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Hydrology and Phosphorus Model for Agricultural Watershed: SWAT simulation of Discharge and Nutrient Flux in the Medway Creek Watershed

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Abstract

High nutrient concentrations in surface water have been a serious concern that impacts water quality and ecology. High Phosphorus concentrations in Medway Creek indicate the presence of a pollution source in the watershed that needs to be identified and quantified. To investigate this issue, the Soil and Water Assessment Tool (SWAT) program has been used in this study with the Geographic Information System (GIS) to model the Medway Creek watershed and assess stream flow and nutrient flux. In this research, the SWAT model has been built, calibrated, and validated using two independent observed data sets to evaluate the SWAT efficiency on monthly and daily simulations. The model has been tested for monthly simulations for the period of 1989 to 1999 and daily for the period 2014 to 2017 to simulate different water resource parameters in the Medway Creek watershed with a focus on stream flow and phosphorus. Discharge and nutrient components are quantified at sub-basin level with monthly and daily time intervals. SWAT-CUP software was incorporated into study by using SUFI-2, an optimization algorithm, to optimize the model parameters and examine the model uncertainty. The model was calibrated over the period of 1989 to 1999 and daily validated for the duration of 2016 to the present. The results show an excellent agreement between the calibrated results and measured data in monthly intervals. R^2 and NSE of 0.85 and 0.65 were achieved for the discharge calibration period and the model captured 92% of observed data, whereas R^2 and NSE for TP calibration was 0.67 for both, with 80% observed data captured in the calibration period. For daily simulations, SWAT successfully generated satisfactory results with lower performance compared to the monthly simulations. Moreover, the calibrated and a validated model used to estimate the future stream flow and TP in Medway Creek using different climate scenarios. The lack of high-frequency surface water monitoring data was the main obstacle during calibration. During the rapid alteration of the land use in the watershed, the developed model is useful for decision makers to assess future impacts and take actions accordingly.

Keywords

Phosphorus, Discharge, SWAT Model, Calibration, Hydrologic modeling, Land use, streams.

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Acronyms

AAFC	Agriculture and Agri-Food Canada
BMP	Best Management Practice
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
HRUs	Hydraulic Response Units
LIO	Land information Inventory
NRCAN	Natural resources Canada
NSE	Nash Sutcliffe Efficiency
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
SPAW	Soil Plant Air Water
SUFI-2	Sequential Uncertainty Fitting
SWAT	Soil and Water Assessment Tool
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
UTRCA	Upper Thames River Conservation Authority
WWTP	Waste Water Treatment Plant
WASCoB	Water And Sediment Control Basin

1. Introduction

Nutrient pollution is a global problem and environmental threat that affects surface water quality and deteriorates food resources and habitats in ecosystems (EPA, 2017). The increase in nutrients in the Great Lakes has caused undesirable implications, including the acceleration of algae proliferation, which impacts the health of aquatic organisms (Lazor, 2014). The United States and Canada have initiated and conducted many projects to reduce the loads of nutrients in the Great Lakes and identify the main sources that cause eutrophication. Therefore, in 2012, Environment Canada conducted a project to investigate the high nutrient loads in Lake Erie as a result of human activities. Phosphorus is an essential element of nutrients, and is exported from a land phase to a water phase. Thames River is one of the Canadian Heritage Rivers that is suffering from high phosphorus concentrations, as shown in Figure (1). The Thames River watershed includes many tributaries ,such as Medway Creek ,one of the developed tributaries that contributes 7% of the Thames River volume, and has significant loads of TP that are delivered to the north branch of Thames River annually (Nürnberg & Lazerte, 2015).As shown in Figures 2 and 3 ,the phosphorus concentrations in Medway Creek are significantly higher than the Ontario provincial water quality objective, which is 0.03 mg/L. The high loads in Medway Creek have negatively impacted water quality and caused eutrophication in the creek. Medway Creek has a significant impact on the health of Thames River by exporting loads of total phosphorus every year. TP and TSS monitoring at the Medway Creek outlet is extremely high compared to the Thames River upstream(Nürnberg & Lazerte, 2015). Much attention has been paid to the Medway Creek watershed in the past two years to apply BMPs (Best Management Practices) in addition to water quality monitoring to reduce the phosphorus exported from the land, which is mainly agricultural, to Medway Creek. Recently, Phosphorus concentration at the Medway Creek upstream monitoring station has reached as high as 6.32 mg/L based on the daily sampling data for UTRCA.

Nutrients are primarily nitrogen and phosphorus, which are needed for crop growing and soil fertilization; however, when the phosphorus concentration exceeds the needed level, it can harm the environment, including water, soil, and fish habitats (Radcliffe and Cabrera, 2007). This increase in phosphorus in the water has been recognized as the main reason for eutrophication and water quality degradation, and results in harmful algal blooms, anoxic conditions, and loss of biodiversity with other adverse effects (Schindler, 1971; Pollman et al., 2002).

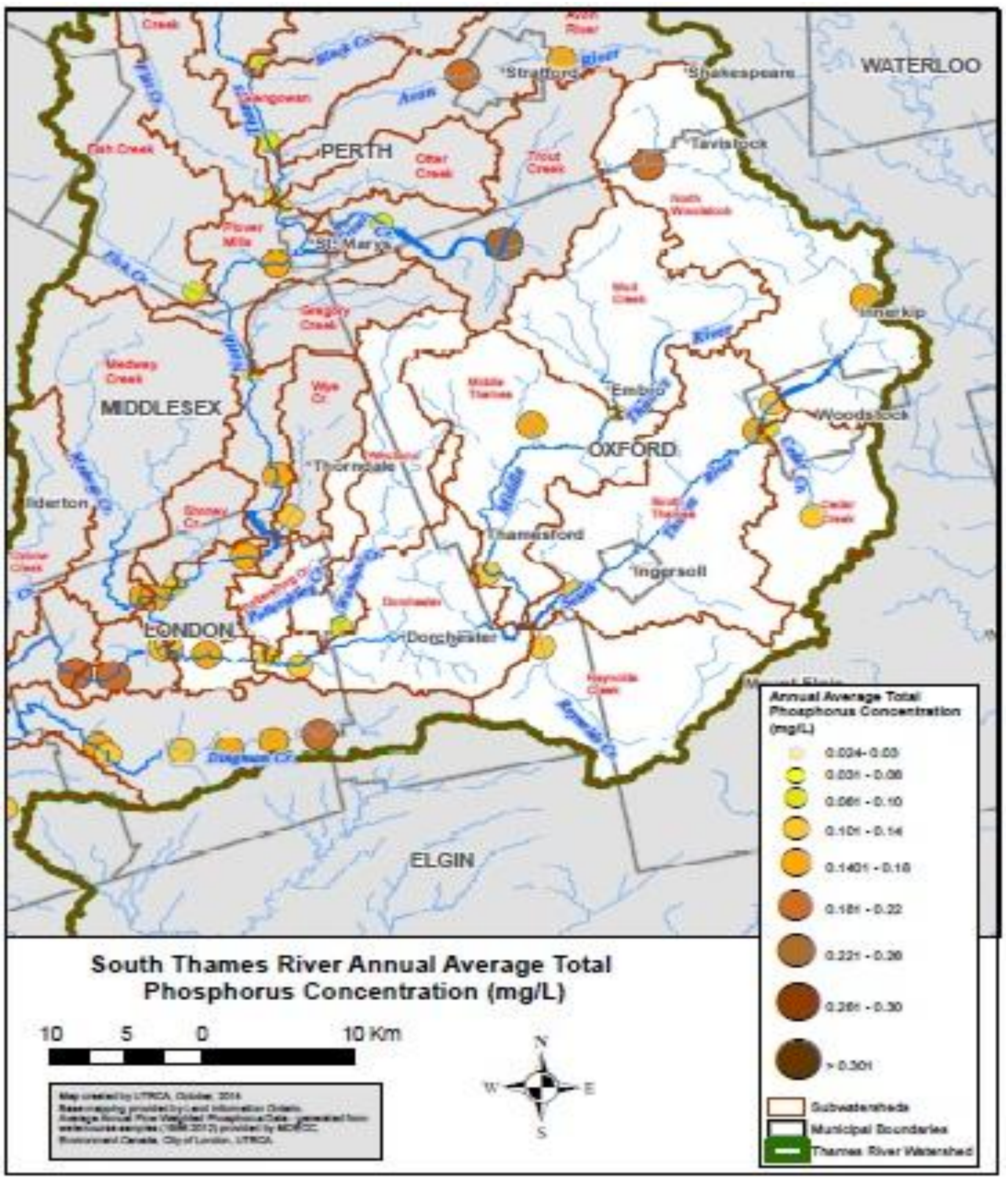


Figure 1 : Annual Average Total phosphorus (mg/l) concentration in Thames River. Source (Nürnberg & Lazerte, 2015)

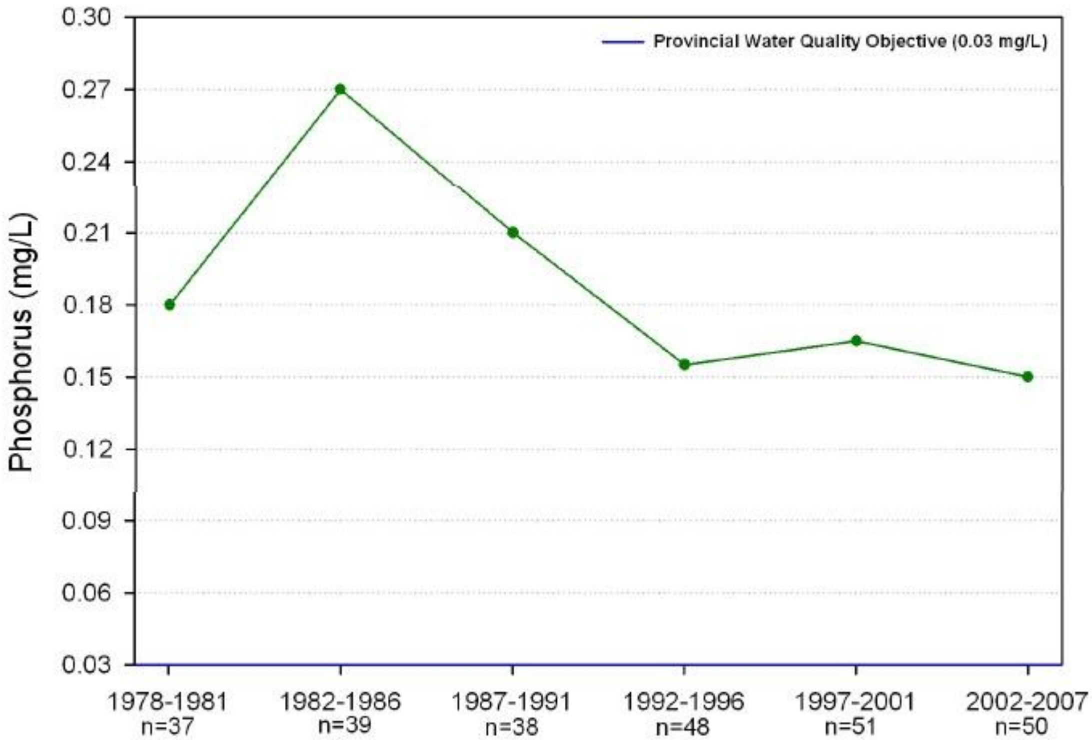


Figure 3 : Average phosphorus concentrations in Medway Creek. Source (Medway CBES

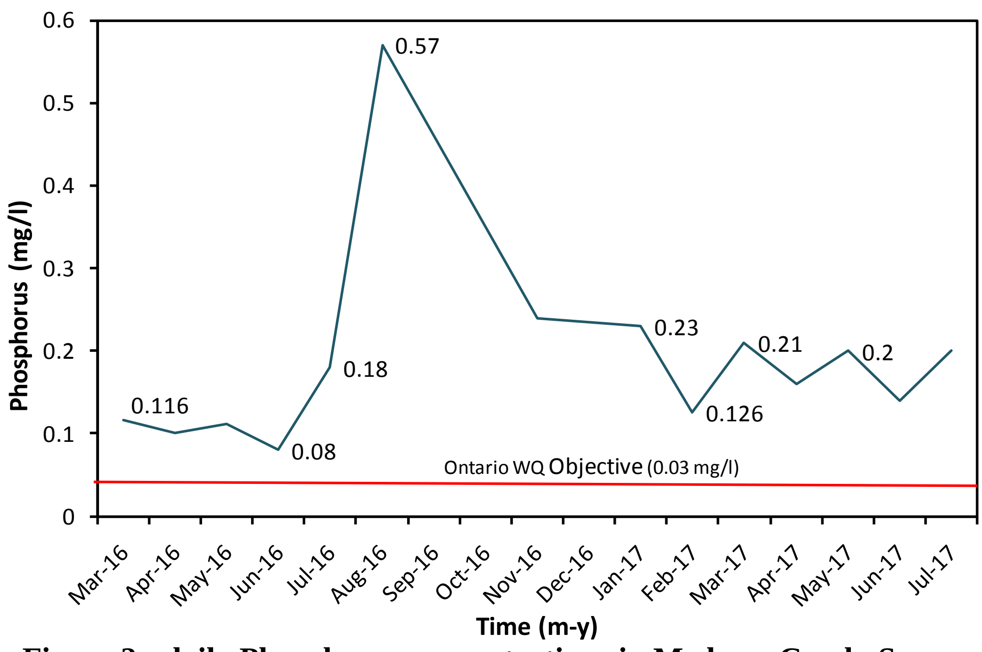


Figure 2: daily Phosphorus concentrations in Medway Creek. Source (UTRCA)

Land management activities are a large source of TP through moving sediments, soil erosion, agricultural land, grazing, and runoff from urban areas (Young et al., 1989). Non-point source which is represented in agricultural areas in Medway Creek, is one of the main sources that exports a huge amount of phosphorus and sediments to Thames River (Nürnberg & Lazerte, 2015). There are different reasons for the increasing TP in freshwater, including fertilizer application and wastewater treatment plants (Conley et al., 2009).

1.1 Eutrophication and phosphorus flux

Eutrophication is a widespread problem that degrades aquatic systems and impair the water quality so that it is no longer suitable for drinking but only for agricultural use (Carpenter et al., 1998). Even though Phosphorus and Nitrogen are the main nutrient responsible for water quality deterioration, P is the key to nutrients enrichment and its reduction translated to excellent improvements in freshwater throughout the world (Conley et al., 2009). Different P reduction strategies have been applied in different water systems with remarkable improvements in water quality. Medway Creek is one of the streams that is suffering from high phosphorus concentration, which can lead to undesirable changes in watercourses. Total phosphorus concentrations have been monitored in Medway Creek since 1979. Over this duration, the TP concentration has been consistently above the EPA's (Environmental Protection Agency) guidelines and Ontario provincial water quality objectives. In some years, the phosphorus level has been as much as nine times the guidelines based on the City of London's surface water monitoring data. Therefore, questions have been raised about the causes of high loads of TP into the stream phase. The nonpoint source represented in agricultural areas has a strong relationship with high loads of phosphorus that accelerate the eutrophication in Medway Creek. In 2007, the UTRCA (Upper Thames River Conservation Authorities) classified the Medway Creek watershed as a primary concern that must take precedence for environmental enhancement. The deterioration of water quality in Medway Creek regarding its high nutrients needs to be improved given the current and future circumstances. Increases in the intensity of nutrients transported into aquatic ecosystems have been associated with human activities, geology, soil and vegetation (Alexander et al., 2008; Baker et al., 1985; Barton et al., 1997; Houser et al., 2010; Johnson et al., 1997; Sliva et al., 2001; Yates et al., 2006). Using high artificial fertilizer rates for growing crops is one of the human activities that increase phosphorus in surface water. Nowadays, humans are aware of the consequences of extensive usage of fertilizers and their role in surface water degradation (Savci, 2012). Agricultural areas, urban areas and wastewater treatment plants are all considered non-point or point sources of phosphorus concentrations that carry P into surface water and groundwater. Recently, dozens of studies have been conducted to simulate phosphorus flux in different watersheds in Canada and all over the world in order to develop strategies for reduction of TP. Agricultural land is dominant in the Medway Creek watershed; therefore there is a high possibility of the presence of non-point source pollution in the watershed. In Medway Creek, phosphorus concentration has decreased in the last 10 years, which demonstrates an improvement in water quality in the watershed; however, more reduction is needed in anticipation of increasing urban growth and climate change.

Figure 4:Aquatic plant growth at Arva Dam in Medway Creek

Source: Elyse Booth

1.2 Water Quality and Land use

Over the last few decades, climate and land use changes have received attention regarding their implications for water quantity and quality. Land-use changes are any alteration of natural landscapes for human use and changes in management systems for human-dominated lands (Turner et al.,2001). It is known that water quality and quantity are strongly related to land use and climate change (Tong & Chen, 2001). Altering land use is considered one of the main factors controlling changing hydrological components (Mander et al., 1998). Land use is one of the factors that affect hydrological processes that take place in the watershed (Tong & Chen, 2001). This effect varies from watershed to watershed and is based on the watershed characteristics and management systems that apply in that watershed. Land use change is relatively a quicker process and has a more noticeable impact than climate change, where the process takes longer to become noticeable (El-Khoury et al., 2015).

There is a significant connection between land use and water quality in the watershed process (Tu, 2011). The water quality conditions of any surface water are a function of the properties of its catchment and are affected by topography, land use, and climate (Hynes,1975). Hundreds of studies have found a strong correlation between land use types and water quality parameters and the relationship varies from positive impacts to negative relationships. Rapid land use changes are leading to the alteration of associated hydrological response in each watershed. When a forest is changed to agricultural land or a pasture is developed in an urban area, that can have an impact on watershed hydrology (Baker & Miller, 2013).The alteration of watershed hydrology response includes changes in evapotranspiration, infiltration, interception, and ground water recharge(Chandler, 2006).

In part of this study, SWAT (Soil and Water Assessment Tool) is applied with ArcGis to investigate the relationship between land use change and watershed hydrology and water quality in Medway Creek Watershed. Land use in Medway Creek watershed has been altered due to growing population and extension of crop land. This alteration has had an impact on water quality and quantity in Medway Creek. Therefore, the present study is intended to simulate the consequences of the increasing population on stream flow and total phosphorus. Agricultural areas contribute much higher levels of nutrients compared to other land use classifications (Tong & Chen, 2001). Taking into account RCP 8.5 and A1B emissions scenarios, the Medway Creek watershed was analyzed to examine the impact of future land use changes on stream flow and TP for the years 2022-2040. The calibrated SWAT model is used for this analysis and to understand the relationship between land use changes and water resources in the Medway Creek watershed.

There have been various land use changes over the time in the southwestern Ontario region; however, the typical land use change is the conversion from grassland to either urban or agricultural area. The Medway creek Watershed is agriculturally dominant land with expanding urban land to the south. The watershed population is growing by 8% every 10 years in the south part of the watershed as shown in Figure (5).

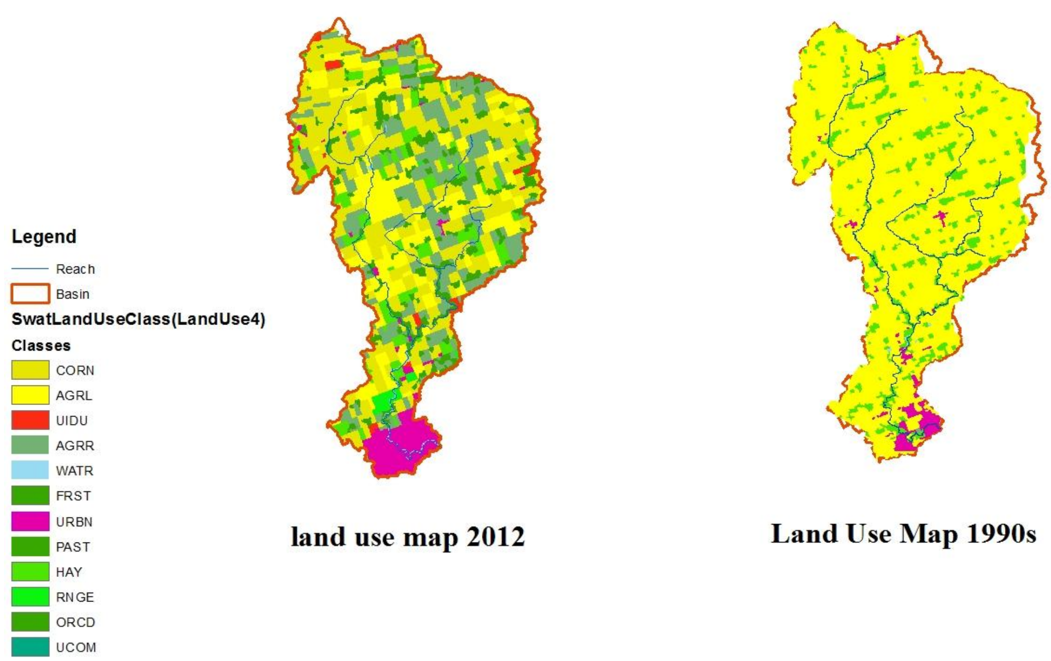


Figure 5 :Medway creek watershed Land use change from 1990s to 2012

1.3 Hydrological Modeling

Watershed models are used as a tool for examining and predicting the effect of watershed processes and management practices on soil and water resources (Moriasi et al., 2007). The applications of watershed models are to assess impact on water resources, determine main pollution sources, and develop management strategies (Singh, 1995a). Hydrological models are currently used as an essential tool for BMPs (Best Management Practices) to investigate and simulate all water resource components and processes that occur on the watershed.

Different types of hydrologic and water quality models that predict water resources constituents are divided into categories based on the concept of simulation (Redcliffe & Cabrera, 2006). Theoretically, statistical models of regression and multivariate statistical techniques are used to predict and understand the relationships between the model variables. The Export Coefficient model (Jorgensen, 1980) is a common water quality model used to analyze the relationship between land use and surface water conditions. The Process based model calculates and represents the watershed hydrological process conceptually using mathematical equations. SWAT (Soil and Water Assessment Tool) is a popular process-based model that has been used widely throughout the world.

SWAT is a continuous, long-term, comprehensive process-based, semi-distributed hydrologic model, developed by the U.S. Department of Agriculture (Neitsch et al., 2005; Zhang et al., 2008; Arnold et al., 2012; Gassman et al., 2007). SWAT simulates flow, surface runoff, sediment yield, nutrient loads, and agricultural chemical yields on daily time steps to long term simulations (Douglas-Mankin, 2010). SWAT model applications vary from a small watershed scale to a continental scale to assess the impact of land use changes and different climate scenarios on water resources. Many studies show the outstanding performance of the SWAT model in simulating different hydrology and water quality components as well as its ability to include most of the processes that take place in the watershed. SWAT is a widely used model constructed to break down the watershed into Hydrologic Response Units (HRUs) based on land use, soil type, and slope. All variables in SWAT are first calculated at an HRU level, then at a sub-basin level and finally at the entire watershed level. Generally, the default SWAT model needs to be calibrated using manual or automatic calibration.

SWAT-CUP (SWAT-Calibration and Uncertainty Procedures) has been recently developed to calibrate and validate the SWAT model using different optimization algorithms and multiple objective functions (K. C. Abbaspour et al., 2015). SWAT-CUP examines the uncertainty and sensitivity of the model to capture most hydrological processes that fall in the model uncertainty. The program allows users to parameterize the model input based on actual processes that happen in the watershed. SUFI-2 (Sequential Uncertainty Fitting) is the algorithm that is utilized in this study as it was found to be a powerful method with high efficiency (K. C. Abbaspour et al., 2015). SUFI-2 analyzes the uncertainty of the model as a range of input parameters and distributes this uncertainty into the output which is expressed as 95PPP (95% of distribution) using Latin hypercube sampling (K. C. Abbaspour,2014). Consequently, 95PPU indicates a desirable performance of calibration and validation when most of the observed data is captured.

The main purpose of the present study is summarized in the following objectives:

1. Simulate hydrology and nutrient constituents for the Medway Creek watershed on a monthly and daily time-step basis using the SWAT model.
2. Calibrate the SWAT model using 10 years of observed data.
3. Investigate the SWAT model's uncertainty and parameter sensitivity.
4. Validate the calibrated SWAT model using daily observed datasets at the upper Medway Creek.
5. Predict the potential implication of land use change on discharge and TP in Medway Creek.
6. Estimate future stream flow and total phosphorus in Medway Creek using different climate scenarios.

1.4 Water quality modeling Background

The development of water quality modeling started more than 70 years ago by developing different methods and mathematical models to simulate and analyze water quality parameters. The evolution of water quality models is associated with surface water problems that happened and needed to be solved.

1920-1970

The first water quality modelling was originally created by Streeter and Phelps in 1925 for the Ohio River, and focused on the investigation of oxygen level in the water as well as effluent from urban areas (Chapra, 2008). The Streeter-Phelps model calculated DO and BOD in surface water systems with constant input and output sources (Koivo & Phillips,1976). Due to the lack of computerization, all the models in the early twentieth century used graphs, analytical tools and geometry to examine the one point source impact on surface water (Chapra, 2008). Furthermore, biofilm models were developed after that by Young & McCarty (Williamson& McCarty, 1976).

1970 -1980

In this period, numerical models were developed to investigate eutrophication and land management practices. Mathematical models were developed to assess non-point source pollution and investigate different land management impacts on surface water. Due to the development of computational tools, the focus turned to nonpoint sources after resolving and regulating the one point source problem. One of the models in this period was the Grand Traverse Bay Model in 1974, which intended to forecast water quality parameters in the bay by including predictions of nitrogen and phosphorus contents (Canale et al., 1974). The development of water quality modeling in this period was associated with an increase in the awareness of environmental protection.

