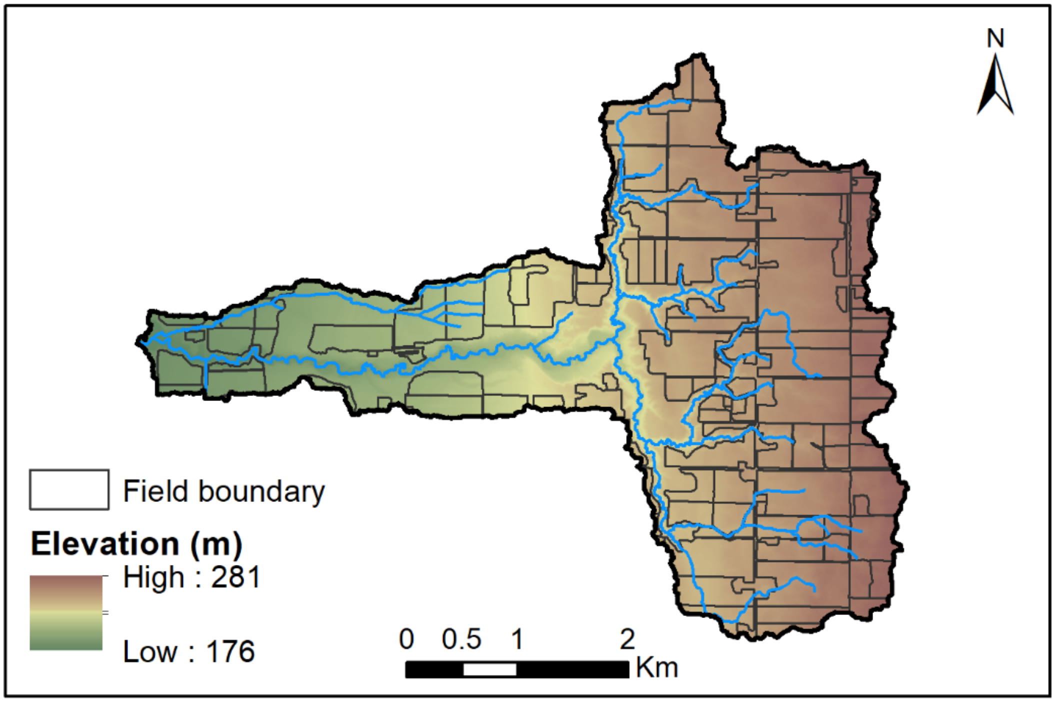


ONFARM

# Modelling Report – Gully Creek

June 28, 2023

Prepared by:

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## 1.0 INTRODUCTION

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

From 2015 to 2018, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and the Ontario Soil and Crop Improvement Association (OSCIA) jointly implemented the Great Lakes Agricultural Stewardship Initiative (GLASI). In GLASI, the Gully Creek subwatershed was selected as one of the six priority subwatersheds for BMP establishment and study. By building upon ABCA’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 Gully Creek subwatershed, primarily conservation tillage, precision nutrient management, cover cropping, soil amendments with manure application, construction of agricultural upland erosion control structures such as Water and Sediment Control Basins (WASCoBs), and windbreaks. As a component of the GLASI, Soil and Water Assessment Tool (SWAT) modelling of the Gully Creek subwatershed was conducted to evaluate the water quality effects of various BMP scenarios (Watershed Evaluation Group, 2018).

The On-Farm Applied Research and Monitoring (ONFARM) program, administered by OMAFRA and OSCIA from 2019 to 2023, further developed soil health and water quality research on farms across Ontario. ONFARM extended previous work under the GLASI priority subwatersheds to evaluate BMP effects on soil health and water quality. In the ONFARM project, ABCA 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 Gully Creek subwatershed. Specifically, the modelling project had the following objectives:

1). Collect and prepare IMWEBs modelling input data;

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

3). Apply IMWEBs modelling to evaluate the environmental effectiveness (including P loss reduction efficacies) and cost effectiveness of the three key BMPs of interest (cover cropping, conservation tillage, and fertilizer/manure incorporation following application) presently existing or being applied in the study watersheds – referred to in this report as 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, and fertilizer/manure incorporation following application) under different implementation levels and placement strategies across the watershed.

## 2.0 STUDY AREA

### 2.1 Location

The Gully Creek subwatershed is located in southwestern Ontario, about 13 km south of the Town of Goderich (Figure 2-1). The Gully Creek subwatershed drains directly to Lake Huron, about 6 km north of Bayfield. The watershed has a drainage area of 1,474 ha.

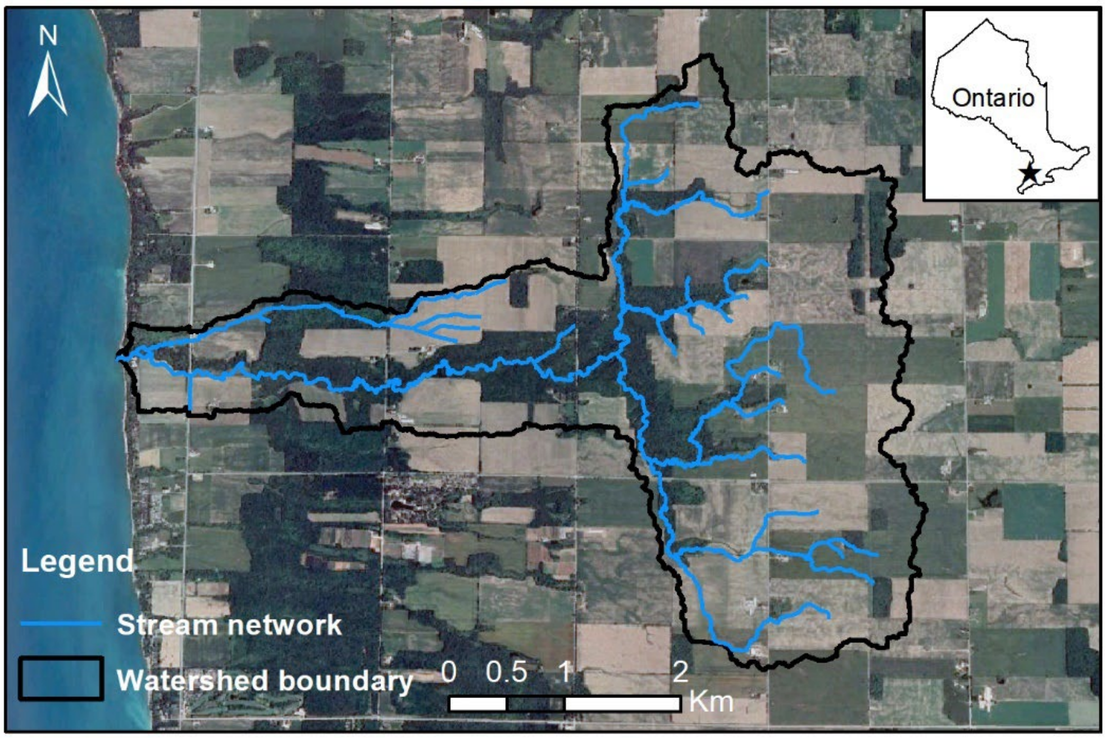


Figure 2-1. The Gully Creek subwatershed within southwestern Ontario

### 2.2 Topography, soil, and landuse

The Gully Creek subwatershed has undulating topography sloping from the highest elevation of 282 m in the east, to the lowest elevation of 176 m at the watershed outlet in the west (Figure 2-2). The watershed is characterized by deep incised gullies along the mainstream and at the watershed outlet. The average slope (according to the 1-m pixel resolution hydro-conditioned LiDAR DEM) is 7.48%, with a minimum of 0.00% in flat areas and up to 370% (75 degrees) at incised gullies (Figure 2-3, Table 2-1).

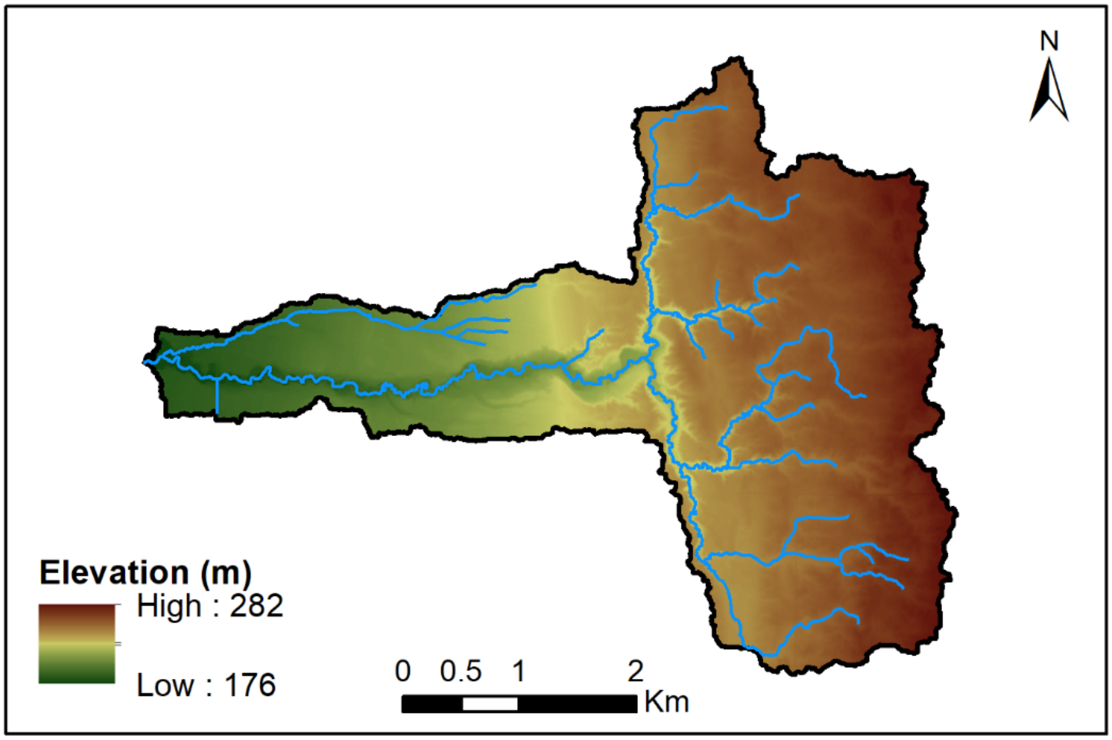


Figure 2-2. Topography of the Gully Creek subwatershed

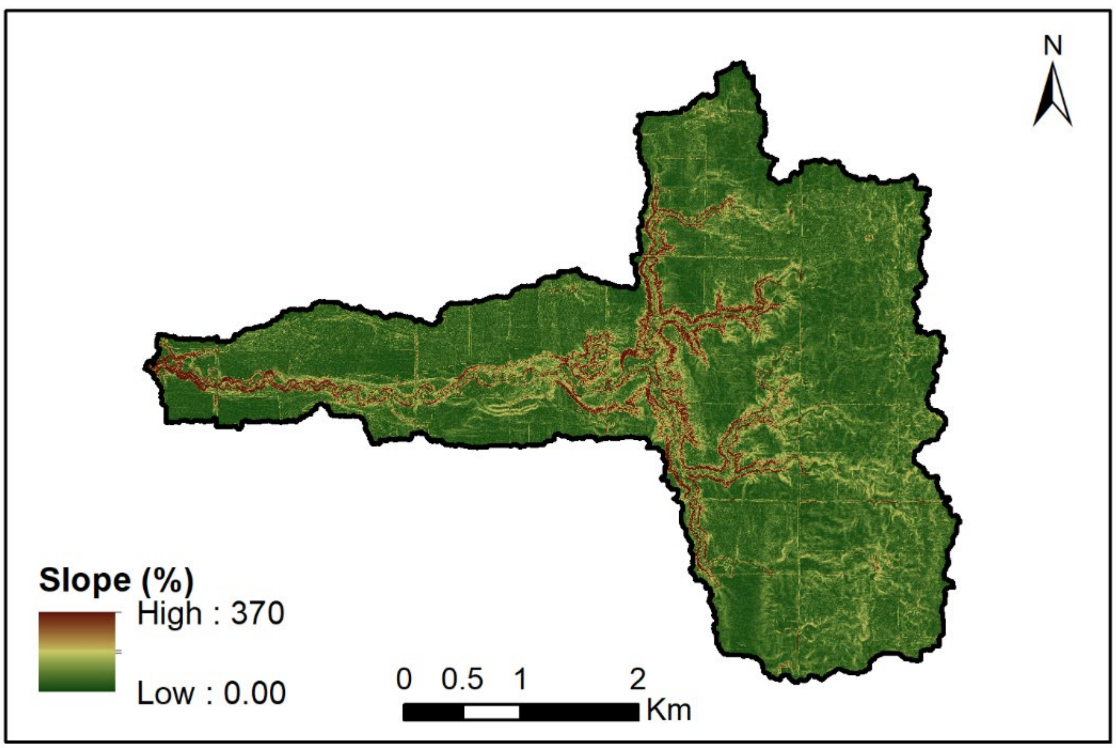


Figure 2-3. Slope of the Gully Creek subwatershed

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

| Class | Elevation (m) | Areal extent | | Slope (%) | Areal extent | |
|---|---|---|---|---|---|---|
| | | ($km^2$) | (%) | | ($km^2$) | (%) |
| 1 | 176 - 207 | 1.27 | 8.58 | 0.00 - 5.77 | 8.86 | 60.1 |
| 2 | 208 - 225 | 1.90 | 12.9 | 5.78 - 17.3 | 4.67 | 31.7 |
| 3 | 226 - 244 | 1.81 | 12.3 | 17.4 - 36.1 | 0.847 | 5.75 |
| 4 | 245 - 260 | 5.35 | 36.3 | 36.2 - 64.9 | 0.293 | 1.99 |
| 5 | 261 - 282 | 4.41 | 29.9 | 65.0 - 370 | 0.065 | 0.438 |
| Average/sum | 246 | 14.7 | 100 | 7.48 | 14.7 | 100 |

The map of soil type distribution based on OMAFRA Soil Survey Complex is shown in Figure 2-4. The soil names and areal extents corresponding to each soil type within the Gully Creek subwatershed are shown in Table 2-2. The eastern headwaters region of the subwatershed is dominated by Clay Loam soil texture, whereas the western downstream region is dominated by Sandy Loam soil texture.

