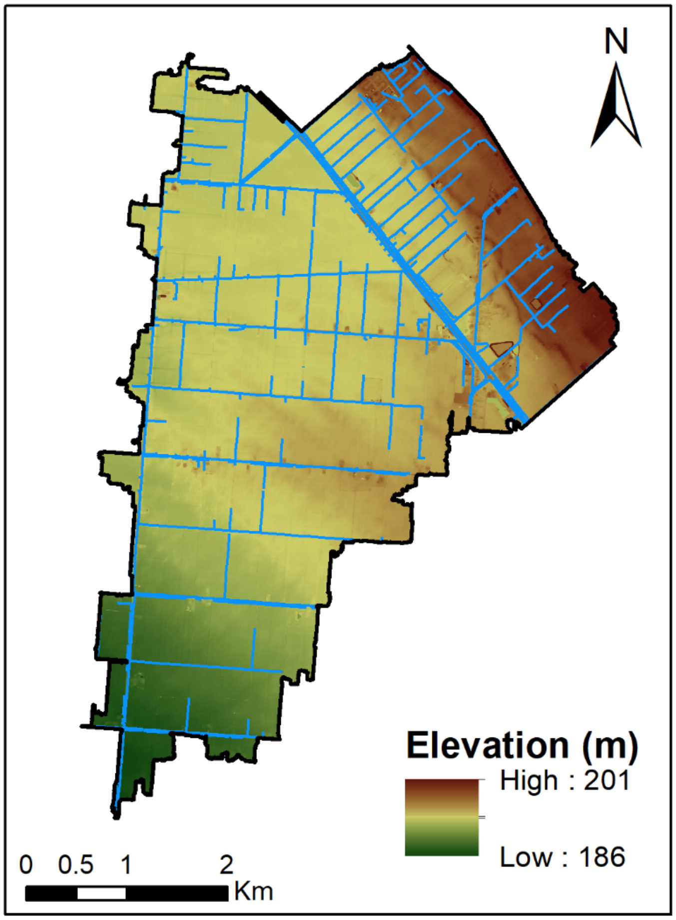

ONFARM

Modelling Report - Wigle Creek

June 28, 2023

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The Watershed Evaluation Group

University of Guelph

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1.0 INTRODUCTION

The Wigle Creek subwatershed in the service area of the Essex Region Conservation Authority (ERCA) is representative of the clay plains of extreme Southwestern Ontario watersheds in the Lake Erie Basin. It has a relatively flat landscape and is dominated by agricultural landuse activities. Evident sediment and nutrient transport from these lowlands 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 Wigle Creek subwatershed was selected as one of the six priority subwatersheds for BMP establishment and study. By building upon ERCA's previous BMP initiatives and monitoring program, the GLASI program invested in establishing monitoring systems for evaluating existing and newly-established BMPs in the Wigle Creek subwatershed, primarily conservation tillage, cover cropping, fertilizer incorporation, precision nutrient management, and vegetative buffer strips. As a component of the GLASI, Soil and Water Assessment Tool (SWAT) modelling of the Wigle 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, ERCA colleagues continued their efforts on BMP experiments and data collection including completing farmer land management surveys and water monitoring. Watershed modelling for BMP assessment was also one of the key components of the ONFARM project.

The purpose of the ONFARM modelling project was to apply the Integrated Modelling for Watershed Evaluation of BMPs (IMWEBs) tool to evaluate the environmental effectiveness and cost effectiveness of three key agricultural BMPs (conservation tillage or no-till, cover cropping, and fertilizer/manure incorporation) in the six priority subwatersheds, including the Wigle 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 and placement strategies across the watershed.

2.0 STUDY AREA

2.1 Location

The Wigle Creek subwatershed is located in southwestern Ontario, about 30 km southeast of the City of Windsor (Figure 2-1). Wigle Creek proper drains directly into Lake Erie, about 3 km west of the Town of Kingsville. The portion of Wigle Creek (i.e. the Wigle Creek sub-watershed) modelled in this study is situated in the middle portion of the Wigle Creek watershed and has a drainage area of 2,109 ha.

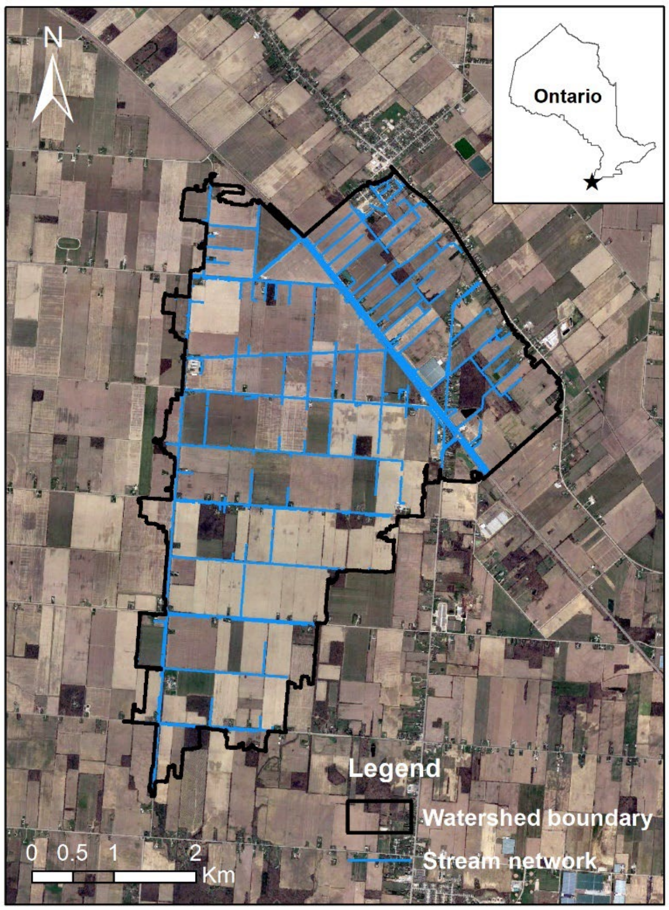

Figure 2-1. Location of the Wigle Creek subwatershed within Wigle Creek and southwestern Ontario

2.2 Topography, soil, and landuse

The Wigle Creek subwatershed has flat topography, ranging from the highest elevation of 201 m to the east, to the lowest elevation of 186 m to the south (Figure 2-2). Elevation ranges from 193 m to 196 m for about 78% of the watershed (Table 2-1). The average slope (according to the 0.5-m pixel resolution hydro-conditioned LiDAR DEM) is 3.36%, with a minimum of 0.00% in flat areas and up to 459% along drainage ditch banks. About 91% of the watershed has slope less than 5.4% (Figure 2-3, Table 2-1).

