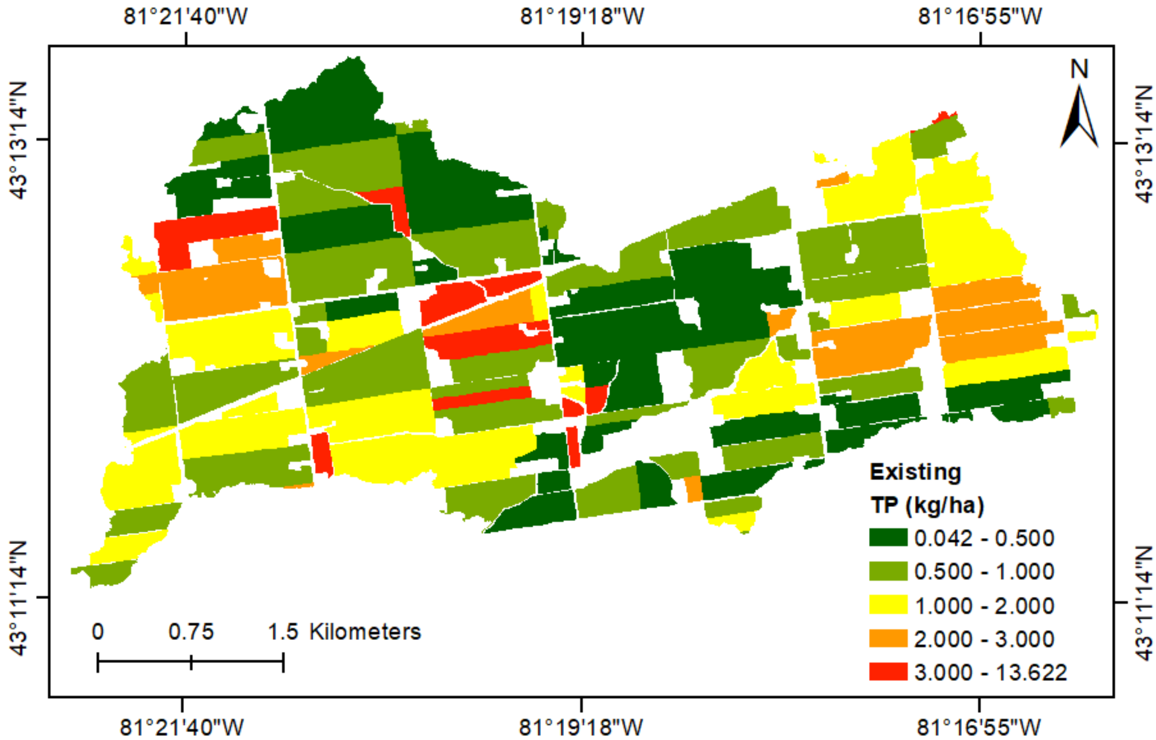

ONFARM

Modelling Summary Report

June 28, 2023

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1. Introduction

Growing concerns about adverse environmental effects of agriculture have led to the establishment of agri-environmental programs that encourage farmers to implement Best/Beneficial Management Practices (BMPs) to reduce pollutant transport to water bodies. In implementing these agri-environmental programs, one important consideration is to evaluate the effectiveness of recommended BMPs in achieving water quality improvement and the cost effectiveness for farmers to implement these BMPs and thus even regard these practices as BMPs.

The Province of Ontario has had several BMP evaluation initiatives in recent years. The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) established a Watershed Based BMP Evaluation (WBBE) program from 2014 to 2016, with study sites in the Gully Creek subwatershed of the Lake Huron Basin and the North Kettle Creek subwatershed of the Lake Erie Basin. The OMAFRA and the Ontario Soil and Crop Improvement Association (OSCIA) implemented the Great Lakes Agricultural Steward Initiative (GLASI) from 2016 to 2018, which initiated the Priority Subwatershed Project (PSP) including the Gully Creek and Garvey Glenn subwatersheds in the Lake Huron Basin's shoreline area, the Upper Medway Creek and Jeannette's Creek subwatersheds of the Lake St. Clair Basin, as well as the North Kettle Creek and Wigle Creek subwatersheds of the Lake Erie Basin. The On-Farm Applied Research and Monitoring (ONFARM) program, administered by the OMAFRA and OSCIA from 2019 to 2023, further developed a soil health and water quality research investigation on farms across Ontario. The ONFARM extended previous work under the GLASI priority subwatershed project to evaluate BMP effects on soil health and water quality. In these programs, BMP experiments and data collection including land management surveys and water monitoring were conducted in collaboration with Conservation Authorities local to those study watershed sites. Watershed modelling for BMP effectiveness assessment was also one of the key components of the ONFARM initiative.

The purpose of the ONFARM modelling project was to apply the Integrated Modelling for Watershed Evaluation of BMPs (IMWEBs) tool to evaluate the pollution reduction effectiveness and cost effectiveness of three key agricultural BMPs (cover cropping, conservation tillage including no-till practices, and fertilizer/manure incorporation following application) in the six priority subwatersheds including the Gully Creek, Garvey Glenn, Upper Medway Creek, North Kettle Creek, Jeannette's Creek, and Wigle Creek subwatersheds. Specifically, the modelling project has the following objectives:

1). Collect and prepare IMWEBs modelling input data;

2). Set up and calibrate IMWEBs modelling to characterize historical/existing conditions;

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

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

2. Study sites

The ONFARM modelling study sites include the following six priority subwatersheds, selected initially under the previous GLASI project.

1). Garvey Glenn subwatershed

The Garvey Glenn subwatershed is located about 15 km north of the Town of Goderich in southwestern Ontario and drains directly into Lake Huron. The watershed has a drainage area of 1,664 ha. The average slope (based on 1-m LiDAR DEM) is 4.3%, with a minimum of 0% in flat areas and up to 211% (65°) in incised gullies. The upland area of the watershed consists of soils with loam and silt loam textures. The mainstream area is flatter and dominated by clay loam and sandy loam soils. Approximately 83.5% of the land is agricultural, while 11.8% is forest, 3.6% is urban (i.e., residential, industrial, and roads), and less than 2.0% is grasslands and wetland. Corn, soybean, and winter wheat are the main three crops grown in the watershed.

2). Gully Creek subwatershed

The Gully Creek subwatershed is located about 13 km south of the Town of Goderich in southwestern Ontario and drains directly into Lake Huron. The watershed has a drainage area of 1,474 ha. The average slope in the watershed (based on 1-m LiDAR DEM) is 7.5% with a minimum of 0% in flat areas and as high as 370% (75°) in incised gully areas. In the upper reach area, clay loam is the dominant soil texture, and the landscape is rolling. The lower reach area is flatter with sandy loam as the dominant soil texture. About 68% of the land is agricultural and 25% is forest, 3.2% is urban (i.e., residential and transportation) and less than 4% is grassland. Corn, soybean, and winter wheat are the main three crops grown in the watershed.

3). Upper Medway Creek watershed

The Upper Medway Creek subwatershed is an upper subbasin of the Medway Creek watershed, which flows into the Thames River at the north end of the City of London in southern Ontario. The Thames River outlets into Lake St. Clair which then drains into the Detroit River, which in turn drains into Lake Erie. The average slope in the watershed (based on 1-m LiDAR DEM) is 5.7% with a minimum of 0% in flat areas and as high as 184% (62°) in incised gully areas (typically greater than 9% in riparian areas). In the upper reach area, the landscape is rolling, and clay loam is the dominate soil texture. The lower reach area is flatter with a greater proportion of silt and loam soils. About 83% of the land is agricultural and 10% is grassland, 5% is built-up (i.e., urban, residential, and transportation), and less than 2% is forest. Corn, soybean, and winter wheat are the main three crops grown in the watershed.

4). North Kettle Creek subwatershed

The North Kettle Creek subwatershed is located in the upper portion of the Kettle Creek watershed in southern Ontario. Kettle Creek flows directly into Lake Erie. The North Kettle Creek study watershed consists of two smaller subwatersheds, the Madter drain on the west and the Holtby drain on the east. Together, they cover a total drainage area of 761 hectares. The average slope (based on 1-m LiDAR DEM) is 3.7%, with a minimum of 0% in flat areas and up to 149% (56°) at incised gullies. The dominant soil types are Gobbles Clay (33.6%) and Tavistock Loam (25.2%). The upper headwater regions are dominated by clay loam textured soils, while the downstream areas are dominated by soils with a loam soil texture. Approximately 83.3% of the land is agricultural, 11.4% is forest or grassland, 5.3% is urban (i.e., residential and transportation), and less than 1% is open water. Corn, soybean, and winter wheat are the main three crops grown in the watershed.

5). Jeannette's Creek subwatershed

The Jeannette's Creek subwatershed, located about 14 km southwest of the city of Chatham, is composed of two smaller subwatersheds with outlets that drain into the Jeannette's Creek, a tributary of the Thames River, which subsequently outlets into Lake St. Clair. Lake St. Clair empties into the Detroit River which flows into Lake Erie. This subwatershed site has a total drainage area of about 1,867 ha (northwestern portion 914.4 ha and southern portion 952.6 ha). The average slope (based on 1-m LiDAR DEM) is 1.8%, with a minimum of 0% in flat areas, and up to 115% (49°) along areas forming the drainage ditch banks. About 95% of the watershed has slope less than 4.5%. The northwestern subwatershed is primarily composed of Rivard Silty Clay soil (36.4%), while the southern subwatershed is dominated by Brookston Clay soil (48.5%). About 97% of the land is agricultural. Corn, soybean, and winter wheat are the main three crops grown in the watershed.

6). Wigle Creek subwatershed

The Wigle Creek subwatershed, a subbasin of the larger Wigle Creek system, is located close to the Town of Kingsville in southwestern Ontario. The Wigle Creek subwatershed has a drainage area of 2,109 ha. Wigle Creek drains directly into Lake Erie. The average slope in this subwatershed portion of Wigle Creek (based on 1-m LiDAR DEM) is 3.4%, with a minimum of 0% in flat areas and up to 459% (78°) along the drainage ditch banks. About 91% of the watershed has slope less than 5.4%. About 98.9% of the Wigle Creek watershed consists of Brookston Clay soil. About 78% of the land is agricultural, about 9% is urban or transportation, and about 13 % is forest or grassland. Corn, soybean, and winter wheat are the main three crops grown in the watershed.

3. IMWEBs modelling procedure for BMP assessment

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 watershed hydrologic model specifically designed for conducting location-specific BMP assessment. The IMWEBs spatial units are further aggregated from cells to subareas to reduce computational time for model simulation while maintaining detailed characterization of land management practices and BMPs (Figure 3-1). 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 (Soil and Water Assessment Tool)/CanSWAT (Canadian version of SWAT), 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 (Hydrologic Response Unit) 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 watershed hydrologic model with characterization of landscape processes including climate, water balance, plant/crop growth, as well as sediment and nutrient fate. The IMWEBs is the only model in Canada that is designed for evaluating water quantity and quality effects of agricultural BMPs over a variety of modelling scales from the site, field, and farm to the watershed scale.

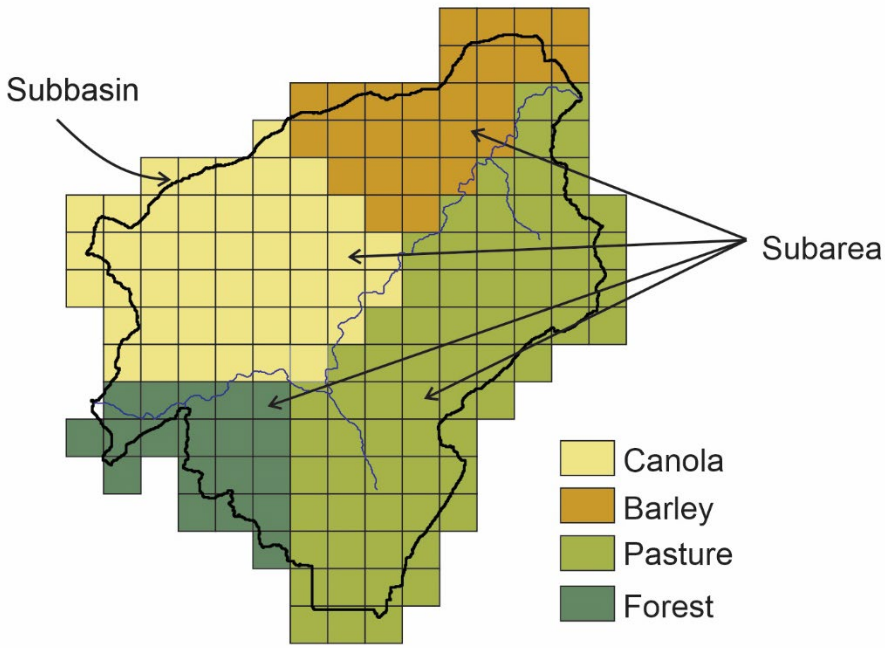

Figure 3-1. A spatial representation of cell, subarea, and subbasin in the IMWEBs model

IMWEBs modelling for BMP assessment follows these procedures:

1). Collect and prepare input data

IMWEBs modelling needs extensive input data, including: watershed boundary, streams and water bodies, farm field boundary, climate, DEM, soil, landuse, land management (seeding and harvesting, tillage, and fertilizer/manure application timing and rates), tile drainage details, existing structural and agronomic BMP descriptions, and others. In the ONFARM project, Conservation Authority staff, involved in monitoring the watersheds, collected a significant portion of the needed input data. The modellers, however, also made significant efforts to gap-fill the dataset where needed. For climate data-filling as an example, climate datasets from nearby Environment and Climate Change Canada (ECCC) stations were used to fill data gaps and/or extend climate data time series not collected by climate stations set up in the watershed as part of the ONFARM study. OMAFRA and AAFC soil data were utilized. Inference calculations were also conducted to prepare necessary soil attribute data. Several months of effort were made to compile and format detailed land management data for each of the six ONFARM priority subwatersheds, using the ONFARM land management survey delivered by the Conservation Authority staff who conducted individual interviews with farmers in the priority subwatersheds. This survey was augmented by a similar survey delivered during GLASI. Windshield surveys of field status (crop type, tillage, residue levels) were also completed annually by Conservation Authorities for the years of interest. In the ONFARM project, Conservation Authority colleagues made significant efforts to survey farmers to collect land management data, and enter the data into an ArcGIS Survey123 product that was developed specifically for this data-collection effort. We reviewed the raw data in Survey123 and assessed that we had to manually transfer the Survey 123 raw data into the IMWEBs input data format by preparing excel tables containing the extensive collected information for each field and for each year of data collection. Due to various issues in the raw data, such as data input errors, missing data, and conversion errors, we made three rounds of efforts from July 2022 to January 2023 to transfer ONFARM land management survey data into an excel table format. Wherever possible, we also utilized windshield survey data to fill data gaps. Furthermore, we utilized the previously-collected GLASI land management data to extend the ONFARM land management for the Garvey Glenn, Gully Creek, and Upper Medway Creek subwatersheds to cover a period from 2001 to 2022. We also utilized AAFC crop inventory data to extend the ONFARM land management for the North Kettle Creek, Jeannette's Creek, and Wigle Creek subwatersheds to a period from 2011 to 2021. The land management data used as input to IMWEBs ultimately included three excel-based tables: a seeding and harvesting table with seeding and harvesting dates and residue level after harvest; a tillage table with spring and fall tillage dates and types; and a fertilizer/manure table with spring and fall fertilizer/manure application dates, types, and incorporation levels.

2). Setup of the IMWEBs model

The first step in IMWEBs setup was to delineate the watershed into subbasins using the DEM and stream network. This established flow routing from overland areas to the channels and then to the watershed outlet. It also generated the relevant topographic parameters such as slope and slope length. During the watershed delineation step, the locations of all in-stream and edge of field monitoring stations for flow and water quality were specified as subbasin outlets in order to allow direct comparison of exported modelling outputs with field-observed flow and water quality data for the purpose of IMWEBs calibration.

The second step in the IMWEBs setup was to characterize the soils and define their distribution and related attributes throughout the watershed. Generalized OMAFRA soil data were combined with more site-specific ONFARM-gathered soil sampling data to produce the soils data layer that IMWEBs ultimately used for watershed soil characterization.

The third step in the IMWEBs setup was to characterize the extent and location of different landuse practices, primarily crop types, across the watershed. This step involved preparing an IMWEBs-compatible landuse data layer that matched the various field-acquired observations including remote satellite crop inventory mapping and annual field and windshield surveys of land activity completed by the local CA for their respective ONFARM subwatersheds.

After establishing the three foundational layers – topography/DEM, soil, and landuse in the IMWEBs setup, the fourth step was to convert the cell-based IMWEBs model to a subarea-based IMWEBs model through parameter aggregation. The subarea layer was created by overlaying the field boundary layer with the subbasin layer. Subareas are the smallest management unit for defining land management practices such as the practice of cover cropping or the use of conservation tillage practices and the implementation of structural BMP practices such as wetlands and riparian buffers. In IMWEBs modelling, these subareas have the advantage of having their results being aggregated back to the farm fields scale, combining the results to generate an overall field perspective for the practices implemented on the various soils and topographies present in the field area.

The fifth step was to characterize the land management activities, based on crop types present in a field. Land management activities data such as the crop planting and harvest dates along with details concerning the rate, timing and placement of fertilizer and manure applications, if any, were collected by each local CA for each field in the watershed where possible. A GIS-based Survey123 tool was developed specifically for the purpose of collecting this field data as part of the ONFARM program. The modelling effort used this information collected in ONFARM and combined it with similar information collected in the earlier GLASI project to define the field activities as best as possible. Having this information is critical to allow the IMWEBs model to best represent the timing and magnitude of runoff flow and nutrient losses. For example, cultivating the soil immediately following a fertilizer application could result in a reduction in P losses from the field if a significant runoff event was experienced a few days following the application. At the same time, the cultivation pass may have made the field more vulnerable to soil erosion, resulting in a trade-off between increased erosion but less direct P fertilizer loss in the runoff water. The timing of these activities in relation to significant runoff events were therefore important to capture from a modelling perspective. In general, the key land management or agronomic-related BMPs that were assessed for water quality benefits under the ONFARM modelling initiative were: conservation/no tillage, cover cropping, and fertilizer/manure incorporation soon after application.

The final step involved in the setup of the IMWEBs model was to identify and describe the location of some select water management practices that had been implemented within the watershed's landscape. Tile drainage was perhaps the most common water management feature in all of these watersheds that needed to be represented in the model. OMAFRA's tile drainage GIS layer was used as the base layer to characterize tile drain distribution, but was then enhanced with additional knowledge, such as tile depth and spacing, gathered when the CA's completed the survey with the landowners. The location and description of other water management features such as WASCoBs and grassed waterways were identified through inspection of aerial photography, through the landowner surveys, or CA records, for incorporation into the IMWEBs model where applicable.

3). Calibrate the IMWEBs model

Calibrating the IMWEBs model involved adjusting model inputs and parameters to optimize the agreement between measured data and model simulation results for realistically characterizing each watershed's historical/existing observed conditions. The performance of IMWEBs flow calibration was evaluated graphically and then statistically based on three indicators, Nash–Sutcliffe coefficient (NSC), Percent bias (PBIAS), and correlation coefficient (CORR). The NSC was calculated by comparing the variance of the differences between simulated and observed values to the variance of observed values on the timestep of the modelling tool. NSE had values ranging from -1 to +1 with a higher positive value indicating a better match of simulated flow with observed flow. PBIAS measured the relative mean difference between predicted and observed values. The optimal value of PBIAS was 0.0, with lower values indicating a more accurate model simulation. CORR measured the degree of dependence of one variable upon another. A higher CORR indicated a higher correlation between observed and simulated values. In contrast to continuous flow monitoring data, Total Suspend Solid (TSS), Nitrogen(N) and Phosphorus (P) were not monitored continuously and therefore had limited sample sizes which were not suitable for calculating NSC. Therefore, only PBIAS and CORR were used for measuring the performance on IMWEBs calibration of TSS, N, and P.

4). Conduct BMP assessment

The calibrated IMWEBs model represented the hydrological and water quality processes under historical/existing observed conditions. These observed conditions included any BMPs implemented in the watershed during the monitoring period. The calibrated IMWEBs model was applied to evaluate the water quality benefits of both the existing actual BMPs, as well as the potential future BMP scenarios for TSS, TN, and TP yield/load reductions, both from the edge of field (EOF) and from the off-site watershed outlet perspective. In the ONFARM modelling project, in the interest of time, and knowing the agronomic BMPs receiving the most focus under the ONFARM project, IMWEBs modelling conducted an assessment of three key land management or agronomic-related BMPs – cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation. These three key BMPs were identified as being of greatest interest by the ONFARM Technical Working Group.

Under observed historical/existing conditions, a subset of farm fields in each of the six ONFARM subwatersheds implemented the three key land management BMPs. In order to evaluate the water quality benefits of three key BMPs under historical/existing conditions, three model scenarios were developed that removed the implementation of these observed BMPs from the study watersheds. These three model scenarios were referred to in this report as the “conventional (no existing BMP)” scenarios (no existing cover cropping scenario, no existing conservation tillage scenario, and no existing fertilizer/manure incorporation scenario). In other words, one model run scenario that removed the practice of interest was created for each of the three key BMPs.

To develop the conventional scenario for cover cropping, existing cover crops in the seeding and harvesting table were removed and the soil cover residue level was reduced, the fall tillage in the tillage table was added, and the N credit assigned to the next year’s crop from planting cover crop was added back in the fertilizer table (66 kg/ha for red clover and 45 kg/ha for other cover crops). To develop the conventional scenario for conservation tillage/no-till, all existing conservation tillage/no-till in the tillage table were changed to conventional tillage (fall moldboard plough and spring secondary tillage if applicable). To develop the conventional scenario for fertilizer/manure incorporation, all fertilizer applications with incorporation in the fertilizer/manure management table were changed to surface application.

Once the IMWEBs modelling was re-setup based on the three conventional no existing BMP scenarios, the IMWEBs model was re-run and model output was generated for each of the three conventional no existing BMP scenarios. The differences of simulated TSS, TN, and TP yield/load results between each of the conventional no existing BMP scenario model runs and the historical/existing conditions (existing actual BMP scenario vs. no existing cover cropping scenario, no existing conservation tillage scenario, or no existing fertilizer/manure incorporation scenario) model runs represented the water quality benefits of each of the three key historical/existing BMPs under evaluation. In the scenario comparison, the differences were associated with those fields that had implemented the key BMPs of interest historically.

In the ONFARM modelling project agreement, potential future BMP assessment was not listed as a component. However, in one of the Technical Working Group meetings, the value of estimating the water quality benefits of complete adoption of the three key BMPs of interest in the watersheds was discussed and the possibility of conducting this potential future BMP assessment was explored. In response to the discussions, the modelling team made an extra effort to conduct potential future BMP assessments in the ONFARM project, which involved a significant amount of workload. We developed three potential future BMP scenarios (potential future cover cropping scenario, potential future conservation tillage scenario, and potential future fertilizer/manure incorporation scenario) corresponding to each of the existing actual BMP scenarios.

To develop the potential future cover cropping scenario, we added cover crops to all cropped fields not currently being cover cropped, including those planted to corn, soybean, and winter wheat. This was achieved by editing the IMWEBs seeding and harvesting input table by increasing the soil cover residue level, removing the fall tillage in the tillage table, and adding an N credit for the following crop to represent planting a cover crop. In consultation with Conservation Authority colleagues, oats was selected as the cover crop after winter wheat (winter killed by the end of the year leaving the crop residue on the soil surface until next spring before planting). Cereal rye was selected as the cover crop after corn and soybean (when the next crop was not winter wheat or a cover crop under observed historical conditions). For all cover crops, 45 kg/ha of N credit was added to next year's crop. To develop the potential future conservation tillage scenario, we changed all existing conventional tillage in the tillage table into conservation tillage. To develop the potential future fertilizer/manure incorporation scenario, we changed all existing no or partial fertilizer/manure incorporation in the fertilizer/manure management table into full incorporation.

Once the IMWEBs modelling was re-setup based on the three potential future BMP scenarios (cover cropping, conservation tillage and fertilizer/manure incorporation), the IMWEBs model was re-run and model output was generated for each of these three potential future BMP scenarios. The differences of simulated TSS, TN, and TP yield/load results between the historical/existing scenario (with existing actual BMPs) model runs and each of the potential future BMP scenario (existing actual BMP scenario vs. potential future cover cropping scenario, potential future conservation tillage scenario, or potential future fertilizer/manure incorporation scenario) model runs represented the water quality benefits of each of the three key potential future BMPs under evaluation. In the scenario comparison, the differences were associated with those fields that had not yet implemented the key BMPs of interest historically and thus represented an estimate of the potential if full adoption of these practices was realized.

We also made further efforts to calculate the differences between no BMP adoption and full BMP adoption of the three key BMPs of interest. This entailed comparing the model run outputs from the following scenario runs: 1). No existing cover cropping scenario vs. potential future cover cropping scenario, 2). No existing conservation tillage scenario vs. potential future conservation tillage scenario, and 3). No existing fertilizer/manure incorporation scenario vs. potential future fertilizer/manure incorporation scenario. The differences in simulated TSS, TN, and TP yield/load results between these three sets of model runs represented the full water quality benefits of existing actual BMP adoption plus potential future BMP adoption, in relation to the conventional scenarios without these BMPs. The effectiveness of both existing and potential future BMPs in terms of full water quality benefits in all fields and in all years provided a consistent set of BMP effectiveness data for calculating BMP environmental effectiveness at the farm field scale, as the impacts of historical/existing BMPs were removed.

4. IMWEBs modelling results under historical/existing conditions

In the ONFARM project, we made efforts to conduct IMWEBs setup and calibration for all six priority subwatersheds and had varying levels of success. The calibration of IMWEBs models for the Garvey Glenn and Upper Medway Creek subwatersheds achieved reasonable performance for flow, TSS, nitrogen and phosphorus simulations and the full suite of IMWEBs model scenarios were run to conduct BMP assessment for these two subwatersheds. The IMWEBs model calibration for the Gully and Jeannettee's Creek subwatersheds achieved reasonable performance for flow, TSS, nitrogen and phosphorus simulations but BMP assessment was not conducted due to time constraints. The calibration of IMWEBs models for the Wigle and North Kettle Creek subwatersheds was conducted for flow simulations but the performance was not satisfactory due to significant mismatches between flow and precipitation data. With these challenges, TSS and nutrient calibration and BMP assessment for the Wigle and North Kettle Creek subwatersheds were not conducted.

