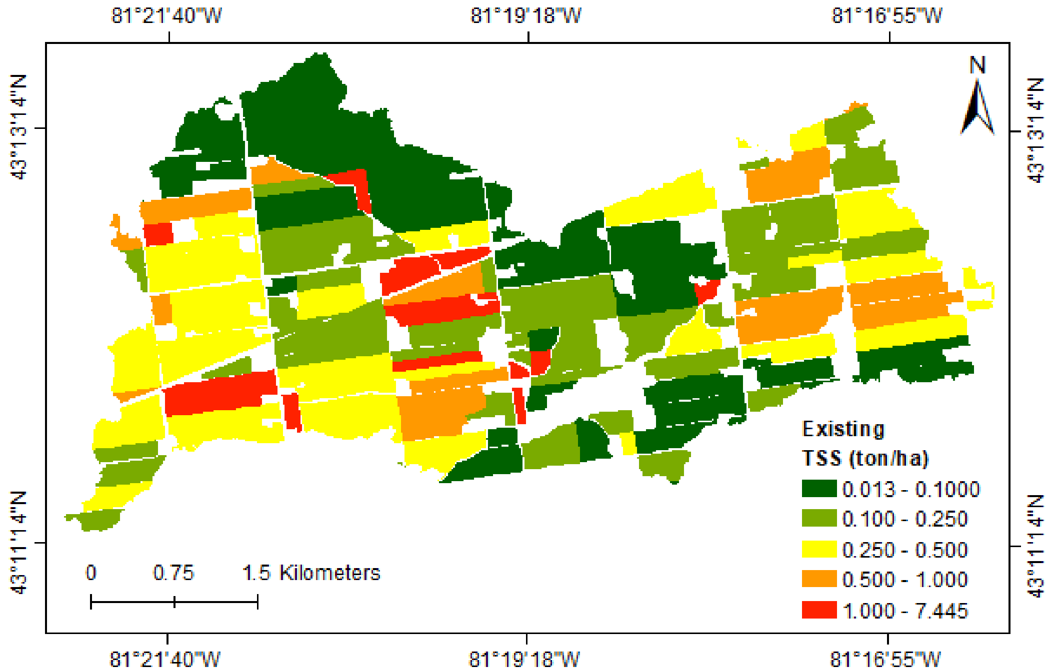

Figure 7-1. Simulated average yearly sediment yield/load at a field scale under historical/existing land management conditions in the Upper Medway Creek subwatershed

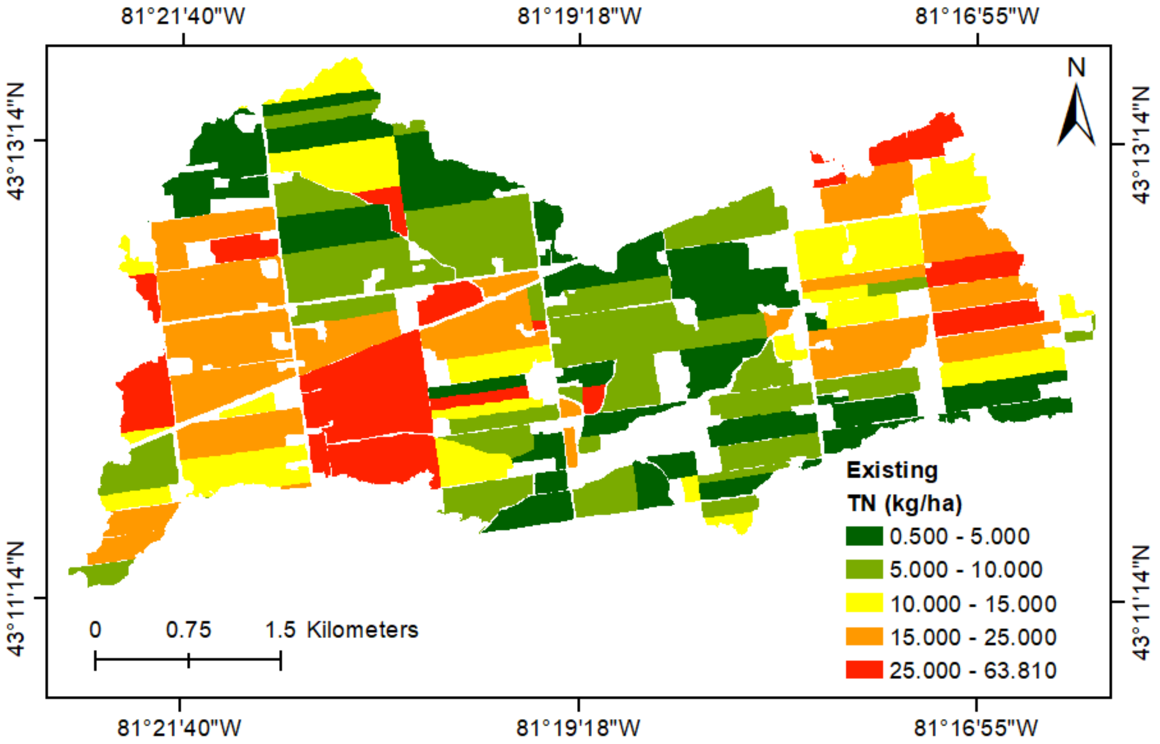

Figure 7-2. Simulated average yearly TN yield/load at a field scale under historical/existing land management conditions in the Upper Medway Creek subwatershed

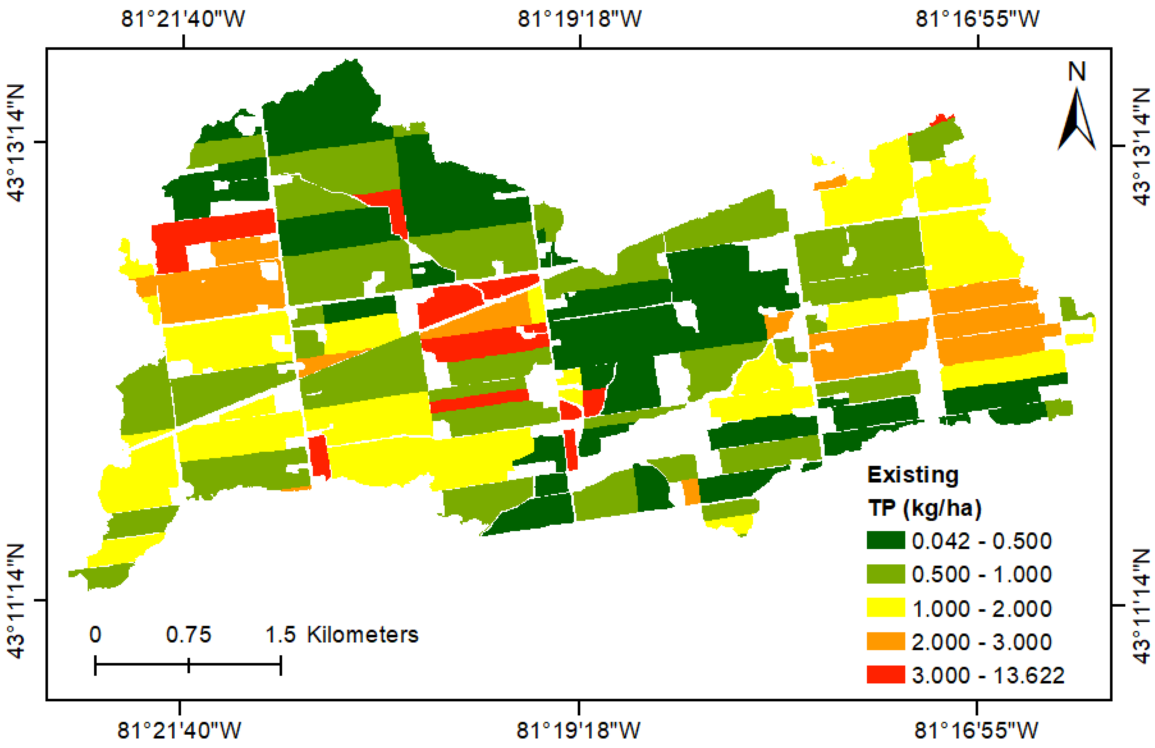

Figure 7-3. Simulated average yearly TP yield/load at a field scale under historical/existing land management conditions in the Upper Medway Creek subwatershed

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

The calibrated Upper Medway IMWEBs model was applied to estimate the water quality benefits of the three 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" scenario. 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 focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 8-1, a large portion of the cropland area (64.7%) had TSS yield/load reduction between 0 and 0.01 ton/ha and about

8.5% of the cropland area had TSS yield/load reduction above 0.02 and as high as 0.2 ton/ha. About 45.3% of the cropland area had TN yield/load reduction between 0 and 0.3 kg/ha and about 18.6% of the cropland area had TN yield/load reduction above 1.0 and as high as 8.9 kg/ha. About 72.7% of the cropland area had TP yield/load reduction between 0 and 0.05 kg/ha and about 3.8% of the cropland area had TP yield/load reduction above 0.1 and as high as 0.2 kg/ha. On average, existing cover crop planting led to TSS, TN and TP yield/load reductions of 1.5%, 3.9% and 1.5% 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 14.8%, 13.8% 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 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 Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (14.8%)	0-0.001 (53.1%)	0.001-0.01 (11.6%)	0.01-0.02 (12.0%)	>0.02 (8.5%)	0.006 (0.394, 1.5%)
TN (kg/ha)	<= 0 (13.8%)	0-0.1 (33.8%)	0.1-0.3 (11.5%)	0.3-1.0 (22.3%)	>1.0 (18.6%)	0.544 (13.861, 3.9%)
TP (kg/ha)	<= 0 (12.7%)	0-0.01 (55.9%)	0.01-0.05 (16.8%)	0.05-0.1 (10.8%)	>0.1 (3.8%)	0.018 (1.190, 1.5%)

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.