1980 – Present

Great research advances in modeling were made in this period using different strategies to represent all the processes that occur in the watershed in the models. Instead of spending time and money on field work, the models have proved their capability in efficiently forecasting different water resource components and evaluating the impact of human activity on the environment. One of the comprehensive forms of the nonpoint source model is the AGNPS (Agricultural Nonpoint Source) model, which was developed by the Agricultural Research Service (ARS), the Minnesota Pollution Control Agency, and the Soil Conservation Service (SCS) (Young et al., 1989). This computer model is an event model that predicts different water quality components, as well as runoff and sediment transport from diffuse sources to surface water (Sharpley et al,.2002). The major limitation of AGNPS is its weakness in handling large basins.

The Soil and Water Tool Assessment model that has been used in the present work was developed by USDA-ARS in the early 1990s to assess the influence of different land management practices on water and soil characteristics (Arnold et al., 2012). SWAT is a public domain software that has been improved over time with the incorporation of different models and modifications, including (CREAMS) The Chemicals, Runoff, and Erosion from Agricultural Management Systems, (GLEAMS) Groundwater Loading Effects of Agricultural Management Systems and Erosion Productivity Impact Calculator (EPIC) models (Knisel 1980; Leonard et al. 1987; Williams et al. 1984) as well as the carbon cycle (Kemanian, 2011), as shown in Figure (6).

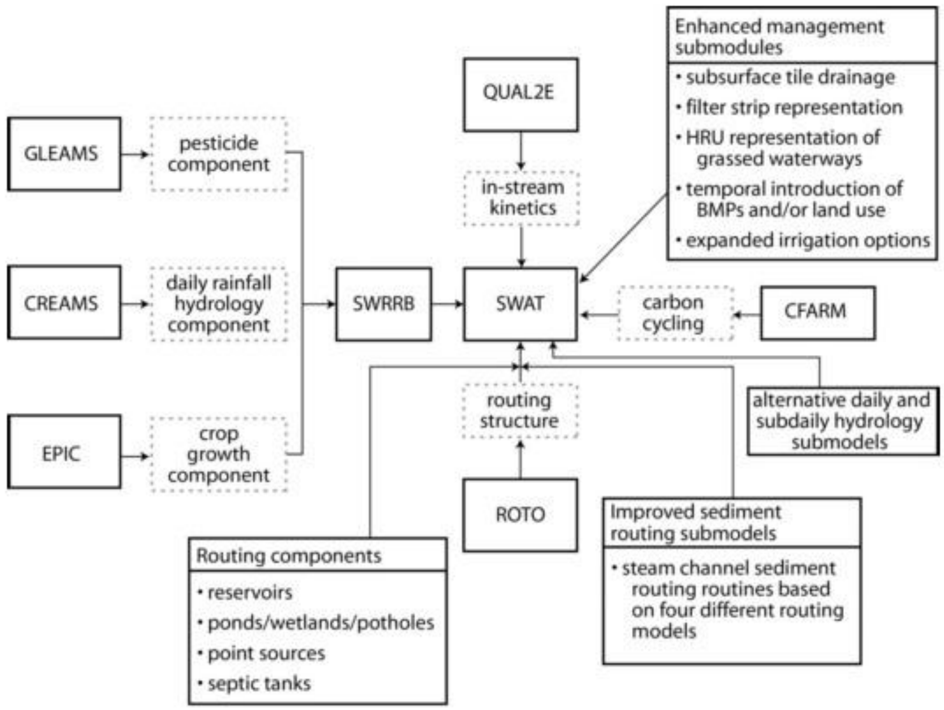


Figure 6: The development of SWAT model plan and processes.

Gassman et al., (2007); Arnold et al., (2012**)**

1.4.1 How SWAT simulates Flow & Total Phosphorus

The main concept of SWAT model is aggregation of the land and channel hydrology. The water mass balance is applied for the land hydrology equation (1) .All equations in this chapter were taken from SWAT theoretical documentation (Neitsch et al., 2005).

$$SW_t = SW_0 + \sum_{t=1}^{t}(R_i - Q_i - ET_i - P_i - QR_i) \quad (1)$$

SW_t= soil water content ($m^3.m^{-3}$) after t days

SW_0= the initial soil water content ($m^3.m^{-3}$)

i=time in days R=the daily precipitation (mm)

Q=runoff (mm/h)

ET =Evapotranspiration (mm)

P =Percolation (mm/h)

QR =Return flow (m^3/h)

It is essential to understand all phosphorus component cycles as well as how SWAT simulates these components from the land phase all the way to the stream to assess all phosphorus portions and help manage all phosphorus forms. Phosphorus exists in different forms in soils and water; however, 6 forms of phosphorus in the soil are calculated in the SWAT model, and divided into organic phosphorus and inorganic phosphorus.

The initial condition of soluble and organic P in soil must be identified by the user or using a SWAT default value, which is 5 mg P kg^{-1} for an unmanaged area under native vegetation and 25mg P kg^{-1} for crop areas (Neitsch et al. 2001a).

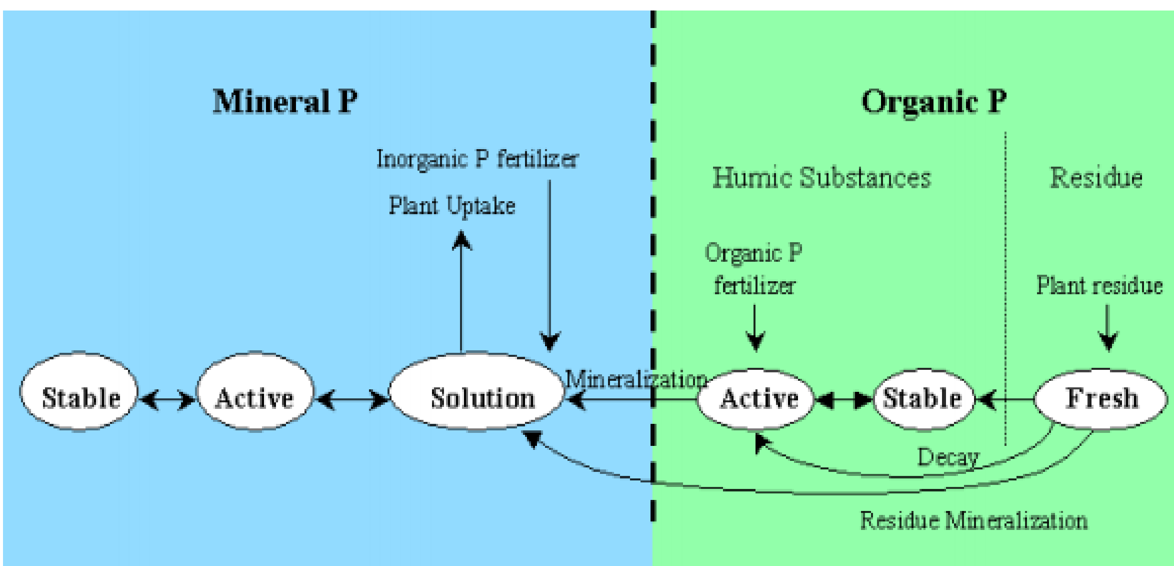


Figure 7: Phosphorus forms diagram. Source: SWAT theoretical documentation (Neitsch et al.,2005)

The SWAT model takes mineralization, decomposition, and immobilization into account using the EPIC version of Jones et al. (1984). The SWAT model aggregates these forms to two main components in the output, the mineral P (tile and soluble P) and organic P (sediment P and organic P). TP is the summation of Mineral P and organic P, and represents the P level in the stream.

The phosphorus in active mineral pool is defined from this equation:-

$$\min P_{active} = P_{solutionly} \cdot \frac{1-Pai}{pai} \quad (2)$$

$min\ P_{activ}$ is the amount of active phosphorus in mineral pool (mg/kg).

$P_{solutionly}$ is the amount of phosphorus in solution (mg/kg).

pai is the phosphorus availability index.

Whereas the stable mineral phosphorus is initiated from the following equation:-

$$\min P_{stable} = 4. \min P_{active} \quad (3)$$

1.4.2 SWAT Performance

In a comparison of the performance of three models, namely SWAT, HSPF and SHETRAN, Nasr et al. (2007) found that SWAT was an appropriate model for simulating daily TP in its application to three catchments in Ireland. Moreover, Saleh and Du (2004) proved that SWAT is better than HSPF in terms of nutrient prediction and its process. However, the complexity of the SWAT structure is one of the limitations that require extensive data input with which to build the model (Benaman et al., 2005).

According to Borah & Bera (2004) SWAT accurately estimates both yearly and monthly simulations, but has low-efficiency predictions for daily simulations.

The SWAT application is applicable in limited data watersheds. Nyeko (2015) used SWAT and other methods for a data scarce catchment to calculate missing variables, particularly in the soil. SWAT was able to generate satisfactory results. In the work by

Yang et al. (2013), SWAT demonstrated excellent performance in modeling different BMPs' impact on water quantity and quality for the Gully Creek watershed, which is located in the Ausable Bayfield Conservation Authority (ABCA). SWAT performance is highly dependent on the accuracy and availability of input data. High resolution, detailed, long term datasets are needed in the SWAT model input to represent the actual processes that occur in the watershed. Therefore, modelers may find it difficult to simulate ungauged watersheds that do not have monitoring stations for water quantity and quality. Due to the scarcity of high frequency datasets, modelers find they must assume the missing parameters to run the SWAT model successfully. Moreover, SWAT encounters difficulty when simulating variables in short period models as it requires warm up time to generate the initial conditions.

Due to the assumptions in the SWAT model structure, the model predominately requires a calibration process, which is the parameterization of model input based on the watershed conditions to decrease model uncertainty (Arnold et al., 2012).

2. Materials and methods

2.1 Study Area

The Medway Creek watershed is 205 km^2 located in the western side of the Upper Thames River watershed in southwestern Ontario. The average slope in the area is 1.29m/km. The watershed includes portions of the municipalities of Middlesex Centre (65%), Lucan Biddulph (20%), the City of London (10%) and Thames Centre (6%). Medway Creek flows for 214 km from the Mitchell moraine (elevation as high as 330 m above sea level) towards the north branch of the Thames River where the elevation is 240 m above sea level. Medway Creek contributes to 7% of the flow of the Thames River and delivers loads of nutrients to the river (Medway Creek Community, 2008). The Medway Creek watershed has an abundance of natural features, including wetlands, forests, and surface water. The Granton wastewater treatment plant discharges into Medway Creek, and it is considered a point source for pollution in this study. Arva dam which is located in the watershed is not operational dam so it has no effect on the model in terms of impacting the stream flow or the creek hydrology.

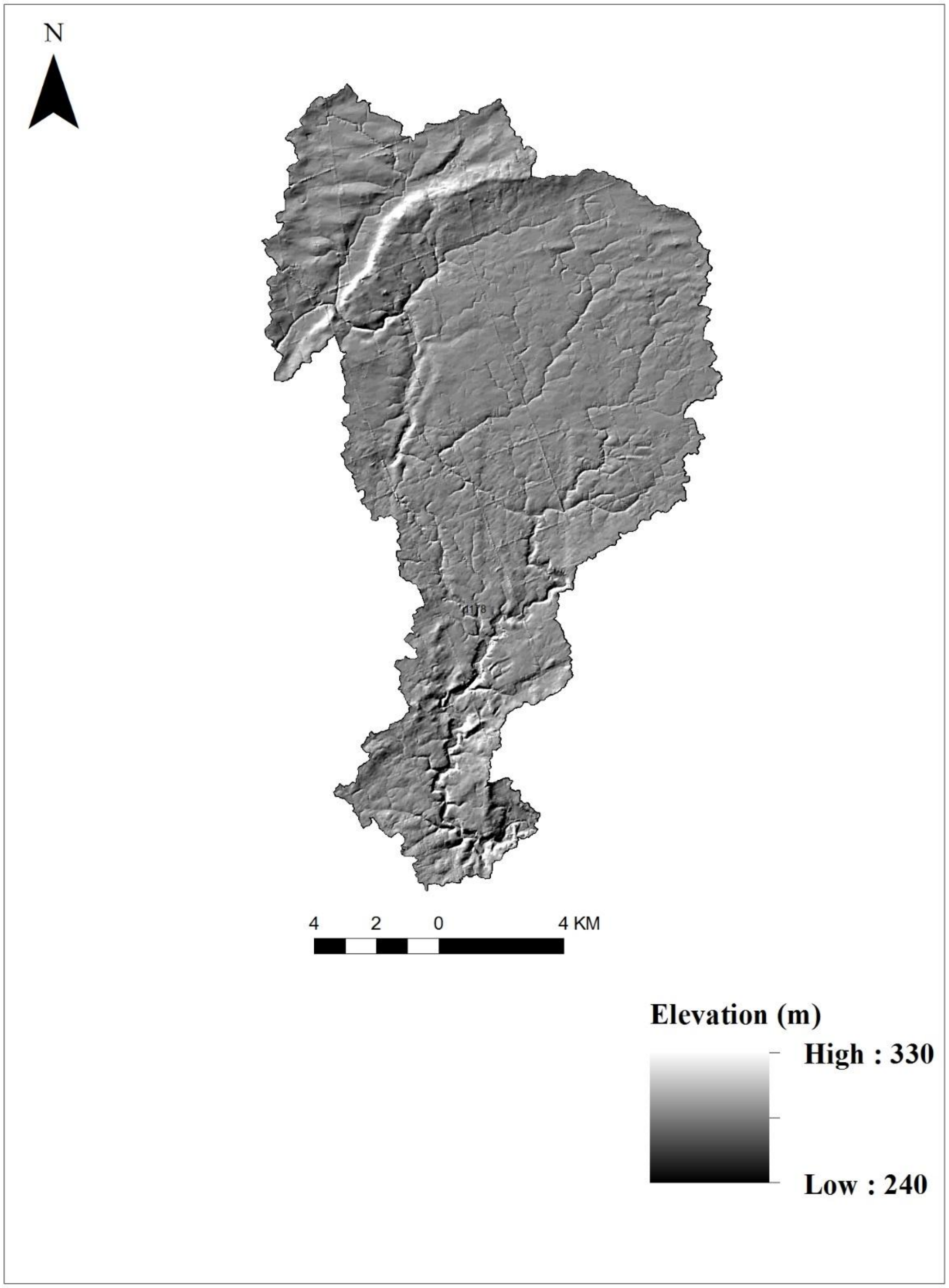
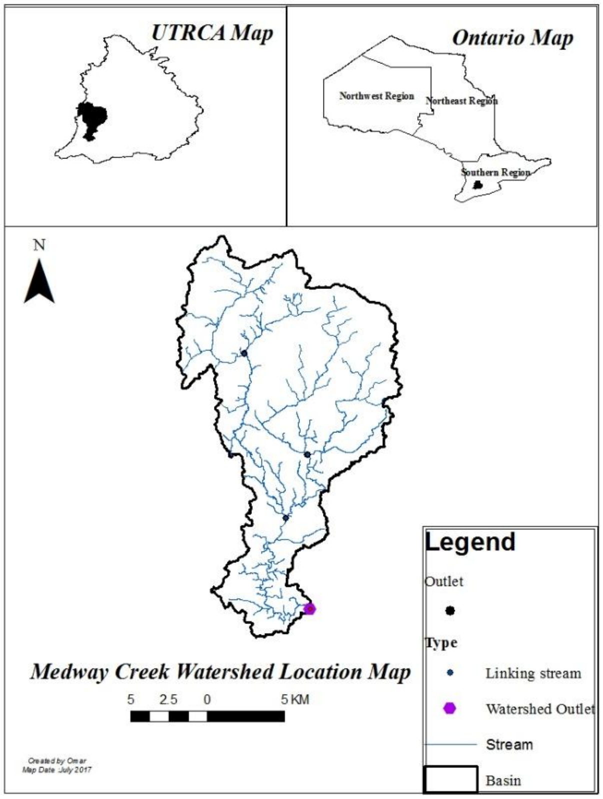
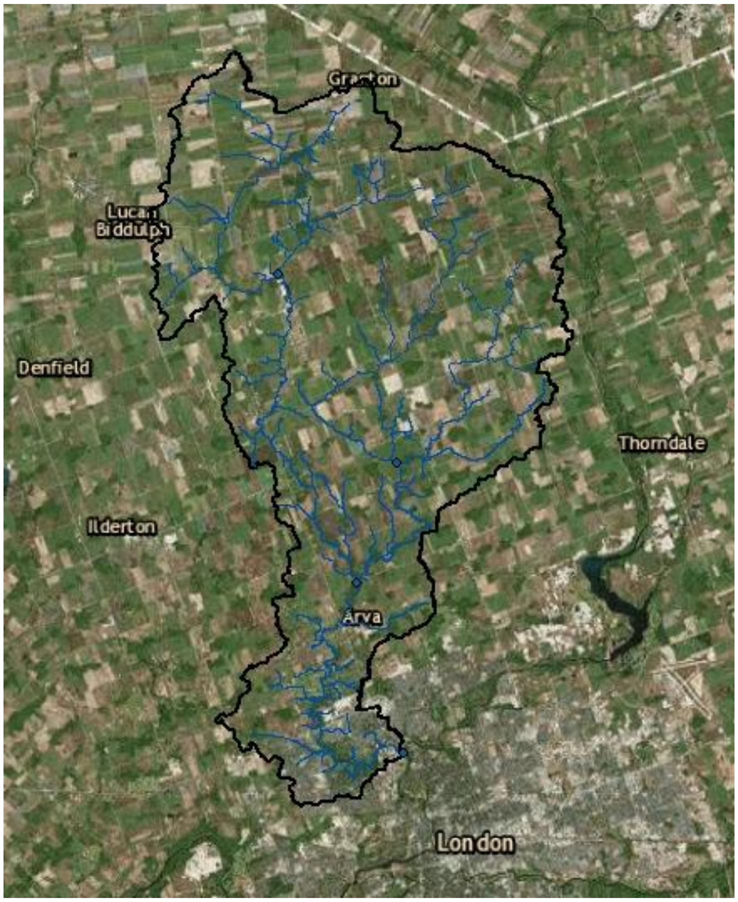


Figure 8: Topography of Medway Creek Watershed

Figure 9,10 :Medway Creek watershed map





Agricultural land dominates the landscape of the Medway Creek watershed and forms 83% of the total watershed area. Corn covers 36% of the watershed area, 21.36% is Soybeans, and 20.25% is Winter wheat see Table (2). The two vital activities that significantly influence the nutrient flux are synthetic fertilizer application and land operations, both of which increase the effect of non-point source pollution in the watershed.

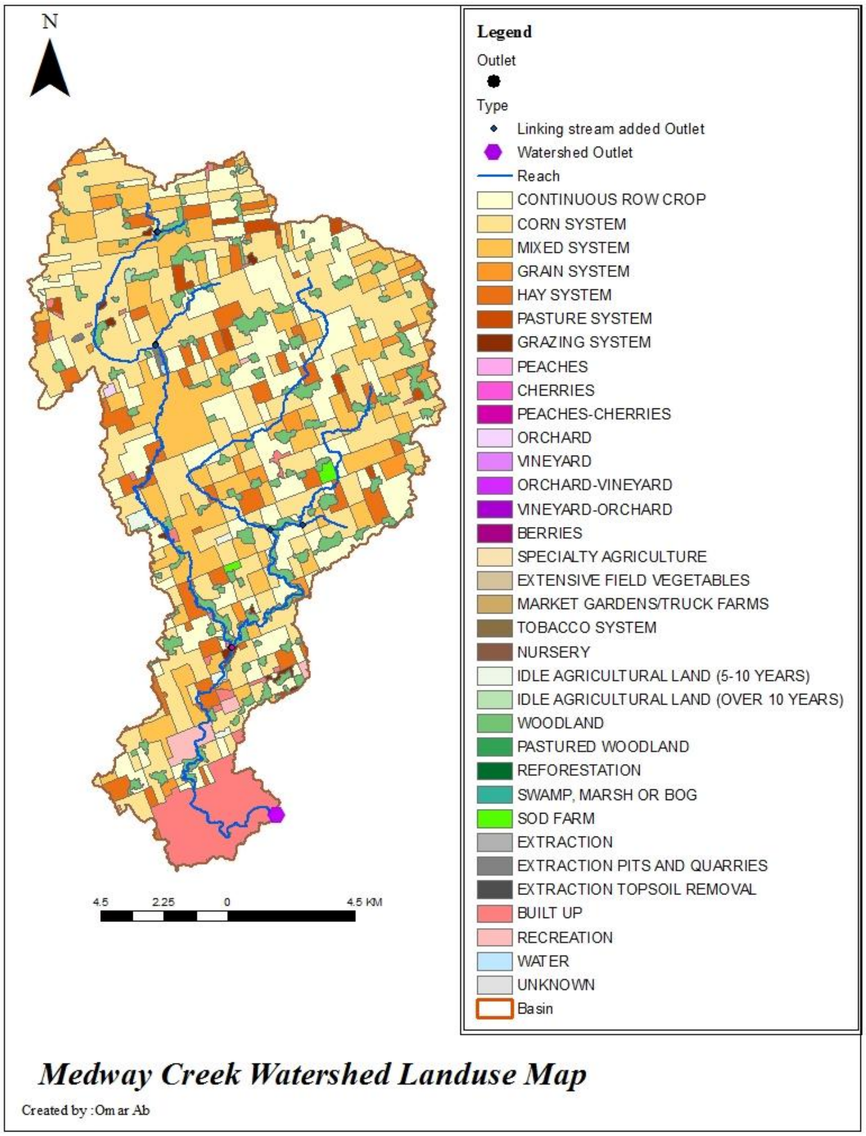


Figure 11: Medway Creek Watershed Land Use Map

2.2 The Soil and Water Assessment Tool (SWAT)

SWAT simulates the impact of different management practices and climate on water, sediments, nutrients, and other agricultural components (Abbaspour et al., 2007). SWAT is a computational model that applies water balance to compute different variables at HRU levels. The foundation of the stream water quality model in SWAT derives from the QUAl2A (or Q2E) model (Brown and Barnwell 1987), which considers all nutrient cycle connections, algae growth, and oxygen demand (Abbaspour et al., 2007). For simulation of runoff, SCS (Soil Conservation Service) has been used in the model to estimate the surface runoff based on the curve number. Moreover, TSS and sediment flux are simulated in SWAT using the Modified Universal Soil Loss Equation. The calculation of nutrients is based on their cycling, which depends on soil nutrients and sediment flux (Neitsch et al.,2011; Asadzadeh et al., 2015)

2.2.1 Data Acquisition and Processing

During ArcSwat (SWAT extension for ArcGIS) procedures, different input data need to be integrated and prepared to properly format and run the SWAT model successfully. Geospatial data is an essential part of input data to build the SWAT model. Although different sources are available for the input data, the SWAT model requires high resolution data to identify all the features in the watershed. With collaboration from the UTRCA, the current monitoring data for Upper Medway Creek is applied in this study to simulate the current condition of the watershed. The monitoring data includes the soil sample data, fertilizer records, land operations, and water quality monitoring for the past two years. SWAT requires the following data in order to run the model:-

1) **Digital elevation model (DEM)**

DEM data is usually available in many different resolutions from different sources; however, in SWAT it is recommended to utilize high resolution DEM to be able to run the model and create accurate stream networks. The DEM used in this work has 10 m resolution after conversion to a raster format and preparation of SWAT input proceedings. LIO (Land Information Ontario) provides DEM datasets that cover all

Ontario with 10 m resolution. There is a variety of DEM sources for Canada and worldwide that can be freely obtained from the Internet, including Natural Resources Canada, Open Government Portal-Canada, and Scholars Geoportal. Moreover, UTRCA provides 1 m resolution of DEM for only Upper Medway Creek under the current project of Medway Creek Priority Sub-watershed Project.

2) Stream Network Data

Stream data plays an essential role in watershed delineation. Using a highly detailed stream network to delineate the whole watershed accurately without missing any parts is highly recommended. Stream data is offered as an integrated hydrologic data package by the Ministry of Natural Resources and Forestry. The stream data is prepared and clipped into the target area to use it as an input for the SWAT model. The Medway Creek watershed comprises 12 streams, including Medway, a tributary of the North Thames, Snake, Colbert, Medway East Branch, Mills-Guest, Risdon, Needham, White-Fitzgerald, Dickenson, Edgewood, Elginfield, and Cook.

3) **Land use Data**

The Ministry of Natural Resources provides a land use map through SOLRIS (Southern Ontario Land Resource Information System) for landscape of natural, rural and urban lands with a scale of (1: 100,000 to 1: 250,000). The agricultural land is specified in detail based on the crop types according to the OMAFRA datasets. Furthermore, crop rotation is incorporated into the model, and thus new land use classes have been built to apply these rotations. SWAT reclassifies land use based on its system, and any land use that does not exist in the SWAT database needs to be added to the SWAT database.