The calibrated IMWEBs models for the Garvey Glenn and Upper Medway Creek subwatersheds were run for the period of 2001-2021 under historical/existing climate and land management conditions including all historical/existing BMPs already in place in the watershed. The simulated average yearly stream flow and also sediment and nutrient yields/loads at watershed outlet and edge of field during the IMWEBs modelling simulation period were documented and presented in either a tabular or graphical format.

1). Garvey Glenn subwatershed

For the Garvey Glenn subwatershed, the average annual precipitation for the period of 2001 to 2021 was 885.5 mm and the simulated annual total runoff/flow was 414.1 mm, with a runoff/flow coefficient of 0.47. The simulated average annual total sediment yield/load at the watershed outlet was 1,440.6 tonnes (0.86 t/ha), of which 1,006.2 tonnes (0.60 t/ha) were from overland sediment yield and 434.4 tonnes (0.26 t/ha) were from channel sediment load. The average overland sediment delivery rate was calculated using the estimated sediment yield associated with the surface runoff and tile flow before it entered into the defined streams/channels divided by the watershed area, while the average channel 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 56,207.8 kg (33.71 kg/ha), of which 9,252.0 kg were in particulate form (16.5%) and 46,955.8 kg were in dissolved form (83.5%). The estimated average annual TP load at the watershed outlet was 1,758.5 kg (1.06 kg/ha), of which 846.9 kg were in particulate form (48.2%) and 911.6 kg were in dissolved form (51.8%) (Table 4-1).

Table 4-1. Simulated average yearly sediment and nutrient yield/load at watershed outlet over the period 2001-2021 under historical/existing land management conditions for the Garvey Glenn subwatershed

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

Figures 4-1, 4-2, and 4-3 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 4-2, the majority of the cropland area (83.8%) had sediment yield/load under 1.0 ton/ha and about 48.0% of the cropland area had sediment yield/load under 0.5 ton/ha. About 16.2% of the cropland area had sediment yield/load above 1.0 ton/ha and as high as 6.2 ton/ha. About 43.4% of the cropland area had TN yield/load under 10 kg/ha. About 19.4% of the cropland area had TN yield/load above 50.0 kg/ha and as high as 88.6 kg/ha, which was likely related to TN load from tile drains in the field and transported from other fields. About 28.0% of the cropland area had TP yield/load under 0.5 kg/ha. About 14.7% of the cropland area had TP yield/load above 3.0 kg/ha and as high as 5.3 kg/ha, which was also likely related to TP load from tile drains in the field and transported from other fields.

Table 4-2. Simulated average yearly sediment, TN, and TP yields/loads at a field scale under historical/existing land management conditions from 2001 to 2021 in the Garvey Glenn subwatershed

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

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

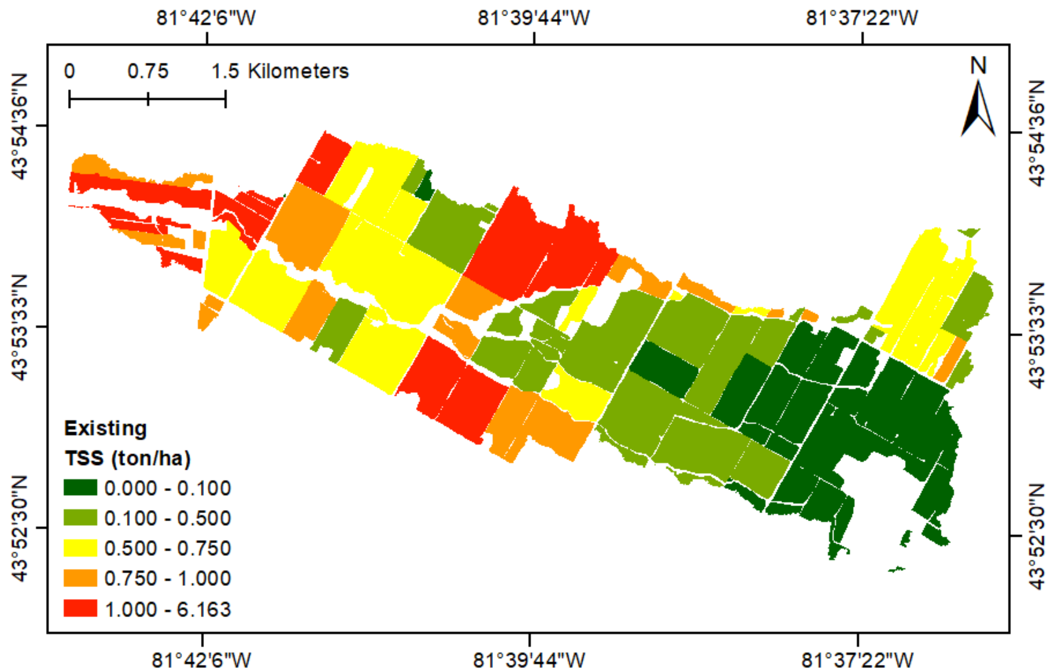

Figure 4-1. Simulated average yearly sediment yield/load at a field scale under historical/existing land management conditions in the Garvey Glenn subwatershed

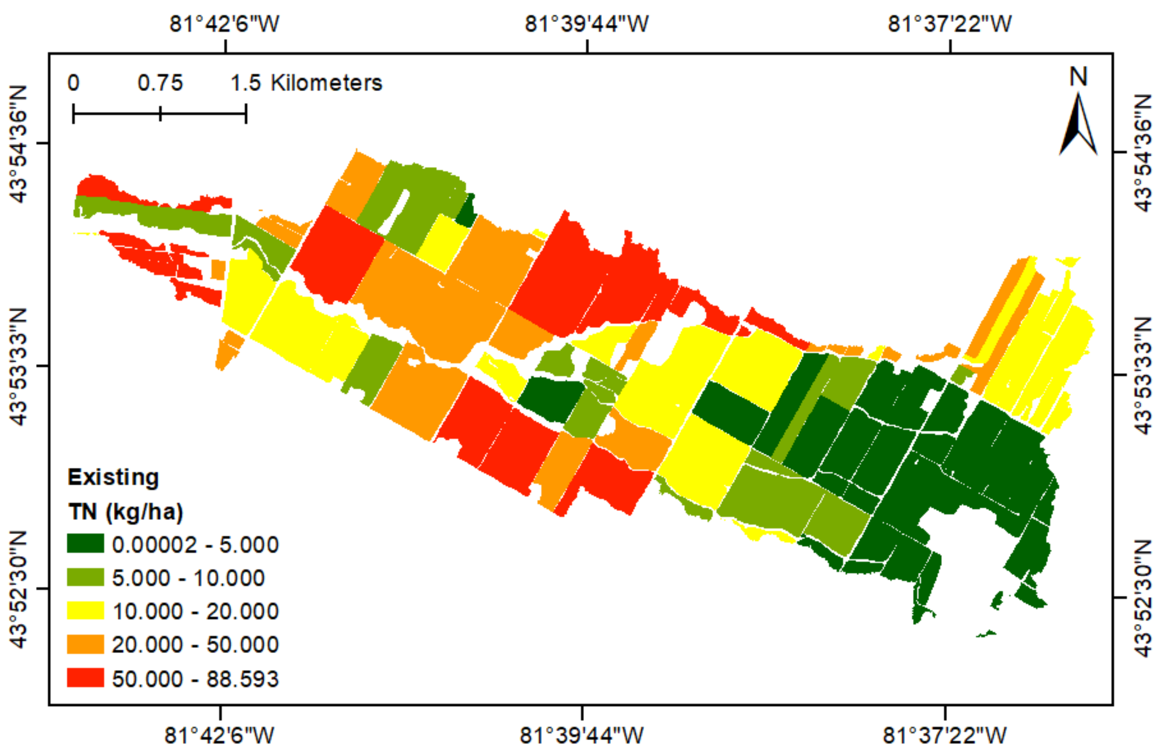

Figure 4-2. Simulated average yearly TN yield/load at a field scale under historical/existing land management conditions in the Garvey Glenn subwatershed

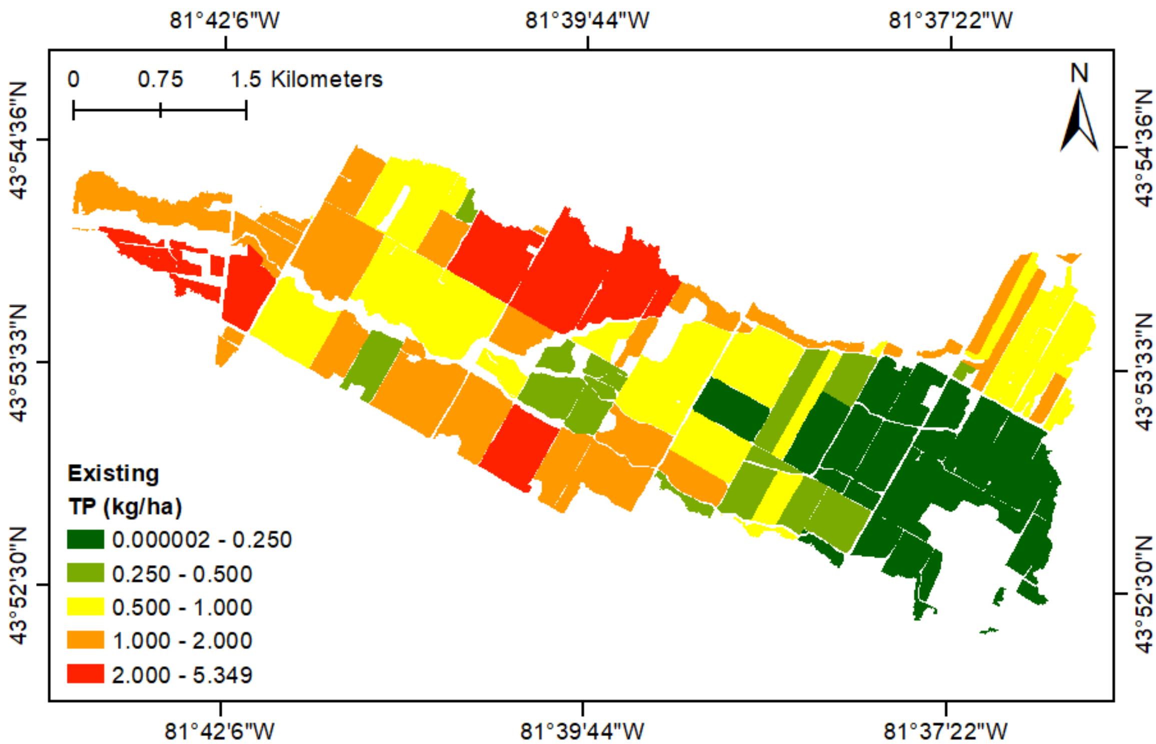

Figure 4-3. Simulated average yearly TP yield/load at a field scale under historical/existing land management conditions in the Garvey Glenn subwatershed

2). Upper Medway Creek subwatershed

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 load at the watershed outlet was 810.1 tonnes (0.41 t/ha), of which 650.7 tonnes (0.33 t/ha) were from overland sediment yield and 159.4 tonnes (0.08 t/ha) were from channel sediment load. The average overland sediment delivery rate was calculated using the estimated sediment yield associated with the surface runoff and tile flow before it entered into the defined streams/channels divided by the watershed area, while the average channel 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 were 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 were in particulate form (59.7%) and 811.6 kg were in dissolved form (40.3%) (Table 4-3).

Table 4-3. Simulated average yearly sediment and nutrient yield/load at 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 %

Figures 4-4, 4-5, and 4-6 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 4-4, 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 drains 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 drains in the field and transported from other fields.

Table 4-4. 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.

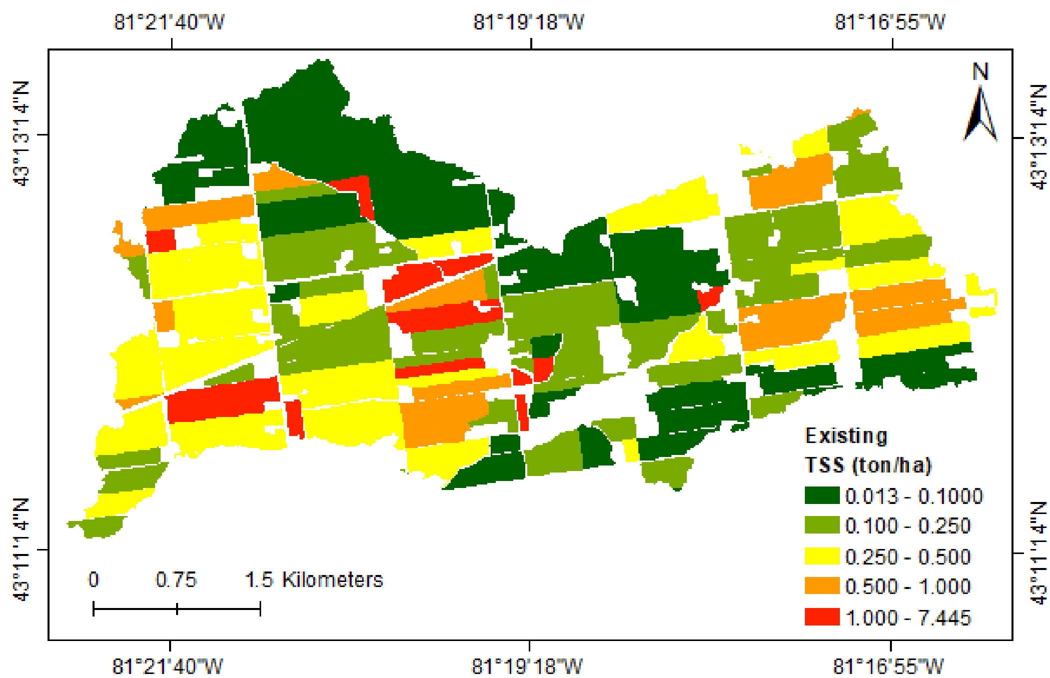

Figure 4-4. Simulated average yearly sediment yield/load at a field scale under historical/existing land management conditions in the Upper Medway Creek subwatershed

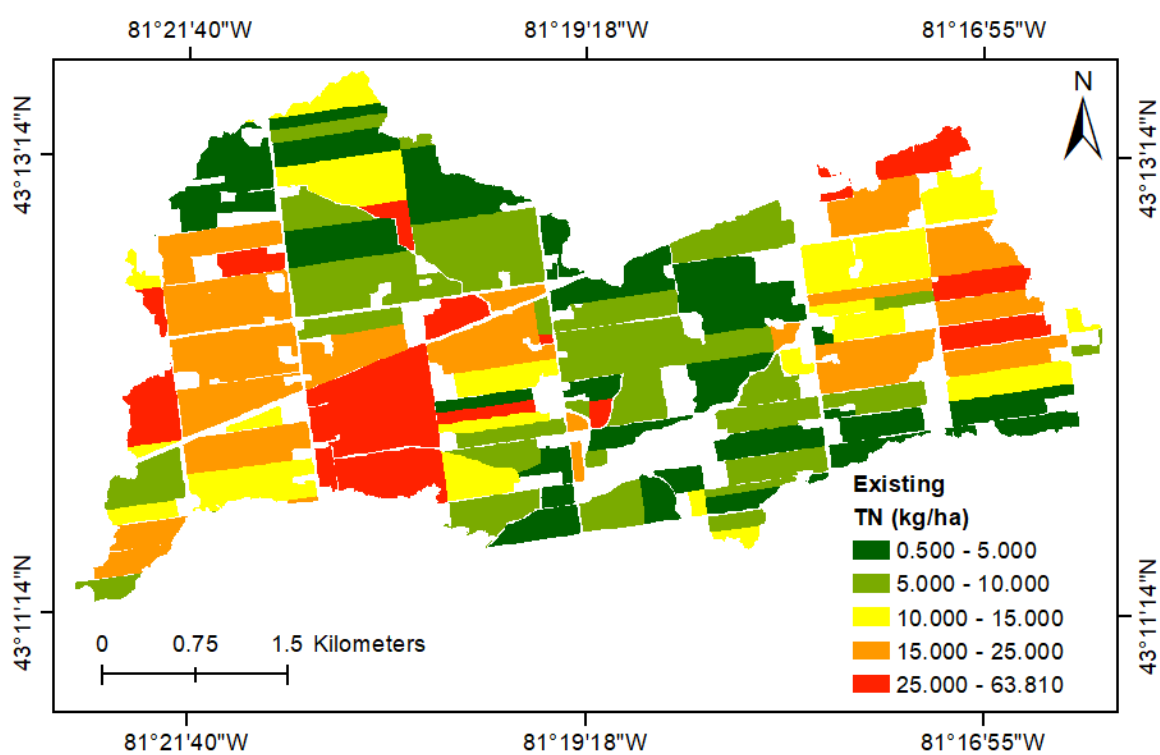

Figure 4-5. Simulated average yearly TN yield/load at a field scale under historical/existing land management conditions in the Upper Medway Creek subwatershed

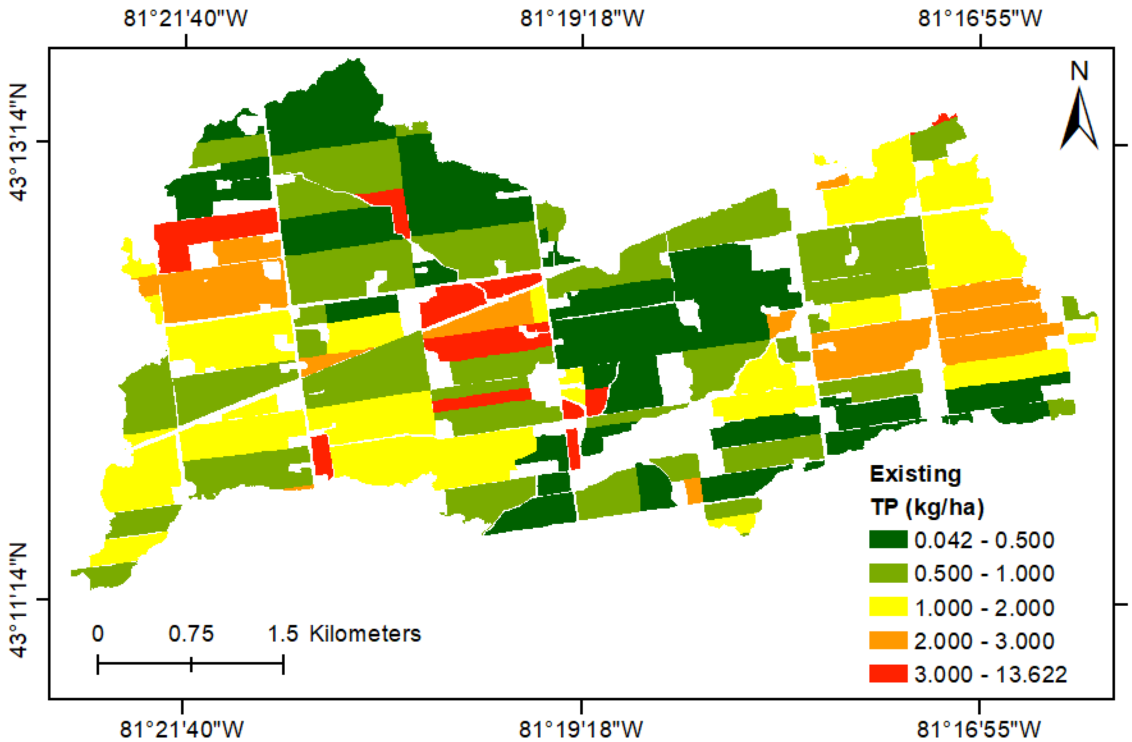

Figure 4-6. Simulated average yearly TP yield/load at a field scale under historical/existing land management conditions in the Upper Medway Creek subwatershed

5. IMWEBs modelling results for assessing the effectiveness of existing actual BMPs

The calibrated IMWEBs models for the Garvey Glenn and Upper Medway Creek subwatersheds were applied to estimate the BMP effectiveness in terms of water quality benefits of three historical/existing land management BMPs: cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation. The IMWEBs model was re-setup based on the conventional no existing BMP scenarios in which each of these three BMPs currently present in the watershed were removed from the historical/existing conditions (i.e. the existing actual BMP scenario). The differences between the IMWEBs modelling results under the conventional no existing BMP scenario and the historical/existing conditions (i.e. existing actual BMP scenario vs. no existing cover cropping scenario, no existing conservation tillage scenario, or no existing fertilizer/manure incorporation scenario) represented the BMP effectiveness in terms of yearly TSS, TN, and TP yield/load reductions for each of the three key BMPs at the levels currently being implemented in the watershed. Note that during the 21 years of IMWEBs simulation period from 2001 to 2021 for the Garvey Glenn and Upper Medway Creek subwatersheds, the BMPs of interest may have only been applied in selected years on a farm field due to crop rotation patterns, farmer choice, and other factors. The BMP effectiveness represented the yearly averages of TSS, TN, and TP yield/load reductions in a farm field despite the fact that the specific BMPs may not have been present in the field every year. For this reason, BMP effectiveness of practices that were not present in a field every year, were dampened when their effects on TSS, TN, and TP losses were averaged across every growing season whether present or not. In this section of the report, we provide more detailed results on the spatial distribution of on-site or edge of field BMP effectiveness for each of the three existing actual BMP scenarios in relation to the conventional no existing BMP scenarios.

1). The Garvey Glenn subwatershed

A. 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 represented the effects of cover cropping on sediment, nitrogen, and phosphorus dynamics in those existing cover cropped fields and related fields on the hydrological pathways. BMP effects were more pronounced in those existing cover cropped fields and the magnitudes of BMP effects were also related to field characteristics such as crop rotation, topography, soil, and others. Figures 5-1, 5-2, and 5-3 show the spatial distribution of simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario from 2001 to 2021. Note that the maps focused on agriculture fields and the white space includes roads, water, and non-agricultural vegetation. Based on the analysis in Table 5-1, about 58.8% of the cropland area had TSS yield/load reduction between 0 and 0.01 ton/ha and about 16.2% of the cropland area had TSS yield/load reduction above 0.02 and as high as 0.08 ton/ha. About 62.8% of the cropland area had TN yield/load reduction between 0 and 0.1 kg/ha and about 13.0% of the cropland area had TN yield/load reduction above 1.0 and as high as 7.2 kg/ha. About 49.2% of the cropland area had TP yield/load reduction between 0 and 0.05 kg/ha and about 14.2% of the cropland area had TP yield/load reduction above 0.1 and as high as 0.4 kg/ha. On average, existing cover crop planting led to TSS, TN, and TP yield/load reductions of 1.4%, 2.6% and 4.7% respectively in relation to corresponding TSS, TN, and TP yields/loads under the no existing cover cropping scenario. The pattern showed the net benefits of existing actual cover crop planting in the watershed. Note that 12.7%, 18.2% and 20.2% of the cropland area had TSS, TN, and TP yield/load no change or even increases in estimates of these water quality parameters in response to cover crop planting. However, the magnitudes of the increases were very small. This pattern may be due to the assumption that the cover crops would be ploughed down in late fall or early spring, possibly making the soil in some places more susceptible to erosion and nutrient loss if storm events occurred.