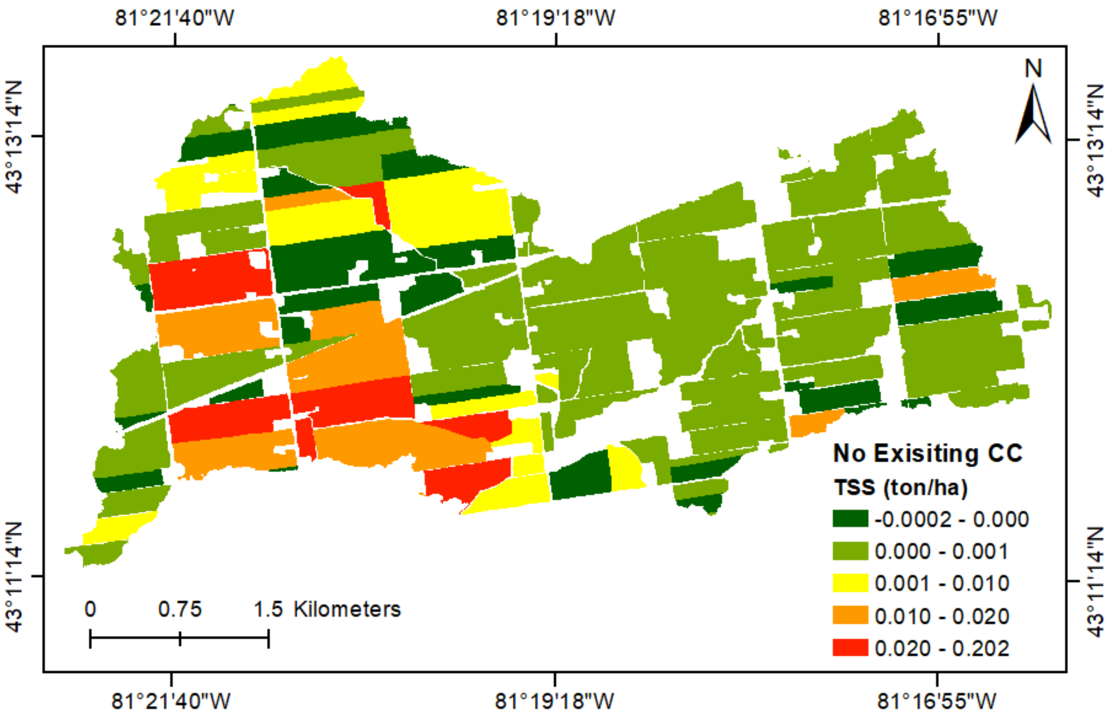

Figure 8-1. Simulated average yearly reduction of TSS yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

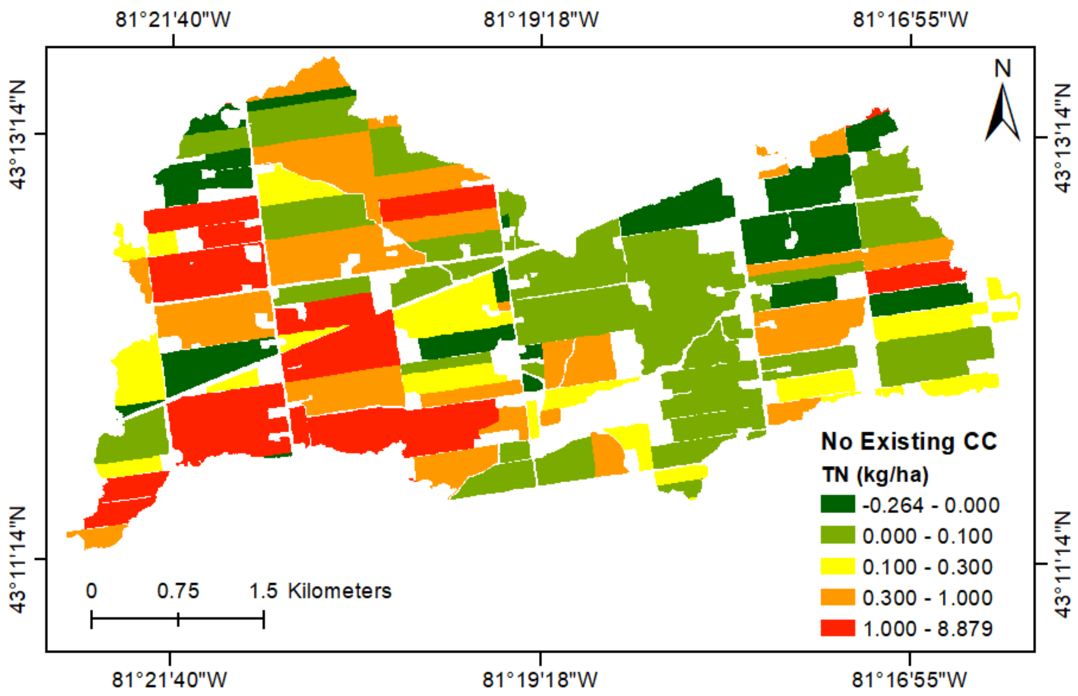

Figure 8-2. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

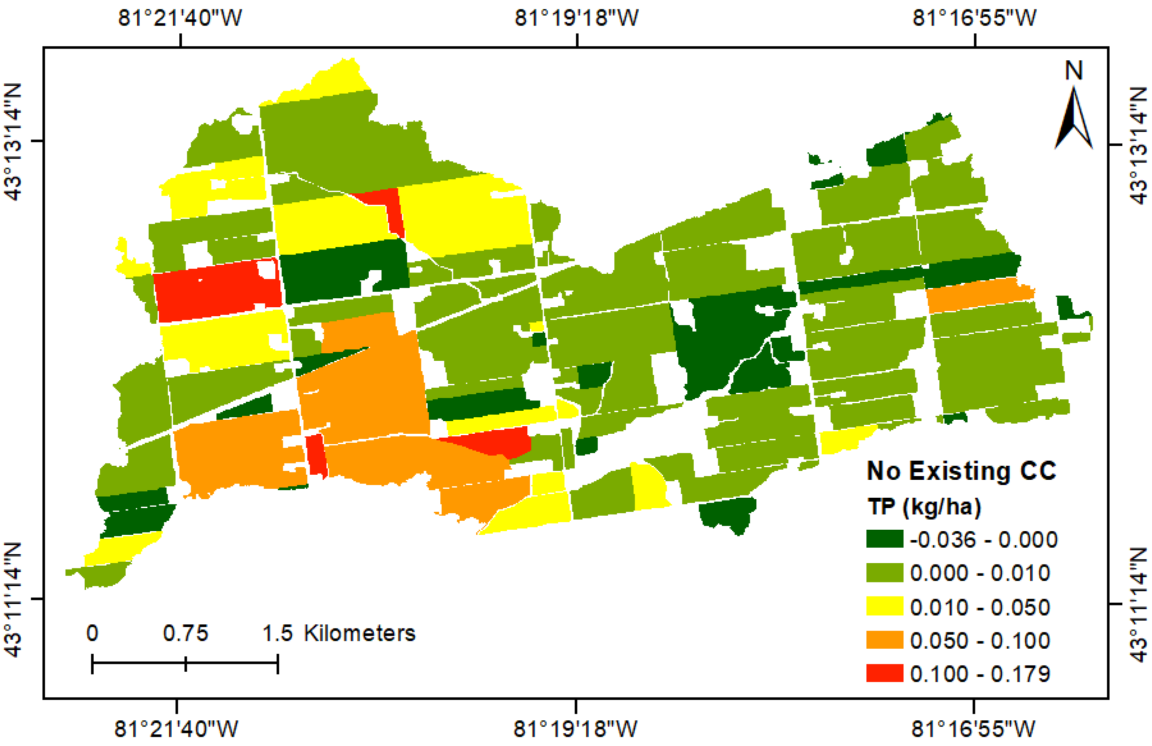

Figure 8-3. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

8.2 IMWEBs results for assessing the effectiveness of existing 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 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 59.0% of the cropland area had TSS yield/load reduction between 0 and 0.05 ton/ha and about 11.1% of the cropland area has TSS yield/load reduction above 0.1 and as high as 1.0 ton/ha. About 47.6% of the cropland area had TN yield/load reduction between 0 and 1.0 kg/ha and about 17.9% of the cropland area had TN yield/load reduction above 3.0 kg/ha and as high as 11.1 kg/ha. About 46.4% of the cropland area had TP yield/load reduction between 0 and 0.05 kg/ha and about 26.2% 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 13.0%, 9.0% and 6.1% 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 a small percentage of the cropland area (5.4%, 10.7% and 7.8%) 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 Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (5.4%)	0-0.02 (34.2%)	0.02-0.05 (24.8%)	0.05-0.1 (24.5%)	>0.1 (11.1%)	0.051 (0.394, 13.0%)
TN (kg/ha)	<= 0 (10.7%)	0-0.5 (24.7%)	0.5-1.0 (22.9%)	1.0-3.0 (23.9%)	>3.0 (17.9%)	1.252 (13.862, 9.0%)
TP (kg/ha)	<= 0 (7.8%)	0-0.025 (19.5%)	0.025-0.05 (26.9%)	0.05-0.1 (19.6%)	>0.1 (26.2%)	0.072 (1.190, 6.1%)

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.

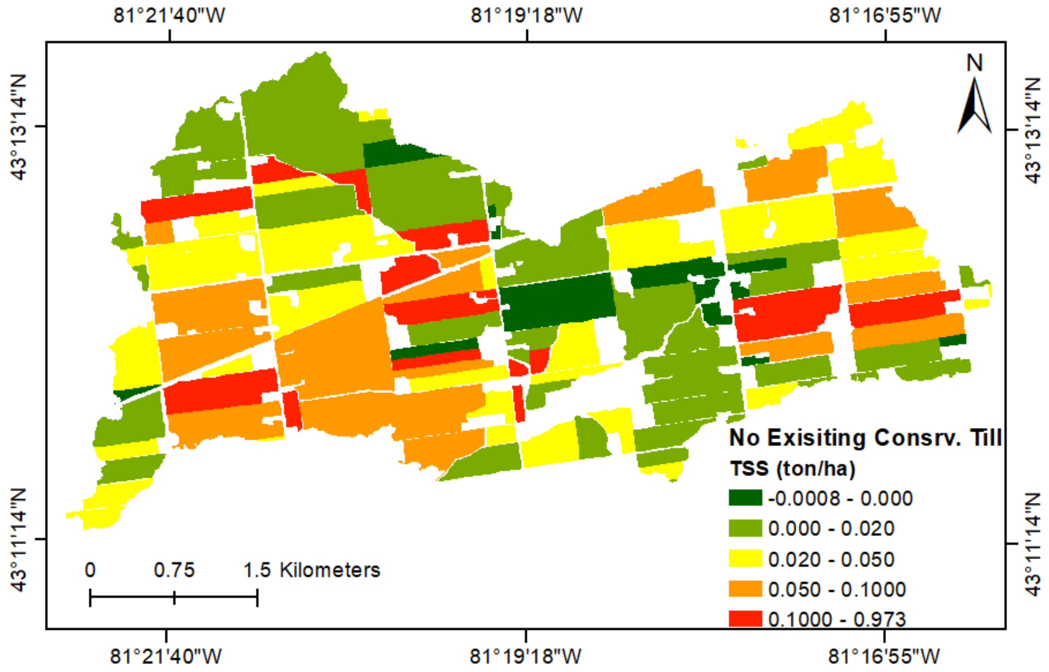

Figure 8-4. Simulated average yearly reduction of TSS yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

