INTERIM REPORT

TESTING THE APPLICABILITY OF THE IMWEBS MODEL, FOR SIMULATING SEDIMENT AND FLOW IN THE GULLY CREEK WATERSHED.

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May 14 2014, Guelph, Ontario

SUMMARY

For this research the imWEBs model, developed by the University of Guelph, was applied to the Gully Creek watershed. The Gully Creek watershed borders Lake Huron and is described to be susceptible to erosion as the steep slopes caused the formation of gullies over the years. The imWEBs model is developed to evaluate the effects of beneficial management practices at a field scale. Before this can be tested the model has to be tested thoroughly to make sure the model operates properly. To do this the model is set up with 2009 and 2010 as warm up years and results are generated for 2011. Results for discharge and sediment yield are generated and these results are compared against measured data of 2011.

For model calibrations a list with 16 parameters is selected, of which two parameters are only used for sediment yield calibration. The parameters for discharge can roughly be categorised in three section, these section are identified after analysing the zero calibration run. The categories are points of improvements that are addressed during model calibration. These are increasing flow by reducing channel losses and reducing evapotranspiration. Shifting the snow melting peaks and increasing the intensity of the peaks. The last aspect is adjusting the output for baseflow.

For discharge the model is calibrated based on the coefficient of efficiency (NSE). Model calibration increased the NSE value from -0,165 to 0,552. The scores on the other goodness-of-fit measures are 0,633 for the coefficient of determination (R^2) and 0,887 for the index of agreement (D). The calibrated results still showed room for improvement as the model didn't capture all the peaks during the winter. This might be explained by the usage of temperature data from a weather station not located in the watershed. Also the model fails to create a good fit with the summer peaks. For the summer data is used from the Gully Creek weather station. Therefore it is expected that the problems are caused by the presence of groundwater. It was found that the watershed has a lot of groundwater and the model might have problems in calculating this properly. Therefore some adjustment had to be made to baseflow but this didn't solve the problem completely. In the end the model still failed to create a good fit with the measured peaks.

For sediment calibration the soil erodibility factor and the cover management factor are calibrated. As there was no continuous measured data available no goodness-of-fit measures are calculated. The calibrated results showed the model was capable of capturing most of the peaks between April and December. However a serious limitation was found for the winter period as no sediment yield was calculated by the imWEBs model. An adjustment of the model is recommended to be able to calibrate the snow cover parameter. This parameter was found to reduce sediment yield during the winter drastically.

Model validation was conducted with a split-sample test. The model is validated against two periods. For the period from 12-7-2010 to 31-12-2010 a NSE value of 0,332 was obtained. For the period from 1-1-2012 to 28-3-2012 a NSE value of 0,085 was obtained. Model validation was conducted very briefly so it is hard to draw conclusions about the applicability of the model based on these numbers.

In general it can be said that the model was able to simulate the processes in the watershed properly. For discharge very comparable results were generated in comparison with a SWAT model study conducted in the Gully Creek area. For sediment yield the model needs to be updated to address for the sediment yield in the winter. Future research should address the influence of groundwater and lake-effect snow in the watershed.

PREFACE

This report is the finishing product of the research conducted for my bachelor thesis in collaboration with the University of Guelph and the University of Twente. The research was supposed to finish in September 2013 but due to some personal setbacks it was postponed. Now, almost I year later, the report is finished and it is time to look back at the process.

The research ended up quite different than it was intended from the start. The research started very optimistic and the model was operational a lot faster than expected. Unfortunately some issues were discovered during model calibration. During the research the imWEBs model was continuously under development. Before conducting this research the model had only been tested briefly meaning that there were still some undiscovered problems with the model. One of the aims of performing this research was to find these problems so the model could be improved. This meant that the model was updated several times during the research. The updates of the model had significant influence on the performance of the model what meant that the calibration process had to start over again several times.

The model was first calibrated without any groundwater recharge (see appendix C). Apparently this module was not enabled when the model was set up for calculating discharge or sediment yield. Also some errors made by myself led to a redo of model calibration resulting in some delays. Unfortunately I wasn't able to regain the lost time meaning that the objectives of the research had to be adapted. In the end almost no model validation was conducted and there was no chance to evaluate the results for each field or for different scenarios. This is a petty because this is the main reason for developing the imWEBs model.

In the last two weeks of my research another model update was issued. This update needed me to adjust some of the database used for setting up the model. I wasn't able to get the model operational after this update. Unfortunately this also meant that no more results could be generated and the research had to be finished with what was already calculated. For model validation it was only necessary to run the model for different watersheds to be able to do a proxy-basin analysis but this wasn't possible anymore.

Even though the research did not go as planned it was a really good experience. The process to get to this report learned me a lot. Also my stay in Guelph was very pleasant. I want to thank everyone for their help and support. I want to thank my supervisor Yongbo Liu, from the University of Guelph, and Jord Warmink, from the University of Twente, for making everything possible. Also I want to thank Zhiqiang Yu, developer of the model, for helping me with any issues regarding the imWEBs model. At last I want to thank Ivana Lung and Liam Woodley for showing me around in Guelph and helping me with any problems I ran into with the model but also with ArcGIS, SQlite or Mapwindow.

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1 INTRODUCTION

1.1 BACKGROUND

In March 2013 the Watershed Evaluation of Beneficial Management Practices (WEBs) program ended. The WEB's program, initiated by the Government of Canada, started in 2004 and aimed at assessing the economic and water quality impacts of selected agricultural beneficial management practices. Out of the seven watersheds incorporated in the WEB's program, two were used for studying integrated modelling. The integrated modelling studies focused on incorporating hydrologic and on-farm economic factors (Agriculture and Agri-Food Canada, 2010).

The Geography Department of the University of Guelph, a research partner in the WEB's program, was assigned to develop the model's interface. The Integrated Modelling of Watershed Evaluation of BMP's (Beneficial Management practices), or in short the imWEBs model, was completed in March 2013. The advantage compared to the Soil and Water assessment Tool (SWAT), the main hydrologic simulation model used in the WEB's program, is that the imWEBs is that it is not limited to a subbasin level but that it has the ability to evaluate single and multiple BMPs at both field and watershed scales (Yang, Liu, & Shen, 2011; Arnold, et al., 2012).

1.2 PROBLEM CONTEXT

The imWEBs model will be applied to the Gully Creek Watershed, a lakeshore Watershed located at the eastern side of Lake Huron. The Gully Creek Watershed is part of the larger Bayfield North watershed within the Ausable Bayfield Conservation Authority (ABCA) jurisdiction. A study conducted by the Ontario Ministry of Natural Resources and the ABCA in the early 1980s show that gully erosion has been a problem for many years. The soil conditions, a mixture of clay and sand, combined with a steep gradient to Lake Huron makes the area prone to erosion. One of the main causes for increasing erosion was the removal of vegetation for agricultural purposes or area development. (Ausable Bayfield Conservation Authority, 2010).

The increased erosion forms a risk for residents living close to the ravines. Increased sediment in the streams due to erosion also has its impacts on water quality. More sediment in the streams limits the number of fish species that can live in the habitat. In addition, nutrients will bind to sediment which can lead to algal problems in the downstream areas (Ausable Bayfield Conservation Authority, 2010). A survey conducted by the ABCA in the Bayfield North communities shows the demand for measures to prevent erosion. One of the suggested measures is the implementation of individual Environmental Property Plans. Implementing BMP's can be more effective if awareness is created under landowners and if erosion prone areas are identified (Ausable Bayfield Conservation Authority, 2010).

The necessity for individual plans is emphasized in a study done to determine the cost effectiveness for BMP's by applying the SWAT model to the Gully Greek Watershed. The study shows considerable spatial variations across farms, fields and sites. These results emphasize the importance of spatial targeting of BMPs (Yang, Liu, & Simmons, 2013). The goal of the imWEBs model is to create a better understanding of the effects of BMPs on soil erosion. Because the model is fully distributed the model is able to show farmers the effects of their choices. By helping these farmers to understand the impact of their decisions it could be possible to create a better trade off in the future.

1.3 RESEARCH GAP

The imWEBs model is designed to evaluate BMPs on a field and farm scale and can therefore be an important asset for creating individual property plans. However there are some aspects to be taken into consideration. Semi-distributed models, such as the SWAT model, have been used for a long time and have a wide spread application. They are well tested and can rely on a solid database making the SWAT model a reliable tool for running simulations on a watershed or subbasin level. However, for creating individual property plans a higher level of detail is needed. The fully distributed imWEBs model is able to evaluate BMPs for a single field but, as it is a newly developed model, applicability has not been tested as thoroughly compared to the SWAT model (Yang & Liu, 2013).

The applicability of the imWEBs model needs to be tested for watersheds with different geospatial and hydrologic characteristics before it can be put into practice. So far the main testing area has been the Tobacco Creek watershed located in Manitoba, Canada. Only in the early development stages the model had been applied to the Gully Creek watershed. The research consisted of a first testing of the imWEBs model by a student from the University of Guelph. The research was mostly explanatory meaning that the conditions used during these test do not correspond with the real conditions in the Gully Creek watershed. The research has not been published publicly.

1.4 RESEARCH QUESTION

The goal of this research is to gain a better understanding of the applicability of the imWEBs model. The research aims at answering the following question:

How well does the imWEBs model perform against measured discharge and sediment yield data?

To be able to test the applicability of the model data from 2009-2011 for landuse, soil distribution and weather data is used for setting up the model. The results are compared against measured data for discharge and sediment yield. Answering the research question will contribute to gaining more understanding of the possibilities that the imWEBs model offers compared to semi-distributed models, such as the SWAT model. By testing the model in the Gully Creek watershed, knowledge about the imWEBs model and modelling in general will be developed. The research question is divided into four sub-questions.

Question 1:	Which parameters can be used to calibrate the model for discharge and sediment yield?
Question 2:	How does the model perform compared to measured discharge data?
Question 3:	How does the model perform compared to measured sediment data?
Question 4	Which factors can be identified to improve the performance of the model?

1.5 OUTLINE REPORT

This report is outlined as followed. In chapter 2 the project area will be described. Chapter 3 will explain which data is used for the research and what adjustment to the data are made. In chapter 4 the imWEBs model will be introduced and an explanation will be given about how the model is prepared for this research. The methodology is described in chapter 5 and the results are presented in chapter 6. The last two chapters are the discussion chapter and the conclusion chapter. In the discussion chapter the results are evaluated and some limitations about this research are presented. It also contains recommendations for future research. In the conclusion chapter answers are given for the research questions mentioned in the previous paragraph.

2 PROJECT AREA

The imWEBs model will be applied to the Gully Creek Watershed, a lakeshore Watershed located at the eastern side of Lake Huron (Figure 2-1). The Gully Creek Watershed is part of the larger Bayfield North watershed within the Ausable Bayfield Conservation Authority (ABCA) jurisdiction. The watershed has a size of 14.3 km^2 (Yang, Liu, & Simmons, 2013).

The climate of Southern Ontario can be considered one of the mildest of any region in Canada. Lake Huron's presence impacts weather patterns throughout the seasons by moderating temperature throughout the year. In the winter Months Lake Huron causes lake-effect snow (County of Huron Economic Development Services, 2013). The growing season starts in the middle of April and ends in late October with an annual average of 160 frost free days (Yang, Liu, & Simmons, 2013).

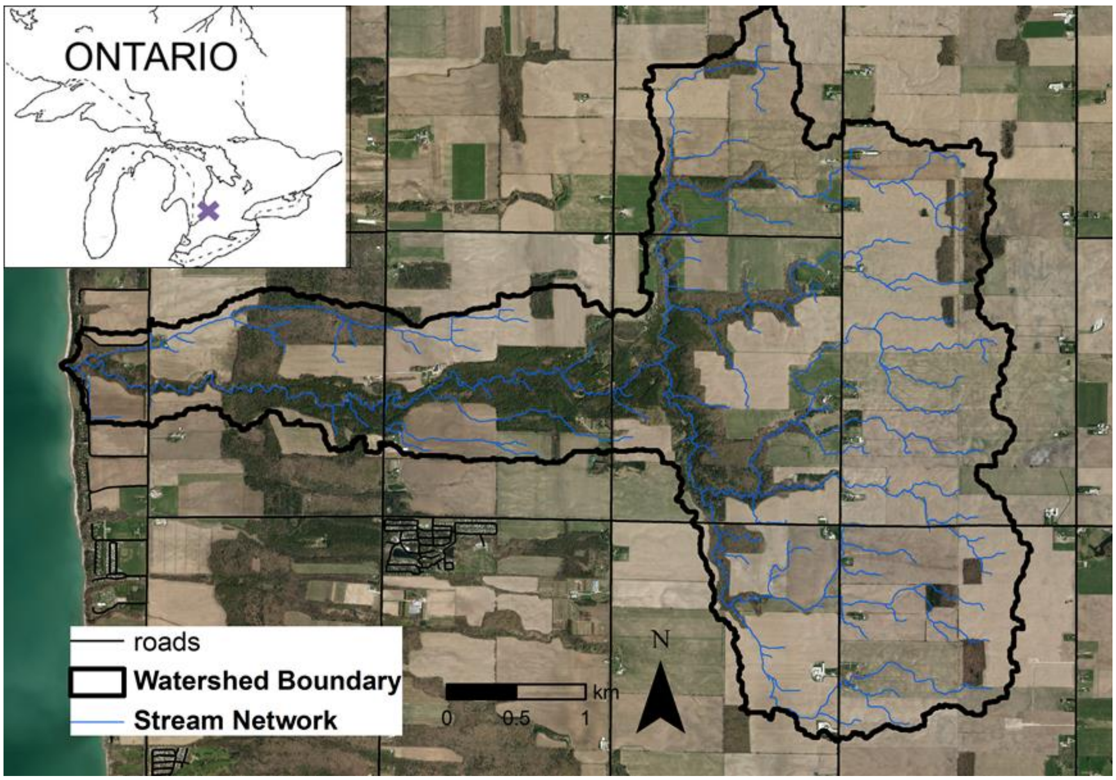

FIGURE 2-1: GULLY CREEK WATERSHED LOCATED IN AUSABLE BAYFIELD CONSERVATION AUTHORITY

In a report published by the ABCA in 2010 it is mentioned that there are no problems regarding water quality in the area. Even though water quality conditions in the Bayfield North Watersheds are typically better than other areas in the ABCA jurisdiction, the area deals with high rates of erosion (Ausable Bayfield Conservation Authority, 2010).

A study conducted by the Ontario Ministry of Natural Resources and the ABCA in the early 1980s show that gully erosion has been a problem for many years. The soil conditions, a mixture of clay and sand, combined with a steep gradient to Lake Huron makes the area prone to erosion. One of the main causes for increasing erosion is the removal of vegetation for agricultural purposes or area development. (Ausable Bayfield Conservation Authority, 2010).

The slope map, shown in Figure 2-2, shows the outline of the stream and is important for identifying erosion prone areas. Areas with a steep slope are more prone to erosion due to increased surface runoff. The maximum slope in the area is 64% and the average slope is 5.24%. Approximately half of the watershed is level or nearly level, with a slope less than 3%. Around 12% of watershed contains steep slopes of 10% and higher.

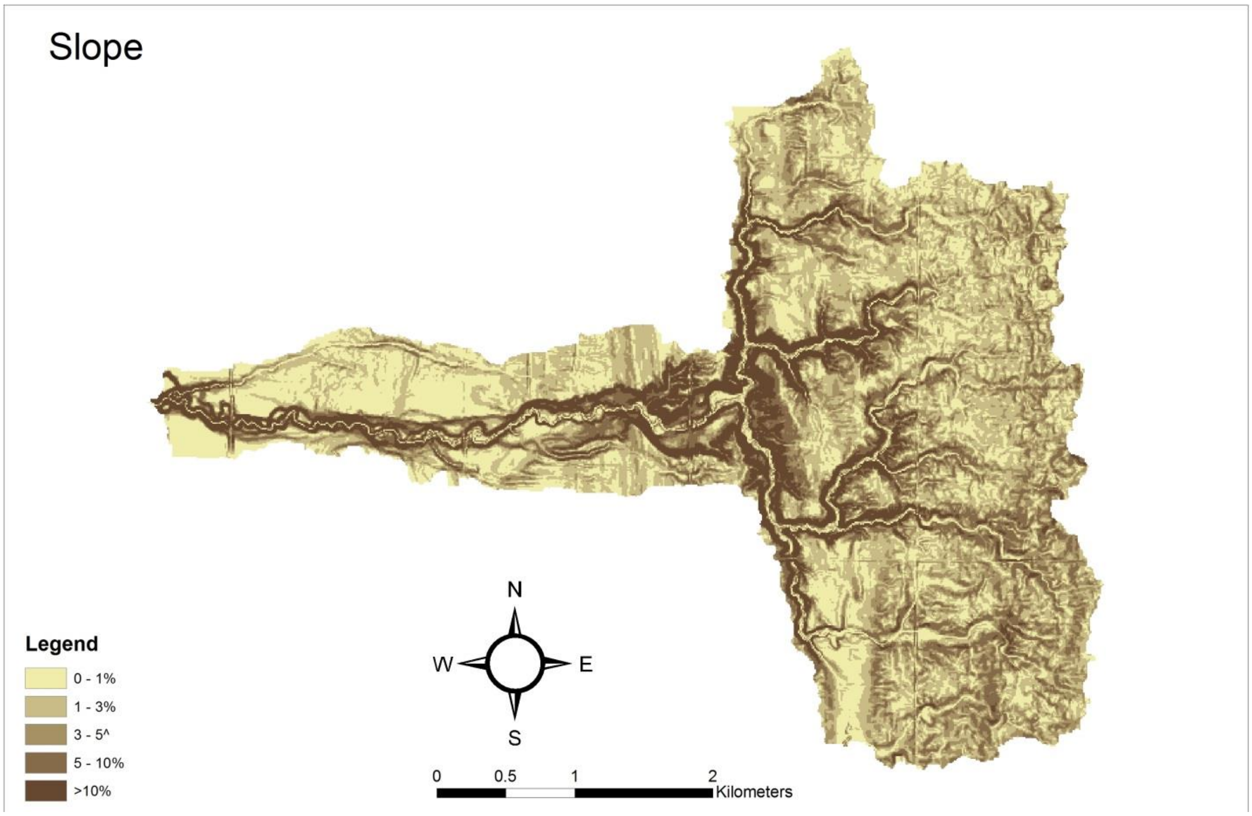

FIGURE 2-2 SLOPE ACROSS THE GULLY CREEK WATERSHED (SIMMONS, 2013)

The soil type distribution in the Gully Creek watershed is displayed in Figure 2-3. The soil types are defined according to the soil classification system of the Canada-Ontario Soil Survey (Yang, Liu, & Simmons, 2013). Clay loam is the dominating soil type in the area and can be found in the eastern part of the watershed. Along the streams the dominating soil type is bottom land. Closer to Lake Huron Sandy Loam is becoming the dominating soil type. Table 2-1 shows the coverage of each soil type in km^2 and as a percentage of the total area of the watershed.