Table 5-1. Simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

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

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

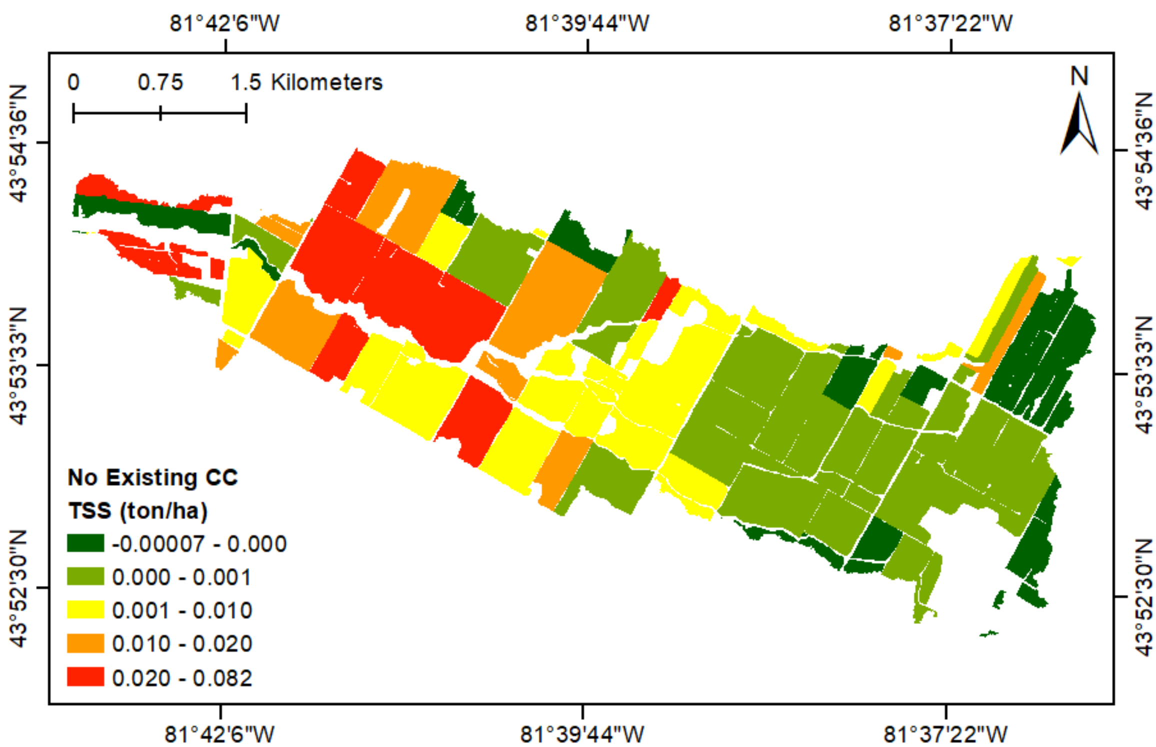

Figure 5-1. Simulated average yearly reduction of TSS yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

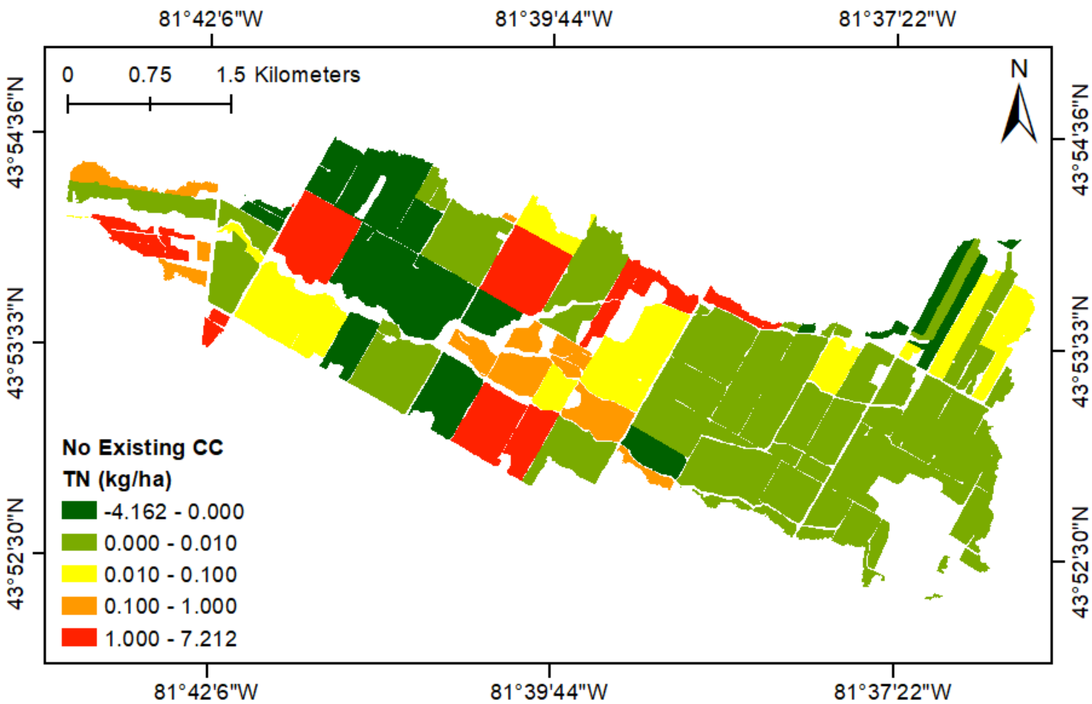

Figure 5-2. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

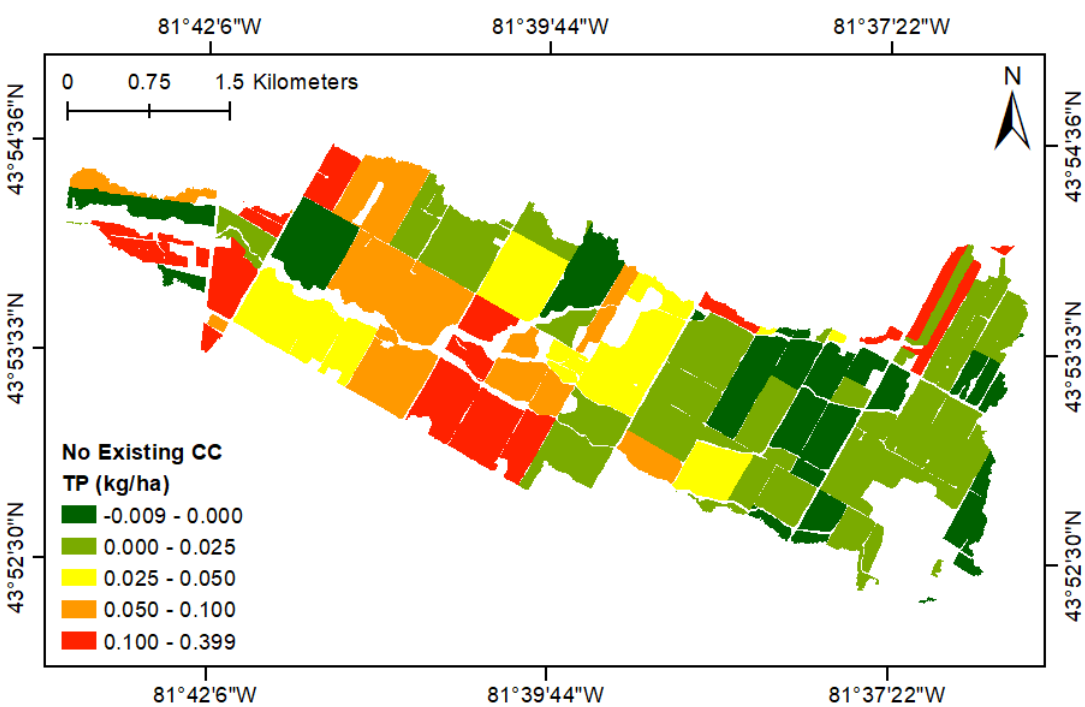

Figure 5-3. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

B. 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 5-4, 5-5, and 5-6 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 5-2, about 56.6% of the cropland area had TSS yield/load reduction between 0 and 0.05 ton/ha and about 14.1% of the cropland area has TSS yield/load reduction above 0.1 and as high as 0.3 ton/ha. About 44.9% of the cropland area had TN yield/load reduction between 0 and 1.0 kg/ha and about 14.9% of the cropland area had TN yield/load reduction above 3.0 kg/ha and as high as 12.4 kg/ha. About 48.9% of the cropland area had TP yield/load reduction between 0 and 0.05 kg/ha and about 15.0% of the cropland area had TP yield/load reduction above 0.1 kg/ha and as high as 0.5 kg/ha. On average, existing conservation tillage application led to TSS, TN, and TP yield/load reductions of 8.7%, 5.2% and 4.0% respectively in relation to corresponding TSS, TN, and TP yields/loads under the no existing conservation tillage scenario. The pattern showed the net benefits of existing actual conservation tillage and no-till application in the watershed. Note that some portion of the cropland area (4.5%, 18.9% and 21.0%) had TSS, TN, and TP yield/load no change or even increases in estimates of these water quality parameters in response to existing adoption of conservation tillage or no-till practices. These areas mostly overlapped with fields with slightly lower TSS yield/load reductions where more nutrient leaching may outweigh soil-associated nutrient retention.

Table 5-2. Simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

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

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

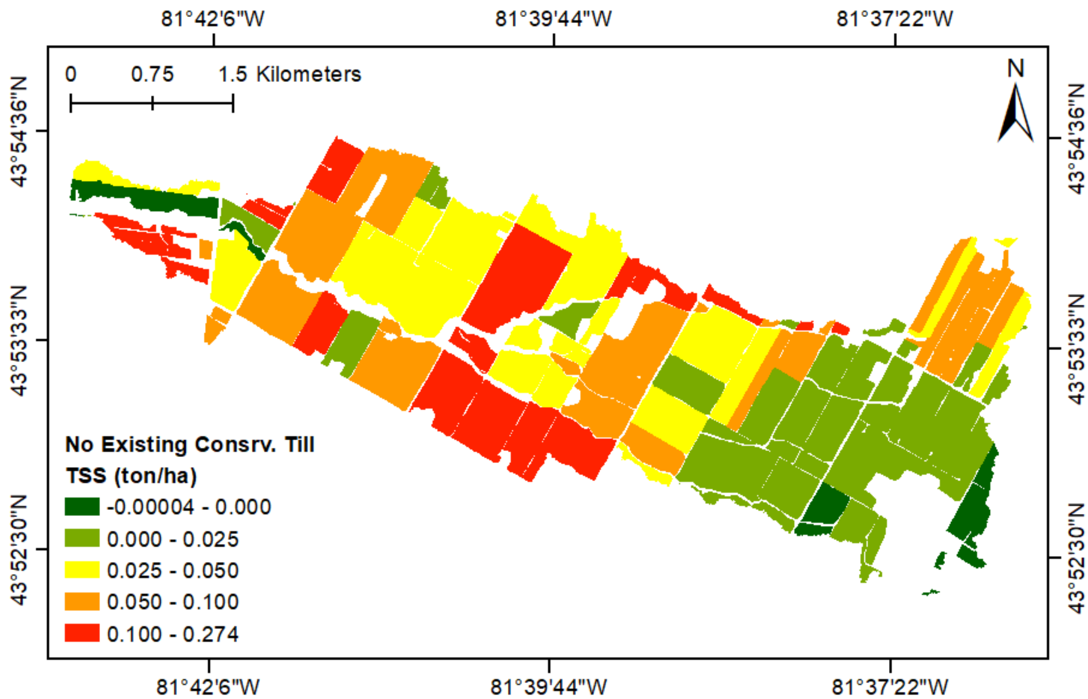

Figure 5-4. Simulated average yearly reduction of TSS yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

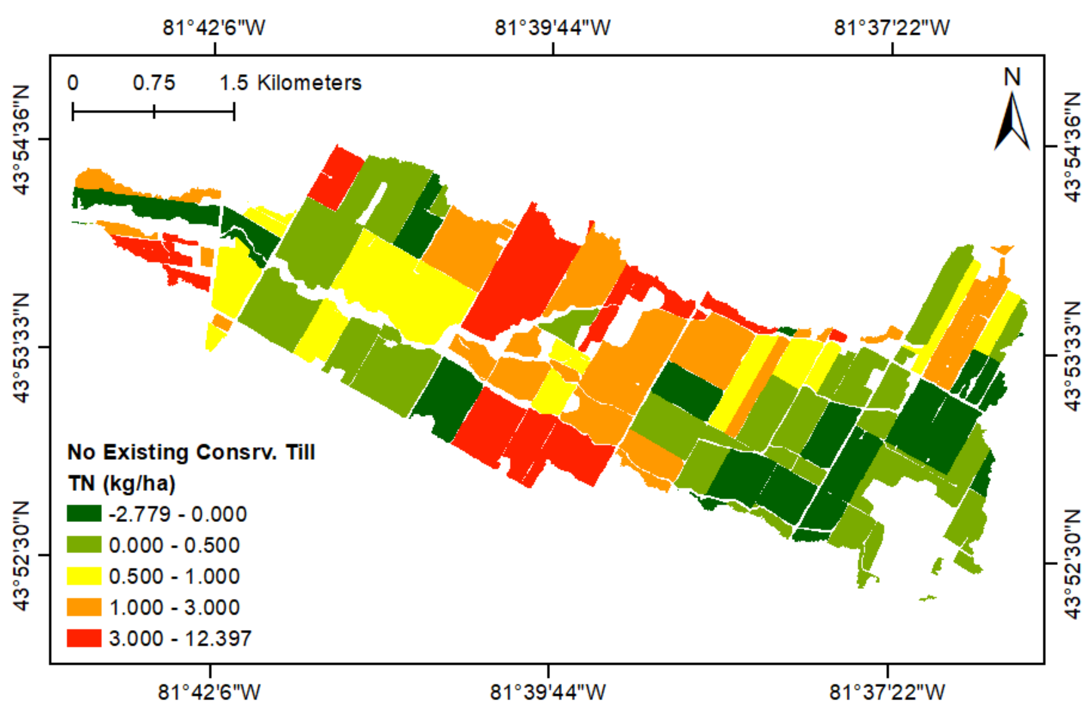

Figure 5-5. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

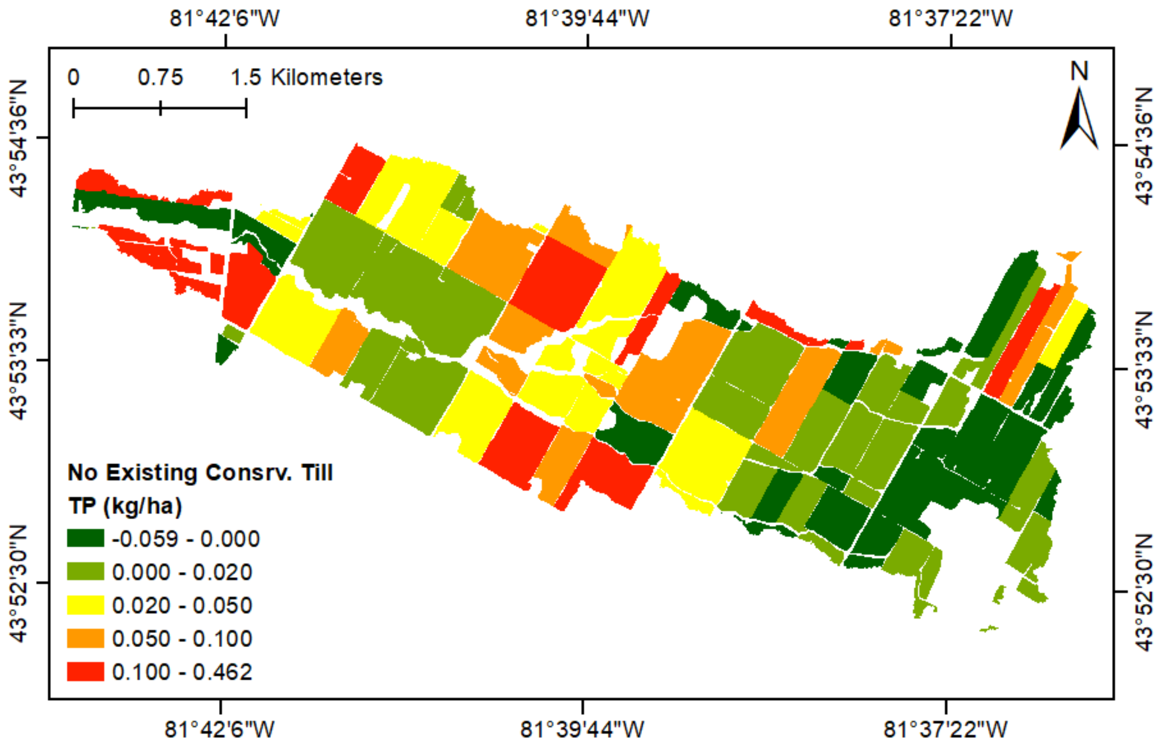

Figure 5-6. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

C. 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 5-7 and 5-8 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 5-3, about 64.7% of the cropland area had TN yield/load reduction between 0 and 3 kg/ha and about 15.8% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 18.6 kg/ha. About 42.7% of the cropland area had TP yield/load reduction between 0 and 0.2 kg/ha and about

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

Table 5-3. Simulated average yearly reductions of TN and TP yields/loads at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

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

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

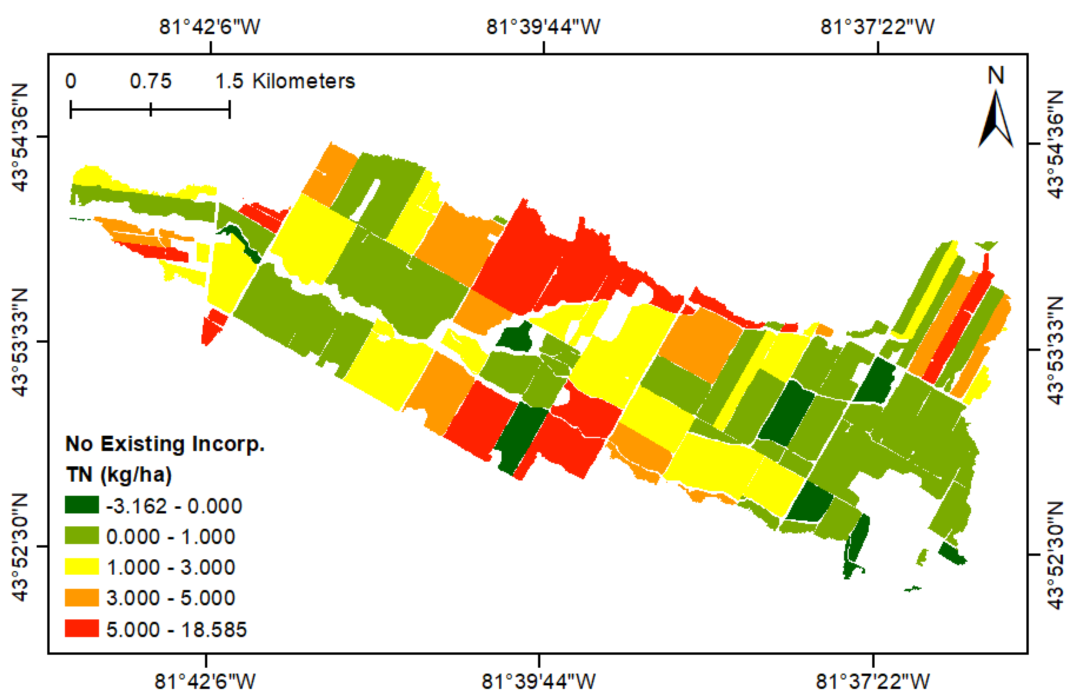

Figure 5-7. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

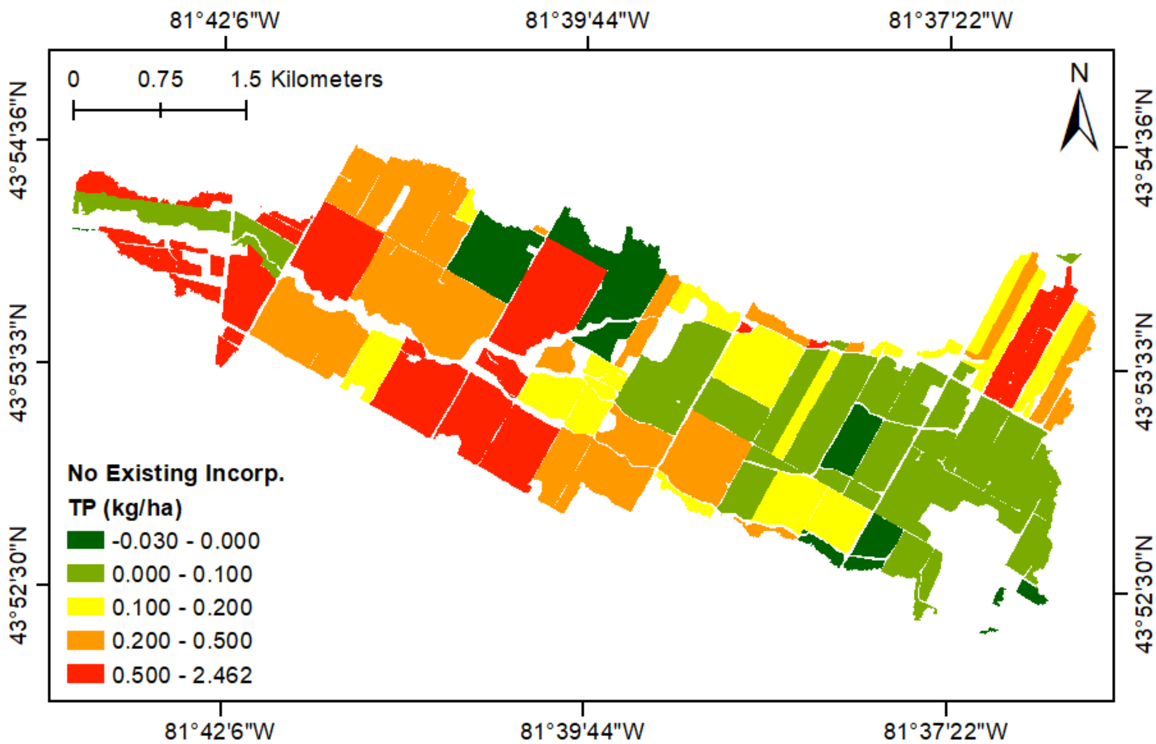

Figure 5-8. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

2). The Upper Medway Creek watershed

A. 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 represented the effects of cover cropping on sediment, nitrogen, and phosphorus dynamics in those existing cover cropped fields and related fields on the hydrological pathways. BMP effects were more pronounced in those existing cover cropped fields and the magnitudes of BMP effects were also related to field characteristics such as crop rotation, topography, soil, and others. Figures 5-9, 5-10, and 5-11 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 5-4, 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 showed the net benefits of existing actual cover crop planting in the watershed. 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 5-4. 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.

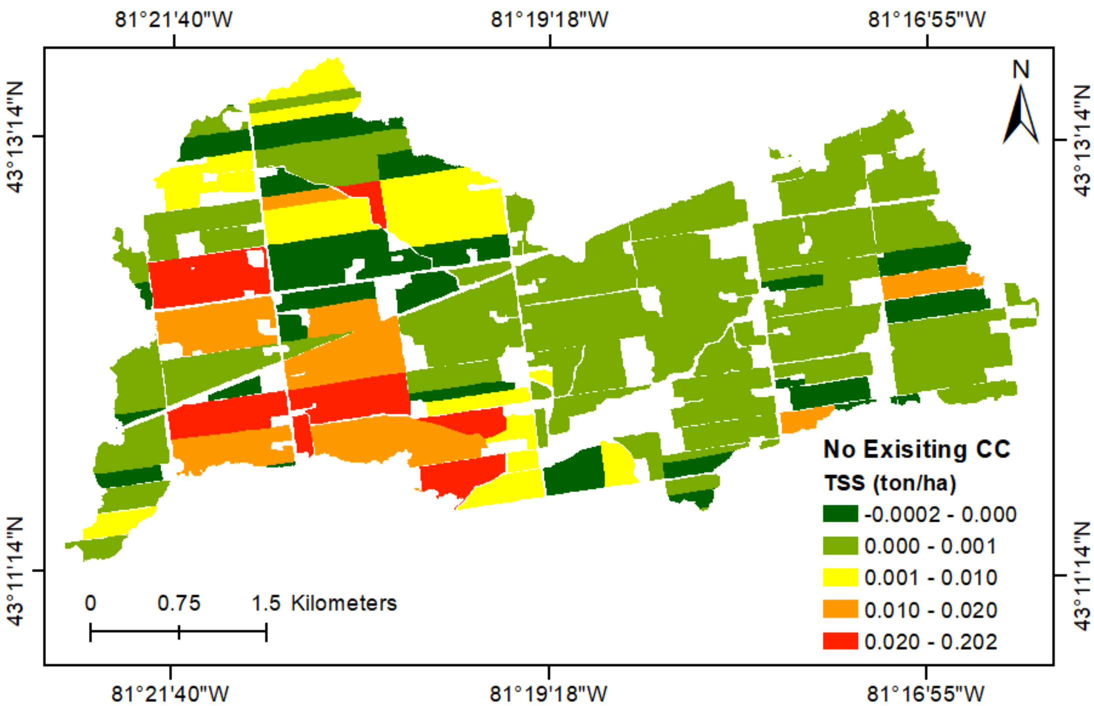

Figure 5-9. Simulated average yearly reduction of TSS yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

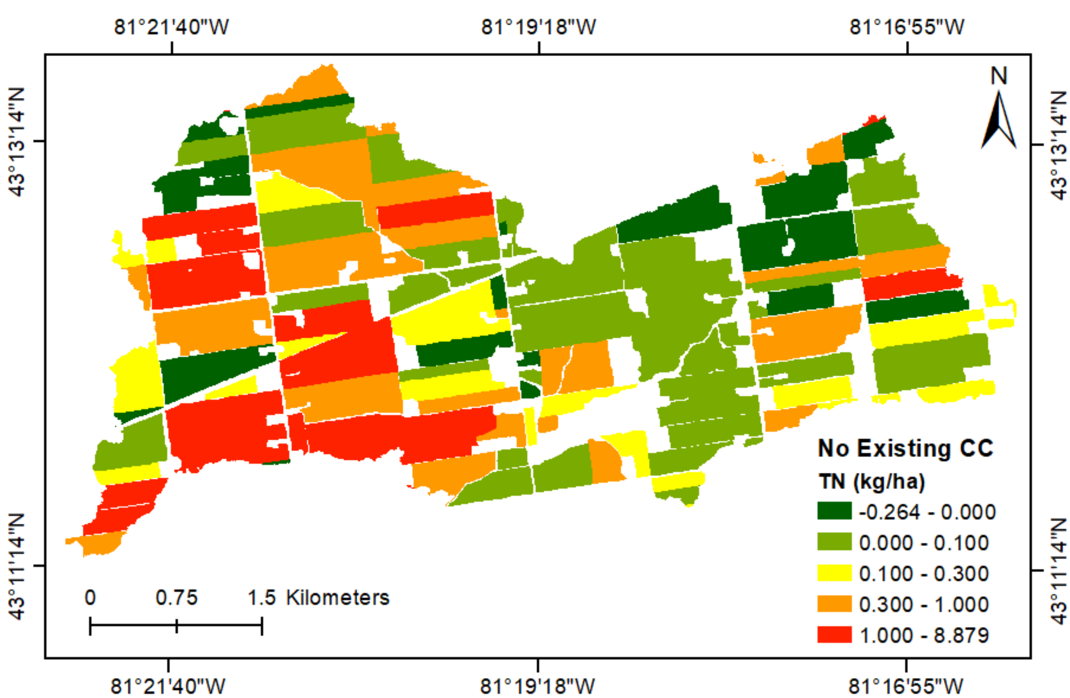

Figure 5-10. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

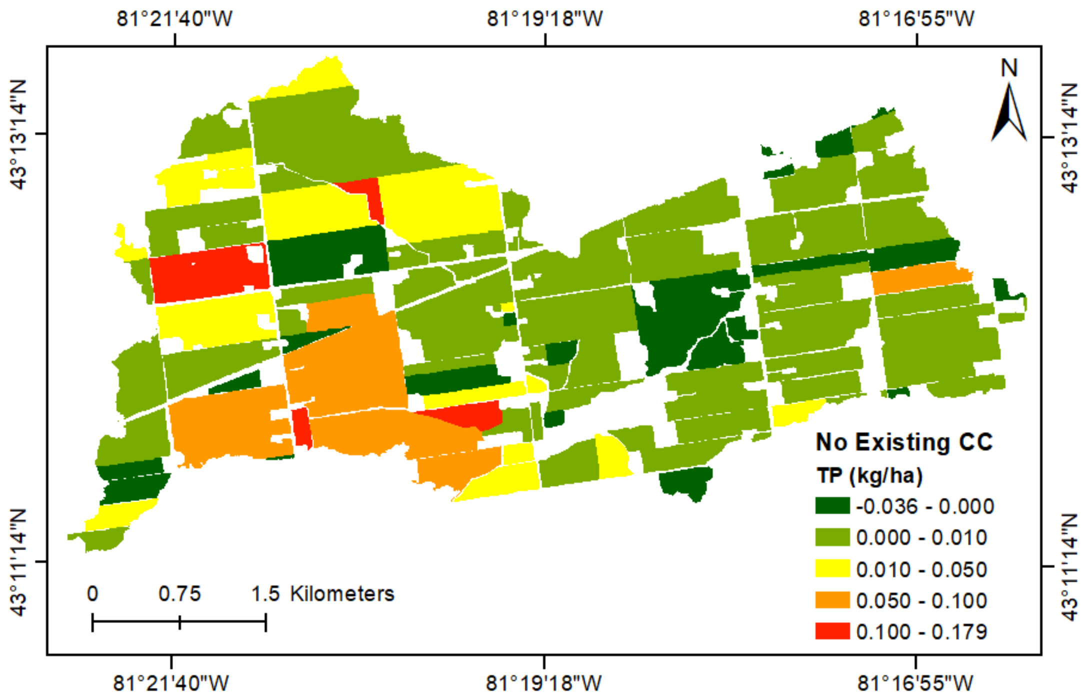

Figure 5-11. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

B. 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 conservation tillage 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 5-12, 5-13, and 5-14 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 5-5, 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 showed 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 existing adoption of conservation tillage or no-till practices. These areas mostly overlapped with fields with slightly lower TSS yield/load reductions where more nutrient leaching may outweigh soil-associated nutrient retention.