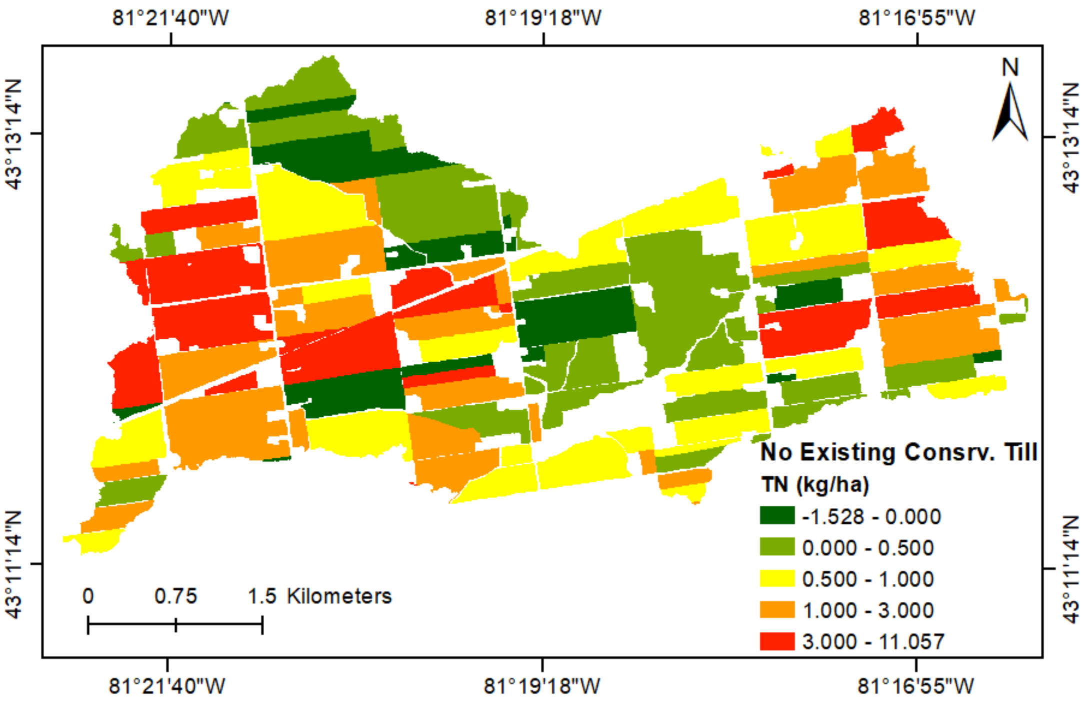

Figure 8-5. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

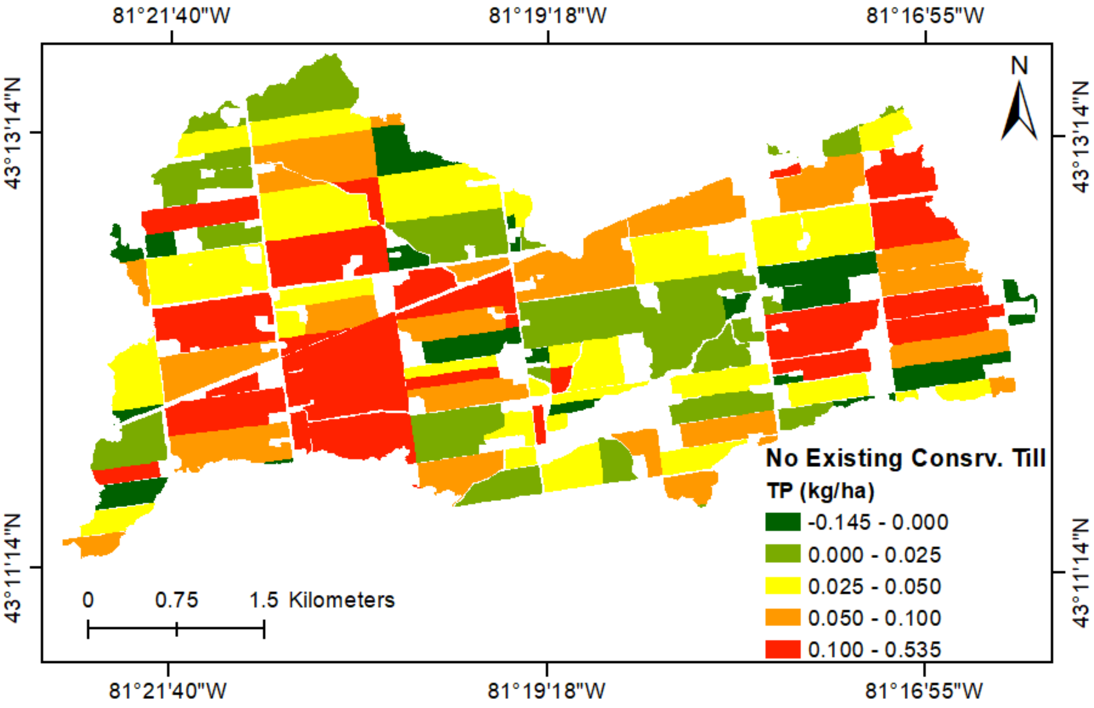

Figure 8-6. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

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 49.0% of the cropland area had TN yield/load reduction between 0 and 0.3 kg/ha and about 17.9% of the cropland area had TN yield/load reduction above 1.0 kg/ha and as high as 8.7 kg/ha. About 61.7% of the cropland area had TP yield/load reduction between 0 and 0.1 kg/ha and about 11.5% of the cropland area had TP yield/load reduction above 0.3 kg/ha and as high as 1.5 kg/ha. On average, existing actual fertilizer/manure incorporation led to TN and TP yield/load reductions of 3.7% and 9.6% 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 19.9% and 2.6% of the cropland areas had TN and TP yield/load no change or even increases in estimates of these water quality parameters in responseto 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 Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
TN (kg/ha)	<= 0 (19.9%)	0-0.1 (31.9%)	0.1-0.3 (17.1%)	0.3-1.0 (13.1%)	>1.0 (17.9%)	0.508 (13.861, 3.7%)
TP (kg/ha)	<= 0 (2.6%)	0-0.05 (37.3%)	0.05-0.1 (24.4%)	0.1-0.3 (24.2%)	>0.3 (11.5%)	0.114 (1.190, 9.6%)

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.

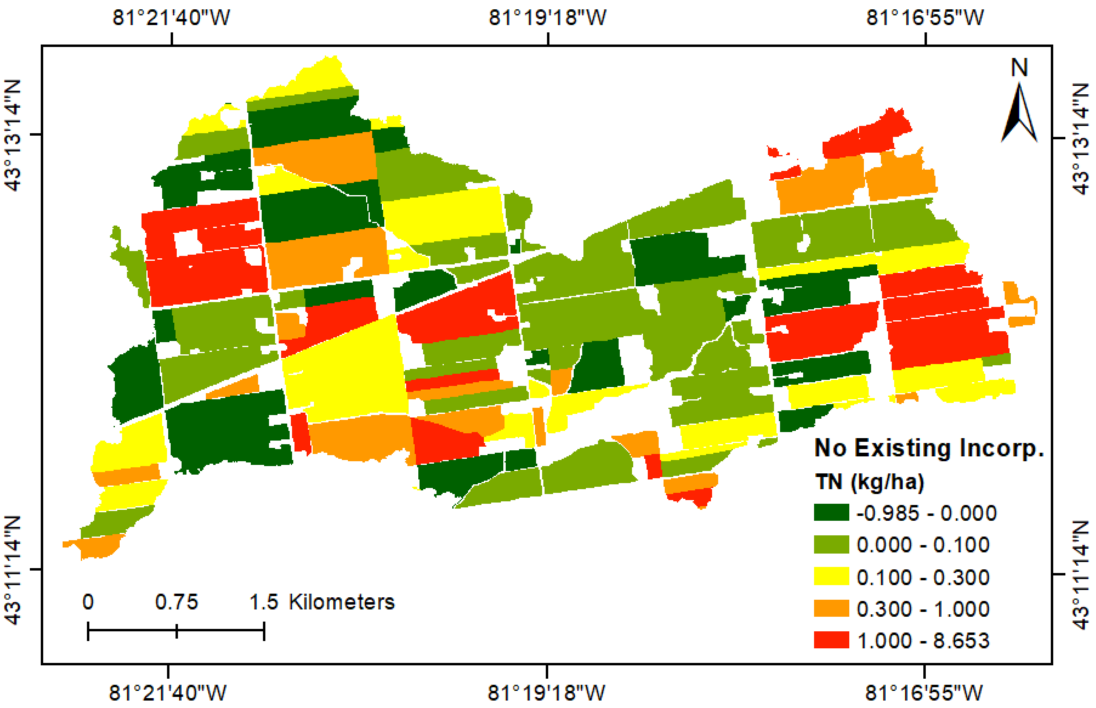

Figure 8-7. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

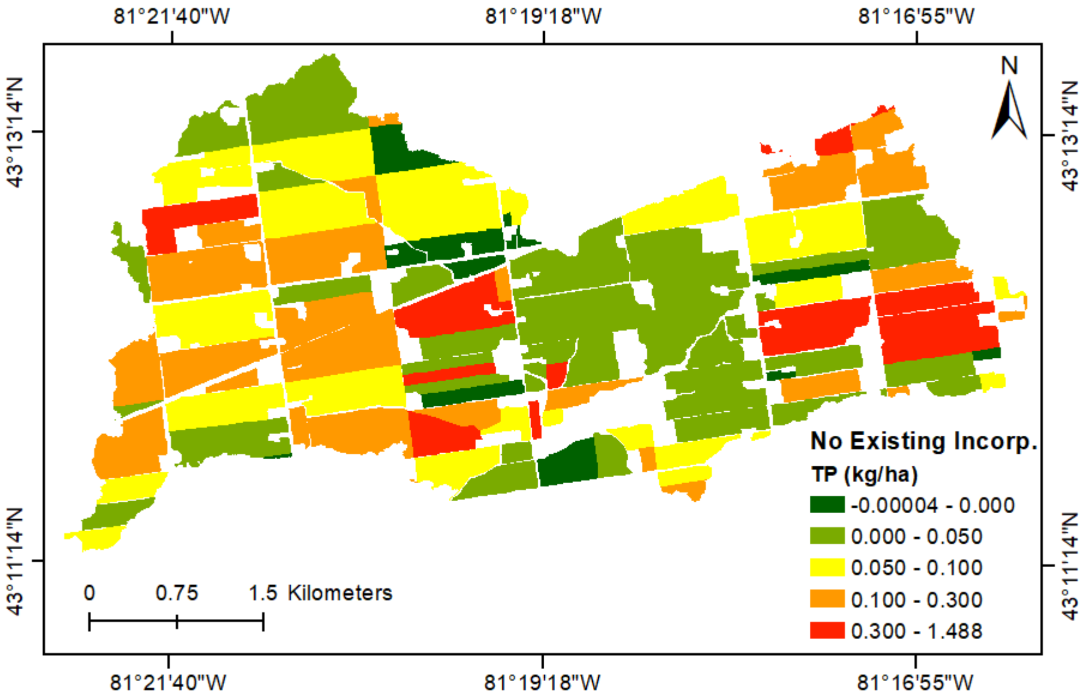

Figure 8-8. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

9.0 IMWEBS MODELLING RESULTS FOR ASSESSING THE EFFECTIVENESS OF ADDITIONAL POTENTIAL BMP ADOPTION

The calibrated Upper Medway 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, slightly more than half of the cropland area (56.0%) had TSS yield/load reduction between 0 and 0.03 ton/ha and about 13.2% of the cropland has TSS yield/load reduction above 0.1 and as high as 1.2 ton/ha. About 48.3% of the cropland area had TN yield/load reduction from 0 to 2.5 kg/ha and about 10.8% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 28.4 kg/ha. About 42.7% of the cropland area had TP yield/load reduction from 0 to 0.1 kg/ha and about 18.2% of the cropland area had TP yield/load reduction above 0.2 kg/ha and as high as 0.9 kg/ha. On average, future cover crop planting led to TSS, TN and TP yield/load reductions of 14.1%, 16.7% and 11.0% 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 to the watershed's water quality. Note that 1.2%, 16.7% and 10.4% 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 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 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 Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (1.2%)	0-0.01 (20.2%)	0.01-0.03 (35.8%)	0.03-0.1 (29.6%)	>0.1 (13.2%)	0.055 (0.394, 14.1%)
TN (kg/ha)	<= 0 (16.7%)	0-1.0 (28.5%)	1.0-2.5 (19.8%)	2.5-5.0 (24.1%)	>5.0 (10.8%)	2.311 (13.861, 16.7%)
TP (kg/ha)	<= 0 (10.4%)	0-0.05 (27.6%)	0.05-0.1 (15.1%)	0.1-0.2 (28.7%)	>0.2 (18.2%)	0.131 (1.190, 11.0%)

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 cover cropping scenario and percentage decrease under the potential future cover cropping scenario.

