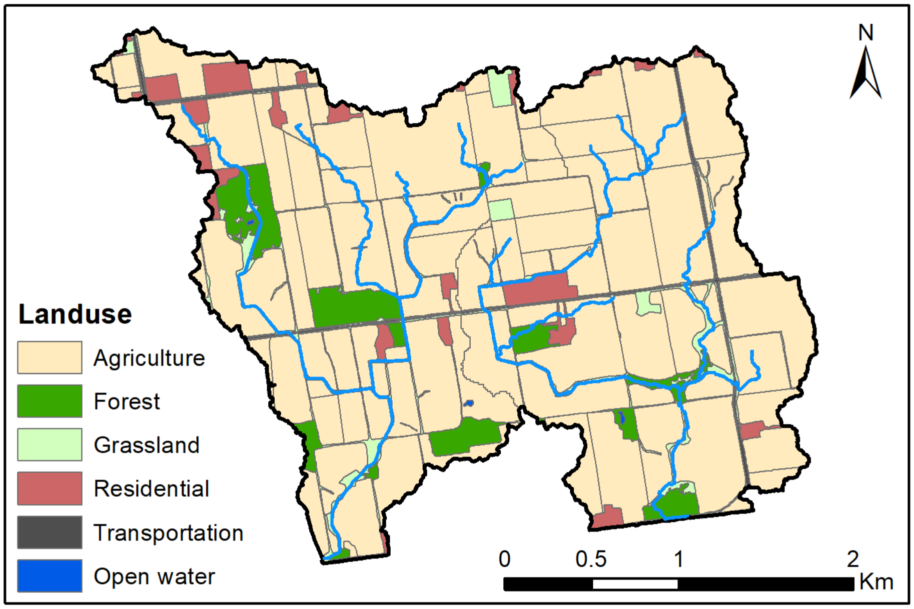

Modelling Report – Kettle Creek

June 28, 2023

Prepared by:

The Watershed Evaluation Group

University of Guelph

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1.0 INTRODUCTION

The North Kettle Creek subwatershed in the service area of the Kettle Creek Conservation Authority (KCCA) is a representative watershed of the lakeshore area in the Lake Erie Basin. It has an undulating landscape and is dominated by agricultural landuse activities. Evident sediment and nutrient transport from these lakeshore watersheds has become one of the major identified concerns to near shore water quality. In response to this growing concern over the adverse environmental effects of agriculture, farmers, conservation authorities and governments have worked together to promote and implement "Best/Beneficial Management Practices" or BMPs that focus on maintaining agricultural activity and farm profitability while protecting the environment.

From 2015 to 2018, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and the Ontario Soil and Crop Improvement Association (OSCIA) jointly implemented the Great Lakes Agricultural Stewardship Initiative (GLASI). In GLASI, the North Kettle Creek subwatershed was selected as one of the six priority subwatersheds for BMP establishment and study and was managed by the Upper Thames River Conservation Authority (UTRCA). By building upon UTRCA's previous BMP initiatives and monitoring program such as the Watershed Based BMP Evaluation Program (WBBE) from 2010 to 2013, the GLASI program invested in establishing monitoring systems for evaluating existing and newly-established BMPs in the North Kettle Creek subwatershed, primarily conservation tillage, cover cropping, Water and Sediment Control Basins (WASCoBs), tile drainage, and grassed waterways. As a component of the GLASI, Soil and Water Assessment Tool (SWAT) modelling of the North Kettle Creek subwatershed was conducted to evaluate the water quality effects of various BMP scenarios (Rudra et al. 2019).

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

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

1). Collect and prepare IMWEBs modelling input data;

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

3). Apply IMWEBs modelling to evaluate the environmental effectiveness (including P loss reduction efficacies) and cost effectiveness of the three key 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.

2.0 STUDY AREA

2.1 Location

The North Kettle Creek study area is located in southwestern Ontario, about 5 km southeast of the City of London (Figure 2-1). The North Kettle Creek watershed area is composed of two separate subwatersheds, including the Madter watershed in the west, and the Holtby watershed in the east. These two North Kettle Creek subwatersheds drain into Kettle Creek, which ultimately drains to Lake Erie. Combined, both the Madter and Holtby subwatersheds cover a drainage area of 761 ha.

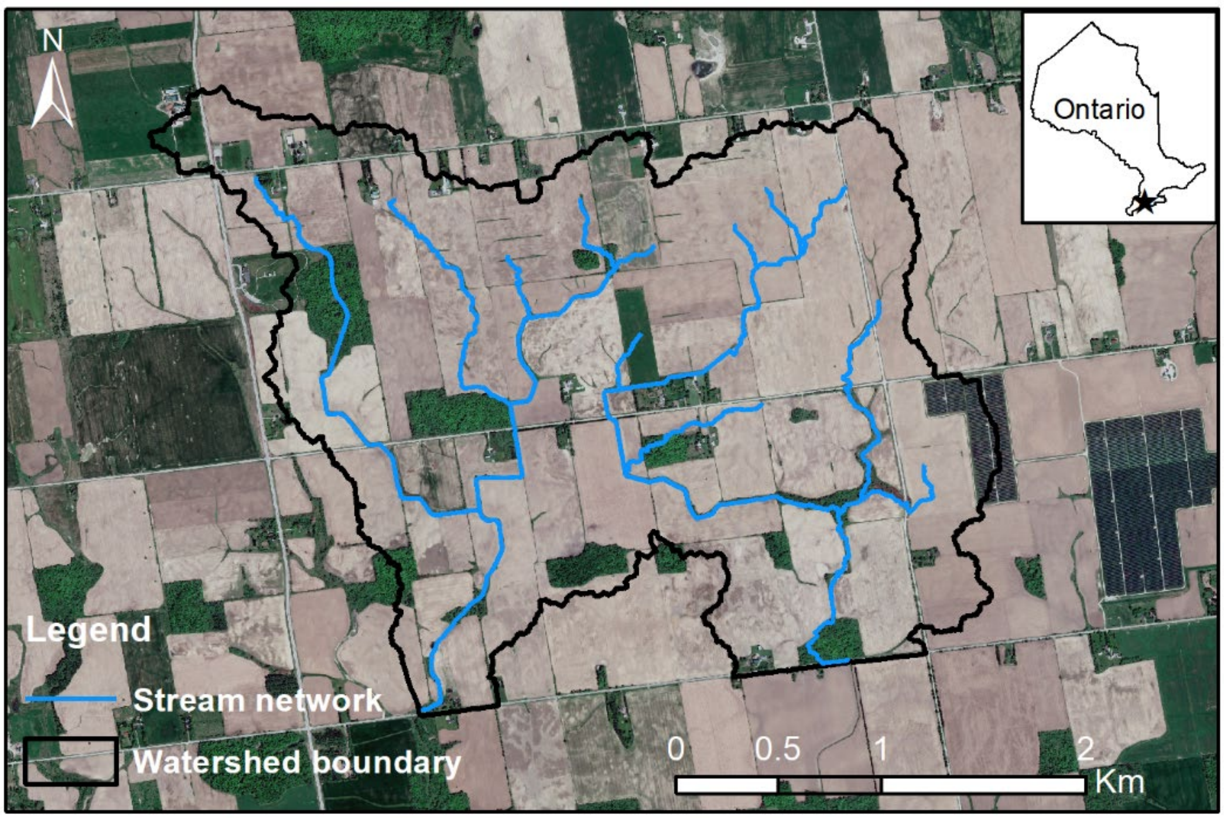

Figure 2-1.The North Kettle Creek subwatershed within southwestern Ontario

2.2 Topography, soil, and landuse

The North Kettle Creek subwatershed has undulating topography sloping from the highest elevation of 286 m in the north, to the lowest elevation of 253 m at the watershed outlets in the south (Figure 2-2). The average slope (according to the 1-m pixel resolution LiDAR DEM) is 3.71%, with a minimum of 0.00% in flat areas and up to 149% (56 degrees) at incised gullies and along watercourse ditch banks (Figure 2-3, Table 2-1).