Table 5-5. 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.

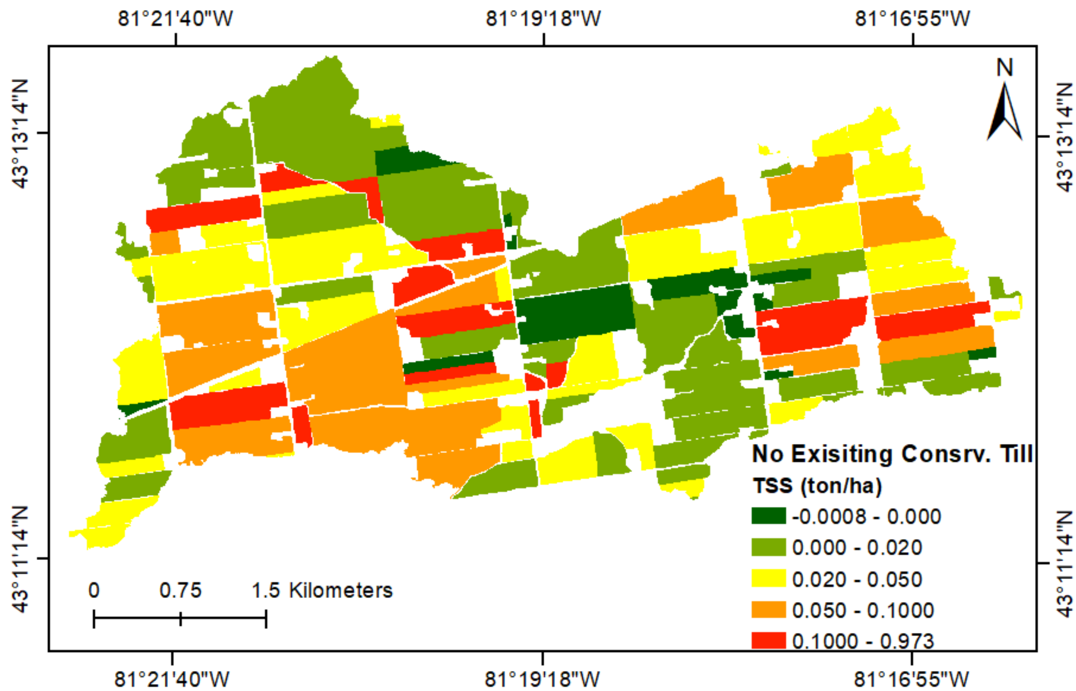

Figure 5-12. Simulated average yearly reduction of TSS yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

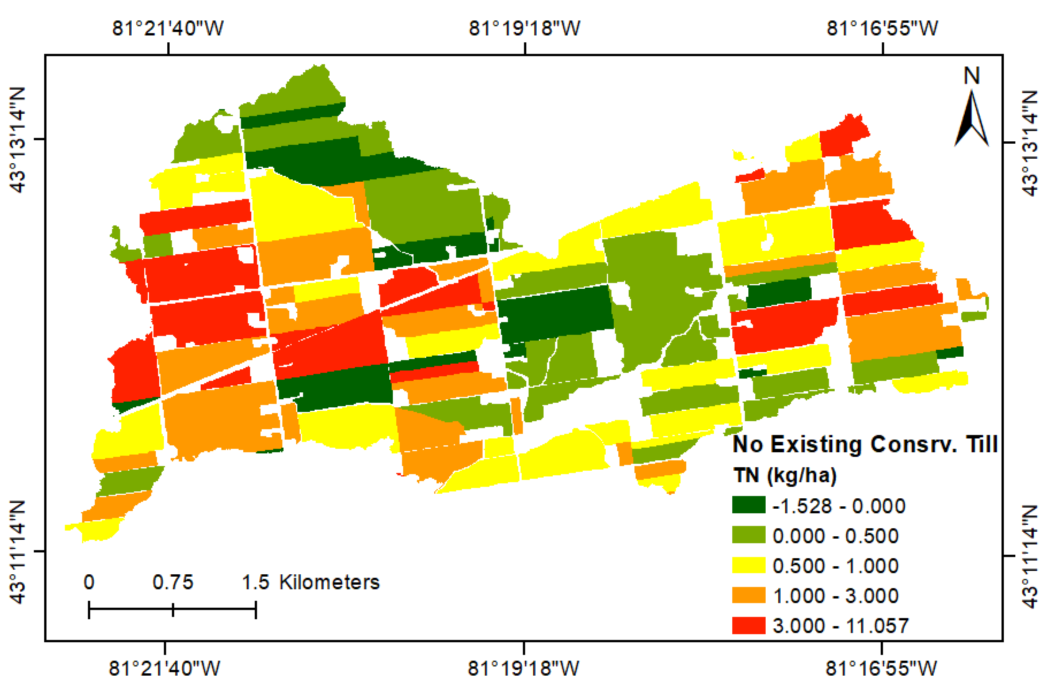

Figure 5-13. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

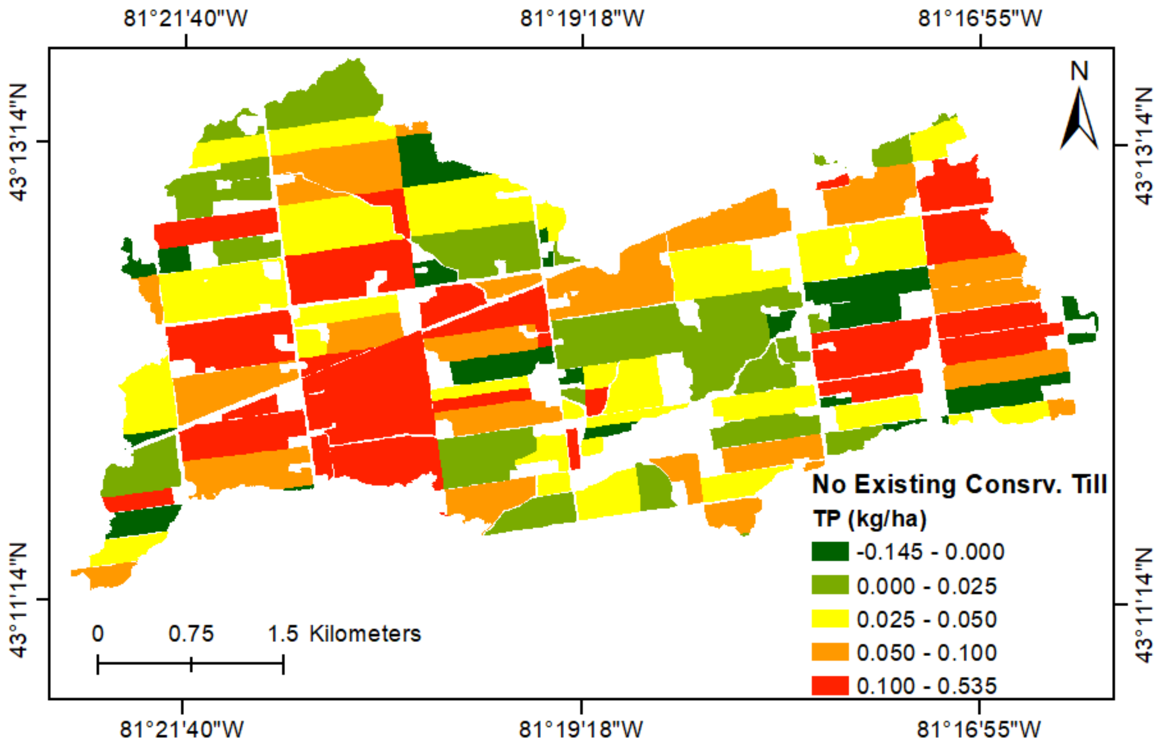

Figure 5-14. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

C. 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 5-15, and 5-16 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 5-6, 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 showed 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 response to fertilizer/manure incorporation. In these areas fertilizer/manure incorporation caused more nutrient leaching.

Table 5-6. 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.

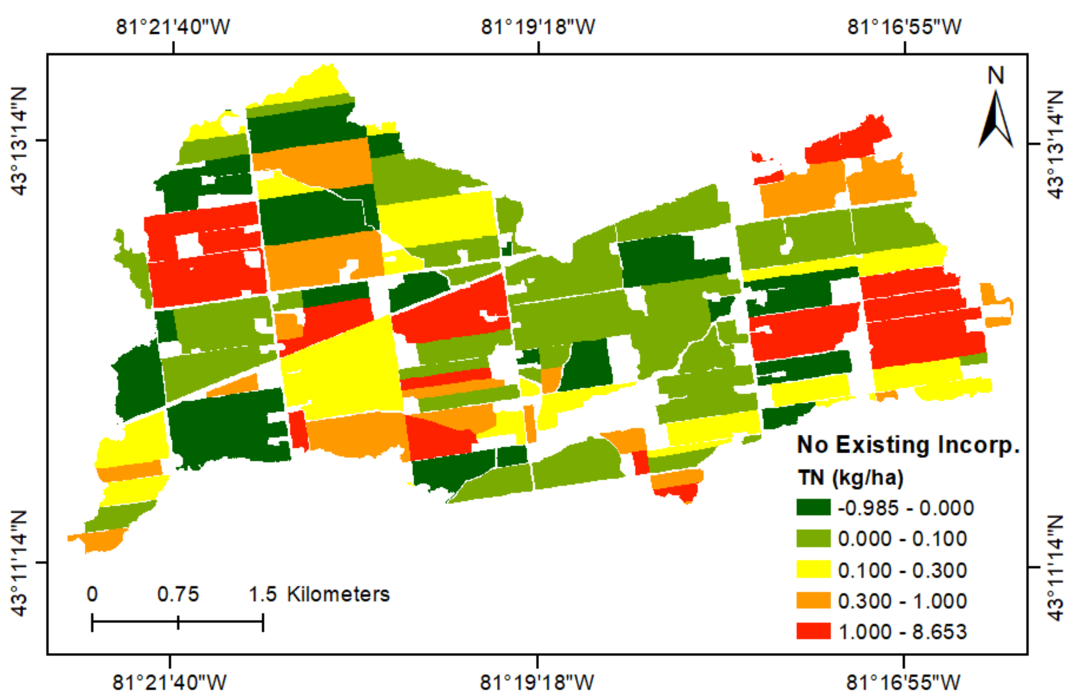

Figure 5-15. Simulated average yearly reduction of TN yield/load at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

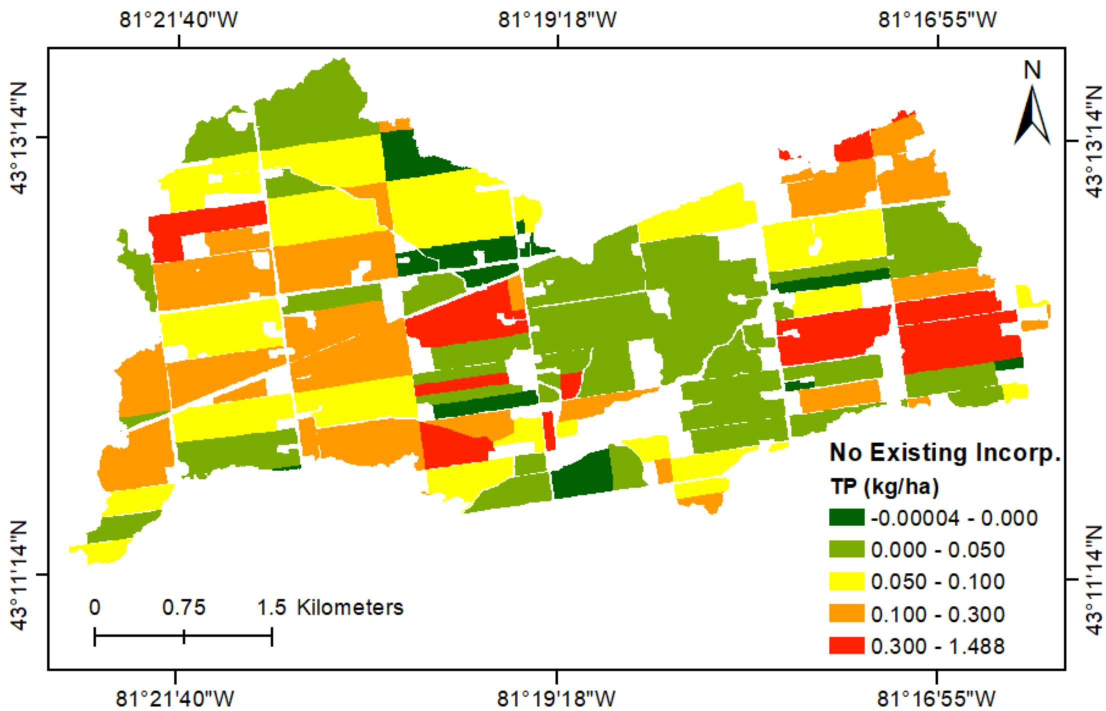

Figure 5-16. Simulated average yearly reduction of TP yield/load at a field scale under the existing actual fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

6. IMWEBs modelling results for assessing the effectiveness of additional potential BMP adoption

The calibrated IMWEBs models for the Garvey Glenn and Upper Medway Creek subwatersheds were applied to estimate the BMP effectiveness in terms of water quality benefits of three potential future land management BMPs, including: cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation. The IMWEBs model was re-setup based on the potential future BMP scenarios in which each of the three potential future BMPs was added to the historical/existing scenario (i.e. existing actual BMP scenario). The differences between the IMWEBs modelling results under the historical/existing conditions and the potential future BMP scenario (i.e. existing actual BMP scenario vs. potential future cover cropping scenario, potential future conservation tillage scenario, or potential future fertilizer/manure incorporation scenario) represented the BMP effectiveness in terms of yearly TSS, TN, and TP yield/load reductions for each of the three potential future BMPs. In the scenario comparison, the differences were those fields without existing BMPs vs. potential future BMPs added to those fields. Note that during the 21 years of IMWEBs simulation period from 2001 to 2021 for the Garvey Glenn and Upper Medway Creek subwatersheds, the BMPs of interest may have only been applied in selected years on a farm field due to existence of the BMP in some years, crop rotation patterns, farmer choice, and other factors. The BMP effectiveness represented the yearly averages of TSS, TN, and TP yield/load reductions in a farm field with a mixture of both existing and potential future BMP during the entire simulation period, and does not necessarily represent the yearly averages of TSS, TN, and TP yield/load reductions with a potential future BMP of interest applied in each year. In this section of the report, we provide more detailed results on spatial distribution of on-site or edge of field BMP effectiveness for each of the three potential future BMP scenarios in relation to the existing actual BMP scenarios.

1). Garvey Glenn subwatershed

A. 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 6-1, 6-2, and 6-3 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 6-1, about 44.8% of the cropland area had TSS yield/load reduction between 0 and 0.05 ton/ha and about 19.6% of the cropland has TSS yield/load reduction above 0.1 and as high as 0.3 ton/ha. About 49.6% of the cropland area had TN yield/load reduction from 0 to 3.0 kg/ha and about 17.1% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 37.9 kg/ha. About 43.6% of the cropland area had TP yield/load reduction from 0 to 0.1 kg/ha and about 13.1% of the cropland area had TP yield/load reduction above 0.2 kg/ha and as high as 1.8 kg/ha. On average, future cover crop planting led to TSS, TN, and TP yield/load reductions of 10.6%, 14.4% and 12.9% respectively in relation to corresponding TSS, TN, and TP yields/loads under the existing actual cover cropping scenario (or historical/existing conditions). The pattern showed the net benefits of potential future cover crop planting in the watershed. Note that 5.6%, 18.4% and 17.3% of the cropland area had TSS, TN, and TP yield/load no change or even increases in estimates of these water quality parameters in response to future cover crop planting. This pattern maybe due to the assumption that the cover crops would be ploughed down in late fall or early spring, possibly making the soil in some places more susceptible to erosion and nutrient loss if storm events occurred.

Table 6-1. Simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Garvey Glenn subwatershed

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

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

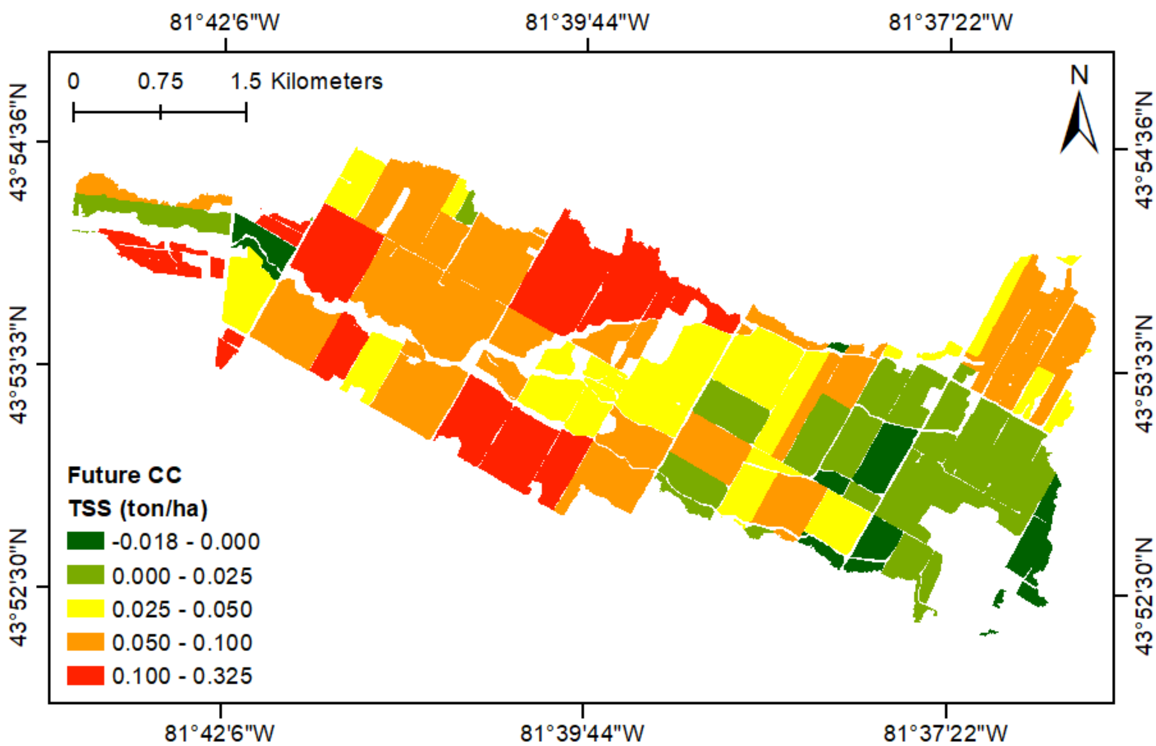

Figure 6-1. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Garvey Glenn subwatershed

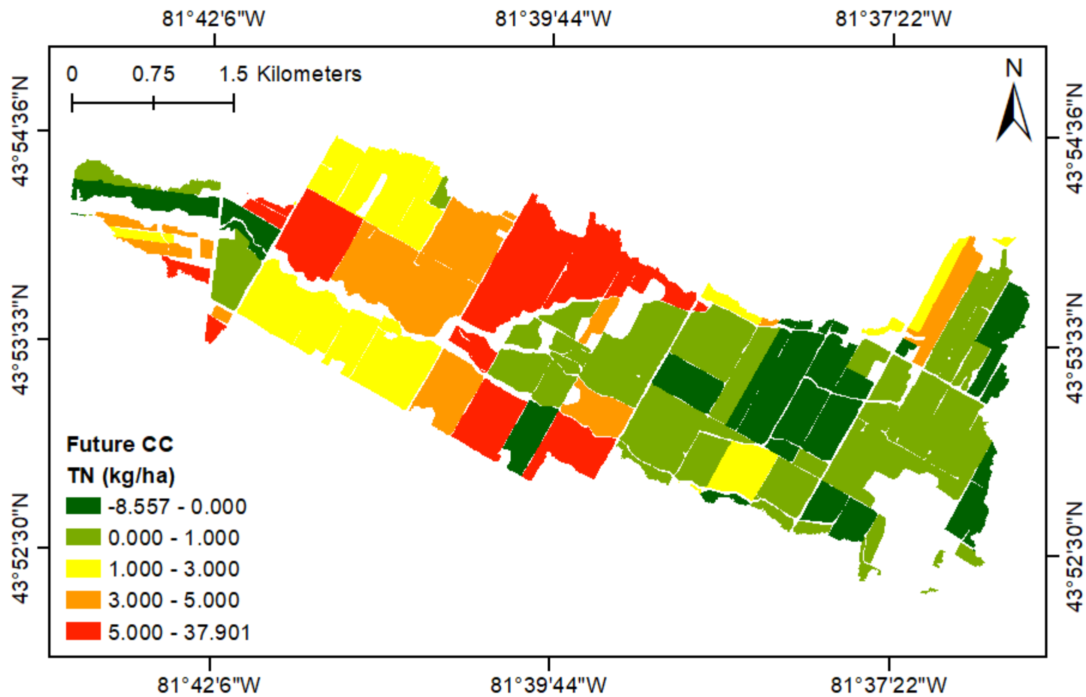

Figure 6-2. Simulated average yearly reduction of TN yield/load at a field under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Garvey Glenn subwatershed

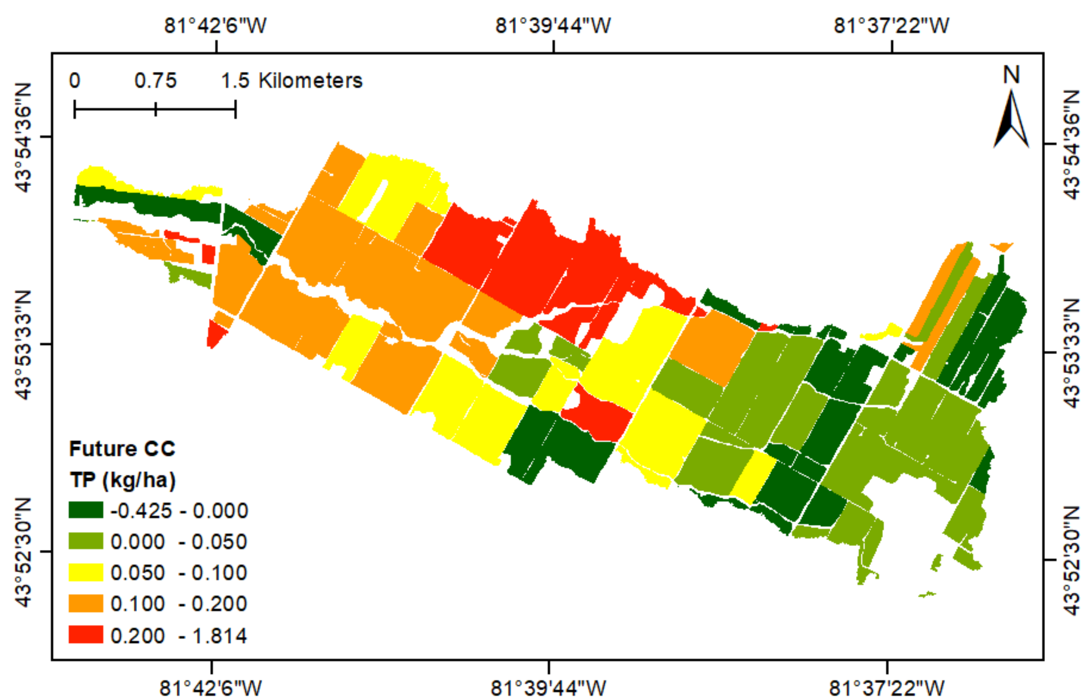

Figure 6-3. Simulated average yearly reduction of TP yield/load at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Garvey Glenn subwatershed

B. 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 6-4, 6-5, and 6-6 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 6-2, about 59.8% of the cropland area had TSS yield/load reduction between 0 and 0.03 ton/ha and 16.7% of the cropland area had TSS yield/load reduction above 0.05 and as high as 0.28 ton/ha. About 36.4% of the cropland area had TN yield/load reduction between 0 and 0.5 kg/ha and 16.8% of the cropland area had TN yield/load reduction above 3.0 kg/ha and as high as 33.2 kg/ha. About 36.9% of the cropland area had TP yield/load reduction between 0 and 0.05 kg/ha and 20.1% of the cropland area had TP yield/load reduction above 0.1 kg/ha and as high as 0.9 kg/ha. On average, potential future conservation tillage/no-till application led to TSS, TN, and TP yield/load reductions of 4.7%, 8.5% and 8.3% respectively in relation to corresponding TSS, TN, and TP yields/loads under the existing actual conservation tillage scenario (or historical/existing conditions). The pattern showed the net benefits of potential future conservation tillage/no-till application in the watershed. Note that 6.0%, 25.0%, and 27.6% of the cropland area had TSS, TN, and TP yield/load no change or even increases in estimated of these water quality parameters in response to full conservation tillage/no-till tillage adoption. These areas mostly overlapped with fields with slightly lower TSS yield/load reductions where more nutrient leaching may outweigh soil-associated nutrient retention.