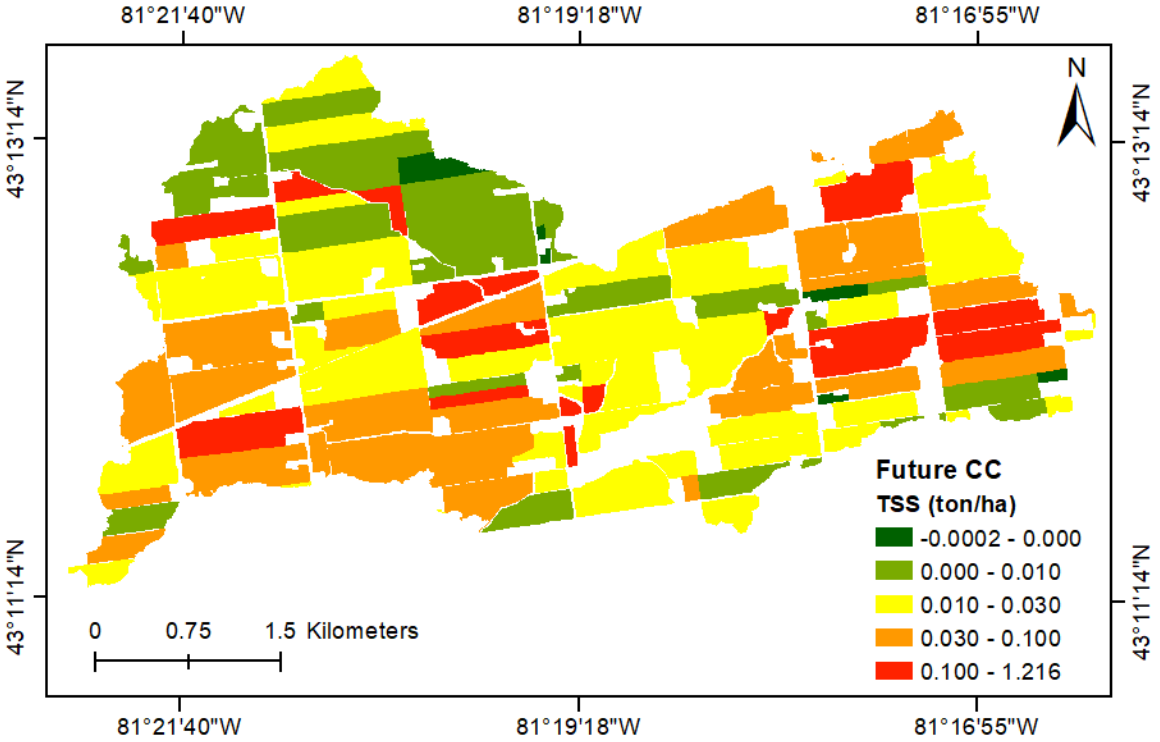

Figure 9-1. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Upper Medway Creek subwatershed

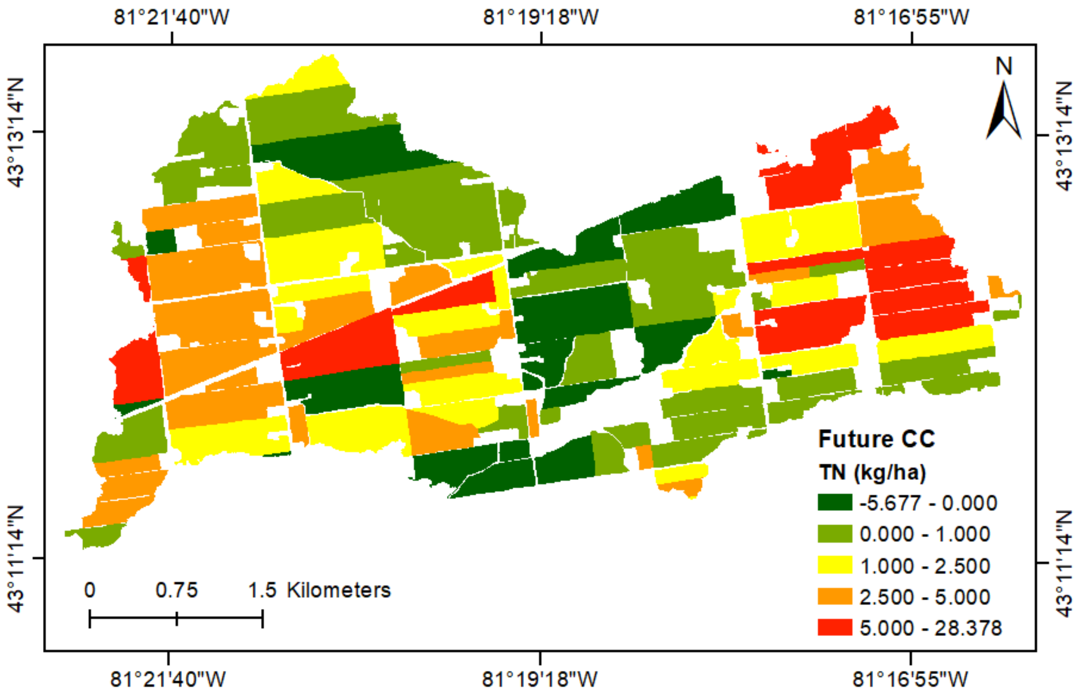

Figure 9-2. Simulated average yearly reduction of TN yield/load at a field under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Upper Medway Creek subwatershed

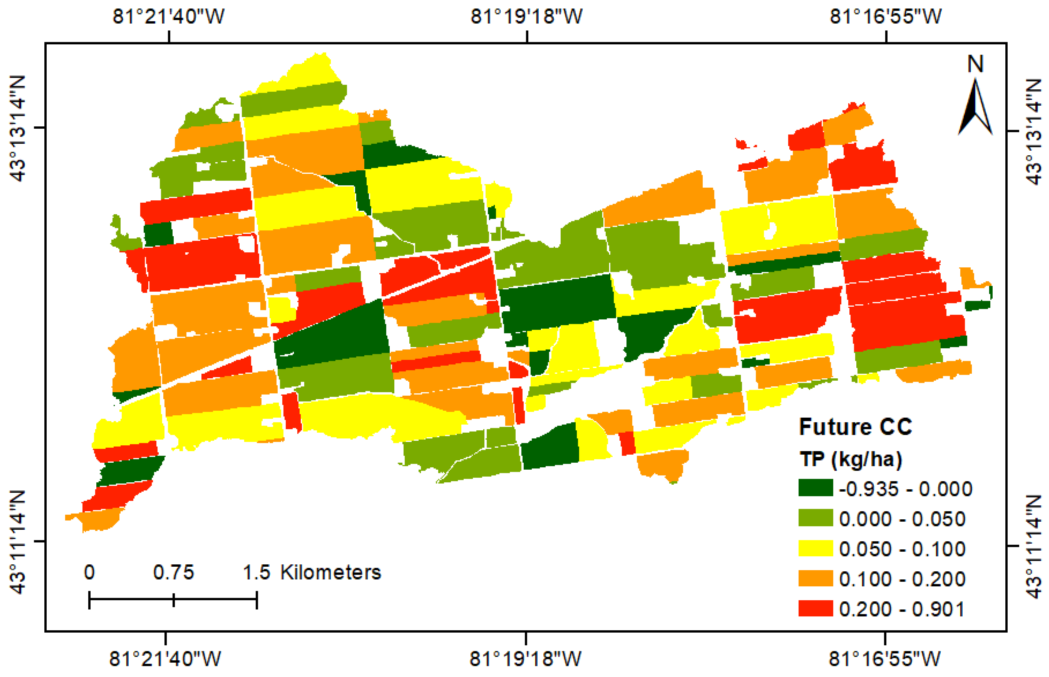

Figure 9-3. Simulated average yearly reduction of TP yield/load at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Upper Medway Creek subwatershed

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 focus on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 9-2, about 54.1% of the cropland area had TSS yield/load reduction between 0 and 0.025 ton/ha and 20.4% of the cropland area had TSS yield/load reduction above 0.05 and as high as 0.83 ton/ha. About 42.4% of the cropland area had TN yield/load reduction between 0 and 0.5 kg/ha and 22.4% of the cropland area had TN yield/load reduction above 1.0 kg/ha and as high as 6.9 kg/ha. About 59.5% of the cropland area had TP yield/load reduction between 0 and 0.1 kg/ha and 11.2% of the cropland area had TP yield/load reduction above 0.2 kg/ha and as high as 1.2 kg/ha. On average, potential future conservation tillage/no-till application led to TSS, TN and TP yield/load reductions of 10.7%, 4.6% and 7.5% 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 to water quality in the watershed. Note that small percentages of the cropland area (1.6%, 11.7% and 9.4%) had TSS, TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to additional adoption of conservation tillage/no-till tillage. 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 Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (1.6%)	0-0.01 (31.8%)	0.01-0.025 (23.3%)	0.025-0.05 (22.9%)	>0.05 (20.4%)	0.042 (0.394, 10.7%)
TN (kg/ha)	<= 0 (11.7%)	0-0.1 (17.6%)	0.1-0.5 (24.8%)	0.5-1.0 (23.5%)	>1.0 (22.4%)	0.641 (13.861, 4.6%)
TP (kg/ha)	<= 0 (9.4%)	0-0.05 (38.6%)	0.05-0.1 (20.9%)	0.1-0.2 (20.0%)	>0.2 (11.2%)	0.090 (1.190, 7.5%)

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.