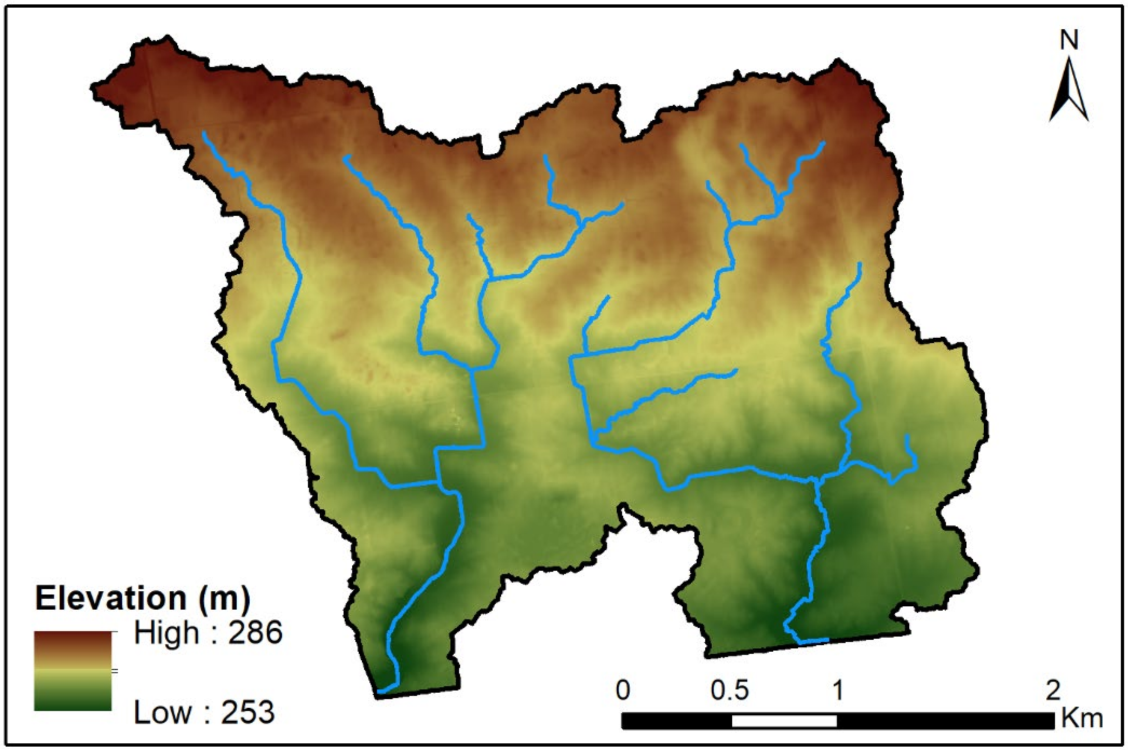

Figure 2-2. Topography of the North Kettle Creek subwatershed

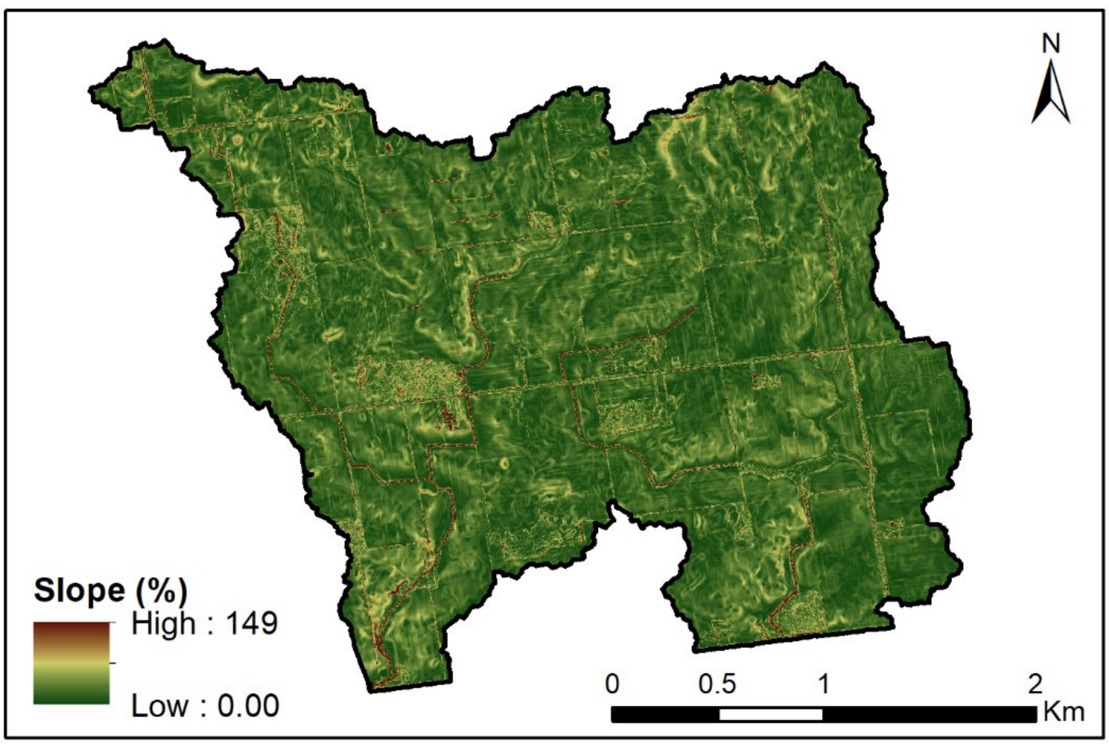

Figure 2-3. Slope of the North Kettle Creek subwatershed

Table 2-1. Elevation and slope areal extent in the North Kettle Creek subwatershed.

Class	Elevation (m)	Area extent		Slope (%)	Area extent	
		(km^2)	(%)		(km^2)	(%)
1	253 - 261	1.08	14.2	0.00 - 2.92	3.75	49.3
2	262 - 266	2.10	27.6	2.93 - 7.01	3.28	43.0
3	267 - 271	1.58	20.8	7.02 - 16.3	0.48	6.27
4	272 - 276	1.54	20.3	16.4 - 32.7	0.08	1.06
5	277 - 286	1.30	17.1	32.8 - 149	0.03	0.397
Average/sum	269	7.61	100	3.71	7.61	100

The map of soil type distribution based on Rudra et al. (2019) GLASI soil layer is shown in Figure 2-4. The soil names and areal extents corresponding to each soil type within the North Kettle Creek subwatershed are listed in Table 2-2. The dominant soil types in the North Kettle Creek subwatershed 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 texture.

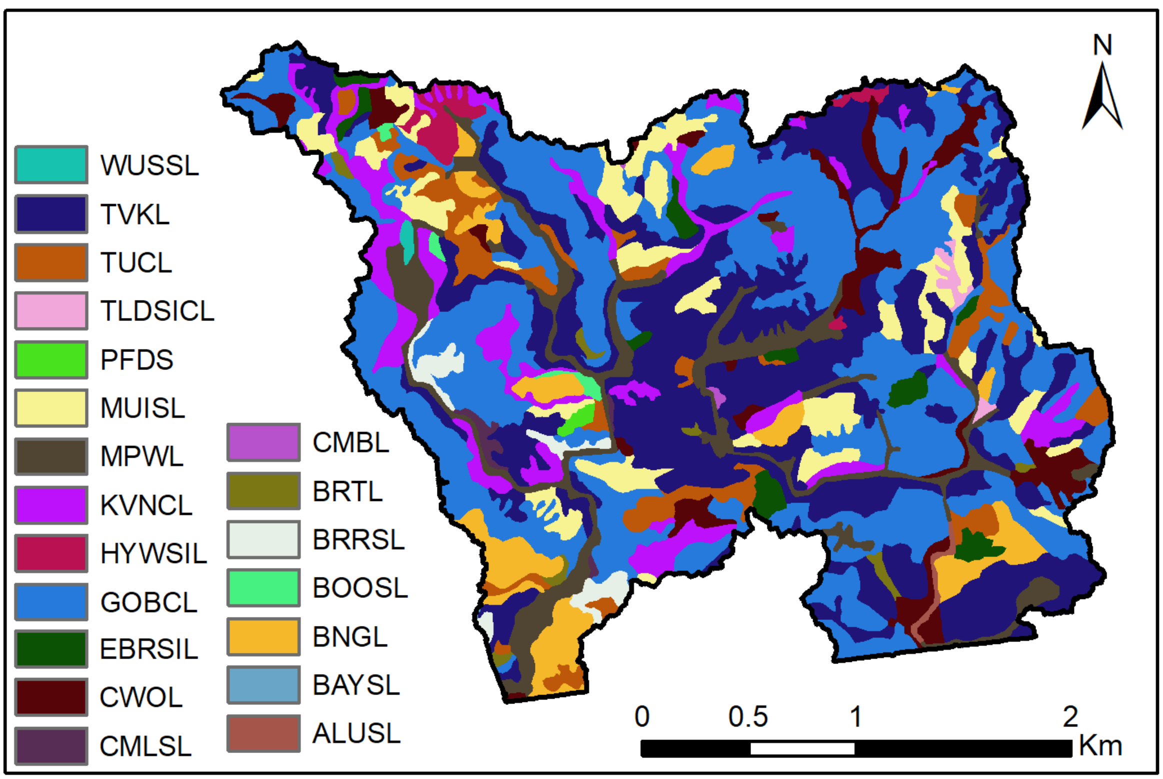

Figure 2-4. Soil types in the North Kettle Creek subwatershed based on Rudra et al. (2019) GLASI soil layer

Table 2-2. Soil types and areal extent in the North Kettle Creek subwatershed

Soil code	Soil type	Hydrologic group	Soil texture	Area (ha)	Watershed area (%)
GOBCL	Gobles Clay	C	C	256	33.6
TVKL	Tavistock Loam	C	L	192	25.2
MPWL	Maplewood Loam	C	L	56.1	7.37
KVNCL	Kelvin Clay Loam	D	CL	53.6	7.04
MUISL	Muriel Sandy Loam	C	SL	51.7	6.79
TUCL	Tuscola Loam	C	L	36.9	4.85
BNGL	Bennington Loam	B	L	35.9	4.71
CWOL	Colwood Loam	C	L	33.4	4.39
EBRSIL	Embro Silty Loam	C	SIL	12.9	1.69
BRRSL	Berrien Sandy Loam	C	SL	9.07	1.19
HYWSIL	Honeywood Silty Loam	B	SIL	8.19	1.08
BRTL	Brant Loam	B	L	4.09	0.538
TLDSICL	Toledo Silty Clay	D	SIC	2.65	0.348
CMLSL	Camilla Sandy Loam	B	SL	2.52	0.331
BOOSL	Bookton Sandy Loam	B	SL	2.17	0.285
ALUSL	Alluvial Sandy Loam	C	SL	1.72	0.225
PFDS	Plainfield Fine Sand	A	S	1.27	0.167
WUSSL	Wauseon Sandy Loam	C	SL	1.01	0.133
CMBL	Crombie Loam	C	L	0.460	0.060
BAYSL	Brady Sandy Loam	B	SL	0.118	0.016
Total				761.00	100.00

Figure 2-5 presents the landuse distribution within the North Kettle Creek subwatershed based on ONFARM field boundaries and a landuse layer generated under the previous GLASI study. The landuse names and associated areas and percentages within the North Kettle Creek subwatershed are listed in Table 2-3. 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.