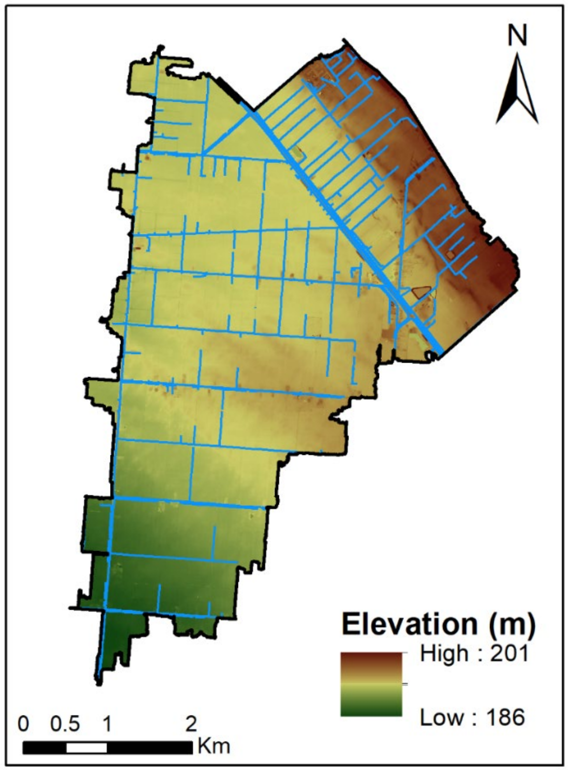

Figure 2-2. Topography of the Wigle Creek subwatershed

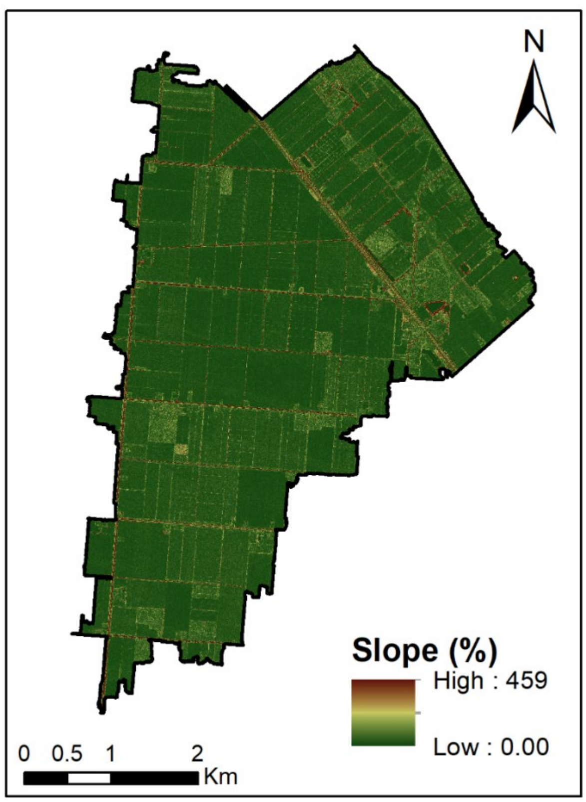

Figure 2-3. Slope of the Wigle Creek subwatershed

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

Class	Elevation (m)	Area extent		Slope (%)	Area extent	
		(km^2)	(%)		(km^2)	(%)
1	186.2 - 192.7	1.94	9.19	0.00 - 5.38	19.2	90.9
2	192.8 - 193.8	2.28	10.8	5.39 - 25.1	1.45	6.87
3	193.9 - 194.6	8.86	42.0	25.2 - 53.8	0.294	1.39
4	194.7 - 195.8	5.30	25.1	53.9 - 107	0.165	0.785
5	195.9 - 201.5	2.71	12.9	108 - 459	0.012	0.059
Average/sum	195	21.1	100	3.36	21.1	100

The map of soil type distribution based on OMAFRA's Soil Survey Complex is shown in Figure 2-4. The Wigle Creek subwatershed is dominated by Brookston clay soil, which composes 98.9% of the watershed (Table 2-2).

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

Soil code	Soil type	Hydrologic group	Soil texture	Area (ha)	Watershed area (%)
CTRC	Caistor clay	C	C	9.05	0.429
BUFL	Burford loam	A	L	15.0	0.710
BKNC	Brookston clay	D	C	2,085	98.9
Total				2,109	100

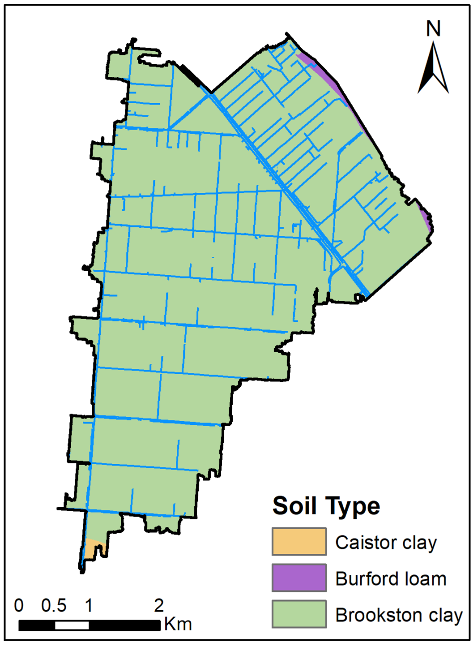

Figure 2-4. Soil types in the Wigle Creek subwatershed based on OMAFRA soil survey data

Figure 2-5 shows the landuse distribution within the Wigle creek subwatershed, based on ONFARM field boundaries and a landuse layer generated under the previous GLASI study. Landuse names and associated areal extents are listed in Table 2-3. About 78% of the land is agriculture, 9% is industrial, residential or transportation, 13% is forest or grassland, and less than 0.5% is open water.

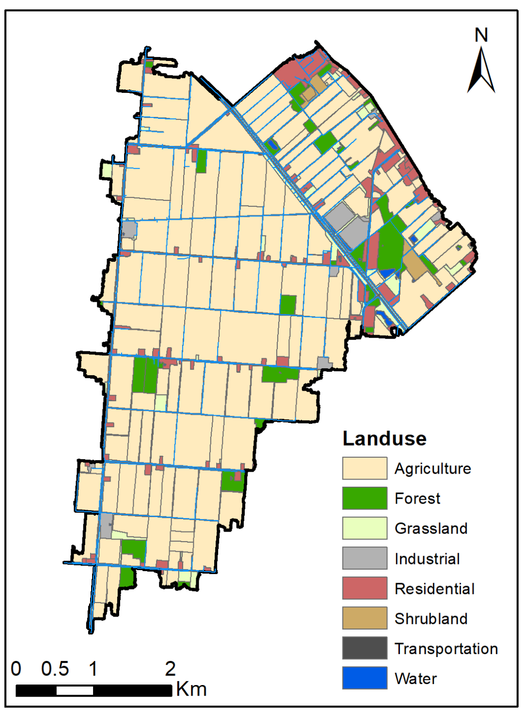

Figure 2-4. Landuse in the Wigle Creek subwatershed, based on ONFARM field boundaries and GLASI landuse layer

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

Landuse type	Area (ha)	Percent (%)
Agriculture	1,641	77.8
Forest	115	5.44
Grassland	142	6.72
Industrial	37.1	1.76
Residential	123	5.81
Shrubland	16.8	0.797
Transportation	27.6	1.31
Water	7.66	0.363
Total	2,109	100

2.3 Climate and hydrology

The input climate data (i.e., daily precipitation, maximum and minimum temperature, solar radiation, wind speed, wind direction, and relative humidity) were collected from two Essex Region Conservation Authority (ERCA) climate stations and five Environment and Climate Change Canada (ECCC) climate 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 ERCA 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.