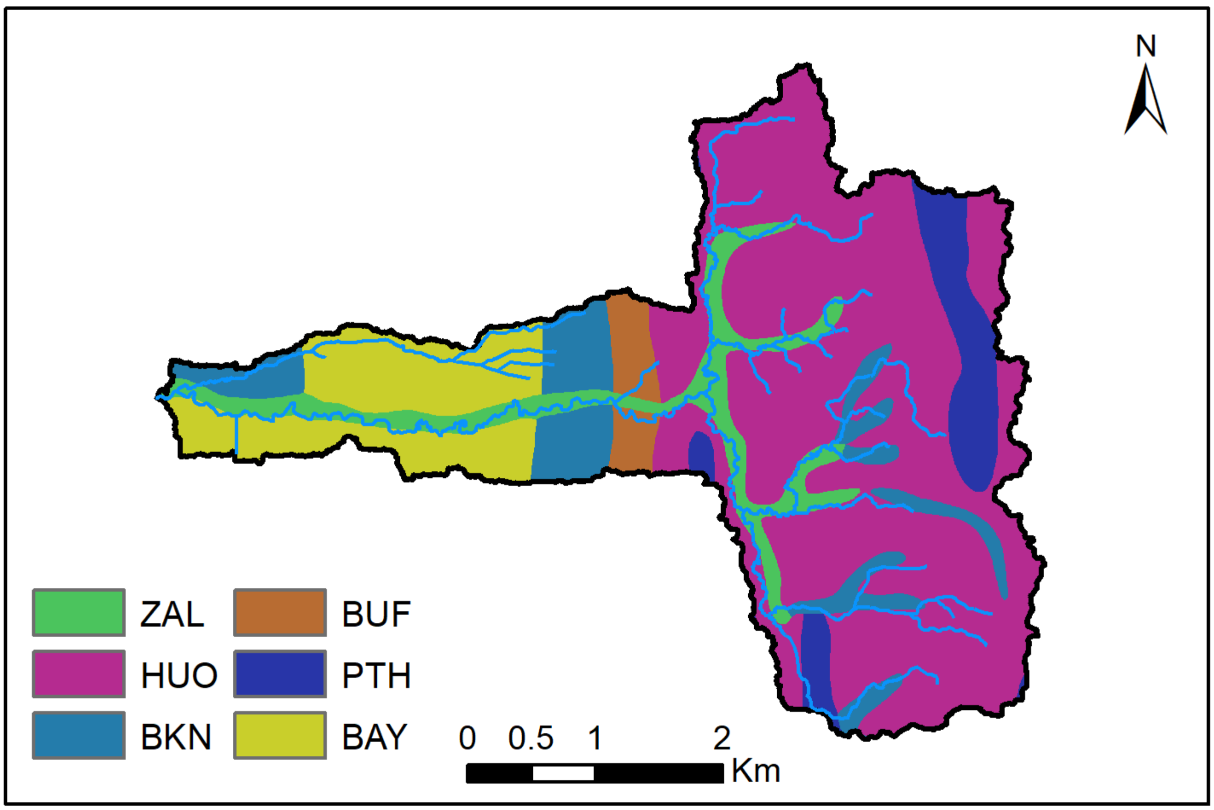


Figure 2-4. Soil types in the Gully Creek subwatershed based on OMAFRA soil survey data

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

| Soil code | Soil type | Hydrologic group | Soil texture | Area (ha) | Area (%) |
|---|---|---|---|---|---|
| HUO | Huron Clay Loam | C | CL | 829 | 56.3 |
| BAY | Brady Sandy Loam | B | SL | 201 | 13.7 |
| BKN | Brookston Clay Loam | D | CL | 158 | 10.7 |
| ZAL | Bottom Land | B | LS | 137 | 9.32 |
| PTH | Perth Clay Loam | C | CL | 104 | 7.06 |
| BUF | Burford Loam | A | L | 44.0 | 2.98 |

Figure 2-5 presents the landuse distribution within the Gully Creek subwatershed. The landuse names and associated areas and percentages within the Gully Creek subwatershed are listed in Table 2-3. Approximately 68% of the land is agricultural, while 25% is forest, 3.2% is urban (i.e., residential and transportation), and less than 4% is grassland.

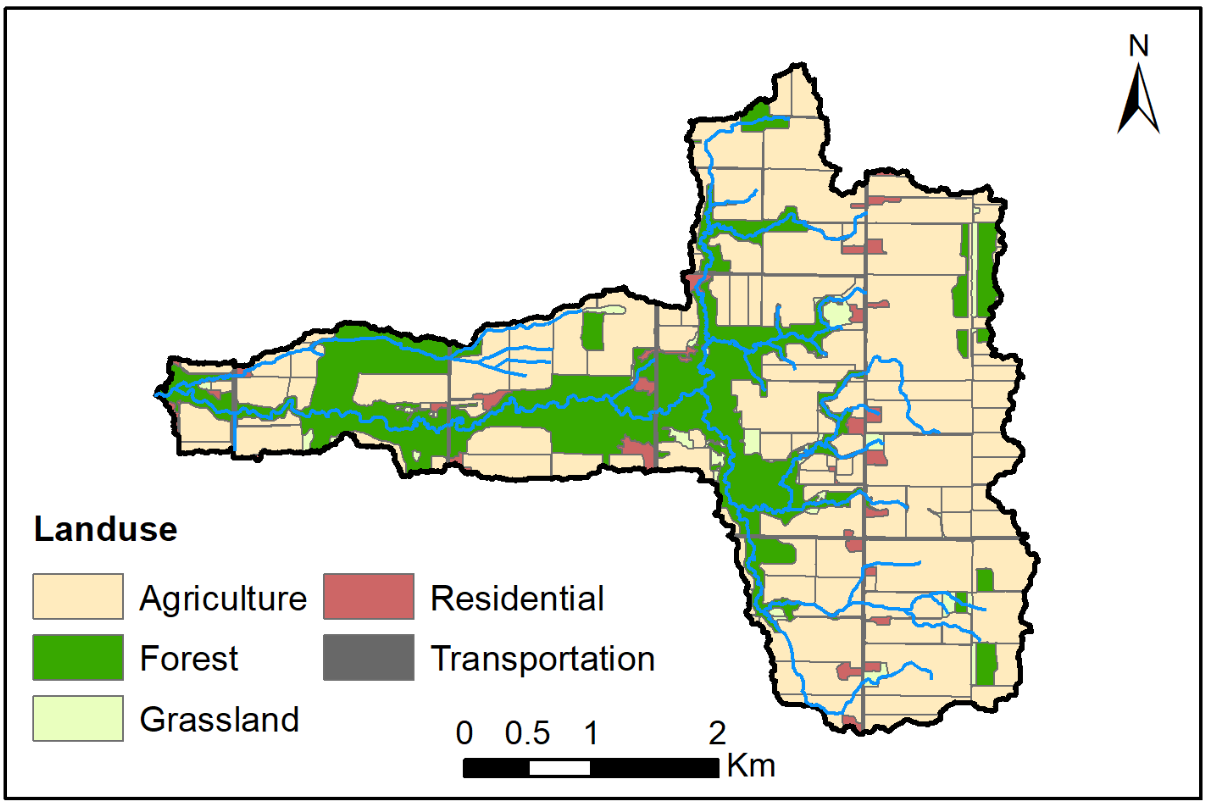


Figure 2-5. Landuse in the Gully Creek subwatershed

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

| Landuse type | Area (ha) | Percent (%) |
|---|---|---|
| Agriculture | 1,001 | 67.9 |
| Forest | 376 | 25.5 |
| Grassland | 49.6 | 3.36 |
| Residential | 38.1 | 2.59 |
| Transportation | 9.26 | 0.629 |
| Total | 1,474 | 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 ABCA stations and seven 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 ABCA 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.

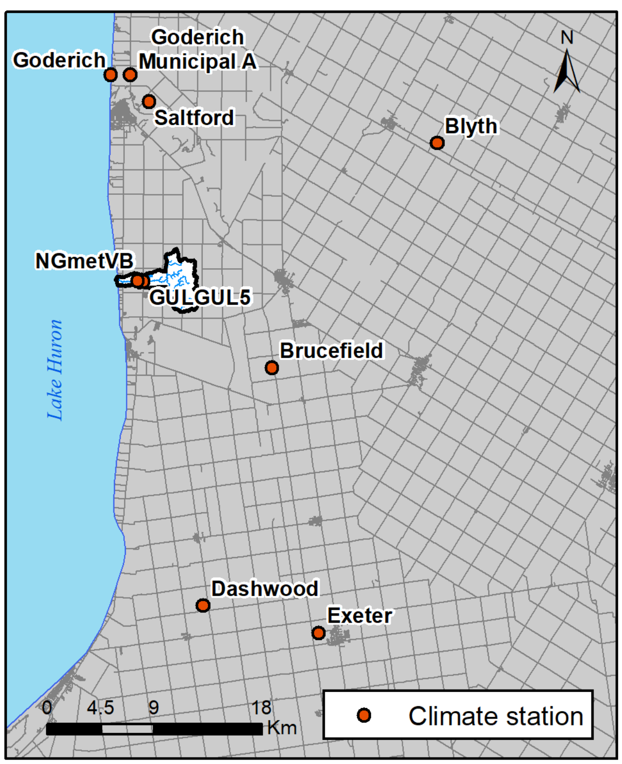


Figure 2-6. Climate monitoring stations for the Gully Creek subwatershed IMWEBs modelling

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

| ID | Name | Latitude | Longitude | Elevation | Frequency | Period | Parameters |
|---|---|---|---|---|---|---|---|
| 1 | Blyth (ECCC) | 43.72 | -81.38 | 351 | Daily | 1970-01-01 to 2010-01-31 | PCP, TMP, RH*, SLR*, WS* |
| 2 | Brucefield (ECCC) | 43.55 | -81.55 | 259 | Daily | 1970-01-01 to 1993-12-31 | PCP, TMP, RH*, SLR*, WS* |
| 3 | Dashwood (ECCC) | 43.37 | -81.62 | 253 | Daily | 1976-04-14 to 2000-12-31 | PCP, TMP, RH*, SLR*, WS* |
| 4 | Exeter (ECCC) | 43.35 | -81.50 | 262 | Daily | 1970-01-01 to 2008-04-15 | PCP, TMP, RH*, SLR*, WS* |
| 5 | Goderich (ECCC) | 43.77 | -81.72 | 214 | Hourly and Daily | 1994-12-30 to 2022-06-30 | PCP, TMP, RH, WS, WD, SLR* |
| 6 | Goderich Municipal A (ECCC) | 43.77 | -81.70 | 213 | Hourly and Daily | 1970-01-01 to 1980-10-31 | PCP, TMP, RH, WS, WD, SLR* |
| 7 | Saltford (ECCC) | 43.75 | -81.68 | 229 | Daily | 1976-01-01 to 1994-09-30 | PCP, TMP, RH*, SLR*, WS* |
| 8 | GULGUL5 (ABCA) | 43.614 | -81.685 | 223 | 5 Minutes | 2013-01-11 to 2022-06-30 | PCP, RH*, SLR*, WS* |
| 9 | NGmetVB (ABCA) | 43.615 | -81.691 | 217 | 5 minutes | 2012-01-01 to 2022-05-19 | PCP, TMP, RH, SLR, WS, WD |

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

The Gully Creek subwatershed has a climate with pronounced seasonal variations. The growing season begins in early May and ends in October with an annual average of about 160 frost free days. At station 9 (ABCA NGmetVB), the average annual precipitation was 793 mm from 2012 – 2021 with a standard deviation of 93 mm. The maximum annual precipitation of 947 mm occurred in 2013, and the minimum was 635 mm, occurring in 2012. The maximum daily precipitation was 63 mm, recorded on July 14, 2015. The average annual temperature was 8.5 °C from 2012 – 2021, ranging from 9.7 °C in 2016 to 6.6 °C in 2014 with a standard deviation of 0.94 °C. Yearly precipitation and average temperature from 2012 – 2021 at station 9 (ABCA NGmetVB) is presented in Figure 2-7. Annual precipitation and temperature are on average increasing from 2012 – 2021.

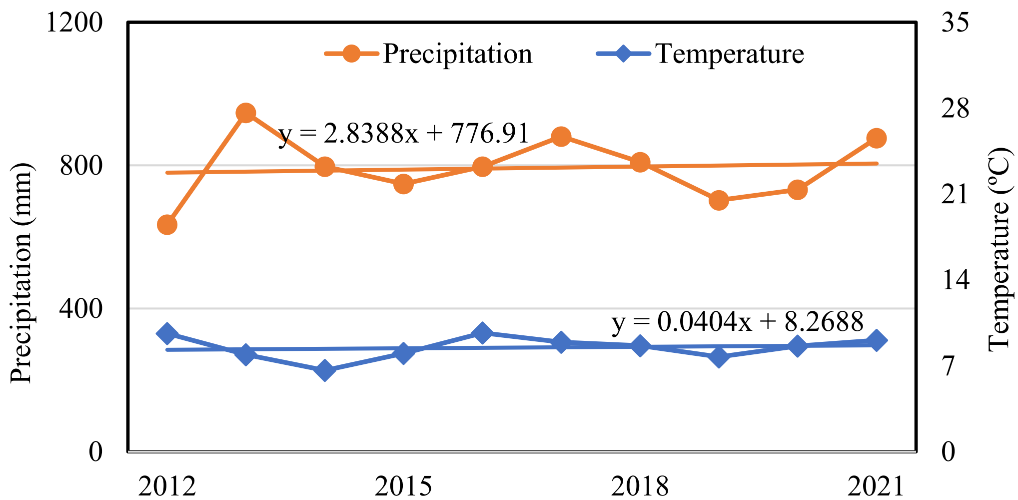


Figure 2-7. Variation of yearly precipitation and average temperature at station 9 (ABCA NGmetVB) from 2012-01-01 to 2021-12-31

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

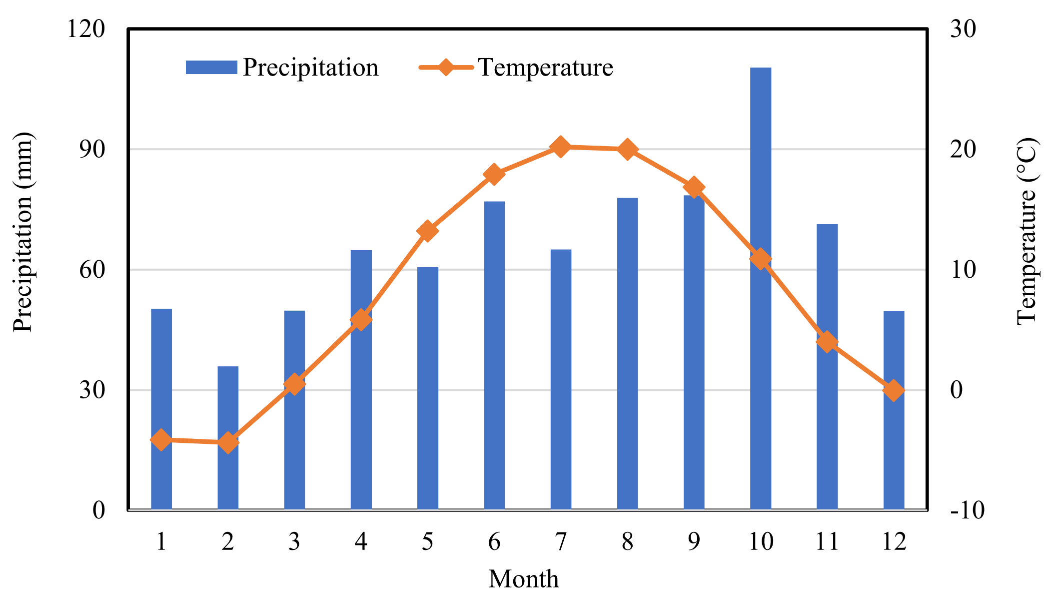


Figure 2-8. Average monthly precipitation and average temperature at station 9 (ABCA NGmetVB) from 2012-01-01 to 2021-12-31

Table 2-5. Average monthly precipitation and temperature at station 9 (ABCA NGmetVB) over the period of 2012 – 2021.

| Month | T_max (°C) | T_min (°C) | T_avg (°C) | Precipitation (mm) |
|---|---|---|---|---|
| 1 | -0.800 | -7.49 | -4.15 | 50.2 |
| 2 | -0.591 | -8.15 | -4.37 | 35.9 |
| 3 | 4.92 | -3.91 | 0.504 | 49.8 |
| 4 | 10.9 | 0.78 | 5.85 | 64.9 |
| 5 | 18.8 | 7.61 | 13.2 | 60.7 |
| 6 | 23.3 | 12.5 | 17.9 | 77.0 |
| 7 | 25.7 | 14.7 | 20.2 | 65.0 |
| 8 | 25.3 | 14.7 | 20.0 | 77.9 |
| 9 | 22.2 | 11.5 | 16.9 | 78.5 |
| 10 | 15.1 | 6.67 | 10.9 | 110 |
| 11 | 7.32 | 0.710 | 4.02 | 71.3 |
| 12 | 2.61 | -2.69 | -0.041 | 49.7 |
| Ave/Sum | 12.9 | 3.91 | 8.41 | 791 |
| Max | 25.7 | 14.7 | 20.2 | 110 |
| Min | -0.800 | -8.15 | -4.37 | 35.9 |
| STDV | 10.1 | 8.45 | 9.27 | 19.4 |

Figure 2-9 presents baseflow separation for the GULGUL5 streamflow monitoring station from 2011-04-15 to 2022-06-30. Based on the SWAT Baseflow Separation tool, baseflow contributed about 41% of total streamflow at GULGUL5 from 2011-04-15 to 2022-06-30. Figure 2-10 presents baseflow separation for the GULGUL2 streamflow monitoring station from 2010-07-12 to 2022-06-30. Based on SWAT Baseflow Separation tool, baseflow contributed about 33% of total streamflow at GULGUL2. Table 2-6 presents average monthly precipitation, runoff, and baseflow at the GULGUL5 station from 2012-01-01 to 2021-12-31. Runoff is highest in the winter months and peaks in March due to snowmelt and frozen soils. Runoff is lowest in July due to higher temperatures and evapotranspiration (Table 2-6 and Figure 2-11).