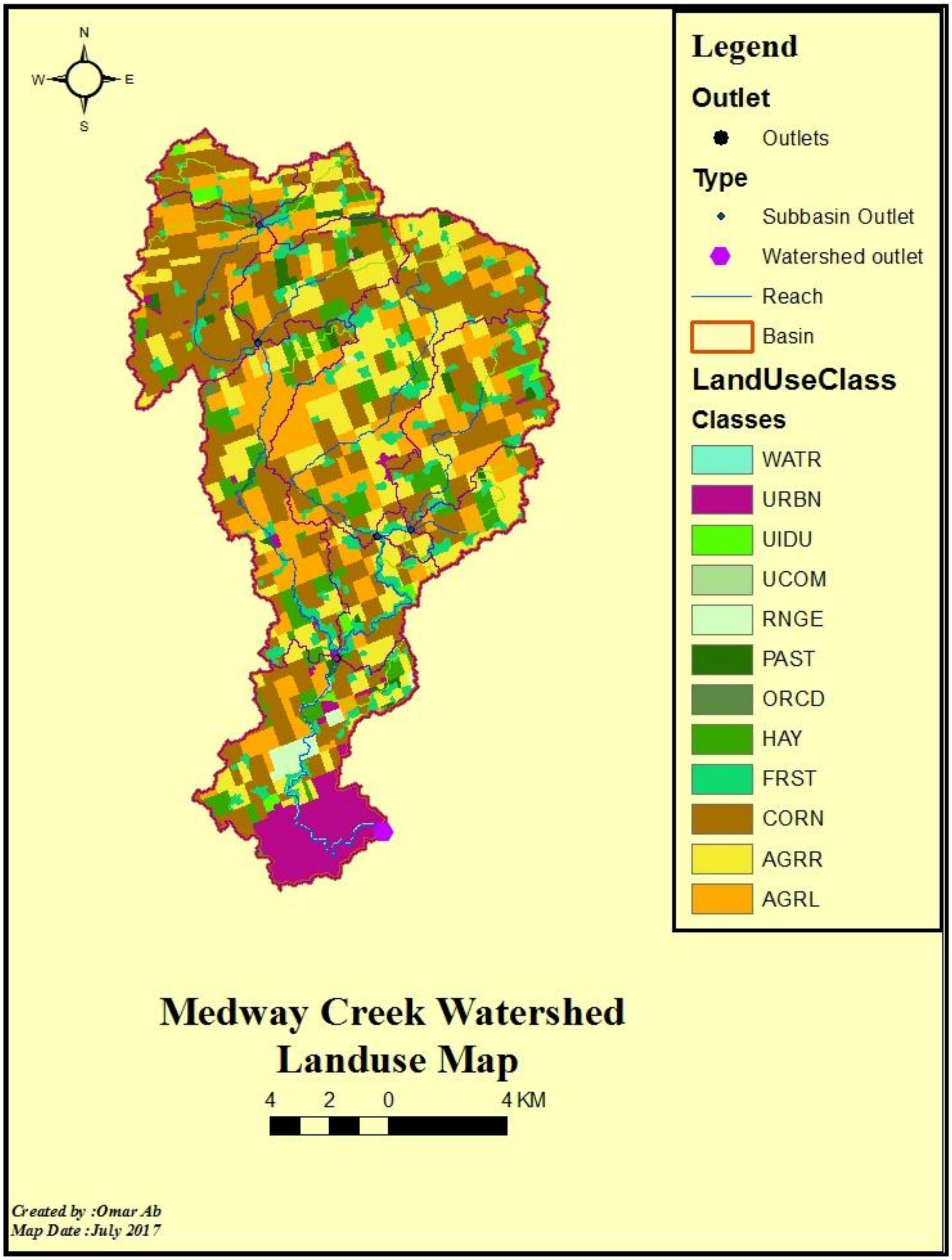


Figure 12: Medway Creek Watershed Reclassified Land Use Map

LAND USE	CODE	AREA (HA)	PERCENTAGE%
Corn	CORN	7174.3720	35.01
Agricultural Land-Generic	AGRL	3997.0248	19.51
Industrial	UIDU	169.1709	0.83
Agricultural Land-Row Crops	AGRR	4234.9103	20.67
Water	WATR	79.2813	0.39
Forest-Mixed	FRST	1619.7744	7.90
Residential	URBN	1162.1564	5.67
Pasture	PAST	313.1861	1.53
Hay	HAY	1524.5494	7.44
Range-Grasses	RNGE	489.4867	0.97
Orchard	ORCD	15.2352	0.07
Commercial	UCOM	3.9807	0.02

Table 1: reclassified land use in SWAT model

The major three crops in Medway creek watershed according to UTRCA are Corn, Soybeans, and winter wheat. The following table shows the average crop percentage of total watershed.

Crop type	Area m^2	Wat.Area %
Corn	7556.132	36.87
Soybeans	4377.685	21.36
Winter wheat	4149.852	20.25
Hay	1407.264	6.87
Pasture	94.864	0.46

Table 2: Crop percentage in Medway Creek Watershed

4) **Soil Data**

Soil data was difficult to obtain especially when it is required to determine more detailed and specific soil properties. Nutrient modeling requires most soil properties including carbon matter, texture, and clay sand content. The Soil Survey Complex, which was developed by OMAFRA &AAFC, provides high quality soil data for Ontario with a scale of 1:50,000, however, there are properties missing, such as soil available water content, saturated hydraulic conductivity and bulk density.

Soil characteristics

USLE- K (Soil erodibility factor) for soil, which represents the ability of soil to erode is one of the missing variables that is calculated based on texture and the organic matter following OMAFRA and Wischemies et al, (1971) method to accurately estimate the average rate of erosion. The soils in the Medway Creek watershed has an average OMC (Organic Matter Content) of 4.9 % of soil weight based on UTRCA soil sampling. The dominant soil texture in the Medway Creek watershed is Silt Loam. SPAW (Soil Plant Air Water) Software has the capability to calculate soil water tension, conductivity and water holding capability based on the soil texture, with adjustments to account for gravel content, compaction, salinity, and organic matter (USDA,2007). The SWAT database has been altered based on the watershed soil characteristics to update all soil properties in the database. The soil tributary in the SWAT database requires the flowing parameters in Table 3, in order to estimate runoff, groundwater recharge, evapotranspiration, sediments, and nutrients flux see Appendix A.

Variable	Definition	Source
SNAM	Soil Name	Soil ON
HYDGRP	Soil Hydraulic Group	Soil ON
SOL_ZMX	Maximum rooting depth of soil profile (mm)	CASIS
ANION_EXCL	Fraction of porosity (void space)	Default value
SOL_CRK	Potential or maximum crack volume of the soil profile	Default value
TEXTURE	Texture of soil layer	Soil ON
SOL_Z	Depth from soil surface to bottom of layer (mm)	CASIS
SOL_BD	Moist bulk density (Mg/m^3 or g/cm^3).	calculated
SOL_AWC	Available water capacity of the soil layer (mm H_2O/mm soil)	calculated
SOL_K	Saturated hydraulic conductivity (mm/hr)	calculated
SOL_CBN	Organic carbon content (% soil weight)	measured
SOL_CLAY, SAND,SILT	Soil,Clay,Silt content (% soil weight)	Soil ON
SOL_ ALB	Moist soil albedo	Default value
SOL_ROCK	Rock fragment content (% total weight	Default value
USLE_K	USLE equation soil	calculated

Table 3: Soil variables for SWAT database input

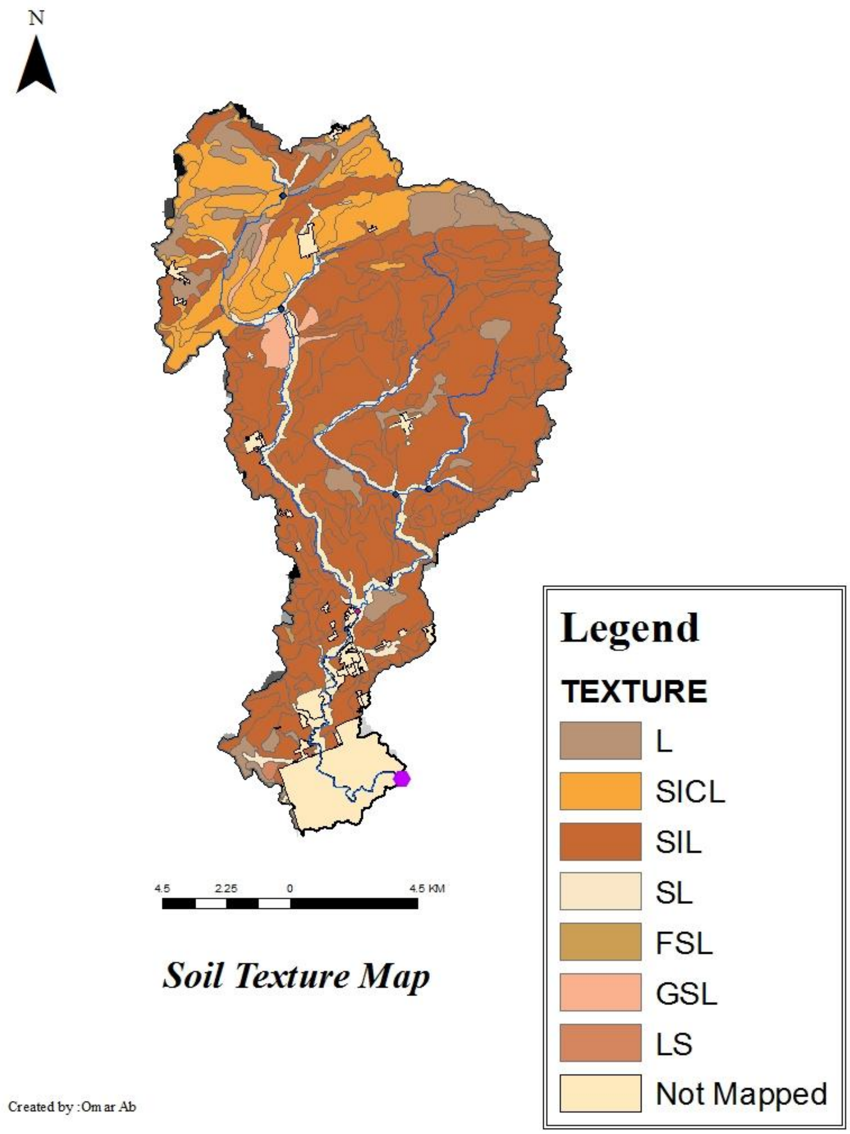


Figure 13: **soil texture map**

5) Weather Data

Although Medway Creek is an un-gauged watershed for the simulation period of 1989 to 1999, the London Int'l Airport station is used in the model for daily interval data as it neighbors the Medway Creek watershed and it has been monitoring precipitation and temperature since 1940. Temperature data were used to calculate Potential Evapotranspiration (PET) in SWAT model using the Penman/Monteith equation. Nevertheless, a few of the daily data were missing and they were collected from the nearby station (London Sharon Drive) which had those missing data.

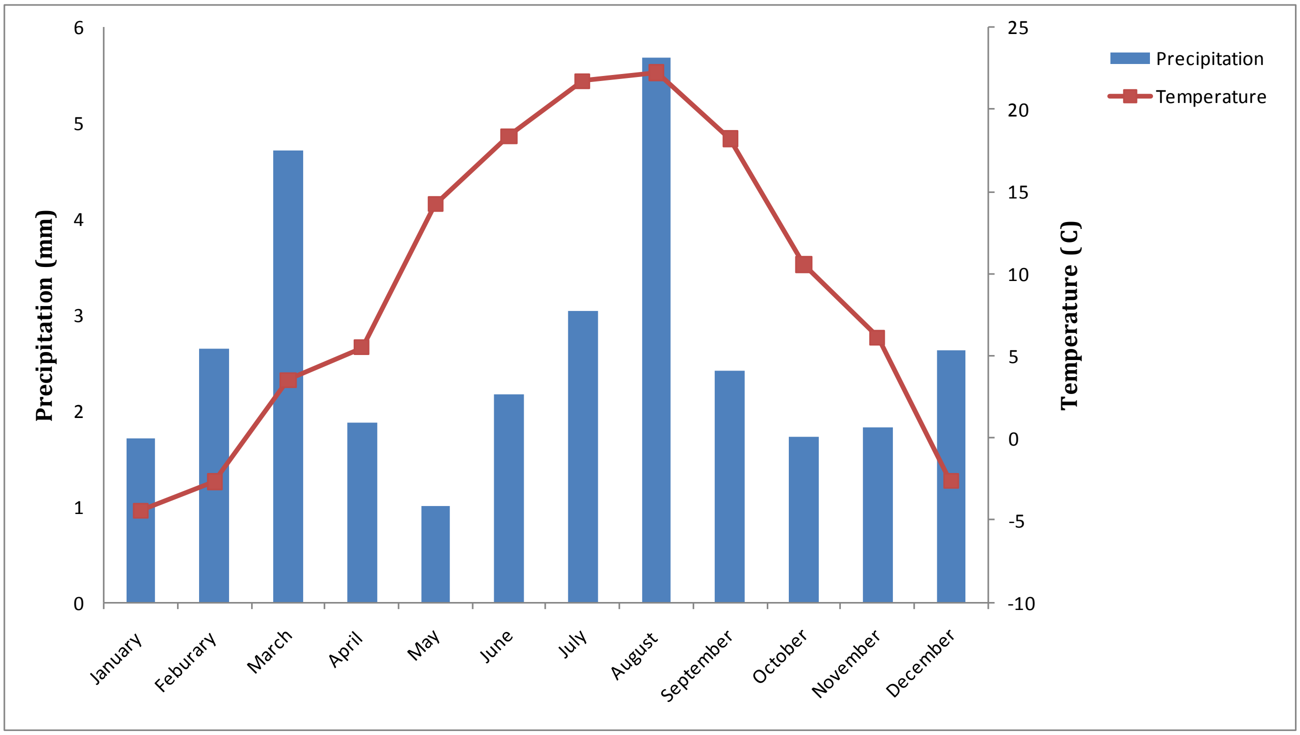


Figure 14: Monthly distribution of Average measured precipitation and temperature in London International Airport in 2016

Station	Latitude	Longitude	Elevation	Frequency
London Int'l Airport	43°01'59.000" N	81°09'04.000" W	278.00m	Daily
London Sharon Drive	43°02'00.000" N	81°17'00.000" W	274.30 m	Daily
London Cs	43°02'00.000" N	81°09'00.000" W	278.00m	Daily

Table 4: Climate data Stations for Medway Creek watershed

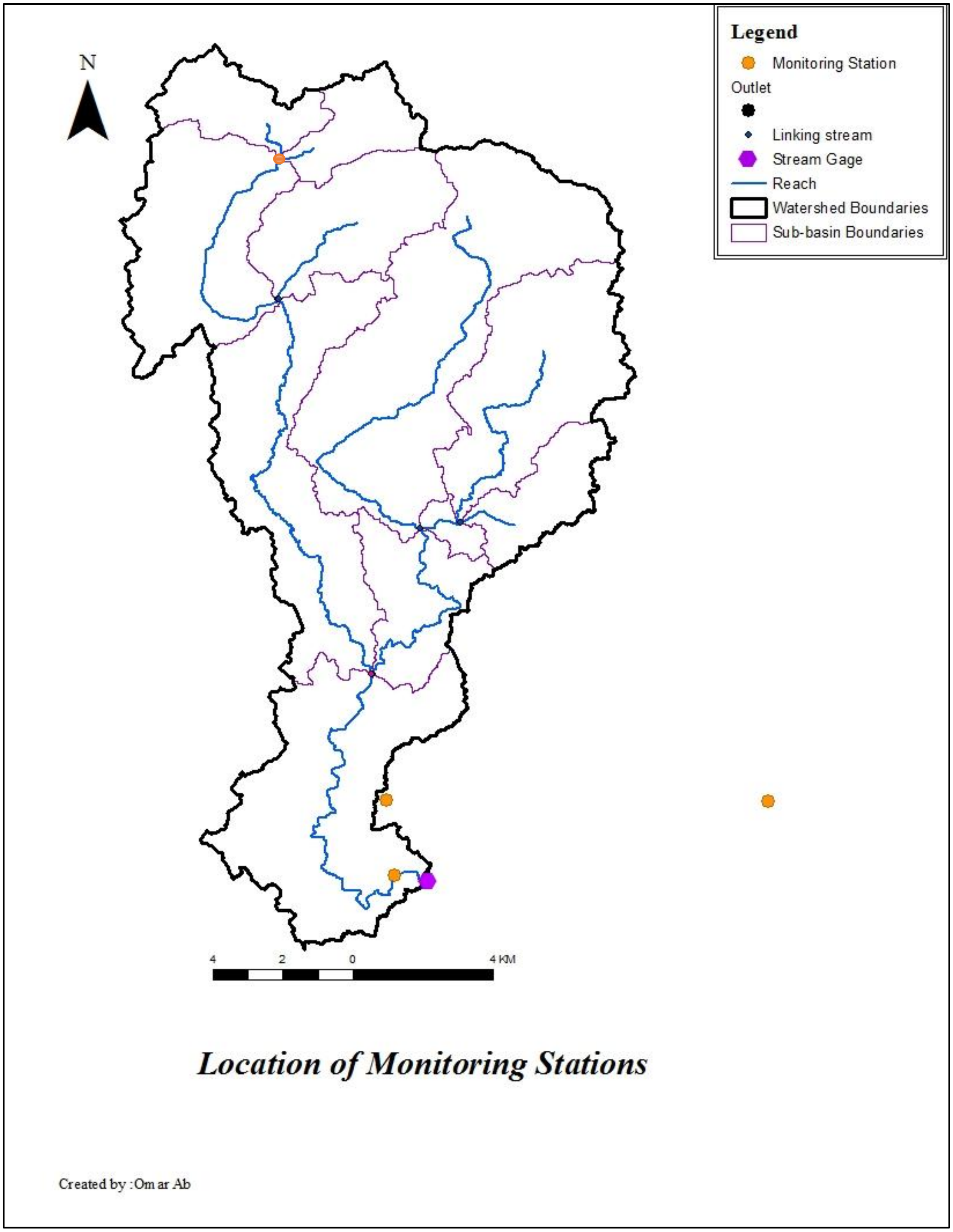


Figure 15: Medway Creek Watershed Monitoring Stations

6) Land Operations

The SWAT model requires detailed information about the land operations that take place in the watershed to assess their impact on the surface water. Each operation should be scheduled at its date with detailed data, including the percentage of the watershed that applies these operations. The typical order of land operations in southern Ontario are followed based on Yang et al (2013). The land operation data that were obtained from UTRCA includes limited information about the land operations in the Upper Medway Creek watershed; therefore, both data are compared and the main land operations that are incorporated in the Medway Creek Watershed Model are: -

- Planting
- Crop Rotation
- Harvest
- Grazing
- Winter cover crop
- Tillage
- Fertilizer Application

Crop rotation in the watershed is a three- year system involving corn, soybeans, and winter wheat. The majority of farms follow this system; however, hay is predominantly not rotated for about 3 years according to UTRCA (Personal Communication, M.Funk).

Tillage systems have a huge impact on the watershed's annual sediments by removing the land cover and making possible erosion through wind and runoff. According to the water quality team at UTRCA (Personal Communication, M. Funk and Craig), the tillage system in the Medway Creek watershed is mostly conventional with increasing conservative type in the last year. The typical tillage systems in south-western Ontario were followed in this study based on the literature review see Table (6). The conventional tillage system is still common in southern Ontario; even though, the conservative tillage significantly improves water quality by reducing TP and sediments loading that export to the streams. SWAT requires specific parameters about each tillage system, including day and month of operation, tillage ID, and CNOP (SCS runoff curve number for moisture condition II).See Appendix A.

Tillage type	Time
Conventional tillage	April & Nov (corn &Soybeans)
Conservative Tillage	May &Oct
No till	Sep (Winter Wheat)

Table 5: the typical Tillage system in Medway Creek Watershed

Fertilizer application rates are the main input in the watershed operation system as they are considered the main source of nutrients in surface water. After analyzing the recommended rates from OMAFRA and UTRCA datasets for applied fertilizer and rates in Leon et al. (2004) and Yang et al. (2013) in southern Ontario, the present study used average rates from previous sources and incorporated them into the SWAT model as shown in Table (7).

In SWAT model, various fertilizer parameters are required, including date and other factors, and are shown in Table 6.

Variable	Definition
FRT_KG	Amount of N and P applied to HRU (kg/ha)
FRT_SURFACE	Fraction of fertilizer applied to top 10mm of soil
FERT_ID	Fertilizer identification number from fertilizer database
Day	Day of operation
Month	Month of operation

Table 6: Fertilizer parameters in SWAT input

The default value of 0.2 was assigned for FRT-SURFACE parameter for all land covers. Each land cover has its own system of land operation as shown in Table (7)

After incorporating all the land management operations that are applied in the Medway Creek watershed, SWAT will define these operations at HRU level and save them in "mgt2" table in the database.

Year (Crop)	Month	operations
1 (Corn)	April	Disc Plow GE23ft
	May	Grow Corn
	May	Fertilizer: N 110kg/ha
	May	Fertilizer: P 22kg/ha
	Nov	Harvest
	Nov	Mouldboard plow
2 (Soybeans)	May	Grow Soybeans
	May	Fertilizer: P 33kg/ha
	Oct	Harvest
3 (Winter wheat)	April	Fertilizer: N 70kg/ha
	July	Harvest
	Nov	Mouldboard plow

Table 7: Agricultural land operations in southern Ontario

Land use	Month	Operations
Hay	May	Plant /beginning of growing
	May	Fertilizer N 25Kg/ha
	May	Fertilizer P 22Kg/ha
	May	Harvest only
	May	Fertilizer N 10Kg/ha
	July	Harvest only
	July	Fertilizer N 10Kg/ha
	August	Harvest and kill
Forest	May	Planet/beginning of growing
	Oct	Kill/end growing season
Range grass	April	Planet/beginning of growing
	Oct	Harvest and kill
Urban area	April	Fertilizer N 12 kg/ha
	April	Fertilizer P 5 kg/ha
	May	Planet/beginning of growing
	June	Fertilizer N 11 kg/ha
	August	Fertilizer N 11 kg/ha
	Sep	Harvest and kill
	Sep	Fertilizer N 11 kg/ha

7) Tile Drainage

According to OMAFRA datasets, tile drainage is a common practice in the Medway Creek watershed, and applies in most agricultural areas. For a tile drained area in SWAT, it is necessary to input a number of parameters, including the tile length and the depth to surface that were obtained from the OMAFRA layer. See Appendix A.

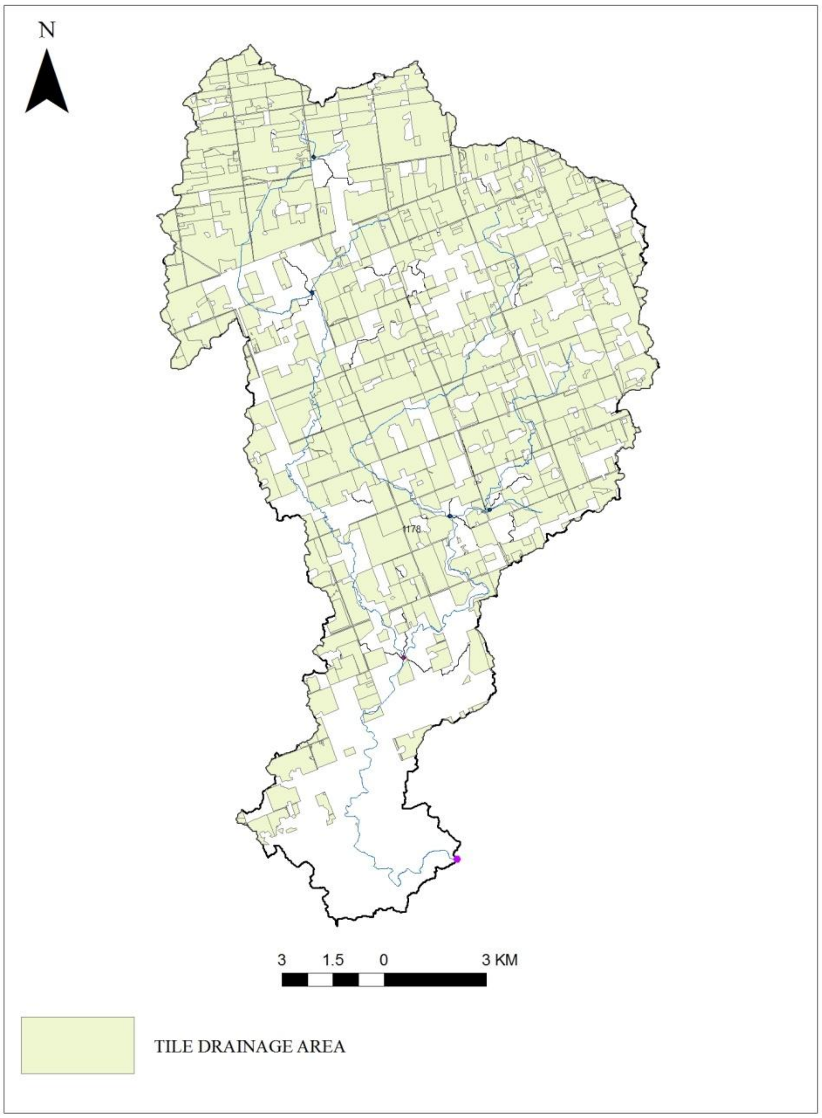


Figure 16: Tile drained area in the Medway creek watershed. Source OMAFRA

Measured Data

Stream flow & water quality data

Given the lack of high frequency monitoring data for Medway creek, the City of London is the only source of long term data monitoring that cover the first period of the model, which is from 1989 to 1999. The City of London datasets provide monthly stream flow and water chemistry data from 1979 to present at the Medway Creek watershed outlet. However, a few months of data were missing and were estimated using simple linear proportion. The data has been evaluated and compared to the measured data obtained from UTRCA, which covers the last two years. The high flow usually occurs in winter and early spring, and associated with snow melting, see Appendix (A). TSS and TP data were collected for the same period and incorporated in the model to calibrate the model parameters. All measured data are shown in Appendix A.

Years	Flow m^3/s	Total Phosphorus mg/L	Total suspended solid mg/L	pH
1992	5.56	0.14	-	7.81
1993	8.53	0.18	14	7.89
1994	1.96	0.09	16.71	7.92
1995	0.96	0.08	29.25	8.01
1996	1.56	0.08	17.4	8.14
1997	2.83	0.08	21.54	8.1
1998	3.54	0.31	21.84	8.01
1999	0.65	0.15	15.18	8.16

Table 8 : Average Yearly measured Flow, TP, TSS, and pH. Source City of London

UTRCA provided access to daily water quality data for the present study project under the GLACI program. The data monitoring started in Feb 2016, and continued until the present time. Water chemistry measured on samples collected in the Upper Medway Creek at Observatory Drive was used to validate the SWAT model in daily time step.

8) Granton WWTP

The Granton Wastewater Treatment Plant is considered the point source for the Medway Creek model and its information has been incorporated into the input to accurately estimate the model output. The Granton plant is a rotating biological type process and it is located at Lot 27, Biddulph Township. The plant influent is discharged into the Upper Medway Creek at the northern sub-basin in the Medway Creek watershed. The population of Granton village is 300 and the WWTP is designed to accommodate 270 (m^3/d). The daily flow of the Granton plant ranges from 96.36 (m^3/d) to 409 (m^3/d); therefore, the average daily flow for the design period, 270 (m^3/d), has been applied in the model. The annual average water chemistry parameters were captured from two sources: the Granton Wastewater Treatment Plant Operations Report 2017, and UTRCA data. See Appendix (A).