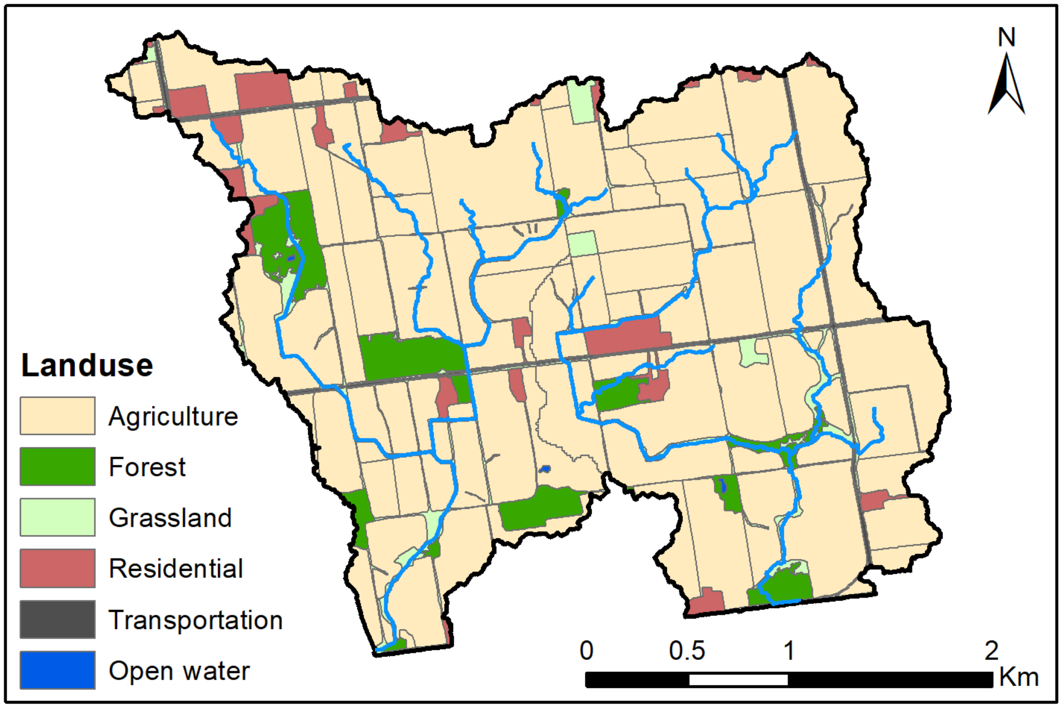

Figure 2-5. Landuse in the North Kettle Creek subwatershed

Table 2-3. Landuse and areal extent of the North Kettle Creek subwatershed

Landuse type	Area (ha)	Area (%)
Agriculture	635	83.3
Forest	44.6	5.86
Grassland	41.8	5.49
Residential	32.9	4.31
Transportation	7.33	0.963
Open water	0.388	0.051
Total	761	100

2.3 Climate and hydrology

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

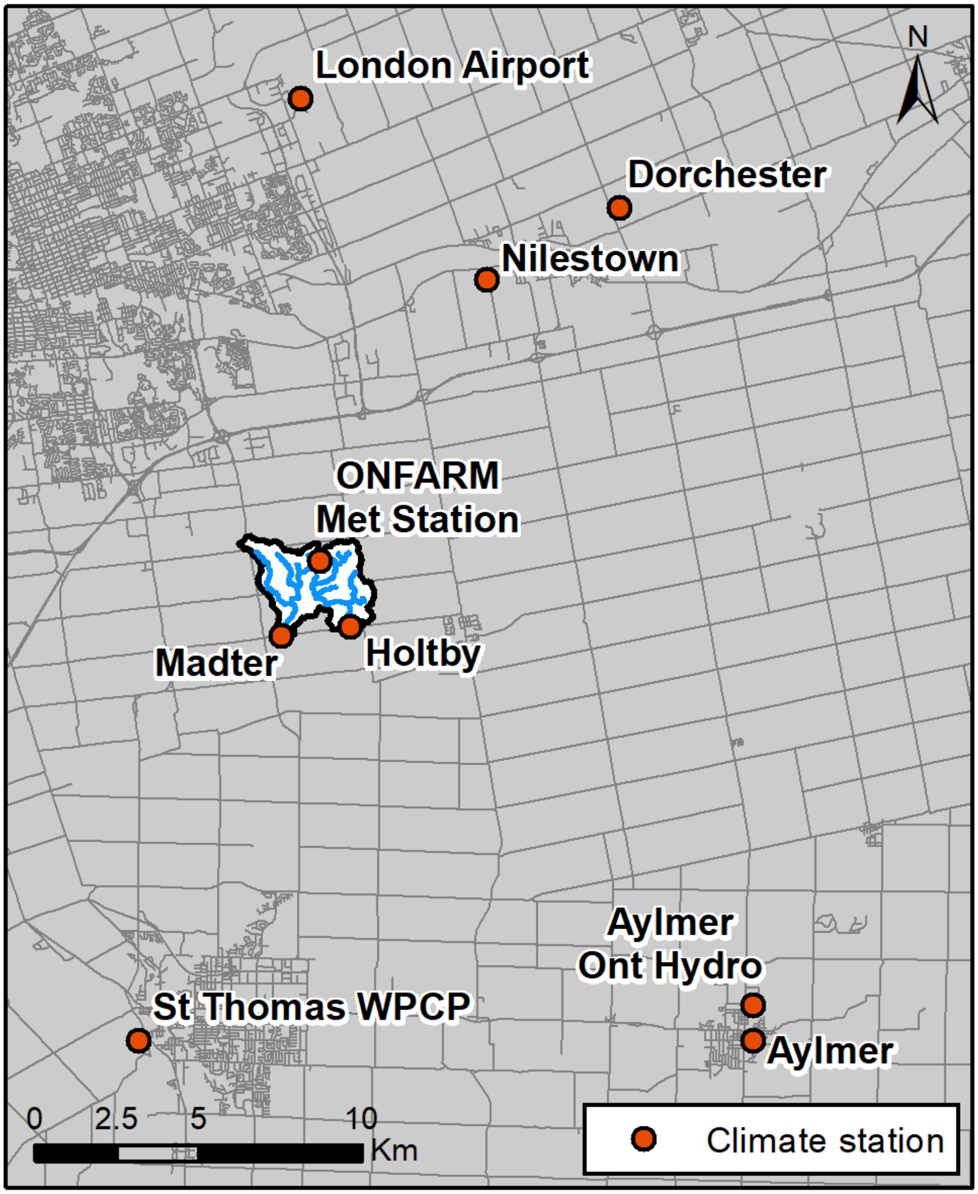

Figure 2-6. Climate monitoring stations for the North Kettle Creek subwatershed IMWEBs model

Table 2-4. Climate stations for the North Kettle Creek subwatershed IMWEBs model.

ID	Name	Latitude	Longitude	Elevation	Frequency	Period	Parameters
1	Aylmer (ECCC)	42.77	-80.98	232	Daily	1996-06-01 to 2004-02-29	TMP, PCP, SLR*, WS*, RH*
2	Aylmer Ont Hydro (ECCC)	42.78	-80.98	236	Daily	1983-05-01 to 2000-08-31	PCP, SLR*, WS*, RH*
3	St Thomas WPCP (ECCC)	42.77	-81.21	209	Daily	1980-05-01 to 2021-12-30	TMP, PCP, SLR*, WS*, RH*
4	Dorchester (ECCC)	43	-81.03	271	Daily	1976-04-14 to 2017-09-08	PCP, SLR*, WS*, RH*
5	London Airport (ECCC)	43.03	-81.15	278	Daily and Hourly	1970-01-01 to 2022-06-30	TMP, PCP, SLR*, WS, RH, WD
6	Nilestown (ECCC)	42.98	-81.08	265	Daily	1997-06-17 to 2001-10-31	TMP, PCP, SLR*, WS*, RH*
7	Holtby (UTRCA)	42.884	-81.131	254	30 minutes	2011-01-07 to 2022-06-30	PCP, SLR*, WS*, RH*
8	Madter (UTRCA)	42.882	-81.157	253	30 minutes	2011-05-02 to 2022-06-30	PCP, SLR*, WS*, RH*
9	ONFARM Met Station (UTRCA)	42.902	-81.142	274	30 Minutes	2020-06-05 to 2022-06-30	RH, SLR, WD, WS

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

The North Kettle Creek subwatershed has a climate with pronounced seasonal variations. The growing season begins in the middle of April and ends in late October with an annual average of about 160 frost free days. At station 5 (ECCC London Airport), the average annual precipitation was 1,023 from 1995 – 2021 with a standard deviation of 142 mm. The maximum annual precipitation of 1,302 mm occurred in

2006, and the minimum was 750 mm, occurring in 1998. The maximum daily precipitation was 89 mm, recorded on September 9, 1996. The average annual temperature was 8.4 °C from 1995 – 2021, ranging from 9.9 °C in 2012 to 6.8 °C in 2014 with a standard deviation of 0.84 °C. Yearly precipitation and average temperature from 1995 – 2021 at station 5 (ECCC London Airport) is presented in Figure 2-7. Annual precipitation and temperature are on average increasing from 1995 – 2021.