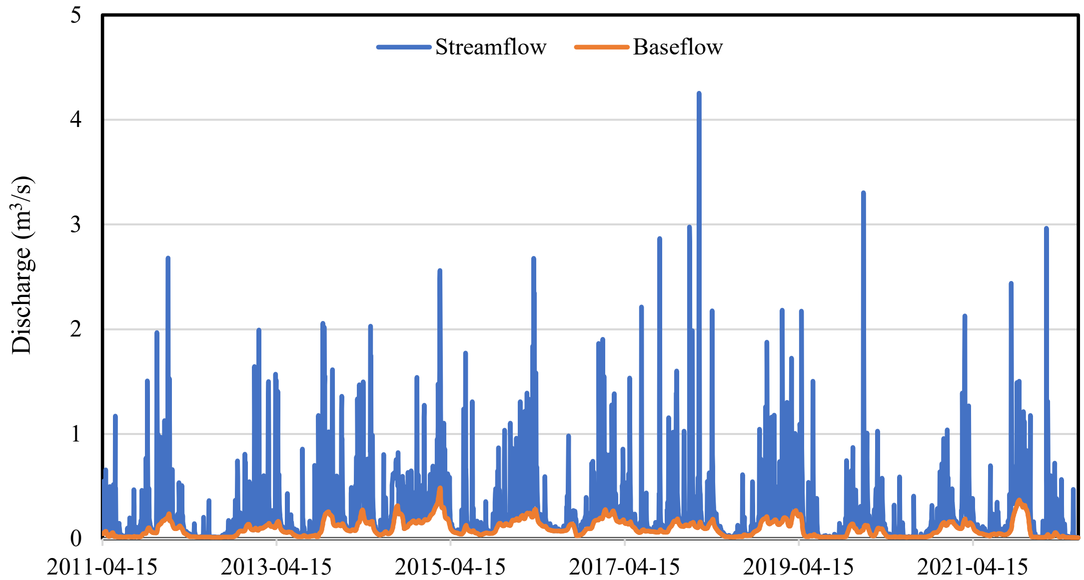


Figure 2-9. Baseflow separation at ABCA GULGUL5 station over the period of 2011-04-15 to 2022-06-30

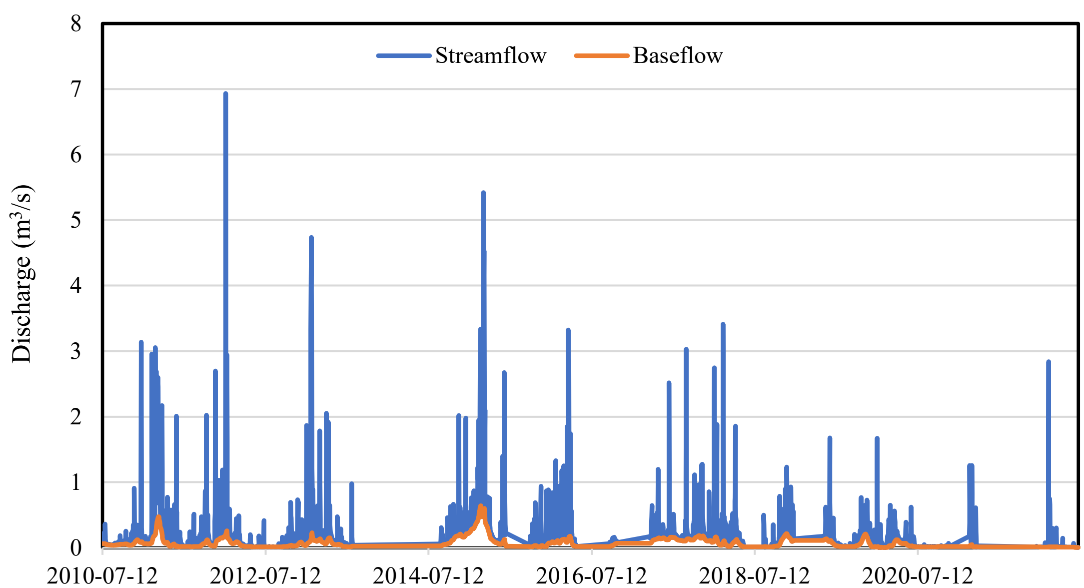


Figure 2-10. Baseflow separation at ABCA GULGUL2 station over the period of 2010-07-12 to 2022-06-30

Table 2-6. Average monthly precipitation, runoff, and baseflow at GULGUL5 station over the period of 2012-01-01 to 2021-12-31.

| Month | Precipitation | Runoff | | | Baseflow | | |
|---|---|---|---|---|---|---|---|
| | (mm) | ($m^3/s$) | (mm) | (% of Precipitation) | ($m^3/s$) | (mm) | (% of Runoff) |
| 1 | 60.3 | 0.398 | 102 | 169 | 0.156 | 40.0 | 39.3 |
| 2 | 41.9 | 0.349 | 81.3 | 194 | 0.153 | 35.6 | 43.8 |
| 3 | 56.8 | 0.393 | 101 | 177 | 0.154 | 39.5 | 39.2 |
| 4 | 76.0 | 0.305 | 75.6 | 99.4 | 0.133 | 33.1 | 43.7 |
| 5 | 68.0 | 0.143 | 36.6 | 53.9 | 0.067 | 17.1 | 46.8 |
| 6 | 84.9 | 0.118 | 29.2 | 34.4 | 0.045 | 11.1 | 37.9 |
| 7 | 74.0 | 0.077 | 19.7 | 26.6 | 0.039 | 10.1 | 51.2 |
| 8 | 88.7 | 0.116 | 29.6 | 33.4 | 0.049 | 12.5 | 42.3 |
| 9 | 89.4 | 0.155 | 38.3 | 42.9 | 0.064 | 15.7 | 41.1 |
| 10 | 119 | 0.237 | 60.6 | 50.9 | 0.087 | 22.2 | 36.6 |
| 11 | 77.1 | 0.338 | 83.7 | 109 | 0.151 | 37.4 | 44.7 |
| 12 | 59.1 | 0.290 | 74.4 | 126 | 0.130 | 33.2 | 44.7 |
| Sum/Ave | 895 | 0.243 | 732 | 93.0 | 0.102 | 307 | 42.6 |
| Max | 119 | 0.398 | 102 | 194 | 0.156 | 40.0 | 51.2 |
| Min | 41.9 | 0.077 | 19.7 | 26.6 | 0.039 | 10.1 | 36.6 |
| STDV | 19.9 | 0.117 | 29.2 | 61.5 | 0.048 | 11.9 | 4.10 |

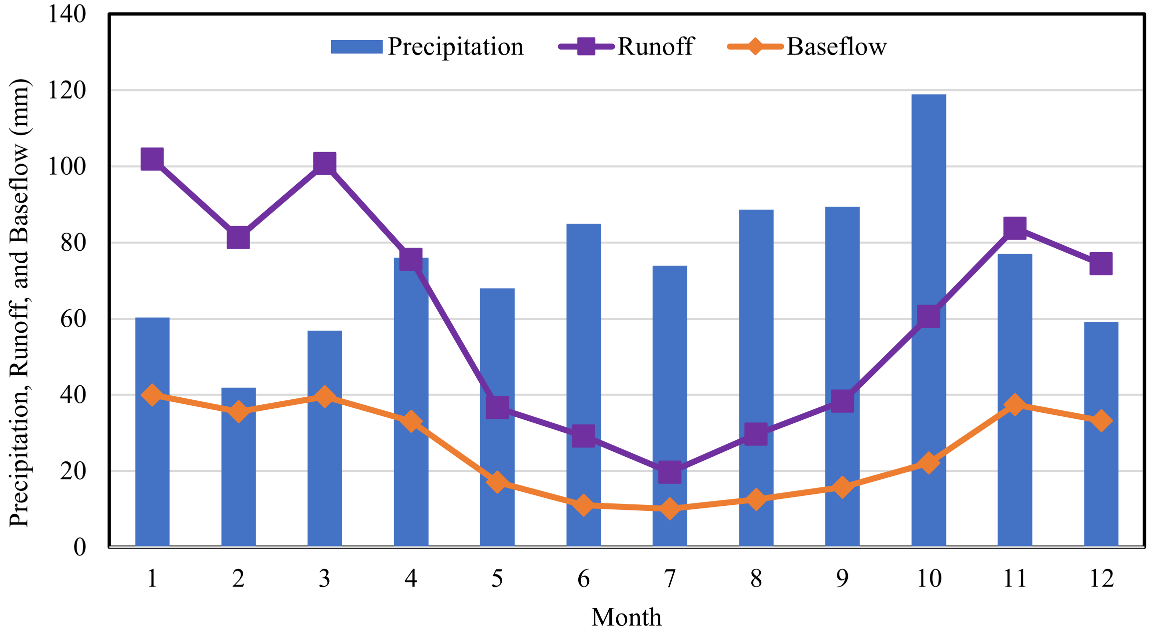


Figure 2-11. Average monthly precipitation, runoff, and baseflow at GULGUL5 station over the period of 2012-01-01 to 2021-12-31.

## 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 Ausable Bayfield Conservation Authority (ABCA), Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), and other sources.

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

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

Note: ABCA stands for Ausable Bayfield 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 Environment and Climate Change Canada (ECCC), National Aeronautics and Space Administration (NASA), and Ausable Bayfield Conservation Authority (ABCA) 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 Ausable Bayfield Conservation Authority (ABCA) monitoring stations (Table 3-2). The locations of these stations are shown in Figure 3-1. Observed data from four stations (GULGUL2, GULFUL5, GULGUL7, and GULGUL8) were used for model calibration. Observed data from the remaining stations were used as reference during model calibration.

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

| Name | Description | Drainage Area ($km^2$) | Flow | Sediment | Nutrient |
|---|---|---|---|---|---|
| BBCULV1 | Grab sample site | - | - | 2011-2013 | 2011-2013 |
| BBCULV2 | Grab sample site | - | - | 2013-2013 | 2013-2013 |
| BBFIELD1 | Field sample site | - | - | 2011-2013 | 2011-2013 |
| BBTILE1 | Tile sample site | - | - | 2011-2012 | 2011-2012 |
| DFCULV1 | Grab sample site | - | - | 2011-2011 | 2011-2011 |
| DFTELB2-HB | Hickenbottom sample site | - | 2013-2022 | 2014 & 2021 | 2014 & 2021 |
| DFTELB2-HBpost | Hickenbottom sample site – inside of hickenbottom | - | - | 2015-2018 | 2015-2018 |
| DFTELB2-Hbpre | Hickenbottom sample site – outside of hickenbottom | - | - | 2015-2018 | 2015-2018 |
| DFTELB2-IN | Overland runoff | - | - | - | 2014 |
| DFTELB3-HB | Hickenbottom sample site | - | 2013-2022 | 2014, 2020-2021 | 2014, 2020-2021 |
| DFTELB3-Hbpost | Hickenbottom sample site – inside of hickenbottom | - | - | 2015-2017 | 2015-2017 |
| DFTELB3-Hbpre | Hickenbottom sample site – outside of hickenbottom | - | - | 2015-2017 | 2015-2017 |
| DFTELB5-HB | Hickenbottom sample site | - | 2013-2022 | 2020-2021 | 2020-2021 |
| DFTELB5-Hbpost | Hickenbottom sample site – inside of hickenbottom | - | - | 2015-2018 | 2015-2018 |
| DFTELB5-Hbpre | Hickenbottom sample site – outside of hickenbottom | - | - | 2015-2018 | 2015-2018 |
| DFTILE1 | Tile sample site | - | 2012-2022 | 2017-2019 | 2017-2019 |
| ETRUNOFF1 | Overland runoff | - | - | 2011-2012 | 2011-2012 |
| ETTILE2 | Tile sample site | - | - | 2011-2012 | 2011-2012 |

| | | | | | |
|---|---|---|---|---|---|
| GULGUL2 | Main branch | 12.6 | 2010-2022 | 2010-2014 | 2010-2014 |
| GULGUL3 | Main branch | 0.863 | 2011-2022 | 2010-2013 | 2010-2013 |
| GULGUL4 | Main branch | 0.492 | - | 2011-2013 | 2011-2013 |
| GULGUL5 | Main branch | 10.5 | 2011-2022 | 2011-2022 | 2011-2022 |
| GULGUL7 | Main branch | 2.40 | 2012-2022 | 2012-2014 | 2012-2014 |
| GULGUL8 | Main branch | 2.83 | 2012-2022 | 2013-2014 | 2013-2014 |
| KV13CCTILL1 | Field sample site | - | - | - | 2014 |
| KVNCTILL1 | Field sample site | - | - | - | 2014 |
| KVNCWOOD1 | Field sample site | - | - | - | 2014 |
| KVNCWOOD2 | Field sample site | - | - | - | 2014 |
| VBTILE1 | Tile sample site | - | 2013-2022 | 2013-2019 | 2013-2019 |
| VBTILE1south | Field sample site | - | - | 2015 | 2015 |

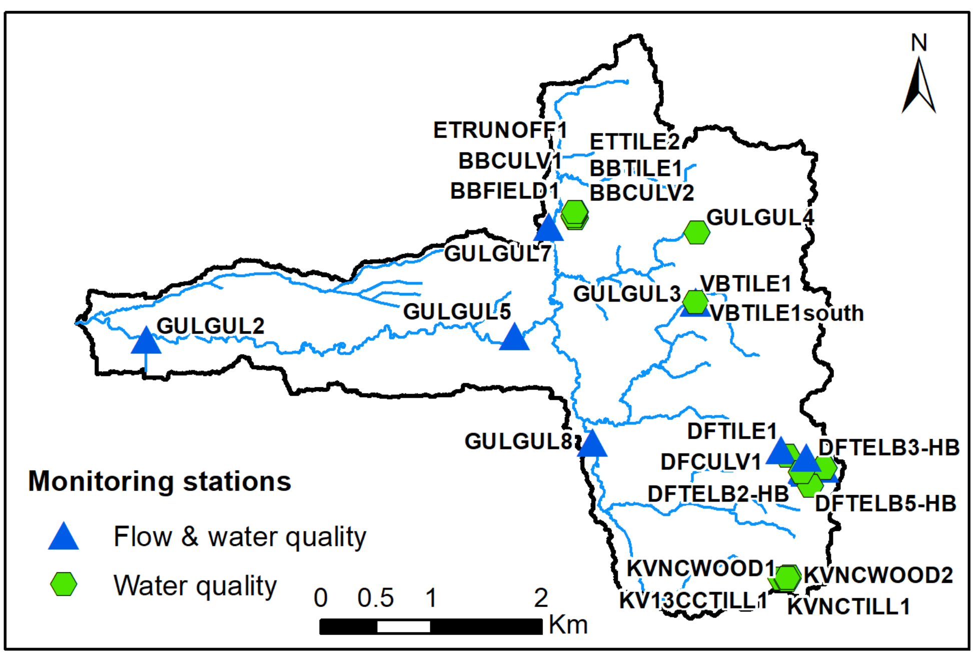


Figure 3-1. Flow and water quality monitoring stations in the Gully Creek subwatershed

### 3.4 Land Management Data

ABCA staff conducted land management surveys in 2012 under the Watershed Based BMP Evaluation (WBBE) program, in 2017 under the GLASI program, and in 2022 under the ONFARM project. The Gully Creek subwatershed IMWEBs modelling utilizes both the 2012 WBBE and 2017 GLASI land management dataset as well as the 2022 ONFARM dataset to establish a land management dataset spanning 2001 – 2022. Table 3-3 describes the key parameters included in the land management dataset. Figure 3-2 shows the field boundary layer used for the collection of land management data for the ONFARM survey.