2.3 Model set up

The ArcGIS interface has been used to prepare the SWAT input data and set up the model. After collecting all geospatial input data, SWAT delineated Medway Creek watershed. To define the stream network, DEM and stream data are required in watershed delineation. Based on the DEM and stream network of 205 (km^2) drainage area, ArcSWAT divided the Medway Creek watershed into 11 sub basins, which were further subdivided into 279 HRUs where each one has unique land-use, soil type, and slope. The number of divided sub-basins can be modified based on the modeler; however, the higher the number of divided sub-basins in the watershed, the more accurately the stream distribution would be delineated. The Medway Creek Watershed is normally divided into three sub-basins; however, in this study, the watershed was divided into 11 sub-basins. The SWAT program calculates the parameters in each HRU and further determines the overall watershed scale. The model was set up for the period of

January1, 1989 to December 31, 1999 with three years as a warm up period. Measured weather data were collected from the London International Airport station because of the lack of climate monitoring data available at the Medway creek watershed. Hydrology and water quality monitoring data from Windermere station, which is located at the watershed outlet, have been incorporated into the model for calibration purposes. The first 3 years, which were the warm up period, were excluded from the model to avoid involving the initial conditions in the calculation. Data availability from Medway creek is infrequent in terms of daily/monthly water quality data monitoring. Most water quality stations are only sampling Medway Creek after storm events and are reported by water quality agencies. To resolve this issue, we have made a simple linear interpolation for missing data, and analyzed the available data for the months around this gap to generate the missing data proportionality.

The SWAT model provides the ability to add point source pollution, which represents treatment plants; so therefore, the Granton wastewater treatment plant is considered a point source discharge for the Medway creek watershed. Arva reservoir, which is in the Medway Creek watershed, is considered in SWAT calculation which may influence the flow and nutrients movement. In accordance with UTRCA, different management practices were incorporated into the Medway Creek watershed in the past 2 years; therefore, these strategies have been considered in SWAT simulation, as mentioned in the land management section.

Figure 17 : the division of sub-basins in SWAT set up

2.4 Calibration, parameterization process

Calibration is the process of adjusting the model input to obtain reasonable results. Models are less useful without calibration. SWAT-CUP was recently developed and provides a decision-making framework that incorporates a semi-automated approach (SUFI-2) using both manual and automated calibration and incorporating sensitivity and uncertainty analyses (Arnold,et al ,.2012). SWAT-CUP is linked to the SWAT model by text in file in the SWAT output. Therefore, SWAT-CUP has the ability to alter SWAT parameters and then compare them to the observed data. SUFI-2 was used in the model calibration and validation to assess uncertainty of the model and its parameters in order to obtain better calibrated results. By having parameter ranges, SUFI-2 can examine the parameter's uncertainties and calculate the model outputs based on 95PPU (95% prediction uncertainties). 95PPUs and objective functions represent the calibration output evaluation for parameter uncertainties.

In SWAT-CUP, the modeler has to know the certain hydrological processes in the actual watershed that need to be calibrated based on the initial SWAT model results. For example, when the default SWAT model has not conducted enough information about the snow or groundwater contribution, this means the snow and groundwater parameters need to be calibrated to match the real values of these parameters. However, the default model should have somewhat acceptable results compared to the measured data, and should demonstrate a logical representation of the main process that happens in the watershed. Based on this concept, the model was calibrated using 16 different parameters and the measured data at the watershed outlet. In SUFI-2 the parameterization has a specific type of inputting the range of parameters with the ability to adjust certain parameters, in particular sub-basin or HRU.

x__<parameter>.<ext>__<hydrogrp>__<soltext>__<landuse>__<subbsn>

x: is a code to indicate the type of change to be applied to the parameter(K. C. Abbaspour et al., 2015).

The measured data for the simulation period is prepared in a specific format and incorporated into the SWAT-CUP with a number of the simulations in order to capture most of the observed data, the main idea in SWAT-CUP is to have back up file that has the original SWAT model files and have the same files that were altered during the parameterization. Therefore, the original values of the parameters are saved in the back up file while the alteration occurs in the other copies of these files and each alteration can be saved in a different file. Moreover, SWAT-CUP suggests different ranges of parameters after each alteration so the modeler can achieve the desirable alteration. Different objective functions can be used in model evaluation, including NSE and R^2.

2.5 Model Validation

The model validation is the process of validating the calibrated model with an independent measured data beyond the calibrated period without any further adjustment to the input parameters. A high performance model in the validation process is the ability of the model to accurately simulate a particular period and match most of the measured data in that period. In this study, the calibrated model has been validated using daily observed data for the years 2016 and 2017.The daily data were obtained from UTRCA, as mentioned before, to test the calibrated model in daily simulation. Due to the lack of long term monitoring data for Medway Creek, The validation was done used two years as it is the only available data that covers the time after calibration processes.

2.6 Model Evaluation

SWAT-CUP has two more factors that represent model performance beside the objective functions. F-factor is the percentage of observed data that is bracketed during calibration processes. When F-factor equals 1, it means the model has captured 100% of measured data. R-factor represents the thickness of the parameters range that has been used through parameterization. When R-factor equals 0, this means the parameters' uncertainty is 0, which is an ideal simulation. The Nash Sutcliffe Efficiency index (NSE) Nash and Sutcliffe (1970) equation (2) and R^2 (3) were both used to evaluate the model efficiency.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_{mean}^{obs}\right)^2}\right] \quad (2)$$

$$R^2 = \left(\frac{\sum_{i=1}^{n}\left(Y_i^{sim} - Y_{mean}^{sim}\right)\left(Y_i^{obs} - Y_{mean}^{obs}\right)}{\left[\sum_{i=1}^{n}\left(Y_i^{sim} - Y_{mean}^{sim}\right)^2\right]^{0.5}\left[\sum_{i=1}^{n}\left(Y_i^{obs} - Y_{mean}^{obs}\right)^2\right]}\right)^2 \quad (3)$$

Where Yi obs is the i th observation for the constituent being evaluated, Yi sim is the i th simulated value for the constituent being evaluated. NSE diverge from −∞ and 1.0, with NSE =1 being the optimal value. Values between 0.0 and 1.0 are ordinarily viewed as adequate levels of performance (Moriasi et al., 2007). R^2 values vary from zero to one, with a value of zero demonstrating that the relationship between the observed value and the simulated value is a nonlinear relationship, whereas a value of one is the ideal value and a linear relationship between the observed and simulated variables.

Figure 18: **NSE rating standards for model evaluation based on ASABE guidelines.** Source (Moriasi et al.,2007).(ASABE standard, 2017)

3. Results and Discussion

3.1 Default SWAT model

The default SWAT model was built using all available data in the Medway Creek watershed and applies current conditions in the watershed in order to obtain reliable results and an appropriate model that adequately captures the hydrological processes in the watershed. The first run of the default SWAT model before calibration performed fairly. The model results agreed somewhat with measured data; however, the model underestimated the flow peaks. The model-predicted TP values were poor. Two objective functions have been utilized in this model and the results are shown in Table 9 and Figure 19 below: -

Variable	R2	NSE	bR2	Mean_sim(Mean_obs)	StdDev_sim(StdDev_obs)
FLOW	0.79	0.48	0.2684	1.23(3.42)	3.72(9.64)
TP	0.37	-0.05	0.0001	60.18(3262.16)	8.74(14328.28)

Table 9: Default model results

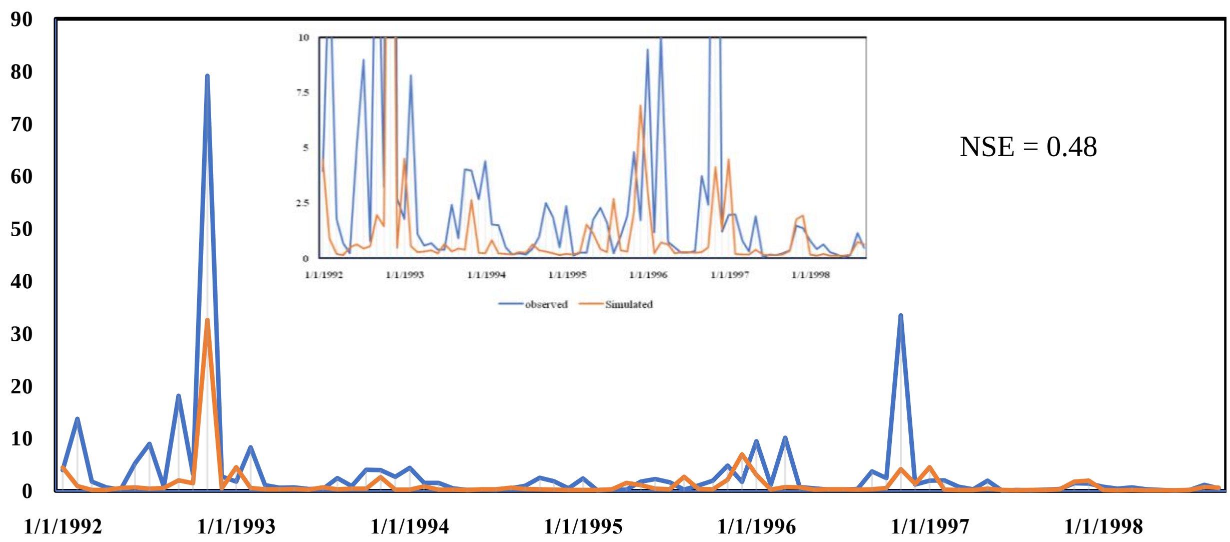


Figure 19 : Monthly observed and simulated discharge in m^3/s in the period 1992-1999 at Watershed outlet

3.2 Model calibration results

SWAT-CUP (calibration and uncertainty procedure) consists of five various methods for model optimization and sensitivity analysis. The model was calibrated for the period of Jan, 1, 1992 to Dec, 31, 1999. The model was monthly calibrated at the watershed outlet using the City of London's observed data from the Windermere station, as shown in Figure 20. The SUFI-2 algorithm generated 95PPU based on the input parameters range that had been identified. The selection of altered parameters was based on different factors including the watershed condition, the literature review of similar watershed situations, and a full understanding of parameters sensitivity. SUFI-2 was found in this study to be efficient enough to simulate stream flow and TP with satisfactory results. In discharge calibration, P-factor (the percentage of captured measured data) was 0.82, whereas R-factor was 0.54. R^2 of 0.85 was obtained with NSE of 0.65, which indicates desirable calibration performance based on the NSE rating standards Figure 18.

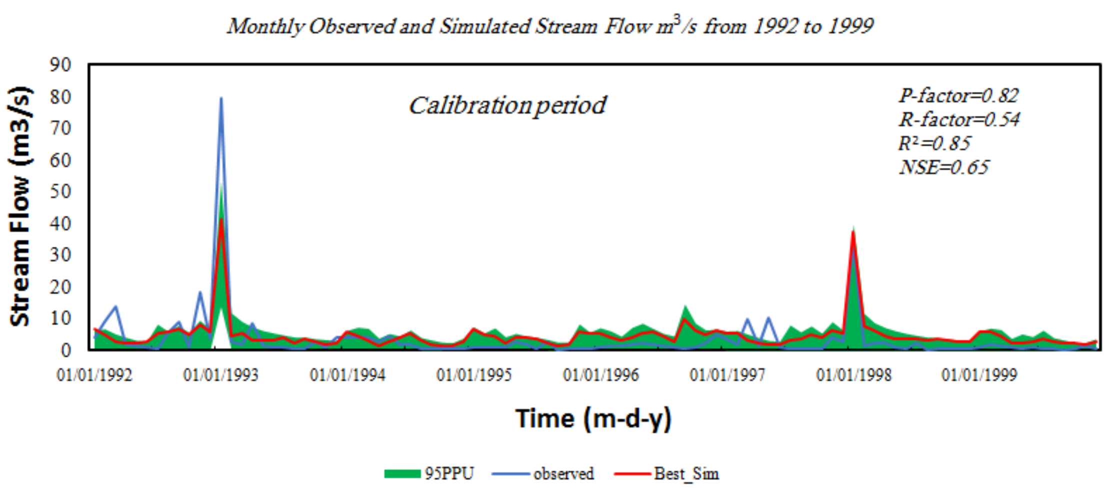


Figure 20: Calibration results for stream flow simulation

TP calibration was challenging because it includes other processes, such as sediments, land operations, and fertilizer applications. Moreover, TP calibration requires extensive knowledge of the phosphorus processes that occur in the Medway Creek watershed, and how they interact with phosphorus flux .An understanding of all physical processes in the watershed helps the modeller to reduce the conceptual model uncertainty (Abbaspour, 2014). For the calibration period, the values of 0.8 and 1.03 were achieved for P and R factors respectively. The value of 0.67 was achieved for NSE andR^2, which demonstrates satisfactory calibration performance.

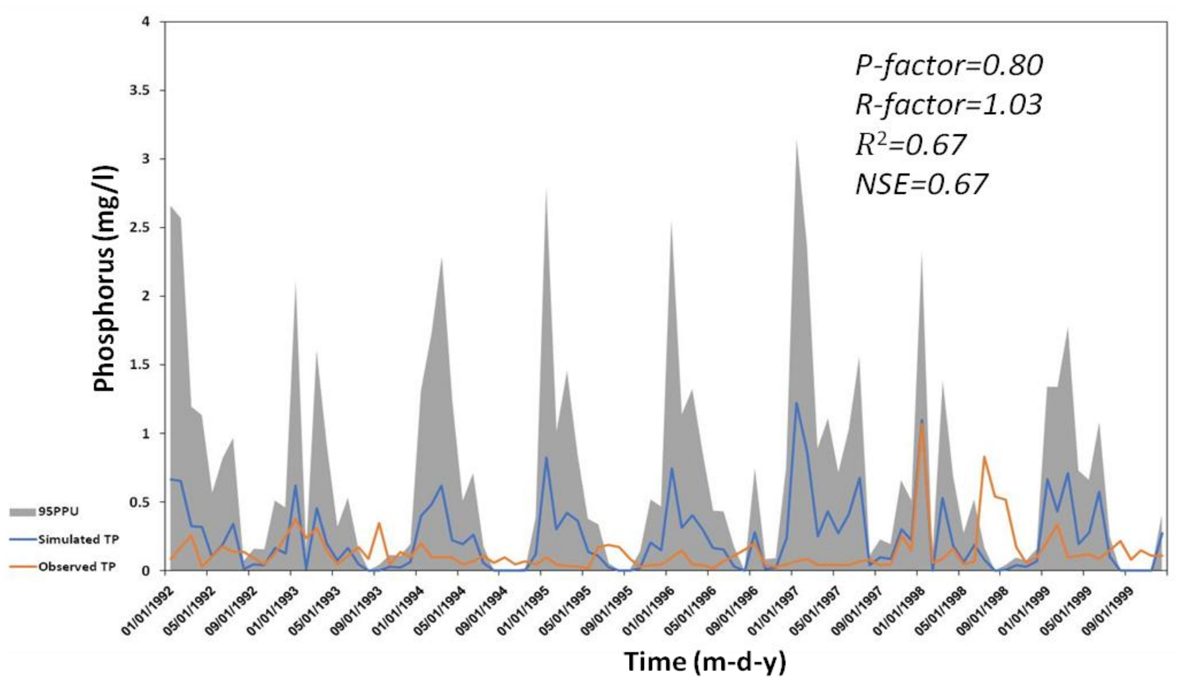


Figure 21: Calibration results for TP simulation

Both the phosphorus and sediments parameters were considered in the calibration process as they are highly connected. Most phosphorus transported to surface water is attached to sediments. Therefore, sediments and nutrients calibration was combined in one parameterization process. Moreover, there is no long term observed data for sediments in the period of 1989 to 1999; however, the sediments simulation will be included in the model validation.

3.3 Sensitivity analysis

According to the Medway Creek Friends Community report (Medway Creek Community, 2008), groundwater has a strong relationship with Medway Creek, and stream flow is controlled by groundwater during dry seasons, which indicates the sensitivity of groundwater parameters in the Medway Creek watershed. For that reason, groundwater parameters need to be adjusted to best understand the processes between groundwater and stream flow.

Ranges of parameters have been set up based on the most sensitive parameters for each variable. CN2 (runoff curve number), ALPHA_BF (Base flow alpha factor), SFTMP (snowfall temperature), and GWQMN (Threshold depth of water in the shallow aquifer) were the most sensitive parameters influencing discharge in Medway Creek. Moreover, Snow parameters have a huge impact on the model performance as Medway Creek watershed is a snow-dominant area. These parameters are including snowfall temperature and snow pack leg factor. Soil parameters, including soil water content and bulk density, were less sensitive to the discharge calibration. Table 10 below demonstrates the sensitive parameters that have been altered during calibration processes.

parameter	Name	Best Value
CN2.mgt	runoff curve number	▲2%
ALPHA_BF.gw	Baseflow alpha factor	0.296989
GW_DELAY.gw	Groundwater delay	54.807404
GWQMN.gw	Treshold depth of water in the shallow aquifer	1.891084
EPCO.bsn	Plant uptake compensation factor	0.294067
SFTMP.bsn	Snowfall temperature	0.526316
SMFMX.bsn	Maximum melt rate for snow during year	5.234355
SMFMN.bsn	Minimum melt rate for snow during the year	8.522861
SMTMP.bsn	Snow melt base temperature	-4.764058
TIMP.bsn	Snow pack temperature lag factor	1.011266
SOL_AWC.sol	Available water capacity of the soil layer	▼1.4%
SOL_K.sol	Saturated hydraulic conductivity	0.446692
SOL_BD.sol	Moist bulk density	▲15.4%

Table 10: Sensitive parameters for stream flow calibration

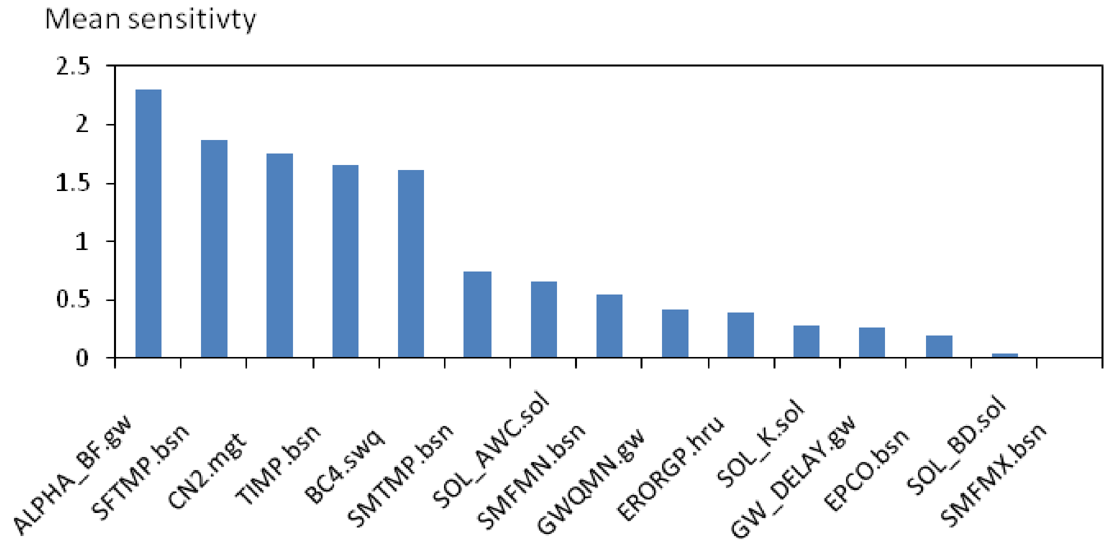


Figure 22: Mean sensitivity of flow parameters

TP calibration proceeded after flow calibration though it was challenging to obtain very good agreement with measured data because the TP cycle involves many components, including sediments, land operations, and fertilizer applications. In the present study, the model was found to be extremely sensitive to the USLE_K (equation for soil erodibility factor (K) because of the fundamental role of Sediments in exporting phosphorus from land to surface water. The following table shows the sensitive parameters for TP calibration.

parameter	Name	Best Value
USLE_K.sol	equation soil erodibility (K) factor	▼85.9%
USLE_P.mgt	USLE equation support	0.497757
GW_DELAY.gw	Groundwater delay	183
GWQMN.gw	Treshold depth of water in the shallow aquifer	1.881079
CH_N2.rte	Manning's "n" value for the main channel	0.083667
CH_k2.rte	Effective hydraulic conductivity	500
CANMX.hru	Maximum canopy storage	100
ERORGP.hru	Organic P enrichment ratio	3.066141
CN2.mgt	runoff curve number	▲1.54%
ALPHA_BF.gw	Baseflow alpha factor	0.379873

Table 11: sensitive parameters for total phosphorus calibration

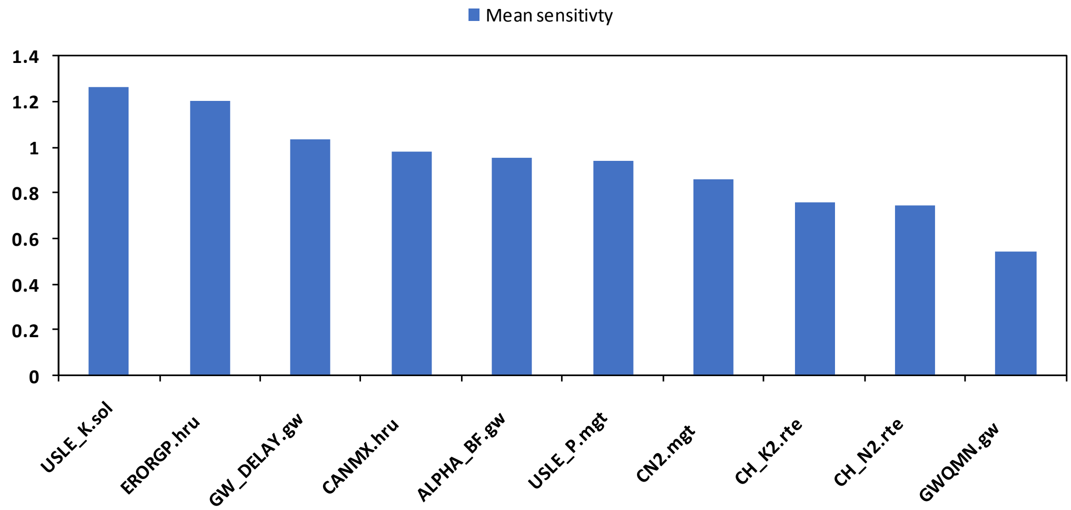


Figure 23: Mean sensitivity of TP parameters

3.4 Model validation results

Under the current conditions of the Medway Creek watershed, the SWAT model has been tested for a daily TP simulation. The water quality monitoring station at the Upper Medway Creek do not cover the whole simulated period; however, it is the only available daily data for the watershed. The model set up for the period of Jan, 1st, 2016 to Oct, 29th, 2017 for daily TP simulation to examine the calibrated SWAT model for daily prediction. Daily climate data was obtained from the London International Airport Station for the simulation period.

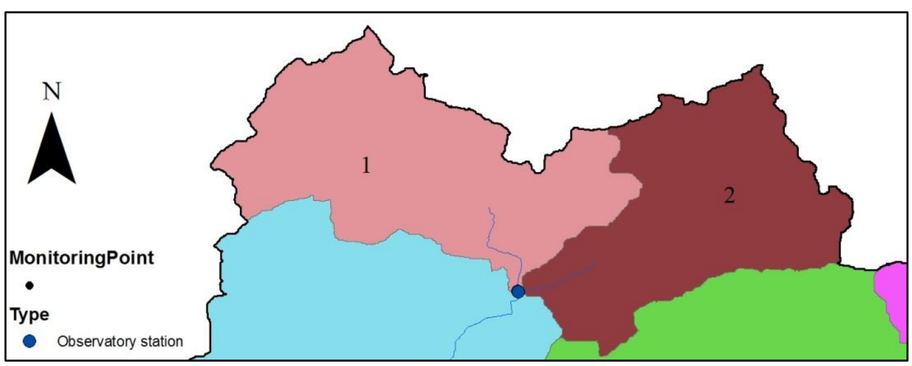


Figure 24: UTRCA monitoring Station at upper Medway Creek

The monitoring station on Observatory Drive started to measure the water chemistry in March 2016. The station does not monitor daily flow and run off in the watershed.

Although there are gaps in the observed data, as shown in Figure (3), these are the only daily data representing TP and TN in Medway Creek.

The calibrated models run over the validation period with no further adjustment by which to examine the calibrated SWAT model with an independent observed dataset. Only sub basin 1 & 2 are considered in the validation process as the monitoring station is located in the Upper Medway Creek, as shown in Figure 24. Daily stream flow, total phosphorus and total nitrogen are simulated at the Observatory station under the current conditions of the watershed as shown in Figures 26, 27, 28 and 29.