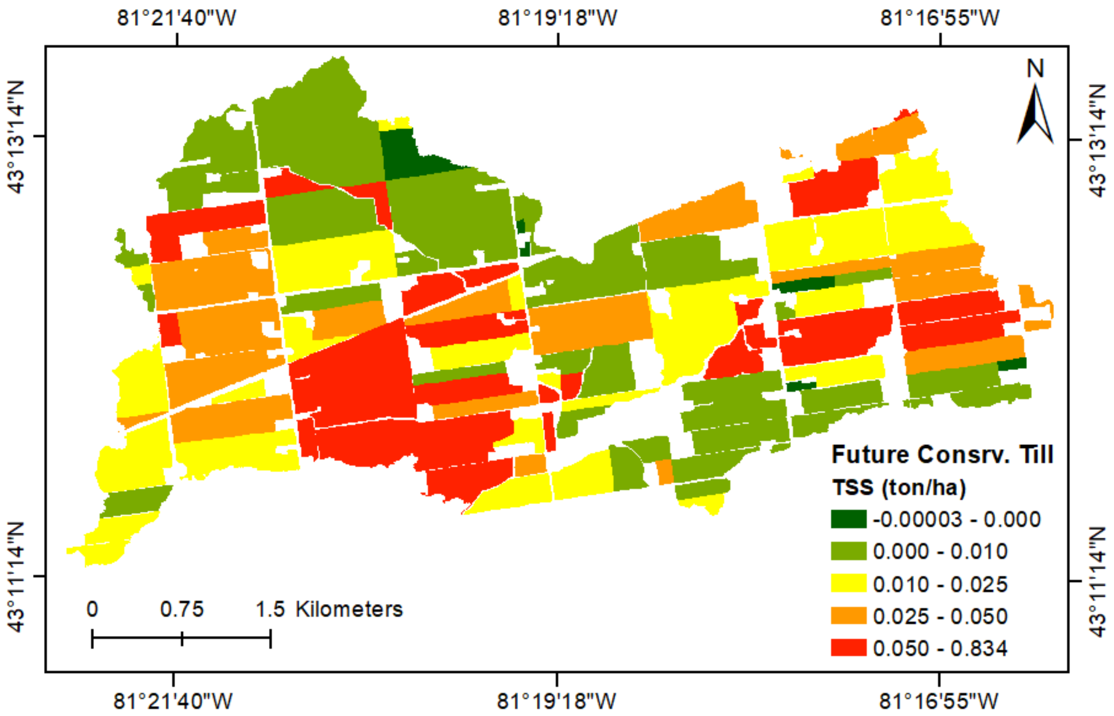

Figure 9-4. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Upper Medway Creek subwatershed

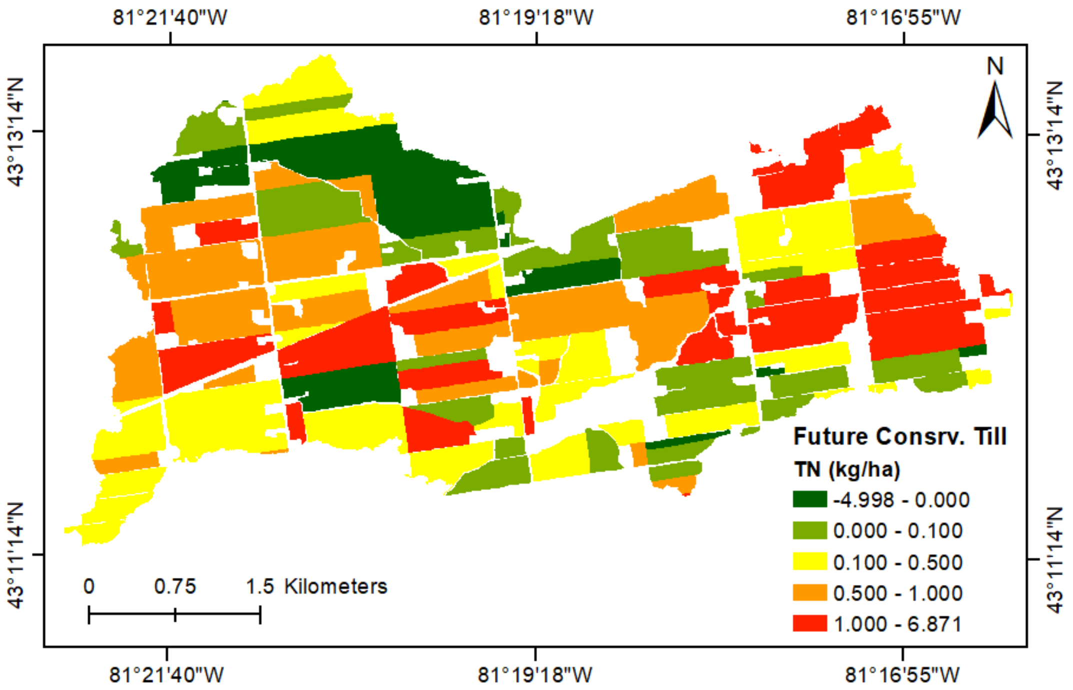

Figure 9-5. Simulated average yearly reduction of TN yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Upper Medway Creek subwatershed

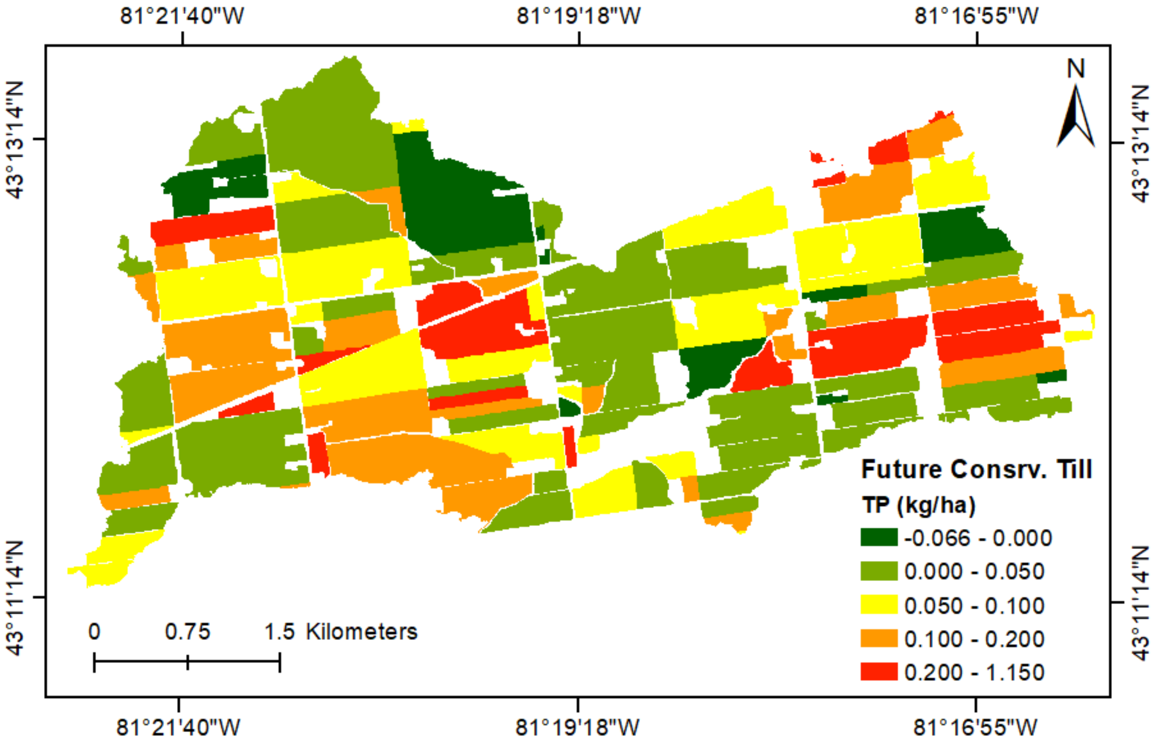

Figure 9-6. Simulated average yearly reduction of TP yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Upper Medway Creek subwatershed

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 46.9% of the cropland area had TN yield/load reduction between 0 and 1.0 kg/ha and about 17.4% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 7.6 kg/ha. Also, a majority of the cropland area (74.6%) had TP yield/load reduction between 0 and 0.5 kg/ha and about 7.5% of the cropland had TP yield/load reduction above 1.0 kg/ha and as high as 3.6 kg/ha. On average, potential future fertilizer/manure incorporation led to TN and TP yield/load reductions of 10.5% and 33.5% 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 13.7% and 1.1% 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/loads at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
TN (kg/ha)	<= 0 (13.7%)	0-0.5 (27.0%)	0.5-1.0 (19.9%)	1.0-3.0 (22.0%)	>3.0 (17.4%)	1.451 (13.861, 10.5%)
TP (kg/ha)	<= 0 (1.1%)	0-0.2 (39.9%)	0.2-0.5 (34.7%)	0.5-1.0 (16.7%)	>1.0 (7.5%)	0.398 (1.190, 33.5%)

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.

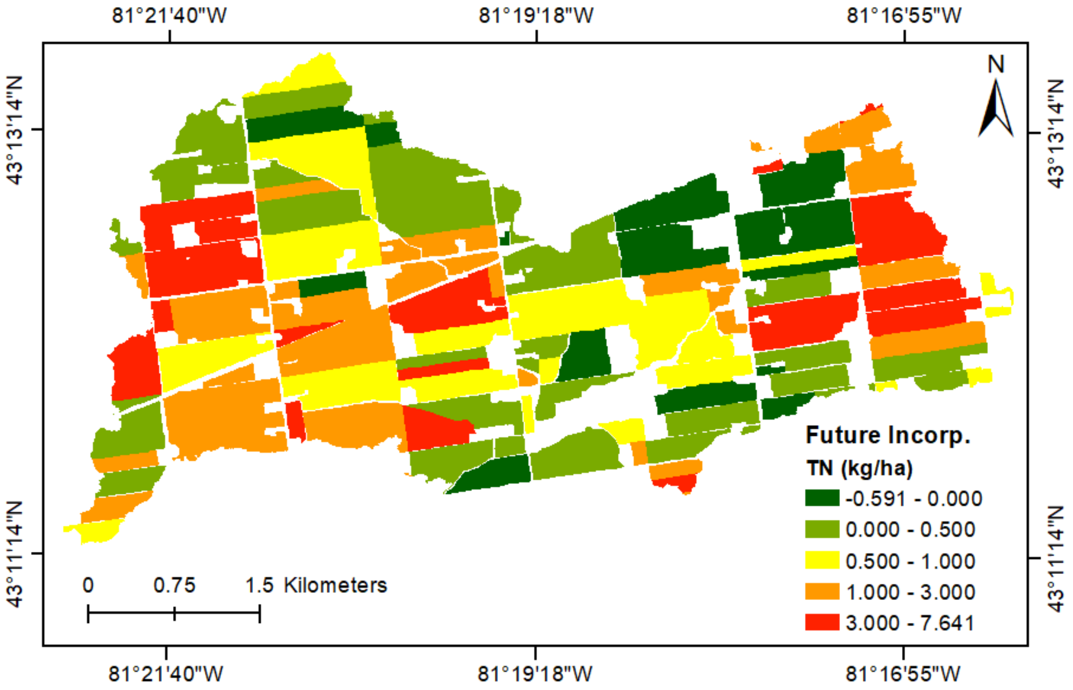

Figure 9-7. Simulated average yearly reduction of TN yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