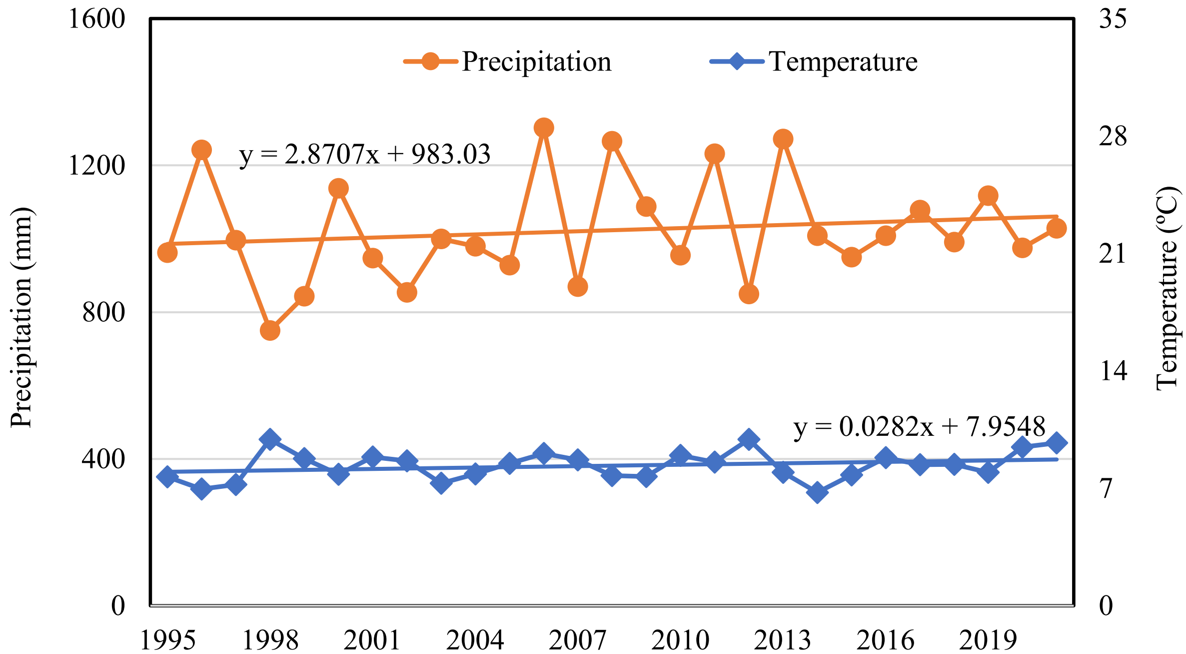

Figure 2-7. Variation of yearly precipitation and average temperature at station 5 (ECCC London Airport) from 1995-01-01 to 2021-12-31

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

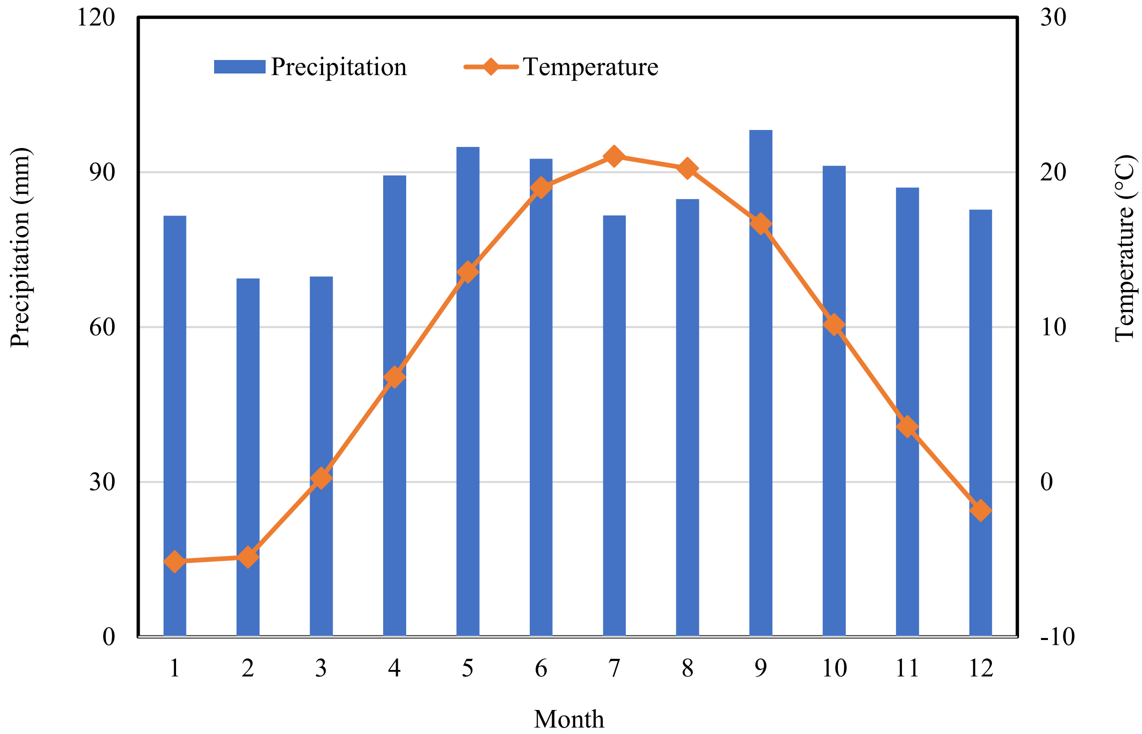

Figure 2-8. Average monthly precipitation and temperature at station 5 (ECCC London Airport) from 1995-01-01 to 2021-12-31

Figure 2-9 presents baseflow separation at Madter station from 2016-01-01 to 2022-06-01, and Figure 2-10 presents baseflow separation at Holtby station over the same time period. Based on the SWAT Baseflow Separation tool, baseflow contributed to about 37% of total streamflow at the Madter outlet, and 10% of total streamflow at the Holtby outlet. Table 2-6 and Table 2-7 present average monthly precipitation, runoff, and baseflow at the Madter and Holtby outlets, respectively. Runoff is highest throughout the winter months from December to March due to snowmelt and frozen soils, and lowest in August due to higher temperatures and evapotranspiration (Figure 2-11 and Figure 2-12).

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

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

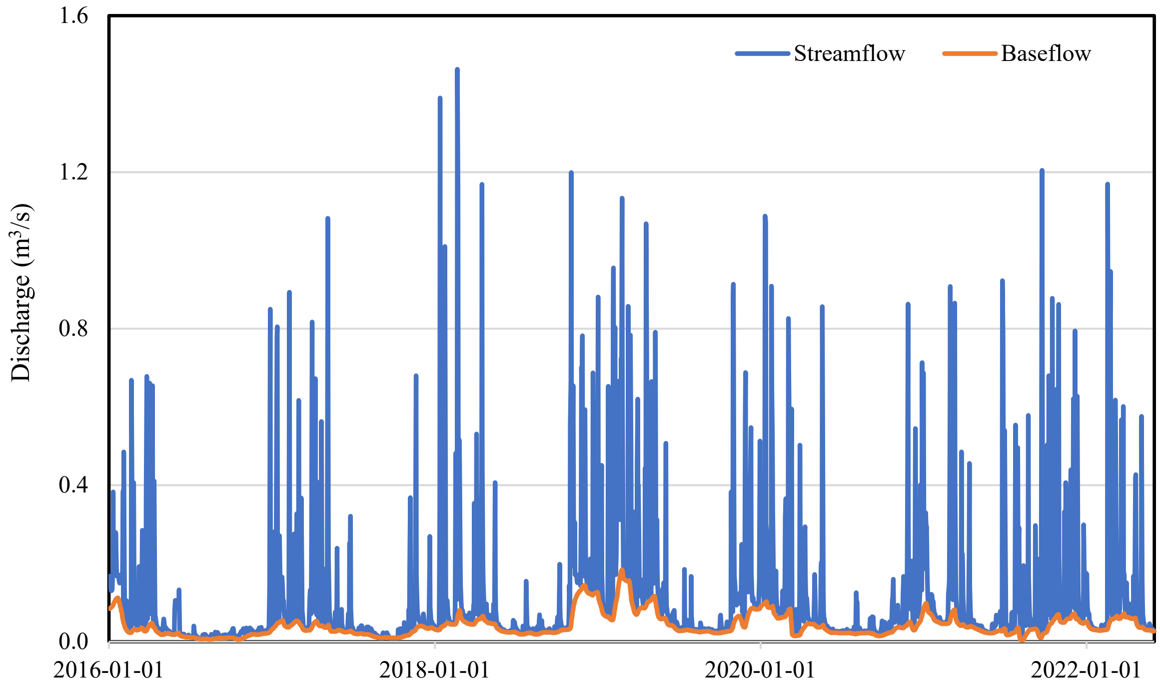

Figure 2-9. Baseflow separation at UTRCA Madter station over the period of 2016-01-01 to 2022-06-01

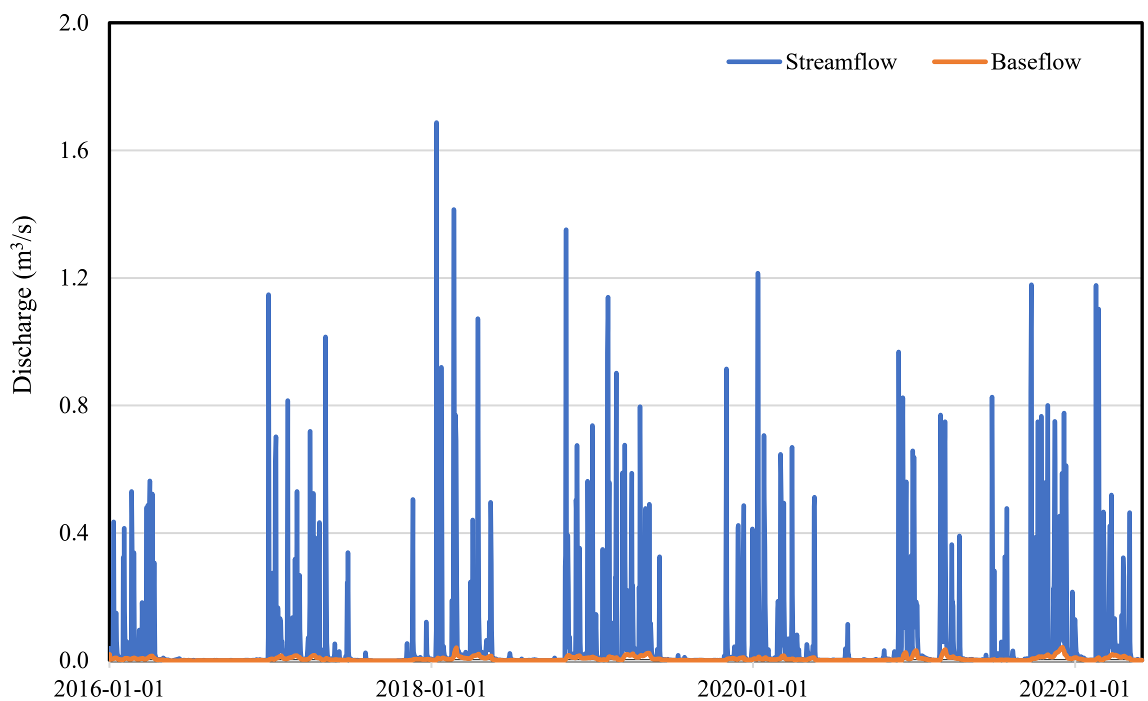

Figure 2-10. Baseflow separation at UTRCA Holtby station over the period of 2016-01-01 to 2022-06-01