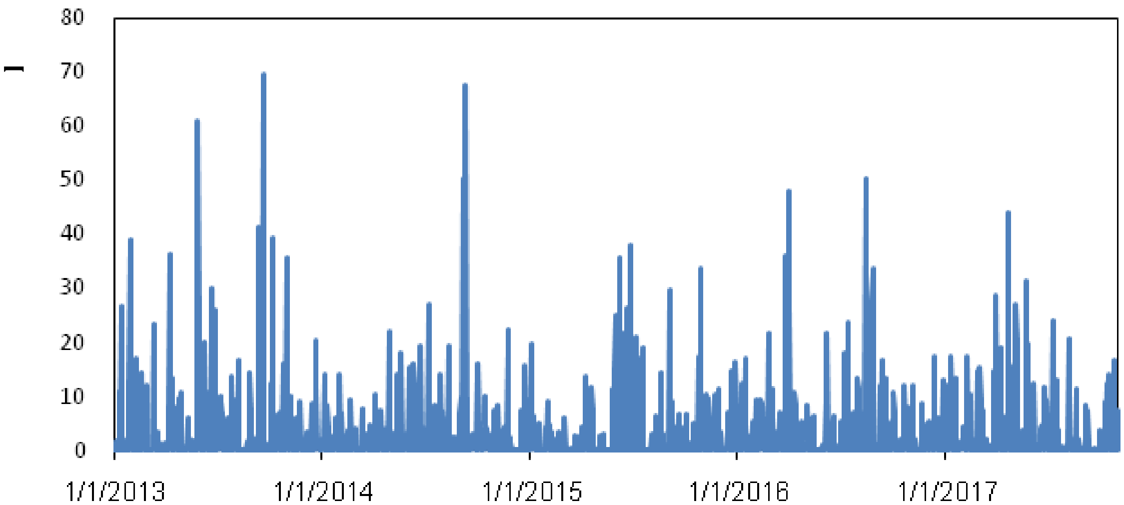


Figure 25: Daily precipitation (mm). source London Int' Airport station)

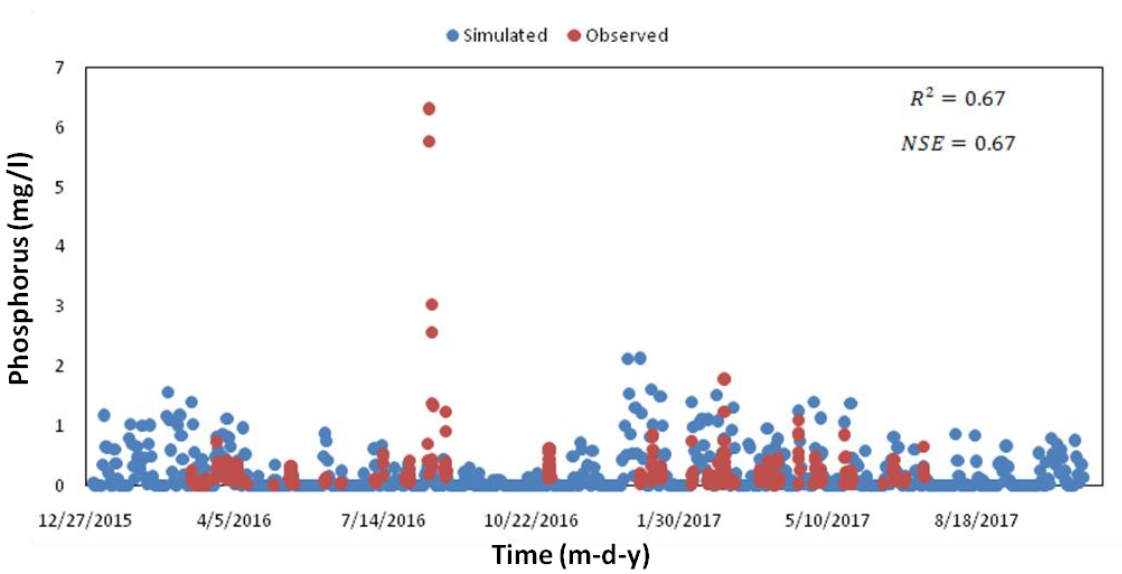


Figure 26: Daily TP simulation for the Upper Medway Creek (at observatory station)

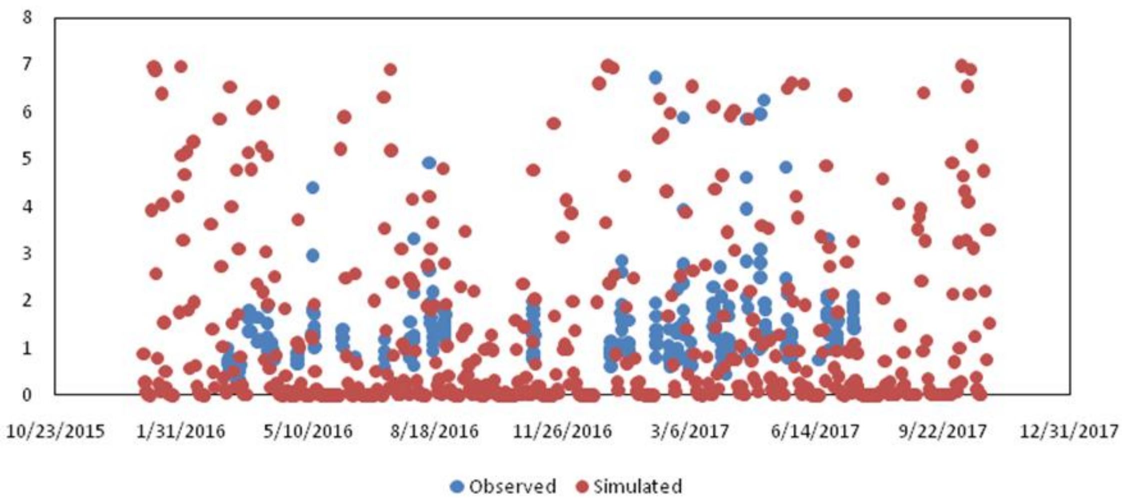


Figure 27: Daily total Nitrogen simulation (at observatory station)

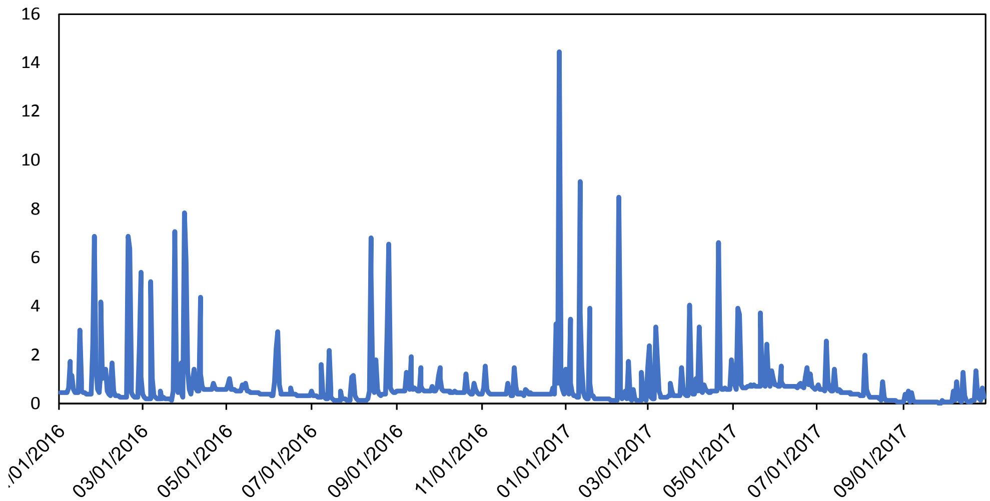


Figure 28: daily stream flow simulation at Medway creek watershed outlet

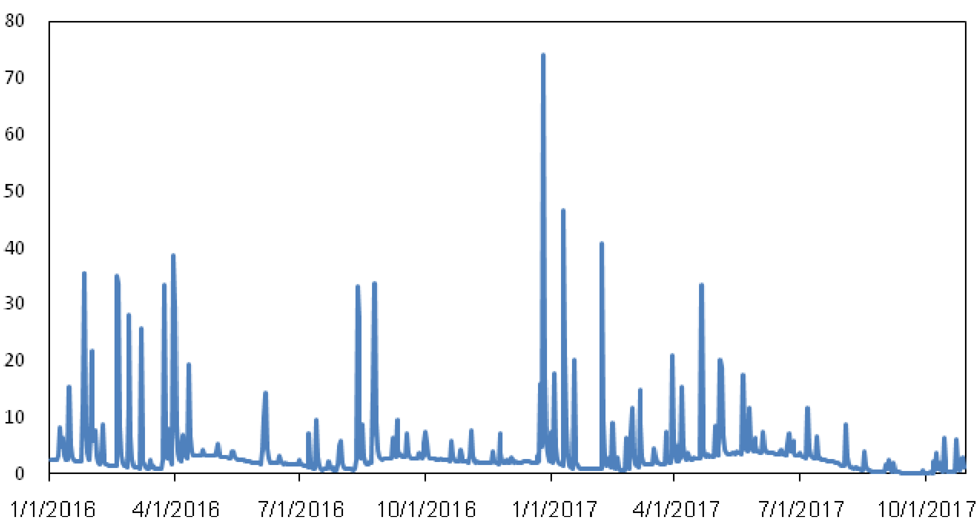


Figure 29: daily stream flow simulation at Observatory station

Figure 26 reveals the obvious agreement between simulated TP and observed data with more than 80% observed data captured.TP reaches the highest values in the high precipitation event to illustrate the dependence of phosphorus on flow. However, total nitrogen simulation in Figure 27 was underestimated with low agreement with the observed values, demonstrating the limitation of not including all nitrogen processes that occur in the watershed. Moreover, there is no monitoring data for daily flow to validate the simulated stream flow in Medway Creek as shown in Figures 28 and 29. The stream flow reaches the highest level in the winter of 2017 with an average of 3.87 (m^3/s) at the watershed outlet. The average monthly TP was 0.94 mg/Land the average TN was 1.46 mg/L in the simulation period at the watershed outlet.

The model has been validated at sub-basin 4, where the UTRCA monitoring station is located (Observatory Drive). The model demonstrated excellent results in TP simulations as shown in Figure 26; however, SWAT was not able to simulate the daily total nitrogen, as shown in Figure 27.

Due to the influence of sediments in the nutrient flux, sediments parameters have a large impact on the nutrients; therefore they are incorporated into the calibration processes. The average sediments yield in the watershed before entering the stream was 0.44 T/ha/yr.

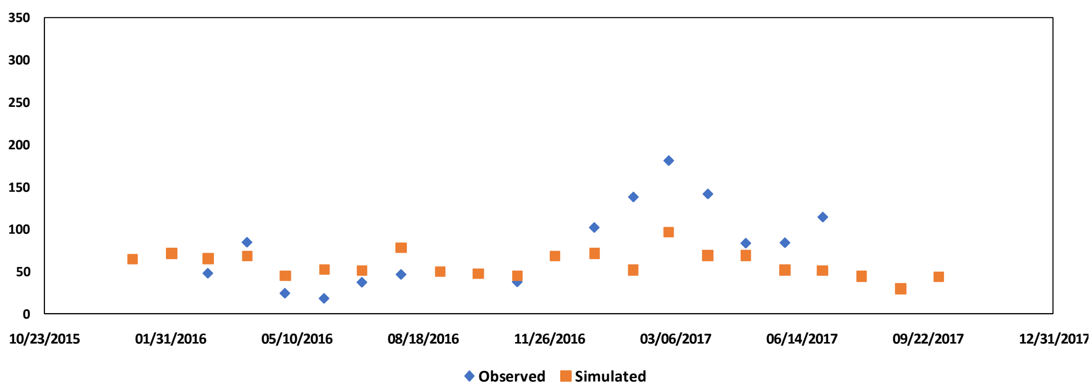


Figure 30: Average monthly TSS (mg/L) simulation at observatory station

Name	Yield/ha	The entire watershed	Note
Sediments	0.44 metric T/ha	9020 T	Total sediments
PP	4.51 kg /ha	92,455 kg	particulate P
DP	0.97 kg /ha	19,885 kg	dissolved P
TP	5.48 kg /ha	112,340 kg	Total P
PN	6.97 kg /ha	142,885 kg	particulate N
DN	1.63 kg /ha	33,415 kg	dissolved N
TN	8.60 kg /ha	176,300 kg	Total N

Table 12: Simulated average yearly sediment, TP and TN Yield at the watershed outlet in 2016 and 2017

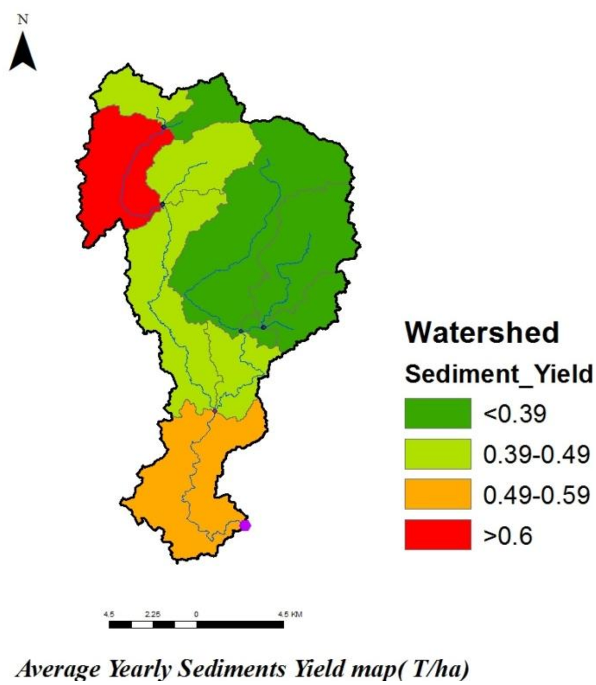


Figure 31: average yearly sediments T/ha in the Medway Creek watershed

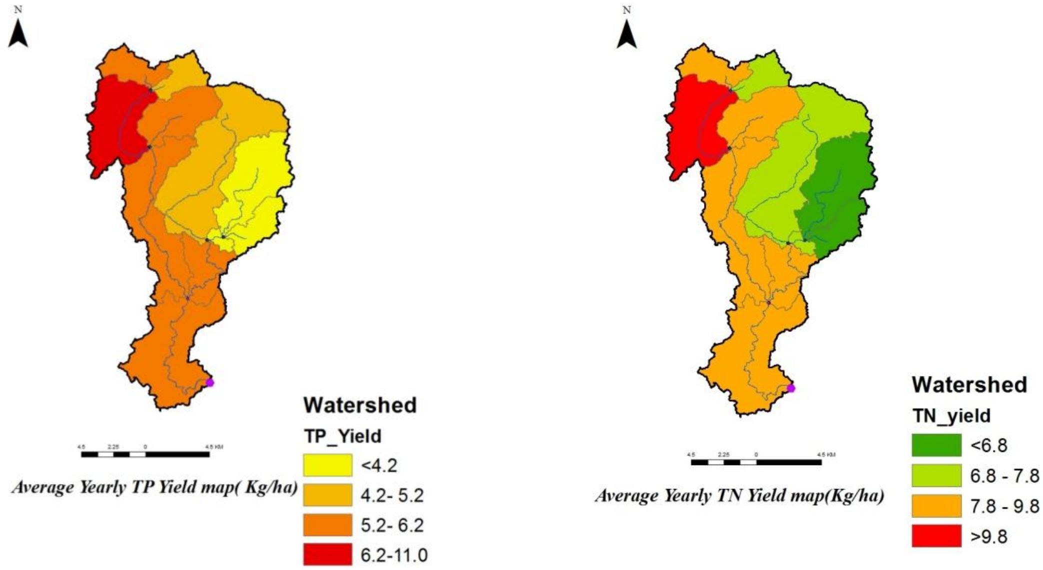


Figure 32: Average yearly TP, TN (kg/ha) in Medway Creek watershed

SWAT estimated the average sediments, TP, and TN yield at sub-basin levels as shown in Figures 31 and 32. At the watershed outlet, the average yearly TP loading was 112,340 kg combined in particulate and dissolved forms. The average yearly TN loading was 176,300 kg.

4. Future scenarios for Medway Creek Watershed

In this part, the calibrated and validated SWAT model is used to simulate how future land use scenarios influence the discharge and phosphors flux in the Medway Creek watershed. As mentioned in the introduction, land use and water quality have a strong relationship that needs to be understood and examined to predict possible impacts of future land use on water quality. This chapter attempts to apply the calibrated and validated SWAT model to predict and examine the hydrological influence of projected land use scenarios on discharge and total phosphorus. RCP 8.5 and A1B scenarios were considered for the period of 2019 to 2040 with three years of warm up to investigate the land use and climate scenario implications compared to the current conditions of the Medway Creek watershed. The analysis assumes that the watershed population will keep growing at a constant rate, which will result in the conversion of hay/pastures to urban areas. Also, grassing areas would be converted to pastures with forested land maintained.

This land use conversion scenario is based on the conversion trend in southern Ontario, which is converting from high to low agriculture with growths in population. Hay and pastures will convert to urban areas in the south part of the watershed as the population expands in that area. The grass land will turn into pastures as shown in Table 13.

N	Initial Land Use	Predicted land use	Year
1	%100 Hay	Urban	2020
2	% 100 Pasture	Urban	2020
3	%100 Grass land	Pasture	2020

Table 13: Land use conversion scenarios in the period 2019 to 2039

Climate data

RCP 8.5 and A1B scenarios have been applied in this study to investigate the effect of different future climate scenarios on stream flow and phosphorus. The climate data were obtained from Ontario Climate Change Data portal for the period of 2019 to 2040 and the data were prepared as inputs in the SWAT format. RCP 8.5 represents high climate change impact scenarios driven by boundary conditions from CanESM2 and assuming no policies will be implemented in the future to reduce greenhouse gases, whereas A1B is similar to RCP 6.0, which represents limiting of greenhouse emissions by applying climate change policies (Moss et al., 2010). CanESM2 which stands for Canadian Earth System Model is the combination of the Fourth Generation Atmospheric General Circulation Model and the Canadian Terrestrial Ecosystem Model (CTEM) (Arora and Boer, 2010; Chylek et al.,2011) See Appendix B.

Land Operations

Recently, the Medway Creek watershed has improved its land management by working to implement best management practices (BMPs) for the majority of farms; however, today more management practices have been applied, especially in the upstream, with supervision by UTRCA under the Upper Medway Priority Sub-watershed Project, which is funded through GLASI (Great Lakes Agricultural Stewardship Initiative). BMPs have had a positive impact on the Medway Creek Watershed and have reduced the sediments and total phosphorus flux to the stream. Due to the lack of information about the projected land management plan and the future BMPs in the watershed, the model has been tested under the existing land management conditions.

The calibrated/validated model was run at monthly intervals to simulate the impact of future land use on discharge and nutrients for two different climate scenarios. Discharge, TP, and TN were simulated at sub-basin levels in both scenarios.

4.1 Results of RCP 8.5 scenario

After applying the land use scenario shown in Table 13 and the climate data for the RCP 8.5 climate scenario (see Appendix B), SWAT was able to predict stream flow as well as the amount of nutrients exported to the stream. Figure 33 shows the predicted stream flow of Medway Creek at the watershed outlet for the period of 2022 to 2040.

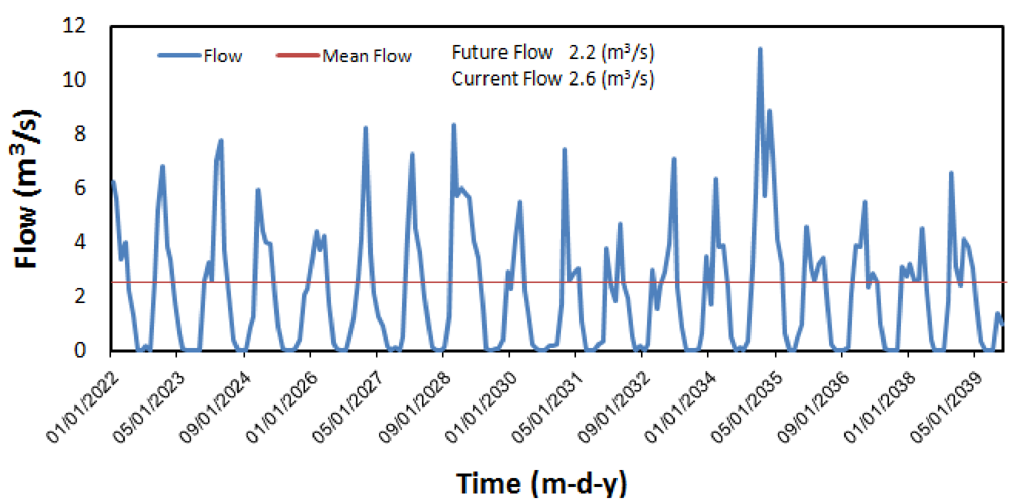


Figure 33: Predicted stream flow for RCP 8.5 scenario at Medway Creek outlet

The average stream flow under RCP8.5 is 2.2 (m^3/s) and it reaches 11.2 (m^3/s) in the beginning of 2035. Compared to the current average of Medway Creek (2.6 m^3/s), there is a slight decrease in the stream flow. Figures 34 and 35 demonstrate the future change in stream flow and TP due to the change in land use and climate in the period of 2022 to 2040. The estimated average TP in the stream at the watershed outlet is 0.85 mg/L in the eighteen-year simulation period, and it is close to the current conditions of Medway Creek. The estimated average monthly TN at the watershed outlet is 2.37 mg/L in the period of 2022 to 2040.

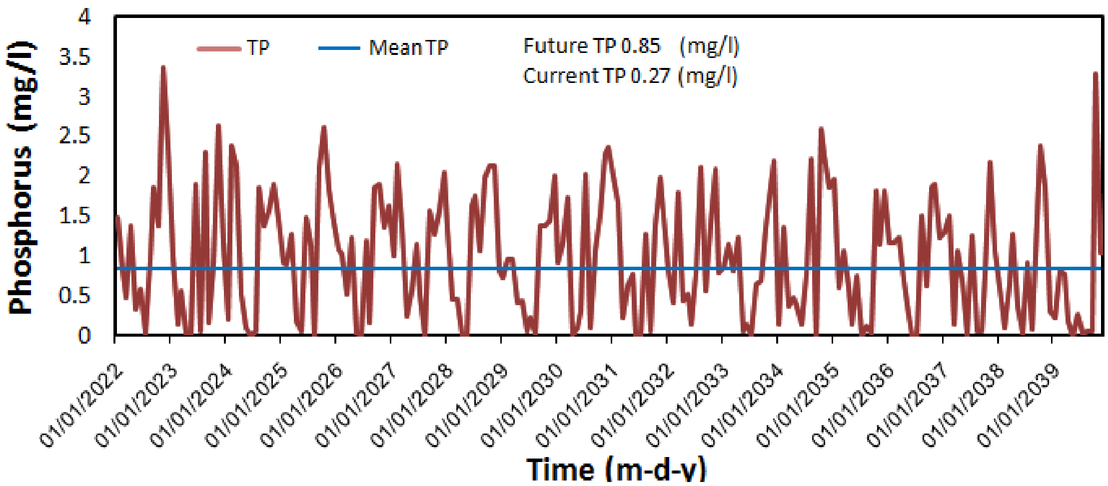


Figure 34: Predicted TP under RCP 8.5 scenario at Medway Creek outlet

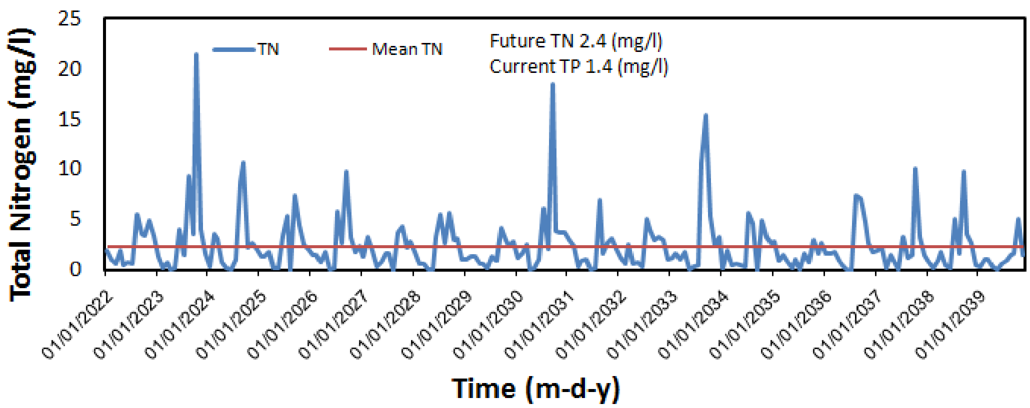


Figure 35: Predicted TN under RCP 8.5 scenario at Medway Creek outlet

Name	Yield/ha	The entire watershed	Note
Sediments	1.04 metric T/ha	21,320 T	Total sediments
TP	6.3 kg /ha	129,150 kg	Total P
TN	9.27 kg /ha	190,035 kg	Total N

Table 14: Simulated average yearly sediment, TP,and TN Yield at the watershed outlet in the period 2022-&2040 under RCP 8.5

Under RCP8.5 climate scenario, there is 15% increase in TP yield and 7.8% in TN yield, compared to the current condition in the Medway Creek watershed.