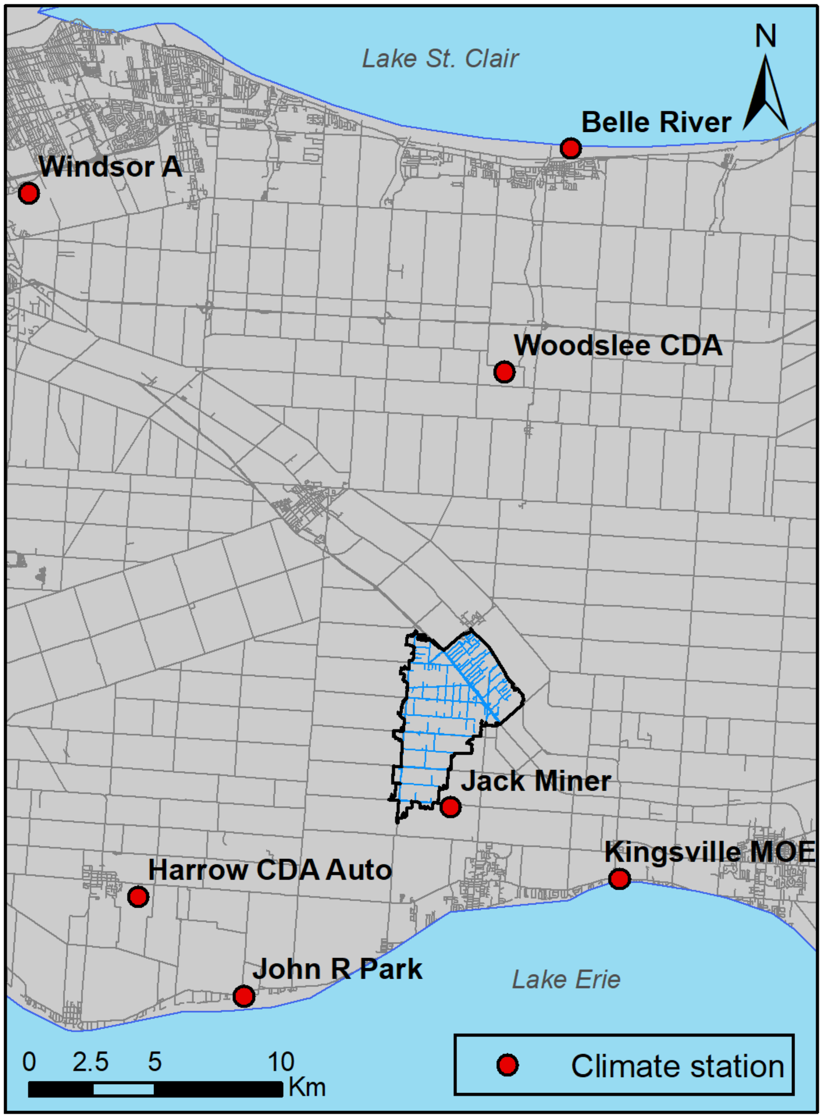

Figure 2-5. Climate monitoring stations for the Wigle Creek subwatershed IMWEBs modelling. Note that Belle River and Windsor A climate stations were used for wind direction data only.

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

ID	Name	Latitude	Longitude	Elevation	Frequency	Period	Parameters
1	Harrow CDA Auto (ECCC)	42.03	-82.90	191	Daily and hourly	1970-01-01 to 2022-06-30	TMP, PCP, RH, WS, WD, SLR*
2	Kingsville MOE (ECCC)	42.04	-82.67	200	Daily	1970-01-01 to 2022-06-30	TMP, PCP, RH*, WS*, SLR*
3	Jack Miner (ERCA)	42.0644	-82.7513	197	Hourly and 15 minutes	2016-07-18 to 2022-06-30	TMP, PCP, RH, WS, WD, SLR
4	Woodslee CDA (ECCC)	42.22	-82.73	183	Daily	1970-01-01 to 2001-12-31	TMP, PCP, RH*, WS*, SLR*
5	Belle River (ECCC)	42.30	-82.70	184	Daily	1994-12-30 to 2005-03-06	WD only
6	John R Park (ERCA)	41.9956	-82.8486	178	Hourly	2019-09-01 to 2022-06-30	TMP, PCP, RH*, WS*, SLR*
7	Windsor A (ECCC)	42.28	-82.96	190	Daily and hourly	1970-01-01 to 2014-10-02	WD only

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

The Wigle Creek subwatershed has a climate with pronounced seasonal variations. The growing season begins in late April and ends in late October with an annual average of about 180 frost free days. At station 2 (ECCC Kingsville MOE), the average annual precipitation was 858 mm from 1995 to 2021 with a standard deviation of 127 mm. The maximum annual precipitation of 1,346 mm occurred in 2011, and the minimum was 667 mm, occurring in 2012. The maximum daily precipitation was 94 mm, recorded on July 21, 2003. The average annual temperature was 10.2 °C from 1995 – 2021, ranging from 11.8 °C in 1998 to 8.64 °C in 2014 with a standard deviation of 0.833 °C. Figure 2-7 shows yearly precipitation, snowfall, and temperature from 1995 – 2021 at station 2 (ECCC Kingsville MOE). Annual precipitation and temperature are on average increasing, while annual snowfall is on average decreasing (Figure 2-7).

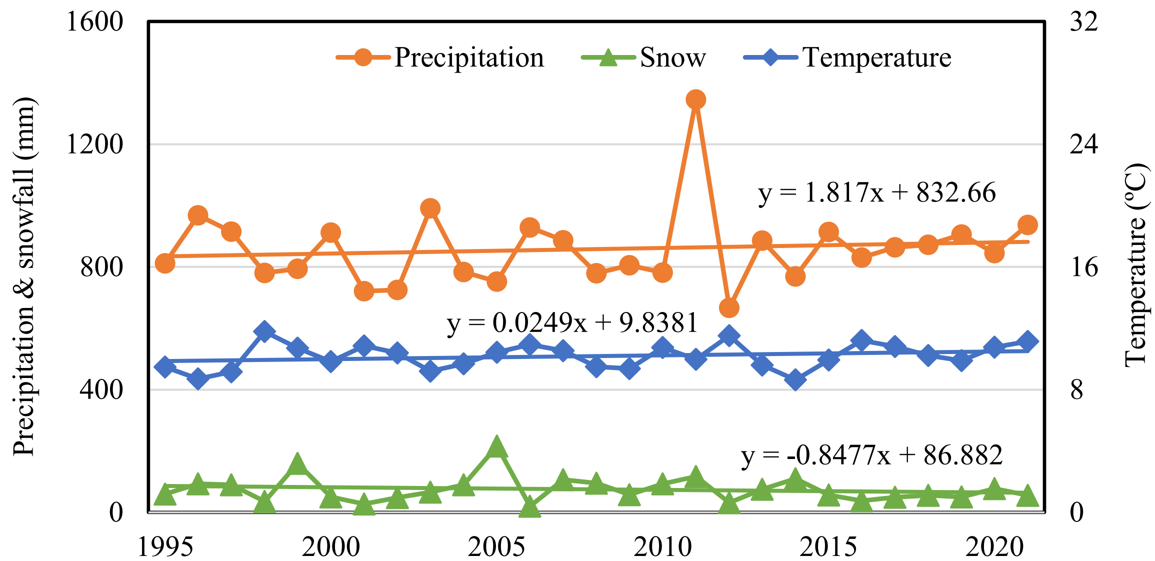

Figure 2-6. Variation of yearly precipitation and average temperature at station 2 (ECCC Kingsville MOE) from 1995-01-01 to 2021-12-31

Temperature is highest in the summer months from June to September, and lowest in the winter months from December to March in the Wigle Creek subwatershed (Figure 2-8 and Table 2-5). Precipitation is distributed somewhat evenly across the seasons, with May having the highest monthly precipitation of 94.5 mm and February having the lowest monthly precipitation of 50.2 mm. Table 2-5 shows that on average, 11.4% of yearly precipitation falls as snow in the Wigle Creek subwatershed. Snowfall occurs from November to April, and the months with the highest average snowfall amounts are January (24.2 mm), February (19.9 mm), and December (15.2 mm).