TABLE 2-1 SOIL TYPE COVERAGE

Soil type	Area (km^2)	Area (%)
Bottom Land	1.37	9.62
Perth Clay Loam	1.05	7.33
Burford Loam	0.36	2.53
Brookston Clay Loam	1.51	10.59
Huron Clay Loam	8.19	57.42
Brady Sandy Loam	1.79	12.51
Total	14.27	100

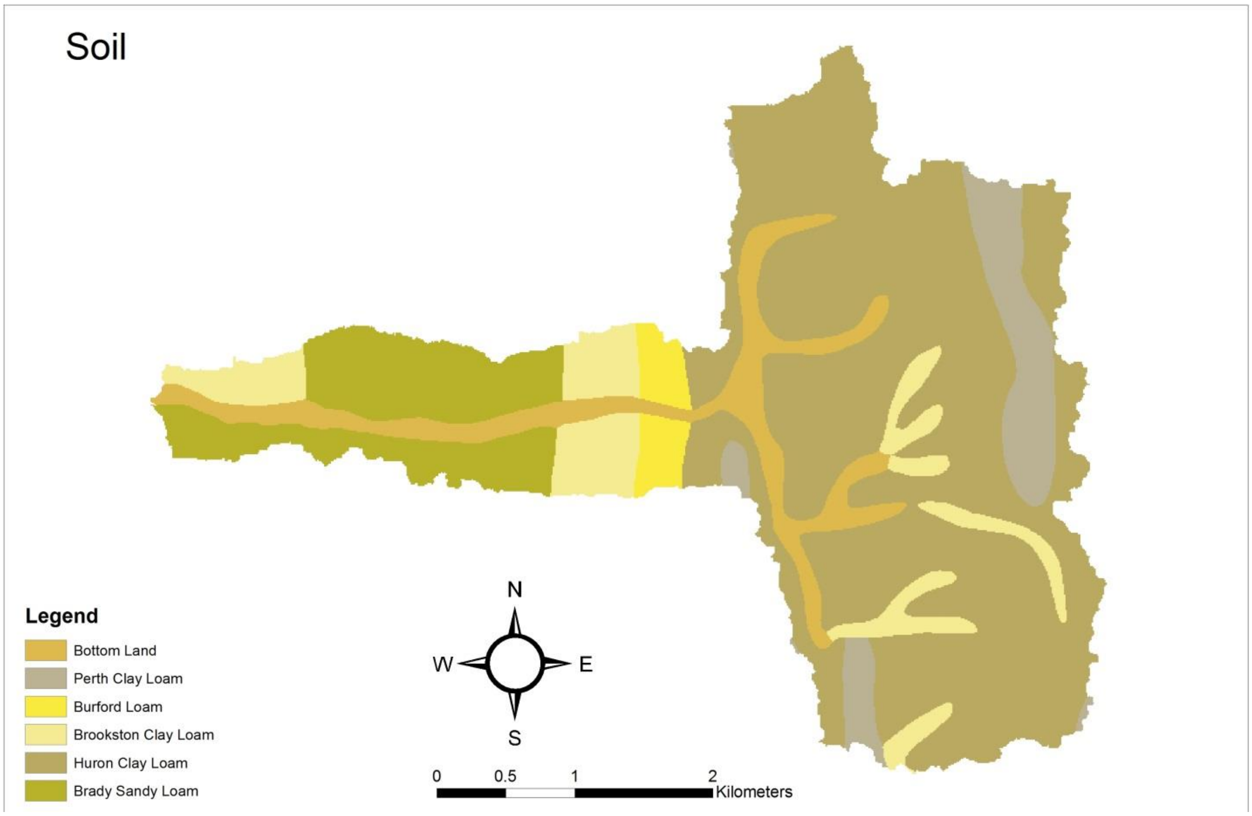

FIGURE 2-3 SOIL TYPE DISTRIBUTION MAP (SIMMONS, 2013)

The coverage of each land use type in 2013 is presented in. The area consist for 26.5% out of forest, ranging from areas with brushes to areas covered with woods. Infrastructure and residential areas cover 3.18% of the area. 68% of the area is used for agricultural purposes. Soybeans (23,32%), Winter Wheat (21,91%) and Corn (19,03) are the dominating crop types.

TABLE 2-2 LANDUSE COVERAGE

Landuse	Area (km^2)	Area (%)
Orchard	0.02	0.15
Hay	0.19	1.36
Forest_Mixed	2.98	20.89
Forest-Deciduous	0.58	4.05
Forest-Evergreen	0.19	1.31
Wetlands-Non-Forested	0.01	0.05
Pasture	0.19	1.34
Range-Brush	0.01	0.07
Water	0.15	1.04
Corn	2.72	19.03
Winter Wheat	3.13	21.91
Meadow Bromegrass	0.12	0.88
Tall Fescue	0.08	0.53
Soybean	3.33	23.32

Field Peas	0.01	0.09
Green Beans	0.11	0.80
Residential-Medium Density	0.05	0.38
Residential_Low Density	0.31	2.18
Transportation	0.09	0.63
Total	14.27	100

Figure 2-4 shows the land use distribution of the Gully Creek watershed in 2013. Most crops are grown in the eastern part of the watershed where the slopes are less steep. The forest areas can be found in the areas close to the streams, where the slopes are steeper.

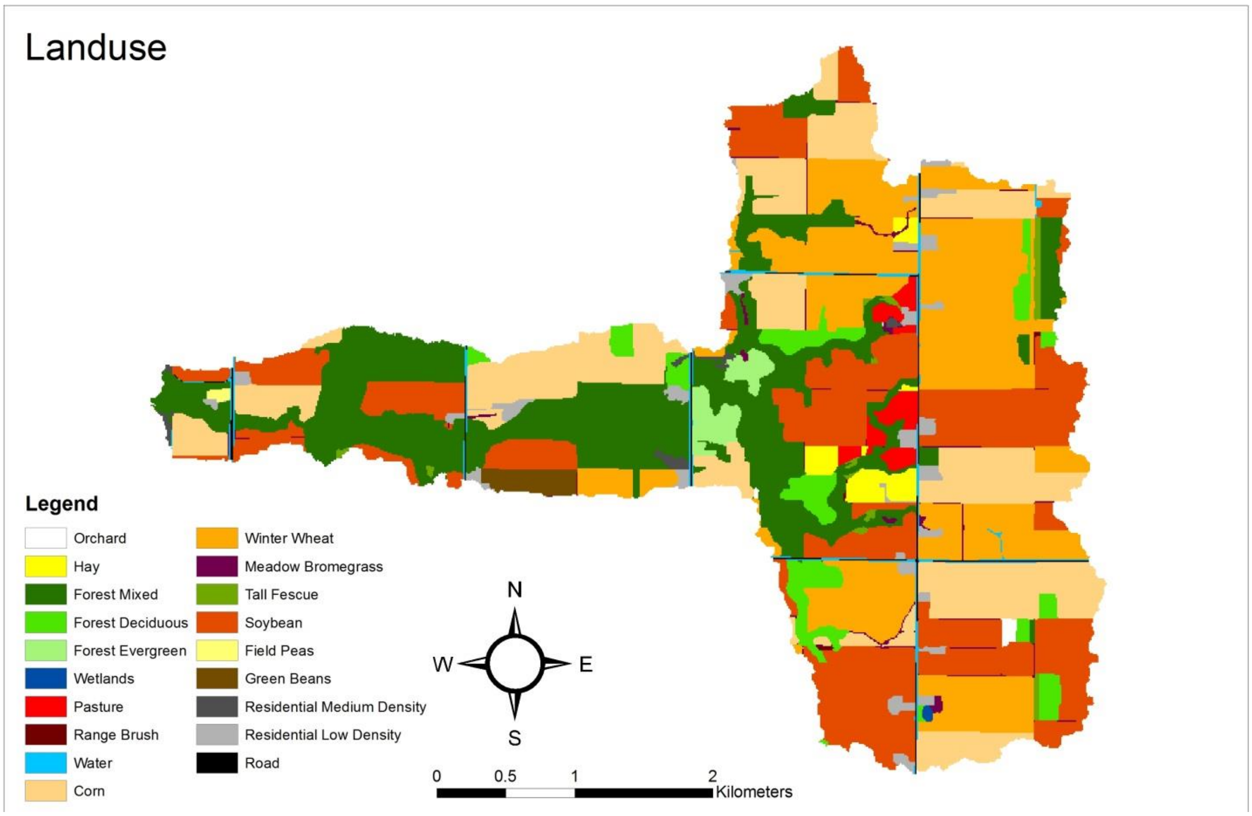

FIGURE 2-4 LANDUSE MAP GULLY CREEK WATERSHED IN 2013 (SIMMONS, 2013)

3 DATA

3.1 SPATIAL DATA

For this research spatial data is used from a study using the SWAT model (Simmons, 2013). The research was conducted by a master student in within the Geography Department of the University of Guelph. This paragraph shows the raw data extracted from the SWAT model and in the next paragraph the changes made to the data will be presented. The maps presented in Figure 2-2, Figure 2-3 and Figure 2-4 are extracted from this research. Table 3-1 shows which raw data is used and what the original source of the data is. No source for the stream and watershed boundary files are given as these are generated from the DEM file (Simmons, 2013).

TABLE 3-1 OVERVIEW OF DATA SOURCES

Data type	imWEBs format	SWAT files	SWAT source
DEM	ASCII	RRD file, 5x5 Lidar DEM	Provincial Digital elevation Model (MNR 2005)
Stream	Shape	Shape file	-
Watershed boundary	Shape	Shape file	-
Land use	ASCII	Shape file	Agricultural Resource Inventory (OMAFRA, 1983), Agri 2012 (ABCA) and Ecological Land Classification System (MNR 2007)
Soil	ASCII	Shape	ON Soils Map (OMAFRA, 2009)
Farms	ASCII	Shape	Agricultural Resource Inventory (OMAFRA, 1983), Agri 2012 (ABCA) and Ecological Land Classification System (MNR 2007)
Fields	ASCII	Shape	Agricultural Resource Inventory (OMAFRA, 1983), Agri 2012 (ABCA) and Ecological Land Classification System (MNR 2007)

To make the maps compatitabile with the imWEBs model some changes had to be made to the maps. The imWEBs model uses the ASCII format, a format for raster's. The data is converted using the conversion tool of ArcMap. The raster's are set to a 10x10 meter cell size. Secondly the maps are lined out to make sure that in all maps a cell covering a 10x10 meter area represents the same surface. The next step consist of snapping the map to the watershed boundary to make sure the total surface of each map is the same. The last step consisted on converting the maps to the NAD1983 UTM zone 17 projection.

It was found that a stream, defined in the stream file, was located outside of the watershed boundary. It is expected that this is caused by setting the maps to a 10x10 raster meaning cells that on the boundary of the watershed are snapped off. To prevent this from happening the stream file is manually adjusted and moved into the watershed.

3.2 PARAMETER DATABASE

Besides spatial data (e.g. the maps presented in paragraph 3.1) the imWEBs model uses three databases, these are the Model Parameter Database, the BMP Database and the Climate Database.

The Model Parameter Database contains model parameters and soil and land use characteristics. The soil characteristics are linked to the soil map true the soil_lookup table. This way imWEBs can import the soil characteristics and link it to the corresponding cells. ImWEBs has 12 predefined soil types but these do not match with the soil types that can be found in the watershed. Therefore a new soil database with the six present soil types is created (See appendix A).

The soil characteristics were extracted from an SWAT excel file and imported to a SQlite, the database tool used for the imWEBs model. Not all required data was available in the SWAT file. Table 3-2 shows the source of the soil data or the method used to calculate missing soil characteristics. Soil textures are defined using the soil texture triangle (Pedosphere, 2011). Based on the fraction of sand, clay and silt the soil is matched to one of the twelve predefined soil types in the original imWEBs soil table. The P_index and the residual moisture are extracted from the original parameter database based on matching soil textures.

TABLE 3-2 DATA SOURCES AND METHODS FOR BUILDING SOIL DATABASE

Data type	Source/method
Bulk Density	Extracted from SWAT data
Sand fraction	Extracted from SWAT data
Clay fraction	Extracted from SWAT data
Silt fraction	Extracted from SWAT data
Texture	Determined using the soil texture triangle
Soil erodibility	Extracted from SWAT data
Saturated hydraulic conductivity	Extracted from SWAT data
Porosity	Formula: 1 – (Bulk Density (Mg/m^3)/2.65 (Mg/m^3))
Wilting Point	Formula: 0.4 * (%Clay * Bulk Density)/100
Field Capacity	AWC (available water capacity) + Wilting Point, AWC was available in the SWAT data
P_index	Assigned by soil texture in the original soil database
Residual Moisture	Assigned by soil texture in the original soil database
Soil hydrologic group	Extracted from SWAT data and converted from letters to number to match imWEBs input

The land use data in the Model Parameter Database contains information of 102 different land use types. The land use map is linked to the parameter database in the same way as the soil map. The land map consists of 10x10 grid cells, each with a unique landuse_ID. This landuse ID matches a land use type from the database. Not all land use types are available in the Model Parameter Database. Table 3-3 shows the list of existing land uses found in the watershed and the assigned imWEBs land use. A land use type is assigned based on matching characteristics with the original land use table (Yang, Liu, & Simmons, 2013).

TABLE 3-3 LANDUSE LOOKUP TABLE

Original land use	imWEBs land use
Plantation Young	Orchard
Forages	Hay
Grass Hay	Hay
Mixed	Forest Mixed
Plantation Mature	Forest Mixed
Shrub/ Thicket	Forest Mixed
Shrub/Thicket Riparian	Forest Mixed
Woodland	Forest Mixed
Deciduous	Forest-Deciduous
Coniferous	Forest-Evergreen
Marsh	Wetlands-Non-Forested
Pasture	Pasture
Roughland	Range-Brush
Ditch	Water
Water	Water
Corn	Corn
Winter Wheat	Winter Wheat
Fencerow	Meadow Bromegrass
Grass Waterway	Meadow Bromegrass
Meadow Riparian	Meadow Bromegrass
Riparian	Meadow Bromegrass
Meadow Upland	Tall Fescue
Soybeans	Soybean
Fallow	Field Peas
Edible Beans	Green Beans
Urban	Residential Medium Density
Farmstead	Residential Low Density
Road	Transportation

3.3 BMP DATABASE

The BMP Database contains all the characteristics, such as crop rotation and the type and amount of tillage and fertilizer used, for all the fields located in the watershed. Fields are defined as the areas with an agricultural landuse. 124 fields can be found in the watershed and these can be matched to one of the 18 farms in the watershed. The crops farmers choose to plant and the amount of tillage and fertilizer used influences runoff, erosion and water quality. Depending on the length and the starting date of the model run the actual landuse will be adjusted according to the information in the BMP Database.

The BMP Database is set up with a six year rotation system. The data for the database is retrieved from the SWAT model and matches the actual practices farmers have used. The crop rotation consists of a crop name and a crop code that is used for linking the fields to the crop parameters. Crop parameters for 97 crops are available in the imWEBs model. The database also contains the dates of seeding and harvesting the crops. For setting up the crop rotation only the following crops are used: barley, corn, edible beans, forages, grass hay, pasture, soybeans and winter wheat.

Tillage rotation is build up out of a list with 104 different types of tillage. The tillage rotation determines how often the fields are plowed and what types of plows are used. A rotation with seven types of tillage is prepared for the Gully area (see appendix B). Tillage is applied four times a year. How often tillage is applied is of strong influence to the sediment yield in the stream. There is also a rotation with four types of fertilizers. The fertilizer data indicates the amount of nitrogen and phosphorous distributed in a field and the type and amount of manure applied to each field. The type of fertilizer is of strong influence to the water quality. As this research will no look into water quality no further emphasize will be on the usage of fertilizer.

3.4 WEATHER STATION DATA

The climate database contains daily data of precipitation, maximum and minimum temperatures and wind speed. No solar radiation or relative moisture data is used. No single weather station was able to provide all the climate data and therefore multiple climate stations are used (see Figure 3-1). In 3Table 3-4 the characteristics of the weather stations from where the climate data is collected are presented.