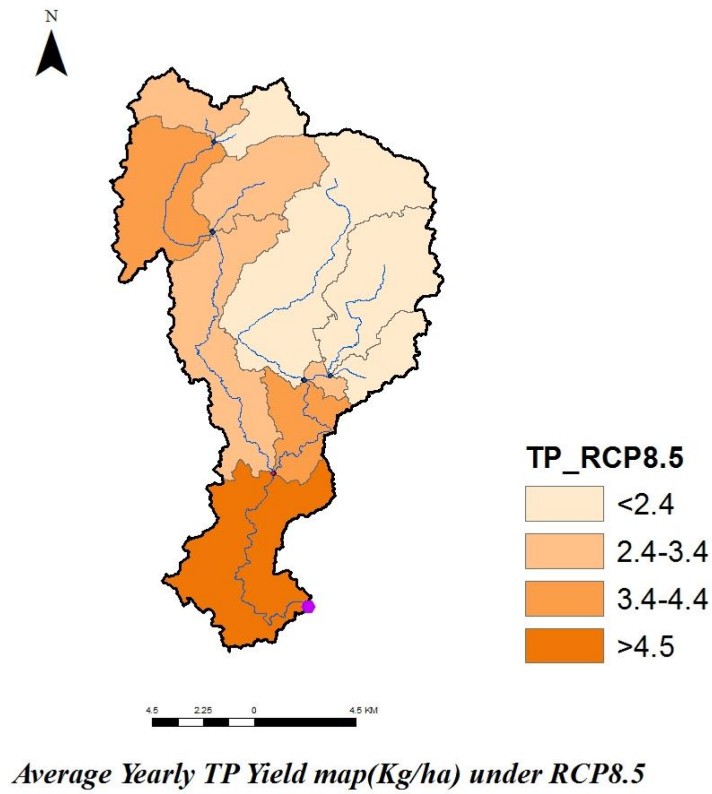


Figure 36: average yearly TP kg/ha in the Medway Creek watershed under RCP8.5 scenario

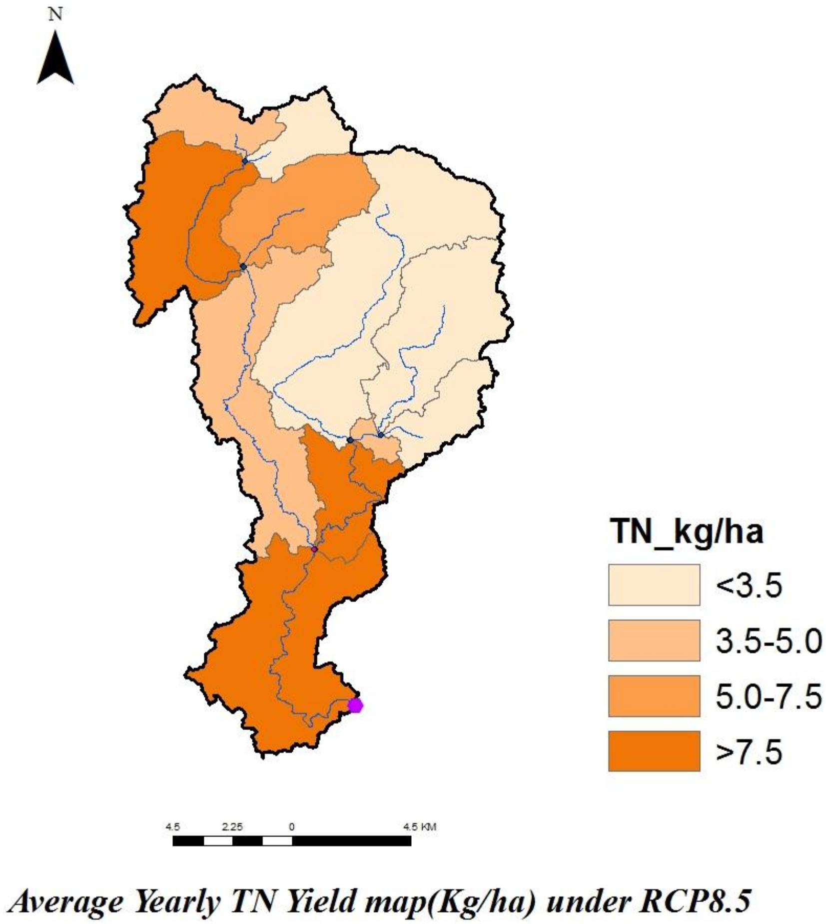


Figure 37: average yearly TN kg/ha in the Medway Creek watershed under RCP8.5 scenario

4.2 A1B scenario Results

Using precipitation and temperature data in the A1B scenario, SWAT simulated different water resource components, as shown in Figures 38 and 39. Sediment and nutrient fluxes were simulated at sub-basin level for the period 2022 to 2040 to examine the impact of projected land use and A1B climate scenario on water quality and quantity.

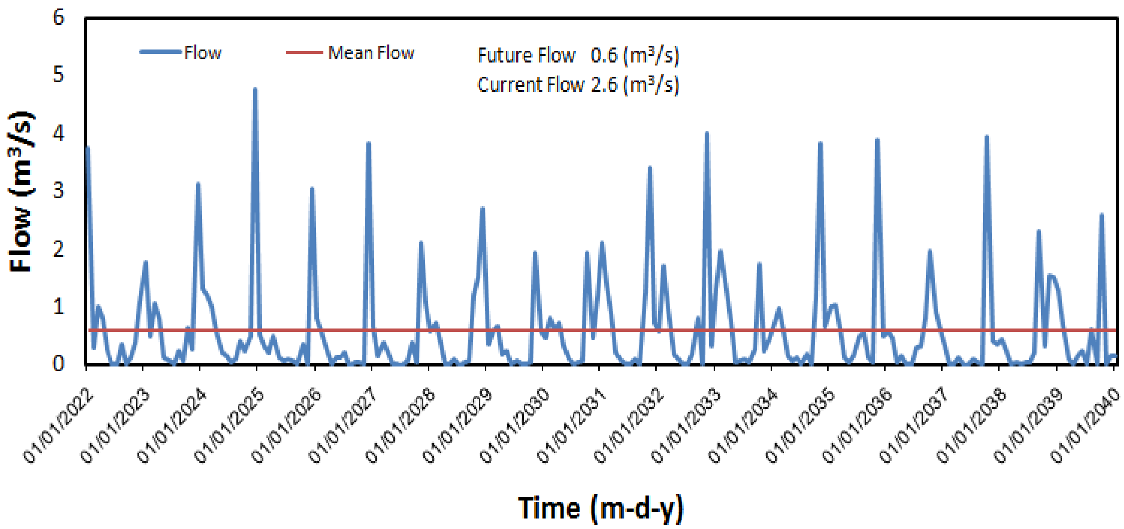


Figure 38: Predicted stream flow under A1B scenario at Medway Creek outlet

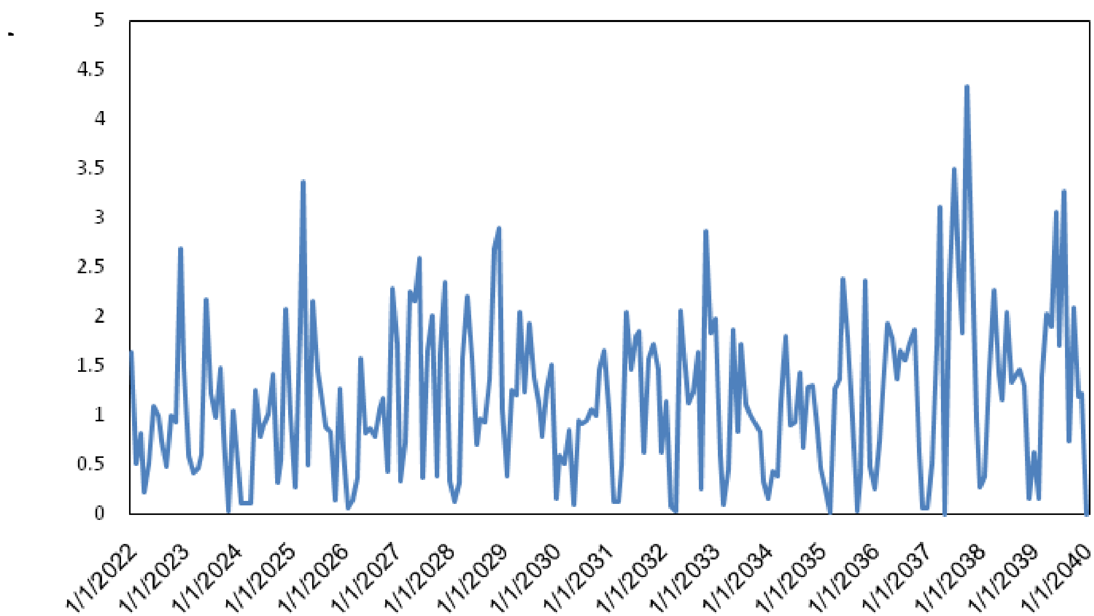


Figure 39: Predicted TP under A1B scenario at Medway Creek outlet

The average monthly flow in the simulation period is 0.6 (m^3/s). The average yearly TP yield is 26,240 kg (1.28 kg/ha) which is lower than the current condition of the watershed. The results for A1B climate scenario show remarkable reduction in nutrients flux in the Medway Creek watershed.

Name	Yield/ha	The entire watershed	Note
Sediments	0.12 metric T/ha	2460 T	Total sediments
TP	1.28 kg /ha	26,240 kg	Total P
TN	3.03 kg /ha	62,115 kg	Total N

Table 15: Simulated average yearly sediment, TP, and TN Yields at the watershed outlet in the period 2022-2040 under A1B climate scenario.

The drop in nutrient flux is most likely results from the conversion of high agricultural land to low agricultural land, which reduces the non point source of nutrients that could impact Medway Creek by exporting high levels of phosphorus and nitrogen. Moreover, the low emission scenario causes low stream flow which results in reduced sediments yields.

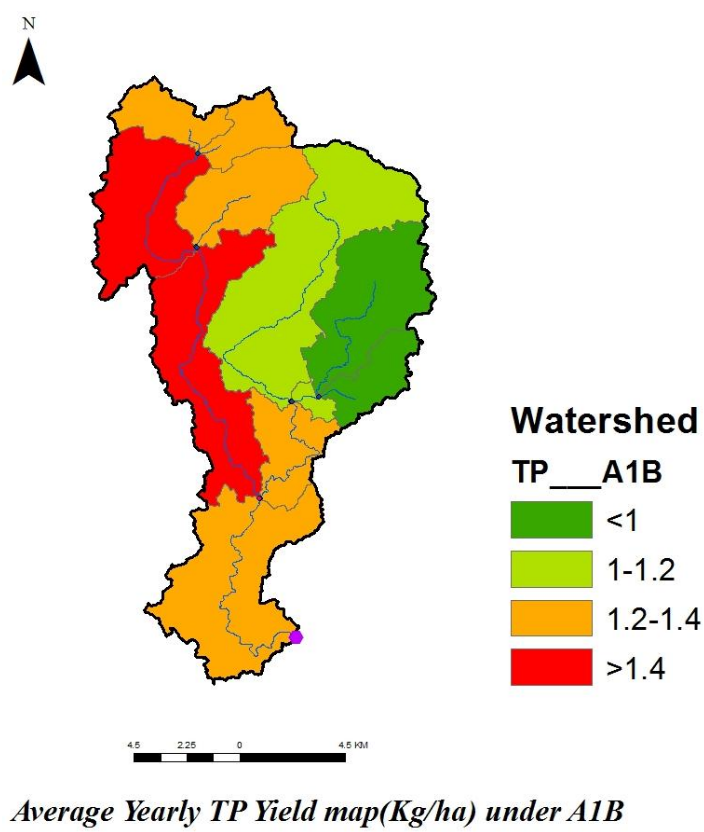
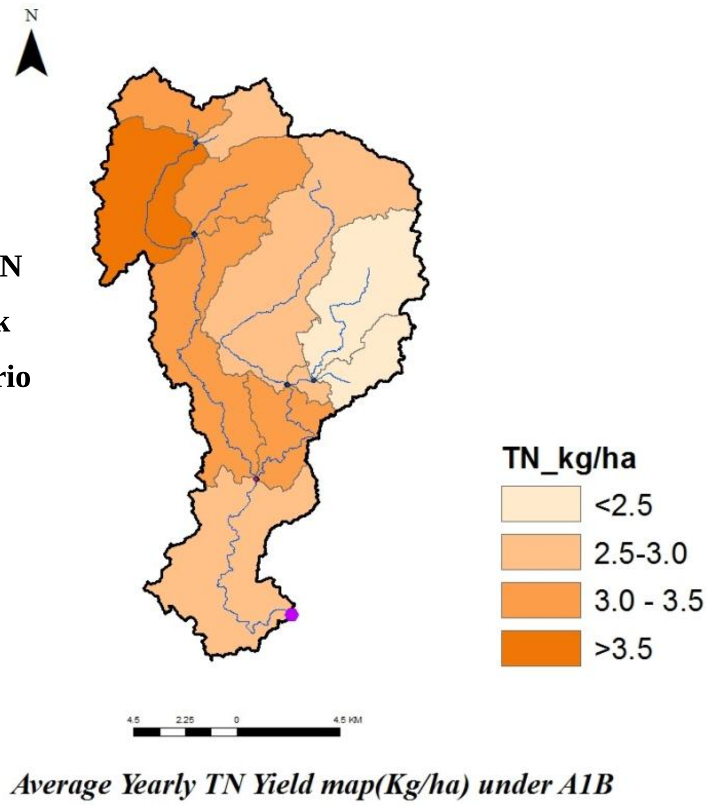


Figure 40: average yearly TP kg/ha in the Medway Creek watershed under A1B climate scenario

Figure 41: average yearly TN kg/ha in the Medway Creek watershed under A1B scenario



5. Discussion

The SWAT model performed successfully in the present study after the incorporation of SWAT-CUP to model the Medway Creek watershed. According to the default model results, SWAT requires a calibration process in order to achieve the best representation of the watershed. Calculated R^2 and NSE values were excellent in flow calibrations, and this indicates the high efficiency of SUFI-2 in calibrating the flow. Moreover, groundwater, snow, and CN2 parameters were found to be the most sensitive in the Medway Creek flow calibration as groundwater contributed an appreciable percentage of the Medway Creek stream flow; however SWAT does not count the groundwater contribution of dissolved P to the stream TP as it is not considered as prime source of phosphorus (White et al.,2014). Sediments and soil characteristics were key to the nutrient export simulation. SWAT must contend with hundreds of parameters, but the calibration model requires a strong background in the actual hydrological process that occurs in the watershed to determine certain parameters that need to be adjusted.

In the daily validation of the period of 2016 to 2017, the calibrated SWAT model captured most of the daily UTRCA observed data in the TP simulation with no further adjustment, indicating the effectiveness and the importance of the calibration to improve the SWAT model's performance. SWAT estimated the average yearly sediments and TP and TN Yield at the sub basin level. The highest TP and TN yields were in the same location as highest sediments yield. Sub basin 4 has the highest level of nutrient yield due to the high slope in that sub basin along with the extensive agricultural land in the sub-basin, which is mostly corn. The Medway Creek Watershed exports an average of 112,340 kg of TP and176, 300 kg of TN annually, both of which are as high as what Nurnberg estimated in her water Quality assessment of the Thames River Watershed (Nürnberg & Lazerte, 2015). The average TP in the stream at the watershed outlet in the period 2016 2017 is 0.9 mg/L which is quite high compared to the Ontario Guideline (0.03 mg/L). Moreover, 82.3% of the phosphorus yield is in particulate form, whereas 81% of the nitrogen is particulate.The only explanation for the high TP is the fertilizer application rates that are applied in the most agricultural areas in the Medway Creek watershed. In addition, land management practices have an impact on surface water through conventional tillage practices that increase the sediments yield. The average simulated TSS is 58.7 mg/L at the watershed outlet, whereas Nurnberg estimated the average TSS of 77mg/l at the watershed outlet. High loads od TP And TN in Medway Creek that are delivered every year to the Thames River come mostly from the western part of the Medway Creek watershed, including sub basins 1, 2, 4, 9, and 11. Therefore, enhancement strategies are needed in these sub basins to reduce loads that export to surface water.

In future scenarios involving climate and land use, the calibrated/validated model has estimated the nutrients flux for each scenario with increases in nutrient levels in RCP8.5 by 15% in the TP simulation and 7.8% in the TN prediction. However, SWAT predicts a large reduction in nutrient yield under the A1B climate scenario by more than 50% in TP and TN yields. Phosphorus is extremely dependent on stream flow; therefore, a high concentration of TP, usually at the beginning of the year, is associated with snow melting. The RCP8.5 climate scenario results show the conditions of future water quality, if no climate and land management policies have been applied, which will result in significant increases in nutrient yields in the watershed. On the other hand, the A1B scenario presented notable reductions in nutrients as well as sediments at the watershed outlet.

5.1 Monitoring data and their impact on model performance

One of the main issues that complicate the hydrologist's job in terms of modeling water quantity and quality is the scarcity of high frequency data for soil nutrients, surface water quality, ground water, fertilizer records, solar radiation, and climate data. Hydrological models rely on the availability of data to successfully perform the simulation, which requires accurate high frequency data to simulate the key hydrologic processes that occur in the watershed and obtain reliable results. Moreover, the more detailed the data used for building the model, the better the representation of the actual conditions of the watershed.

With regards to the data collection step, there is no doubt that many surface water systems in Canada have ineffective monitoring systems and low frequency historical data. The Medway Creek watershed has two monitoring systems that are considered low frequency data monitoring as they only take samples after storm events, so there is a huge gap for modelers in modeling the watershed. The City of London samples Medway Creek at Windermere station monthly to measure water chemistry and flow. However, this monitoring usually starts from early spring to the end of the year, and ignores the most important period, the snow melting period, when the TP concentration increases to reach its highest levels. COL is the only source for long-term monitoring data for Medway creek. UTRCA monitors the Medway creek upstream through the Priority Sub Watershed Project; however, this project started in Feb 2016, and does not provide long-term data for the Medway Creek simulation. The Priority Sub Watershed Project currently focuses on applying BMPs in the Upper Medway Creek watershed to see how they would impact the water quality in the stream.

Fertilizer is applied in the Medway Creek watershed without records, even though it is the main driver of nutrients in the stream. The Medway Creek watershed is an agricultural watershed that produces several crops annually. Artificial fertilizers are needed in most agricultural areas in the watershed. Therefore, synthetic fertilizer application records would be essential in water quality modelling to calculate nutrient yields that are exported from the agricultural land to the streams.

Soil nutrient properties in the Medway Creek watershed are mostly unknown, including soil P level, organic matter content, which affects crop yield, as well as the TP export. Soil samples are needed every so often to measure soil nutrient levels and P loss from agricultural areas. Runoff and sediments are keys to P loss from non-point sources that are not measured in the Medway creek watershed. There is scarcity of data on sediments and runoff in the watershed, which was one of the reasons for simulating these components.

Climate data are not measured within the watershed boundaries, which required using the nearby station with long term climate data. The model would have performed better if the watershed was gauged because using weather data outside of the watershed was not the most desired option and would have negatively impacted the results.

6. Conclusions and recommendations

A hydrology and phosphorus model was built for the Medway Creek watershed in southwestern Ontario using SWAT and SWAT-CUP. SWAT analyzed the current concerns of high nutrient levels in Medway Creek by simulating the nutrient flux at the sub-basin level and estimating the sediments, TP, and TN yields. The model results were found to be satisfactory to very good based on model evaluation. The model was run from 1989 to 1999 with three years warm up and was calibrated using COL observed at the watershed outlet. Different strategies were used in the calibration process to efficiently adjust SWAT parameters to improve SWAT prediction. The calibration processes improved SWAT performance to capture more than 80% of observed data. SWAT-CUP ran over 2000 times to analyze the model uncertainty and achieve the best range of sensitive parameters. R^2 and NSE were used to evaluate the model and the respective values of 0.85 and 0.65 were obtained during the calibration process.

The calibrated SWAT model was successfully validated using an independent daily observed dataset for the period of January 2016 to October 2017. The daily observed data on water chemistry was obtained from the UTRCA monitoring station on Observatory Drive. A high percentage of daily observed data captured by the calibrated SWAT model and average yearly nutrient yield were estimated at the watershed outlet. Large quantities of nutrients are exported to the Thames River every year and were estimated by SWAT to reach 5.48 kg/ha of TP and 8.60 kg/ha of TN. Sediment yields were calculated at the sub-basin level to reach 0.44 T/ha and 9020 T for the entire watershed.

Land use and climate scenarios were set up for the calibrated/validated model to investigate the impact of these scenarios on water quantity and quality. A high increase in TP and TN in RCP 8.5 was observed, compared to an obvious reduction in nutrient levels in the A1B scenario. A TP load of 6.3 kg/ha was estimated under RCP8.5 while a value of s 1.28 kg/ha was estimated under the A1B scenario. A TN load of 9.27 kg/ha was predicted in RCP8.5 in contrast to TN, which was as low as 3.03kg/ha under the A1B scenario. The conversion of Agricultural land to urban land slightly reduced the nutrients flux at the watershed outlet. The model results could be used as an essential tool for decision makers to take actions towards the high yields of nutrients in the watershed and focus on the critical sub basins that export most of the phosphorus and nitrogen loads into Medway Creek. Moreover, this model identified the high sediments and nutrients fields that require BMPs to efficiently reduce the nutrients loads and improve the health of Medway Creek.

6.1 Recommendations

The research has highlighted a number of areas that require further studies and management. Based on the results, the following are recommended:

1. Monitor nutrients concentrations continually along Medway Creek to track the increase in nutrient levels in the stream and improve land management accordingly.

2. Monitor sediment characteristics and load moving into Medway Creek watershed to help determine the source of sediments exported to the stream.
3. Record application rates of either manure or artificial fertilizer in the watershed by surveying all farms to obtain a reliable estimate of total N and P applied to land.
4. Sample soil every so often to measure soil nutrient and examine the loss of phosphorus by runoff.
5. Monitor climatic conditions and trends in the watershed, including precipitation, solar radiation, wind speed, evapotranspiration, etc., to accurately model water resource components in the watershed.
6. Monitor stream flow in Medway Creek effectively and frequently to capture flow fluctuations over the year.
7. High TSS results in the model requiring an intense water quality system at the upstream and downstream locations. Monitoring is needed to help decision makers apply different strategies in the high TSS areas.
8. Install automated water quality stations along Medway Creek, instead of random sampling systems, to provide water chemistry changes during the year.
9. Monitor TP and TN loads in the upstream section (sub basin 4) of the Creek. High loads would require different actions, including regulating applied fertilizer loads, in that area and reducing sediment yields. It would also be necessary to monitor all management practices that occur in that area closely.
10. Medway Creek watershed is an extensive agricultural Watershed that forms a non-point source of pollution for surface water. It is therefore necessary to take steps to reduce the impact of this diffuse source on water quality.
11. Reduce the conventional tillage system in the watershed, especially in sub-basin 4, and implement in-field erosion control structures in order to minimize sediment yields.
12. Involve the public in the monitoring programs system by recording all the management practices that they apply on the land as well as increase their awareness of the consequences of these practices.

13. Improve the public consultations in the Medway Creek watershed to increase the public engagement in important initiatives that lead to enhance the water and land management in the watershed.

6.2 Future Work

After investigating the nutrient sources and modeling the nutrients flux in the Medway Creek watershed, extensive work is required to investigate the same issue in Lake Erie as it suffers from eutrophication. One of the SWAT model's advantages is that the model can be transferred to other similar watershed with the same characteristics. Therefore, a calibrated /validated SWAT model is able to be transferred to other watersheds, by re-characterizing the watershed conditions.

In order to reduce the accelerated eutrophication in Medway Creek particularly, and in the Great Lakes generally, long term and efficient monitoring projects are presently necessary to improve the performance of similar models in southwestern Ontario. A daily monitoring project is required at Medway Creek's downstream location to analyze the impact of BMPs on water quality.

Medway Creek Priority Sub watershed Project that is applying BMPs in the Medway Creek watershed requires a high performance modeling to examine the future impact of applied BMPs on the water quality. In addition, multiple scenarios are needed to determine the cost efficient practices and the suitable places for BMPs.

6.3 References

Abbaspour, K. C. (2014). SWAT-CUP 2012: SWAT Calibration and Uncertainty Programs - A User Manual. Science And Technology, 106. https://doi.org/10.1007/s00402-009-1032-4

Abbaspour, K. C., Rouholahnejad, E., Vaghefi, S., Srinivasan, R., Yang, H., & Kløve, B. (2015). A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. Journal of Hydrology, 524, 733–752. https://doi.org/10.1016/j.jhydrol.2015.03.027

Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., … Srinivasan, R. (2007). Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. Journal of Hydrology, 333(2–4), 413–430. https://doi.org/10.1016/j.jhydrol.2006.09.014

Alexander, R. B., Smith, R. A., Schwarz, G. E., Boyer, E. W., Nolan, J. V., & Brakebill, J. W. (2008). Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi river basin. Environmental Science & Technology, 42(3), 822-830. doi: 10.1021/es0716103

Arora, V. K., & Boer, G. J. (2010). Uncertainties in the 20th century carbon budget associated with land use change. Global Change Biology, 16(12), 3327-3348.

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., … Jha, M. K. (2012). Swat: Model Use, Calibration, and Validation. Asabe, 55(4), 1491–1508. https://doi.org/ISSN 2151-0032

Asadzadeh, M., Leon, L., McCrimmon, C., Yang, W., Liu, Y., Wong, I., … Bowen, G. (2015). Watershed derived nutrients for Lake Ontario inflows: Model calibration considering typical land operations in Southern Ontario. Journal of Great Lakes Research, 41(4), 1037–1051. https://doi.org/10.1016/j.jglr.2015.09.002

Baker, A. (2003). Land Use and Water Quality. Hydrological Processes, 17, 2499-2501.

DOI: 10:1002/hyp.5140 Baker, D. (1985). Regional water-quality impacts of intensive row-crop agriculture - A Lake Erie basin case-study. Journal of Soil and Water Conservation, 40(1), 125-132.

Baker, T. J., & Miller, S. N. (2013). Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed. Journal of Hydrology, 486, 100–111. https://doi.org/10.1016/j.jhydrol.2013.01.041

Barton, D. R. & Farmer (1997). The effects of conservation tillage practices on benthic invertebrate communities in headwater streams in southwestern Ontario, Canada. Environmental Pollution, 96: 2, 207–215

Brown, L. C., & Barnwell, T. O. (1987). The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: Documentation and user manual (p. 189). US Environmental Protection Agency. Office of Research and Development. Environmental Research Laboratory.

Carpenter, S. R., Caraco, N. F., Correll, D. L., W.Howarth, R., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, 8(1998), 559–568. https://doi.org/10.1890/1051-0761(1998)008[0559:NPOSWW]2.0.CO;2

Canale, R. P., Hineman, D. F., & Nachiappan, S. (1974). A biological production model for Grand Traverse Bay. University of Michigan.

Chandler, D. G. (2006). Reversibility of forest conversion impacts on water budgets in tropical karst terrain. Forest Ecology and Management, 224(1–2), 95–103. https://doi.org/10.1016/j.foreco.2005.12.010

Chapra, S. C. (2008). Surface water-quality modeling. Waveland press.