Table 6-2. Simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Garvey Glenn subwatershed

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

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

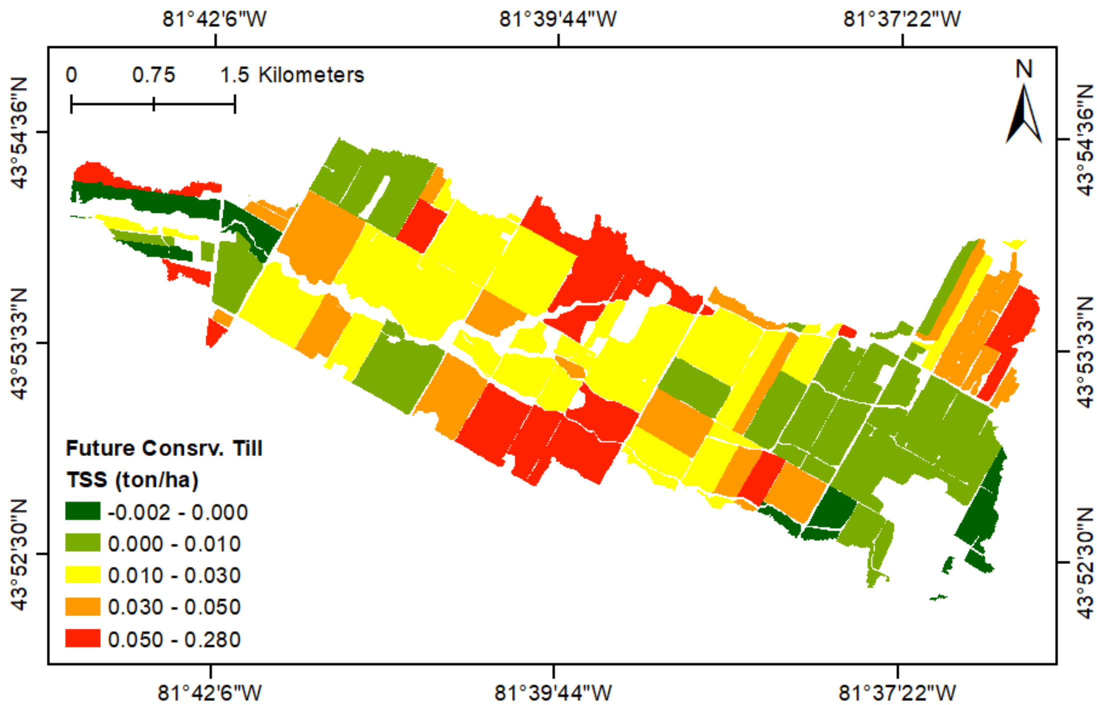

Figure 6-4. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Garvey Glenn subwatershed

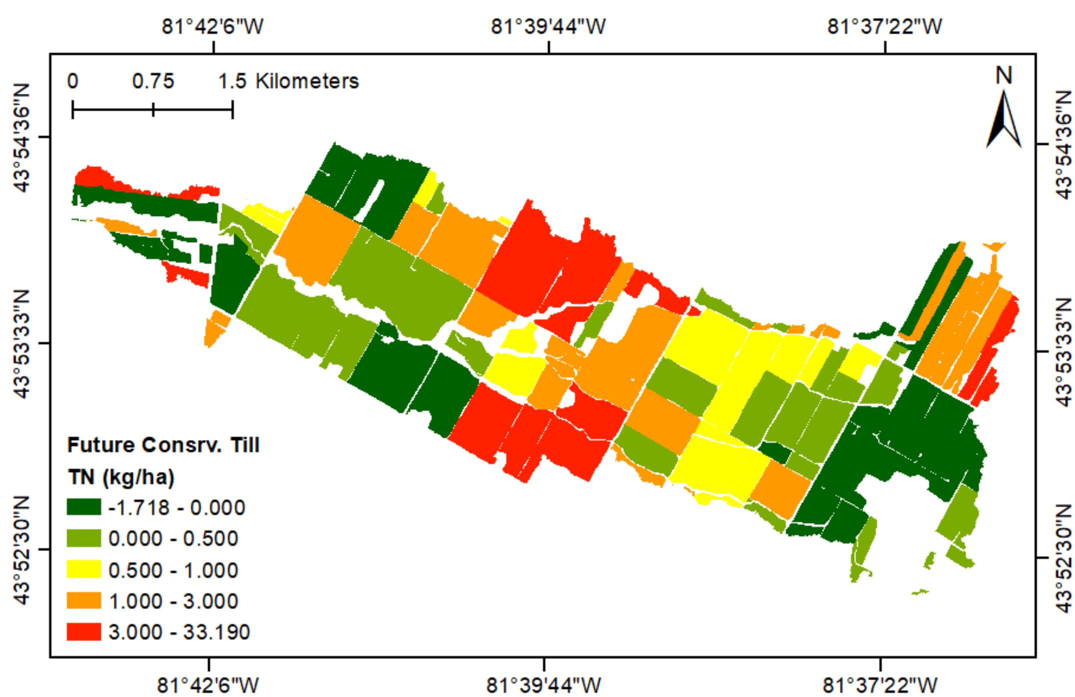

Figure 6-5. Simulated average yearly reduction of TN yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Garvey Glenn subwatershed

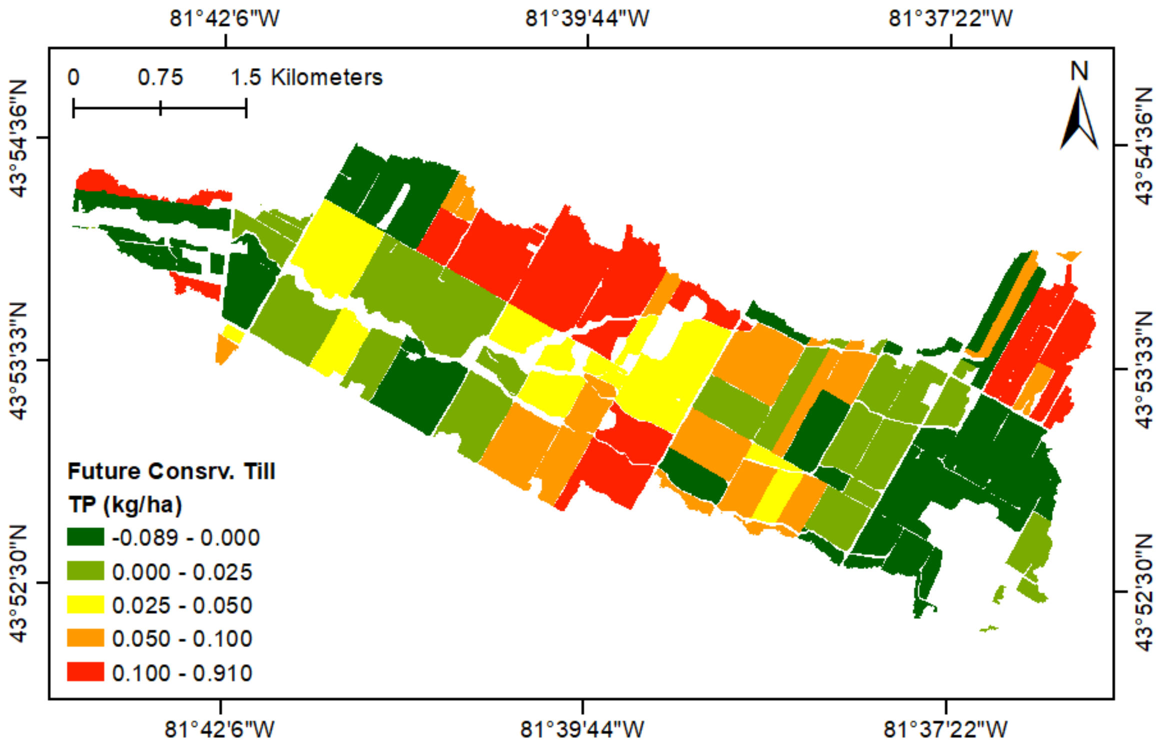

Figure 6-6. Simulated average yearly reduction of TP yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Garvey Glenn subwatershed

C. 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 6-7 and 6-8 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 6-3, about 52.8% of the cropland area had TN yield/load reduction between 0 and 2.5 kg/ha and about 21.5% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 16.8 kg/ha. Also, about 63.1% of the cropland area had TP yield/load reduction between 0 and 0.25 kg/ha and about 14.9% of the cropland had TP yield/load reduction above 1.0 kg/ha and as high as 3.3 kg/ha. On average, potential future fertilizer/manure incorporation led to TN and TP yield/load reductions of 12.6% and 37.9% respectively in relation to corresponding TSS, TN, and TP yields/loads under the existing actual fertilizer/manure incorporation scenario (or historical/existing conditions). The pattern showed the net benefits of potential future fertilizer/manure incorporation in the watershed. Note that about 4.5% and 5.5% of the cropland areas had TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to fertilizer/manure incorporation. In these areas fertilizer/manure incorporation caused more nutrient leaching.

Table 6-3. 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 Garvey Glenn subwatershed

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

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

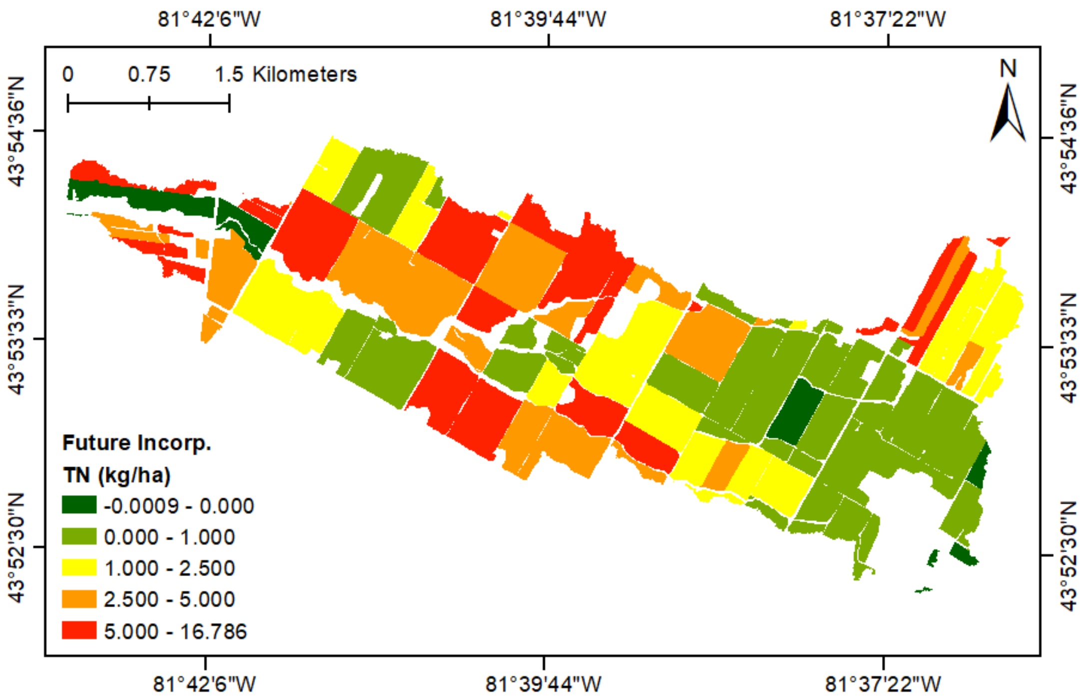

Figure 6-7. Simulated average yearly reduction of TN yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

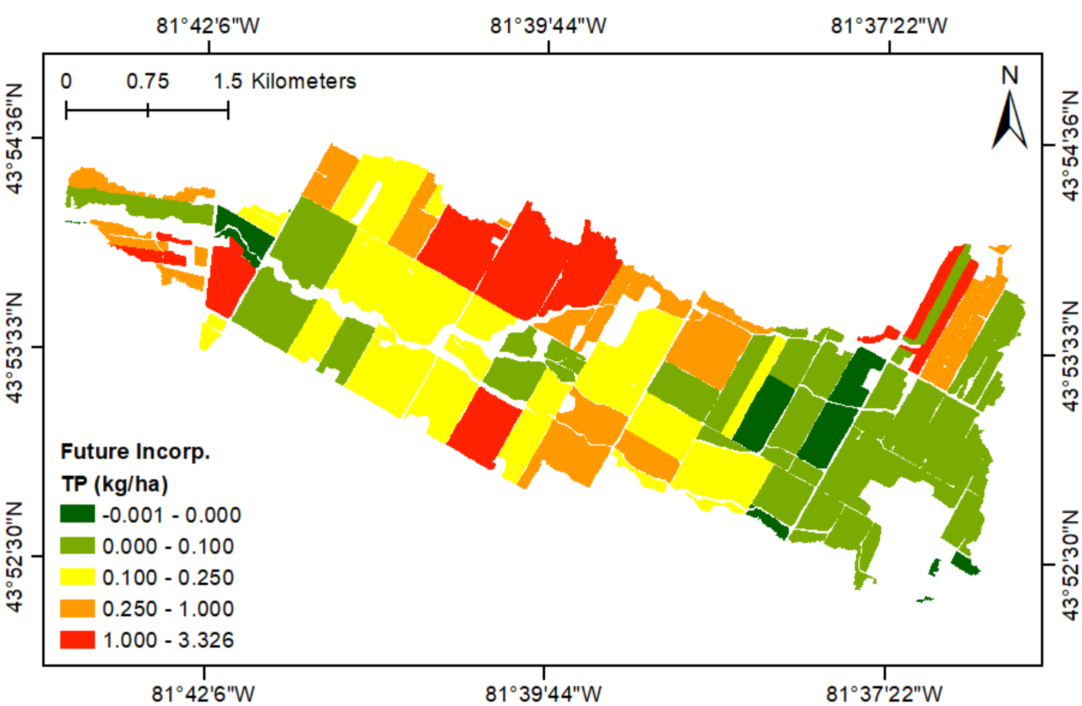

Figure 6-8. Simulated average yearly reduction of TP yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

2). Upper Medway Creek watershed

A. 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 6-9, 6-10, and 6-11 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 6-4, 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 showed the net benefits of potential future cover crop planting in the watershed. Note that 1.2%, 16.7% and 10.4% of the cropland area had no change in TSS, TN, and TP yield/load or even increases in estimates of these water quality parameters in response to full adoption of 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 6-4. 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.

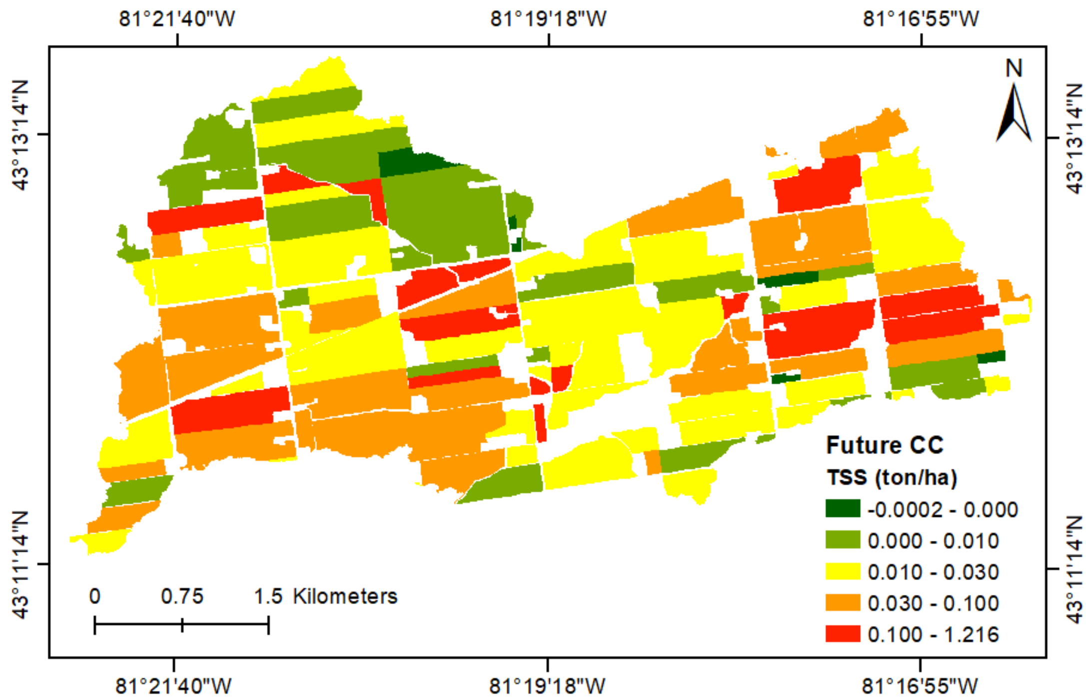

Figure 6-9. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Upper Medway Creek subwatershed

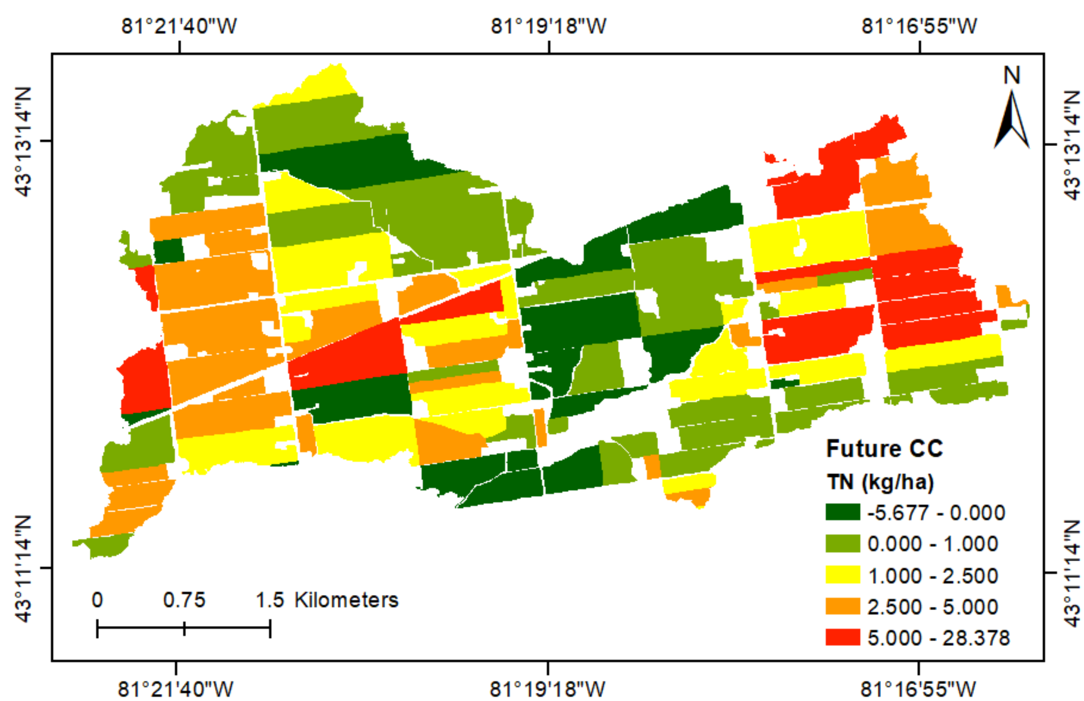

Figure 6-10. Simulated average yearly reduction of TN yield/load at a field under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Upper Medway Creek subwatershed

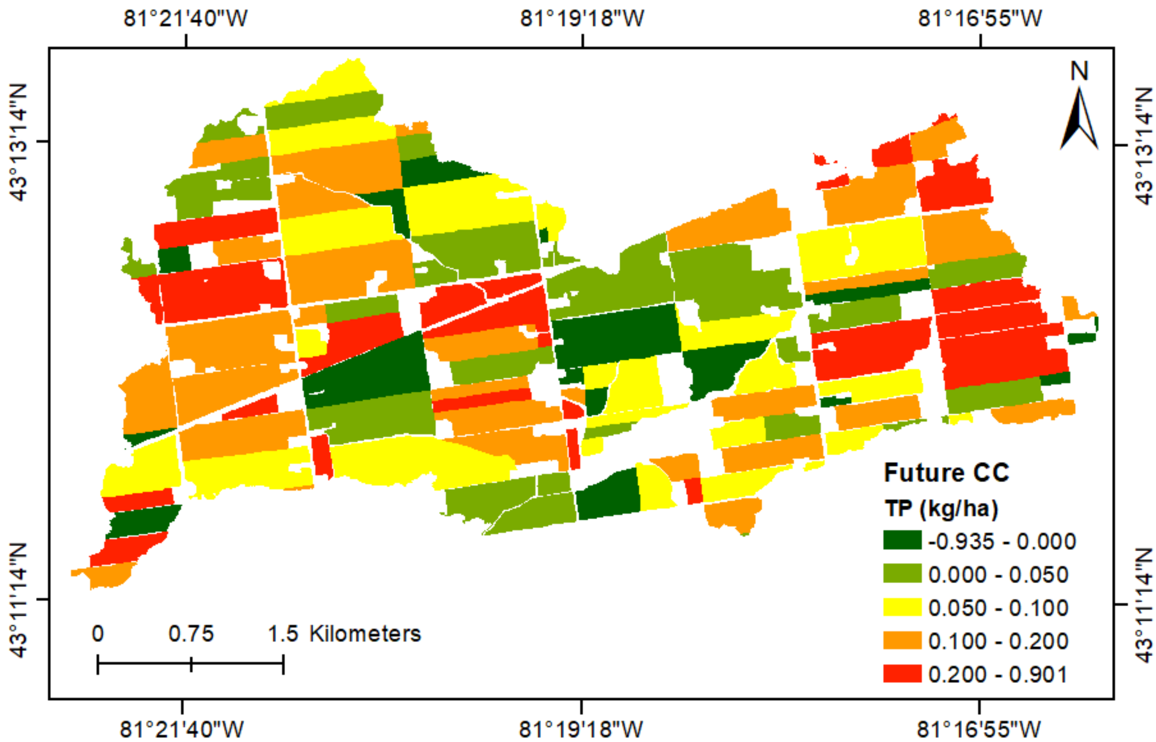

Figure 6-11. Simulated average yearly reduction of TP yield/load at a field scale under the potential future cover cropping scenario in relation to the existing actual cover cropping scenario in the Upper Medway Creek subwatershed

B. 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 6-12, 6-13, and 6-14 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 6-5, 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 showed the net benefits of potential future conservation tillage/no-till application 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 full conservation tillage/no-till practice adoption. These areas mostly overlapped with fields with slightly lower TSS yield/load reductions where more nutrient leaching may outweigh soil-associated nutrient retention.

Table 6-5. 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.

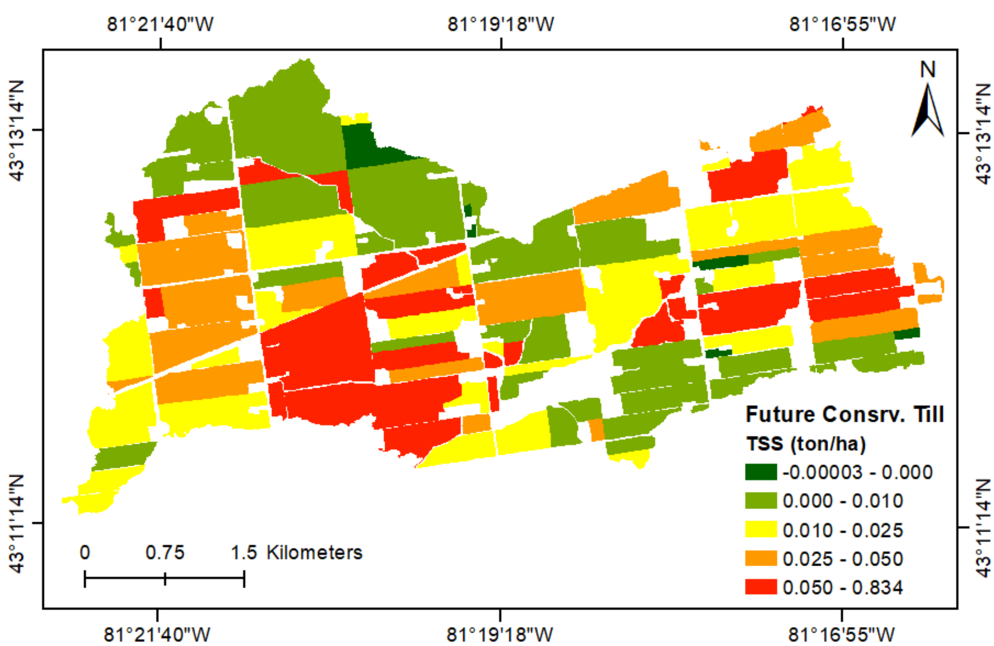

Figure 6-12. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Upper Medway Creek subwatershed

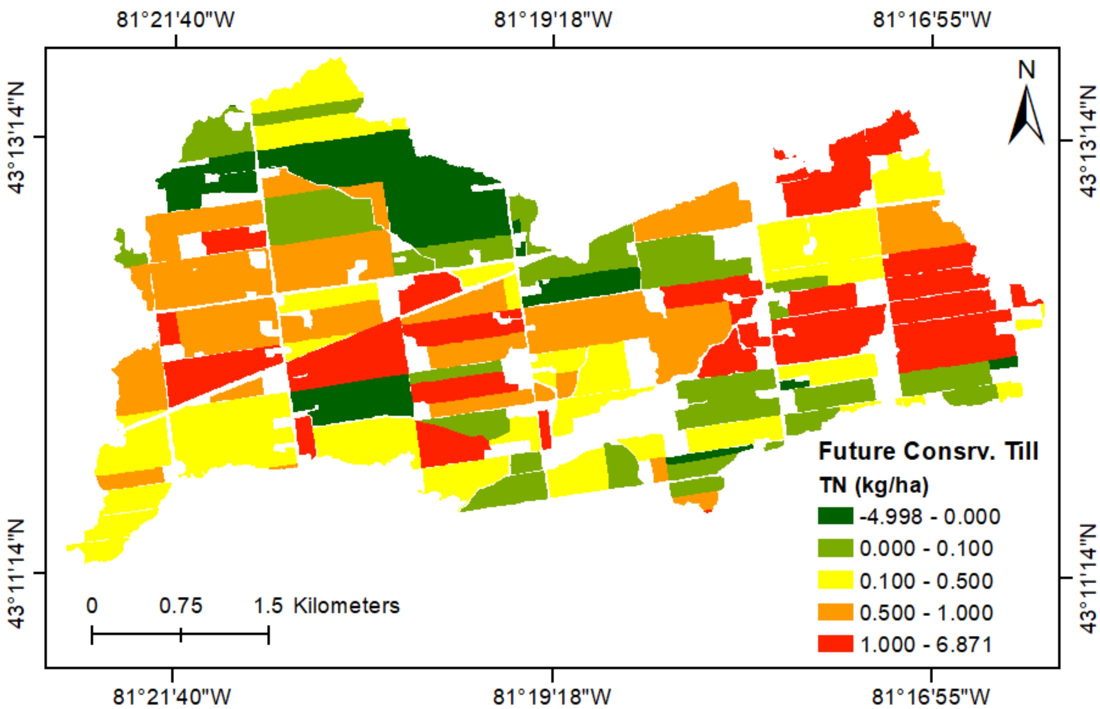

Figure 6-13. Simulated average yearly reduction of TN yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Upper Medway Creek subwatershed

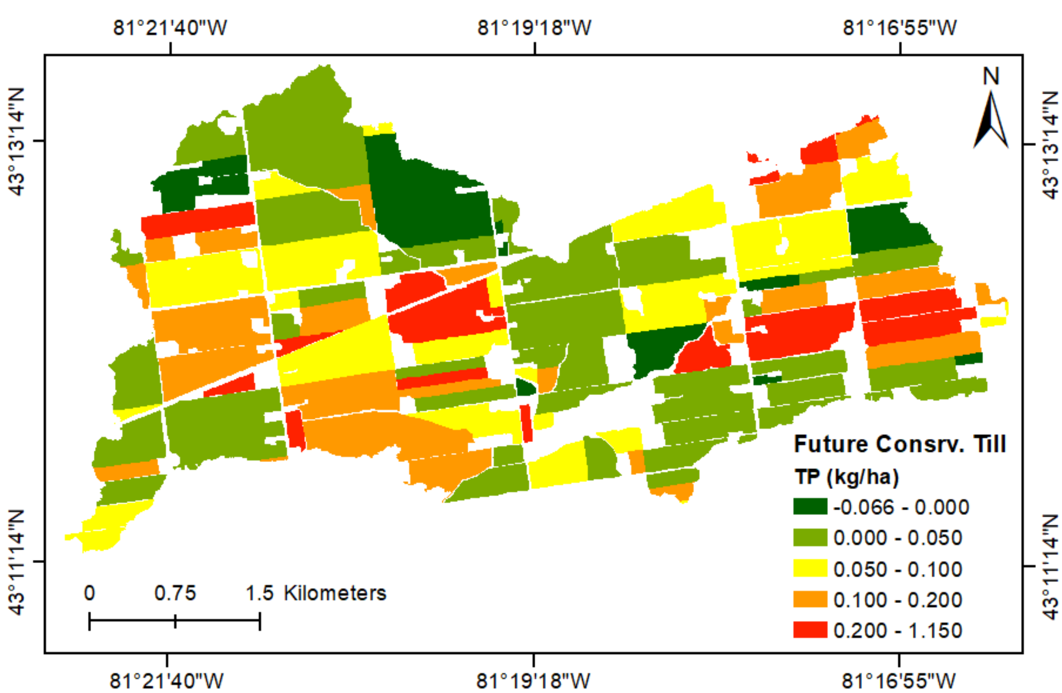

Figure 6-14. Simulated average yearly reduction of TP yield/load at a field scale under the potential future conservation tillage scenario in relation to the existing actual conservation tillage scenario in the Upper Medway Creek subwatershed

C. 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 6-15 and 6-16 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 6-6, 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, 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 showed 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 even increases in estimates of these water quality parameters in response to fertilizer/manure incorporation. In these areas fertilizer/manure incorporation caused more nutrient leaching.