Table 3-3. Land management parameters surveyed under the GLASI and ONFARM programs in the Gully 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 |

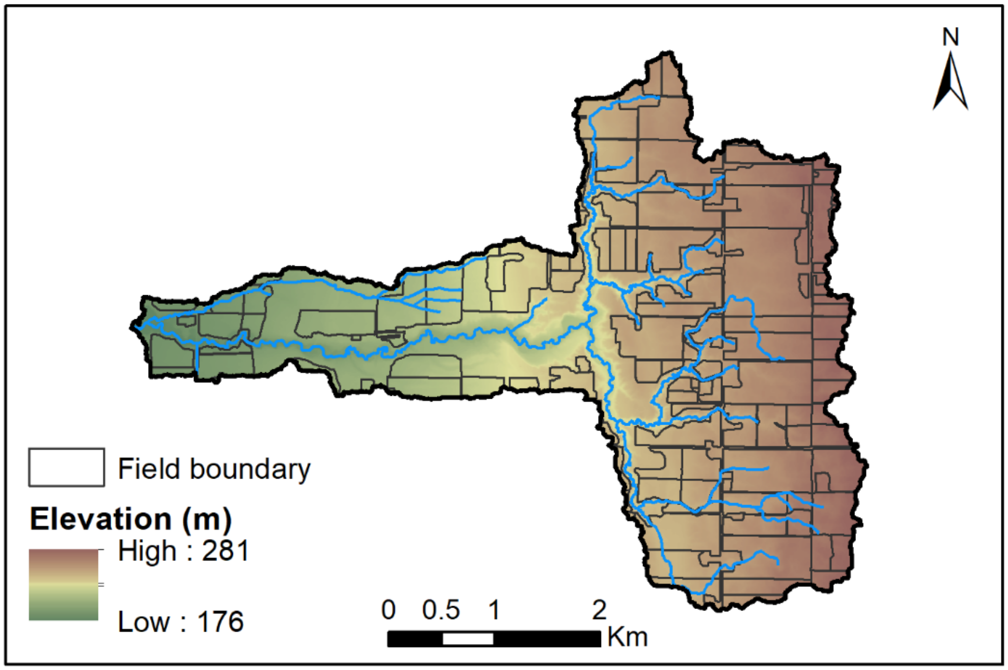


Figure 3-2. Field boundaries for the Gully Creek subwatershed IMWEBs modelling

### 3.5 Existing BMPs

There are 47 Water and Sediment Control Basins (WASCoBs) associated with 11 cluster WASCoB outlets (each cluster outlet receives water from multiple WASCoBs) in the Gully Creek subwatershed, based on information from the GLASI modelling report (Figure 3-3).

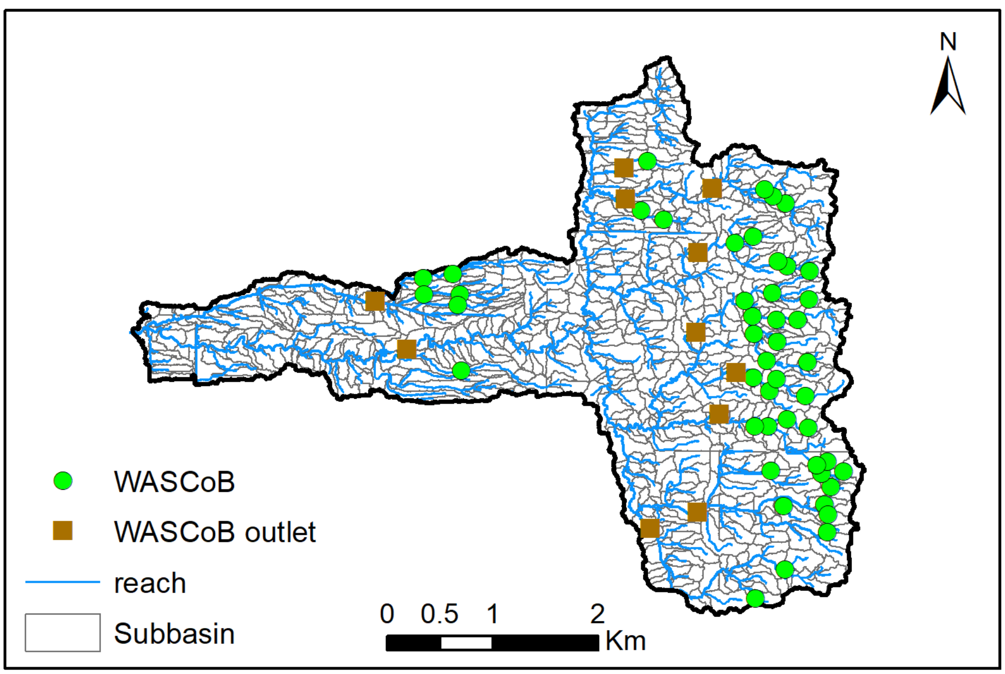


Figure 3-3. Existing Water and Sediment Control Basins (WASCoBs) in the Gully Creek subwatershed.

## 4.0 IMWEBS MODEL SETUP

### 4.1 Overview of the IMWEBs model

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

### 4.2 Watershed delineation

The IMWEBs model uses the Digital Elevation Model (DEM) and stream network to delineate the watershed boundary. The watershed was delineated by burning the stream network into the DEM to ensure accurate flow routing. The flow and water quality monitoring stations as well as the WASCOB outlets were specified as subbasin outlets. The stream initiation threshold was set to 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 Gully Creek subwatershed IMWEBs modelling, which contains 784 subbasins.

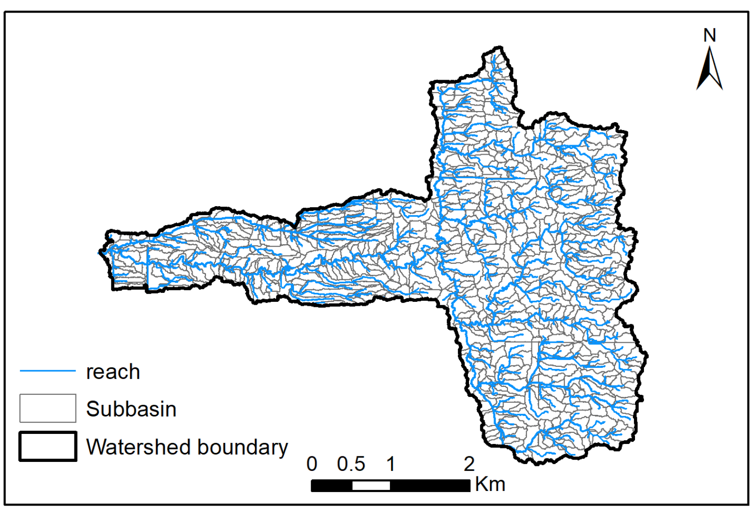


Figure 4-1. Delineated watershed boundary, subbasins, and reaches for the Gully Creek IMWEBs modelling

## 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 Gully Creek IMWEBs modelling. A summary of soil characterization for the Gully 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 Gully Creek subwatershed, a total of five distinct landuse types were identified based on the landuse data. The landuse types and associated areas and percentages within the Gully 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 Gully Creek subwatershed modelling, which contains 2,417 subareas.

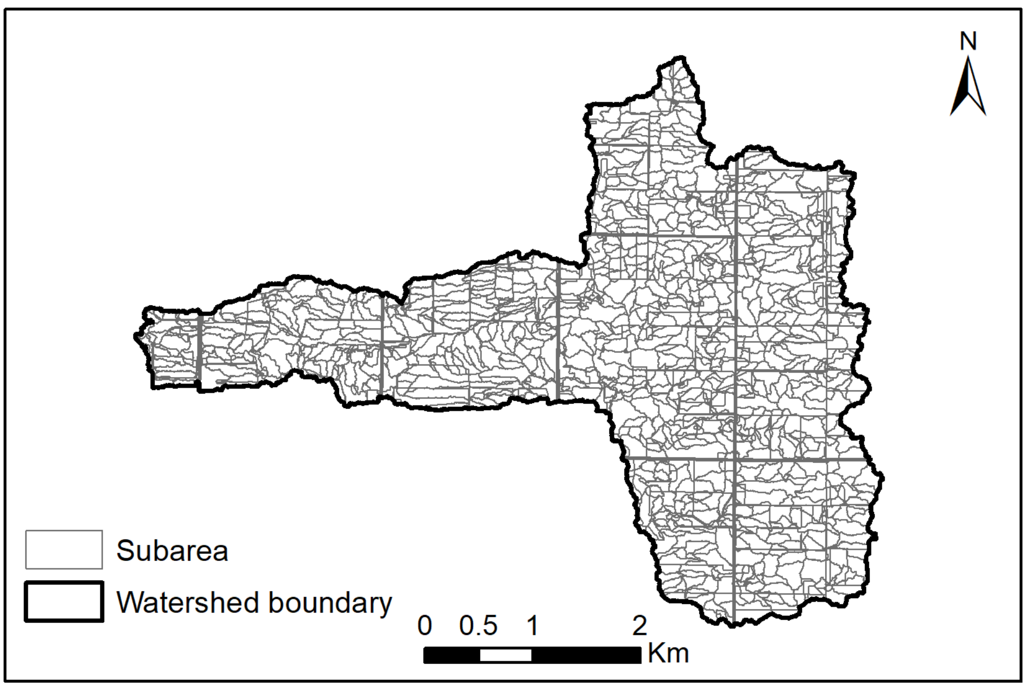


Figure 4-2. Subarea layer for the Gully Creek subwatershed IMWEBs modelling

## 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. ABCA staff conducted land management surveys in the Gully Creek subwatershed in 2012, 2017 and 2022 to establish a 22-year land management dataset spanning from 2001 – 2022. Table 3-4 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 Gully Creek subwatershed. The ONFARM land management survey contained tile drain spacing and tile depth data, which was incorporated into the IMWEBs model. For fields that did not have tile drain spacing and depth data listed in the survey, the dominant depth and spacing from the survey was assumed. Table 4-1 presents tile drain parameters for the Gully Creek subwatershed, including radius and the dominant tile spacing and tile depth from the ONFARM survey. Note that we also added the parameters for simulating controlled tile drain in IMWEBs setup which include start and end months for controlled tile drain and depth of controlled tile drain.

Table 4-1. Tile drain parameters for the Gully 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 | 9,144 | 762 | 500 |

## 4.8 Water and Sediment Control Basin (WASCoB) characterization

There were 47 WASCoBs setup in the Gully Creek IMWEBs model, based on information from the GLASI modelling report. Figure 3-3 shows the locations of these WASCoBs as well as the corresponding cluster outlets in the Gully Creek subwatershed. The cluster outlets are the points where multiple surface inlets upstream outletting to subsurface tile drainage systems eventually outlet into the surface stream. Parameterization of WASCoBs in the Gully Creek subwatershed IMWEBs model made use of the information available from the GLASI project. Table 4-2 lists key WASCoB parameters used in the Gully Creek subwatershed IMWEBs model. The IMWEBs model requires three WASCoB storage volumes be defined, the normal storage volume, the emergency storage volume, and dead storage. Because no emergency spillways were designed in these WASCOBs, the maximum volume was set to the normal volume, and the maximum surface area was set to the normal surface area. Dead storage was assumed to be zero.

Table 4-2. WASCoB characteristics in Gully Creek subwatershed

| ID | WASCoB ID | Type | Installation year | Subbasin | Drainage area (ha) | Outlet reach | Cluster Outlet ID | Volume (m3) | Surface area (ha) | Capacity ($m^3$/day) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | VBSBF3 | Standpipe | 2017 | 179 | 0.003 | 139 | OutVBSB | 176 | 0.107 | 1,382 |
| 2 | VBSBF2 | Standpipe | 2017 | 178 | 0.016 | 139 | OutVBSB | 4,280 | 0.907 | 1,382 |
| 3 | VBSBF1 | Standpipe | 2017 | 150 | 11.5 | 139 | OutVBSB | 40.0 | 0.031 | 1,382 |
| 4 | SB2 | Standpipe | 2015 | 572 | 5.18 | 524 | OutSD | 937 | 0.331 | 1,210 |
| 5 | AF1 | Standpipe | 2012 | 688 | 0.069 | 694 | OutVF_M_AF | 25.7 | 0.015 | 1,728 |
| 6 | AF2 | Standpipe | 2012 | 712 | 0.332 | 694 | OutVF_M_AF | 290 | 0.137 | 1,728 |
| 7 | AF3 | Standpipe | 2012 | 731 | 0.002 | 694 | OutVF_M_AF | 76.4 | 0.05 | 1,728 |
| 8 | DFTELB3 | Standpipe | 2012 | 649 | 0.012 | 601 | OutVW_DFTEL | 488 | 0.141 | 1,469 |
| 9 | DFTELB5 | Standpipe | 2012 | 668 | 3.62 | 601 | OutVW_DFTEL | 1,139 | 0.333 | 1,210 |
| 10 | DFTELB2 | Standpipe | 2012 | 656 | 0.352 | 601 | OutVW_DFTEL | 1,904 | 0.437 | 1,469 |
| 11 | DFTELB4 | Standpipe | 2012 | 643 | 2.50 | 601 | OutVW_DFTEL | 103 | 0.044 | 1,469 |
| 12 | DFTELB1 | Standpipe | 2012 | 656 | 8.09 | 601 | OutVW_DFTEL | 375 | 0.112 | 1,210 |
| 13 | R2 | Standpipe | 2003 | 104 | 8.73 | 81 | OutR | 2,375 | 0.522 | 1,382 |
| 14 | R1 | Standpipe | 2003 | 96 | 0.002 | 81 | OutR | 2,215 | 0.449 | 1,382 |
| 15 | VBSM2 | Standpipe + French Drain | 2014 | 437 | 0.003 | 407 | OutVBSM | 4,486 | 0.862 | 2,419 |
| 16 | VBSM1-a | Standpipe + French Drain | 2014 | 411 | 0.002 | 407 | OutVBSM | 231 | 0.129 | 3,283 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 17 | VBSM3 | Standpipe + French Drain | 2014 | 361 | 0.002 | 407 | OutVBSM | 2,500 | 0.637 | 4,925 |
| 18 | VBSM2-b | Standpipe + French Drain | 2014 | 306 | 17.3 | 407 | OutVBSM | 1,047 | 0.287 | 5,357 |
| 19 | VBSM4 | Standpipe + French Drain | 2014 | 316 | 0.002 | 407 | OutVBSM | 2,916 | 0.825 | 8,208 |
| 20 | VBSM1-b | Standpipe + French Drain | 2014 | 306 | 0.002 | 407 | OutVBSM | 219 | 0.093 | 5,098 |
| 21 | VBSM2-c | Standpipe + French Drain | 2014 | 250 | 0.216 | 407 | OutVBSM | 479 | 0.178 | 3,888 |
| 22 | VBSM5 | Standpipe + French Drain | 2014 | 221 | 0.005 | 407 | OutVBSM | 7,682 | 1.104 | 25,920 |
| 23 | VBSM1 | Standpipe + French Drain | 2014 | 503 | 0.002 | 407 | OutVBSM | 373 | 0.133 | 2,419 |
| 24 | VBH1 | Standpipe | pre-2010 | 218 | 0.002 | 256 | OutVBH | 708 | 0.305 | 605 |
| 25 | VBH3 | Standpipe | pre-2010 | 196 | 28.3 | 256 | OutVBH | 909 | 0.224 | 605 |
| 26 | VBH4 | Standpipe | pre-2010 | 236 | 12.6 | 256 | OutVBH | 229 | 0.108 | 605 |
| 27 | VBH2 | Standpipe | pre-2010 | 236 | 0.002 | 256 | OutVBH | 3,910 | 1.11 | 605 |
| 28 | VW3 | Standpipe | pre-2010 | 592 | 0.064 | 601 | OutVW_DFTEL | 192 | 0.072 | 1,210 |
| 29 | VW2 | Standpipe | pre-2010 | 612 | 0.004 | 601 | OutVW_DFTEL | 220 | 0.114 | 1,210 |
| 30 | VW1 | Standpipe | pre-2010 | 610 | 0.004 | 601 | OutVW_DFTEL | 91.7 | 0.064 | 1,210 |
| 31 | VW4 | Standpipe | pre-2010 | 592 | 0.003 | 601 | OutVW_DFTEL | 101 | 0.099 | 1,210 |
| 32 | VF1 | Standpipe | 2009 | 666 | 0.002 | 694 | OutVF_M_AF | 5,071 | 1.014 | 5,184 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 33 | V2 | Standpipe | 2005 | 782 | 0.002 | 725 | OutV | 573 | 0.188 | 691 |
| 34 | VBSM1-c | Standpipe + French Drain | 2014 | 261 | 0.003 | 407 | OutVBSM | 50.0 | 0.030 | 3,024 |
| 35 | P1 | Wetland | 2010 | 497 | 0.003 | 464 | OutP | 30.0 | 0.028 | 0 |
| 36 | V1 | Standpipe | 2003 | 765 | 0.005 | 725 | OutV | 13,423 | 1.361 | 4,061 |
| 37 | VBNB30-1 | Standpipe + French Drain | 2015 | 85 | 20.9 | 72 | OutVBNB | 53.7 | 0.024 | 1,382 |
| 38 | VBNB30-2 | Standpipe + French Drain | 2015 | 85 | 2.68 | 72 | OutVBNB | 225 | 0.090 | 1,382 |
| 39 | VBNB30-3 | Standpipe | 2012 | 85 | 0.002 | 72 | OutVBNB | 29.6 | 0.017 | 1,382 |
| 40 | M1 | Standpipe | 2016 | 695 | 3.78 | 694 | OutVF_M_AF | 458 | 0.080 | 3,456 |
| 41 | VBH5 | Standpipe | pre-2010 | 277 | 5.19 | 256 | OutVBH | 247 | 0.101 | 605 |
| 42 | C1 | Standpipe | 2015 | 46 | 0.011 | 43 | OutC | 123 | 0.047 | 1,469 |
| 43 | VBSB1 | Standpipe | 2012 | 148 | 16.8 | 139 | OutVBSB | 791 | 0.201 | 1,469 |
| 44 | VBSB2 | Standpipe | 2014 | 130 | 0.009 | 139 | OutVBSB | 74.5 | 0.043 | 1,469 |
| 45 | SB1 | Standpipe | 2015 | 499 | 0.021 | 524 | OutSD | 1,498 | 0.355 | 1,210 |
| 46 | SB4 | Standpipe | 2016 | 535 | 1.33 | 524 | OutSD | 24.6 | 0.018 | 1,210 |
| 47 | SB3 | Standpipe | 2015 | 566 | 0.002 | 524 | OutSD | 98.0 | 0.043 | 1,210 |

## 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 2010-01-01 to 2022-06-30 was used for model calibration. Observed data from four streamflow monitoring sites (GULGUL2, GULFUL5, GULGUL7, and GULGUL8) were used for model calibration. Observed data from the remaining stations were used as references during model calibration. The model was calibrated firstly for flow; followed by sediment, particulate P, and particulate N; and lastly dissolved P and dissolved N.