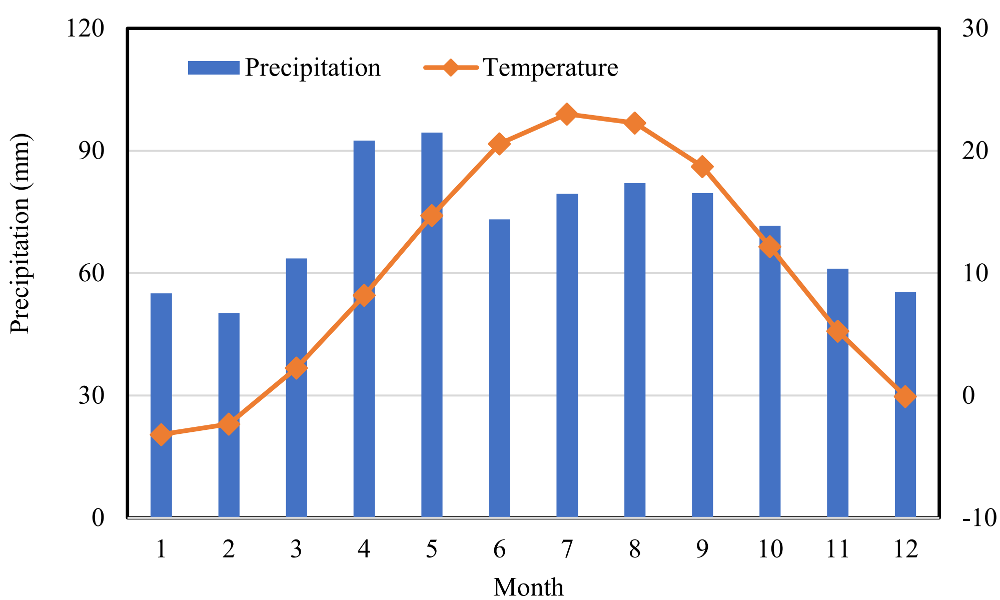

Figure 2-7. Average monthly precipitation and average temperature variation at station 2 (ECCC Kingsville MOE) from 1995-01-01 to 2021-12-31

Table 2-5. Average monthly precipitation and temperature at station 2 (ECCC Kingsville MOE) from 1995-01-01 to 2021-12-31.

Month	T_max (°C)	T_min (°C)	T_avg (°C)	Precipitation (mm)	Snowfall (mm)	(%)
1	-0.138	-6.23	-3.19	55.1	24.2	43.9
2	0.983	-5.63	-2.32	50.2	19.9	39.6
3	6.07	-1.58	2.24	63.6	11.9	18.6
4	12.5	3.81	8.18	92.5	1.68	1.81
5	19.1	10.3	14.7	94.5	0.00	0.00
6	24.7	16.4	20.6	73.1	0.00	0.00
7	27.1	18.9	23.0	79.4	0.00	0.00
8	26.3	18.2	22.3	82.1	0.00	0.00
9	22.8	14.6	18.7	79.6	0.00	0.00
10	15.8	8.56	12.2	71.6	0.00	0.00
11	8.39	2.14	5.26	61.1	3.24	5.30
12	2.63	-2.79	-0.079	55.4	15.2	27.4
Ave/Sum	13.9	6.40	10.1	858	76.0	11.4
Max	27.1	18.9	23.0	94.5	24.2	43.9
Min	-0.138	-6.23	-3.19	50.2	0.00	0.00
STDV	10.2	9.35	9.75	14.7	8.96	16.7

Figure 2-9 presents baseflow separation at the Wigle Creek outlet station (Wigle 1 – see Figure 3-1) from 2016 – 2022. Based on the SWAT Baseflow Separation tool, baseflow contributed to about 20% of total streamflow at the Wigle Creek outlet from 2016-01-07 to 2022-06-30.

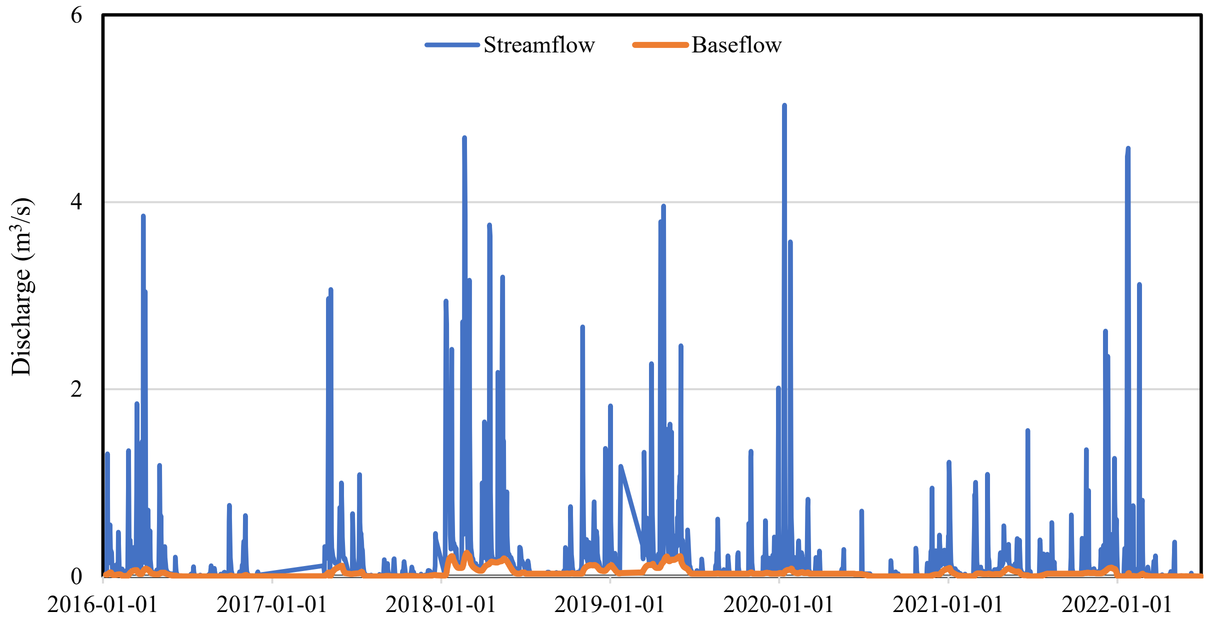

Figure 2-8. Baseflow separation at ERCA Wigle 1 station over the period of 2016 – 2022

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 Essex Region Conservation Authority (ERCA), Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), and other sources.