Table 6-6. 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.

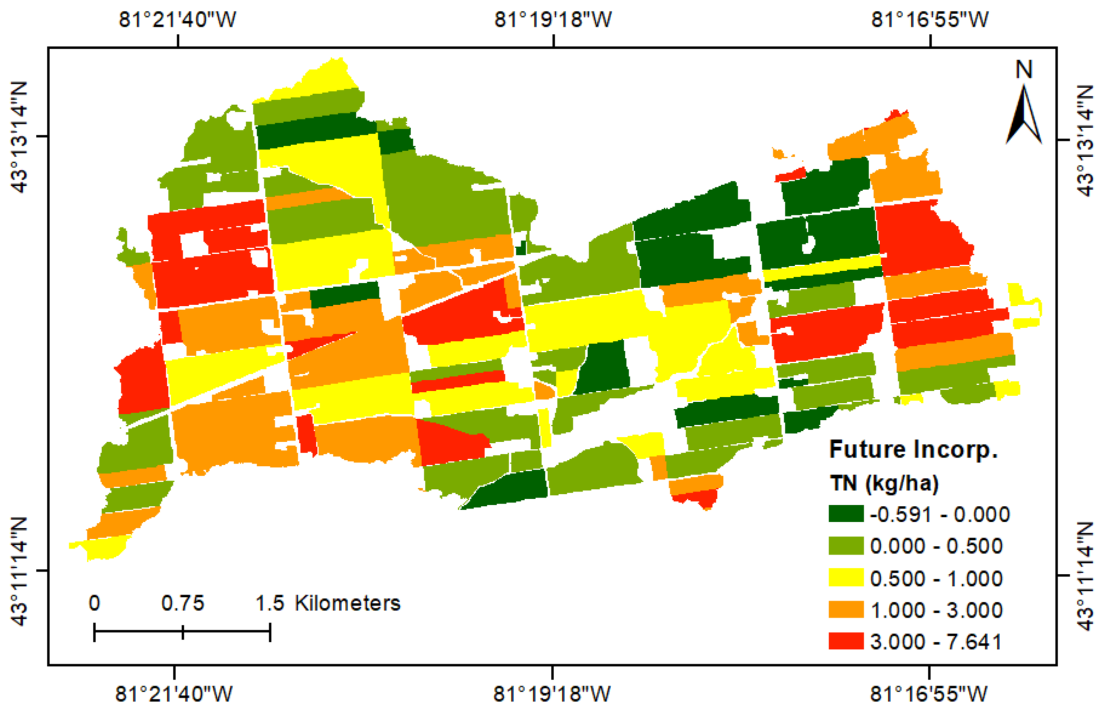

Figure 6-15. Simulated average yearly reduction of TN yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

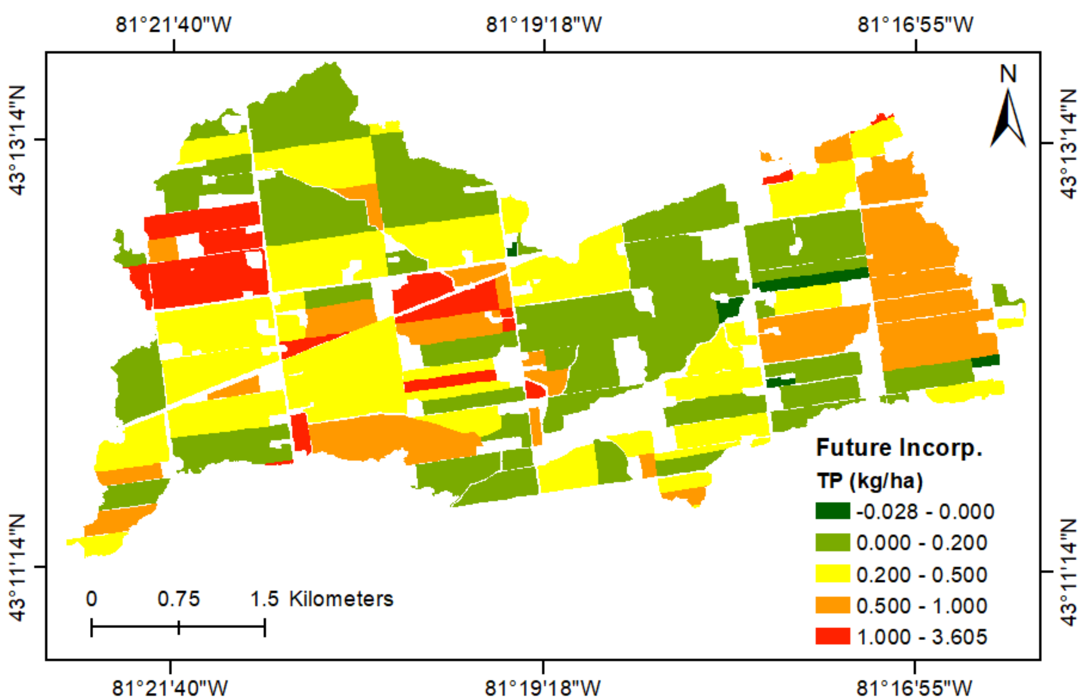

Figure 6-16. Simulated average yearly reduction of TP yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the existing actual fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

7. IMWEBs modelling results for assessing the effectiveness of full adoption of selected BMPs

This section of the report focusses on estimating the full TSS and nutrient yield reduction capacity of the three key BMPs. This is achieved by comparing differences in the conventional no existing BMP IMWEBs model outputs with the potential future IMWEBs model runs. Specifically, differences of IMWEBs results between three pairs of conventional no existing BMP scenarios and potential future BMP scenarios: 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 were tabulated and mapped. Note that the potential future BMP scenarios also included those fields and years where the historical/existing BMPs were in place. In this approach, the BMP assessment covered all fields and years by comparing the scenarios without any of the BMPs of interest in place and the scenarios where the full potential of implementing these BMPs were realized. The differences of simulated TSS, N, and P yield/load results between the paired conventional no existing BMP scenarios and potential future BMP scenarios represented the full water quality benefits of existing actual BMP adoption plus potential future BMP adoption, in relation to the conventional scenarios without these BMPs. The effectiveness of both existing actual and potential future BMPs in terms of full water quality benefits in all fields and in all years provided a consistent set of BMP effectiveness data for calculating BMP effectiveness at the farm field scale as the impacts of historical/existing BMPs were removed. The sections which follow provide a more detailed summary of the findings from comparing the output from these various IMWEBs modelling scenarios for all three key BMPs focussed on under the ONFARM project.

1). Garvey Glenn subwatershed

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

The differences between the IMWEBs modelling results under the conventional no existing cover cropping scenario and the potential future cover cropping scenario represented the effects of cover cropping on sediment, nitrogen, and phosphorus dynamics in all fields and in all years. The magnitudes of BMP effects were related to field characteristics such as crop rotation, topography, soil, and others. Figures 7-1, 7-2, and 7-3 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 7-1, about 37.6% of the cropland area had TSS yield/load reduction between 0 and 0.05 ton/ha and 22.4% of the cropland had TSS yield/load reduction above 0.1 ton/ha and as high as 0.4 ton/ha. About 43.1% of the cropland area had TN yield/load reduction from 0 to 1 kg/ha and about 19.3% of the cropland area had TN yield/load reduction above 5 kg/ha and as high as 39.1 kg/ha. About 37.7% of the cropland area had TP yield/load reduction from 0 to 0.1 kg/ha and about 19.6% of the cropland area had TP yield/load reduction above 0.3 kg/ha and as high as 1.9 kg/ha. On average, potential future cover crop planting led to TSS, TN, and TP yield/load reductions of 11.8%, 16.6% and 16.8% respectively in relation to corresponding TSS, TN, and TP yields/load under the conventional no existing cover cropping scenario. The pattern showed the full benefits of both existing actual and potential future cover crop planting in the watershed. Note that about 5.3%, 19.2% and 14.6% of the cropland areas had TSS, TN, and TP yield/load no change or even increases in estimates of these water quality parameters in response to full watershed adoption of the cover cropping practice 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 7-1. Simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

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

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

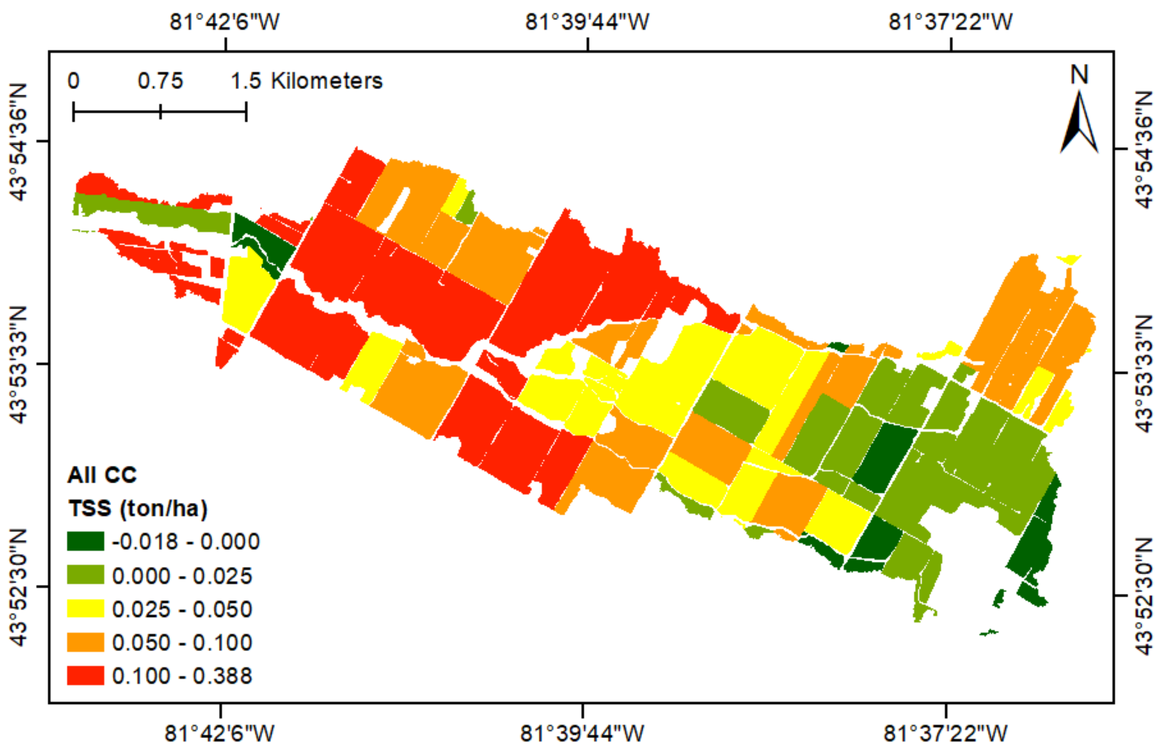

Figure 7-1. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

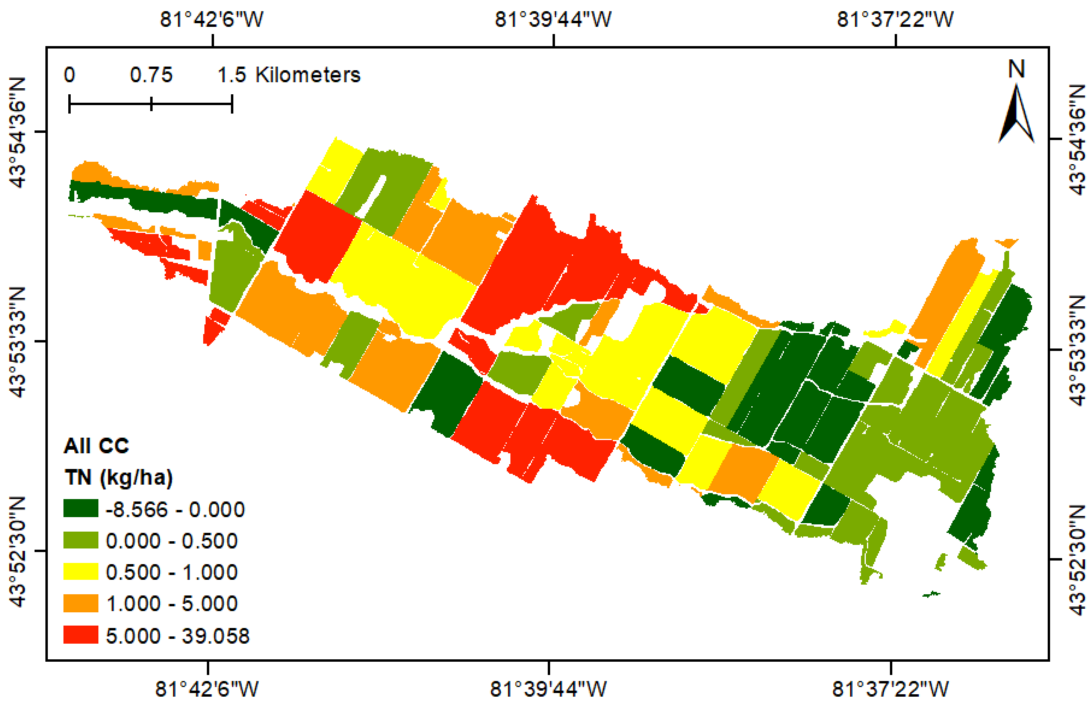

Figure 7-2. Simulated average yearly reduction of TN yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

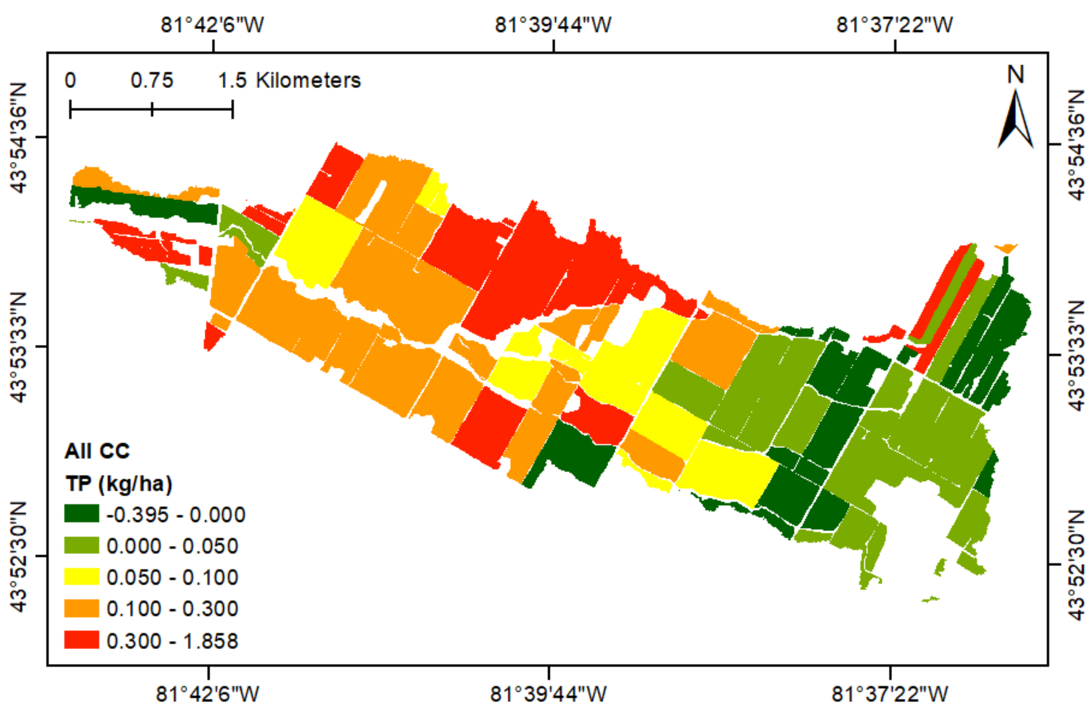

Figure 7-3. Simulated average yearly reduction of TP yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Garvey Glenn subwatershed

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

The differences between the IMWEBs modelling results under the conventional no existing conservation tillage scenario and the potential future conservation tillage scenario represented the effects of conservation tillage on sediment, nitrogen, and phosphorus dynamics in all fields and in all years. The magnitudes of BMP effects were related to field characteristics such as crop rotation, topography, soil, and others. Figures 7-4, 7-5, and 7-6 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 7-2, about 63.0% of the cropland area had TSS yield/load reduction between 0 and 0.1 ton/ha and 11.0% of the cropland area had TSS yield/load reduction above 0.2 and as high as 0.4 ton/ha. About 45.5% of the cropland area had TN yield/load reduction between 0 and 2.0 kg/ha and 16.7% of the cropland area had TN yield/load reduction above 5.0 kg/ha and as high as 36.7 kg/ha. About 53.4% of the cropland area had TP yield/load reduction between 0 and 0.1 kg/ha and 19.2% of the cropland area had TP yield/load reduction above 0.2 kg/ha and as high as 1.0 kg/ha. On average, existing actual and potential future conservation tillage/no-till application led to TSS, TN, and TP yield/load reductions of 12.3%, 13.1% and 11.8% respectively in relation to corresponding TSS, TN, and TP yields/loads under the no existing conservation tillage scenario. The pattern showed the full benefits of both existing actual and potential future conservation tillage and no-till application in the watershed. Note that 4.8%, 13.7%, and 12.7% of the cropland area had TSS, TN, and TP yield/load no change or even increases in estimates of these water quality parameters in response to full watershed adoption of conservation tillage or no-till practices. These areas mostly overlapped with fields with slightly lower TSS yield/load reductions where more nutrient leaching may outweigh soil-associated nutrient retention.

Table 7-2. Simulated average yearly reductions of TSS, TN, and TP yields/loads at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

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

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

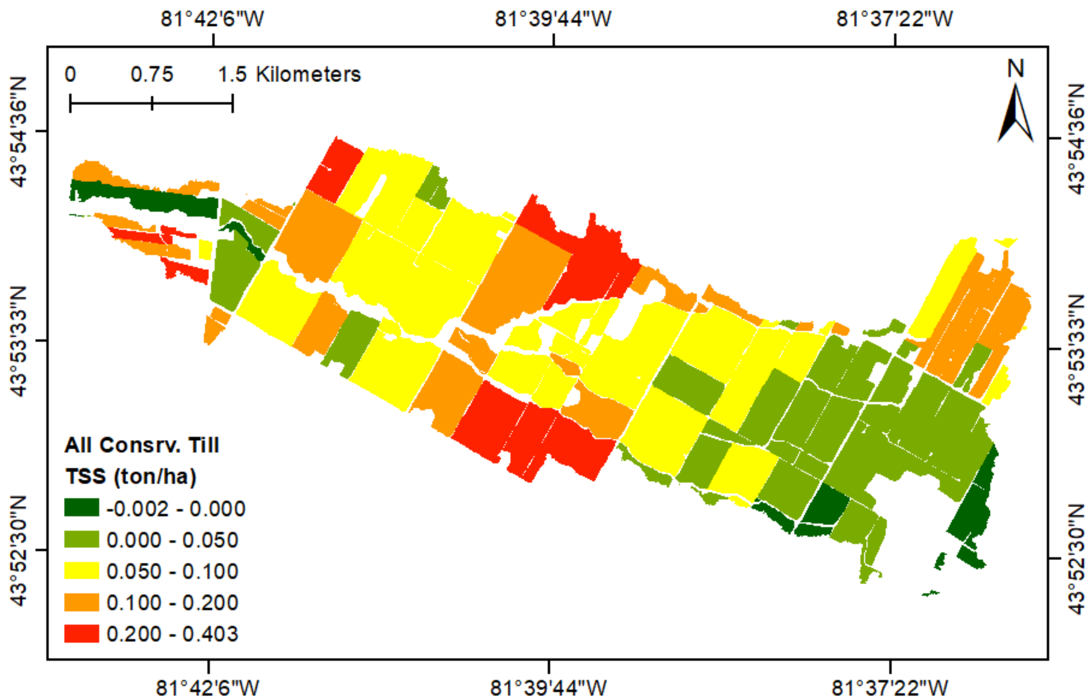

Figure 7-4. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

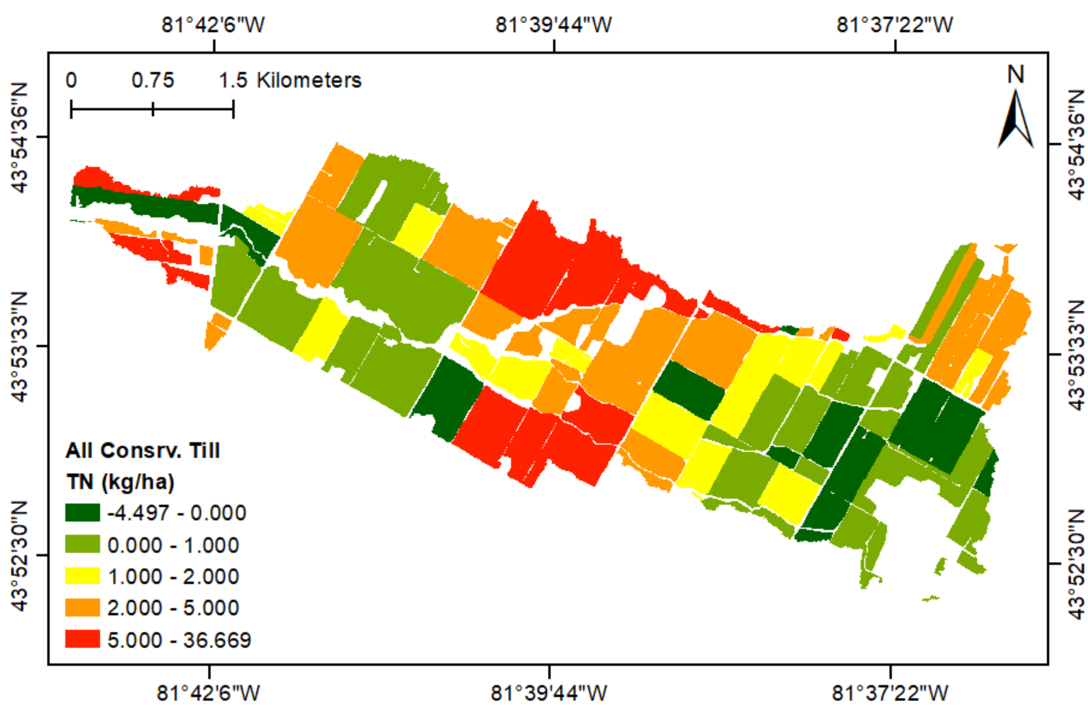

Figure 7-5. Simulated average yearly reduction of TN yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