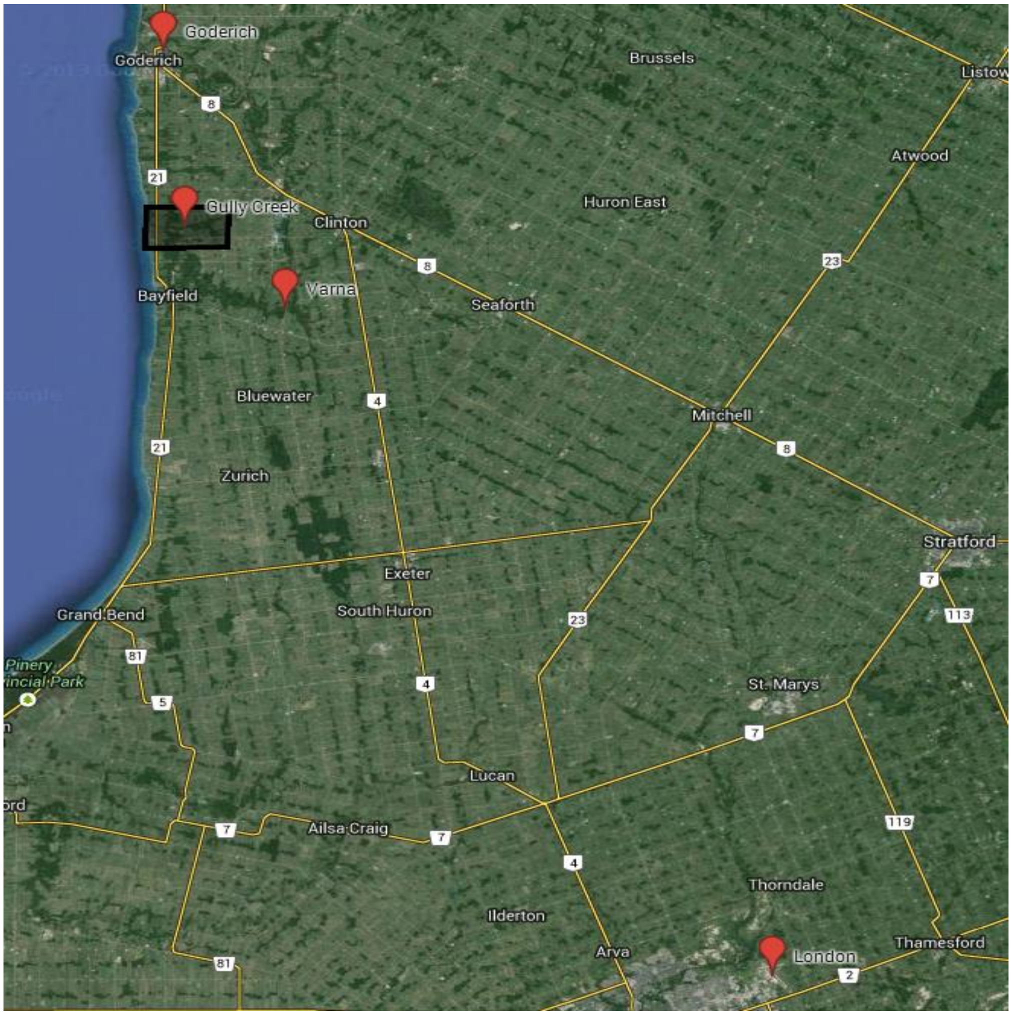

FIGURE 3-1 LOCATION OF WEATHER STATIONS (RETRIEVED FROM GOOGLE MAPS).

3TABLE 3-4 WEATHER STATIONS (SOURCE: ABCA & ENVIRONMENT CANADA)

Station	**Start Date** **End Date**	**Latitude**	**Longitude**	**Distance to Gully Creek**	**Notes**
Gully Creek	April 29, 2011 March 28, 2012	43°36'53" N	81°40'52" W	-	No snow data
Varna	April 6, 1989 March 31, 2012	43°33'4" N	81°35'22" W	10.22km	No snow data
London	July 1, 1940 July 19, 2012	43°01'59" N	81°09'04" W	77.60km	Includes snow data

Precipitation and temperature data was prepared for the SWAT model and is originally extracted from the ABCA and Environment Canada websites. The precipitation data was set up for the winter months using data gathered from the weather station in London, because the other stations had no snow data. The winter is defined as the period from November 1 to April 14 and summer from April 15 to October 30. For the summers data from the Varna weather station is used until the Gully weather station was operational on April 29 2011. For the temperature data the same division is made, meaning that winter data from London and summer data from Varna and Gully are used. Again, data from Gully is used instead of data from Varna from April 29 2011.

Wind speed data from the London weather station is used. This data is available on the Environment Canada website. Stations closer to the Gully Creek area had no wind speed measures except for the Goderich weather station (see Figure 3-1). Data from the London weather station is chosen as I was told by Yongbo Liu that this data matches the conditions in the Gully Creek Watershed the best. The wind speed data was measured on an hourly basis and averaged to generate daily values. Data gaps were filled by extrapolating from the closest available data. Data is prepared from 1-1-2009 till 20-3-2012 and in total there were 44 gaps present. The largest gap was twelve hours.

In Figure 3-2 the monthly rainfall, the average temperature and the average soil temperature for 2011 are presented. These are the results of a combination of weather stations as described above. Approximately 60% of precipitation occurs as rainfall from April to October, the remainder falls as snow during the five remaining winter months (Yang, Liu, & Simmons, 2013). The average precipitation from January 2001 to March 2012 is 2.87mm. The average daily rainfall in 2011 was 3.18mm making it the third wettest year. Only 2008 (3.87mm) and 2004 (3.19mm) had higher precipitation values.

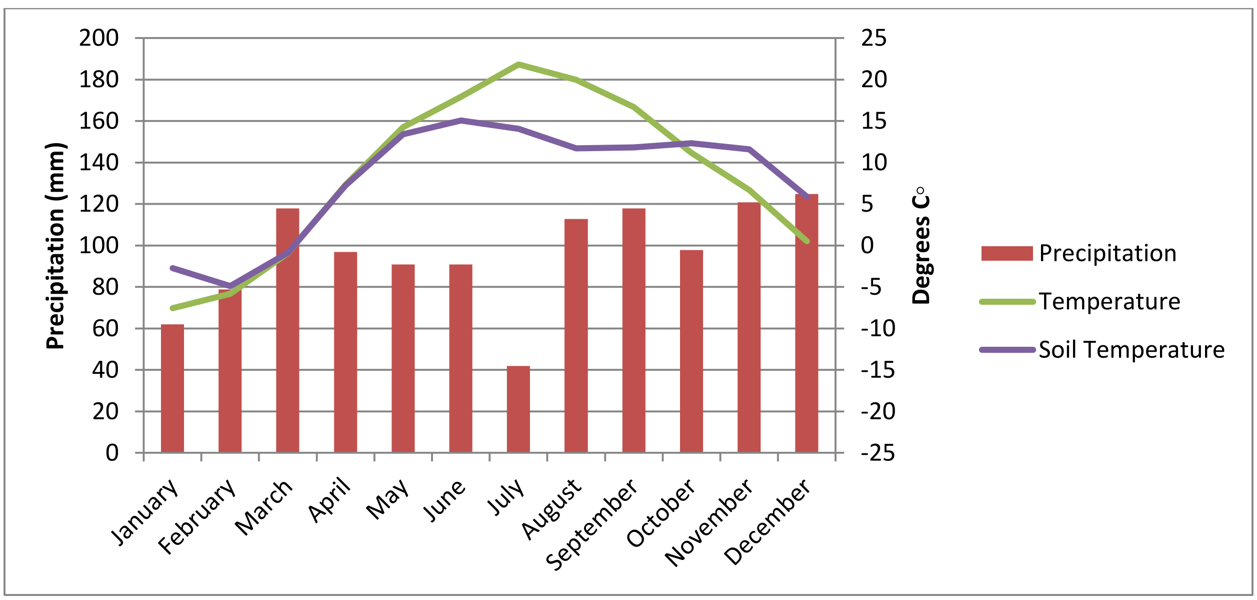

FIGURE 3-2 ASSEMBELED WEATHER DATA FOR 2011

3.5 MEASUREMENT STATION DATA

The results of the model will be compared to measured data for discharge and sediment yield. In total there are five measurement stations in the watershed. In this research only data from the GulGul2 measurement station is used. The location of the stations in the watershed is shown in Figure 3-3.

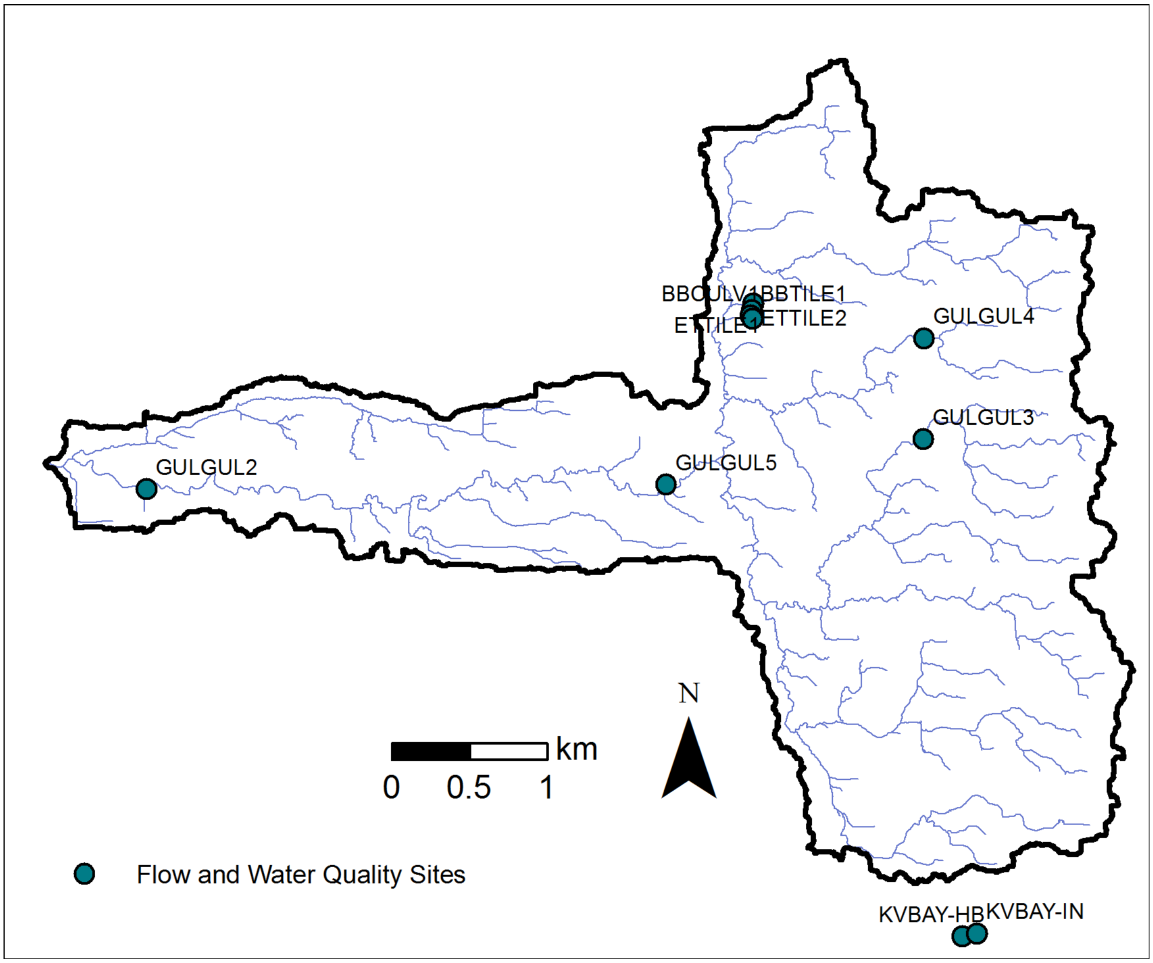

FIGURE 3-3 LOCATION OF MEASURMENT STATIONS

Data from a swat study conducted at the University of Guelph is used for the calibration of the model. The data was prepared in the SWAT study based on the original data retrieved from the ABCA. Daily data for discharge and sediment was available (Yang, Lui, & Simmons, 2013). Figure 3-4 shows the discharge measured at the GulGul2 measurement station for 2011.

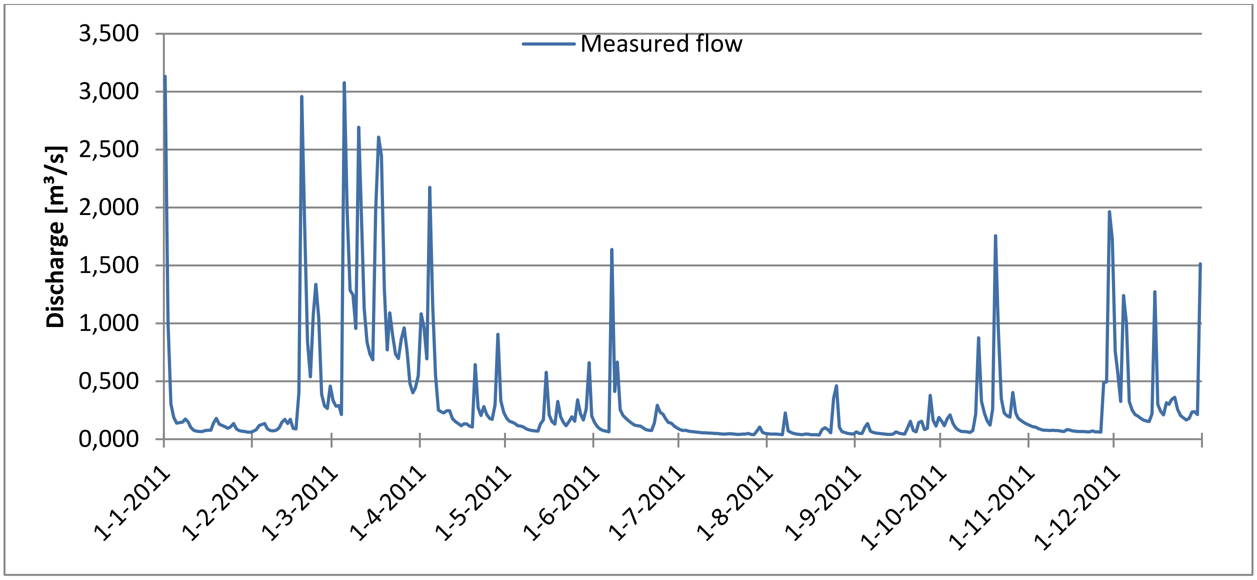

FIGURE 3-4MEASURED DISCHARGE AT THE OUTLET OF THE GULLY CREEK WATERSHED

The available measurements for sediment are shown in Figure 3-5. The measurements are plotted against the measured discharge as presented in Figure 3-4, this helps to show the relation between sediment yield and discharge.

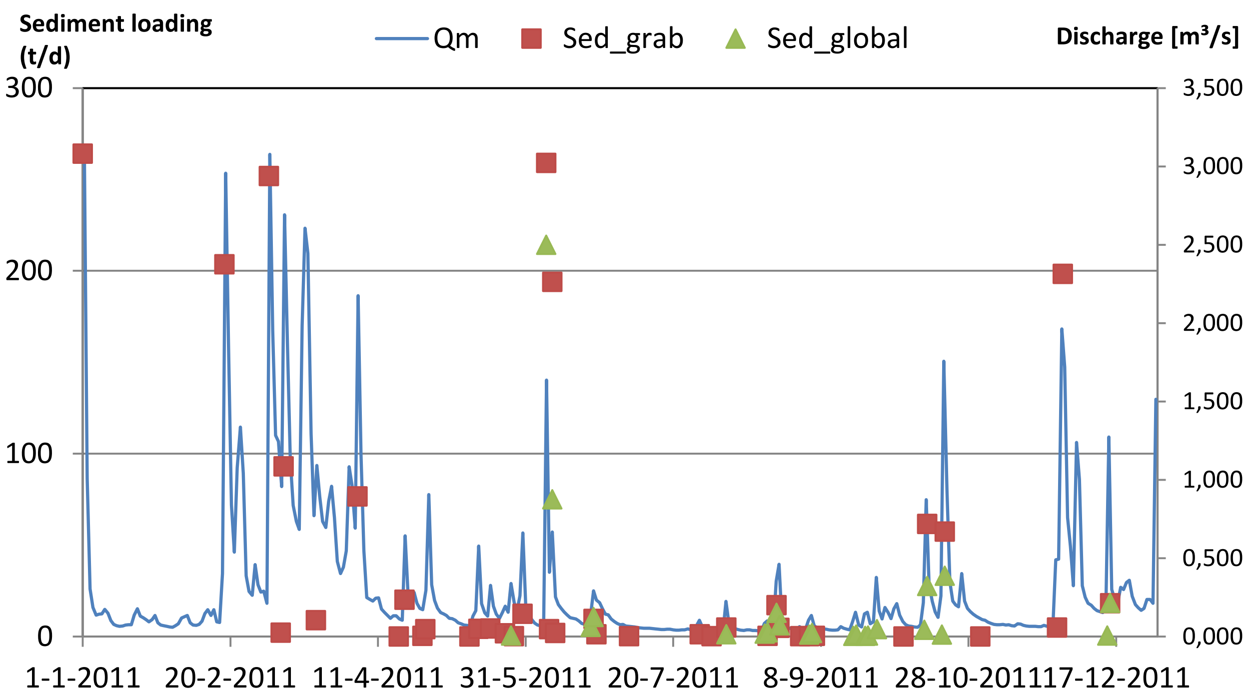

FIGURE 3-5 MEASURED SEDIMENT AT THE OUTLET OF THE GULLY CREEK WATERSHED

4 MODEL DESCRIPTION

The imWEBs model is a fully distributed, cell-based modular modelling system. The model is developed to examine hydrologic and water quality processes and for evaluating place-based BMP effects in small agricultural watersheds (Chung & Lung, 2013). The system uses a user friendly open-source GIS interface and is specially designed to evaluate the impact of BMPs on water quality at site/field/farm/watershed scales (Yang & Liu, 2013). The imWEBs model focuses on spatial and temporal distribution of hydrologic and water quality effects of BMPs (Yang & Liu, 2013). The ImWEBs model can be integrated with economic and ecological models and is flexible in defining model objectives and methods (Yang, Liu, & Shen, 2011).