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

Data	Format	Source	Use
LiDAR DEM (0.5x0.5 m)	TIFF	ERCA	Model setup
Soil	Shape	OMAFRA	Model setup
Land use	Shape	ERCA & Rudra et al. (2019)	Model setup
Crop inventory 2011-2021	TIFF (30x30 m)	AAFC	Model setup and crop rotation
Stream network	Shape	ERCA	Watershed delineation
Waterbodies	Shape	ERCA	Watershed delineation
Boundary	Shape	ERCA	Watershed delineation
Climate, flow, and water quality stations	Shape	ERCA, ECCC, NASA	Model setup

Field boundary	Shape	ERCA	Model setup
Tile drain	Shape	OMAFRA	Model setup

Note: ERCA stands for Essex Region 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.

3.2 Climate Data

The IMWEBs requires daily precipitation, minimum temperature, maximum temperature, relative humidity, wind speed, wind direction, and solar radiation as input for the model. Climate data were prepared for 1970-01-01 to 2022-06-30 using Environment and Climate Change Canada (ECCC), National Aeronautics and Space Administration (NASA), and Essex Region Conservation Authority (ERCA) 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 ERCA monitoring stations (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 Wigle Creek subwatershed

Name	Description	Drainage Area (km^2)	Flow	Sediment	Nutrient
HFN	Grab sample site	0.017	-	2020-2022	2020-2022
HFM	Grab sample site	0.016	-	2020-2022	2020-2022
HFS	Grab sample site	0.023	-	2020-2022	2020-2022
W CD	Grab sample site	1.02	-	2016-2017	2016-2017
W DD	Grab sample site	17.9	-	2016-2017	2016-2017
W KD	Grab sample site	14.9	-	2016-2017	2016-2017
W Rd6	Grab sample site	7.75	-	2016-2022	2016-2022
Wigle 1	Main branch	20.6	2016-2022	2015-2022	2015-2022

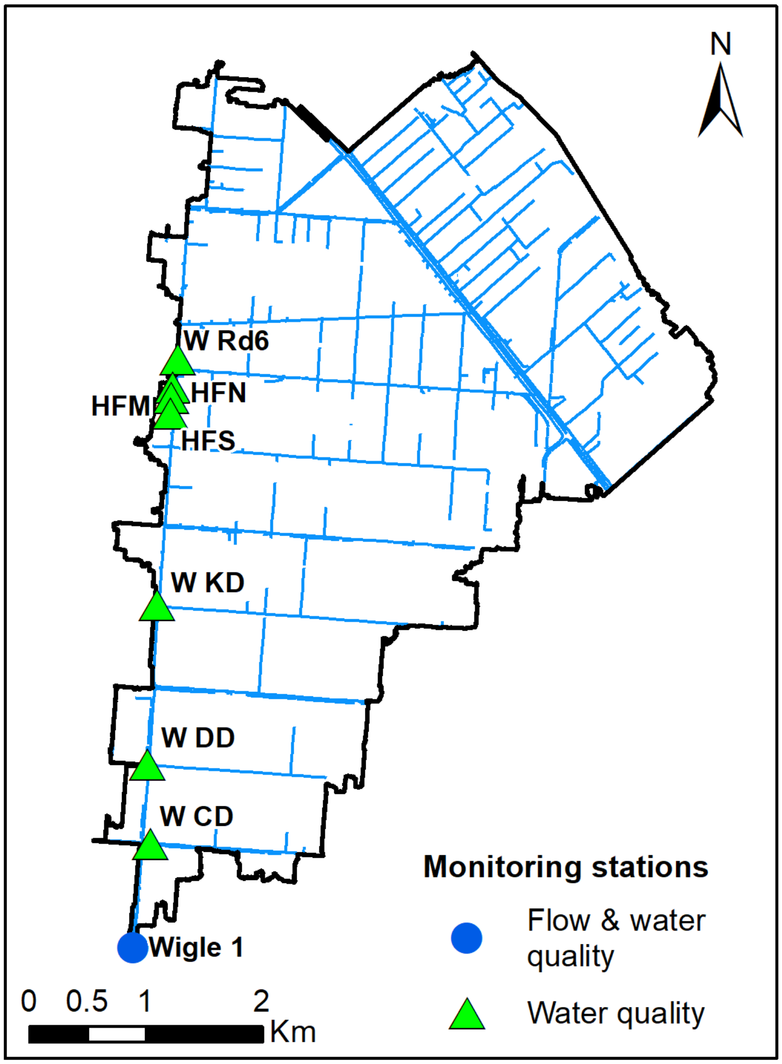

Figure 3-1. Flow and water quality monitoring stations in the Wigle Creek subwatershed

3.4 Land Management Data

ERCA staff conducted land management surveys for the ONFARM project in 2022. Table 3-3 describes the key parameters included in the land management dataset. ERCA staff also collected windshield survey and GLASI survey for several years in 2016 – 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 and GLASI surveys. These datasets were combined to establish a land management database spanning 2011 – 2022 for the Wigle 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 Wigle Creek subwatershed.

Items	Description
Land features	Field 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

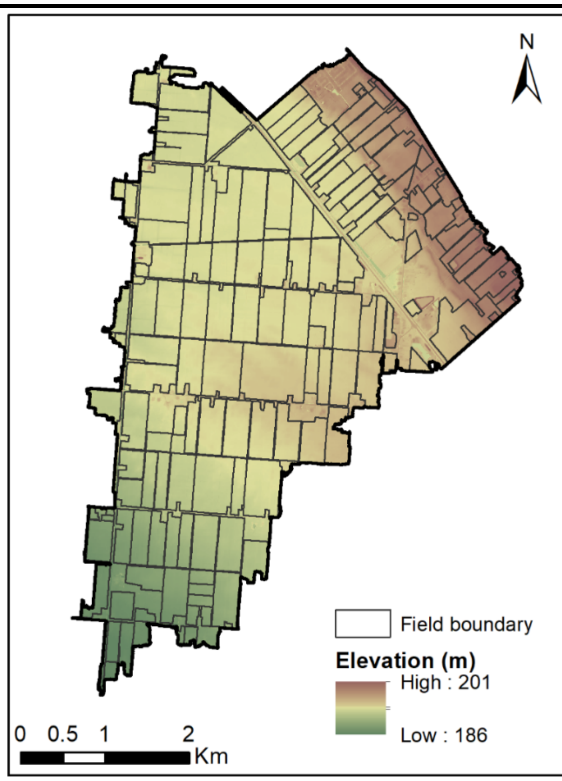

Figure 3-2. Field boundaries used for the Wigle Creek subwatershed IMWEBs modelling

4.0 IMWEBS MODEL SETUP

4.1 Overview of the IMWEBs model

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

4.2 Watershed delineation

The IMWEBs model uses the Digital Elevation Model (DEM) and stream network to delineate the watershed boundary. The watershed was delineated by burning the stream network into the DEM to ensure accurate flow routing. The flow and water quality monitoring stations were specified as subbasin outlets. The stream initiation threshold was set to 1 ha, in order to delineate subbasins for the monitoring stations with the smallest contributing areas. Figure 4-1 shows the delineated watershed for the Wigle Creek IMWEBs modelling, which contains 1,466 subbasins.