Chylek, P., Li, J., Dubey, M. K., Wang, M., & Lesins, G. (2011). Observed and model simulated 20th century Arctic temperature variability: Canadian earth system model CanESM2. Atmospheric Chemistry and Physics Discussions, (8), 22893-22907.

Conley, D. J., Paerl, H. W., Howarth, R. W., Boesch, D. F., Seitzinger, S. P., Havens, K. E., … Likens, G. E. (2009). ECOLOGY: Controlling Eutrophication: Nitrogen and Phosphorus. Science, 323(5917), 1014–1015. https://doi.org/10.1126/science.1167755

Douglas-Mankin, K. R., Srinivasan, R., & Arnold, J. G. (2010). Soil and Water Assessment Tool (SWAT) model: Current developments and applications. Transactions of the ASABE, 53(5), 1423-1431.

El-Khoury, A., Seidou, O., Lapen, D. R. L., Que, Z., Mohammadian, M., Sunohara, M., & Bahram, D. (2015). Combined impacts of future climate and land use changes on discharge, nitrogen and phosphorus loads for a Canadian river basin. Journal of EnvironmentalManagement(Vol.151).ElsevierLtd. https://doi.org/10.1016/j.jenvman.2014.12.012

Enviromental Protection Agency.(2017).Nutrient Polution.retrieved from https://www.epa.gov/nutrientpollution/problem

Gassman, P. W., Reyes, M. R., Green, C. H., & Arnold, J. G. (2007). The soil and water assessment tool: historical development, applications, and future research directions. Transactions of the ASABE, 50(4), 1211-1250.

Houser, J. N. & Richardson, W. B. (2010). Nitrogen and phosphorus in the upper Mississippi river: Transport, processing, and effects on the river ecosystem. Hydrobiologia, 640(1), 71-88. doi: 10.1007/s10750-009-0067-4

Hynes, H. B. N. (1975). Edgardo Baldi memorial lecture. The stream and its valley. Verhandlungen der Internationalen Vereinigung fur theoretische und angewandte Limnologie, 19, 1-15.

Johnson, L.B., Richards, C., Host, G. & Arthur, J.W. (1997). Landscape influences on water chemistry in Midwestern stream ecosystems. Freshwater Biology, 37(1), 193-208. doi: 10.1046/j.1365-2427.1997.d01-539

Jorgensen, J. R., Wells, C. G., & Metz, L. J. (1980). Nutrient changes in decomposing loblolly pine forest floor. Soil Science Society of America Journal, 44(6), 1307-1314.

Kemanian, A. R., Julich, S., Manoranjan, V. S., & Arnold, J. R. (2011). Integrating soil carbon cycling with that of nitrogen and phosphorus in the watershed model SWAT: theory and model testing. Ecological modelling, 222(12), 1913-1921.

Koivo, A. J., & Phillips, G. (1976). Optimal estimation of DO, BOD, and stream parameters using a dynamic discrete time model. Water Resources Research, 12(4), 705-711.

Lazor, R. L. (2014). Land use interactions drive southwestern Ontario stream nutrient concentrations.

Leon, L. F., Booty, W. G., Bowen, G. S., & Lam, D. C. L. (2004). Validation of an agricultural non-point source model in a watershed in southern Ontario. Agricultural Water Management, 65(1), 59-75.

Mehaffey, M. H., Nash, M. S., Wade, T. G., Ebert, D. W., Jones, K. B., & Rager, A. (2005). Linking land cover and water quality in New York City's water supply watersheds. Environmental monitoring and assessment, 107(1-3), 29-44.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Binger, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50(3), 885–900. https://doi.org/10.13031/2013.23153

Nasr, A., Bruen, M., Jordan, P., Moles, R., Kiely, G., & Byrne, P. (2007). A comparison of SWAT, HSPF and SHETRAN/GOPC for modelling phosphorus export from three catchments in Ireland. Water Research, 41(5), 1065-1073.

Natural Resources Conservation Service.(2007).SPAW Hydrology and Water Budgeting.retrievedfrom https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/drainage/?cid=stelprdb1045331

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., & King, K. W. (2005). Soil and water assessment tool theoretical documentation. Grassland. Soil and Water Research Laboratory, Temple, TX.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2011). Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute.

Nürnberg, G., & Lazerte, B. (2015). Water Quality Assessment in the Thames River Watershed - Nutrient and Sediment Sources, (March), 95.

Nyeko, M. (2015). Hydrologic Modelling of Data Scarce Basin with SWAT Model: Capabilities and Limitations. Water Resources Management, 29(1), 81–94. https://doi.org/10.1007/s11269-014-0828-3

Pollman, C. D., Landing, W. M., Perry, J. J., & Fitzpatrick, T. (2002). Wet deposition of phosphorus in Florida. Atmospheric Environment, 36(14), 2309-2318.

Radcliffe, D.E., and M.L. Cabrera (ed.). Modeling phosphorus in the environment. CRC Press, Boca Raton, FL. Modeling phosphorus in the environment. CRC Press, Boca Raton, FL. 2007.

Saleh, A., & Du, B. (2004). Evaluation of SWAT and HSPF within BASINS program for the upper North Bosque River watershed in central Texas. Transactions of the ASAE, 47(4), 1039.

Savci, S. (2012). An agricultural pollutant: chemical fertilizer. International Journal of EnvironmentalScienceand.Retrievedfrom http://search.proquest.com/openview/d0a1967effb187e43367e3f46ae630d1/1?pq-origsite=gscholar&cbl=2027401

Schindler, D. W. (1971). Carbon, nitrogen, and phosphorus and the eutrophication of freshwater lakes. Journal of Phycology, 7(4), 321-329.

Schoonover, J. E., Lockaby, B. G., & Pan, S. (2005). Changes in chemical and physical propertiesof stream water across an urban-rural gradient in western Georgia. Urban Ecosystems, 8(1), 107-124.

Sharpley, A. N., Chapra, S. C., Wedepohl, R., Sims, J. T., Daniel, T. C., & Reddy, K. R. (1994). Managing agricultural phosphorus for protection of surface waters: Issues and options. Journal of environmental quality, 23(3), 437-451.

Sharpley, A. N., Kleinman, P. J. A., McDowell, R. W., Gitau, M., & Bryant, R. B. (2002). Modeling phosphorus transport in agricultural watersheds: processes and possibilities. Journal of Soil and Water Conservation, 57(6), 425+. Retrieved from http://go.galegroup.com/ps/i.do?p=AONE&sw=w&u=lond95336&v=2.1&it=r&id=GALE%7CA97218068&sid=summon&asid=b0a265df65270fd815a3d0bb2c50f3e5

Sliva, L. & Williams, D.D.(2001). Buffer zone versus whole catchment approaches to studying land use impact on river water quality. Water Resources, 35, 3462–3472.

Stutter, M. I., Langan, S. J., & Demars, B. O. L. (2007). River sediments provide a link between catchment pressures and ecological status in a mixed land use Scottish River system. Water Research, 41(12), 2803-2815.

Tong, S. T. Y., & Chen, W. (2001). Modeling the relationship between land use and surface water quality. New Zealand Journal of Marine and Freshwater Research, 66(1), 323–349. https://doi.org/10.1006/jema.2002.0593

Tu, J. (2011). Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. Applied Geography.Retrievedfrom http://www.sciencedirect.com/science/article/pii/S0143622810000846

Turner, M. G., & Gardner, R. H. (2001). Landscape Ecology in Theory and Practice.

White, M. J., Storm, D. E., Mittelstet, A., Busteed, P. R., Haggard, B. E., & Rossi, C. (2014). Development and testing of an in-stream phosphorus cycling model for the Soil and Water Assessment Tool. Journal of environmental quality, 43(1), 215-223.

Williamson, K., & McCarty, P. L. (1976). A model of substrate utilization by bacterial films. Journal (Water Pollution Control Federation), 9-24.

Woli, K. P., Nagumo, T., Kuramochi, K., & Hatano, R. (2004). Evaluating river water quality through land use analysis and N budget approaches in livestock farming areas. Science of the Total Environment, 329(1), 61-74.

Yang, W., Liu, Y., Simmons, J., Oginskyy, A., & McKague, K. (2013). SWAT Modelling of Agricultural BMPs and Analysis of BMP Cost Effectiveness in the Gully Creek Watershed. University of Guelph, Guelph, Ontario. xi.

Yates, A., Bailey, R., & Schwindt, J. (2006a). No-till cultivation improves stream ecosystem quality. Journal of Soil and Water Conservation, 61(1), 14-19.

Yates, A. G., Culp, J. M., & Chambers, P. A. (2012). Estimating nutrient production from human activities in subcatchments of the Red River, Manitoba. Journal of Great Lakes Research, 38, 106-114.

Young, R. A., Onstad, C. A., Bosch, D. D., & Anderson, W. P. (1989). AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. Journal of soil and water conservation, 44(2), 168-173.

Appendices

Appendix A

SWAT model's input data and observed data

- **Observed data for monthly simulation**

Observed data used in this study is obtained from two sources as mentioned in the data acquisition chapter. The city of London data that has been used in the monthly simulation is showing in Table A-1: -

DATA	FLOW cms	TP KG/m	TP mg/L	DATA	FLOW cms	TP KG/m	TP mg/L
01/01/1992	3.94	919.1232	0.09	01/01/1996	0.842	87.28	0.1
02/01/1992	8.83	5082.6	0.175	02/01/1996	1.138	117.96	0.15
03/01/1992	13.72	9246.182	0.26	03/01/1996	1.434	148.64	0.05
04/01/1992	1.78	138.4128	0.03	04/01/1996	1.73	179.3664	0.04
05/01/1992	1.23	227.835	0.105	05/01/1996	2.27	117.6768	0.02
06/01/1992	0.68	317.2608	0.18	06/01/1996	1.61	292.1184	0.07
07/01/1992	0.23	83.4624	0.14	07/01/1996	1.13	231.03	0.113
08/01/1992	5.21	1890.605	0.14	08/01/1996	0.67	169.94	0.156
09/01/1992	8.98	6921.418	0.095	09/01/1996	0.21	108.864	0.2
10/01/1992	0.75	97.2	0.05	10/01/1996	1	103.68	0.04
11/01/1992	18.14	6112.454	0.13	11/01/1996	1.94	150.8544	0.03
12/01/1992	3.24	42026.1	0.255	12/01/1996	4.81	623.376	0.05
01/01/1993	79.13	77939.88	0.38	01/01/1997	3.265	512.3	0.07
02/01/1993	2.7	1679.616	0.24	02/01/1997	1.72	401.2416	0.09
03/01/1993	1.77	1422.23	0.31	03/01/1997	9.45	979.776	0.04
04/01/1993	8.28	3219.264	0.15	04/01/1997	1.17	121.3056	0.04
05/01/1993	1.1	142.56	0.05	05/01/1997	10.13	1050.278	0.04
06/01/1993	0.58	165.3696	0.11	06/01/1997	0.73	75.6864	0.04
07/01/1993	0.68	299.6352	0.17	07/01/1997	0.5	90.72	0.07
08/01/1993	0.37	86.3136	0.09	08/01/1997	0.25	51.84	0.08
09/01/1993	0.37	335.664	0.35	09/01/1997	0.25	25.92	0.04
10/01/1993	2.41	312.336	0.05	10/01/1997	0.34	44.064	0.05
11/01/1993	0.91	330.2208	0.14	11/01/1997	3.72	2506.982	0.26
12/01/1993	4.03	1044.576	0.1	12/01/1997	2.41	937.008	0.15
01/01/1994	4.01	1036.79	0.2	01/01/1998	33.44	92743.83	1.07
02/01/1994	3.99	1029.01	0.1	02/01/1998	1.2	186.624	0.06
03/01/1994	3.97	1021.248	0.1	03/01/1998	1.96	457.2288	0.09
04/01/1994	2.67	692.064	0.1	04/01/1998	1.99	825.2928	0.16
05/01/1994	4.39	568.944	0.05	05/01/1998	0.79	102.384	0.05
06/01/1994	1.51	273.9744	0.07	06/01/1998	0.3	54.432	0.07
07/01/1994	1.5	427.68	0.11	07/01/1998	1.91	4109.098	0.83
08/01/1994	0.48	74.6496	0.06	08/01/1998	0.03	41.9904	0.54
09/01/1994	0.17	44.064	0.1	09/01/1998	0.17	229.1328	0.52
10/01/1994	0.22	28.512	0.05	10/01/1998	0.13	57.2832	0.17
11/01/1994	0.17	30.8448	0.07	11/01/1998	0.21	32.6592	0.06
12/01/1994	0.45	58.32	0.05	12/01/1998	0.36	93.312	0.1

01/01/1995	0.582	62.79	0.1	01/01/1999	0.915	694.397	0.22
02/01/1995	0.714	67.26	0.05	02/01/1999	1.47	1295.482	0.34
03/01/1995	0.846	71.73	0.035	03/01/1999	1.36	352.512	0.1
04/01/1995	0.98	76.2048	0.03	04/01/1999	0.79	238.464	0.11
05/01/1995	2.51	130.1184	0.02	05/01/1999	0.4	124.416	0.12
06/01/1995	1.84	810.7776	0.17	06/01/1999	0.63	146.9664	0.09
07/01/1995	0.48	236.3904	0.19	07/01/1999	0.28	108.864	0.15
08/01/1995	2.37	1044.317	0.17	08/01/1999	0.17	96.9408	0.22
09/01/1995	0.12	27.9936	0.09	09/01/1999	0.04	8.2944	0.08
10/01/1995	0.25	19.44	0.03	10/01/1999	0.15	58.32	0.15
11/01/1995	0.25	25.92	0.04	11/01/1999	1.14	325.0368	0.11
12/01/1995	0.546	56.6	0.05	12/01/1999	0.47	134.0064	0.11

Table A-1 City of London observed data at the Medway Creek watershed outlet

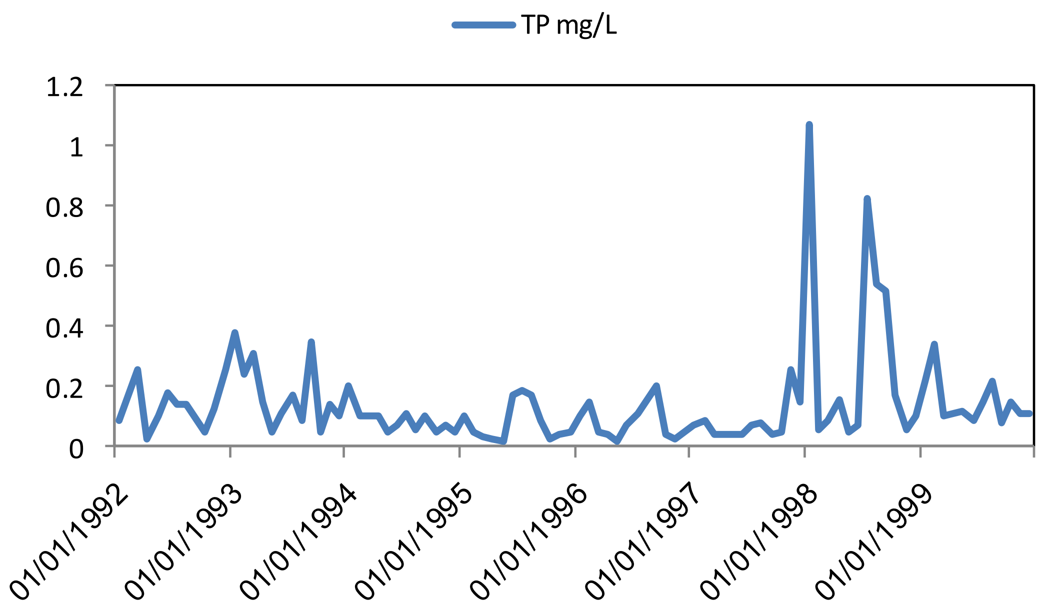


Figure (A-1) TP monitoring at Medway Creek watershed outlet.

Source: City of London

- **Soil data and land use' attributes tables**

The soil layer has 267 polygons and each soil has 1 to 2 layers. All soil data prepared and integrated from different sources into SWAT format. The flowing table shows the structure of soil attributes table that has been prepared for SWAT input.

OBJECTID	MUID	SEQN	SNAM	S5ID	CMPPCT	NLAYERS	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	TEXTURE
1	VT028	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
2	VT028	1	AVISTOCK - TILL PHASE	CAN	100	2	C	1500	0.5	0.5	L
3	VT029	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
4	VT027	1	COLWOOD	CAN	100	1	C	1500	0.5	0.5	L
5	VT027	1	BRYANSTON	CAN	100	2	B	1500	0.5	0.5	SIL
6	VT028	1	NOT MAPPED	CAN	100	1	B	1500	0.5	0.5	SIL
7	VT030	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
8	VT030	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
9	VT030	1	PERTH	CAN	100	1	C	1500	0.5	0.5	SICL
10	VT023	1	ERODED CHANNEL	CAN	100	1	B	1500	0.5	0.5	SL
11	VT023	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
12	VT023	1	PERTH	CAN	100	1	C	1500	0.5	0.5	SICL
13	VT023	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
14	VT025	1	TOLEDO	CAN	100	1	D	1500	0.5	0.5	SICL
15	VT025	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
16	VT025	1	HURON	CAN	100	2	C	1500	0.5	0.5	SIL
17	VT025	1	TOLEDO	CAN	100	2	D	1500	0.5	0.5	SICL
18	VT025	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
19	VT043	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SIL
20	VT043	1	HURON	CAN	100	2	C	1500	0.5	0.5	L
21	VT044	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	L
22	VT017	1	NOT MAPPED	CAN	100	1	C	1500	0.5	0.5	SIL
23	VT017	1	BRYANSTON	CAN	100	2	B	1500	0.5	0.5	SIL
24	VT021	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
25	VT033	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SICL
26	VT033	1	TAVISTOCK	CAN	100	2	C	1500	0.5	0.5	L
27	VT033	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
28	VT030	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
29	VT032	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
30	VT032	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
31	VT033	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
32	VT033	1	CROMBIE	CAN	100	1	C	1500	0.5	0.5	SIL
33	VT033	1	BEVERLY	CAN	100	2	C	1500	0.5	0.5	SICL
34	VT034	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
35	VT035	1	HURON	CAN	100	2	C	1500	0.5	0.5	SIL
36	VT035	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
37	VT036	1	HURON	CAN	100	2	C	1500	0.5	0.5	SIL
38	VT036	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
39	VT037	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
40	VT004	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	L
41	VT006	1	HURON	CAN	100	2	C	1500	0.5	0.5	SIL
42	VT006	1	TOLEDO	CAN	100	2	D	1500	0.5	0.5	SICL
43	VT037	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
44	VT038	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
45	VT040	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
46	VT040	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
47	VT040	1	PERTH	CAN	100	1	C	1500	0.5	0.5	SICL
48	VT040	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
49	VT040	1	HURON	CAN	100	1	C	1500	0.5	0.5	SIL
50	VT042	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
51	VT043	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SIL
52	VT044	1	VITTORIA - TILL PHASE	CAN	100	2	C	1500	0.5	0.5	FSL
53	VT045	1	AVISTOCK - TILL PHASE	CAN	100	2	C	1500	0.5	0.5	L
54	VT045	1	FANSHAWE	CAN	100	1	B	1500	0.5	0.5	SIL
55	VT021	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SIL
56	VT021	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
57	VT023	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
58	VT046	1	VITTORIA - TILL PHASE	CAN	100	1	C	1500	0.5	0.5	FSL
59	VT046	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
60	VT049	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SIL

61	VT002	1	CROMBIE	CAN	100	1	C	1500	0.5	0.5	SIL
62	VT002	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
63	VT002	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
64	VT002	1	BRYANSTON	CAN	100	1	B	1500	0.5	0.5	SIL
65	VT002	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
66	VT002	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
67	VT003	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
68	VT004	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
69	VT004	1	HURON	CAN	100	2	C	1500	0.5	0.5	SIL
70	VT007	1	PERTH	CAN	100	2	C	1500	0.5	0.5	L
71	VT007	1	AVISTOCK - TILL PHASE	CAN	100	2	C	1500	0.5	0.5	SICL
72	VT007	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	L
73	VT007	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
74	VT007	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	SIL
75	VT007	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	L
76	VT007	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	SIL
77	VT007	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	L
78	VT008	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
79	VT008	1	PERTH	CAN	100	1	C	1500	0.5	0.5	SIL
80	VT009	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
81	VT010	1	HURON	CAN	100	1	C	1500	0.5	0.5	SICL
82	VT010	1	BURFORD	CAN	100	2	A	1500	0.5	0.5	SIL
83	VT014	1	AVISTOCK - TILL PHASE	CAN	100	2	C	1500	0.5	0.5	GSL
84	VT015	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	L
85	VT015	1	PERTH	CAN	100	2	C	1500	0.5	0.5	L
86	VT016	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
87	VT016	1	VALLEY COMPLEX	CAN	100	1	C	1500	0.5	0.5	SICL
88	VT016	1	BRYANSTON	CAN	100	2	B	1500	0.5	0.5	SIL
89	VT016	1	BROOKSTON	CAN	100	1	D	1500	0.5	0.5	SIL
90	VT016	1	NOT MAPPED	CAN	100	1	B	1500	0.5	0.5	SICL
91	VT016	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
92	VT017	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
93	VT017	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	SIL
94	VT049	1	BRYANSTON	CAN	100	2	B	1500	0.5	0.5	L
95	VT049	1	TEESWATER	CAN	100	2	B	1500	0.5	0.5	SIL
96	VT050	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
97	VT050	1	FANSHAWE	CAN	100	2	B	1500	0.5	0.5	SIL
98	VT050	1	CAMILLA	CAN	100	2	B	1500	0.5	0.5	SIL
99	VT051	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SL
100	VT051	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SIL
101	VT052	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
102	VT053	1	BRYANSTON	CAN	100	2	B	1500	0.5	0.5	SIL
103	VT053	1	FANSHAWE	CAN	100	2	B	1500	0.5	0.5	SIL
104	VT055	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
105	VT056	1	THORNDALE	CAN	100	1	B	1500	0.5	0.5	SIL
106	VT056	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SIL
107	VT059	1	THORNDALE	CAN	100	1	B	1500	0.5	0.5	SIL
108	VT059	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
109	VT059	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
110	VT059	1	NISSOURI	CAN	100	1	C	1500	0.5	0.5	SIL
111	VT060	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
112	VT060	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
113	VT063	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SIL
114	VT065	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
115	VT065	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	SIL
116	VT065	1	NISSOURI	CAN	100	2	C	1500	0.5	0.5	L
117	VT065	1	EMBRO	CAN	100	1	C	1500	0.5	0.5	SIL
118	VT065	1	TUSCOLA	CAN	100	2	C	1500	0.5	0.5	L
119	VT066	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
120	VT067	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
121	VT068	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
122	VT068	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
123	VT068	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
124	VT071	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
125	VT072	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SIL
126	VT072	1	BRYANSTON	CAN	100	1	B	1500	0.5	0.5	L
127	VT075	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
128	VT078	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	GSL
129	VT078	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	SIL
130	VT079	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL

131	VT079	1	BURFORD	CAN	100	2	A	1500	0.5	0.5	SIL
132	VT079	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
133	VT079	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
134	VT079	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
135	VT080	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	GSL
136	VT080	1	HURON	CAN	100	2	C	1500	0.5	0.5	L
137	VT081	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
138	VT081	1	BURFORD	CAN	100	2	A	1500	0.5	0.5	L
139	VT081	1	TUSCOLA	CAN	100	2	C	1500	0.5	0.5	SIL
140	VT081	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
141	VT081	1	TUSCOLA	CAN	100	2	C	1500	0.5	0.5	SIL
142	VT082	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
143	VT082	1	FANSHAWE	CAN	100	1	B	1500	0.5	0.5	SIL
144	VT082	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SIL
145	VT082	1	FANSHAWE	CAN	100	2	B	1500	0.5	0.5	SICL
146	VT082	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	GSL
147	VT082	1	FANSHAWE	CAN	100	1	B	1500	0.5	0.5	SIL
148	VT082	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SIL
149	VT082	1	BURFORD	CAN	100	2	A	1500	0.5	0.5	SIL
150	VT082	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
151	VT082	1	CROMBIE	CAN	100	1	C	1500	0.5	0.5	SIL
152	VT082	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
153	VT083	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
154	VT083	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
155	VT083	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SICL
156	VT084	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	L
157	VT084	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SIL
158	VT084	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SIL
159	VT086	1	TUSCOLA	CAN	100	2	C	1500	0.5	0.5	SIL
160	VT086	1	CROMBIE	CAN	100	1	C	1500	0.5	0.5	SIL
161	VT086	1	CROMBIE	CAN	100	1	C	1500	0.5	0.5	L
162	VT086	1	THORNDALE	CAN	100	1	B	1500	0.5	0.5	SIL
163	VT087	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
164	VT087	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	SIL
165	VT087	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
166	VT087	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
167	VT087	1	CROMBIE	CAN	100	1	C	1500	0.5	0.5	SIL
168	VT087	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
169	VT087	1	BRYANSTON	CAN	100	2	B	1500	0.5	0.5	SIL
170	VT087	1	BRYANSTON	CAN	100	1	B	1500	0.5	0.5	SIL
171	VT087	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	L
172	VT088	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
173	VT088	1	THORNDALE	CAN	100	1	B	1500	0.5	0.5	SICL
174	VT089	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
175	VT089	1	TUSCOLA	CAN	100	2	C	1500	0.5	0.5	SIL
176	VT089	1	HURON	CAN	100	2	C	1500	0.5	0.5	SIL
177	VT090	1	THORNDALE	CAN	100	1	B	1500	0.5	0.5	SIL
178	VT090	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
179	VT091	1	CROMBIE	CAN	100	2	C	1500	0.5	0.5	SICL
180	VT091	1	NOT MAPPED	CAN	100	1	C	1500	0.5	0.5	SIL
181	VT091	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SL
182	VT091	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
183	VT091	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
184	VT091	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SIL
185	VT093	1	BRYANSTON	CAN	100	2	B	1500	0.5	0.5	SL
186	VT093	1	ERODED CHANNEL	CAN	100	1	B	1500	0.5	0.5	SIL
187	VT093	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SL
188	VT094	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SL
189	VT094	1	ERODED CHANNEL	CAN	100	1	B	1500	0.5	0.5	SICL
190	VT094	1	THORNDALE	CAN	100	1	B	1500	0.5	0.5	SICL
191	VT094	1	ERODED CHANNEL	CAN	100	1	B	1500	0.5	0.5	SICL
192	VT094	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SICL
193	VT094	1	PERTH	CAN	100	1	C	1500	0.5	0.5	SICL
194	VT095	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SIL
195	VT095	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SIL
196	VT095	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SIL
197	VT095	1	NOT MAPPED	CAN	100	1	C	1500	0.5	0.5	SIL
198	VT096	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SIL
199	VT096	1	THORNDALE	CAN	100	1	B	1500	0.5	0.5	SIL
200	VT096	1	HONEYWOOD	CAN	100	1	B	1500	0.5	0.5	SIL