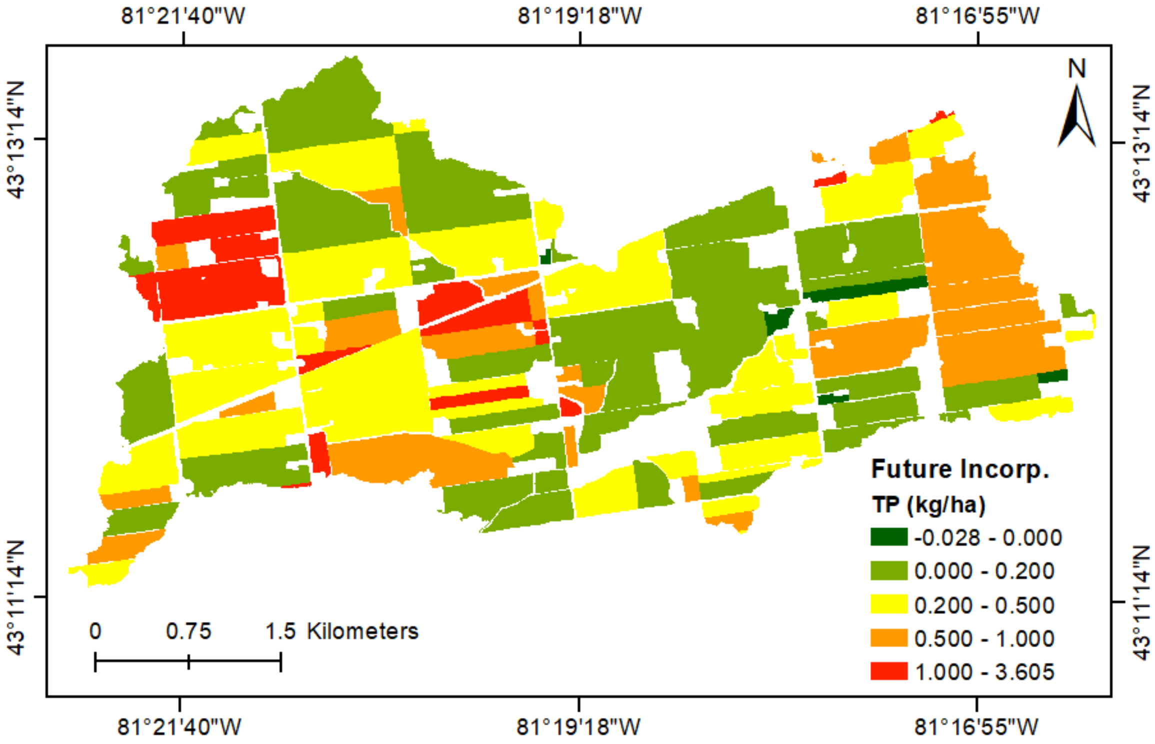

Figure 9-8. Simulated average yearly reduction of TP yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

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

The calibrated Upper Medway IMWEBs model was applied to estimate the water quality benefits of full adoption of the three key soil health-related 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.

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 potential 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, a large portion of the cropland area (68.2%) had TSS yield/load reduction between 0 and 0.05 ton/ha and 14.1% of the cropland had TSS yield/load reduction above 0.1 ton/ha and as high as 1.2 ton/ha. About 43.9% of the cropland area had TN yield/load reduction from 0 to 2 kg/ha and about 20.5% of the cropland area had TN yield/load reduction above 5 kg/ha and as high as 28.8 kg/ha. About 40.2% of the cropland area had TP yield/load reduction from 0 to 0.1 kg/ha and about 19.5% of the cropland area had TP yield/load reduction above 0.2 kg/ha and as high as 0.9 kg/ha. On average, potential future cover crop planting led to TSS, TN and TP yield/load reductions of 15.3%, 19.8% and 12.3% respectively in relation to corresponding TSS, TN and TP yields/loads under the conventional no existing cover cropping scenario. The pattern shows the potential net benefits of complete adoption of cover crop planting across the watershed on its water quality. Note that about 1.3%, 13.7% and 18.5% 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 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 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 Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (1.3%)	0-0.025 (36.6%)	0.025-0.05 (31.6%)	0.05-0.1 (16.3%)	>0.1 (14.1%)	0.061 (0.400, 15.3%)
TN (kg/ha)	<= 0 (13.7%)	0-1.0 (25.9%)	1.0-2.0 (17.0%)	2.0-5.0 (23.0%)	>5.0 (20.5%)	2.855 (14.405, 19.8%)
TP (kg/ha)	<= 0 (7.1%)	0-0.05 (23.0%)	0.05-0.1 (17.2%)	0.1-0.2 (33.2%)	>0.2 (19.5%)	0.149 (1.208, 12.3%)

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 conventional no existing cover cropping scenario and percentage decrease under the potential future cover cropping scenario.

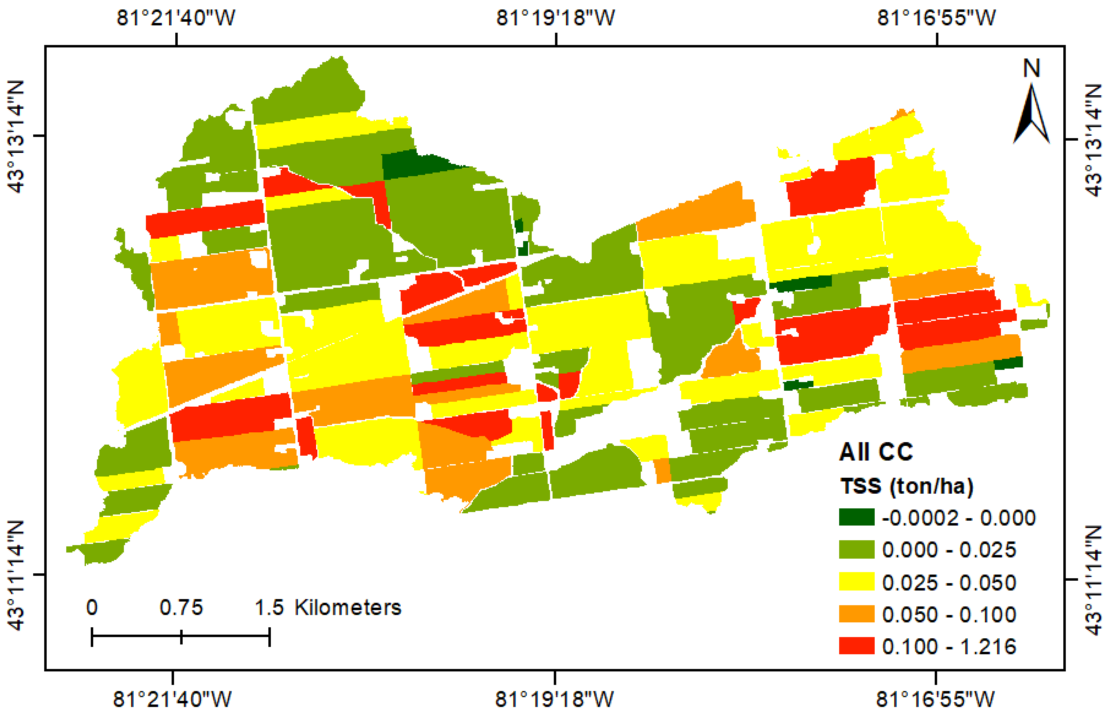

Figure 10-1. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

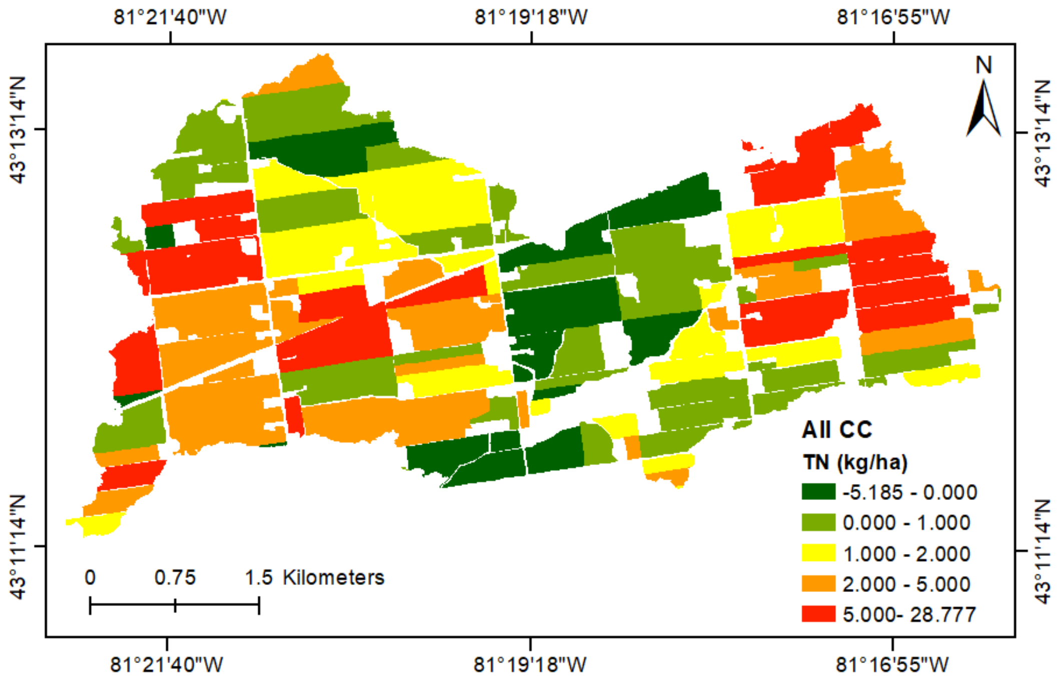

Figure 10-2. Simulated average yearly reduction of TN yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

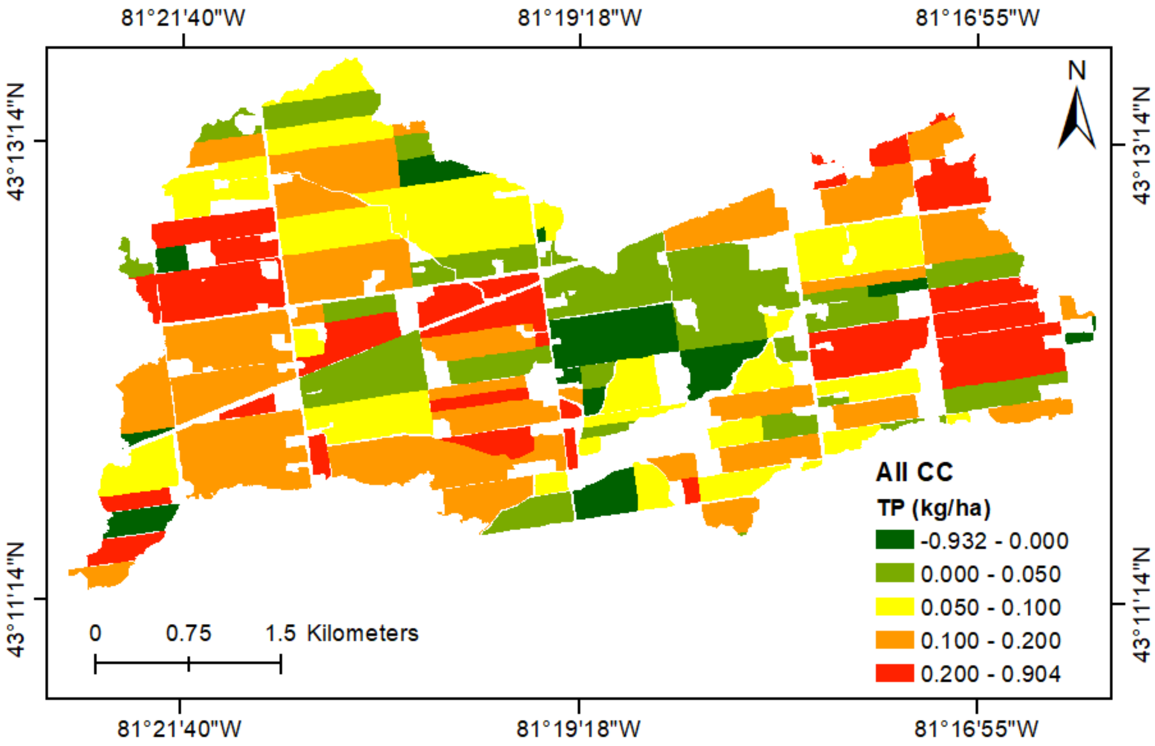

Figure 10-3. Simulated average yearly reduction of TP yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