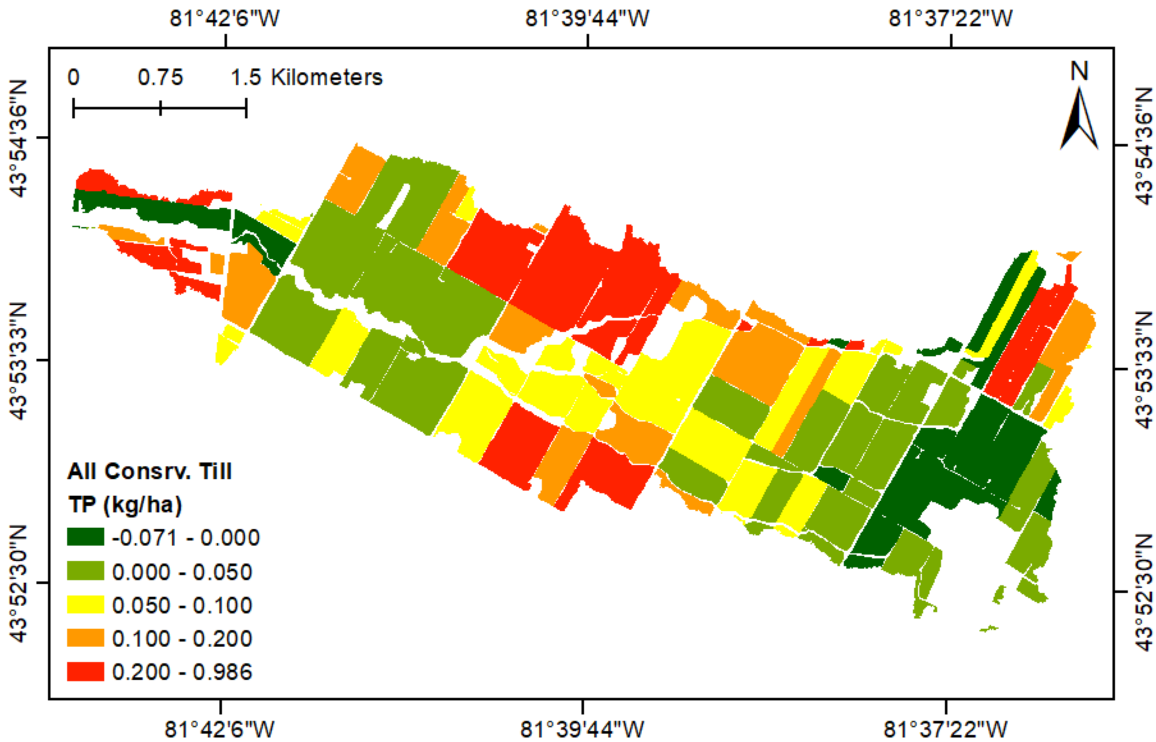

Figure 7-6. Simulated average yearly reduction of TP yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Garvey Glenn subwatershed

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

The differences between the IMWEBs modelling results under the conventional no existing fertilizer/manure incorporation scenario and the potential future fertilizer/manure incorporation scenario represented the effects of fertilizer/manure incorporation on sediment, nitrogen, and phosphorus dynamics in all fields and in all years. The magnitudes of BMP effects were related to field characteristics such as crop rotation, topography, soil, and other factors. Figures 7-7 and 7-8 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 7-3, about 54.6% of the cropland area had TN yield/load reduction between 0 and 5.0 kg/ha and about 21.2% of the cropland area had TN yield/load reduction above 10.0 kg/ha and as high as 33.0 kg/ha. Also, about 44.8% of the cropland area had TP yield/load reduction between 0 and 0.5 kg/ha and about 24.6% of the cropland had TP yield/load reduction above 1.0 kg/ha and as high as 3.9 kg/ha. On average, existing actual and potential future fertilizer/manure incorporation led to TN and TP yield/load reductions of 19.3% and 52.4% respectively in relation to corresponding TSS, TN, and TP yields/loads under the conventional no existing fertilizer/manure incorporation scenario. The pattern showed the full benefits of both existing actual and potential future fertilizer/manure incorporation in the watershed. Note that 3.8% and 1.9% of the cropland areas had TN and TP yield/load no change or even increases in estimates of these water quality parameters in response to fertilizer/manure incorporation. In these areas fertilizer/manure incorporation caused more nutrient leaching.

Table 7-3. Simulated average yearly reductions of TN and TP yields/loads at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

	Low[1]	Medium low[1]	Medium[1]	Medium high[1]	High[1]	Average[2]
TN (kg/ha)	<= 0 (3.8%)	0-1.0 (23.5%)	1.0-5.0 (31.1%)	5.0-10.0 (20.3%)	>10.0 (21.2%)	5.886 (30.519, 19.3%)
TP (kg/ha)	<= 0 (1.9%)	0-0.25 (34.6%)	0.25-0.5 (10.2%)	0.5-1.0 (28.7%)	>1.0 (24.6%)	0.752 (1.433, 52.4%)

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

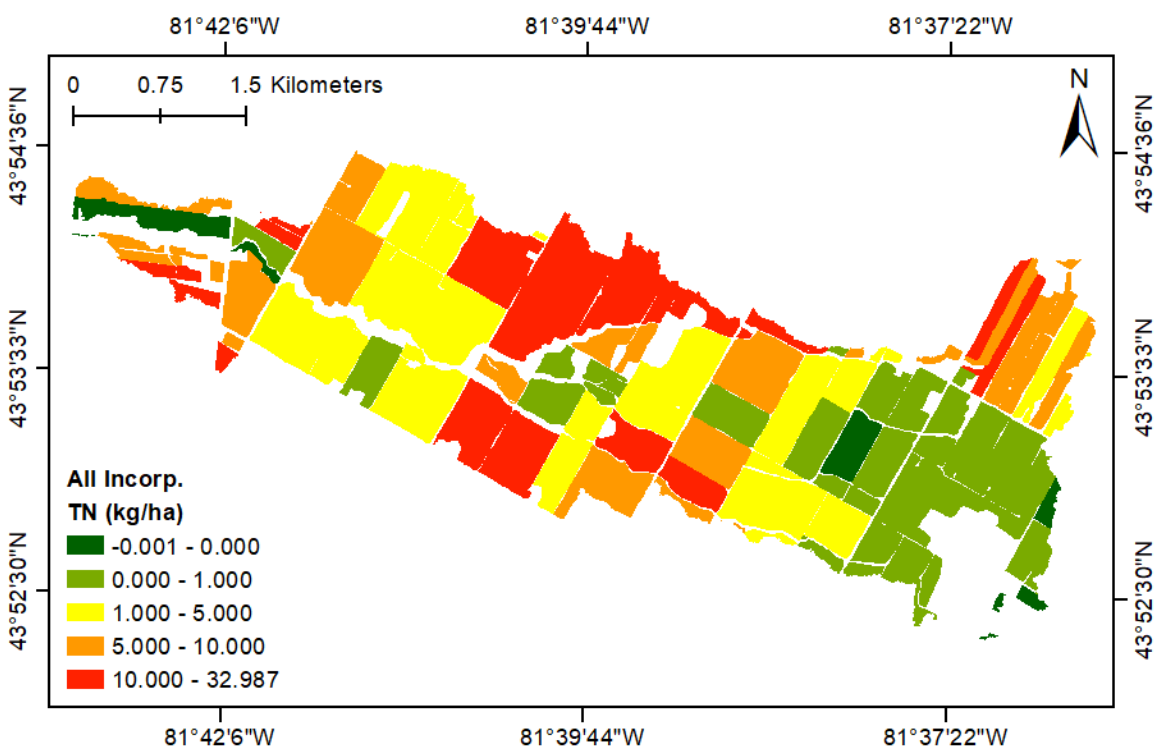

Figure 7-7. Simulated average yearly reduction of TN yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

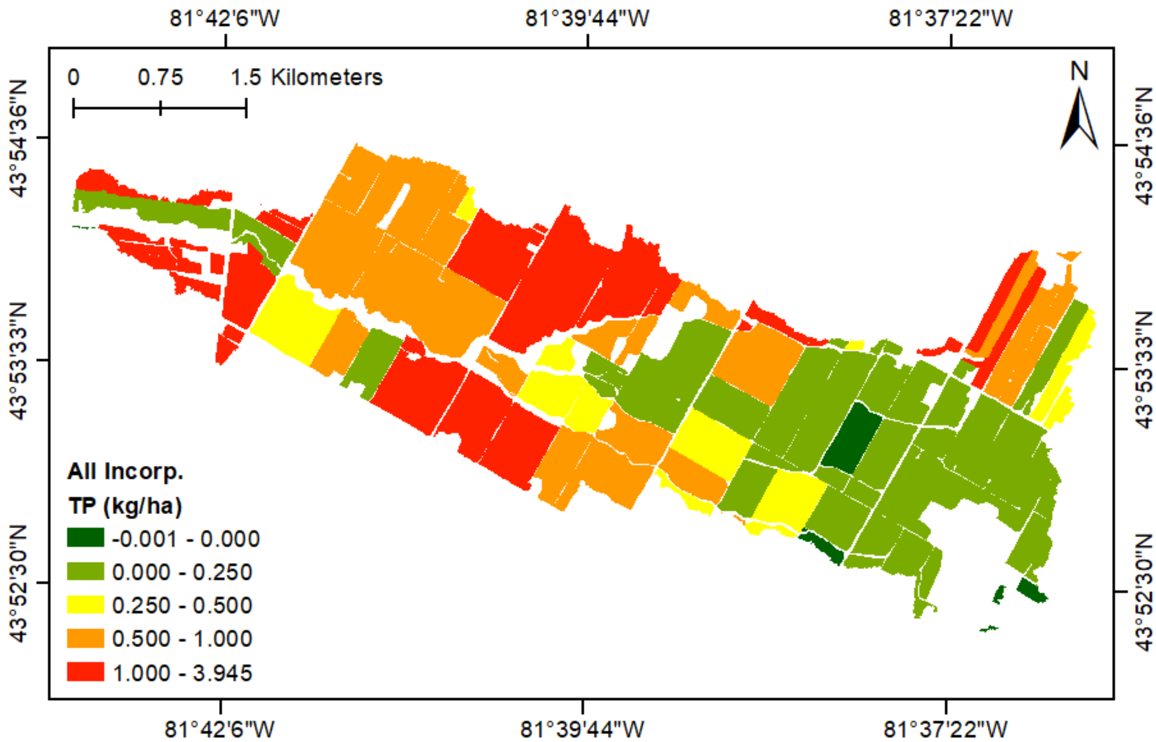

Figure 7-8. Simulated average yearly reduction of TP yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Garvey Glenn subwatershed

2). Upper Medway Creek watershed

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

The differences between the IMWEBs modelling results under the conventional no existing cover cropping scenario and the potential future cover cropping scenario represented the effects of cover cropping on sediment, nitrogen, and phosphorus dynamics in all fields and in all years. The magnitudes of BMP effects were related to field characteristics such as crop rotation, topography, soil, and others. Figures 7-9, 7-10, and 7-11 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 7-4, 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 showed the full benefits of both existing actual and potential future cover crop planting in the watershed. 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 the 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 7-4. 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.

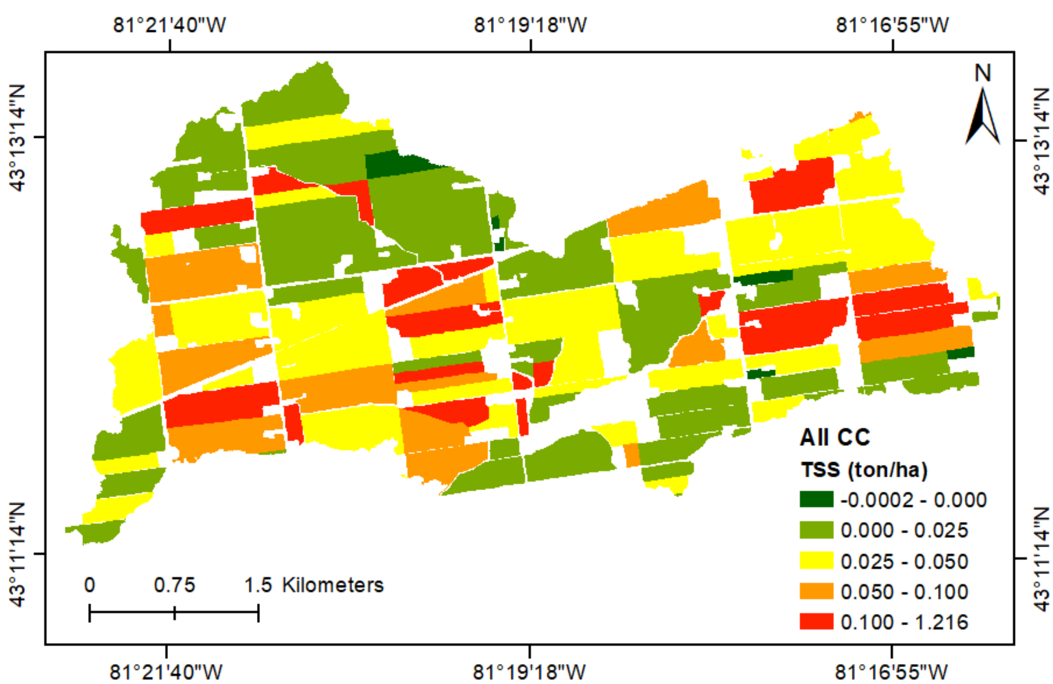

Figure 7-9. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

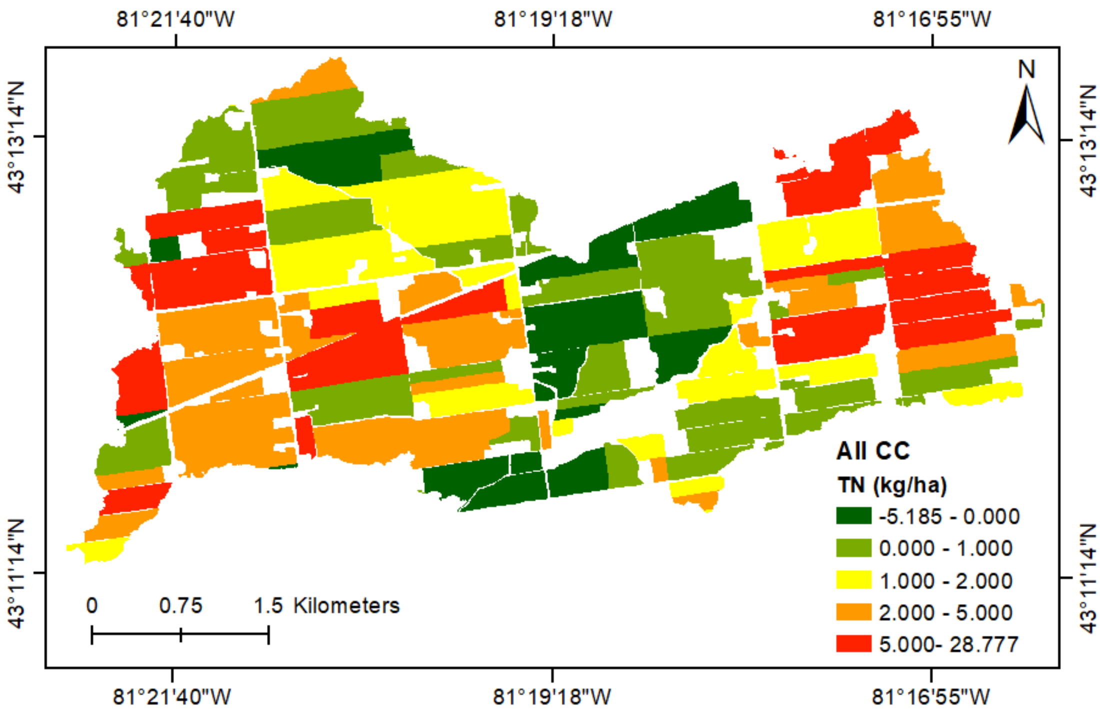

Figure 7-10. Simulated average yearly reduction of TN yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

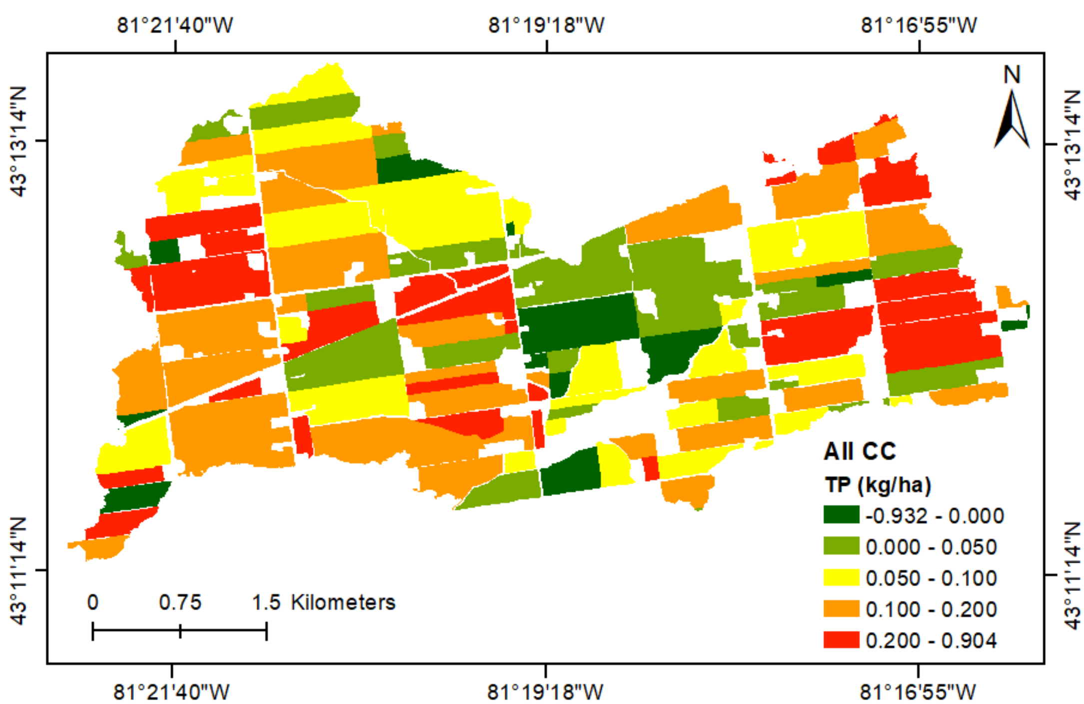

Figure 7-11. Simulated average yearly reduction of TP yield/load at a field scale under the potential future cover cropping scenario in relation to the conventional no existing cover cropping scenario in the Upper Medway Creek subwatershed

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

The differences between the IMWEBs modelling results under the conventional no existing conservation tillage scenario and the potential future conservation tillage scenario represented the effects of conservation tillage on sediment, nitrogen, and phosphorus dynamics in all fields and in all years. The magnitudes of BMP effects were related to field characteristics such as crop rotation, topography, soil, and others. Figures 7-12, 7-13, and 7-14 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 7-5, 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 full benefits of both existing actual and potential future conservation tillage and no-till application 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 conservation tillage/no-till tillage application. These areas mostly overlapped with fields with slightly lower TSS yield/load reductions where more nutrient leaching may outweigh soil-associated nutrient retention.

Table 7-5. 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.

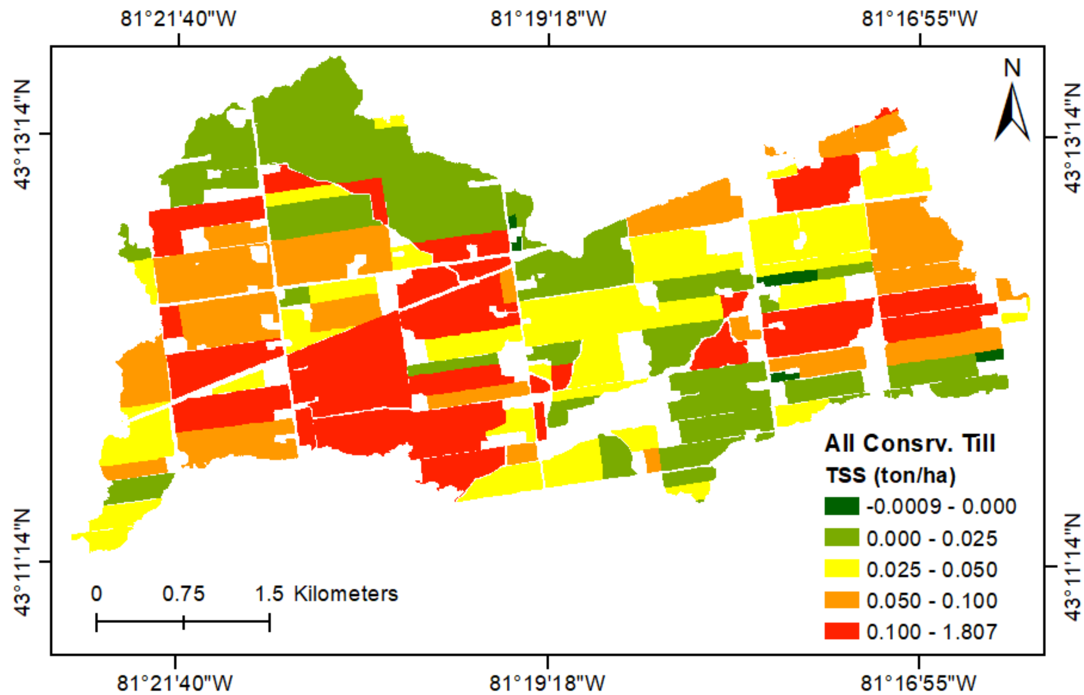

Figure 7-12. Simulated average yearly reduction of TSS yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

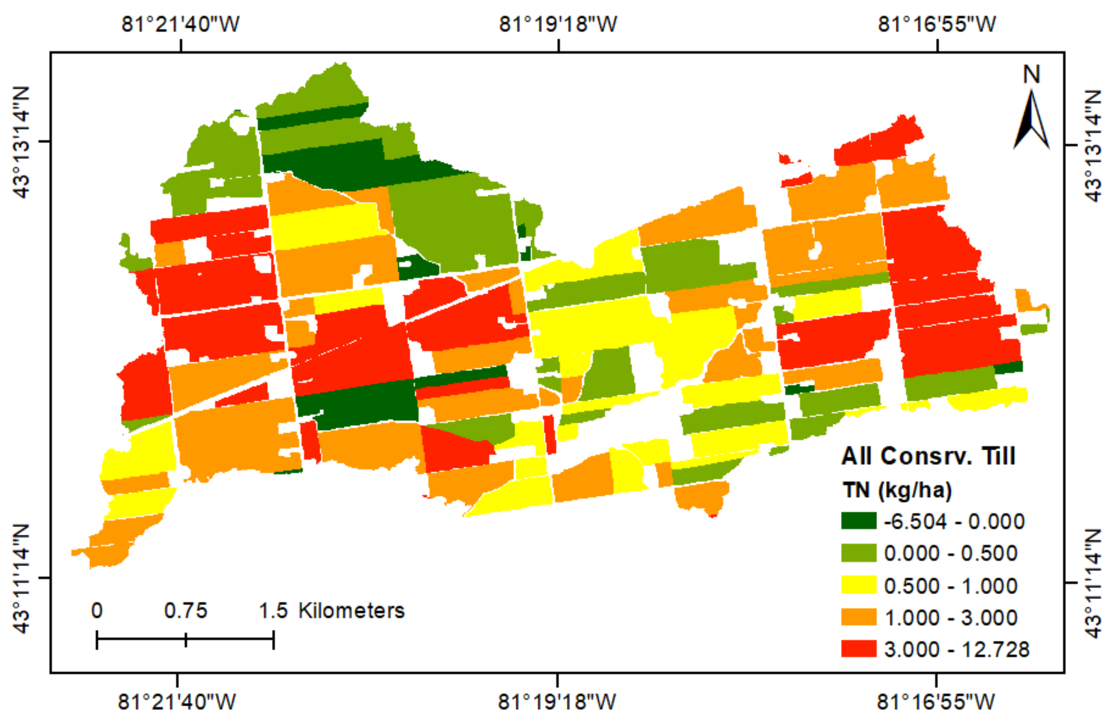

Figure 7-13. Simulated average yearly reduction of TN yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

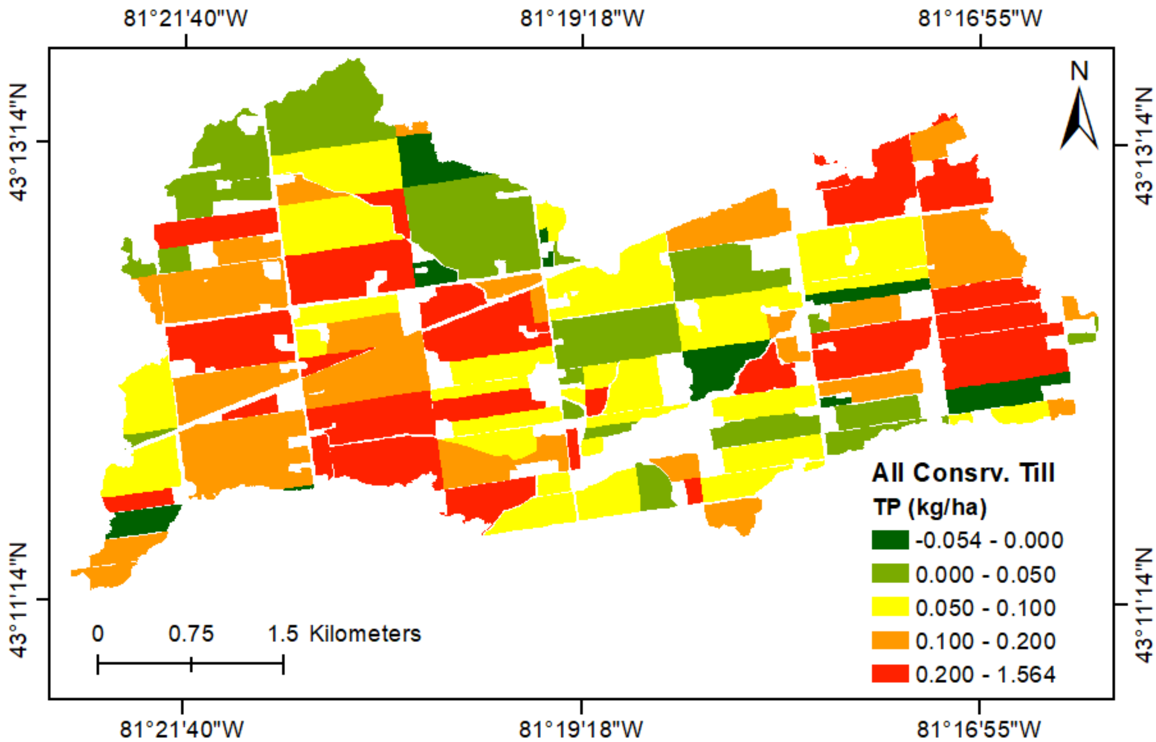

Figure 7-14. Simulated average yearly reduction of TP yield/load at a field scale under the potential future conservation tillage scenario in relation to the no existing conservation tillage scenario in the Upper Medway Creek subwatershed

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

The differences between the IMWEBs modelling results under the conventional no existing fertilizer/manure incorporation scenario and the potential future fertilizer/manure incorporation scenario represented the effects of fertilizer/manure incorporation on sediment, nitrogen, and phosphorus dynamics in all fields and in all years. The magnitudes of BMP effects were related to field characteristics such as crop rotation, topography, soil, and others. Figures 7-15 and 7-16 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 7-6, 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 showed the full benefits of both existing actual and potential future fertilizer/manure incorporation 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 fertilizer/manure incorporation. In these areas fertilizer/manure incorporation caused more nutrient leaching.