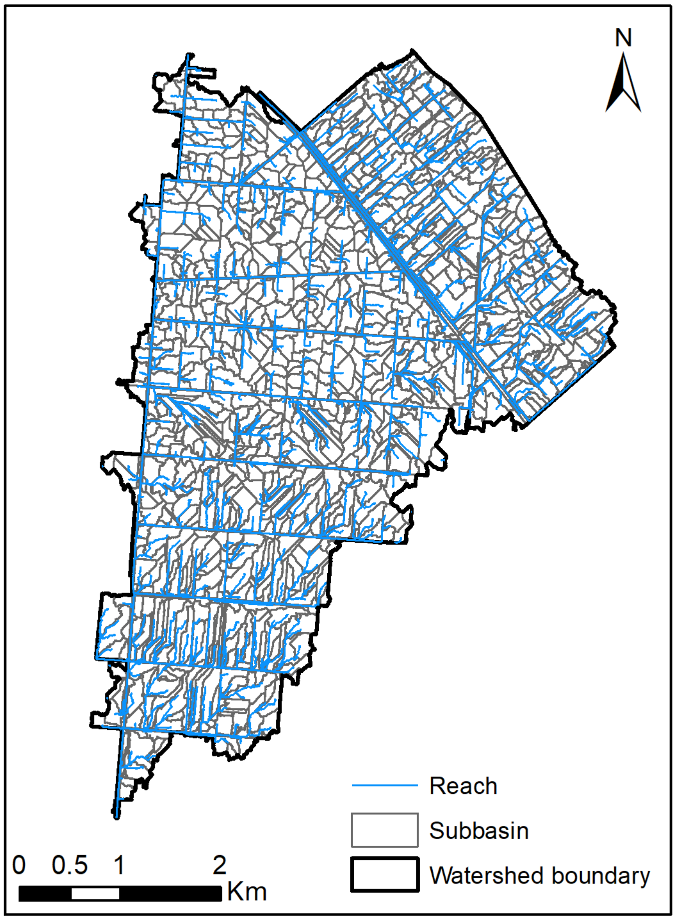

Figure 4-1. Delineated watershed boundary, subbasins, and reaches for the Wigle Creek IMWEBs modelling

4.3 Soil characterization

Soil properties are important factors in controlling infiltration and soil water movement, and play a key role in surface runoff, groundwater recharge, evapotranspiration, soil erosion, and the transport of chemicals. The OMAFRA Soil Survey Complex was used to define soil type distribution and key soil parameters for the Wigle Creek IMWEBs modelling. A summary of soil characterization for the Wigle Creek subwatershed IMWEBs modelling is provided in Table 2-2.

4.4 Landuse characterization

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

4.5 Subarea definition

The IMWEBs model uses subareas to reduce the computer processing times associated with the cell-based IMWEBs model. Subareas are the smallest management unit for defining land management operations and structural BMPs. The subarea layer was created by intersecting the field boundary layer with the subbasin layer. Figure 4-2 presents the subarea layer for the Wigle Creek subwatershed modelling, which contains 5,155 subareas.

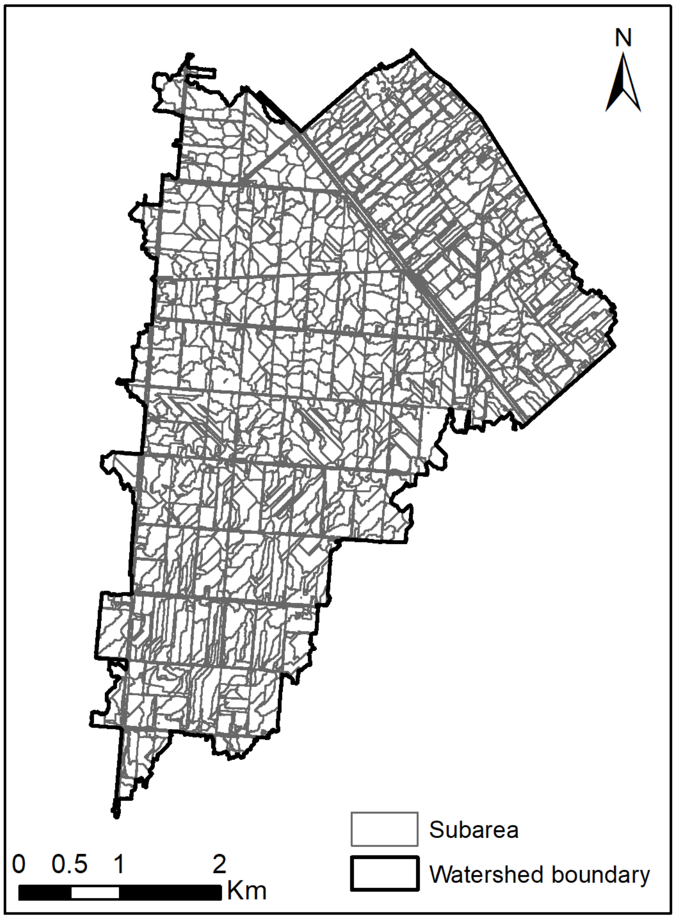

Figure 4-2. Subarea layer for the Wigle Creek subwatershed IMWEBs modelling

4.6 Land management operations

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

4.7 Tile drain characterization

All fields were assumed to be tile drained in the Wigle Creek subwatershed based on information provided by ERCA. The ONFARM land management survey contained tile drain spacing and tile depth data, which were incorporated into the IMWEBs modelling. For fields that did not have tile drain spacing and depth data listed in the survey, the dominant depth and spacing from the survey was assumed. Table 4-1 presents tile drain parameters for the Wigle Creek subwatershed, including the dominant tile radius, spacing and 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 Wigle Creek subwatershed IMWEBs modelling.

Start month for controlled tile drain	End month for controlled tile drain	Radius (mm)	Spacing (mm)	Tile drain Depth (mm)	Controlled tile drain depth (mm)
April	October	50	7,620	610	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 the historical/existing observed conditions. Observed data from monitoring site Wigle 1 was used for model calibration with flow and water quality data available from 2016-01-01 to 2021-12-31. The water quality data at the other 7 stations were used for reference purposes only during model calibration. The typical model calibration procedure was to calibrate firstly for flow; followed by sediment, particulate P, and particulate N; and lastly dissolved P and dissolved N.

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

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

where NSC is the Nash-Sutcliffe efficiency, Qo_i 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.

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

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 typically used for measuring the performance on IMWEBs calibration of TSS, N and P.

5.2 Flow calibration

We examined precipitation and flow data pattern during 2016-2021 and identified significant data challenges:

1. There were several days with significant mismatch between observed precipitation and flow data.
   1). 2017-11-05, 58 mm of precipitation and flow under 0.001 m^3/s combined with positive temperature.
   2). 2017-11-18 and 2017-11-19, -> 43 mm of precipitation and flow under 0.03 m^3/s combined with positive temp.
   3). 2018-01-10, 0 precipitation, no snow accumulation, positive temperature, very high measured flow.
   4). 2020-01-12, 0 precipitation, no snow accumulation, positive temp, very high measured flow.
2. There were 222 days with missing flow records (Figure 5-1), which were 10.2% of the total days during this period. Most of the missing flow data (139 points) were between the end of 2016 and beginning of 2017. There were also more missing data in middle of 2019 and some days in 2020.