For this research the model will be set up using the data prepared and described in the previous chapter. The model will be used to predict discharge and sediment yield for 2011 based on precipitation, temperature and wind speed data. The model will use 2009 and 2010 as a warm up year to set the initial conditions. The model allows the implementations of scenarios. Scenarios can be created to determine the effect of the usage of different fertilizers, types of tillage and crops. Also it can be used to assess the impact of BMP's (beneficial management practices). However, no scenario study is conducted due to time restrictions.

The model is prepared according to the flowchart presented in Figure 4-1. This chapter will elaborate the sections data preparation, watershed delineation and model setup. Model execution and model calibration will be discussed later on.

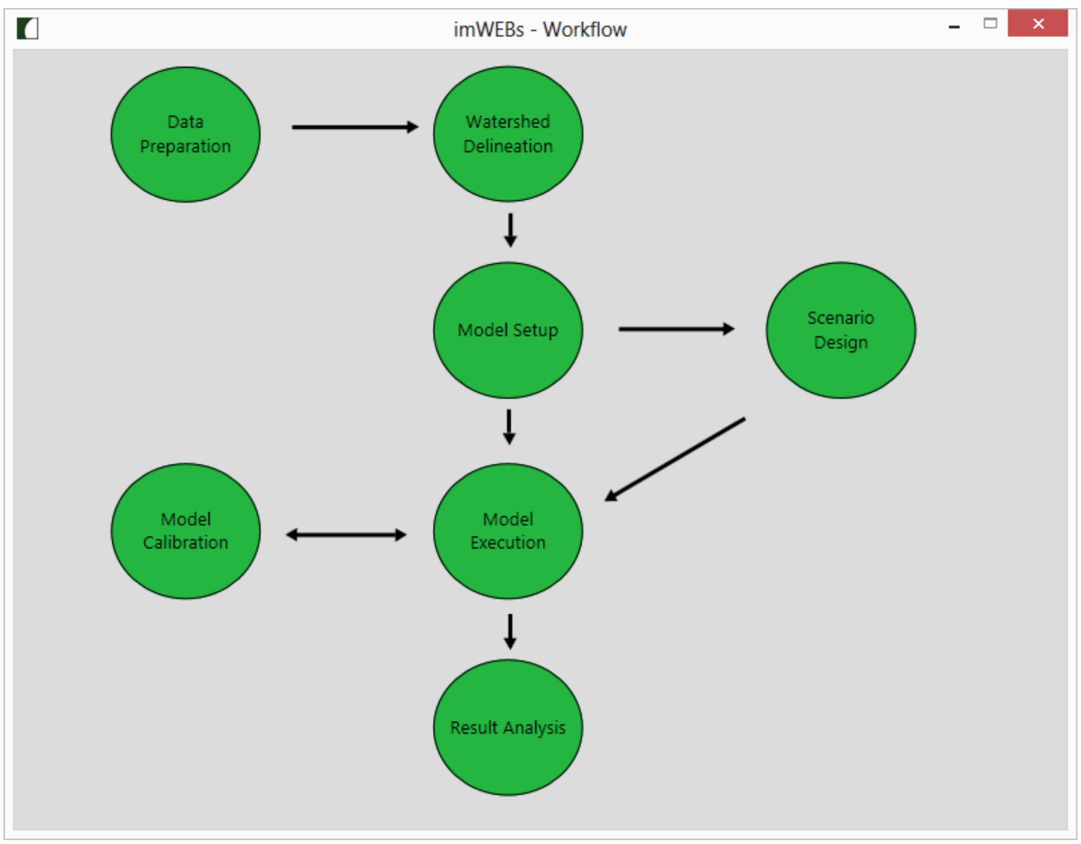

FIGURE 4-1 IMWEBS MODEL FLOWCHART (CHUNG & LUNG, 2013)

The model starts with importing all the data. In the Data Preparation section the databases and lookup tables are imported to the model. In the Watershed Delineation the spatial data is added to the model. For delineating the watershed it is necessary to determine the threshold area. The threshold area determines the amount of cells or the area the model will add up before it defines a stream. Based on the threshold area imWEBs can automatically define subbasins. A smaller threshold area leads to a denser distribution of streams throughout the watershed and to more subbasins. For a more in depth analysis of the area a small threshold area is desirable but this will also decrease model performance. Together with the supervisor of this study it was decided that 25 subbasins provides enough detail. Therefore the threshold area is set to 2500 grid cells.

In the Model Setup section the user has to determine the objective of the model and consequently the complexity of the model. As mentioned earlier the model objective will be set to discharge and sediment meaning no results for plant growth and water quality will be generated. Being flexible in setting the objective allows the user to run the model without the need to have all the data available as well as that it increases the performance speed of the model.

Depending on the chosen objective a list of classes becomes available. Each class contains methods that used to determine how the processes in the watershed are simulated. Table 4-1 shows the methods used in this research.

TABLE 4-1 METHODS USED FOR SETTING UP THE IMWEBS MODEL

Modules	Method
PET	Hargreaves
Interpolation	Average uniform
PET landcover	Landuse
Interception storage capacity	Sin curve
Interception	Mass balance
Snow redistribution	Mass balance
Snow sublimation	PET fraction
Snowmelt	Degree day
Snow balance	Water balance
Soil temperature	Finn Plauborg
Infiltration	SCS curve number
Depression	Fill and spill
Percolation	Pore index
Subsurface runoff	Darcy
Soil ET	Linear moisture
Groundwater	Reservoir
Soil water	Water balance
Overland flow	IUH overland
Interflow	IUH interflow
Flow routing	Muskingum
Erosion C-factor	Landuse
Erosion	MUSLE_AS
Sediment transport	Stream power
Sediment routing	Variable channel dimension

Only for PET, Interpolation, Interception, Flow routing and Erosion there are multiple methods present. For running the model, climate data of precipitation, minimum and maximum temperature and wind speed is used. As no solar radiation or relative humidity data is used, the Hargreaves method is used for calculating PET.

The Penman-Monteith and the Priestley-Taylor method both need solar radiation and relative humidity data to calculate the PET. The read method requires prepared PET data which wasn't available.

The interpolation method is set to Average uniform as the model is setup with one weather station located inside the Gully Creek watershed. This means that the weather data is set as an average across the watershed meaning that for every location the same data is applied. The Grid, Inverse Distance, Linear Triangle and Thiessen Polygon methods all need multiple weather stations for calculating the distributed parameter for precipitation, temperature and PET.

Four infiltration methods are available in the imWEBs model. All methods have the required data to and can be used for setting up the model. For model calibration the SCS curve number will be used. The SCS curve number calculates infiltration based on the accumulated runoff, the depth of rainfall and the retention parameter. It uses the initial abstraction for surface storage and interception and considers infiltration prior to runoff.

The Muskingum method is applied for determining flow routing. The Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages.

Erosion is calculated with the MUSLE (modified universal soil loss equation) methods. Two MUSLE methods are available, MUSLE_AS and MUSLE_I30. The MUSLE_AS method uses peak flow determined from the area and slope of raster cells. The MUSLE_I30 method uses peak flows based on the maximum 30 minute intensity. As the model is set to daily time steps the MUSLE_I30 method calculates peak flows based on averaged hourly data, making results less accurate compared to regular hourly data. Therefore the MUSLE_AS method is used for simulations.

5 METHODOLOGY

5.1 ZERO CALIBRATION RUN

The imWEBs model has no automatic calibration function. There is also no option for doing a sensitivity analysis. In addition, performing a manual sensitivity analysis is hard as the fully distributed parameters have high interdependency making a manual sensitivity analysis too time consuming. Because not all parameters are very sensitive a zero calibration run is conducted to make a selection of the most important parameters.

To do this output for discharge in 2011 will be compared to the measured discharge at the GulGul2 measurement station (see Figure 3-3). The model will also create daily values for the soil water balance and the reach water balance as these water balances provide helpful insight in the creation of discharge. Sediment yield will not be analysed for the zero calibration run. Calibration will focus on discharge first and after discharge is calibrated a calibration will be done to improve sediment yield.

Unfortunately there is no data available of other imWEBs studies and there is no measured data to compare the soil water balance and the reach water balance. This means the analysis will be conducted based on shared knowledge and experience of the geography department as there is no published literature available on calibrating the imWEBs model. So far there is only one other location for which the imWEBs model is applied but this is still ongoing research. There is information available about calibrations done for the SWAT model but it was found that the calibration of the SWAT model was not comparable to the calibration of the imWEBs model. However it does provide some guidance for the analysing the outcomes of the imWEBs model.

5.2 DISCHARGE CALIBRATION

Based on the analysis of the zero calibration run and the shared knowledge in the department a selection of parameters will be made. Based on the trial-and-error principal these parameters will be tested on their sensitivity. If parameters turn out to be sensitive and improve the outcomes of the model they are added for the final calibration. In total there are 14 parameters selected for calibrating the model for discharge. These parameters are adjusted in small steps to find an optimal situation.

The so called optimal situation is approached based on the score of the goodness-of-fit measures. Three goodness-of-fit measures will be used to give a full view on the performance, these are the Coefficient of Efficiency (NSE), the Coefficient of determination (R^2) and the Index of Agreement (D). The goodness-of-fit measures have been found to be a good way of assessing the performance of a model. The model is calibrated based on the coefficient of Efficiency. As only one measure may lead to the possibility to interpretation errors the other two measures are calculated afterwards to give a full review of the performance (Legates & McCabe Jr., 1999).

The NSE is used to measure the predictive power of the model. Values can range from $-\infty$ to 1, with a value of 1 indicating a perfect fit. A NSE value lower than zero means that the mean value of the observed data is a better predictor than the model. The NSE is calculated with formula (1) in which O is the observed data and S is the simulated data.

$$NSE = 1 - \frac{\sum_{t=1}^{N}(O_t - S_t)^2}{\sum_{t=1}^{N}(O_t - \bar{O})^2} \tag{1}$$

The Coefficient of determination describes the proportion of the total variance in the observed data that can be explained by the model. R^2 can range from 0.0 to 1.0 and a higher value for R^2 means there is better agreement between simulated and observed data. R^2 is calculated with formula (2) (Biondi, Freni, Iacobellis, Mascaro, & Montanari, 2012).

$$R^2 = \left(\frac{\sum_{t=1}^{N}(O_t - \bar{O})(S_t - \bar{S})}{\left[\sum_{t=1}^{N}(O_t - \bar{O})^2\right]^{0,5}\left[\sum_{t=1}^{N}(S_t - \bar{S})^2\right]^{0,5}}\right)^2 \tag{2}$$

The Index of agreement represents the ratio between the mean square error and the “potential error” for a range of observed and measured data. The index of Agreement is a useful measures as it is less sensitive tot differences in the measured and simulated data means and variances compared to relation-based measures. D can range from 1 to 0 with 1 representing a perfect agreement between the measured data and the performance of the model. D can be calculating using formula (3) (Legates & McCabe Jr., 1999).

$$D = 1 - \frac{\sum_{t=1}^{N}(O_t - S_t)^2}{\sum_{t=1}^{N}\left(|S_t - \bar{O}| + |O_t - \bar{O}|\right)^2} \tag{3}$$

5.3 SEDIMENT CALIBRATION

Sediment calibration is conducted after the model is calibrated for discharge. As there is no continuous data available sediment calibration is conducted based on graphical fit between the measured and simulated data. Just as with discharge calibration parameters are calibrated on a trial-and-error principal meaning that the output is evaluated and accepted if there is improvement. Formula (4) shows how sediment yield is calculated. Q and q_p are calibrated during discharge calibration so no adjustment will be made to these parameters. The erosion control practice parameter will not be calibrated because this only works if there are control practices added to the BMP database. The slope length and gradient factor will not be calibrated as it doesn’t seem feasible to make adjustments to the geographical characteristics of the watershed.

$$Y = 11.8 \times \left(Q \times q_p\right)^{0.56} \times K \times LS \times C \times P \tag{4}$$

With:

Y	=	the sediment yield to the stream network in metric tons
Q	=	the runoff volume from a given rainfall event in m^3
q_p	=	the peak flow rate in $m^3 s^{-1}$
K	=	the soil erodibility factor
LS	=	the slope length and gradient factor
C	=	the cover management factor
P	=	the erosion control practice factor

5.4 MODEL VALIDATION

Model validation is done with a split sample test for discharge only. For the split-sample test the data is split in two segments of which one is used for calibrating the model and the other for validating the model (Klemes, 1986). Results are compared to measured discharge data at the GulGul2 measurement station for the periods July-December 2010 and January- March 2012. The data of 2011 cannot be used as this data is already used for calibrating the model. For model validation the same goodness-of-fit measures are calculated as for model calibration (i.e. NSE, R^2 and D).

6 RESULTS

6.1 ZERO CALIBRATION

Figure 6-1 shows the discharge results of the zero calibration run. The NSE run is -0,165. R^2 is 0,033 and D is 0,406. If you add up the daily values presented in Figure 6-1 the total flow adds up to 60,45m^3/s as where the total flow adds up to 114,38m^3/s.

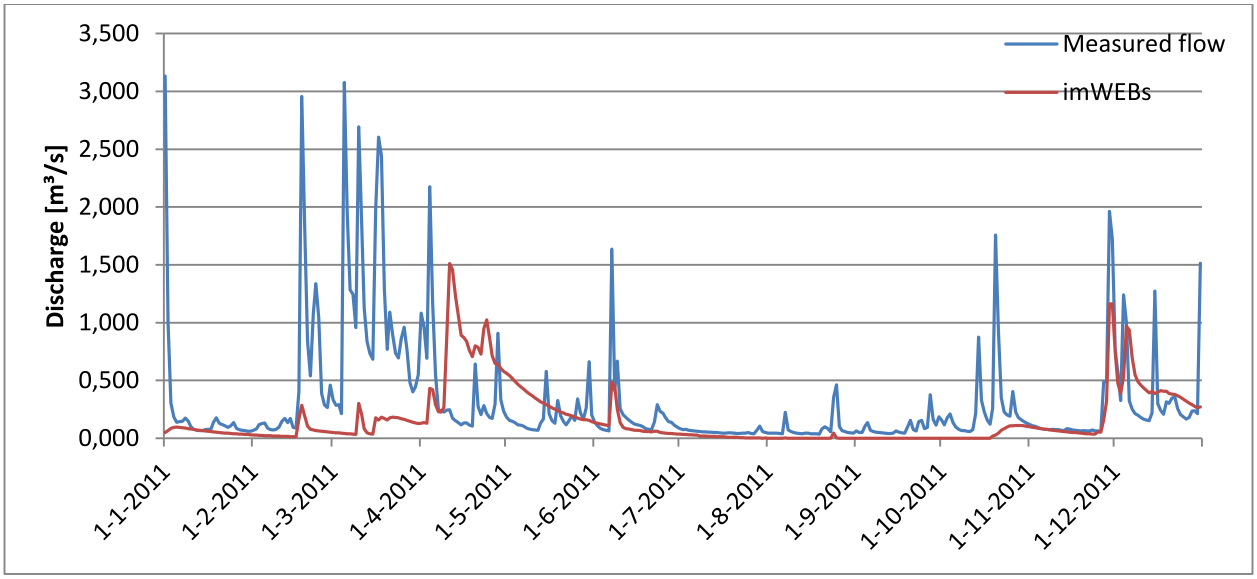

Figure 6-1 Discharge – zero calibration

To increase the NSE value total flow should be increased. Analysis of the reach water balance showed that that there was more water leaving the stream than water flowing back into the stream. To prevent this from happening, the channel bottom and channel bank hydraulic conductivity parameters should be lowered to decrease the amount of water leaving the stream. A second point was that there was a lot of water evaporating from the stream. This can be addressed by lowering the reach evapotranspiration factor.

By comparing the results of the soil water balance with observations from previous SWAT studies, it could be concluded that there was too much evapotranspiration (Yang, Liu, & Simmons, 2013; Simmons, 2013). The K_pet parameter can be adjusted to lower the evapotranspiration in the watershed. Also the k_blow parameter, a parameter influencing the amount of snow blown into or out of the watershed, is selected to increase total flow. If lake-effect snow isn't modeled this factor might compensate for the absence of lake-effect snow. Lake-effect snow is a phenomena that occurs at the Great Lakes and, as mentioned earlier in the area description, it can be found in the Gully watershed as well (County of Huron Economic Development Services, 2013). Large bodies of water increase air moisture and when the air cools down above land it leads to large amounts of snow (Scott, 2010).

Figure 6-1 shows that the model failed with the timing of the spring melt peak. Right now the peak is calculated to occur in April. The measured data however shows that the spring melt peak starts half way in February. It also shows that it consists of multiple peak instead of the one calculated by the model. To address this problem the calculated and measured discharge are compared against the daily temperatures during the winter months (i.e. January 1 – April 14). The temperatures are retrieved from the hydrologic database meaning that the temperatures are measured at the London weather station (see paragraph 3.4). Figure 6-2 shows that the with the imWEBs model almost no flow is calculated indicating that some adjustments should be made to snow and temperature related parameters. Another thing worth pointing out is that the measured peaks mostly overlap the days with temperatures above 0.