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

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

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

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

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

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

Where $\overline{Qo}$ and $\overline{Qs}$ are means of observed and simulated values. A higher CORR indicates a higher correlation between observed and simulated values. In contrast to continuous flow monitoring data, most Total Suspend Solid (TSS), Nitrogen(N) and Phosphorus (P) monitoring data have limited samples, which 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

Stream flow calibration was undertaken for four major monitoring sites: GULGUL2, GULGUL5, GULGUL7, and GULGUL8, and the observed data from other monitoring sites were used as references. Table 5-1 presents the parameters used for water balance and flow routing calibration and Table 5-2 lists the performance statistics for flow calibration at the four major monitoring sites. Figures 5-1, 5-2, 5-3, and 5-4 show the graphs of measured vs. simulated flow at the four major monitoring sites. A satisfactory flow calibration was achieved at the four major monitoring sites resulting in a NSC of 0.56 to 0.72, a model bias of -16.36% to 15.0%, and a CORR of 0.47 to 0.65 based on the criteria outlined in Moriasi et. al (2007).

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

| Parameter | Definition | Value |
|---|---|---|
| **runoff_co** | Potential runoff coefficient | -0.15* |
| **K_pet** | Correction factor for PET | -0.6 |
| **Surface_lag** | Surface lag coefficient | -0.25 |
| **rootdepth** | Root depth | -0.25* |
| **fieldcap_layer0** | Soil field capacity for layer 0 | -0.1* |
| **fieldcap_layer1** | Soil field capacity for layer 1 | -0.1* |
| **fieldcap_layer2** | Soil field capacity for layer 2 | -0.1* |
| **porosity_layer0** | Soil porosity for layer 0 | 0.1* |
| **porosity_layer1** | Soil porosity for layer 1 | 0.1* |
| **porosity_layer2** | Soil porosity for layer 2 | 0.1* |
| **poreindex_layer0** | Pore size distribution index for layer 0 | -0.3* |
| **poreindex_layer1** | Pore size distribution index for layer 1 | -0.3* |
| **poreindex_layer2** | Pore size distribution index for layer 2 | 1.0* |
| **conductivity_layer0** | Soil hydraulic conductivity for layer 0 | 0.3* |
| **conductivity_layer1** | Soil hydraulic conductivity for layer 1 | 0.3* |
| **conductivity_layer2** | Soil hydraulic conductivity for layer 2 | 0.3 |
| **kg** | Baseflow recession coefficient | -0.0009 |
| **base_ex** | Baseflow recession exponent | 1.3 |
| **K_run** | Runoff exponent when net rainfall approaches to zero | -1.5 |
| **P_max** | Maximum rainfall intensity | -15 |
| **soil_ta0** | Empirical coefficient for estimating soil temperature | -3.7 |
| **SHC_crop** | Snow holding capacity of cropland | 10 |

| | | |
|---|---|---|
| **s_frozen** | Frozen moisture relative to porosity with no infiltration | -0.25 |
| **t_soil** | Soil freezing temperature | 1.5 |

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

Table 5-2. Model performance for flow simulation at four major monitoring sites in the Gully Creek subwatershed

| Station | Period | NSC | PBIAS | CORR |
|---|---|---|---|---|
| GULGUL2 | 2010-2022 | 0.72 | 10.6% | 0.47 |
| GULGUL5 | 2011-2022 | 0.70 | 15.0% | 0.53 |
| GULGUL7 | 2012-2022 | 0.56 | -16.36% | 0.53 |
| GULGUL8 | 2012-2022 | 0.67 | 14.24 | 0.65 |

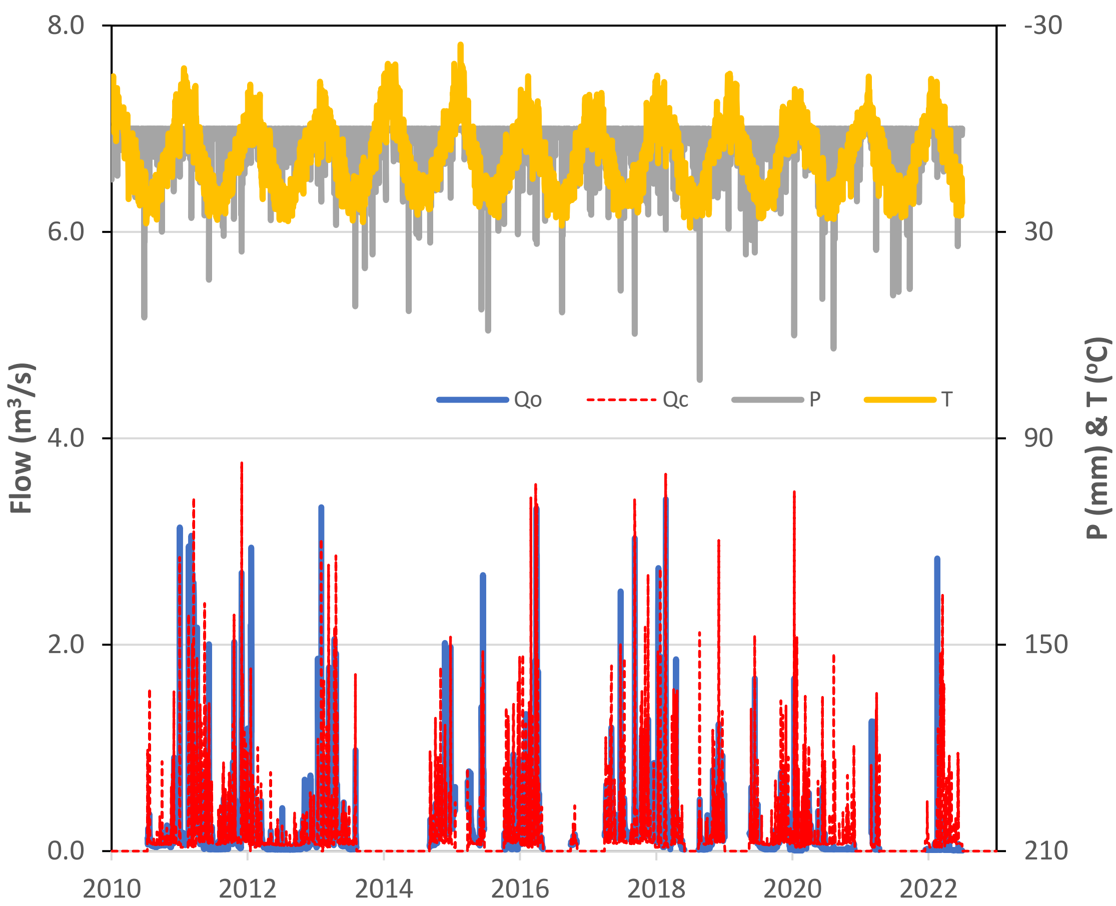


Figure 5-1. Measured vs. simulated flow at the GULGUL2 site

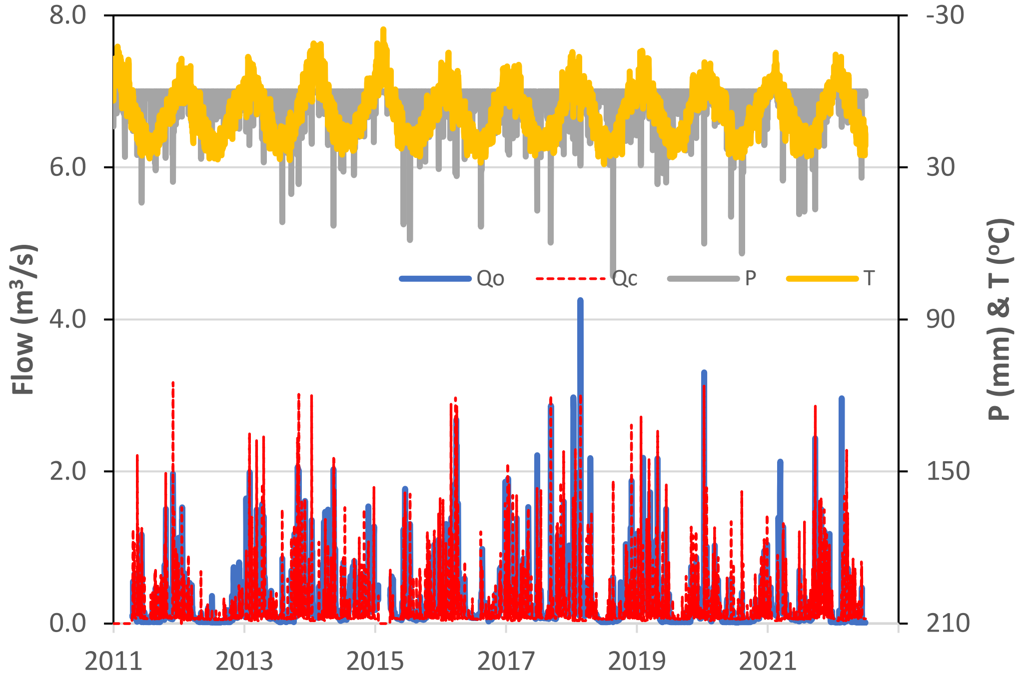


Figure 5-2. Measured vs. simulated flow at the GULGUL5 site

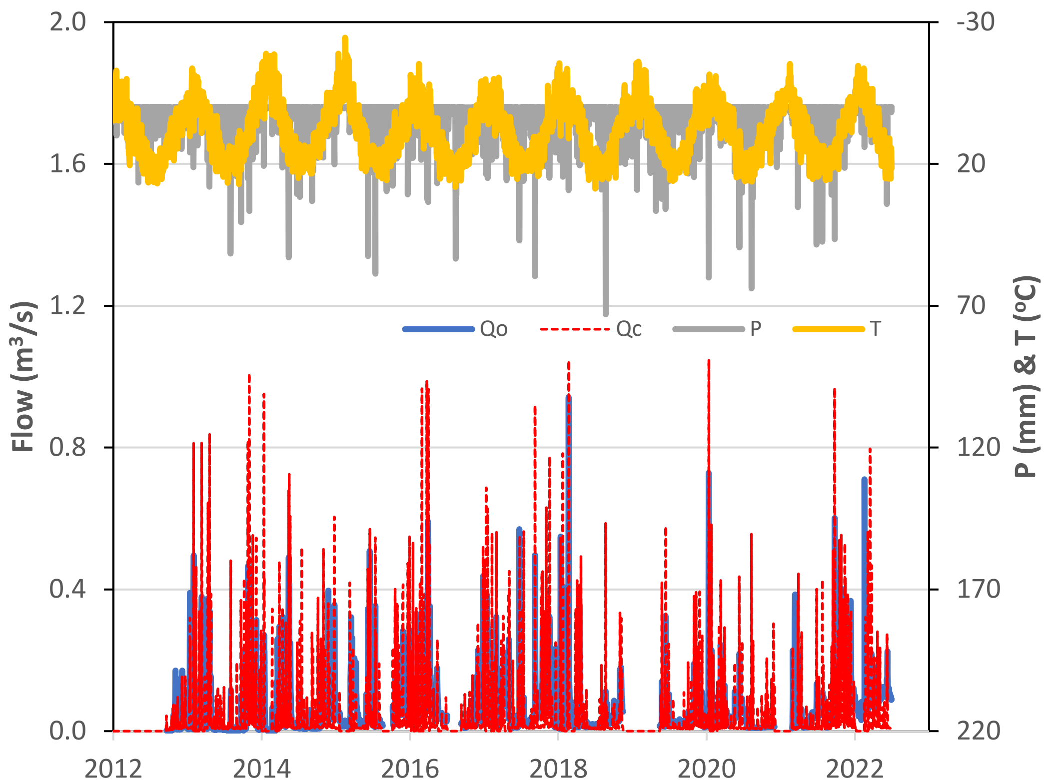


Figure 5-3. Measured vs. simulated flow at the GULGUL7 site

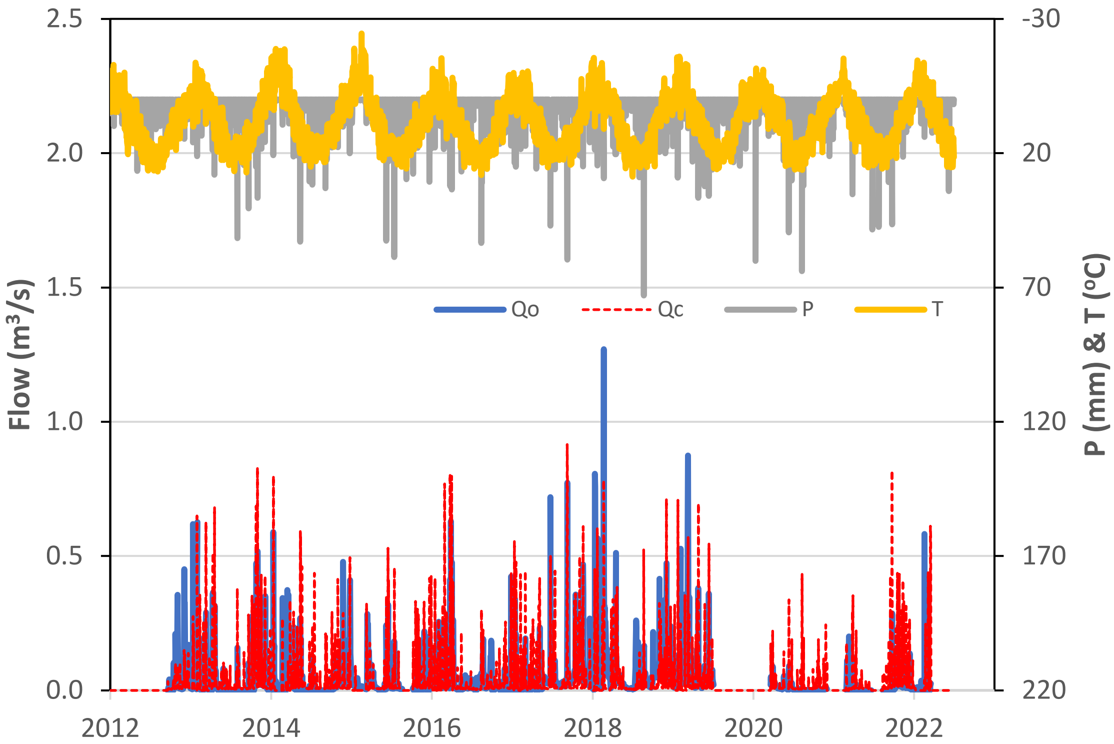


Figure 5-4. Measured vs. simulated flow at the GULGUL8 site

### 5.3 Sediment calibration

Sediment load calibration was completed for four major monitoring sites: GULGUL2, GULGUL5, GULGUL7, and GULGUL8, and the observed data from other monitoring sites were used as references. Table 5-3 presents the parameters used for soil erosion and sediment transport calibration and Table 5-4 lists the performance statistics for sediment load calibration at the four major monitoring sites. Figures 5-5, 5-6, 5-7, and 5-8 show the graphs of measured vs. simulated sediment load at the four major monitoring sites. A satisfactory sediment load calibration was achieved at the four major monitoring sites resulting in a model bias of -15.0% to 18.4%, and a CORR of 0.61 to 0.99 based on the criteria outlined in Moriasi et. al (2007).