Table 2-6. Average monthly precipitation, runoff, and baseflow observed at the UTRCA Madter station over the period of 2016-01-01 to 2021-12-31

Month	Precipitation	Runoff			Baseflow		
	(mm)	(m^3/s)	(mm)		(mm)	(m^3/s)	(mm)
1	44.1	0.179	124	1	44.1	0.179	124
2	51.8	0.192	121	2	51.8	0.192	121
3	97.6	0.175	122	3	97.6	0.175	122
4	90.6	0.134	90.0	4	90.6	0.134	90.0
5	73.4	0.098	67.7	5	73.4	0.098	67.7
6	75.7	0.057	38.4	6	75.7	0.057	38.4
7	84.0	0.046	32.0	7	84.0	0.046	32.0
8	77.3	0.039	27.1	8	77.3	0.039	27.1
9	63.2	0.043	28.9	9	63.2	0.043	28.9
10	81.9	0.085	59.2	10	81.9	0.085	59.2
11	59.7	0.150	101	11	59.7	0.150	101
12	40.9	0.144	99.7	12	40.9	0.144	99.7
Sum/Ave	840	0.112	911	Sum/Ave	840	0.112	911
Max	97.6	0.192	124	Max	97.6	0.192	124
Min	40.9	0.039	27.1	Min	40.9	0.039	27.1
STDV	18.2	0.057	38.3	STDV	18.2	0.057	38.3

Table 2-7. Average monthly precipitation, runoff, and baseflow observed at the UTRCA Holtby station over the period of 2016-01-01 to 2021-12-31

Month	Precipitation	Runoff			Baseflow		
	(mm)	(m^3/s)	(mm)		(mm)	(m^3/s)	(mm)
1	76.6	0.092	66.7	1	76.6	0.092	66.7
2	40.4	0.101	66.7	2	40.4	0.101	66.7
3	70.3	0.105	75.8	3	70.3	0.105	75.8
4	75.5	0.066	45.8	4	75.5	0.066	45.8
5	68.8	0.045	32.1	5	68.8	0.045	32.1
6	69.3	0.015	10.4	6	69.3	0.015	10.4
7	81.0	0.010	7.51	7	81.0	0.010	7.51
8	81.1	0.003	2.09	8	81.1	0.003	2.09
9	67.4	0.014	9.94	9	67.4	0.014	9.94
10	68.8	0.039	27.9	10	68.8	0.039	27.9
11	54.4	0.078	54.9	11	54.4	0.078	54.9
12	45.6	0.088	63.4	12	45.6	0.088	63.4
Sum/Ave	799	0.055	463	Sum/Ave	799	0.055	463
Max	81.1	0.105	75.8	Max	81.1	0.105	75.8
Min	40.4	0.003	2.09	Min	40.4	0.003	2.09
STDV	13.2	0.038	26.9	STDV	13.2	0.038	26.9

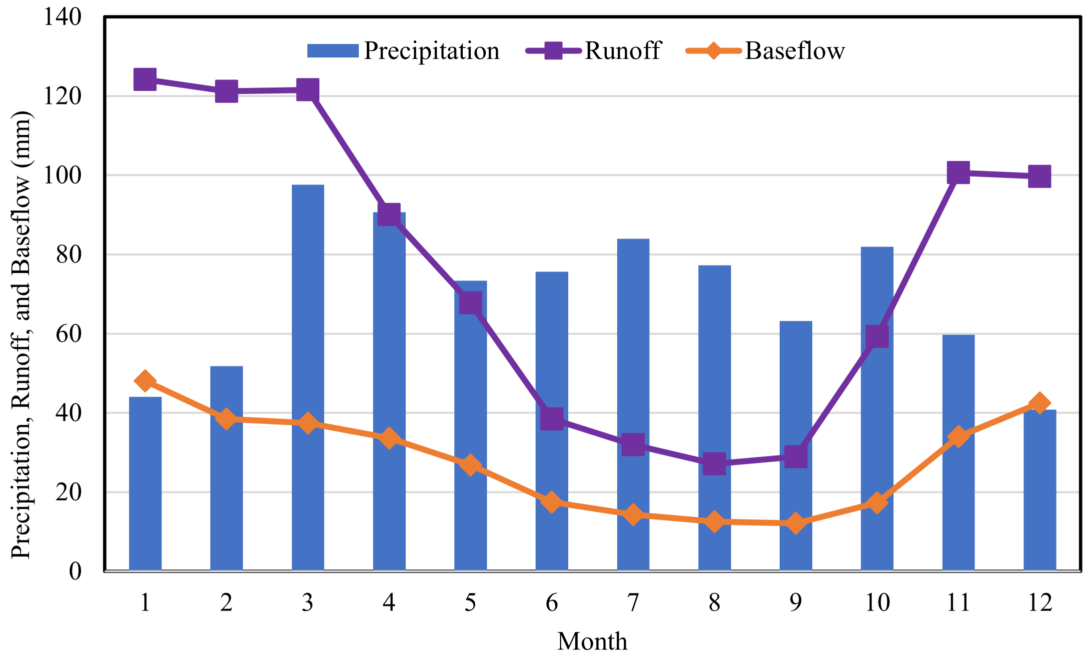

Figure 2-11. Average monthly precipitation, runoff, and baseflow observed at the UTRCA Madter station over the period of 2016-01-01 to 2021-12-31

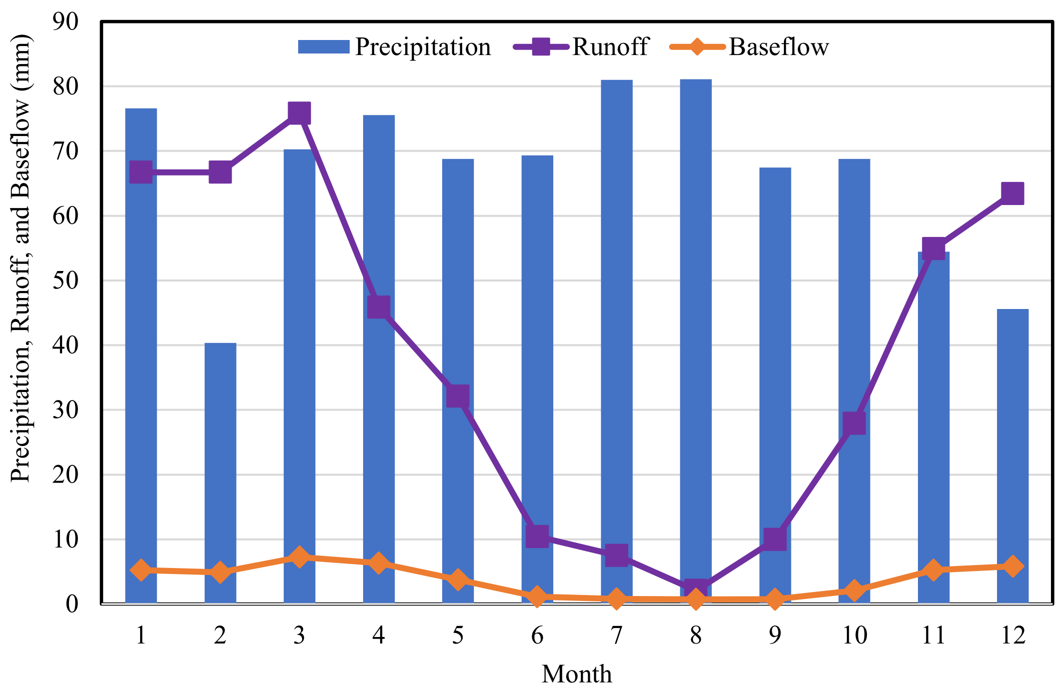

Figure 2-12. Average monthly precipitation, runoff, and baseflow observed at the UTRCA Holtby station over the period of 2016-01-01 to 2021-12-31

3.0 DATA COLLECTION AND PREPARATION

3.1 GIS Data

Geospatial data required for IMWEBs model setup include topography, soil, landuse, stream network, and others (Table 3-1). These data were prepared using data from UTRCA, OMAFRA, and other sources.

Table 3-1. GIS data available for the North Kettle Creek subwatershed

Data	Format	Source	Use
LiDAR DEM (1x1 m)	TIFF	UTRCA	Model setup
Soil	Shape	Rudra et al. (2019)	Model setup
Land use	Shape	UTRCA, Rudra et al. (2019)	Model setup
Crop inventory 2011-2021	TIFF (30x30 m)	AAFC	Crop rotation
Stream network	Shape	UTRCA	Watershed delineation
Boundary	Shape	UTRCA	Watershed delineation
Existing BMPs	Shape	UTRCA	Model setup
Climate, flow, and water quality stations	Shape	UTRCA, ECCC, NASA	Model setup
Field boundary	Shape	UTRCA	Model setup
Tile drain	Shape	OMAFRA	Model setup
Transportation	Shape	MNRF	Presentation purpose

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

3.2 Climate Data

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

3.3 Flow and Water Quality Data

Data used in IMWEBs model calibration includes stream flow (discharge), sediment concentration and load, and nutrient (nitrogen and phosphorus) concentration and load at a daily scale. These data were prepared from UTRCA monitoring stations established at the outlet of the Madter and Holtby subwatersheds (Table 3-2). The locations of these stations are shown in Figure 3-1.