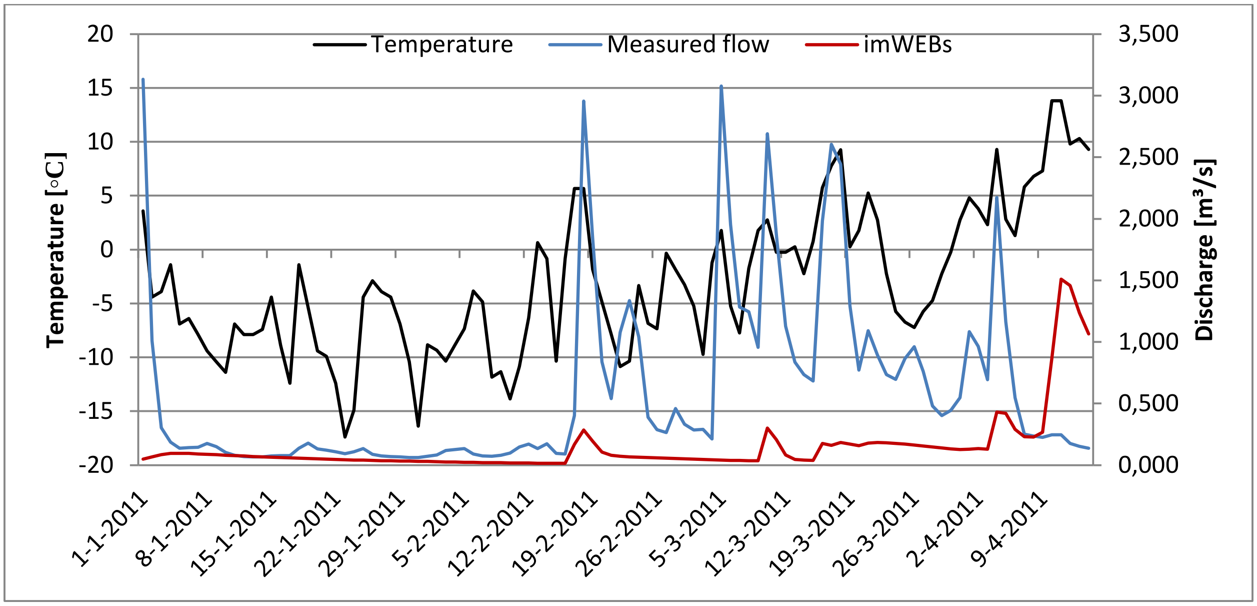

FIGURE 6-2 TEMPERATURE AND DISCHARGE DURING THE WINTER

To make sure the imWEBs model calculates snow melt better the following parameters are selected for model calibration. These are the Soil freezing temperature, the snowfall temperature and the snowmelt temperature. Lowered these parameters will lead to a shift of the melting peak, resulting in an earlier melting period. The C_snow parameter, the temperature impact factor, will be increased to intensify snow melting peaks. This is done to make sure the model captures the short but intense peaks.

The last point that should be resolved during model calibration is the absence of flow during the summer. Figure 6-1 shows that between July and November almost no flow is calculated. At the same time the peaks that are calculated continue for a long time. These peaks should have a larger decline after they occur. The poreindex, the baseflow recession coefficient (for the water balance and for discharge) and the groundwater revap coefficient are calibrated to create a better fit. The adjustments made to these parameters will lead to less baseflow and more runoff and recharge.

6.2 DISCHARGE CALIBRATION

Table 6-1 shows the parameters used for model calibration. It shows their initial value and the changes made during model calibration. ImWEBs offered two possibilities for making changes, absolute change and relative change. Relative change is only used for the pore-index. The poreindex is a distributed parameter and therefore the initial value is set to -99. The relative change of 1.6 means that the poreindex for all soil types are multiplied by 1.6.

TABLE 6-1 CALIBRATED PARAMETERS

Parameter	Description	Initial value	Change	Type of change
k_chb	Channel bottom hydraulic conductivity	10mm/hr	-9.85	Absolute
k_bank	Channel bank hydraulic conductivity	10mm/hr	-9.85	Absolute
ep_ch	Reach evaporation adjustment factor	1.0	-0.85	Absolute
K_pet	PET Correction factor	1.0	-0.5	Absolute
MSK_co1	Weighting factor of bankful flow	0.15	0.25	Absolute
k_blow	Fraction of snow into or out of the watershed	0	1	Absolute
T0	Snowmelt temperature	2.5 ◦C	-3.5	Absolute
t_soil	Soil freezing temperature	0.0 ◦C	-0.2	Absolute
T_snow	Snowfall temperature	1.5 ◦C	-1.5	Absolute
c_snow	Temperature impact factor	3.0 mm/◦C/Δt	1.85	Absolute
poreindex	Pore size distribution index	-99	1.6	Relative
kg	Baseflow recession coefficient (Water balance)	0.05	0.15	Absolute
rv_co	Groundwater revap coefficient	0,1	-0.05	Absolute
Kg	Baseflow recession coefficient (Discharge)	0.01	0.04	Absolute

Figure 6-3 and Table 6-2 represents the model performance for 2011 after doing calibrations. Total flow went up to acceptable amount. After calibrations the calculated total flow is 121,67m3/s whereas the measured total flow is equal to 114,38m^3/s. The NSE coefficient of 0,552 shows the model improved a lot during model calibration, but there is a lot to improve regarding the predictive power of the model. The R^2 coefficient show that 63,3% (for 2011) of the variance in measured data can be explained by the model. The model performances good with regard to the index of agreement (D) meaning that the measured error is close to the potential error in the data. The value of D equals 0,887.

TABLE 6-2 MODEL PERFORMANCE

	NSE	R^2	D
Before calibrations	-0,165	0,033	0,406
After calibrations	0,552	0,633	0,887

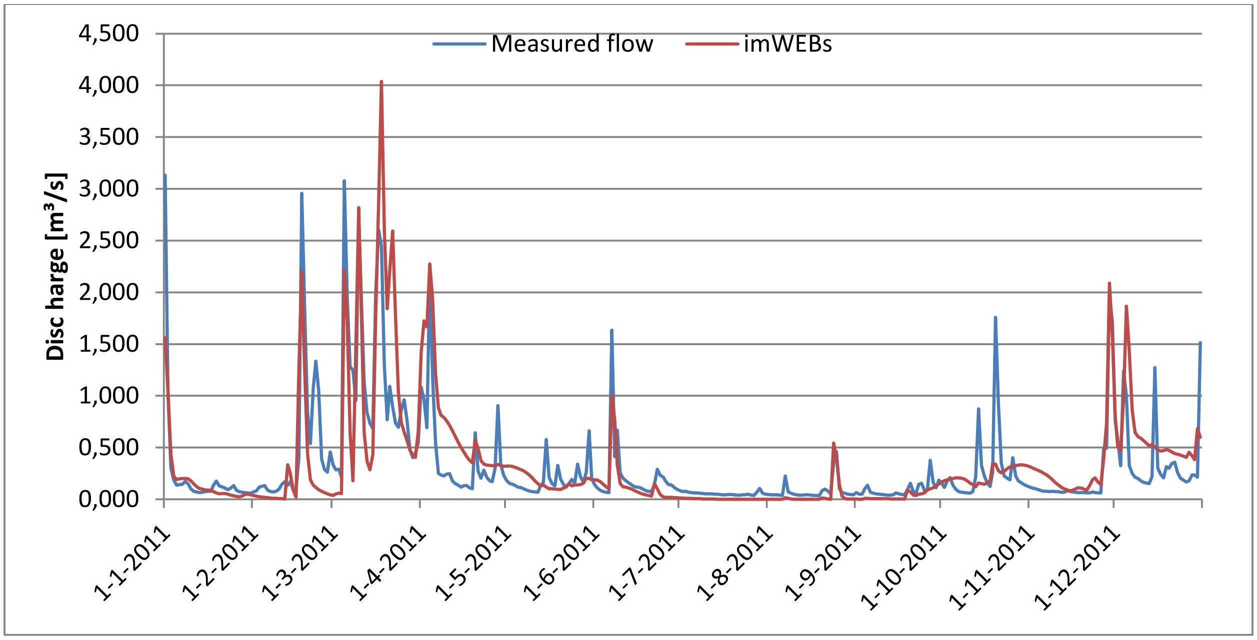

FIGURE 6-3 CALIBRATED MODEL

The NSE and R^2 coefficients indicate there is still a lot of room for improvement in the model. The following sections will address some problems that might explain the outcomes of the NSE and R^2. During model calibration it was found that the model showed some problems with infiltration and baseflow. Figure 6-4 shows three highlighted areas where some of these problems are identified.

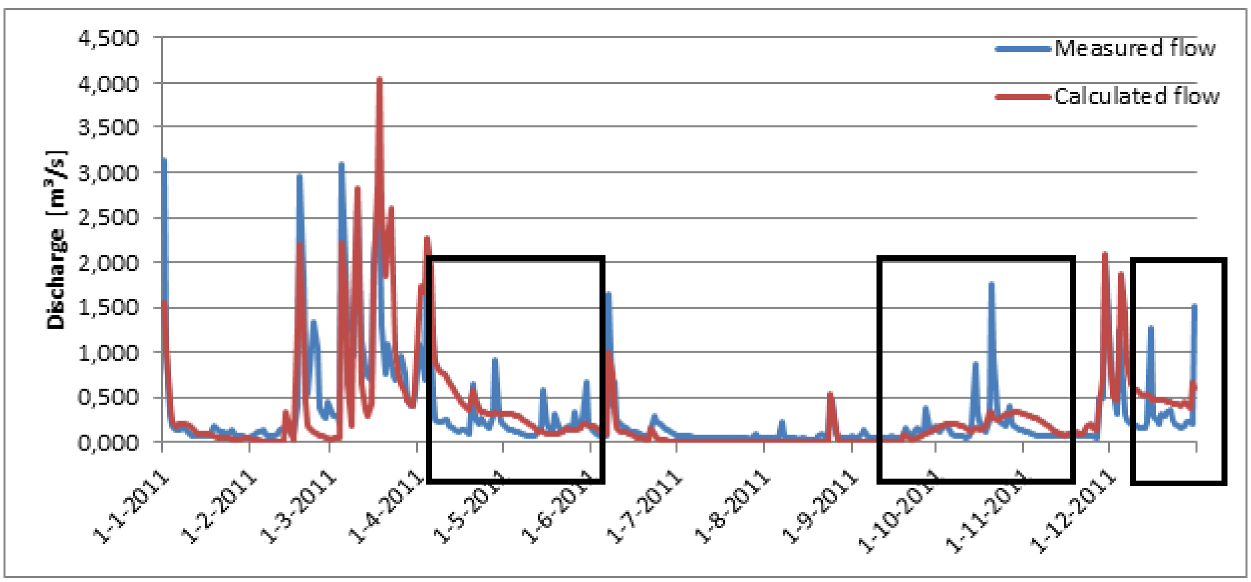

FIGURE 6-4 DISCHARGE CALIBRATED MODEL

An explanation for this problem is found in the precipitation, evapotranspiration and infiltration data. Roughly these components explain how much and where the water flows in the soil. The total amount of precipitation is 1153mm, the total amount of evapotranspiration is 608mm and the total amount of infiltration is 738mm. Figure 6-5 shows the distribution of these components over the year. The rough assumption is that the part of precipitation that doesn't evaporates or infiltrates will become runoff. There are some other components that should be added to the equation but these are less significant because the total values are lower. Therefore are for instance interception (198mm), depression (83mm) and percolation (276mm) not added to Figure 6-5.

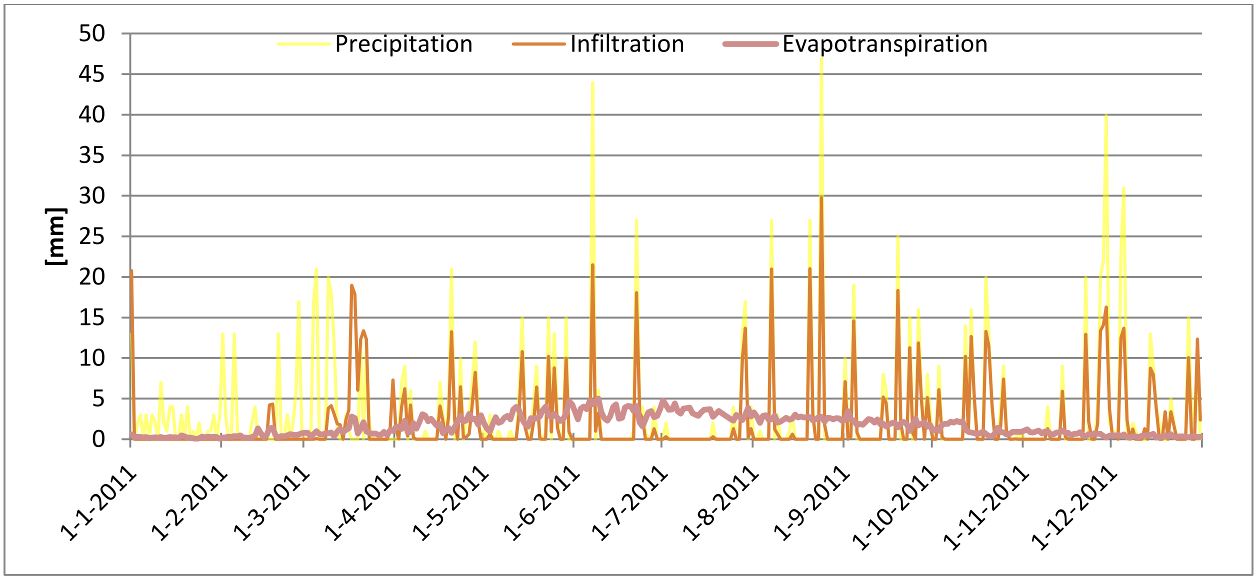

FIGURE 6-5 PRECIPITATION, EVAPOTRANSPIRATION AND INFILTRATION

Figure 6-6 shows as small section of Figure 6-5. As evapotranspiration is relatively constant over the year it is left out of the graph to make it more organized. The discharge data, as calculated with the imWEBs model, and the measured data are added. For precipitation and infiltration a second y-axis is added on the right side of the figure. What the figure shows is that only if there is a large surplus of precipitation discharge is generated. For instance the peaks between 14 April and the end of May are not captured by the imWEBs model as most of the water infiltrates to the soil. If you take in account evapotranspiration losses there is nothing left to become surface runoff. The same can be said about the peaks measured in October. The measured data shows two large peaks but these are not captured by the imWEBs model. On the other side, the two peaks that are captured by the imWEBs model (i.e. beginning of June and end of August), shows that precipitation is almost twice as much as infiltration. This also count for the peaks captured and the end of November.

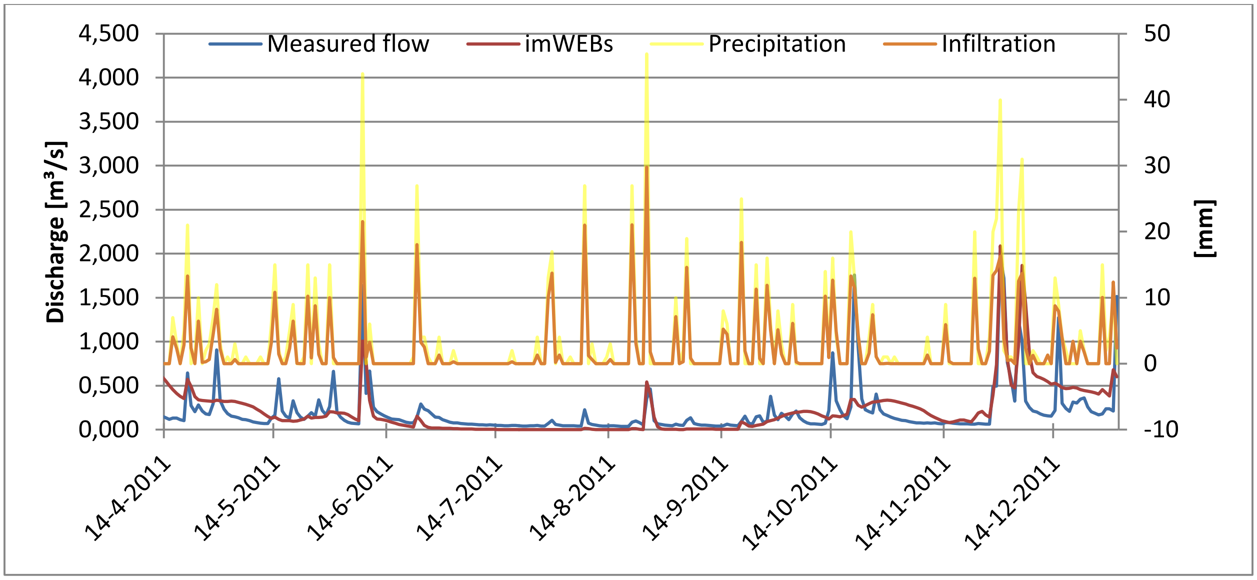

FIGURE 6-6 DISCHARGE EXPLAINED BY PRECIPITATION AND INFILTRATION

This problem is addressed during model calibration but not resolved completely. The K_pet factor has been calibrated to reduce the amount of water evaporating. But also changes to the baseflow coefficient and the poreindex have been made to influence runoff. Calibrating these parameters improved the fit for baseflow but didn't prevent large amounts of water infiltrating to the soil. As Figure 6-5 and Figure 6-6 point out, infiltration might be an important factor explaining the absence of certain peaks calculated by the imWEBs model.

Two possibilities can be considered to improve the output of the model. One possibility is that the precipitation data used is not accurate. Data is retrieved from stations outside of the watershed (see paragraph 3.4). For the winter from November 1st to April 14th data from London is used. Summer data is used from the weather station located in Varna. However, on the 29th of April the Gully weather station was operational and this data was used for the period after the 29th. This means that the errors in the summer cannot be caused by a mismatch in precipitation data. For the winter months this is very possible though, especially because lake-effect snow might be left out of the measurements at the London weather station.

Another possibility is that the landuse and soil characteristics lead to large amount of infiltration when using the SCS curve number. Maybe if the model was calibrated while using a different module a better fit could be found. Also it might be possible that a different infiltration method is more sensitive to calibrations allowing the user to make better adjustments.