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 potential 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 50.0% of the cropland area had TSS yield/load reduction between 0 and 0.05 ton/ha and 27.6% of the cropland area had TSS yield/load reduction above 0.1 and as high as 1.8 ton/ha. About 37.5% of the cropland area had TN yield/load reduction between 0 and 1.0 kg/ha and 26.8% of the cropland area had TN yield/load reduction above 3.0 kg/ha and as high as 12.7 kg/ha. About 44.2% of the cropland area had TP yield/load reduction between 0 and 0.1 kg/ha and 27.4% of the cropland area had TP yield/load reduction above 0.2 kg/ha and as high as 1.6 kg/ha. On average, existing actual and potential future conservation tillage/no-till application led to TSS, TN and TP yield/load reductions of 21.0%, 12.5% and 12.9% respectively in relation to corresponding

TSS, TN and TP yields/loads under the no existing conservation tillage scenario. The pattern showed the potential net benefits of full adoption of conservation tillage or no-till practices in the watershed. Note that very small percentages of the cropland area (0.7%, 6.3% and 5.1%) had TSS, TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to complete 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 Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
Sediment (ton/ha)	<= 0 (0.7%)	0-0.025 (28.8%)	0.025-0.05 (21.2%)	0.05-0.1 (21.7%)	>0.1 (27.6%)	0.093 (0.445, 21.0%)
TN (kg/ha)	<= 0 (6.3%)	0-0.5 (20.5%)	0.5-1.0 (17.0%)	1.0-3.0 (29.4%)	>3.0 (26.8%)	1.892 (15.113, 12.5%)
TP (kg/ha)	<= 0 (5.1%)	0-0.05 (18.8%)	0.05-0.1 (25.4%)	0.1-0.2 (23.3%)	>0.2 (27.4%)	0.162 (1.263, 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 no existing conservation tillage scenario and percentage decrease under the potential future conservation tillage scenario.

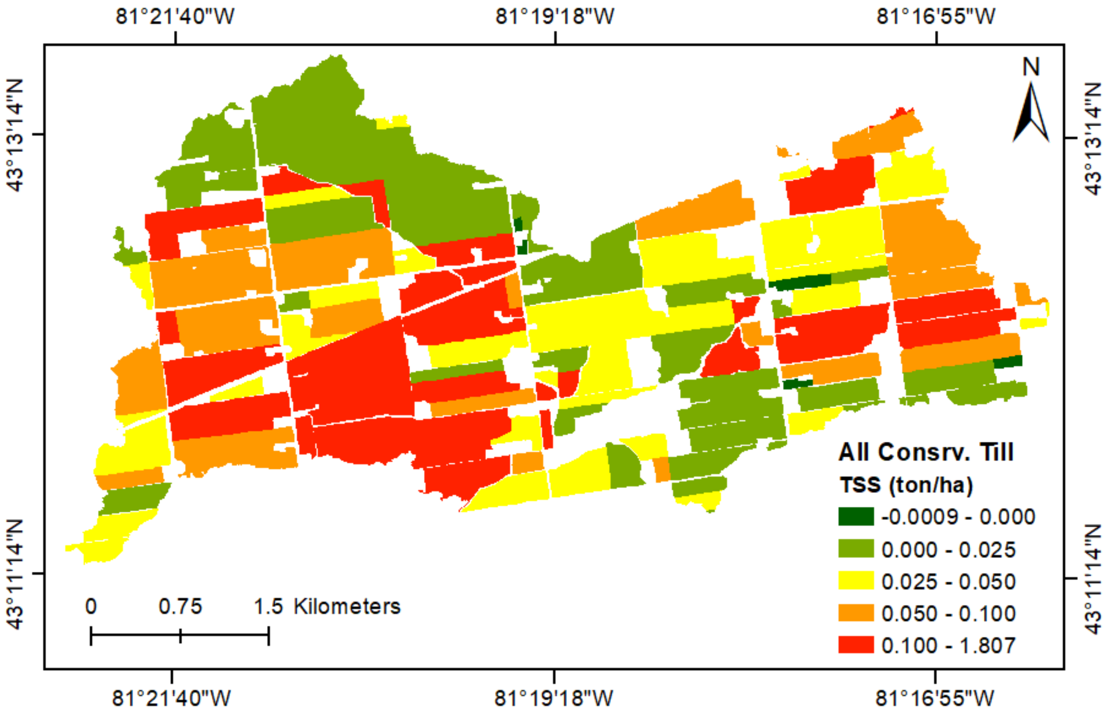

Figure 10-4. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

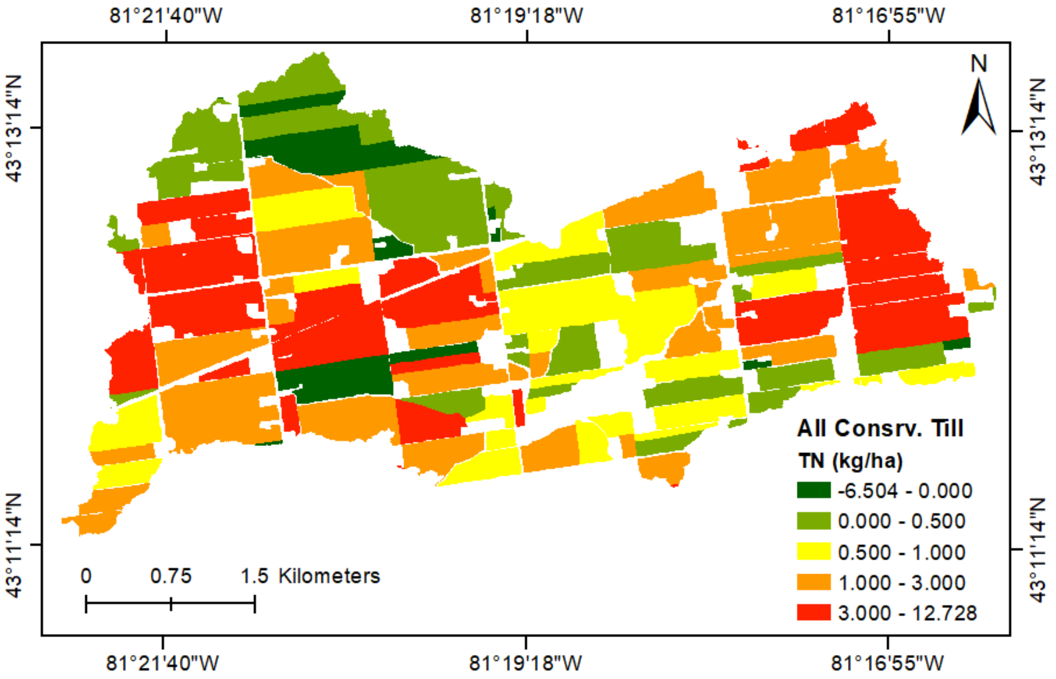

Figure 10-5. Simulated average yearly reduction of TN yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

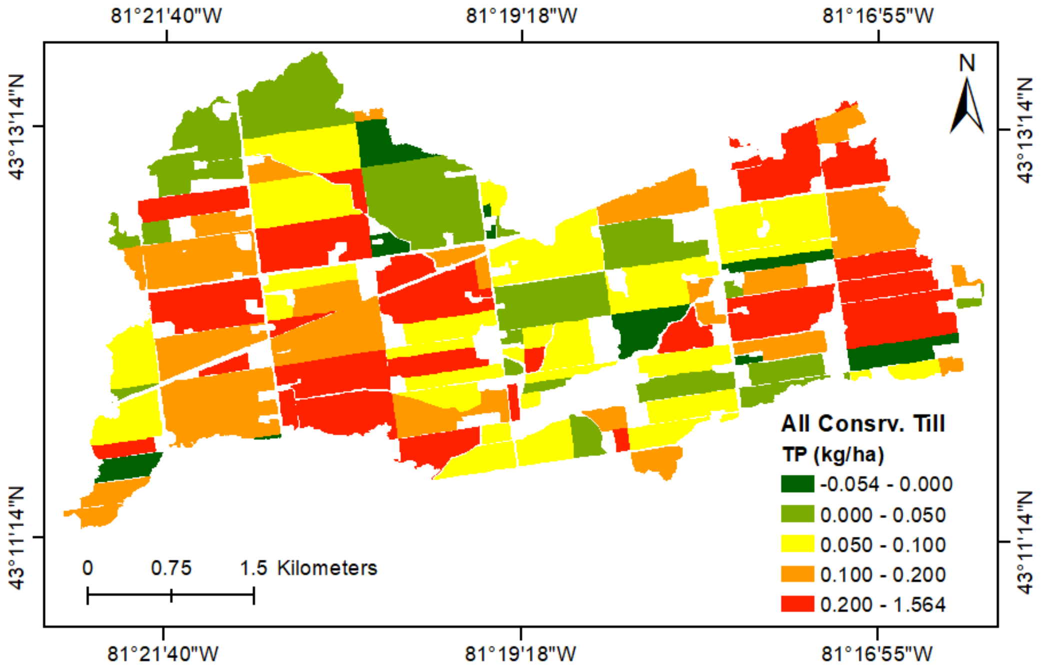

Figure 10-6. Simulated average yearly reduction of TP yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

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 potential 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 40.4% of the cropland area had TN yield/load reduction between 0 and 1.0 kg/ha and about 22.1% of the cropland area had TN yield/load reduction above 3.0 kg/ha and as high as 15.3 kg/ha. Also, about 58.1% of the cropland area had TP yield/load reduction between 0 and 0.4 kg/ha and about 16.8% of the cropland had TP yield/load reduction above 1.0 kg/ha and as high as 4.2 kg/ha. On average, existing actual and potential future fertilizer/manure incorporation led to TN and TP yield/load reductions of 13.6% and 39.3% respectively in relation to corresponding TSS, TN and TP yields/loads under the conventional no existing fertilizer/manure incorporation scenario. The pattern shows the potential net benefits of complete adoption of the fertilizer/manure incorporation BMP on water quality in the watershed. Note that 12.2% and 1.1% 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 full watershed adoption of 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 Upper Medway Creek subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
TN (kg/ha)	<= 0 (12.2%)	0-0.25 (13.7%)	0.25-1.0 (26.7%)	1.0-3.0 (25.3%)	>3.0 (22.1%)	1.958 (14.369, 13.6%)
TP (kg/ha)	<= 0 (1.1%)	0-0.2 (25.7%)	0.2-0.4 (32.4%)	0.4-1.0 (24.0%)	>1.0 (16.8%)	0.512 (1.304, 39.3%)

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.