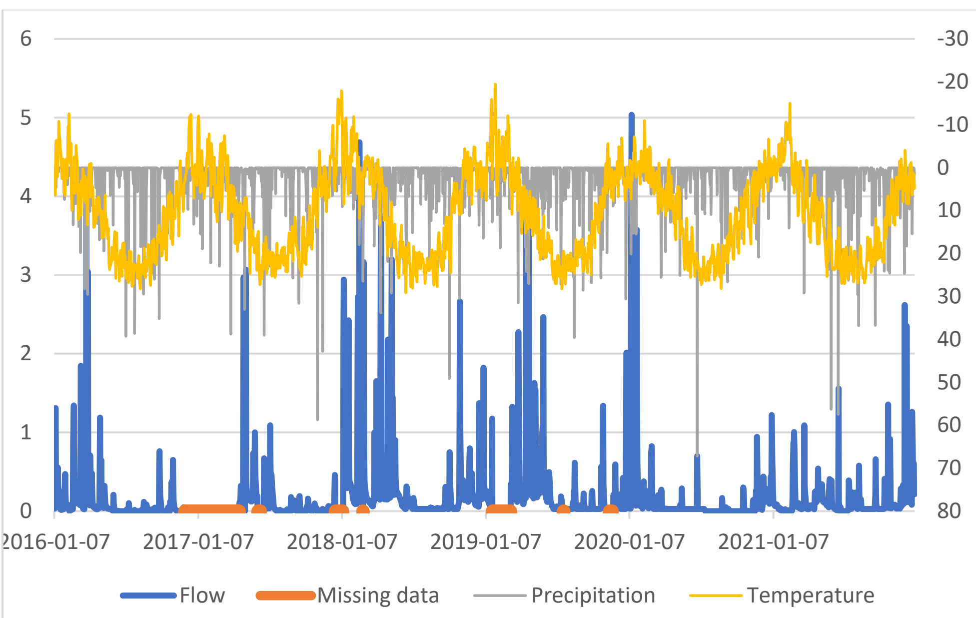

Figure 5-1. The time periods with missing flow records in the Wigle Creek subwatershed

3. There were 333 constant daily flow records of 0.028 m^3/s in 2017, 2018, 2019, 2020, and 2021 (Figure 5-2), which were 15.2% of the total days during this period. There were several long periods of constant 0.028 m^3/s flow. There was a possibility that these periods had no flow values (dried up) and were replaced with a constant 0.028 m3/s flow.
   1). 2018-07-13 to 2018-08-17, 2018-08-24 to 2018-09-20, 2018-10-16 to 2018-10-27.
   2). 2019-06-28 to 2019-07-16, 2019-07-25 to 2019-08-15, 2019-08-26 to 2019-09-30, 2019-10-13 to 2019-10-25.
   3). 2020-03-13 to 2019-03-18, 2020-03-26 to 2020-07-23.
   4). 2021-08-20 to 2021-10-14.

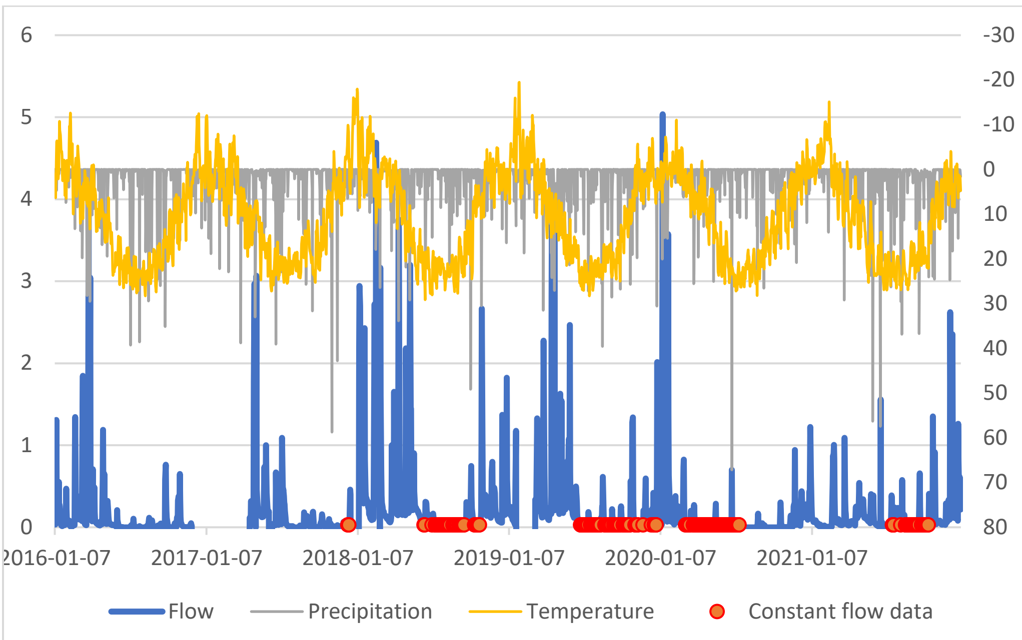

Figure 5-2. The time periods with constant flow records in the Wigle Creek subwatershed

We made efforts to calibrate flow for the Wigle Creek IMWEBs model with all flow records. We achieved a NSC of 0.28, a PBIAS of 17.1% and a CORR of 0.6, which indicated a poor model performance based on the criteria outlined in Moriasi et. al (2007) (Figure 5-3).