Table 3-2. Water quality and flow monitoring stations within the North Kettle Creek subwatershed

Name	Description	Drainage Area (km^2)	Flow	Sediment	Nutrient
Madter*	Outlet	3.86	2016-2022	2016-2018	2016-2022
Holtby*	Outlet	3.70	2016-2022	2016-2018	2016-2022
Edge of Field N	Edge of field site	-	2020-2022	2020-2022	2020-2022
Edge of Field S	Edge of field site	-	2020-2022	2020-2022	2020-2022

Note: Stations with asterisks were used for calibration.

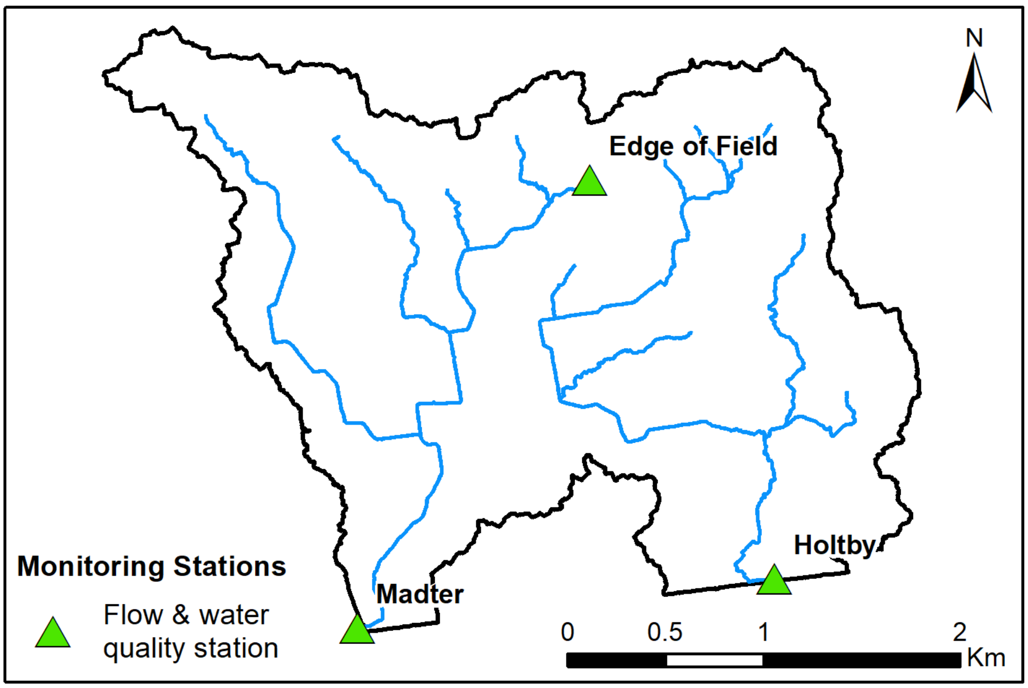

Figure 3-1. Flow and water quality monitoring stations in the North Kettle Creek subwatershed

3.4 Land Management Data

UTRCA staff conducted land management surveys for the ONFARM project in 2022. Table 3-3 describes the key parameters included in the land management dataset. UTRCA staff also collected windshield surveys for several years in 2010, 2011, and 2015-2021 that describe the crop grown, spring tillage type, fall tillage type, and the presence of an overwintering cover crop. AAFC annual crop inventories were used to fill any gaps that existed after compiling the ONFARM land management survey and the windshield surveys. These datasets were combined to establish a land management database spanning

2011 – 2022 for the North Kettle Creek subwatershed IMWEBs modelling. Figure 3-2 shows the field boundary layer used for the collection of land management data.

Table 3-3. Land management parameters surveyed under the ONFARM program in the North Kettle Creek subwatershed.

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

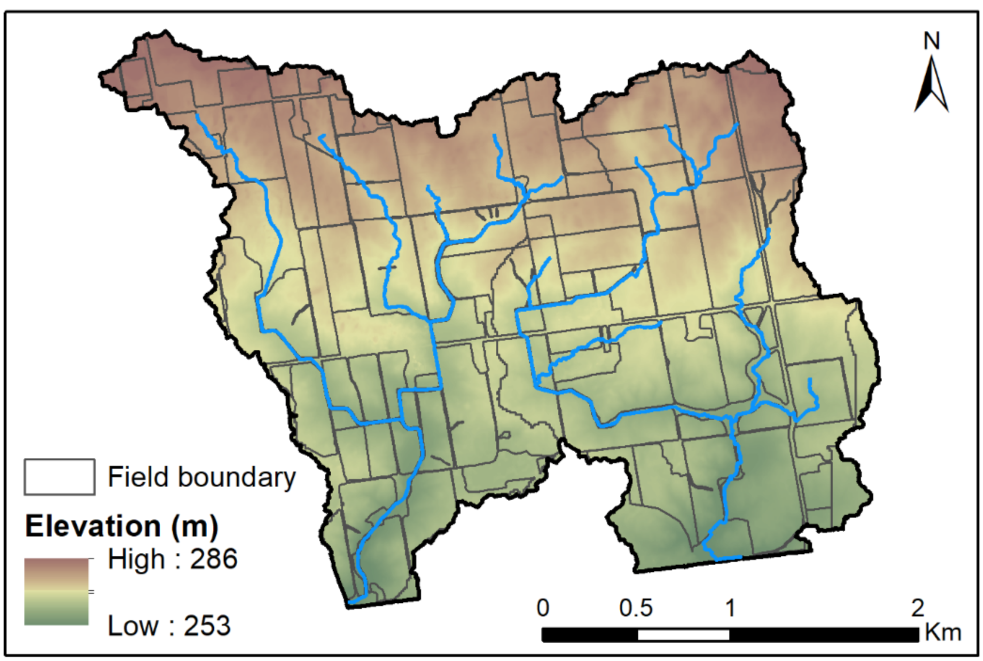

Figure 3-2. Field boundaries for the North Kettle Creek subwatershed IMWEBs model

4.0 IMWEBS MODEL SETUP

4.1 Overview of the IMWEBs model

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

4.2 Watershed delineation

The IMWEBs model uses the Digital Elevation Model (DEM) and stream network to delineate the watershed boundary. The watershed was delineated by burning the stream network into the DEM to ensure accurate flow routing. The flow and water quality monitoring stations were specified as subbasin outlets. The stream initiation threshold was set to 5 ha, in order to delineate subbasins for the monitoring stations with the smallest contributing areas. Figure 4-1 shows the delineated watershed for the North Kettle IMWEBs model, which contains 82 subbasins.

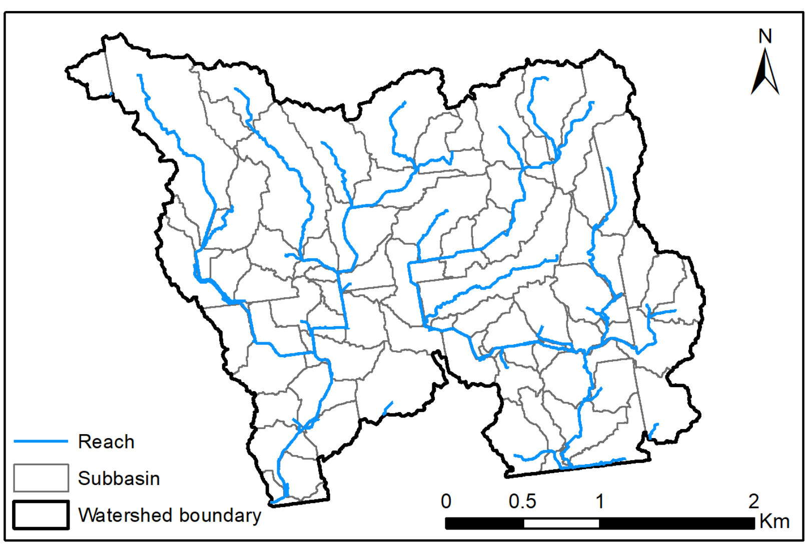

Figure 4-1. Delineated watershed boundary, subbasins, and reaches for the North Kettle Creek subwatershed IMWEBs model

4.3 Soil characterization

Soil properties are important factors in controlling infiltration and soil water movement, and play a key role in surface runoff, groundwater recharge, evapotranspiration, soil erosion, and the transport of chemicals. The soil layer prepared by Rudra et al. (2019) for the North Kettle GLASI SWAT model was used to define soil type distribution and key soil parameters for the North Kettle IMWEBs model. A summary of soil characterization for the North Kettle Creek subwatershed IMWEBs model is provided in Table 2-2.

4.4 Landuse characterization

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

4.5 Subarea definition

The IMWEBs model uses subareas to decrease the computer processing times associated with the cell-based IMWEBs model. Subareas are the smallest management unit for defining land management operations and structural BMPs. The subarea layer was created by intersecting the field boundary layer with the subbasin layer. Figure 4-2 presents the subarea layer for the North Kettle Creek subwatershed IMWEBs model, which contains 597 subareas.