Another aspect worth looking into is the changes made to adjust for snow melt. Calibrations of these snow related parameter led to a shift of the melting period. It was also used to increase the intensity of these melting peaks. However some of the changes made can be seen as not feasible, for instance decreasing the snowmelt temperature drastically. Figure 6-2 in the previous paragraph showed that no flow was generated even though the temperature was above zero degrees. Figure 6-7 shows the same figure but now for the calibrated model. The data is shown for the winter months meaning it ends at 14th of April.

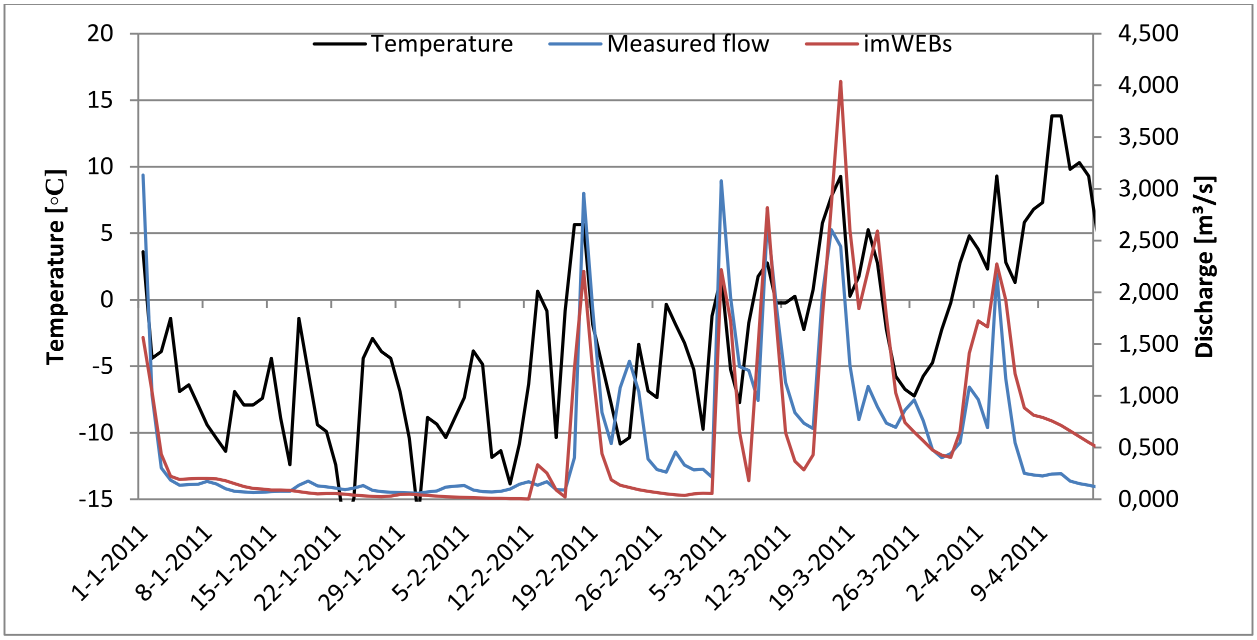

FIGURE 6-7 DISCHARGE AND TEMPERATURE DURING THE WINTER

The figure above shows that the peaks now do occur when temperature rises above zero degrees. One of the peaks is not captured by imWEBs, the peak measured between 19-2-2011 and 26-2-2011 does not show up at all. Also there is one peak added by imWEBs, this is the peak shown in red between 19-3-2011 and 26-3-2011. Figure 6-7 shows that the fit created by calibrating the model is good but finding an explanation that validates these changes is hard to find. One of the reasons can be that temperatures at the Gully Creek Watershed differ from the measured temperatures in London. The melting temperatures are lowered which will mean that the Gully Creek Watershed is warmer. Also the two peaks that aren't captured indicate that there is a daily variance between the temperatures. The first peak that is measured can be caused by temperatures above zero that weren't measured in London. The second missing peak is calculated but not measured meaning the temperatures at that time were lower in the Gully Creek Watershed.

6.3 SEDIMENT CALIBRATION

There are very little measurements available to compare the outcomes of the imWEBs model with and as these are not continuous no goodness-of-fit values are calculated. The data retrieved from the SWAT study is shown in Figure 6-8. Figure 6-8 also shows the zero calibration results for sediment yield. Zero calibration means that the results are not calibrated for sediment yield but they are already calibrated for discharge as described in the previous chapter. The figure shows that there is very little sediment yield calculated. The calculated results only match the measured data if there is almost no sediment measured. No values above 50 tons/day are calculated.

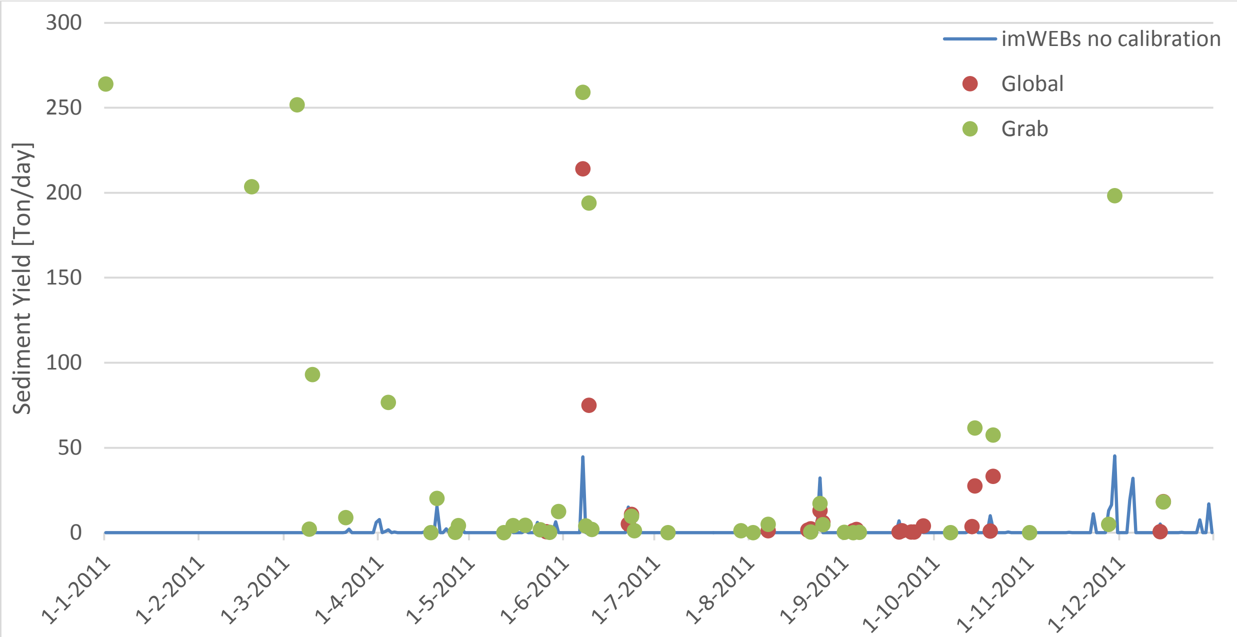

FIGURE 6-8 SEDIMENT YIELD WITHOUT SEDIMENT CALIBRATION

For sediment calibration two parameters are taken into account, the soil erodibility factor and the cover management factor. The soil erodibility factor and the cover management factor are both distributed parameters, meaning no initial value is present in the database but the values are retrieved from the characteristics of each cell corresponding to the soil database. Results without calibration showed that the simulated values during a peak event were too low. For the soil erodibility factor an absolute change of 0.2 is applied. For the cover management factor an absolute change of 0.8 is applied. The changes made to these parameters might solve errors in the original data. The soil characteristics are manually added to the database and therefore it is possible that these are not realistic. The same can be said for the cover management factor that might adjust mistakes made in the landuse map. The results after calibration are displayed in Figure 6-9.

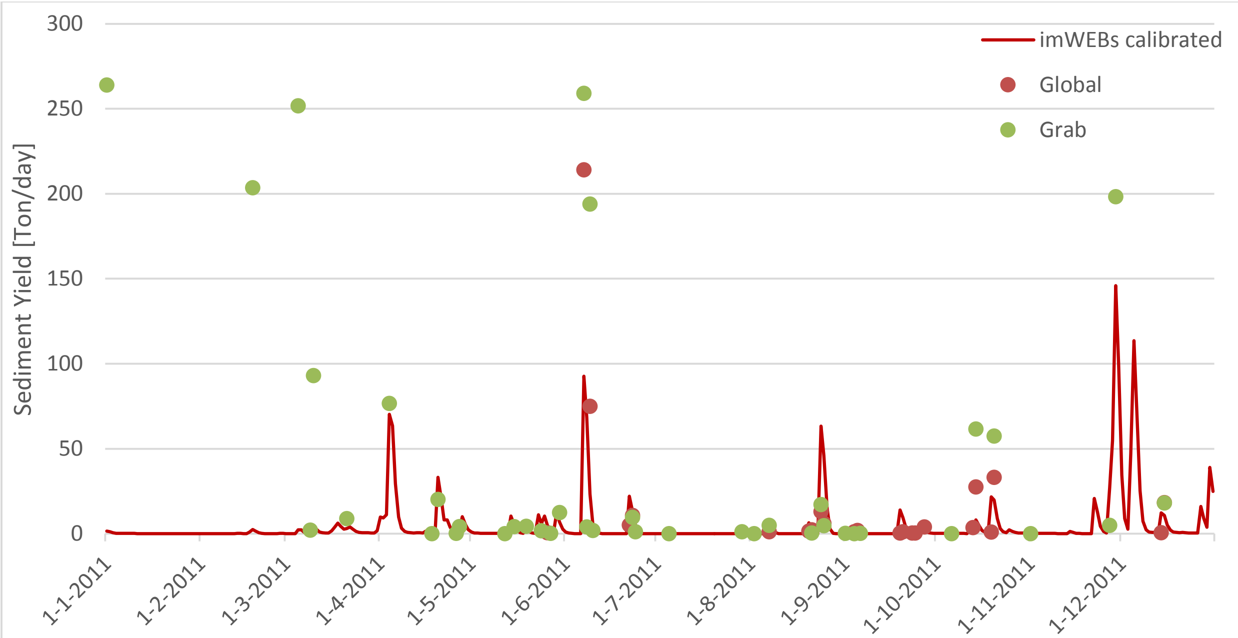

FIGURE 6-9 SEDIMENT YIELD FOR 2011

The sediment results after calibration (see Figure 6-9) show there is a problem during the winter months. The formula used to calculate the sediment yield of each cell shows that sediment yield is influenced by both surface runoff and rainfall. Surface runoff from the depression module is used to calculate the runoff volume from a rainfall event. As there are high runoff peaks during this period it is expected that sediment yield would be high as well (see Figure 6-10).

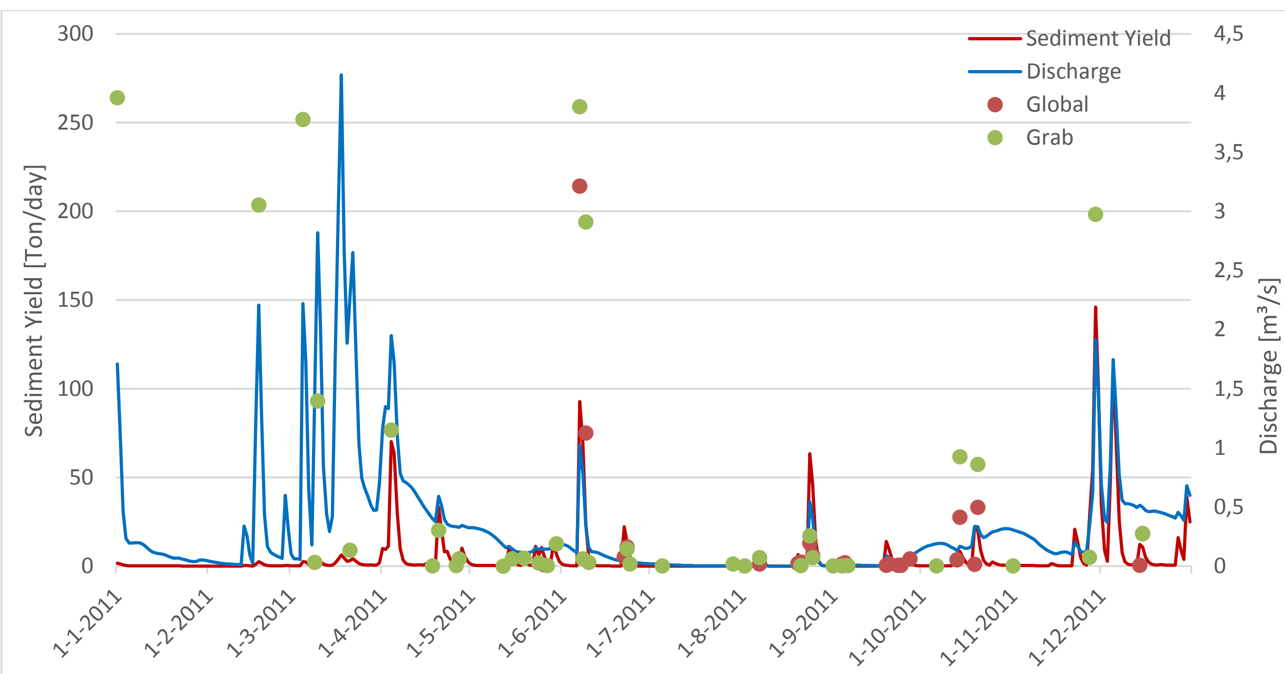

FIGURE 6-10 DISCHARGE AND SEDIMENT YIELD

A reason for the bad sediment results might be caused by the effects of snow cover on the erodibility of the ground. In the model the following formula is used to correct sediment yield if the land is covered in snow:

$$sed = \frac{sed'}{exp\left[\frac{3SNO}{25.4}\right]}$$

The SNO component, a parameter for the water content of the snow cover, was standardized in the imWEBs model, meaning the model didn't allow this parameter to be calibrated. Lowering the SNO parameter would lead to an increase in sediment yield. It might not be realistic to adjust the cover factor for fields because the snow will prevent the sediment from eroding. But as described in the area description gully erosion is the major cause of erosion in this watershed. It is possible that there is no coverage of snow in the gullies in practice but that it is simulated like there is snow in the model.

6.4 MODEL VALIDATION

Model validation will be performed for two period based on a split-sample test. This means that the model is calibrated for 2011 as described in paragraph 6.2. Model validation will be done for the period from 12-7-2010 to 31-12-2010 (see Figure 6-11) and from 1-1-2012 to 28-3-2012 (see Figure 6-12). The performance of the model is measured with the goodness-of-fit measures described in the methodology chapter. The scores for both validation periods are shown in table Table 6-3.