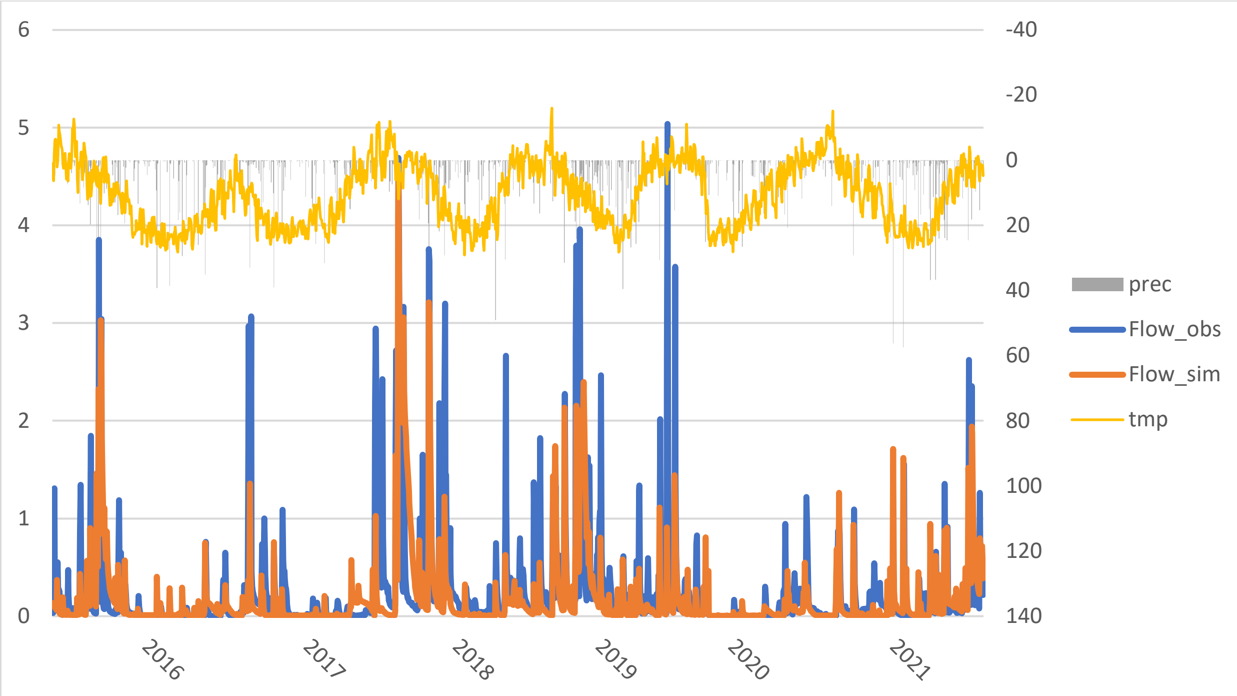

Figure 5-3. Flow calibration for the Wigle Creek watershed with all flow records

We made efforts to adjust precipitation or flow data for those days with significant mismatch between observed precipitation and flow data based on judgement.

1). 2017-11-05, 58 mm of precipitation and flow under 0.001 m3/s combined with positive temperature. The precipitation was changed to 0.

2). 2017-11-18 and 2017-11-19, -> 43 mm of precipitation and flow under 0.03 m3/s combined with positive temp. The precipitation was changed to 0.

3). 2018-01-10, 0 precipitation, no snow accumulation, positive temperature, very high measured flow. The precipitation was added by 40 mm.

4). 2020-01-12, 0 precipitation, no snow accumulation, positive temp, very high measured flow. The precipitation was added by 20 mm.

After that we made efforts to calibrate the Wigle Creek IMWEBs model and excluded those periods with constant 0.028 m3/s flow in the model performance calculation. We achieved a NSC of 0.6, a PIAS of 0.3% and a CORR of 0.6, which indicated a good model performance based on the criteria outlined in Moriasi et. al (2007) (Figure 5-4). However, our adjustment of precipitation or flow data maybe not a scientifically valid practice. Preferably we can work with ERCA monitoring staff to make these adjustments based on other sources of data and their local experience. The significant limitation in model calibration will likely cause problems on watershed flow prediction and TSS and nutrient calibration. Therefore, we decided not to proceed with TSS and nutrient calibration and BMP assessment for the Wigle Creek watershed.

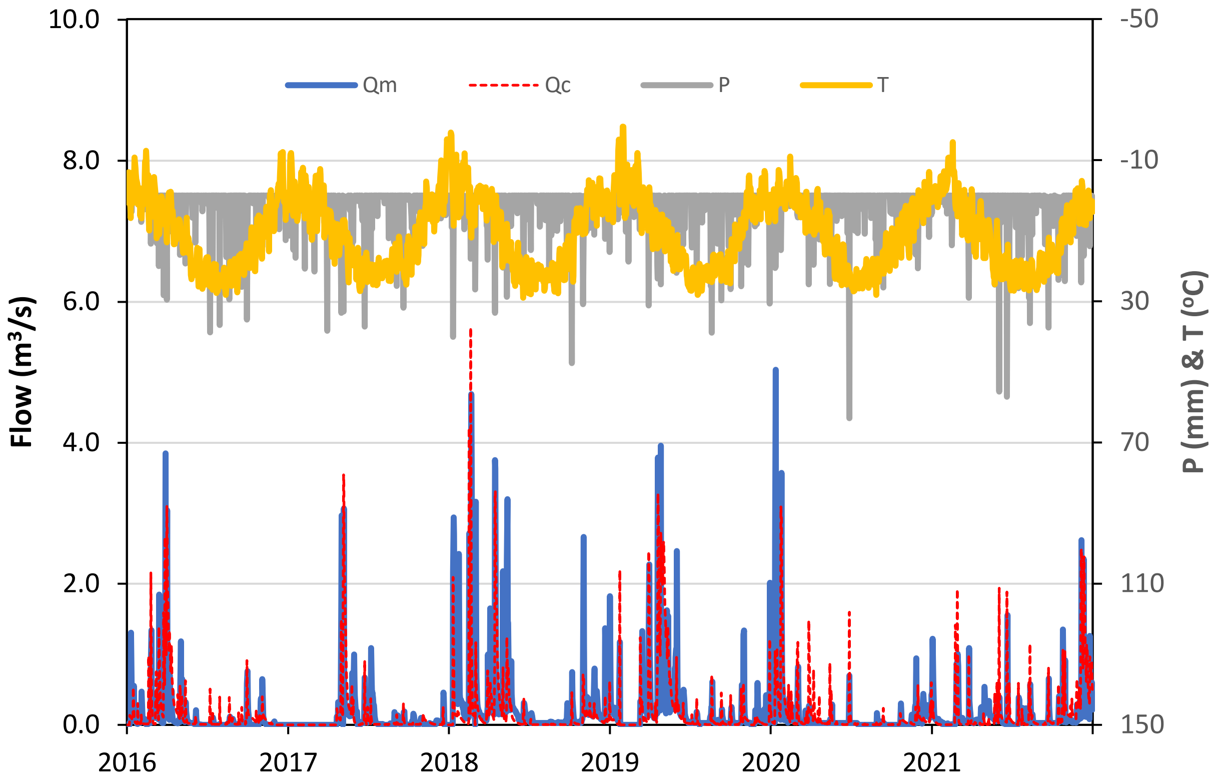

Figure 5-4. Flow calibration for the Wigle Creek watershed with adjusted precipitation and excluded flow records (Note: Qm. measured flow; Qc, calculated/simulated flow; P, precipitation; T, temperature)

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 AND BMP ASSESSMENT APPROACHES

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 in the watershed. 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 Wigle 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, GLASI and windshield surveys, such as conservation tillage, no-till, cover crops, and fertilizer/manure incorporation for the period from 2011 to 2022, respectively. 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 BMP 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 Assumption 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 cropping scenario was defined by adding either oats or rye as a cover crop to all crop fields and all years that did not already have an existing cover crop in the existing actual BMP scenario. 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 Wigle 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 Wigle Creek subwatershed in order to develop a reliable model that could be applied to simulate average yearly stream flow 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 Garvey Glenn and Upper Medway Creek subwatersheds.

8.0 BMP COST-EFFECTIVENESS ANALYSIS

No BMP cost-benefit analysis was done for the Wigle Creek watershed. No BMP assessment was done for the Wigle Creek watershed. Therefore, no BMP cost-effectiveness was done for the Wigle Creek watershed. Readers are referred to other ONFARM watershed modelling reports (for the Garvey Glenn and Upper Medway Creek subwatersheds) which had successful watershed calibration and BMP assessment results to obtain examples of the BMP cost-effectiveness analysis approach.

9.0 CONCLUSIONS

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 Wigle 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 Wigle 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

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