Table 5-3. Calibrated soil erosion and sediment transport parameters for the Gully Creek Subwatershed IMWEBs model

| Parameter | Definition | Value |
|---|---|---|
| **USLE_K_layer1** | K-factor for MUSLE | -0.07* |
| **USLE_C** | C-factor for MUSLE | -0.07* |
| **USLE_P** | The erosion control practice factor | -0.28* |
| **spexp** | Exponent in sediment transport equation | 1.0 |
| **spcon** | Coefficient in sediment transport equation | 0.1 |
| **vcrit** | Critical velocity for sediment deposition | 0.5 |

Note: * ratio of relative parameter change, e.g. USLE_C modified = USLE_C-0.07×USLE_C

Table 5-4. Model performance for sediment load simulation at four major monitoring sites in the Gully Creek subwatershed

| Station | Period | PBIAS | CORR |
|---|---|---|---|
| GULGUL2 | 2010-2012 | -15.0% | 0.61 |
| GULGUL5 | 2011-2022 | 18.4% | 0.71 |
| GULGUL7 | 2013-2014 | 17.7% | 0.76 |
| GULGUL8 | 2013-2013 | 18.0% | 0.99 |

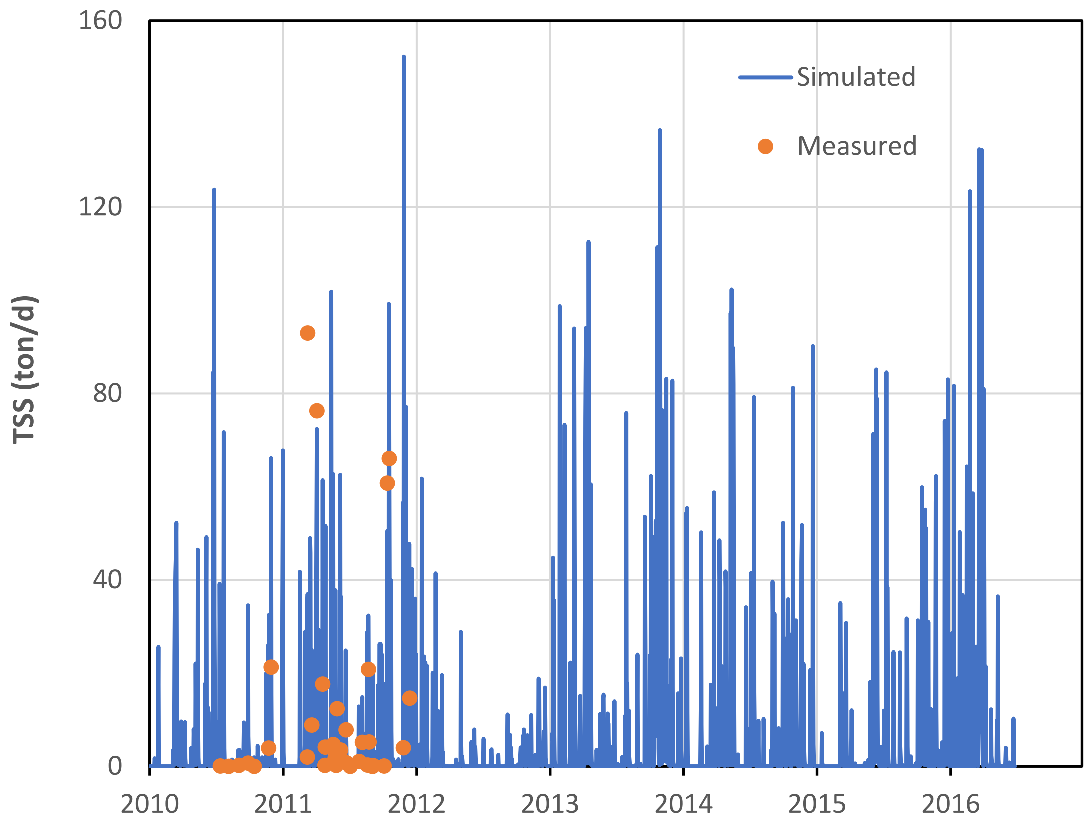


Figure 5-5. Measured vs. simulated sediment load at the GULGUL2 site

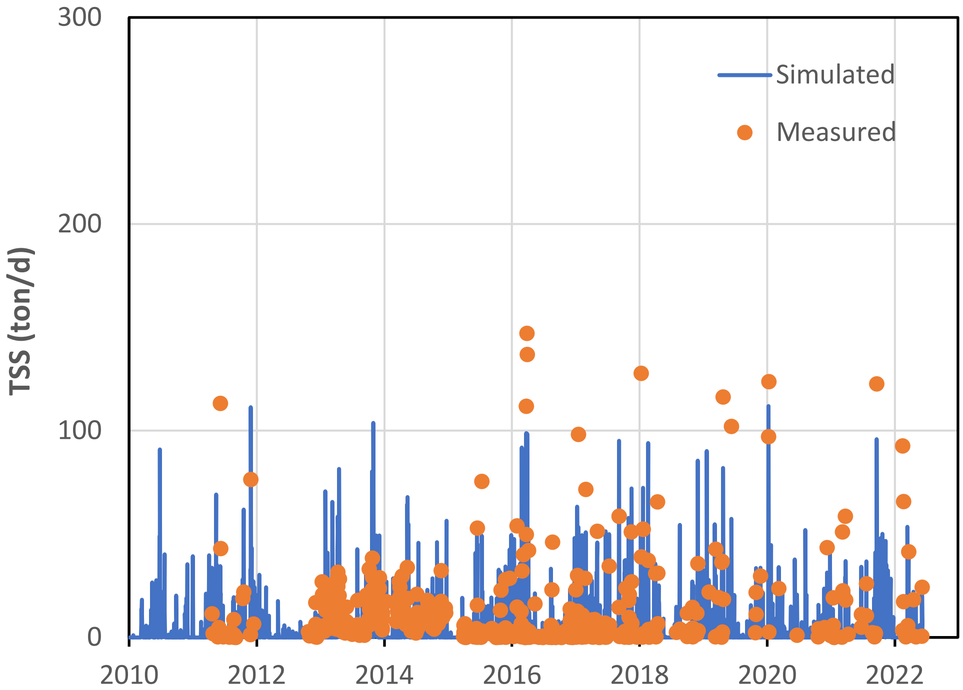


Figure 5-6. Measured vs. simulated sediment load at the GULGUL5 site

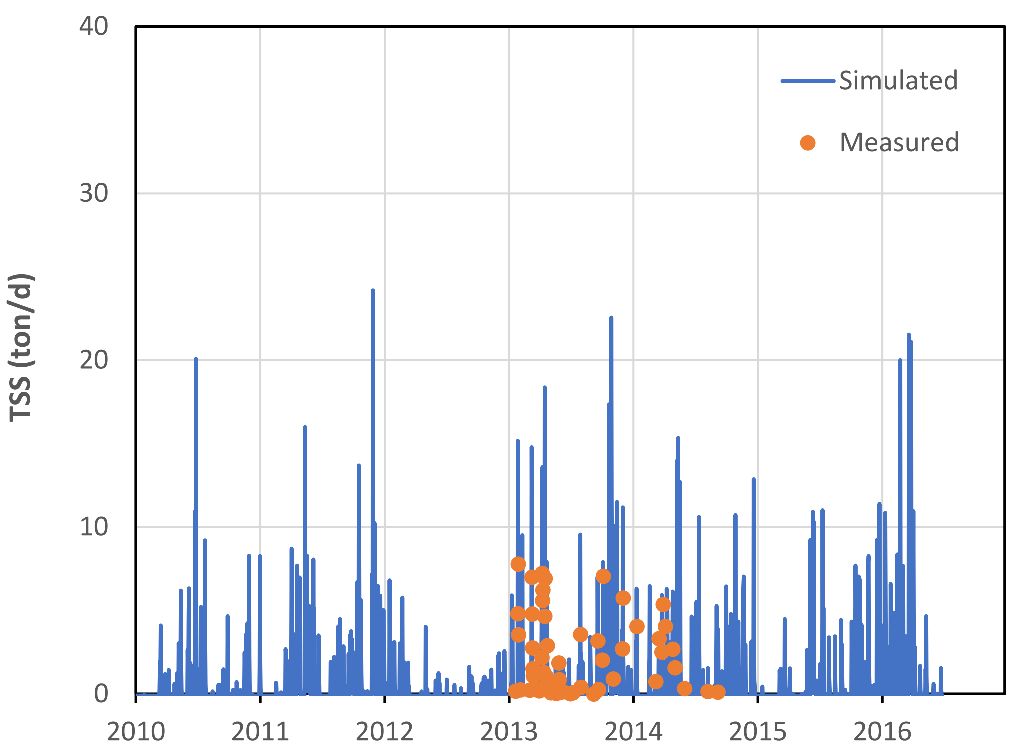


Figure 5-7. Measured vs. simulated sediment load at the GULGUL7 site

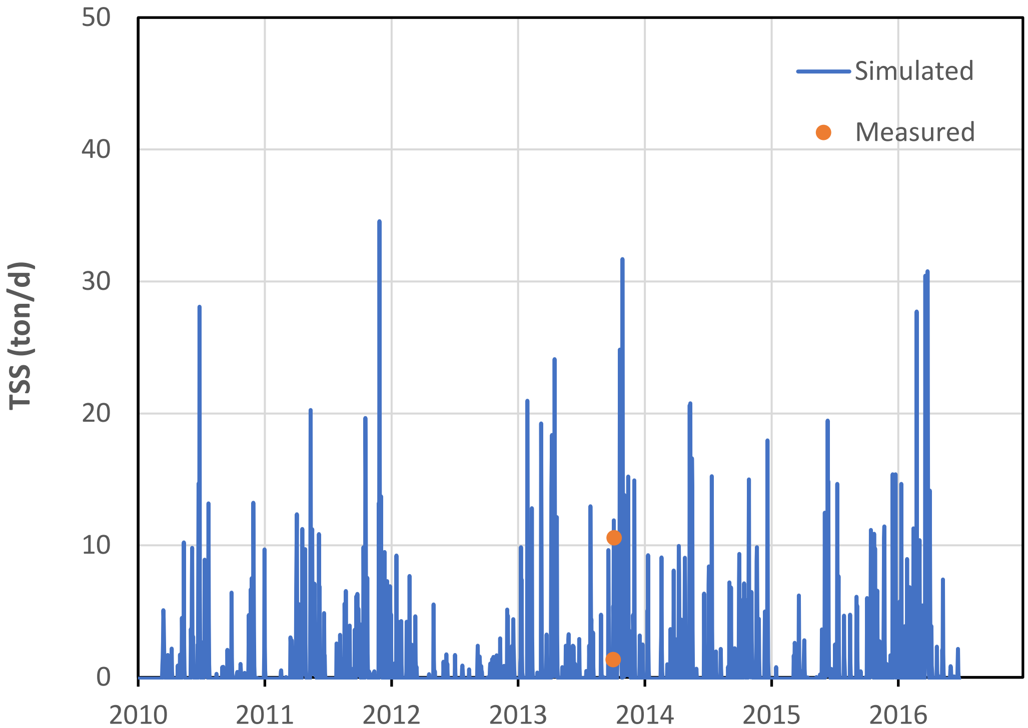


Figure 5-8. Measured vs. simulated sediment load at the GULGUL8 site

### 5.4 Nutrient calibration

We conducted particulate, dissolved, and total phosphorus load calibration for four major water quality monitoring sites: GULGUL2, GULGUL5, GULGUL7, and GULGUL8, and the observed data from other water quality monitoring sites were used as references. Table 5-5 presents the parameters used for dissolved and particulate phosphorus load calibration and Table 5-6 lists the performance statistics for total phosphorus load calibration at the four major monitoring sites. Figures 5-9, 5-10, 5-11, and 5-12 show the graphs of measured vs. simulated total phosphorus load at the four major monitoring sites. A satisfactory total phosphorus load calibration was achieved at the four major monitoring sites resulting in a model bias of 14.8% to 29.5%, and a CORR of 0.38 to 0.94 based on the criteria outlined in Moriasi et. al (2007).

Table 5-5. Calibrated phosphorus parameters for the Gully Creek Subwatershed IMWEBs model

| Parameter | Definition | Value |
|---|---|---|
| **initialSoilOrganicP** | Initial organic P concentration in soil, SOL_ORGP | 5.0 |
| **initialSoilSolutionP** | Initial soluble P concentration in soil, SOL_SOLP | -2.0 |
| **organicP_coefficient** | Organic phosphorus adjustment coefficient | 0.4 |
| **phosphrusPartiCo** | Phosphorus partitioning coefficient | 110 |
| **phosphrusPercoCo** | Phosphorus percolation coefficient | 4.0 |
| **gwOrganicP** | Organic P concentration in groundwater loading to reach | 0.001 |
| **P_enrich** | Phosphorus enrichment ratio | -2 |

Table 5-6. Model performance for total phosphorus load simulation at four major monitoring sites in the Gully Creek subwatershed

| Station | Period | PBIAS | CORR Monthly NSC |
|---|---|---|---|
| GULGUL2 | 2010-2013 | 19.0% | 0.84 |
| GULGUL5 | 2011-2022 | 14.8% | 0.38 |
| GULGUL7 | 2012-2014 | 29.5% | 0.94 |
| GULGUL8 | 2013-2014 | 17.9% | 0.80 |