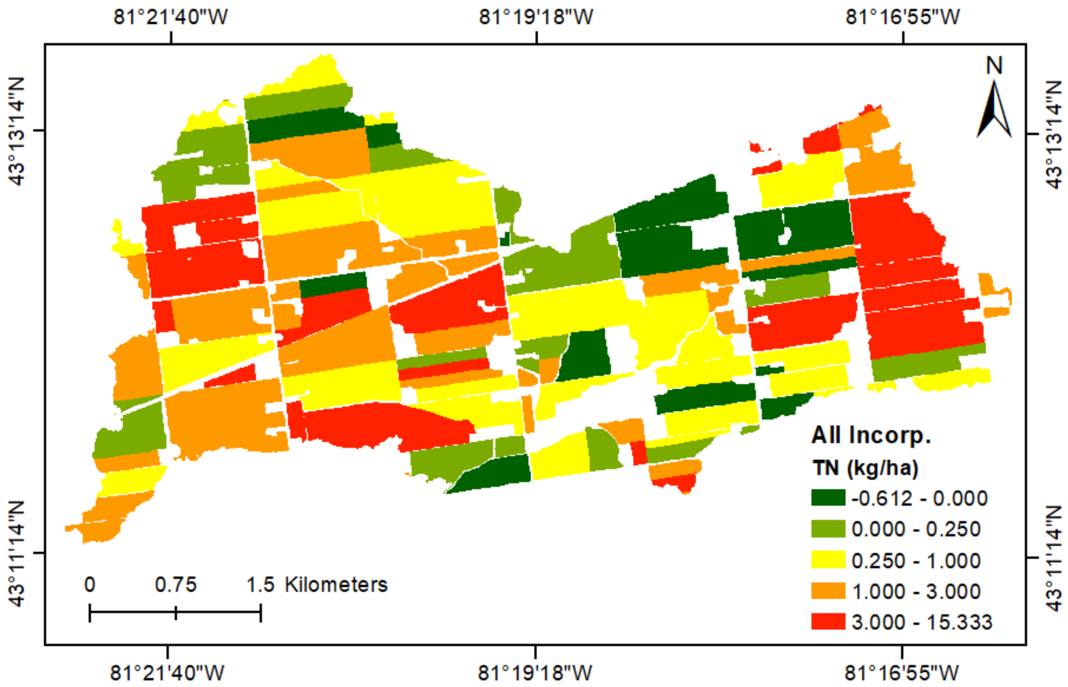

Figure 10-7. Simulated average yearly reduction of TN yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

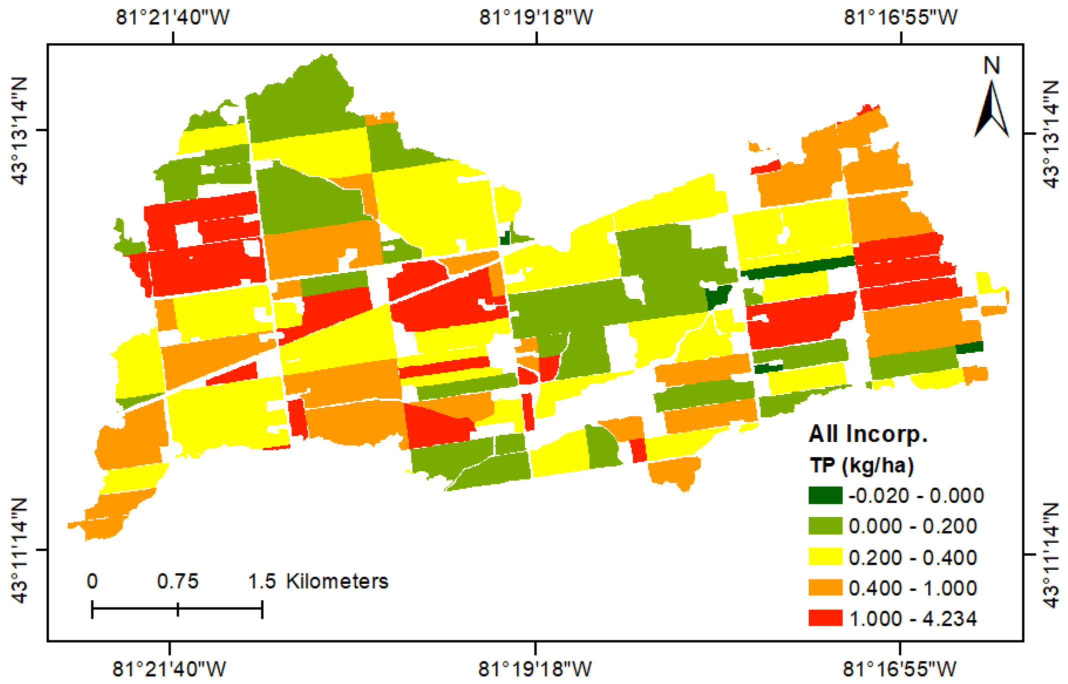

Figure 10-8: Simulated average yearly reduction of TP yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

11.0 BMP COST-BENEFIT ANALYSIS

BMP cost-benefit analysis (CBA) was another important component of the ONFARM project. Modellers worked with UTRCA staff to conduct a CBA for BMPs in the Upper Medway Creek subwatershed. Seven farmers provided data on implementing the cover crop BMP (Table 11-1). Note that in the CBA, two growers (UT6 and UT10) used the cover crop for forage, which generated revenue and led to net benefits of cover crop. 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. CBA for cover crops in the Upper Medway Creek subwatershed ($/acre/yr)

Farmer	Acres in PSP	Cover crop type	Seed cost	Operating/ Maintenance cost	Labor cost	Pesticide cost	Fertilizer cost	Total cost	Forage value	Net cost-benefit
UT2	470	Cereal rye - 2019	9.25	15				24.25		24.25
UT2	470	Cereal rye - 2021	6.8	30				36.8		36.8
UT6	20	Oats for feed	30				96	126	-520	-394
UT7	246	Oats after WW	34.34	25		18		77.34		77.34
UT7	142	Cereal rye after corn	5		13			18		18
UT10	24	Cover crop-2021	22.6	8.4	61.6		30.5	123.1	-160	-36.9
UT10	26	Cover crop - 2017	17.73	20	1	17		55.73	-111	-55.27

Besides cover crops, the CBA of modifying equipment to facilitate fertilizer/manure incorporation was also provided by one producer. Farmer UT7 implemented Tillage & Nutrient Application Equipment Modifications (150 acres in the subwatershed). The operating/maintenance cost was $2/acre/yr. The labor cost was $1.67/acre/yr. The net cost was therefore $3.67/acre/yr. Yield and nutrient conserving benefits were not quantified.

Farmer UT7 also provided CBA information related to implementing an “Erosion Control Structure” with a drainage area of 138 acres. The construction cost was $4,612. The fuel and electricity cost was $739. The labor cost was $900. The net cost was therefore $6,251. Soil conservation benefits were not assigned a value; thus benefits were not quantified.

12.0 BMP COST-EFFECTIVENESS ANALYSIS

The cost-benefit analysis of cover cropping in the Upper Medway Creek subwatershed showed a wide range of values from -$394/acre/yr to $77.34/acre/yr. For cost effectiveness analysis, we assumed a medium value of $36.8/acre/yr or $90.9/ha/yr for the cover cropping BMP. Based on IMWEBs modelling, the average TP yield/load reduction achieved with cover cropping was 0.149 kg/ha. For the cover cropping BMP, the cost effectiveness of applying this practice for TP yield/load reduction was therefore $610.3/kg of TP in the Upper Medway Creek subwatershed.

There was no cost-benefit analysis completed for the conservation tillage/no-till BMP for the Upper Medway Creek subwatershed. Instead, based on the cost-benefit analysis data collected for conservation tillage/no-till in the Gully Creek subwatershed (reduced cost of -$23/acre/yr or increased cost of $67/acre/yr), we assumed the net cost of the conservation tillage/no-till BMP at $22/acre/yr or $54.4/ha/yr. Based on IMWEBs modelling, the average TP yield/load reduction achieved through implementing conservation tillage was 0.162 kg/ha in the Upper Medway watershed. For the conservation tillage/no-till BMP, the cost effectiveness for TP yield/load reduction was therefore $335.6/kg of TP.

The cost-benefit analysis of Tillage & Nutrient Application Equipment Modifications for the Upper Medway Creek subwatershed had a value of $3.67/acre/yr, which was unexpectedly low. For comparison, the cost-benefit analysis of Tillage & Nutrient Application Equipment Modifications for the North Kettle Creek subwatershed had a value of $22.25/acre/yr, which seemed more reasonable. For the cost of fertilizer/manure incorporation BMP, we assumed $22.25/acre/yr or $55.0/ha/yr. Based on IMWEBs modelling, the average TP yield/load reduction associated with fertilizer/manure incorporation was 0.512 kg/ha/yr. For fertilizer/manure incorporation, the cost effectiveness for TP yield/load reduction was $107.4/kg of TP in the Upper Medway Creek subwatershed.

In the Upper Medway Creek subwatershed, the BMP cost effectiveness for cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation was $610.3, $335.6 and $107.4 for per kg of TP yield/load reduction respectively. Therefore, fertilizer/manure incorporation was the most cost-effective and cover cropping was the least cost-effective BMP for TP yield/load reduction.

Note that both BMP costs and effectiveness (in terms of TP yield/load reduction) had a wide range of values. Accordingly, BMP cost effectiveness also had a wide range of values. Further data analysis, particularly for BMP cost, would be helpful to better estimate BMP cost effectiveness values.

13.0 GENERAL SUMMARY AND FUTURE RECOMMENDATIONS

In the ONFARM project we developed IMWEBs modelling for evaluating the water quality benefits of three BMPs, namely cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation 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 of the three key 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 moldelling 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 put a dollar cost on 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 Upper Medway Creek 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. 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 Upper Medway Creek 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 1.258 kg/ha/yr for the Upper Medway Creek subwatershed, full adoption of the three agronomic BMPs will contribute to a TP yield/load reduction of 0.823 kg/ha/yr if TP yield/load reductions of individual BMPs were added together, which represented 65.4% 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 Upper Medway Creek subwatershed.

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

Cover cropping	Existing actual BMP adoption[1]	Potential future BMP adoption[2]	Full BMP adoption[3]
Avg TP load reduction (kg/ha)	0.018	0.131	0.149
Avg TP load without BMP scenario (kg/ha)[4]	1.190	1.190	1.208
Percent reduction in load from BMP scenario	1.5%	11.0%	12.3%
Conservation Tillage	Existing actual BMP adoption[1]	Potential future BMP adoption[2]	Full BMP adoption[3]
Avg TP load reduction (kg/ha)	0.072	0.090	0.162
Avg TP load without BMP scenario (kg/ha)[4]	1.190	1.190	1.263
Percent reduction in load from BMP scenario	6.1%	7.5%	12.9%
Fertilizer/manure incorporation	Existing actual BMP adoption[1]	Potential future BMP adoption[2]	Full BMP adoption[3]
Avg TP load reduction (kg/ha)	0.114	0.398	0.512
Avg TP load without BMP scenario (kg/ha)[4]	1.190	1.190	1.304
Percent reduction in load from BMP scenario	9.6%	33.5%	39.3%

[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 Upper Medway Creek subwatershed. The rankings of BMP effectiveness in terms of per ha TP yield/load reduction from high to low were fertilizer/manure incorporation, conservation tillage, and cover cropping. The rankings of BMP cost from low to high had a slightly different pattern, conservation tillage, fertilizer/manure incorporation, 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 Upper Medway Creek subwatershed

	TP yield/load reduction (kg/ha)	BMP cost ($/ha)	Cost effective-ness ($/kg of P reduction)
Cover cropping	0.149	90.9	610.3
Conservation Tillage	0.162	54.4	335.6
Fertilizer/ manure incorporation	0.512	55.0	107.4

14. 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.

14.0 REFERENCES

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