201	VTW	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
202	VTPIT	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
203	VT094	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
204	VT094	1	TUSCOLA	CAN	100	2	C	1500	0.5	0.5	SIL
205	VT094	1	HURON	CAN	100	2	C	1500	0.5	0.5	SIL
206	VT095	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
207	VT095	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
208	VT095	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SIL
209	VT095	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SIL
210	VT096	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
211	VT096	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
212	VT096	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SIL
213	VTW	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SIL
214	VTPIT	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
215	VT094	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	L
216	VT094	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SL
217	VT094	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SL
218	VT095	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SL
219	VT095	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SL
220	VT095	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SL
221	VT095	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SL
222	VT096	1	COLWOOD	CAN	100	2	C	1500	0.5	0.5	SL
223	VT096	1	ERODED CHANNEL	CAN	100	1	B	1500	0.5	0.5	SL
224	VT096	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SL
225	VTW	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	L
226	VTPIT	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	L
227	VT094	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
228	VT094	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	L
229	VT094	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	L
230	VT095	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	L
231	VT095	1	TUSCOLA	CAN	100	2	C	1500	0.5	0.5	L
232	VT095	1	NOT MAPPED	CAN	100	1	C	1500	0.5	0.5	L
233	VT095	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	LS
234	VT096	1	MAPLEWOOD	CAN	100	2	C	1500	0.5	0.5	SIL
235	VT096	1	ERODED CHANNEL	CAN	100	1	B	1500	0.5	0.5	L
236	VT096	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SIL
237	VTW	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
238	VTPIT	1	BUILT UP AREA	CAN	100	1	C	1500	0.5	0.5	SIL
239	VT094	1	BUILT UP AREA	CAN	100	1	B	1500	0.5	0.5	SIL
240	VT094	1	FOX	CAN	100	2	A	1500	0.5	0.5	SIL
241	VT094	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
242	VT095	1	TUSCOLA	CAN	100	2	C	1500	0.5	0.5	L
243	VT095	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	L
244	VT095	1	HURON	CAN	100	2	C	1500	0.5	0.5	L
245	VT095	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	L
246	VT096	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SL
247	VT096	1	THORNDALE	CAN	100	1	B	1500	0.5	0.5	SIL
248	VT096	1	BRYANSTON	CAN	100	2	B	1500	0.5	0.5	SIL
249	VTW	1	TUSCOLA	CAN	100	2	C	1500	0.5	0.5	SIL
250	VTPIT	1	NOT MAPPED	CAN	100	1	C	1500	0.5	0.5	SIL
251	VT094	1	NOT MAPPED	CAN	100	1	C	1500	0.5	0.5	SIL
252	VT094	1	WATER	CAN	100	1	C	1500	0.5	0.5	SIL
253	VT094	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
254	VT095	1	ERODED CHANNEL	CAN	100	1	B	1500	0.5	0.5	SL
255	VT095	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
256	VT095	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
257	VT095	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
258	VT096	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
259	VT096	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
260	VT095	1	EMBRO	CAN	100	2	C	1500	0.5	0.5	SIL
261	VT095	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
262	VT095	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
263	VT096	1	PERTH	CAN	100	2	C	1500	0.5	0.5	SICL
264	VT096	1	HURON	CAN	100	2	C	1500	0.5	0.5	SIL
265	VT095	1	ERODED CHANNEL	CAN	100	1	B	1500	0.5	0.5	SL
266	VT095	1	THORNDALE	CAN	100	2	B	1500	0.5	0.5	SIL
267	VT095	1	NOT MAPPED	CAN	100	1	B	1500	0.5	0.5	SIL

Table A-2 Soil data attributes in SWAT set up

OBJECTID	SOL_Z1	SOL_BD1	SOL_AWC1	SOL_K1	SOL_CBN1	CLAY1	SILT1	SAND1	ROCK1	SOL_ALB1	USLE_K1	SOL_EC1
1	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.37	0
2	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.1	0
3	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.37	0
4	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
5	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
6	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
7	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
8	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
9	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
10	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.3	0
11	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
12	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
13	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
14	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
15	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
16	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
17	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
18	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
19	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
20	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
21	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
22	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
23	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
24	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
25	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
26	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
27	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
28	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
29	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
30	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
31	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
32	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
33	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
34	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
35	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
36	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
37	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
38	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
39	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
40	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
41	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
42	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
43	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
44	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
45	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
46	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
47	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
48	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
49	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
50	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
51	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
52	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
53	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
54	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
55	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
56	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
57	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
58	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
59	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
60	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0

61	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
62	100	1.57	0.17	4.28	4.9	34	56	10	0	0.13	0.3	0
63	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
64	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
65	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
66	100	1.57	0.17	4.28	4.9	34	56	10	0	0.13	0.3	0
67	100	1.57	0.17	4.28	4.9	34	56	10	0	0.13	0.3	0
68	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
69	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
70	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
71	100	1.61	0.13	10.17	4.9	34	56	10	0	0.13	0.3	0
72	100	1.61	0.13	10.17	4.9	0	0	0	0	0.13	0.3	0
73	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
74	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
75	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
76	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
77	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
78	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
79	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
80	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
81	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
82	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
83	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
84	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
85	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
86	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
87	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
88	100	1.44	0.17	1.9	4.9	20	60	20	0	0.13	0.3	0
89	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
90	100	1.57	0.17	4.28	4.9	34	56	10	0	0.13	0.3	0
91	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
92	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
93	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
94	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
95	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
96	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
97	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
98	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
99	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
100	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
101	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
102	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
103	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
104	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
105	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
106	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
107	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
108	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
109	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
110	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
111	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
112	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
113	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
114	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
115	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
116	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
117	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
118	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
119	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
120	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0

121	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
122	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
123	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
124	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
125	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
126	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
127	100	1.57	0.17	4.28	4.9	10	60	65	0	0.13	0.3	0
128	100	1.57	0.17	4.28	4.9	0	0	0	0	0.13	0.12	0
129	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
130	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
131	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
132	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
133	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
134	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
135	100	0	0	0	4.9	0	0	0	0	0.13	0.12	0
136	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
137	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
138	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
139	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
140	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
141	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
142	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
143	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
144	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
145	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
146	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
147	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
148	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
149	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
150	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
151	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
152	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
153	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
154	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
155	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
156	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
157	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
158	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
159	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
160	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
161	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
162	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
163	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
164	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
165	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
166	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
167	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
168	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
169	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
170	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
171	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
172	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
173	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
174	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
175	100	1.57	0.17	4.28	4.9	0	0	0	0	0.13	0.3	0
176	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
177	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
178	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
179	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
180	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0

181	100	1.57	0.17	4.28	4.9	0	0	0	0	0.13	0.3	0
182	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
183	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
184	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
185	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.3	0
186	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
187	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.3	0
188	100	1.63	0.09	37.83	4.9	0	0	0	0	0.13	0.3	0
189	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
190	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
191	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
192	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
193	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
194	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
195	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
196	100	1.57	0.17	4.28	4.9	0	0	0	0	0.13	0.3	0
197	100	1.57	0.17	4.28	4.9	0	0	0	0	0.13	0.3	0
198	100	1.57	0.17	4.28	4.9	0	0	0	0	0.13	0.3	0
199	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
200	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
201	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
202	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
203	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
204	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
205	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
206	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
207	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
208	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
209	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
210	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
211	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
212	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
213	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
214	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
215	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
216	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
217	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
218	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
219	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
220	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
221	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
222	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
223	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
224	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
225	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
226	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
227	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
228	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
229	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
230	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
231	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
232	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
233	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
234	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
235	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
236	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
237	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
238	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
239	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
240	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0

241	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
242	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
243	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
244	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
245	100	1.61	0.13	10.17	4.9	18	40	42	0	0.13	0.3	0
246	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.12	0
247	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
248	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
249	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
250	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
251	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
252	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
253	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
254	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
255	100	1.44	0.17	1.9	4.9	34	56	10	0	0.13	0.3	0
256	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
257	100	1.63	0.09	37.83	4.9	10	25	65	0	0.13	0.3	0
258	100	1.57	0.17	4.28	4.9	20	60	20	0	0.13	0.3	0
259	100	1.51	0.25	19.44	4.9	20	60	20	0	0.13	0.3	0
260	100	1.45	0.33	4.28	4.9	20	60	20	0	0.13	0.3	0
261	100	1.39	0.41	4.28	4.9	20	60	20	0	0.13	0.3	0
262	100	1.33	0.49	4.28	4.9	20	60	20	0	0.13	0.3	0
263	100	1.27	0.57	4.28	4.9	34	56	10	0	0.13	0.3	0
264	100	1.21	0.65	4.28	4.9	20	60	20	0	0.13	0.3	0
265	100	1.15	0.73	1.9	4.9	20	60	20	0	0.13	0.12	0
266	100	1.09	0.81	4.28	4.9	20	60	20	0	0.13	0.3	0
267	100	1.03	0.89	1.9	4.9	20	60	20	0	0.13	0.3	0

Table A-3 Soil data attributes for layer # (1) In SWAT set up

SLOPE	AREA	PERCENTAGE %
0-2.19	13536.8196	66.06
>2.19	6954.9104	33.94

Table A-4 Slope reclassification in SWAT set up

LAND USE	CODE	AREA (HA)	PERCENTAGE%
Corn	CORN	7174.3720	35.01
Agricultural Land-Generic	AGRL	3997.0248	19.51
Industrial	UIDU	169.1709	0.83
Agricultural Land-Row Crops	AGRR	4234.9103	20.67
Water	WATR	79.2813	0.39
Forest-Mixed	FRST	1619.7744	7.90
Residential	URBN	1162.1564	5.67
Pasture	PAST	313.1861	1.53
Hay	HAY	1524.5494	7.44
Range-Grasses	RNGE	489.4867	0.97
Orchard	ORCD	15.2352	0.07
Commercial	UCOM	3.9807	0.02

Table A-5 Land use reclassification SWAT set up

SOIL	AREA (HA)	PERCENTAGE%
BEVERLY	46.6434	0.23
BROOKSTON	51.1660	0.25
BRYANSTON	368.2703	1.80
BUILT UP AREA	1148.1196	5.60
BURFORD	298.9721	1.46
CAMILLA	6.7318	0.03
COLWOOD	747.9513	3.65
CROMBIE	569.4955	2.78
EMBRO	6147.4982	30.00
ERODED CHANNEL	526.1972	2.57
FANSHAWE	226.4435	1.11
FOX	26.2187	0.13
HONEYWOOD	30.1056	0.15
HURON	719.8256	3.51
MAPLEWOOD	360.2150	1.76
NISSOURI	17.3714	0.08
NOT MAPPED	346.3867	1.69
PERTH	2225.2425	10.86
TAVISTOCK	23.3113	0.11
TAVISTOCK - TILL PHASE	303.5364	1.48
TEESWATER	9.3162	0.05
THORNDALE	4816.8899	23.51
TOLEDO	362.5076	1.77
TUSCOLA	336.7787	1.64
VALLEY COMPLEX	722.2641	3.52
VITTORIA - TILL PHASE	23.4155	0.11
WATER	30.8559	0.15

Table A-6 Soil reclassification in SWAT set up

Granton WWTP

The water chemistry of Granton that is incorporated in SWAT model is attached in this table:-

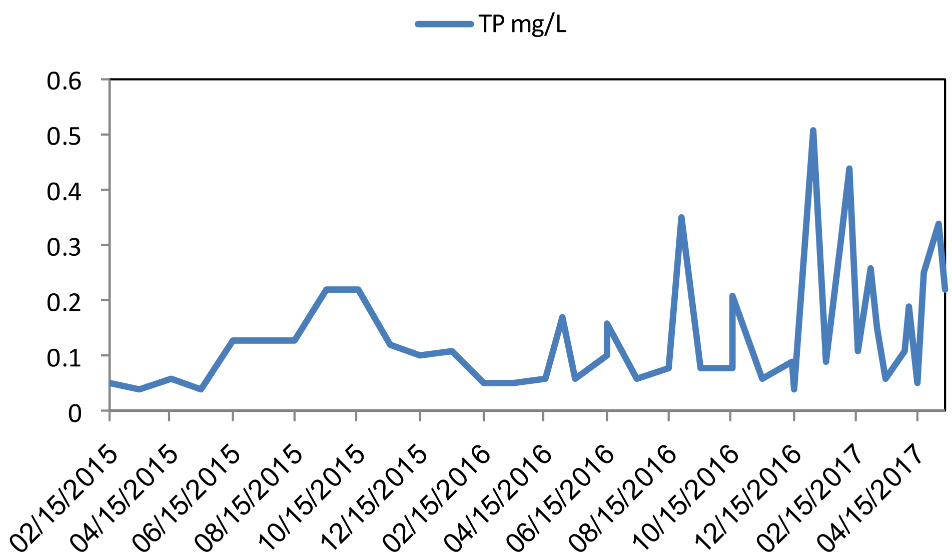


Figure A-2 TP concentration in Granton WWTP effluent

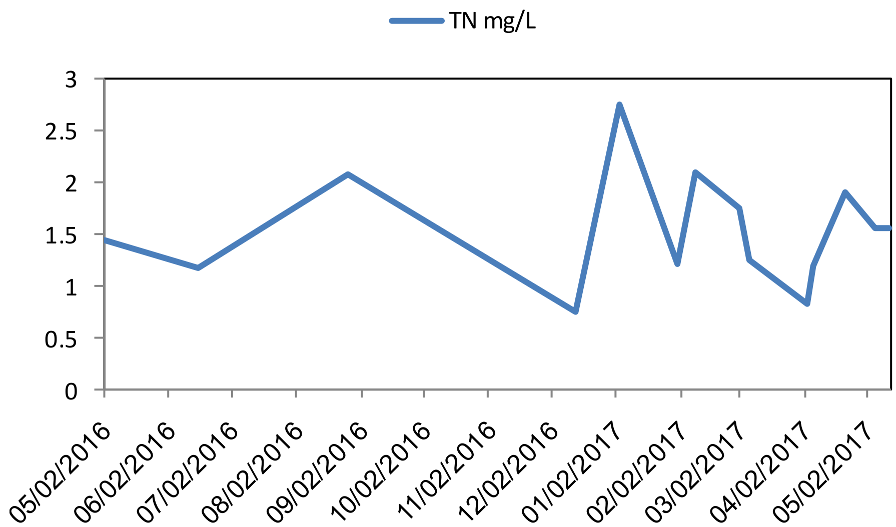


Figure A-3 TN concentration in Granton WWTP effluent

SWAT requires the input data of selected point source to be constant (average) daily loading, or in time step such as annual, monthly, or daily records. Due to the limited daily data of Granton WWTP, the average data of Granton plant were incorporated as shown in Table A-7.

Variable	Value
Flow (m^3)	270
Sediments (m)	3.13038
Organic N (Kg)	0.7041214
Organic P (kg)	0.0367
Nitrate NO3 (Kg)	4
Ammonia NH3 (Kg)	0.022860009
Nitrite NO2 (kg)	0.379
Mineral P (Kg)	0.157
CBOD Kg	0.321

Table A-7 average daily variables in Granton WWTP effluent

- **Tile drainage parameters**

Parameters	Value	Note
DDRAIN_BSN	900	Depth of subsurface drain(mm)
TDRAIN-BSN	24	Time to drain soil to field capacity (hours)
GDRAIN_BSN	3	Tile drain lag time (hours)
RE-BSN	50	effective radius of drain
SDRAIN-BSN	15000	Dist between two drains
DRAIN-CO-BSN	10	Drainage coefficient (default value)
PC_BSN	1.042	Pump capacity (default value)
LATIKSATF_BSN	1	Multiplication factor (default value)

Table A-8 Tile drainage parameters in SWAT input

Appendix B

RCP 8.5 and A1B data

RCP 8.5 and A1B scenarios

Precipitation and temperature data

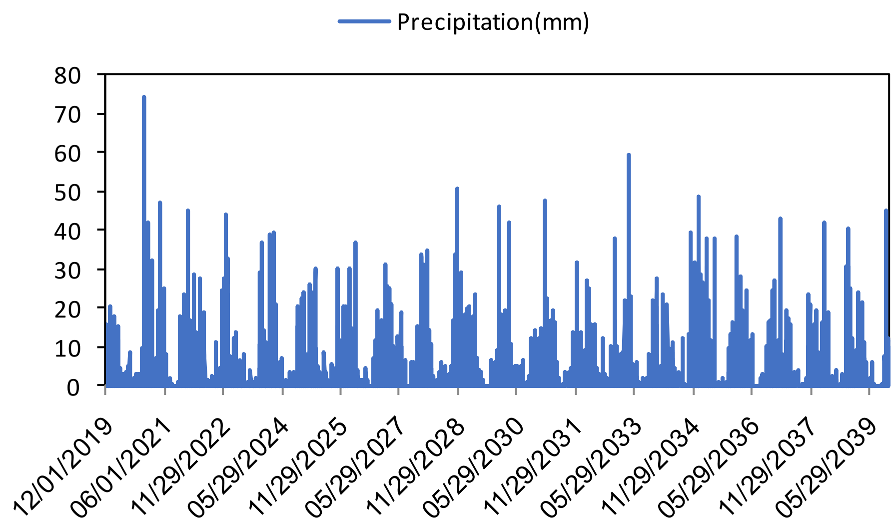


Figure A-4 future precipitation data for the period 2019 to 2040 under RCP 8.5

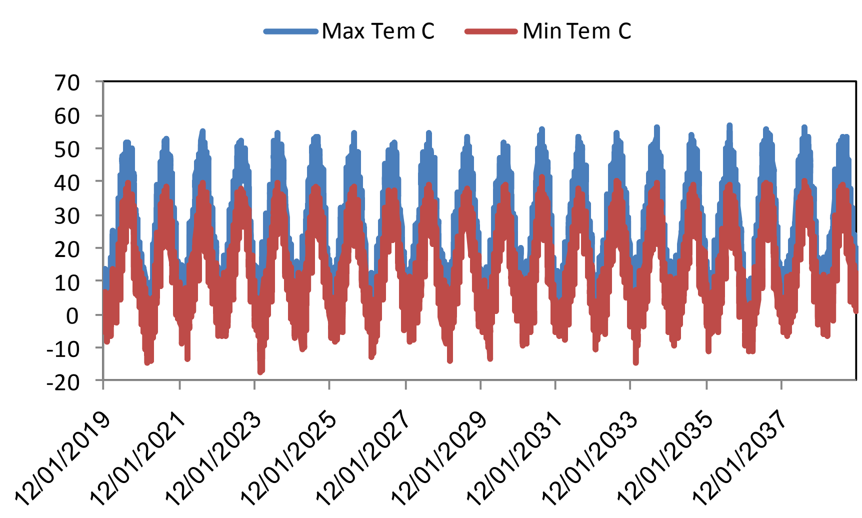


Figure A-5 future min/max temperature C^{o} for the period 2019 to 2040 under RCP 8.5 scenario

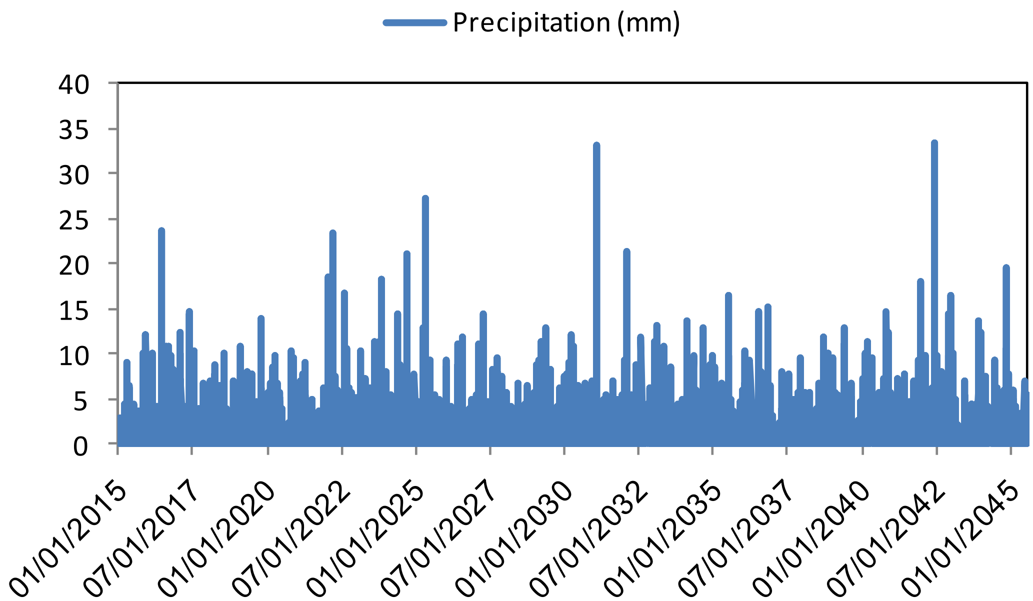


Figure A-6 future precipitation data for the period 2015 to 2045 under A1B scenario

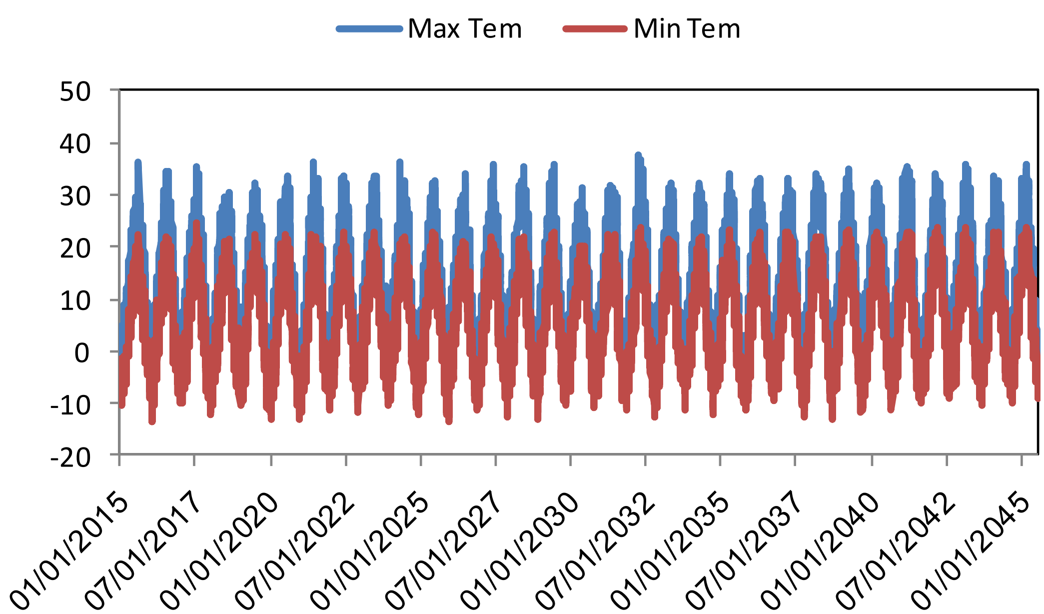


Figure A-7 future min/max temperature C^o for the period 2015 to 2045 under A1B scenario

- **RCP 8.5 Results**

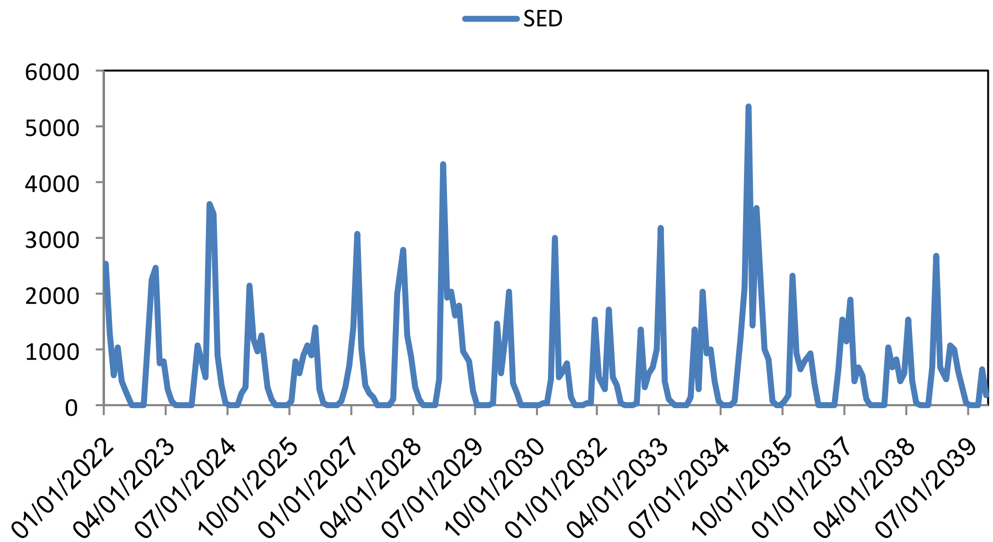


Figure A-8 predicted Sediments (metric T) transported with water at the watershed outlet under RCP 8.5 scenario

Curriculum Vitae

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