Table 7-6. 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.

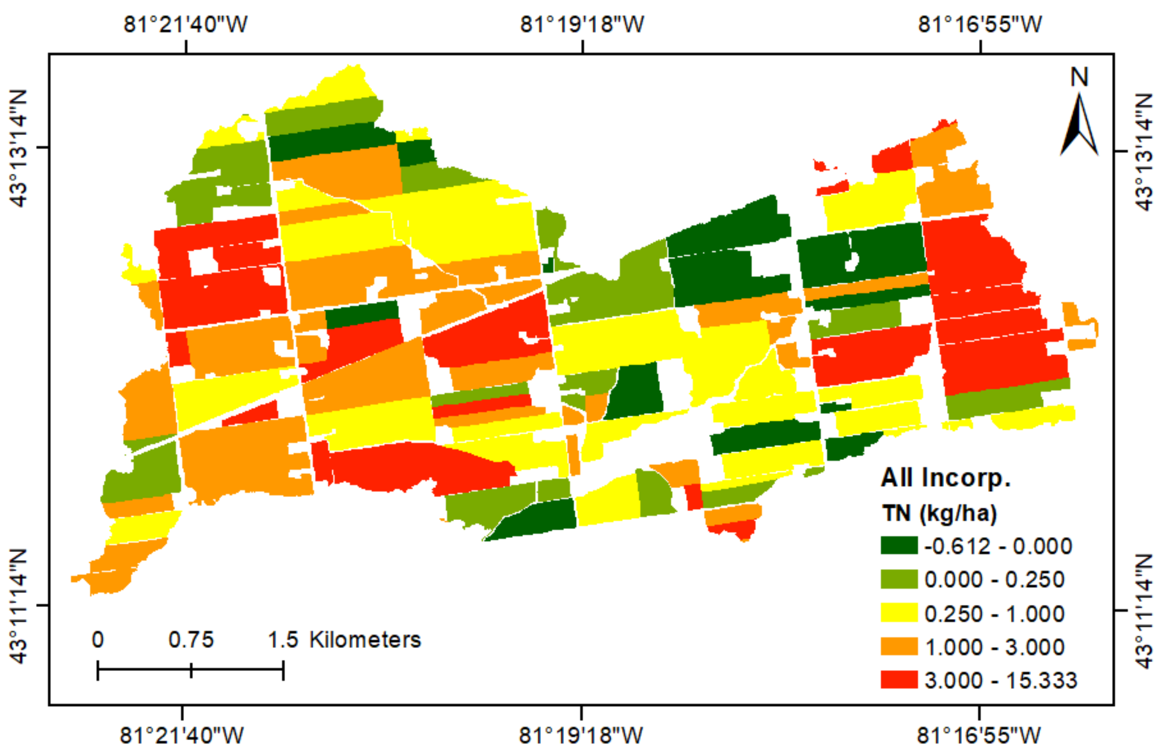

Figure 7-15. Simulated average yearly reduction of TN yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

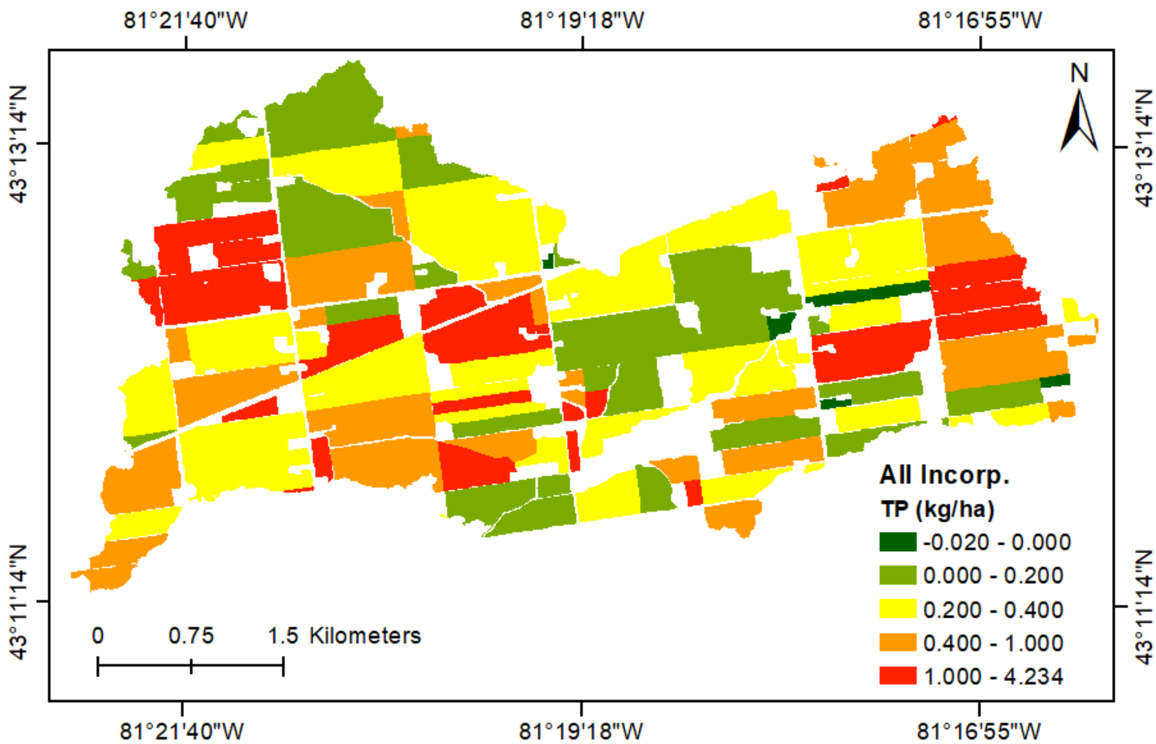

Figure 7-16. Simulated average yearly reduction of TP yield/load at a field scale under the potential future fertilizer/manure incorporation scenario in relation to the conventional no existing fertilizer/manure incorporation scenario in the Upper Medway Creek subwatershed

8. BMP cost-benefit analysis

BMP cost-benefit analysis (CBA) was another important component of the ONFARM project. However, due to challenges in data collection, CBA data were only gathered for the Garvey Glenn, Gully Creek, Upper Medway Creek, and North Kettle Creek subwatersheds. Note that in presenting the various 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.

1). The Garvey Glenn subwatershed

We worked with staff at MVCA to conduct a CBA for BMPs in the Garvey Glenn subwatershed. Four farmers provided data for cover crop only. One farmer provided data for cover crop and Tillage and Nutrient Application Equipment (No-till Drill) (Table 8-1).

Table 8-1. CBA for cover crops in the Garvey Glenn Subwatershed

Farmer (acres in the subwatershed)	Seed cost ($/ac)	Pesticide cost ($/ac)	Operating/ maintenance cost ($/ac)	Labour cost ($/ac)	Nitrogen credit or yield increase benefit ($/ac)	Net cost-benefit ($/ac)
MV-3 (95 acres)	20		20	8		48
MV-5 (80 acres)	30	10	20	4		64
MV-4 (100 acres)	35	10	15	4	-32	32
MV-2 (250 acres)	20		30	3	-15	38
MV-6 (50 acres)	20		30	5		55
Note: 1. There is inconsistency in pesticide cost. MV-5, MV-2, and MV-6 have no pesticide cost data. 2. There is inconsistency in nitrogen credit (MV02) or yield increase (MV-4). MV-3, MV-5, and MV-6 have no nitrogen credit or yield increase benefit data, which makes their values of net cost minus benefit inflated in comparing to those of the M-2 and MV-4.						

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

2). The Gully Creek subwatershed

ABCA staff worked on a CBA for the following BMPs: cover crop (Table 8-2), Water and Sediment Control Basin (WASCoB; a type of erosion control structure) (Table 8-3), adding organic amendments to soil (Table 8-4) and reduced tillage based on data from four farmers in the Gully Creek watershed (Table 8-5). With their permission, we included their CBA in this report (with adaptation to be consistent with the CBA approach completed for MVCA and UTRCA).

Table 8-2. CBA for cover crops in the Gully Creek subwatershed

Farmer	Erodibility	Area influenced by BMP (ac)	Seed costs ($/ac)	Planting costs ($/ac)	Termination costs ($/ac)	Future crop Yield bump * ($/ac)	Harvested crop Yield ($/ac)	Erosion prevention ** ($/ac)	Net Cost-benefit ($/ac)
G4- fall tilled	High	234	20	27	26	-132	0	-130	-189
G4- fall tilled	Low	234	20	27	26	-132	0	-50	-109
G8- unharvested, winter killed	High	8	40	27	0	-132	0	-130	-195
G8- unharvested, winter killed	Low	8	40	27	0	-132	0	-50	-115
G8- harvested	High	34	40	27	104***	-132	-300****	-130	-391
G8- harvested	low	34	40	27	104***	-132	-300****	-50	-311

*15% yield increase equivalent to increasing from 150 bu/ac to 172 bu/ac of $6/bu grain corn. Yield bump is due to improved soil conditions, not due to improved fertility.

**cover crops have potential to drop one full soil erosion class: assumed, using Wall et al 1997, Appendix A. Erosion prevention calculated under 2 scenarios: high and low erosion. Cover crops can reduce erosion under HIGH erodibility conditions from high erosion class (10-15 tons/ac) to moderate erosion class (5-10 tons/ac) = diff 5 tons/ac. Also, this occurs under low conditions from moderate (5-10 tons/ac) to low (3-5 tons/ac) = diff 2 tons/ac. 5 and 2 tons/acre saved at 1.4T/m3 and $40/m3 purchase price (estimate for landscaper screened topsoil).

***termination costs = harvest costs of annual winter-killed cover crops

****estimate from dairy farmer experienced at feeding cover crops balage.

Table 8-3. CBA for WASCoBs in the Gully Creek subwatershed

			COSTS		BENEFITS			NET
Farmer	**Area influenced by BMP (ac)**	**Purchase costs ($)**	**Annual purchase costs * ($/yr)**	**Land removed from production** $/yr**	**Yield increase *** ($/yr)**	**Avoidance of filling rills **** ($/yr)**	**Avoidance of topsoil loss ***** ($/yr)**	**Net Cost-benefit ($/yr)**
G4 – 1 *broad* based berm	0.22 464m of rills	34,500	1,208	0	-66	-464	-1,680	-1,002
G5 – 12 *broad* based berms	1.84 3732m of rills	137,211	4,802	0	-552	-3,732	-13,440	-12,922
G8 – 3 *broad* based berms	0.32 799m of rills	26,555	929	0	-96	-799	-2,880	-2,846
G4 alternative								
G4 – 1 *narrow* based <u>small</u> berm	0.22 464m of rills 0.13ac footprint	7,000	245	26	-66	-464	-1,680	-1,939
G4 – 1 *narrow* based <u>large</u> berm	0.22 464m of rills 0.23ac footprint	12,000	420	46	-66	-464	-1,680	-1,744

* purchase cost amortized over 30 year life span, with 5% annual interest
** net cost = revenue (150bu@$6/bu corn) - expenses ($700 OMAFRA pub60) = $900-$700 = net $200 per full acre. Appendix B
*** 50% yield increase equivalent to increasing from 100 bu/ac to 150 bu/ac of $6/bu grain corn
**** $1.00/m of rill filled in
***** rill volume= 0.3m deep by 0.3m wide by length of rill @ $40/m3 (estimate from landscaper screened topsoil)

Table 8-4. CBA for adding organic amendments to soil in the Gully Creek subwatershed

		COSTS			BENEFITS	NET
Farmer	**Area influenced by BMP (ac)**	**Purchase costs * ($/ac)**	**Spreading costs ($/ac)**	**Incorporation costs ($/ac)**	**nutrient Replacement costs** ($/ac)**	**Net Cost-benefit ($/ac)**
G4-broiler	234	0	56	18	- 310.4*	-236.4
G4-compost	234	733	56	18	-293**	514
G5-hog finisher, liquid	42	0	56	18	-196.4***	-122.4
G5-dairy liquid	42	0	56	18	-86.8****	-12.8

* organic amendments produced off-farm have easily defined purchase costs. Organic amendments, that are produced on-farm, are frequently treated as a waste product (negative value) and disposed of as inexpensively as possible. The fertility value of on-farm manure is typically proportional to the nutritional value of the feedstocks and proportional to the manure's dry matter content. Occasionally, some livestock farmers will trade manure for wheat straw, so the manure does have some value.

**see APPENDIX C Agdex#-538 Available Nutrients and Value for Manure From Various Livestock Types, August 2013

Available Nutrients and Value for Manure From Various Livestock Types (gov.on.ca)

NOTE: *values are representative of 2013 values and would change annually as fertilizer costs change. Appendix C shows how nutrient replacement costs have changed from 2012 to 2021.*

* 4,000gal/ac @ $77.6 per 1,000 gallons
** 10T/ac @ $73 per T
*** 4,000gal/ac @ $49.10 per 1,000 gallons
**** 4,000gal/ac @ $21.70 per 1,000 gallons

Table 8-5. CBA for reduced tillage in the Gully Creek subwatershed

		COSTS			BENEFITS		NET
Farmer	**Area influenced by BMP (ac)**	**Conventional tillage costs * ($/ac)**	**Reduced-tillage costs * ($/ac)**	**Other costs (planter modifications) ($/ac)**	**Yield ($/ac)**	**Soil improvements ($/ac)**	**Net Cost-benefit ($/ac)**
G3 – ***strip*** till vs conventional till	78	51	28	-	same	Less compaction Better soil structure	-23
G – ***no-till*** vs conventional till	78	51	0	2 *	120**	Less compaction Better soil structure	67 (first 3-5 years) -53 (after 3-5 years)
*equal to the difference between conventional planter/drill and a reduced till planter/drill. OMAFRA 2018 custom rates in Appendix D **20 bushel yield penalty @ $6/bushel corn first 3-5 years of transition. Zero yield penalty after years 3-5.							

3). The Upper Medway subwatershed

We worked with UTRCA staff to conduct a CBA for BMPs in the Upper Medway Creek subwatershed. Seven farmers provided data on cover crop (Table 8-6). Note that in the CBA, two growers (UT6 and UT10) used the cover crop for forage production, which generated revenue and led to net benefits of cover crop.

Table 8-6. CBA for cover crops in the Upper Medway Creek subwatershed (cost in $/acre/yr)

Farmer	Acres in PSP	Cover crop type	Seed cost	Operating/ Maintenance cost	Labour 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 labour cost was $1.67/acre/yr. The net cost-benefit 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 labour cost was $900. The net cost-benefit was therefore $6,251. Soil conservation benefits were not assigned a value, thus benefits were not quantified.

4). The North Kettle Creek subwatershed

We worked with UTRCA staff to conduct a CBA for BMPs in the North Kettle subwatershed.

UT3 farmer implemented “Equipment Modifications to Improve Manure Application” (470 acres in the subwatershed). The operating/maintenance cost was $20/acre/yr. Other cost was $62.5/acre/yr. The total cost was $82.5/acre/yr. The reduced input cost was -$0.76/acre/yr. The net cost-benefit was $81.7/acre/yr, which indicated costs were over benefits. Note that this was a conservative or high-end estimation of net cost-benefit assuming that the farmer will continue to use their old conventional planting equipment forever with no maintenance costs. If the cost for using the old or buying a new conventional planting equipment was factored into the estimation, the value of net cost-benefit would be lower.

UT3 farmer implemented “Tillage & Nutrient Application Equipment Modifications” (400 acres in PSP). The equipment cost is $22.2/acre/yr. Labour cost is $1.25/acre/yr. The total cost is $23.45/acre/yr. The reduced input cost is -$1.2/acre/yr (benefits). The net cost-benefit is $22.25/acre/yr, which means costs are over benefits.

UT3 farmer implemented “Equipment Modifications to Reduce Compaction” (470 acres in PSP). The equipment cost is $1.26/acre/yr. The total cost is $1.26/acre/yr. The yield increase benefit is assumed to be -$10/acre/yr. The net cost-benefit is -$8.7/acre/yr, which means benefits are over costs.

UT3 farmer implemented cover crop (120 acres in PSP). The seed cost is $12.25/acre/yr. The operating/maintenance cost is $23/acre/yr. The net cost-benefit is $35.25/acre/yr, which means costs are over benefits (benefits were not quantified).

9. BMP cost-effectiveness analysis

As complete IMWEBs modelling for BMP assessment was only done for the Garvey Glenn subwatershed and Upper Medway Creek subwatershed, BMP cost-effectiveness was only conducted for these two subwatersheds.

1). Garvey Glenn subwatershed

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

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

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

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

2). Upper Medway Creek subwatershed

The cost-benefit analysis of cover cropping for 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 for conservation tillage/no-till for the Upper Medway Creek subwatershed. Instead, based on the cost-benefit analysis data collected for conservation tillage/no-till for the Gully Creek subwatershed (reduced cost of -$23/acre/yr or increased cost of $67/acre/yr), we assumed the 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/no-till was 0.162 kg/ha/yr. For the conservation tillage/no-till BMP, the BMP cost effectiveness for TP yield/load reduction was therefore $335.6/kg of TP in the Upper Medway Creek subwatershed.

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 BMP 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 reductions) had a wide range of values. Accordingly, BMP cost effectiveness also has a wide range of values. Further data analysis, particularly for BMP cost, would be helpful to better estimate BMP cost effectiveness values.

10. Conclusions

In the ONFARM project we developed IMWEBs modelling for evaluating the water quality benefits of three key soil health beneficial management practices – cover cropping, conservation tillage/no-till and fertilizer/manure incorporation BMPs in the six priority subwatersheds. The IMWEBs modelling was setup based on watershed boundary, stream network, climate, topography/DEM, soil, landuse, and historical/existing land management and BMPs. It was then calibrated based on observed flow and water quality monitoring data. We made efforts to calibrate IMWEBs modelling for all six priority subwatersheds with various levels of success. In the end, only the calibrated IMWEBs modelling for the Garvey Glenn and Upper Medway Creek subwatersheds was applied for BMP assessment. For these two subwatersheds, the calibrated IMWEBs modelling was re-setup and subsequently run to simulate an absence of each of the 3 evaluated BMPs in the study watersheds. This was achieved by removing from the model's input datasets each of the three existing key BMPs in those fields and years where they were present. Other model setups went to the other extreme, and assumed full adoption of the three 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 of these model setups were used as the basis for arriving at estimates of the benefits of the three 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 study watersheds. The differences between the IMWEBs results under the no existing BMP scenario and the existing actual BMP scenario represented the water quality benefits of historical/existing BMPs. These existing actual BMP effectiveness results can be used to understand what have been achieved by previously implemented BMPs in the study watersheds. The differences between the IMWEBs results under the existing actual BMP scenario and the potential future BMP scenarios represented the water quality benefits of potential future BMPs. These potential future BMP effectiveness results can be used to understand what can be further achieved by implementing these BMPs in the entire study watershed. Further, we estimated the differences between the IMWEBs results under the conventional no existing BMP scenario without BMPs and potential future BMP scenarios with both historical/existing and potential future BMPs, which represented the full water quality benefits of the three key BMPs in all fields and in all years. The BMP effectiveness results at the farm field scale can be used to identify priority locations for potential future BMP implementation. In addition, we worked with Conservation Authority colleagues to conduct a BMP cost-benefit analysis (for Garvy Glenn, Gully Creek, Upper Medway Creek, and North Kettle Creek subwatersheds) and a cost effectiveness analysis (for Garvey Glenn and Upper Medway Creek subwatersheds). The cost effectiveness analysis put a dollar cost on removing 1 kg of TP using the three BMPs studied under ONFARM.

Table 10-1 provides a summary of the TP yield/load reductions for cover cropping, conservation tillage, and fertilizer/manure incorporation BMPs in the Garvey Glenn and Upper Medway Creek subwatersheds. The results showed that the magnitudes of TP yield/load reductions for the existing actual BMP adoption were relatively smaller, which reflected the relatively lower numbers of field/years with historical/existing BMP adoption. The only exception was the relatively larger TP yield/load reduction resulting from fertilizer/manure incorporation BMP adoption in the Garvey Glenn subwatershed, which has had greater BMP implementation. 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 these subwatersheds. 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 (1.242 kg/ha/yr for the Garvey Glenn subwatershed and 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 1.080 kg/ha/yr for the Garvey Glenn subwatershed and 0.823 kg/ha/yr for the Upper Medway Creek subwatershed if TP yield/load reductions of individual BMPs were added together, which represented 87.0% and 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 two subwatersheds.

Table 10-1. TP yield/load reductions for cover cropping, conservation tillage, and fertilizer/manure incorporation BMPs in the Garvey Glenn and Upper Medway Creek subwatersheds

BMP	**Garvey Glenn**			**Upper Medway**		
Cover cropping	**Existing actual BMP adoption[1]**	**Potential future BMP adoption[2]**	**Full BMP adoption[3]**	**Existing actual BMP adoption[1]**	**Potential future BMP adoption[2]**	**Full BMP adoption[3]**
Avg TP load reduction (kg/ha)	0.051	0.142	0.193	0.018	0.131	0.149
Avg TP load without BMP scenario (kg/ha)[4]	1.099	1.099	1.150	1.190	1.190	1.208
Percent reduction in load from BMP scenario	4.7%	12.9%	16.8%	1.5%	11.0%	12.3%

Conservation Tillage	Existing actual BMP adoption[1]	Potential future BMP adoption[2]	Full BMP adoption[3]	Existing actual BMP adoption[1]	Potential future BMP adoption[2]	Full BMP adoption[3]
Avg TP load reduction (kg/ha)	0.044	0.091	0.135	0.072	0.090	0.162
Avg TP load without BMP scenario (kg/ha)[4]	1.099	1.099	1.143	1.190	1.190	1.263
Percent reduction in load from BMP scenario	4%	8.3%	11.8%	6.1%	7.5%	12.9%
Fertilizer/manure incorporation	**Existing actual BMP adoption[1]**	**Potential future BMP adoption[2]**	**Full BMP adoption[3]**	**Existing actual BMP adoption[1]**	**Potential future BMP adoption[2]**	**Full BMP adoption[3]**
Avg TP load reduction (kg/ha)	0.335	0.417	0.752	0.114	0.398	0.512
Avg TP load without BMP scenario (kg/ha)[4]	1.099	1.099	1.433	1.190	1.190	1.304
Percent reduction in load from BMP scenario	30.4%	37.9%	52.4%	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 10-2 provided a summary of TP yield/load reduction, cost, and cost effectiveness for cover cropping, conservation tillage, and fertilizer/manure incorporation BMPs in the Garvey Glenn and Upper Medway Creek subwatersheds. TP yield/load reductions from fertilizer/manure incorporation in both subwatersheds were the highest among the three agronomic BMPs. BMP effectiveness for cover cropping and conservation tillage had a mixed pattern. TP yield/load reduction for cover cropping was higher than that for conservation tillage in the Garvey Glenn subwatershed but the pattern was opposite in the Upper Medway Creek subwatershed. While both subwatersheds had a higher BMP cost for cover cropping and a relatively lower BMP cost for fertilizer/manure incorporation, the BMP costs between the two subwatersheds differed substantially. BMP cost for cover cropping in the Garvey Glenn subwateshed was higher than that in the Upper Medway Creek watershed, whereas the BMP cost for fertilizer/manure incorporation cost in the Garvey Glenn subwateshed was lower than that in the Upper Medway Creek watershed. Differences in BMP costs were possibly related to their available equipment (in particular the higher costs associated with purchasing new equipment) and the availability of manure or other organic amendment sourced on-farm. The BMP cost effectiveness (as a dollar cost per 1 kg of TP removed) also had a mixed pattern. BMP cost effectiveness for cover cropping had comparable value in both subwatersheds as the least cost-effective BMP. Conservation tillage in the Upper Medway Creek subwatershed was more cost effective than that in the Garvey Glenn subwatershed; in both subwatersheds, conservation tillage was found to be the second most cost-effective BMP. Fertilizer/manure incorporation in the Garvey Glenn subwatershed was more cost effectiveness than that in the Upper Medway Creek subwatershed, but was ultimately the most cost-effective BMP by far. The mixed patterns of TP yield/load reductions, costs, and cost effectiveness across BMPs and across subwatersheds were related to the differences in BMP implementation and watershed characteristics.

Table 10-2. TP yield/load reduction, cost, and cost effectiveness for cover cropping, conservation tillage, and fertilizer/manure incorporation BMPs in the Garvey Glenn and Upper Medway Creek subwatersheds

	Garvey Glenn			Upper Medway		
	TP yield/load reduction (kg/ha)	BMP cost ($/ha)	Cost effective-ness ($/kg of P reduction)	TP yield/load reduction (kg/ha)	BMP cost ($/ha)	Cost effective-ness ($/kg of P reduction)
Cover cropping	0.193	117.1	606.9	0.149	90.9	610.3
Conservation Tillage	0.135	54.4	402.7	0.162	54.4	335.6
Fertilizer/ manure incorporation	0.752	34.6	46.0	0.512	55.0	107.4

11. 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 CAs, 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 in 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 reasons for possible 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 watershed areas 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.