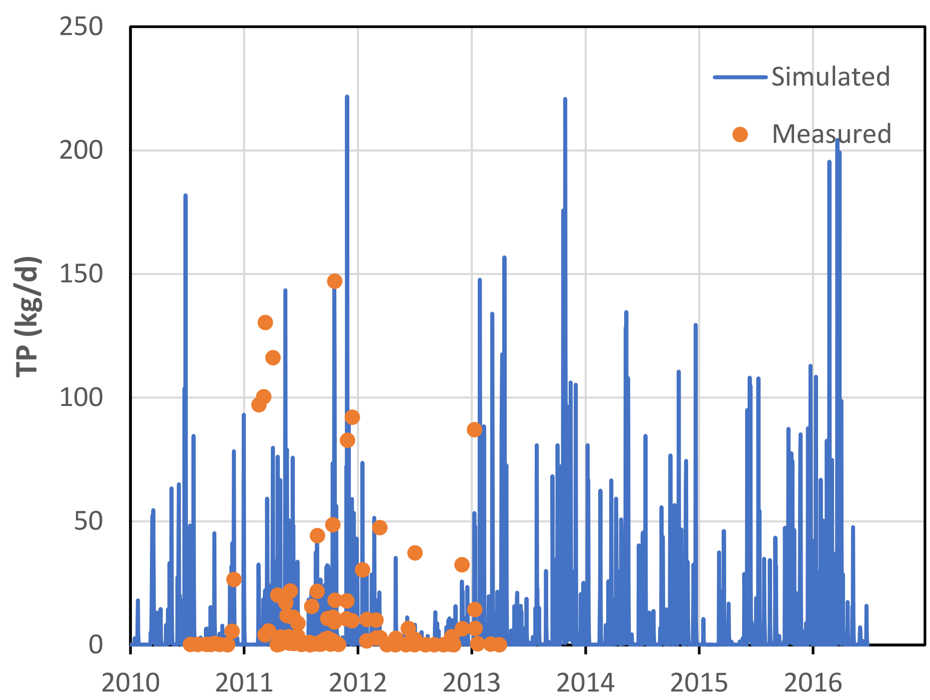


Figure 5-9. Measured vs. simulated total phosphorus load at the GULGUL2 site

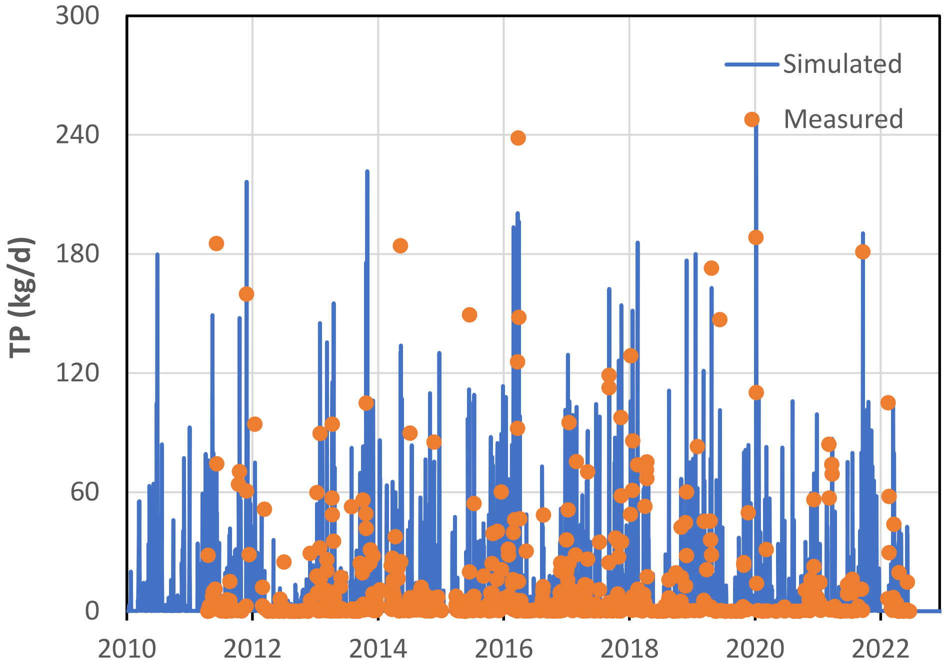


Figure 5-10. Measured vs. simulated total phosphorus load at the GULGUL5 site

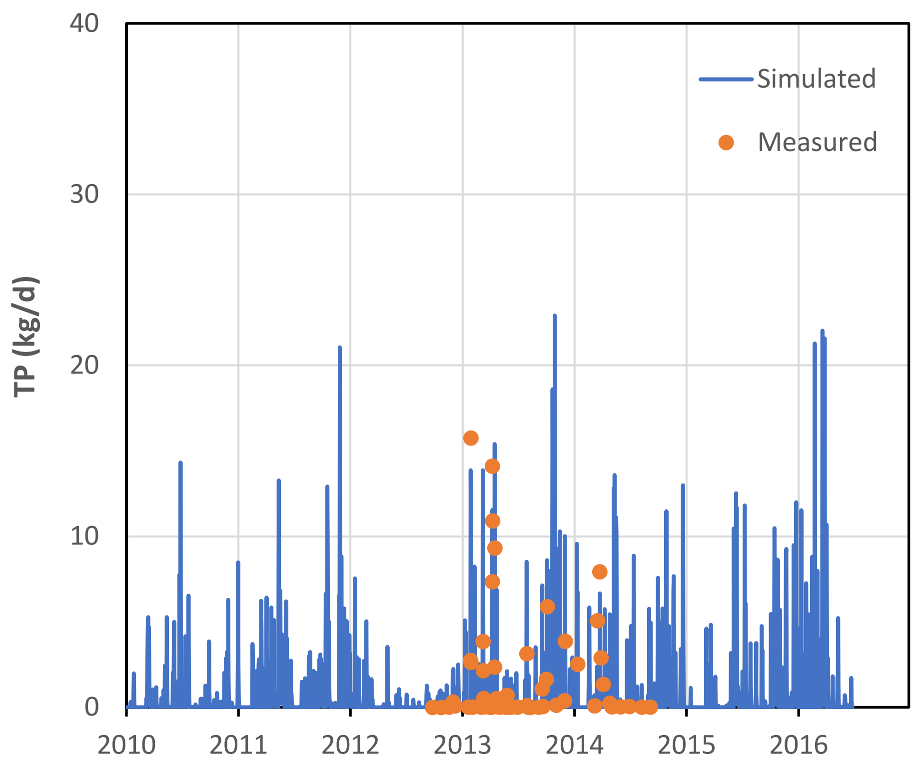


Figure 5-11. Measured vs. simulated total phosphorus load at the GULGUL7 site

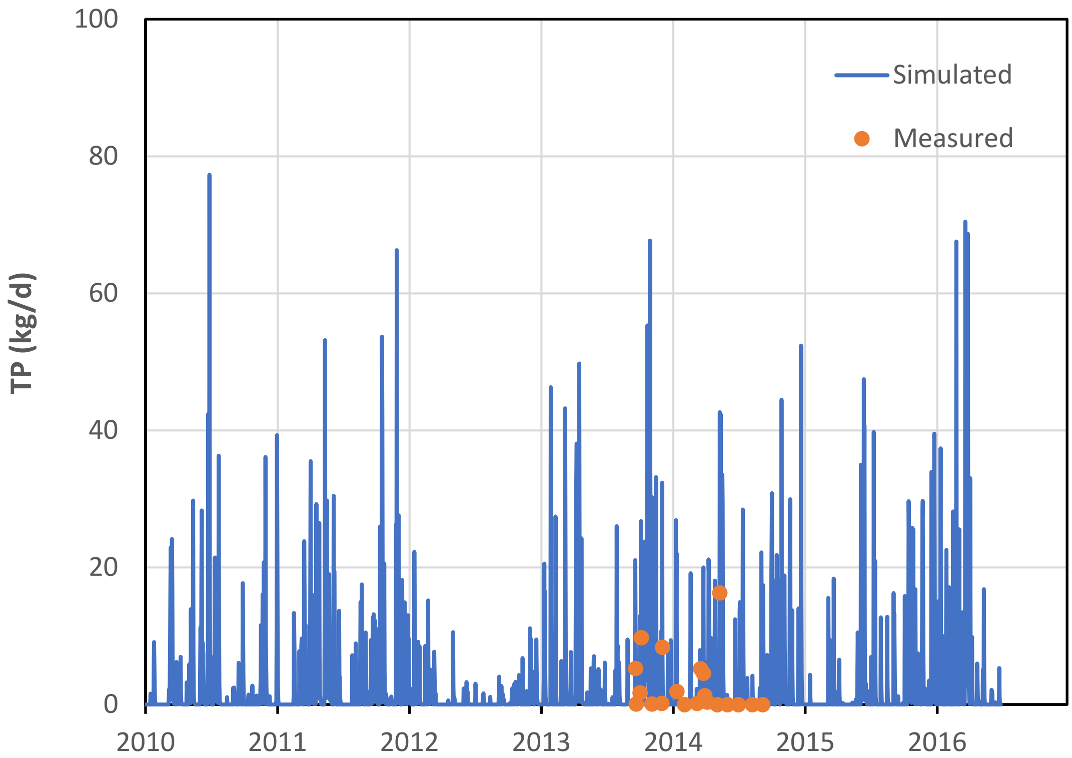


Figure 5-12. Measured vs. simulated total phosphorus load at the GULGUL8 site

We conducted particulate, dissolved and total nitrogen load calibration for the four major monitoring sites – GULGUL2, GULGUL5, GULGUL7, and GULGUL8 and the observed data from other monitoring sites were used as references. Table 5-7 presents the parameters used for dissolved and particulate nitrogen load calibration and Table 5-8 lists the performance statistics for total nitrogen load calibration at the four major monitoring sites. Figures 5-13, 5-14, 5-15, and 5-16 show the graphs of measured vs. simulated total nitrogen load at the four major monitoring sites. A satisfactory total nitrogen load calibration was achieved at the four major monitoring sites resulting in a model bias of -9.2% to 12.2%, and a CORR of 0.38 to 0.83 based on the criteria outlined in Moriasi et. al (2007).

Table 5-7. Calibrated nitrogen parameters for the Gully Creek Subwatershed IMWEBs model

| Parameter | Definition | Value |
|---|---|---|
| **initialSoilOrganicN** | Initial organic N concentration in soil, SOL_ORGN | 10.0 |
| **initialSoilNO3** | Initial NO3 concentration in soil, SOL_NO3 | 3.0 |
| **organicN_coefficient** | Organic nitrogen adjustment coefficient | 0.1 |
| **nitratePercoCo** | Nitrate percolation coefficient | 0.15 |
| **gwNO3** | $NO_3$ concentration in groundwater loading to reach | 0.003 |
| **gwOrganicN** | Organic N concentration in groundwater loading to reach | 0.003 |
| **organicN_enrich** | Organic nitrogen enrichment ratio | -2.0 |

Table 5-8. Model performance for total nitrogen load simulation at four major monitoring sites in the Gully Creek subwatershed

| Station | Period | PBIAS | CORR Monthly NSC |
|---|---|---|---|
| GULGUL2 | 2010-2013 | 12.2% | 0.70 |
| GULGUL5 | 2011-2022 | -9.2% | 0.46 |
| GULGUL7 | 2012-2014 | 6.5% | 0.38 |
| GULGUL8 | 2013-2014 | -7.5% | 0.83 |