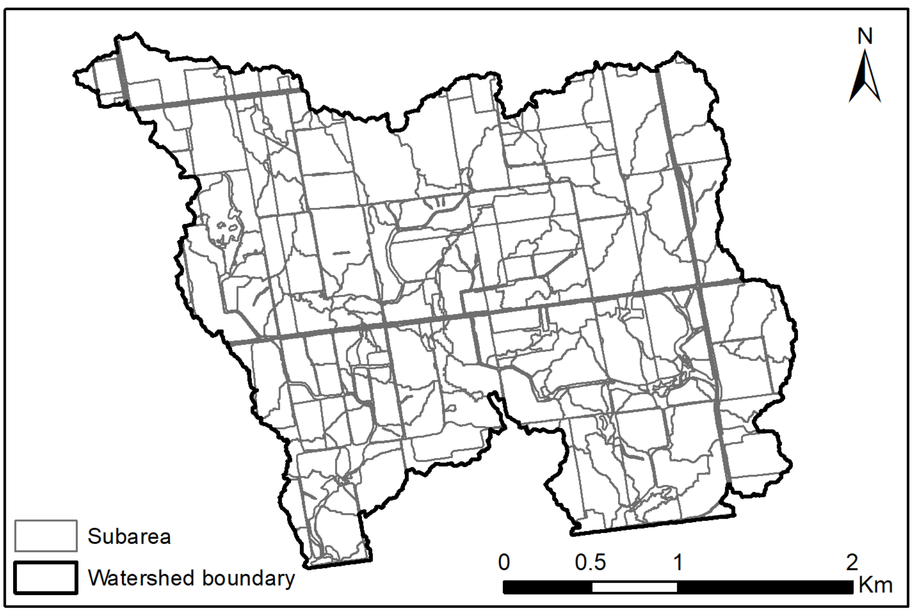

Figure 4-2. Subarea layer for the North Kettle Creek subwatershed IMWEBs model

4.6 Land management operations

Land management operations are a critical input for the IMWEBs model. Land management operations effect plant growth, nutrient availability, and nutrient and sediment transport throughout the watershed. UTRCA staff conducted land management surveys in the North Kettle Creek subwatershed, which were used to establish a 12-year land management dataset spanning from 2011 – 2022. Table 3-3 describes the key parameters included in the land management dataset.

4.7 Tile drain characterization

The OMAFRA Tile Drainage Area dataset was used to define the spatial distribution of tile drainage in the North Kettle Creek subwatershed. The ONFARM land management survey contained tile depth data, which was incorporated into the IMWEBs model. For fields that did not have tile depth listed in the survey, the dominant depth from the survey was assumed. Table 4-1 presents key tile drain parameters for the North Kettle Creek subwatershed, including the ONFARM survey data on tile radius, spacing, and dominant tile depth. Note that we also added the parameters for simulating controlled tile drain in IMWEBs setup which include start and end months for controlled tile drain and depth of controlled tile drain.

Table 4-1. Tile drain parameters for the North Kettle Creek subwatershed IMWEBs model.

Start month for controlled tile drain	End month for controlled tile drain	Radius (mm)	Spacing (mm)	Tile drain depth (mm)	Controlled tile drain depth (mm)
April	October	50	10,000	762	500

5.0 IMWEBs MODEL CALIBRATION

5.1 Overview of IMWEBs model calibration

Calibrating the IMWEBs model involves adjusting model inputs and parameters to optimize the agreement between measured data and model simulation results for realistically characterizing watershed historical/existing observed conditions. A simulation period of 2016 to 2022 was used for model calibration. Flow and water quality data collected at the Madter and Holtby monitoring stations were used for model calibration. The water quality data at the edge of field site were used for reference purpose only during model calibration. The model was calibrated firstly for flow; followed by sediment, particulate P, and particulate N; and lastly dissolved P and dissolved N.

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

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

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

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

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

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

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

5.2 Flow calibration

We encountered significant challenges with flow calibration for the North Kettle Creek watershed. For the Holtby subwatershed, we identified a large number of flow records over 75 m^3/s, mostly in 2012 and 2014. For the Madter watershed, we also identified two flow records over 75 m^3/s in 2012. Based on a recommendation from UTRCA staff, we were advised to use flow data from 2016 onward for ONFARM IMWEBs modelling.

Unfortunately, we continued to face data challenges in flow calibration for the IMWEBs. Specifically, 1). Hotby and Madter are adjacent but have considerably different precipitation records (Figure 5-1). Realistically these two monitoring locations should have comparable precipitation data. UTRCA staff suggested that tree obstruction at monitoring sites may have caused the problem. 2). Madter flow data are systematically larger than the Hotlby station (more than double in almost every month) (Table 2-6 and Table 2-7). Landscape characteristics in Holtby and Madter are different to a certain extent. These features may cause some differences in the fractions of observed surface flow, interflow, and groundwater flow but the total flow at the outlets should be comparable in magnitude. 3). Madter's yearly flow is more than the observed precipitation for the same time period (Table 2-6). This pattern is unrealistic, suggesting severe issues related to the rating curve for this flow monitoring station.

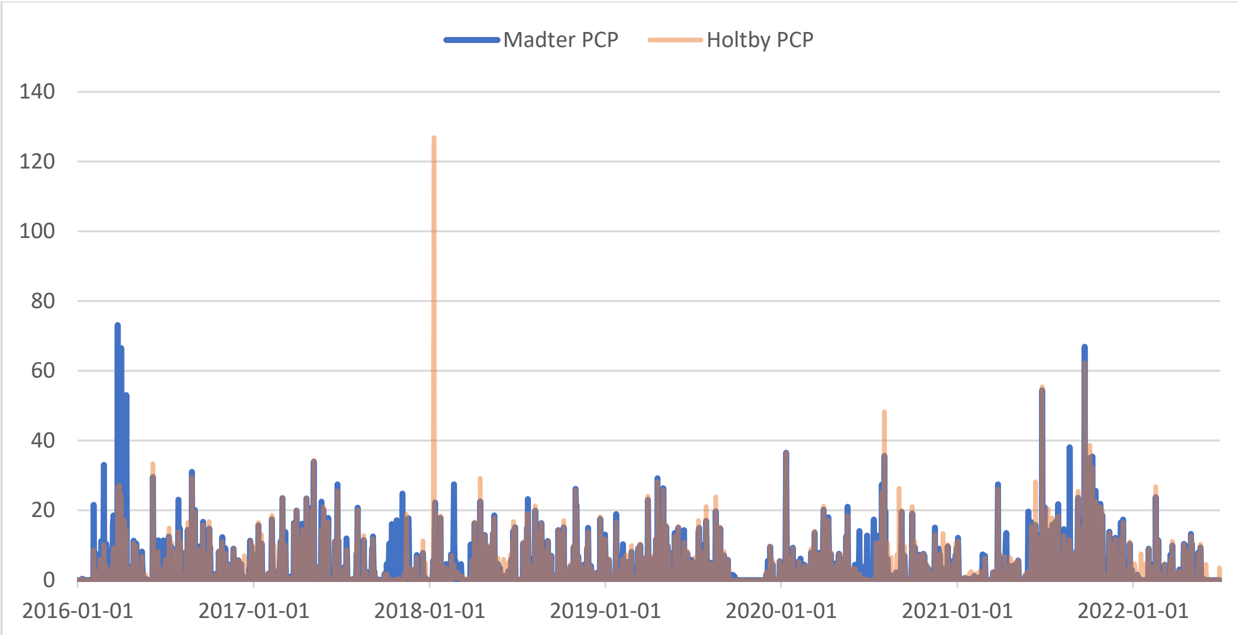

Figure 5-1. A comparison of precipitation (mm) at Madter and Holtby monitoring locations

Despite these challenges, we made efforts to calibrate the North Kettle IMWEB model. Figure 5-2 and Figure 5-3 show measured vs. simulated flow for the Madter and Hotlby subwatersheds. We were able to achieve a NSC of 0.47 and a model bias of -0.2% for the Holtby subwatershed, which indicated a reasonable model performance based on the criteria outlined in Moriasi et. al (2007). However, for the Madter subwatershed, we achieved a NSC of 0.34 and a model bias of -45.6%, which indicated an unsatisfactory model performance with significant flow under-estimation based on the criteria outlined in Moriasi et. al (2007). Likely the unsatisfactory model performance for the Madter subwatershed was caused by a combination of flow and precipitation data inaccuracies. With these data challenges, we decided not to proceed with further calibrating the North Kettle IMWEBs model as we were not able to achieve an acceptable model performance.