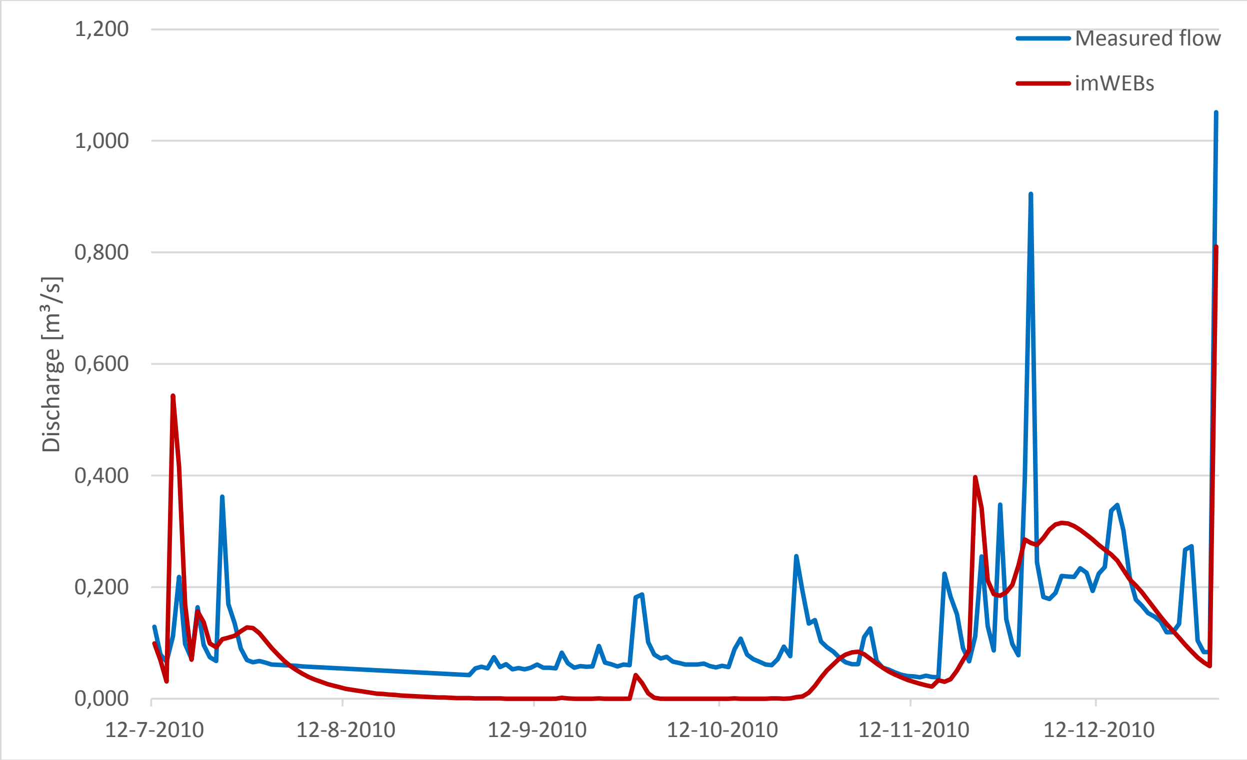

FIGURE 6-11 MODEL VALIDATION 2010

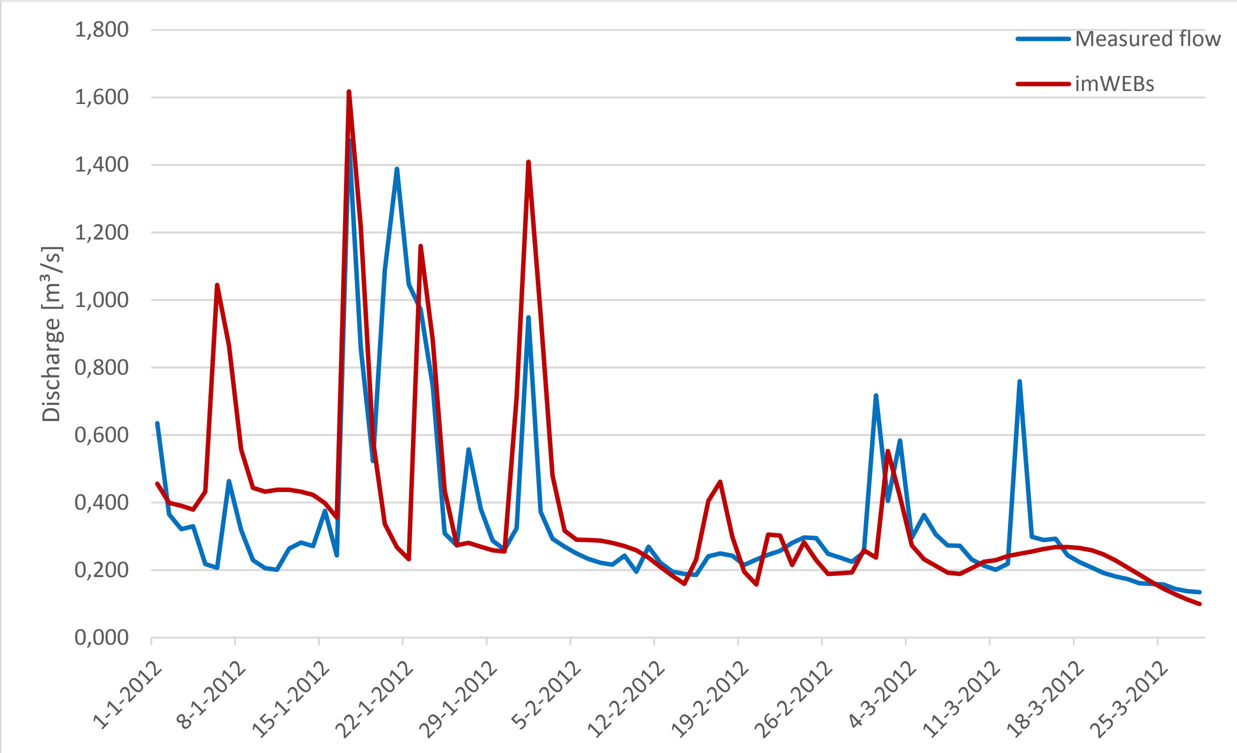

FIGURE 6-12 MODEL VALIDATION 2012

Based on the graphical representation in the figures above and the low scores on the goodness-of-fit measures it can be concluded that the model is not calibrated optimally. Almost all the peaks in Figure 6-11 aren't captured by the model. Only the last peak at the end of the year is captured properly but this is most likely caused because the rest of the peak is used during model calibration. Figure 6-12 already shows some more representative results. The model still failed to create a good fit with the measured data but at least it captured most of the measured peaks. That the performance based on the goodness-of-fit measures is worse is most likely caused by the fact that total flow is larger in the 2012 period and therefore the errors can be larger.

TABLE 6-3 MODEL VALIDATION SCORES

	NSE	R^2	D
2010	0,332	0,485	0,813
2012	0,085	0,329	0,752

7 DISCUSSION

7.1 RESULTS

The imWEBs model was developed to evaluate management practices on a field and farm scale. Before this research was conducted very little was known about the performance of model. So far the model had been tested only once in 2011 with an early version of the model. At the same time as this study was conducted the model was also tested on the Tabacco Creek Watershed in Manitoba. This research was conducted to gain a better understanding of the applicability of the imWEBs model. To do this the imWEBs model was tested on the Gully Creek watershed for 2011. In the discussion chapter the results of this study will be discussed. The imWEBs model has the advantage that it can evaluate the outcomes on a field scale, which can help enable stakeholders to make better decisions regarding erosion and water quality. But before policy makers can use the imWEBs model its applicability needs to be tested.

As the imWEBs model has not been tested thoroughly it is difficult to collect enough data to do a good comparison between other studies. In 2011 the imWEBs model was tested for the first time in the geography department of the University of Guelph. The report shows the results of the model set up against four years of data in five different ways. The performance of the model is valuated with the NSE and the values range from -3,57 to 0.11, with 0.11 being the only positive score by any of the models (Nesbitt, 2011). For this research one of the first versions of the model was used. Since then a lot is improved. The report showed there was a strong differentiation between the different ways the model was set up. This was also done for this research by setting up the model with different methods for infiltration and flow routing. The outcomes using the different methods were almost equal. As there was no time to calibrate the models it wasn't possible to conclude if one method performed better or worse that the other (see appendix D).

A more comparable study is comparing the outcome of the imWEBs model to a SWAT modelling study (Yang, Liu, & Simmons, 2013). Figure 7-1 shows the results of the two models and the measured discharge data. A comparison with the SWAT model is a good indication of how well the imWEBs model is able to simulate the conditions in the Gully Creek Watershed. The NSE for the SWAT model is 0.64 whereas the imWEBs model has a NSE of 0.552. The two models are very comparable as they are set up with almost the same data, only the format of the data is adjusted to make it applicable for the imWEBs model.

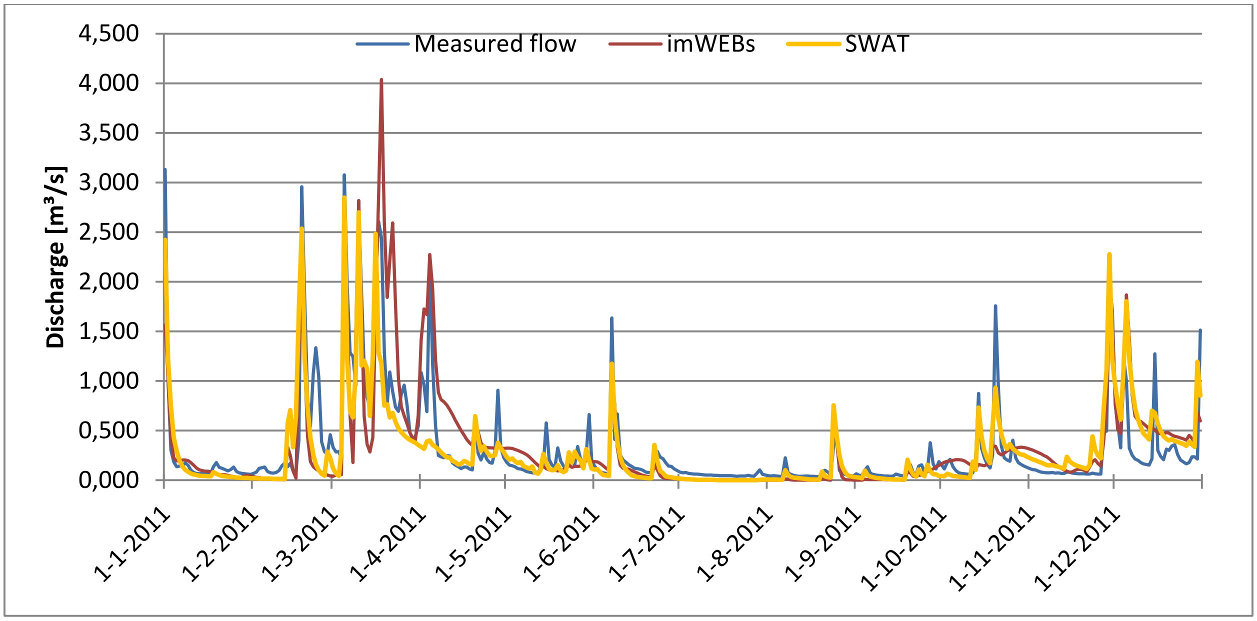

FIGURE 7-1 DISCHARGE COMPARISON

Even though the NSE values for both models are close to each other some difference can be seen when looking at Figure 7-1. As mentioned in the results chapter, the SWAT model seems to better calibrated regarding baseflow. When comparing the two models it is clear that in the SWAT model the flow is decreasing much faster after a peak and follows more the line of the measured data. At the same time it can be found that both models had difficulties simulating the peaks in April and May. The same thing counts for the peaks measured in October, both models have trouble simulating the height of the peaks and simulate too much baseflow instead. It was tried to calibrate the imWEBs model better, this led to an increase of the NSE value from 0,552 to 0,614, but the results seem to be invalid. The increased baseflow led to a linear decrease of flow after the large melting peaks which did not seem realistic (see appendix E).

Figure 7-2 shows a comparison between the sediment yield calculated by the SWAT model and the imWEBs model. It is clear that the outcomes of the SWAT model fit the measured data better. Where the imWEBs model didn't calculate any sediment yield during the winter, the SWAT models succeeds in capturing these peaks. In general the SWAT model calculated more sediment yield throughout the whole year and seems to do a better job in fitting the measured data. For a part this will be explained by a more elaborate model calibration. However for the winter months the imWEBs model needs to be improved as it fails to capture the erosion even though there a high discharge peaks calculated (see Figure 6-10).

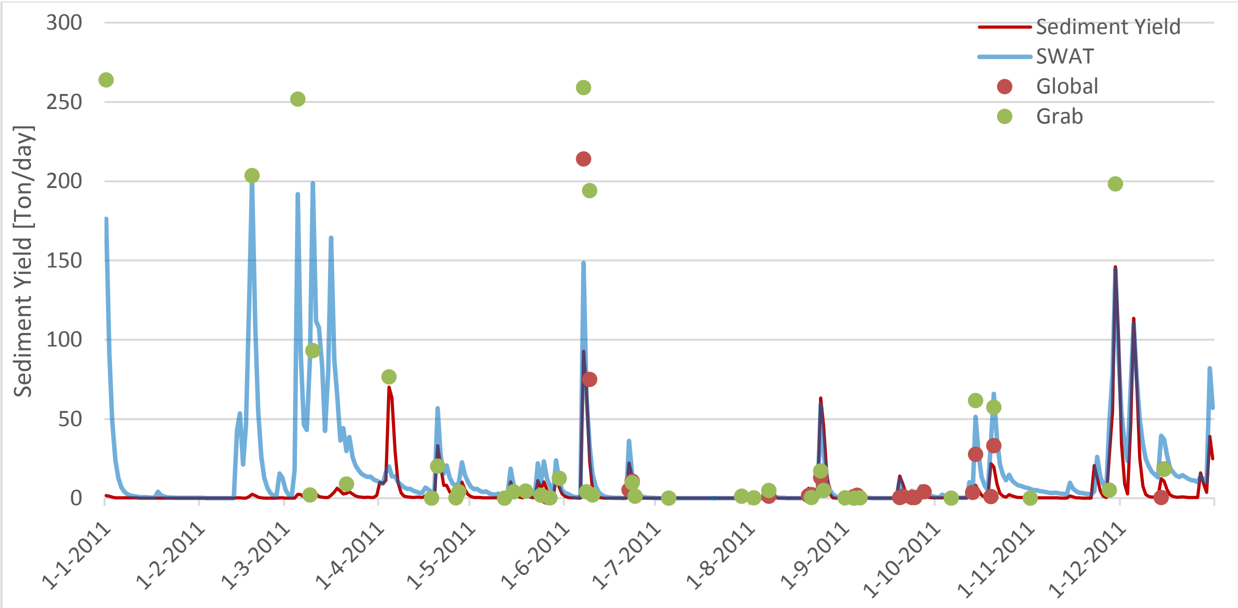

FIGURE 7-2 SEDIMENT YIELD COMPARISON

Calibrating the imWEBs model better will improve the results, the current goodness-of-fit measures show that there is a lot of room for improvement. The model should be improved so it will include sediment yield in the winter. As mentioned in the results chapter, the absence of erosion in the winter might be caused by the coverage of snow. To adjust this an update for the model was prepared but there was no time left to see if model performance increased. For the other peaks it might be possible to create a better fit by calibrating more extensively. Nevertheless it is expected that most changes will be by better discharge calibrations. For sediment calibration only two parameters were used and this will not be sufficient to create a proper fit. How discharge can be calibrated better will be discussed later in this chapter.

7.2 LIMITATIONS

Besides a comparing and valuating the outcomes of the model it is worth pointing out some of the limitations that might explain the outcomes of the model. The availability of weather data is an important factor in this research. Data from weather stations outside of the study area is used and during model calibrations some parameters are adjusted to make the data more applicable to the study area.

To start with model had to be set up with the Hargreaves method for calculating the PET. This is done because there was no solar radiation or relative humidity data available. During model calibration it was found that the model had trouble on simulating sufficient flow and calculated too much evapotranspiration. To adjust for this problem the PET correction factor was adjusted during model calibration. If the solar radiation and relative humidity data were added to the database this would probably lead to a better simulations of the soil and water balance. More data will decrease the amount of data the model has to calculate on its own.

In general there is inaccuracy can be found in the climate data. The weather station in the Gully Creek watershed, which would be the most accurate, only started operating in 2011 and had significant more data gaps compared to the other weather stations. To build up the climate database weather data from other stations is used. Most data is used from the weather station in London, Ontario. The London weather station is around 90km away from the Gully Creek Watershed. Therefore there is some inaccuracy between the data from London and the conditions in the Gully Creek watershed. As pointed out in the results chapter there is some indication of temperatures mismatches during the winter. Some of the measured peaks were not captured as the measured temperatures were too low and at the same time some peaks were calculated by the model that were not measured.

Nevertheless this does not provide an explanation for the missing peaks during the summer. In this period the Gully Creek weather station was already operational and precipitation and temperature data was used from this weather station. An explanation can be the usage of wind data from the London weather station. The London weather station was selected as it was expected that these match the conditions of the Gully Creek watershed the best. Therefore the Goderich weather station, which is only 10-15 km from the Gully Creek watershed, isn't used.

Unfortunately no information was found to back this expectation up and there was no time to compare the data from both weather stations. But it is worth mentioning that there are differences in the average hourly wind speed from both stations for 2011 and that differences in wind speed are found to significantly influence hydrologic processes. The London weather station measured an average wind speed of 14,08km/h and the Goderich weather station a wind speed of 16,13km/h. Roughly said there is a wind speed difference of 14,56% between the Goderich and London weather station. A study on the effects of surface wind speed showed that a 29% decline in wind speed resulted in 1-3% less evapotranspiration and 1-6% more runoff (Liu, Zhang, Tang, & Zhang, 2013). This point out that the decision for using one of the two stations might have a strong influence on the outcome of the model.

7.3 FURTHER RESEARCH

Due to some complications and limited time available the imWEBs model was not tested to its fullest. The model distinguishes from the SWAT model because it is a distributed model. This offers the possibility to examine the watershed in much more detail. This is interesting if you want to evaluate the choice of crops planted or the location or choice of erosion reducing measures. Before this can be done the model has to be tested more thoroughly but this is definitely worth examining in later stages.

Before this can be done a few problems discovered during this research should be solved. On of this is the problem found with presence of groundwater. Site visits and observations performed by the Geography Department showed that the Gully Creek Watershed has a lot of groundwater, which might explain why both the SWAT model as the imWEBs mode have difficulties simulating baseflow. At the same time as when this research was conducted another study was going on with the imWEBs model on a watershed in Manitoba. This watershed is known for having almost no groundwater. As it was never experienced before with the imWEBs model it might be of interest to look into this with following research.

One of the suggestions to improve the performance of the imWEBs model and to be able to better test the applicability is setting up the model with a separate groundwater model linked to it. In this case it would be necessary to perform some groundwater measurements in the area to have sufficient data available for model calibration. Doing these measurements might prove that the Gully Creek

Watershed has a lot of groundwater flowing through the area and this would explain why the model has trouble simulating this. The position of the watershed might be the explanation for high amount of groundwater flowing through this. The watershed is bordering Lake Huron and therefore it is possible that this increase groundwater levels. Also the shape of the watershed, which is wide in the upstream part, might work as a groundwater catchment area.

Another point of interest, also pointed out in the research chapter, is the influence of Lake-effect snow. Lake effect snow is described as an important factor in the Gully Creek climate but it is possible that the effects are not measurable in London (County of Huron Economic Development Services, 2013). The London weather stations is located around 50km away from Lake Huron and 40km from Lake Erie. This might explain why there is not enough snow calculated in the imWEBs model. To adjust for Lake-effect Snow the factor for snow blown into the watershed was adjusted during model calibration. It will be interesting to measure and quantify the effect of lake-effect snow. This could be done by improving the Gully Creek weather station so it can measure snowfall as well. If the amount of lake-effect snow is known it can be validated if the changes made during model calibration are acceptable or that another cause for the problem should be searched for.

As the model was still undertaking updates regularly it was difficult to do an elaborate model study. Model calibration had to be redone with every update. For this study the model was only calibrated using one set of methods (i.e. SCS curve number for infiltration and Muskingum method for flow routing etc.). The infiltration problems found during this research might be solved when a different infiltration method is used. The model offers four different methods so emphasize should be on calibrating with different methods to see if model performance will increase.

8 CONCLUSIONS

The goal of the research was to test the performance of the imWEBs model and to determine the applicability of the model to the Gully Creek watershed. The applicability is tested by setting up the model and comparing the results against measured discharge and sediment yield data.

For model calibration 16 parameters are selected. These parameters are found to be sensitive to the model output. It isn't possible to say if all the other parameters cannot be used for model calibration. A lot of parameters are tested and most of them were not sensitive. However, because the model was tested with one selection of methods it worth mentioning that choosing different methods might allow for better model calibration. The 16 parameters that are used were chosen to adjust the model for channel and evapotranspiration losses, for shifting the snow melt peak, for adjusting baseflow and increasing sediment yield.