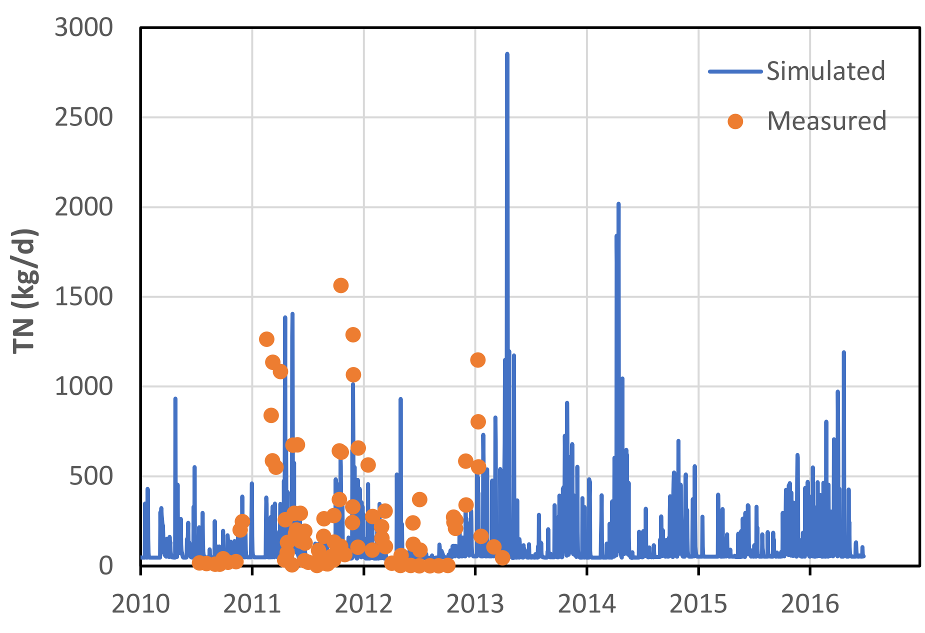


Figure 5-13. Measured vs. simulated total nitrogen load at the GULGUL2 site

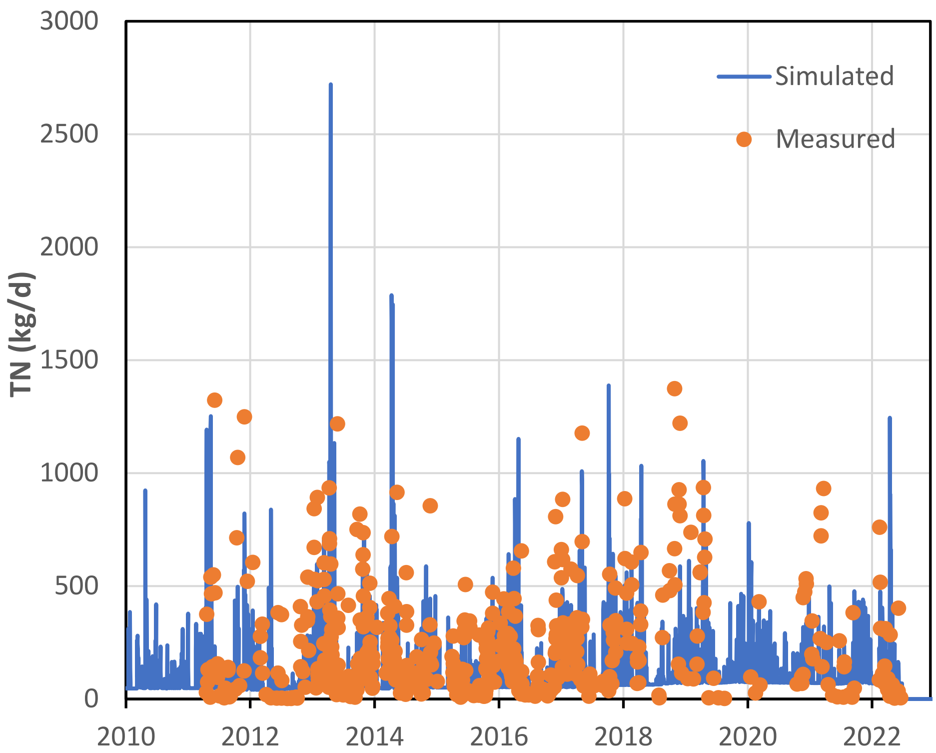


Figure 5-14. Measured vs. simulated total nitrogen load at the GULGUL5 site

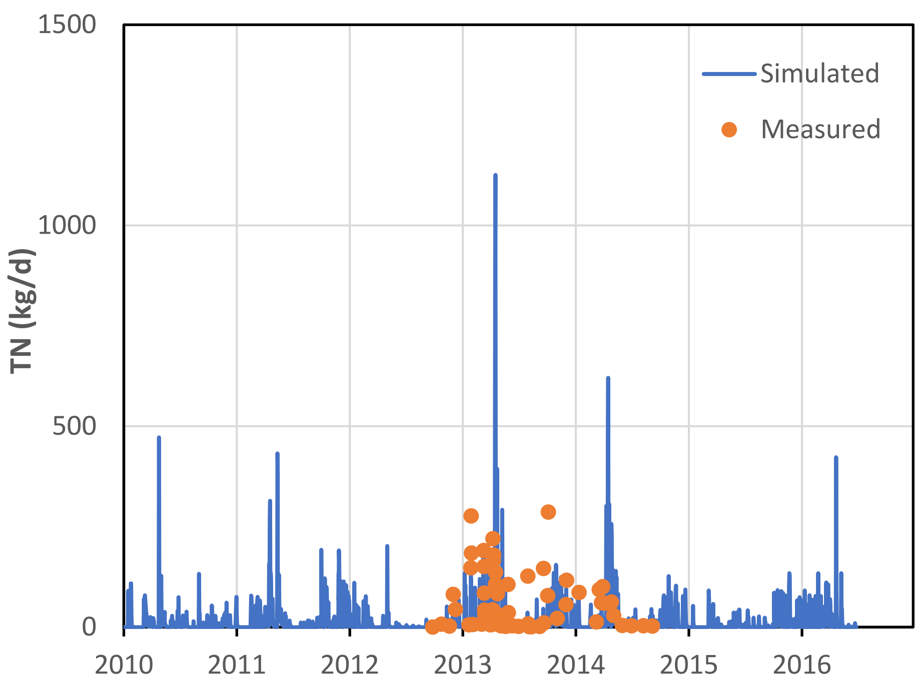


Figure 5-15. Measured vs. simulated total nitrogen load at the GULGUL7 site

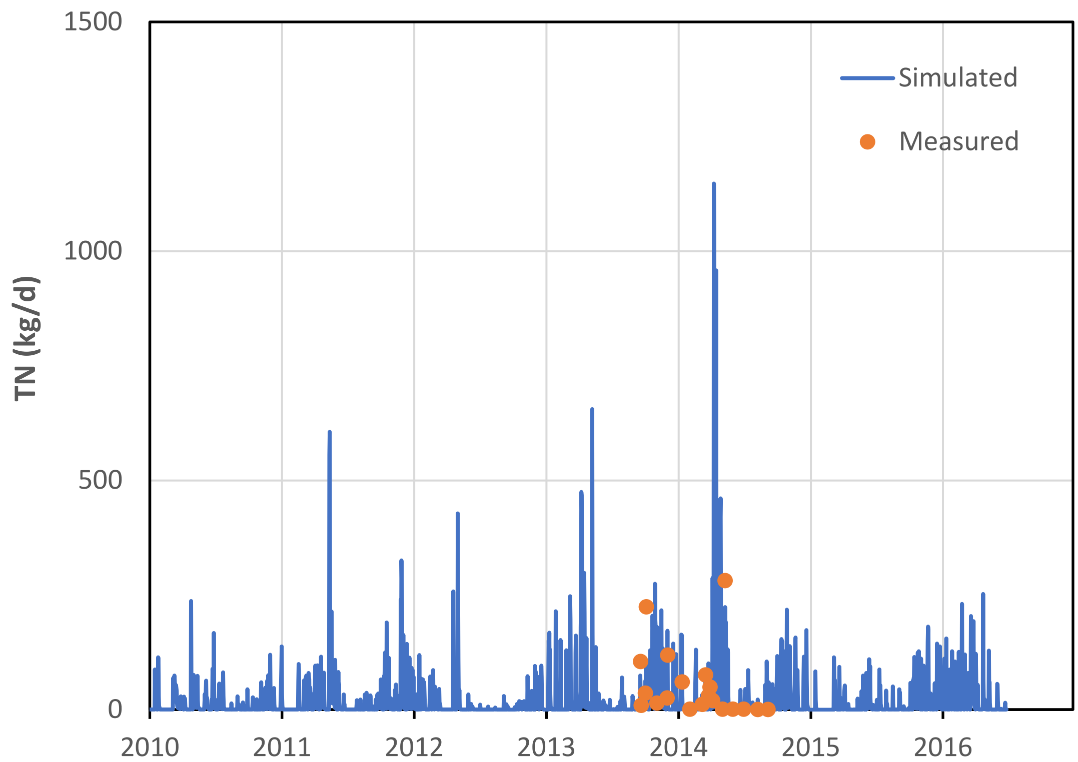


Figure 5-16. Measured vs. simulated total nitrogen load at the GULGUL8 site

## 6.0 DEFINITION OF BMP SCENARIOS AND BMP ASSESSMENT APPROACHES

In IMWEBs modelling, the crop management, tillage management, and fertilizer/manure management input tables, prepared using the information collected through the landowner interviews and roadside observations represented the actual land management conditions occurring in the watershed landscape including established BMPs. These conditions represented the actual field conditions that produced the streamflow and water quality observations made at the various watershed monitoring stations. The model run that utilized this input dataset was defined as the existing actual BMP scenario. In addition to this "existing actual BMP" scenario, model input files were constructed to represent two additional theoretical field conditions, namely the "no existing BMP" condition and the "potential future BMP" condition. Within each of these main field conditions, there were three sub-scenarios prepared that focused on the three soil health-related BMPs (cover cropping, conservation tillage including no-till, and fertilizer/manure incorporation following application). Model output was then compared between these various model runs, in order to arrive at an estimate of the potential efficacy of these key BMPs with respect to water quality improvement under varying levels of adoption of these practices across the watershed. A comparison of model outputs between the "existing actual BMP" scenario and the "no existing BMP" scenario provided an estimate of the efficacy of historical/existing BMP adoption. A comparison of model outputs between the "existing actual BMP" scenario and the "potential future BMP" scenario provided an estimate of the efficacy of additional potential BMP adoption. Furthermore, a comparison of model outputs between the "no existing BMP" scenario and the "potential future BMP" scenario provided an estimate of the efficacy of full adoption of these practices across the watershed.

The specific scenario runs compared to achieve this were as follows: no existing cover cropping scenario vs. potential future cover cropping scenario, no existing conservation tillage scenario vs. potential future conservation tillage scenario, and no existing fertilizer/manure incorporation scenario vs. potential future fertilizer/manure incorporation scenario. Unfortunately, we were not able to proceed with the BMP assessment due to time constraints. BMP assessment results however are expected to be in the similar order of magnitude on this study watershed as was calculated for other ONFARM watersheds (Garvey Glenn and Upper Medway Creek subwatersheds) for which the BMP assessment work was completed.

### 6.1 Existing actual BMP scenario

The "existing actual BMP" scenario characterizes all of the historical/existing BMPs or established BMPs in the Gully Creek subwatershed. This includes the key soil health-related BMPs of interest in this study as well as a good number of other soil conservation structural and agronomic best practices. These all needed to be represented in the model as they are present and influence the water flow and quality observations. There are 47 existing Water and Sediment Control Basins (WASCoBs) in the Gully Creek subwatershed. The locations of these existing WASCOBs are shown in Figure 3-4. The land management data for the historical/existing BMP scenario includes all land management BMPs collected through the WBBE, GLASI and ONFARM windshield and landowner interview surveys, including the key practices of interest, namely conservation tillage/no-till, cover crops, and fertilizer/manure incorporation for the period from 2001 to 2022.

### 6.2 No existing BMP scenarios

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

### 6.3 Potential future BMPs scenarios

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

#### 6.3.1 Assumptions used in developing potential future BMP scenarios

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

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

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

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

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

### 6.4 BMP assessment approaches

Assessing the water quality benefits of implementing the three key soil health-related BMPs, identified by the ONFARM study's technical working group (TWG), was not carried out for the Gully Creek watershed because of a lack of available time at the end of the study. The model datasets, however, could be prepared and model runs could be generated at a future date if feasible. The BMP assessment approach planned to be used is identical to the approach described in corresponding reports for other ONFARM watersheds for which the analysis was fully completed, namely the Garvey Glenn and Upper Medway Creek subwatersheds. Readers are suggested to refer to these reports for a full description of the BMP assessment approach details.

It is expected that the results of the BMP assessment analysis for the Gully Creek watershed, if completed, would be in the similar order of magnitude as was obtained from these other ONFARM watersheds (Garvey Glenn and Upper Medway Creek subwatersheds) given the similar approaches used, similar crops and level of adoption observed in this watershed compared to these other watersheds.

## 7.0 IMWEBS MODELLING RESULTS UNDER BOTH HISTORICAL/EXISTING AND THEORETICAL CONDITIONS/SCENARIOS

With the IMWEBs model input variables calibrated against available streamflow and water quality measurement data, the IMWEBs model was run for the period of 2001-2021 for the Gully Creek subwatershed. The simulated average yearly stream flow along with the sediment and nutrient yields/loads at the watershed outlet during the IMWEBs modelling simulation period were documented and presented in a tabular format.

For the Gully Creek subwatershed, the average annual precipitation for the period of 2010 to 2021 was 862 mm and the simulated annual total runoff/flow was 509 mm, with a runoff/flow coefficient of 0.59. The simulated average annual total sediment load at the watershed outlet was 2,524 tonnes (1.74 t/ha), of which 1,453 tonnes (1.00 t/ha) were from overland sediment yield and 1,071 tonnes (0.74 t/ha) were from channel sediment load. The average overland sediment delivery rate was calculated using the estimated sediment yield associated with the surface runoff and tile flow before it entered into the defined streams/channels divided by the watershed area. The average channel sediment delivery rate was calculated by dividing the total channel/stream sediment load by the watershed area. The estimated average annual TN load at the watershed outlet was 45,945 kg (31.62 kg/ha), of which 7,333 kg was in particulate form (16.0%) and 38,612 kg was in dissolved form (84.0%). The estimated average annual TP load at the watershed outlet was 3,401 kg (2.34 kg/ha), of which 2,191 kg was in particulate form (64.4%) and 1,210 kg wase in dissolved form (35.6%) (Table 7-1).

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

| | | | | | | |
|---|---|---|---|---|---|---|
| Overland sediment yield | 1,453 | t | 1.00 | t/ha | 57.6 | % |
| Channel sediment load | 1,071 | t | 0.74 | t/ha | 42.4 | % |
| Total sediment | 2,534 | t | 1.74 | t/ha | 100 | % |
| Particulate P | 2,191 | kg | 1.51 | kg/ha | 64.4 | % |
| Dissolved P | 1,210 | kg | 0.83 | kg/ha | 35.6 | % |
| TP | 3,401 | kg | 2.34 | kg/ha | 100 | % |
| Particulate N | 7,333 | kg | 5.05 | kg/ha | 16.0 | % |
| Dissolved N | 38,612 | kg | 26.57 | kg/ha | 84.0 | % |
| TN | 45,945 | kg | 31.62 | kg/ha | 100 | % |

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

The calibrated Gully Creek IMWEBs model can be applied to estimate the water quality benefits of the three key soil health-related BMPs including cover cropping, conservation tillage/no-till and fertilizer/manure incorporation under the current level of adoption of these practices by landowners across the watershed in relation to no adoption of these measures. Due to project time constraints, however, these model runs were not completed, their output not compared, and the results not tabulated. It is expected that the results would be very similar to those arrived at for the other ONFARM watersheds (Garvey Glenn and Upper Medway Creek subwatersheds) for which such work was completed. Completing this work in the future for the Gully Creek watershed, however, would confirm this.

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

The calibrated Garvey Glenn IMWEBs model can be applied to estimate the water quality benefits of additional adoption of the three key soil health-related BMPs including cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation in relation to the current level of adoption of these same BMPs in the watershed. Due to project time constraints, however, these model runs were not completed, their output not compared, and the results not tabulated. It is expected that the results would be very similar to those arrived at for the other ONFARM watersheds (Garvey Glenn and Upper Medway Creek subwatersheds) for which such work was completed. Completing this work in the future for the Gully Creek watershed, however, would confirm this.

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

The calibrated Gully Creek IMWEBs model can be applied to estimate the water quality benefits of full adoption of the three key soil health-related BMPs of interest including cover cropping, conservation tillage/no-till, and fertilizer/manure incorporation in relation to the entire absence of implementation of these BMPs in the watershed. Due to project time constraints, however, these model runs were not completed, their output not compared, and the results not tabulated. It is expected that the results would be very similar to those arrived at for the other ONFARM watersheds (Garvey Glenn and Upper Medway Creek subwatersheds) for which such work was completed. Completing this work in the future for the Gully Creek watershed, however, would confirm this.

## 11.0 BMP COST-BENEFIT ANALYSIS

BMP cost-benefit analysis (CBA) was another important component of the ONFARM project. ABCA staff completed a CBA for the cover crop BMP (Table 11-1), the Water and Sediment Control Basin (WASCoB) BMP - a type of erosion control structure see Table 11-2), adding organic amendments to soil (Table 11-3) and the conservation tillage BMP. Much of the CBA findings were based on data from four farmers in the Gully Creek watershed (Table 11-4). With their permission, we included their CBA in the report (with adaptation to be consistent with CBA data collected by MVCA and UTRCA for their respective ONFARM study watersheds). Note that in the components of the CBA, positive and negative numbers indicate costs and benefits respectively based on the fact that in most cases BMP costs outweigh benefits and positive numbers are used to represent positive net costs minus benefits. For the net cost-benefit, positive numbers indicate costs are over benefits while negative numbers indicate benefits are over costs.

Table 11-1. CBA for cover crops in the Gully Creek subwatershed

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

*15% yield increase equivalent to increasing from 150 bu/ac to 172 bu/ac of $6/bu grain corn. Yield bump is due to improved soil conditions, not due to improved fertility.
**cover crops have potential to drop one full soil erosion class: assumed, using Wall et al 1997, Appendix A. Erosion prevention calculated under 2 scenarios: high and low erosion. Cover crops can reduce erosion under HIGH erodibility conditions from high erosion class (10-15 tons/ac) to moderate erosion class (5-10 tons/ac) = diff 5 tons/ac. Also, this occurs under low conditions from moderate (5-10 tons/ac) to low (3-5 tons/ac) = diff 2 tons/ac. 5 and 2 tons/acre saved at 1.4T/m3 and $40/m3 purchase price (estimate for landscaper screened topsoil).
***termination costs = harvest costs of annual winter-killed cover crops
****estimate from dairy farmer experienced at feeding cover crops balage.

Table 11-2. CBA for WASCoBs in the Gully Creek subwatershed

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

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

Table 11-3. CBA for adding organic amendments to soil in the Gully Creek subwatershed

| | | COSTS | | | BENEFITS | NET |
|---|---|---|---|---|---|---|
| Farmer | Area influence d by BMP (ac) | Purchas e costs * ($/ac) | Spreadi ng costs ($/ac) | Incorporati on costs ($/ac) | nutrient Replaceme nt costs** ($/ac) | Net Cost- benefit ($/ac) |
| | | | | | | |
| G4-broiler | 234 | 0 | 56 | 18 | - 310.4* | -236.4 |
| G4-compost | 234 | 733 | 56 | 18 | -293** | 514 |
| G5-hog finisher, liquid | 42 | 0 | 56 | 18 | -196.4*** | -122.4 |
| G5-dairy liquid | 42 | 0 | 56 | 18 | -86.8**** | -12.8 |

* organic amendments produced off-farm have easily defined purchase costs. Organic amendments, that are produced on-farm, are frequently treated as a waste product (negative value) and disposed of as inexpensively as possible. The fertility value of on-farm manure is typically proportional to the nutritional value of the feedstocks and proportional to the manure's dry matter content. Occasionally, some livestock farmers will trade manure for wheat straw, so the manure does have some value.
**see APPENDIX C Agdex#-538 Available Nutrients and Value for Manure From Various Livestock Types, August 2013
Available Nutrients and Value for Manure From Various Livestock Types (gov.on.ca)
**NOTE:** values are representative of 2013 values and would change annually as fertilizer costs change. Appendix C shows how nutrient replacement costs have changed from 2012 to 2021.

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

Table 11-4. CBA for reduced tillage in the Gully Creek subwatershed

| | | COSTS | | | BENEFITS | | NET |
|---|---|---|---|---|---|---|---|
| Farmer | Area influenced by BMP (ac) | Conventional tillage costs * ($/ac) | Reduced-tillage costs * ($/ac) | Other costs (planter modifications) ($/ac) | Yield ($/ac) | Soil improvements ($/ac) | Net Cost-benefit ($/ac) |
| G3 – ***strip*** till vs conventional till | 78 | 51 | 28 | - | same | Less compaction Better soil structure | -23 |
| | | | | | | | |
| G – ***no-till*** vs conventional till | 78 | 51 | 0 | 2 * | 120** | Less compaction Better soil structure | 67 (first 3-5 years) -53 (after 3-5 years) |

*equal to the difference between conventional planter/drill and a reduced till planter/drill. OMAFRA 2018 custom rates in Appendix D
**20 bushel yield penalty @ $6/bushel corn first 3-5 years of transition. Zero yield penalty after years 3-5.

## 12.0 BMP COST-EFFECTIVENESS ANALYSIS

BMP effectiveness analysis consists of combining the findings from the various relevant IMWEBs BMP effectiveness model runs with cost-benefit analysis findings. The result would be a cost/kg of P reduced for each of the key BMPs of interest. Given that no BMP assessments could be completed for the Gully Creek watershed due to time constraints, it was not possible to complete a BMP cost effectiveness analysis for the Gully Creek watershed.

## 13. GENERAL SUMMARY AND FUTURE RECOMMENDATIONS

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

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

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

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

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

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

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

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

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

2). Develop paired experimental sites for BMP assessment

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

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

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

## 13.0 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.

Watershed Evaluation Group 2018. SWAT Modelling and Assessment of Agricultural BMPs in the Gully Creek Watershed Research. A Report Submitted to the Ausable Bayfield Conservation Authority, Ontario Soil and Crop Improvement Association, and Ontario Ministry of Agriculture, Food, and Rural Affairs, 118 pages, University of Guelph.