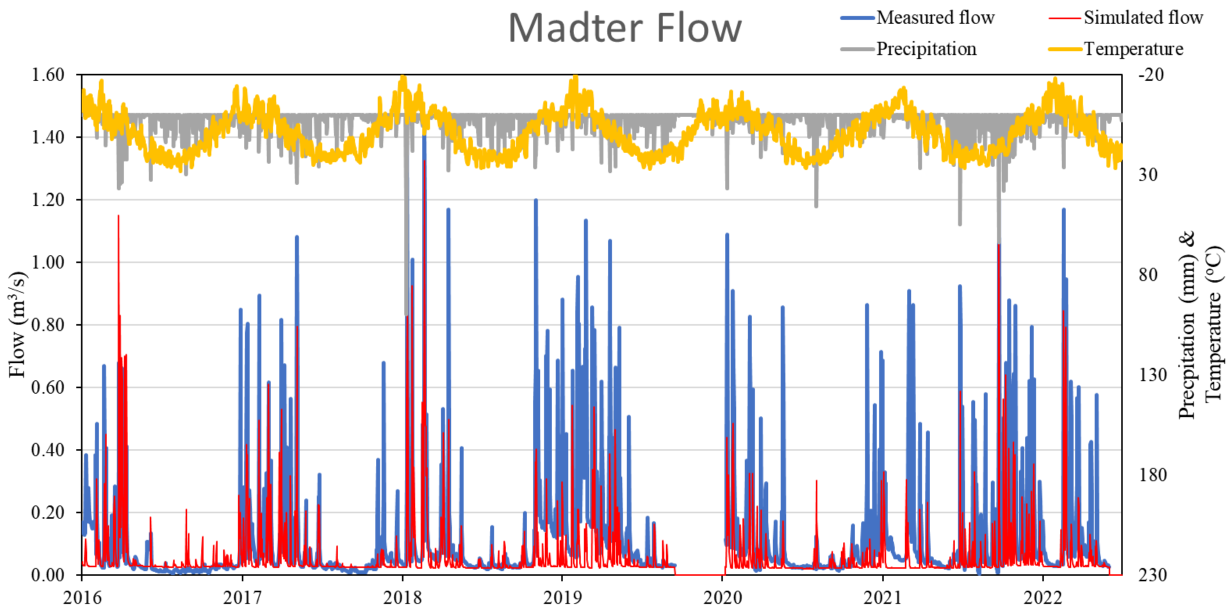

Figure 5-2. Measured vs. simulated flow at Medter outlet

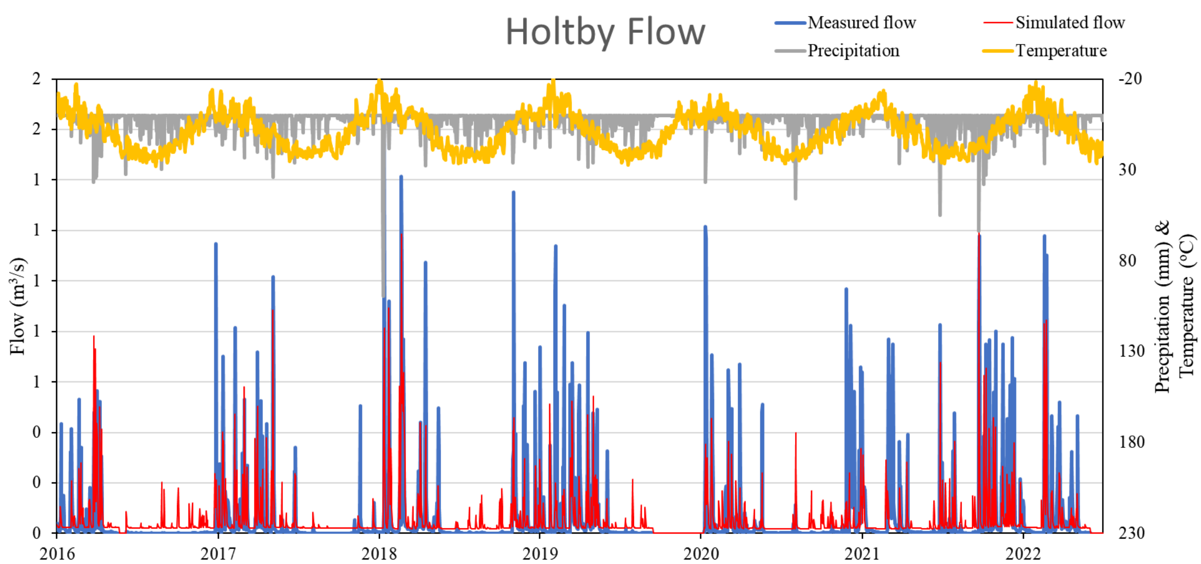

Figure 5-3. Measured vs. simulated flow at Holtby outlet

5.3 Sediment calibration

Given the inability to achieve suitable flow calibration results for these watersheds, sediment calibration could not have been completed with sufficient accuracy. Therefore, sediment calibration of the model was not completed.

5.4 Nutrient calibration

Given the inability to achieve suitable flow or sediment calibration results for these watersheds required for the nutrient calibration, the nutrient calibration of the model was not completed.

6.0 DEFINITION OF BMP SCENARIOS

In IMWEBs modelling, the historical/existing scenario was essentially the calibration run because it incorporated the crop management, tillage management, and fertilizer/manure management tables describing the historical/existing land management conditions, including established BMPs, which were in place in the watershed at the time the flow and water quality was being monitored at the watershed outlet. In the project, we already re-constructed IMWEBs input land management tables to develop various BMP scenarios. If the IMWEBs calibration had been successful, then new IMWEBs model runs would have been conducted for evaluating the efficacies of the three key soil health focused BMPs of interest, namely cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation practices. Unfortunately, we were not able to proceed with BMP assessment due to significant limitations in IMWEBs model calibration.

6.1 Existing actual BMP scenario

The existing actual BMP scenario characterizes the historical/existing BMPs including the already established BMPs in the North Kettle Creek subwatershed. The crop management, tillage management, and fertilizer/manure management data for the existing actual BMP scenario includes all land management BMPs collected through the ONFARM and windshield surveys, such as conservation tillage, no-till, cover crops, and fertilizer/manure incorporation. These data were formatted into excel spreadsheets suitable for use as input into the IMWEBs model and used as the land use dataset for the attempts at model calibration.

6.2 No existing BMPs scenarios

If the IMWEBs calibration of this study area had of been successful, then model runs would have been executed with the adjusted land management datasets excluding each of the three key BMPs (cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation). The revised land management input datasets for each BMP would allow the model to simulate a situation without each of these three key BMPs in practice in the watershed (i.e. no existing cover cropping scenario, no existing conservation tillage/no-till scenario, and no existing fertilizer/manure incorporation scenario). With the inability to perform a proper calibration of the model, however, these additional runs could also not be completed with any level of confidence. Therefore, the input datasets for the various no existing BMP scenario runs, while completed, were not utilized.

6.3 Potential future BMPs scenarios

If the IMWEBs calibration of this study area had of been successful, then model runs would have been executed with adjusted land management datasets to include all potential situations in the watershed landscape where each of the three key BMPs (cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation) could have been implemented. The revised land management input datasets would allow the model to simulate a situation where each of these three key BMPs were fully adopted across the landscape. These model runs therefore would identify the maximum potential efficacy of implementing these three key BMPs fully across the watershed (i.e. potential future BMPs scenarios in addition to historical/existing BMPs). With the inability to perform a proper calibration of the model, however, these additional runs could also not be completed with any level of confidence. Therefore, the land management input datasets for the various potential future BMP scenario runs, while completed, were not utilized.

6.3.1 Assumptions used in developing potential future BMP scenarios

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

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

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

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

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

6.4 BMP assessment approaches

Unfortunately, we were not able to conduct BMP assessment for the North Kettle Creek watershed because of the limitations in flow calibration. An approach to assess the efficacy of the three key BMPs of interest, however, was developed. We suggest readers refer to appropriate sections of ONFARM modelling reports completed for the Garvey Glenn and Upper Medway Creek subwatersheds, for which watershed calibration was achieved, allowing the procedures to be executed. These reports describe the methodology fully and also present the results of the model run comparisons for BMP assessment for those subwatersheds.

7.0 IMWEBs MODELLING RESULTS UNDER BOTH EXISTING AND THEORETICAL CONDITIONS/SCENARIOS

The intent was to calibrate the IMWEBs model using data collected for the period of 2011-2021 (10+ years) for the North Kettle Creek subwatershed in order to develop a reliable model that could be applied to simulate average yearly streamflow and also generate predictive sediment and nutrient concentration and subsequently load estimates at watershed outlet. Unfortunately, we were not able to develop a calibrated model for this study area. This in turn meant it was inappropriate to simulate estimates of streamflow or sediment or nutrient loads under theoretical “no BMP” or “potential future” (full adoption) of the three soil health-related BMPs of interest (cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation). For a more complete description of IMWEBs model results in situations where success was achieved in all modelling tasks, refer to ONFARM modelling reports for the Upper Medway Creek and Garvey Glenn subwatersheds.

8.0 BMP COST-BENEFIT ANALYSIS

We worked with UTRCA staff to conduct a cost benefit analysis (CBA) for BMPs implemented in the North Kettle study area. Note that in the components of the CBA, positive and negative numbers indicate costs and benefits respectively based on the fact that in most cases BMP costs outweigh benefits and positive numbers are used to represent positive net costs minus benefits. For the net cost-benefit, positive numbers indicate costs are over benefits while negative numbers indicate benefits are over costs. The following summarizes the findings of costs associated with select BMPs.

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.

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

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

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

9.0 BMP COST-EFFECTIVENESS ANALYSIS

Without estimates of per hectare reduction of phosphorus losses for the three key agronomic BMPs, which were intended to have been generated by a calibrated and functional watershed model, it is not possible to complete a BMP cost-effectiveness analysis of the key BMPs of interest. Readers are referred to other ONFARM watershed modelling reports (for the Upper Medway Creek and Garvey Glenn subwatersheds) which had successful watershed calibration and BMP assessment results to obtain examples of the BMP cost-effectiveness analysis approach.

10. CONCLUSIONS AND FUTURE RECOMMENDATIONS

In the ONFARM project we developed IMWEBs modelling for evaluating the water quality benefits of cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation BMPs in the North Kettle Creek subwatershed. The IMWEBs model was set up based on watershed boundary, stream network, climate, topography/DEM, soil, landuse, and historical/existing land management and BMPs. We made efforts to calibrate the IMWEBs model to the observed streamflow using observed weather inputs for the North Kettle Creek subwatershed but achieved a poor model performance due to significant data challenges. This had cascading effects on our ability to achieve the remaining objectives of the watershed modelling tasks for this subwatershed. A comprehensive model-based assessment of the efficacy and P-reducing cost-effectiveness ($kg of P reduced/yr) of the three soil health-related BMPs under focus (cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation) could therefore not be successfully completed for this ONFARM watershed.

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

1). Support the development of a long-term 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 are exactly the same), but hope resources can be provided for this important component of the BMP assessment initiatives.

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

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

10.0 REFERENCES

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., and Veith, T. L. 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Transactions of the ASABE, 50(3): 885-900. (doi: 10.13031/2013.23153).

Nash, J.E. and Sutcliffe, J.V. (1970) River Flow Forecasting through Conceptual Models Part 1 – A Discussion of Principles. Journal of Hydrology, 10: 282-290.

Rudra, R., Daggupati, P., Shrestha, N. K., Shukla, R. (2019) Investigating Phosphorus Reduction Strategies in Kettle Creek Paired Watershed using Hydrological and Water Quality Modeling.