After the calibrations are conducted the performance of the model is tested by comparing it against discharge data for 2011. Also the model is validated for discharge for the period 12-7-2010 – 31-12-2010 and for 1-1-2012 to 28-03-2012. The results are shown in Table 8-1. The performance of the model for model calibration show there is room for improvement. For model validation the model shows bad performance but this might be strengthened by the small validation period used.

TABLE 8-1 GOODNESS-OF-FIT SCORES FOR DISCHARGE

	NSE	R^2	D
MODEL CALIBRATION (2011)	0,552	0,633	0,887
MODEL VALIDATION (2010)	0,332	0,485	0,813
MODEL VALIDATION (2012)	0,085	0,329	0,752

For sediment calibrations two parameters were selected. The soil erodibility factor and the cover management factor. Both parameters showed to be very sensitive. All the other sediment related parameters didn't influence the outcome of the model. An increase of these two parameters created a potential good fit with the measured data. However the model failed to capture all the peaks during the winter. The model needs to be updated first to solve this problem before the performance for sediment yield can be evaluate properly.

After calibration there were still some issues that should be addressed during future research. The model seemed to have trouble to calculate baseflow. Observations showed that the watershed deals with large amounts of groundwater. It is possible that there is a lot of groundwater inflow from neighboring watersheds that is not captured by the model. Another point of interest is the effect of lake-effect snow, this is described as an important factor influencing weather conditions near the Great Lakes. Future research should determine the influence of these two conditions to see if the changes made during model calibration are valid.

The results of this research do not provide sufficient background to conclude if the imWEBs model is applicable. Right now the model performs worse than the SWAT model. But before anything can be said about the applicability of the model the issues described above should be addressed and tested more. Testing the model with different methods and calibrating it more thoroughly might improve the performance of the model sufficiently. Also the usage of the Gully Creek weather station will reduce the error in the data used and will allow the user for better model calibration.

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APPENDIX A: SOIL CHARACTERISTICS

Soil code	Bottom Land	Perth Clay Loam	Burford Loam	Brookston Clay Loam	Huron Clay Loam	Brandy Sandy Loam
Bulk density	1.08	1.32	1.26	1.27	1.25	1.06
Sand fraction	0.15	0.21	0.35	0.16	0.18	0.61
Clay fraction	0.25	0.31	0.12	0.37	0.27	0.12
Silt fraction	0.6	0.48	0.53	0.47	0.55	0.27
Texture	4	9	4	8	4	3
Soil erodibility	0.1	0.25	0.21	0.24	0.25	0.17
Saturated hydraulic conductivity	4.94	4.4	11.57	3.36	3.79	31.43
Porosity	0.59	0.50	0.52	0.52	0.53	0.60
Wilting point	0.11	0.16	0.06	0.19	0.14	0.05
Field capacity	0.43	0.32	0.32	0.39	0.39	0.31
P_index	5	8.3	5	8.3	5	4.5
Residual moisture	0.02	0.08	0.02	0.04	0.02	0.04
Soil hydrologic group	3	2	4	1	2	3

APPENDIX B: TILLAGE CHARACTERISTICS

Tillage Type	Depth (mm)	Mixing efficiency	CNOP/ CN2
Generic No-till mixing	25	0.05	1.02
Field Cultivator LT15FT	100	0.30	1.00
Moldboard Plow REG GE10B	150	0.95	1.10
Chisel Plow LE15FT	150	0.30	1.00
Disk Plow GE23FT	100	0.85	1.00
Deep Ripper – Subsoiler	350	0.25	1.00
No Till	0	0.00	1.00

APPENDIX C: NO GROUNDWATER RECHARGE

The zero calibration run is the first run off the model with all the parameters set to their initial values. The results from the zero calibration run helps indicating initial problems and forms an important basis for model calibration. For the zero calibration run infiltration is calculated using the SCS curve number and the Muskingum method is set for calculating flow routing.

The first model run generated almost no discharge. A fast calibration was conducted to determine if the problem could be solved by calibrating the model properly. The calibrations solely aimed at generating more flow, meaning there was no emphasis on the other outcomes. The results after calibrating the model are shown in Figure 0-1.

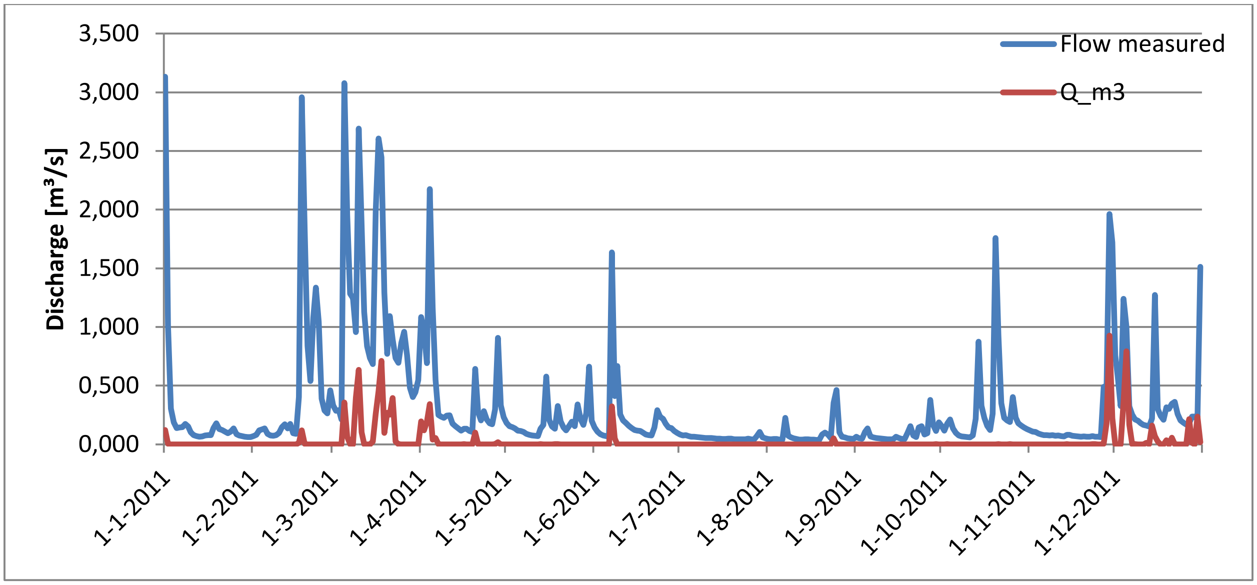

FIGURE 0-1 DISCHARGE WITHOUT GROUNDWATER RECHARGE

The simulated discharge (Q_m^3) is still very low after the model is calibrated. The sum of the daily values for the measured flow is 114,38m^3/s compared to a total of 9,26m^3/s for the simulated total flow.

By analysing the reach and soil water balance it was found that the low discharge results were cause by the absence of groundwater in the model. The soil water balance shows that after a rain event a lot of water infiltrates to the soil but there is never any recharge back to the surface. The small peaks that were generated might be a result of snow melt or high intensity rainfall for situations where the soil is fully saturated and no or little water can infiltrate.

It was found that the problem was caused by a missing module responsible for calculating the recharge of groundwater. Because the model was not set to the highest objective (which would be plant growth) but to discharge and sediment, not all modules were needed for running the model. This meant that the recharge module was not enabled when the objective was set to sediment. An update of the model was performed to make sure the groundwater recharge was also calculated for discharge and sediment. With the updated model a new zero calibration run was conducted. The results of this run are shown in Figure 6-1.

APPENDIX D: METHOD COMPARISON

As described in the Model Setup paragraph, multiple methods can be used for calculating the infiltration and flow routing. To compare the applicability of other methods, results will be compared for the SCS curve number with different flow routing methods and for the Muskingum method with different infiltration methods. Thereafter the model will be calibrated using the SCS curve number for calculating infiltration and the Muskingum method for flow routing. Only if there is enough time the model will be calibrated using different methods to see if this will lead to more differentiation in the results.

For comparing different methods the model is set up using two infiltration methods, the SCS curve number and the Modified rational method. These two methods are then tested for several flow routing methods. Results are compared against measured flow data of 2011 at the outlet of the watershed.

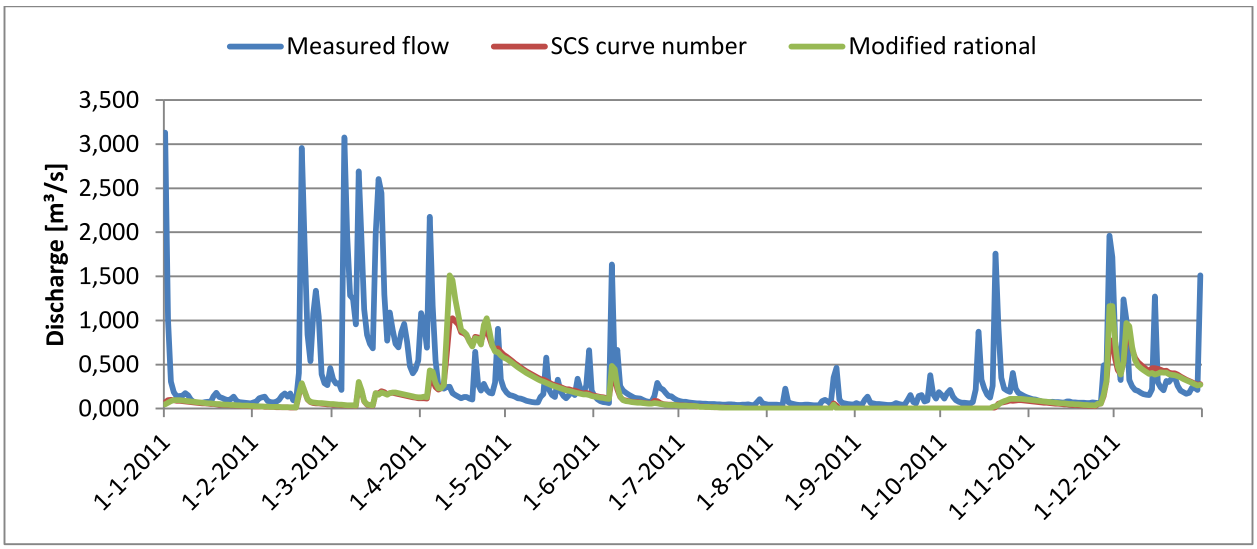

FIGURE 0-1 DISCHARGE COMPARISON USING MUSKINGUM FLOW ROUTING METHOD

Figure 0-1 compares the result using the Muskingum method for flow routing and two different methods for infiltration. The goodness-of-fit measures presented in Table 0-1 show that both methods perform bad. However, they do show very similar results. This indicates that both methods have equal potential of being able to simulate the real conditions. It must be said that these results are generated without calibrating the model. It is possible that calibrating the model will lead to bigger differences in the performance of the model. Based on the given NSE values it can be said that the model performs poorly. A negative NSE value means that the mean of the measured data is a better indicator than the results generated by the model.

TABLE 0-1 GOODNESS-OF-FIT RESULTS FOR MUSKINGUM FLOW ROUTING METHOD

	Total flow (m^3/s)	NSE	R^2	D
SCS curve number	60,45	-0,165	0,033	0,406
Modified Rational	57,65	-0,158	0,026	0,383

Figure 0-2 and Figure 0-3 show the results of comparing different flow routing methods. The flow routing methods are tested both with the SCS curve number and the Modified Rational method. No results are generated for non-linear storage using the Modified Rational method. The results representing the performance of each model are shown in Table 0-2 for the SCS curve number method and inTable 0-3 for the Modified Rational method.

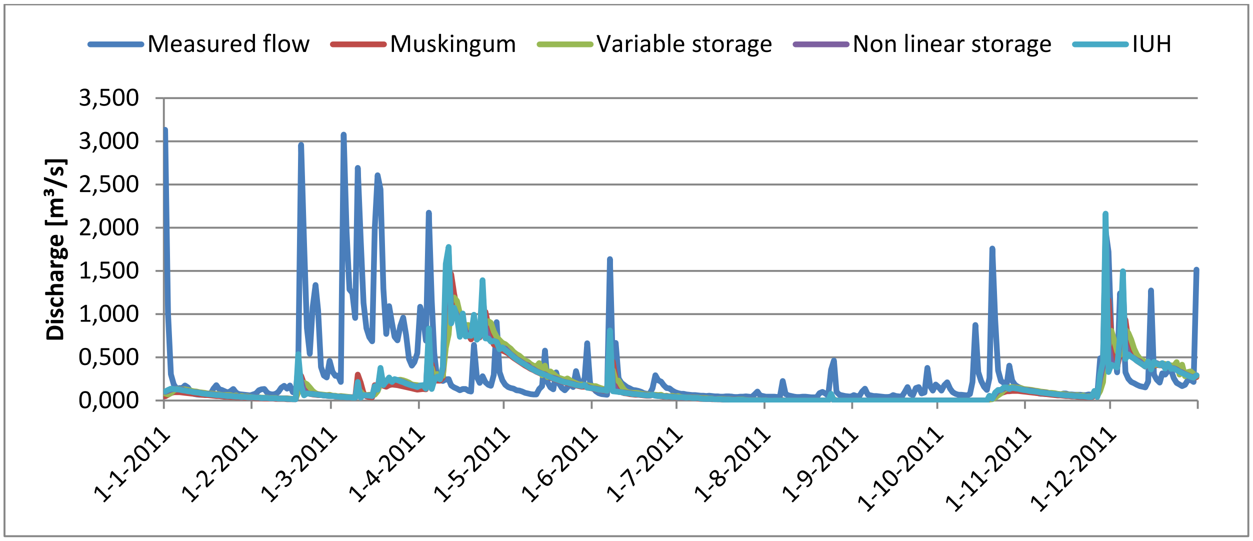

FIGURE 0-2 FLOW ROUTING METHODS USING SCS CURVE NUMBER METHOD

TABLE 0-2 GOODNESS-OF-FIT RESULTS WITH THE SCS CURVE NUMBER METHOD

SCS curve number	Total flow (m^3/s)	NSE	R^2	D
Muskingum	60,45	-0,165	0,033	0,406
Variable storage	64,10	-0,206	0,012	0,360
Non-linear storage	63,38	-0,154	0,038	0,422
IUH	63,41	-0,168	0,039	0,430

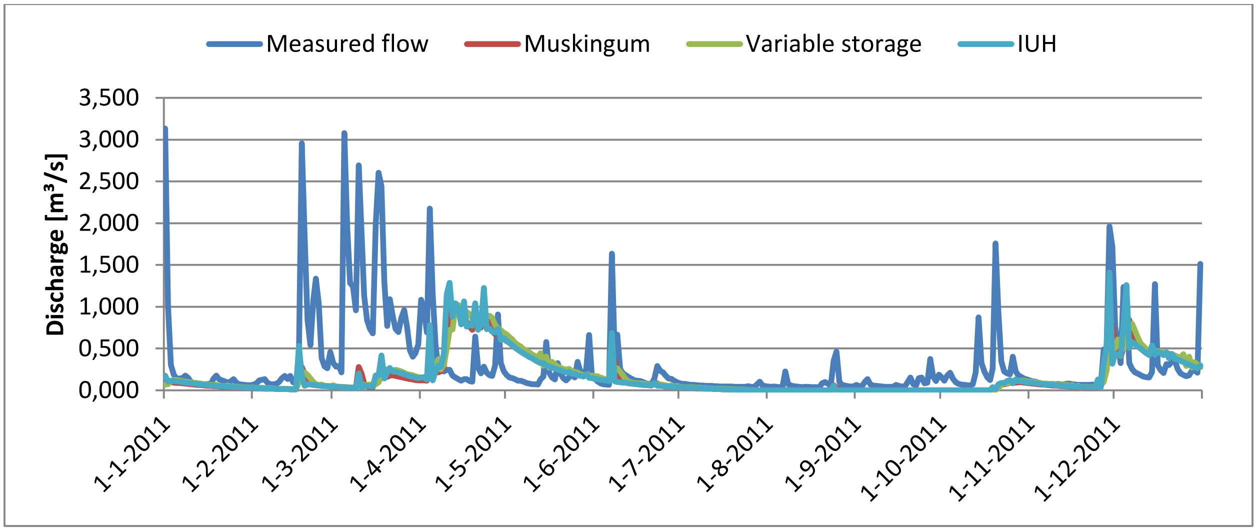

FIGURE 0-3 FLOW ROUTING METHODS USING MODIFIED RATIONAL METHOD

TABLE 0-3 GOODNESS-OF-FIT RESULTS WITH THE SCS MODIFIED RATIONAL METHOD

Modified Rational	Total flow (m^3/s)	NSE	R^2	D
Muskingum	57,65	-0,158	0,026	0,383
Variable Storage	61,86	-0,217	0,009	0,354
IUH	61,21	-0,149	0,036	0,418

Based on Figure 0-1, Figure 0-2 and Figure 0-3 it can be concluded that there is very little difference between all the methods tested. The total flow (see Table 0-2 and Table 0-3) is lowest using the Muskingum method. The goodness-to-fit indicators show very little differences but in general show that the model performance needs to be improved. The NSE values are all negative meaning they all perform worse than the mean of the measured data. The Coefficient of Determination (R^2) is also very low, meaning that the models are only capable of explaining a very small proportion of the variance in the measured data (Legates & McCabe Jr., 1999). The values for D, ranging from 0,35 to 0,43, indicate that the mean squared errors of the model are considerably higher than the potential error (Willmott, Robeson, & Matsuura, 2012).

APPENDIX E: INCREASED BASEFLOW

The figure below shows the results with increased baseflow. As described in the results chapter the NSE value increased but the figure clearly shows that the linear decrease of baseflow from April onwards is not realistic.