Estimating Sediment and Nutrient Loading in the Davis Creek Watershed Using Soil and Water Assessment Tool (SWAT)

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ESTIMATING SEDIMENT AND NUTRIENT LOADING IN THE DAVIS CREEK WATERSHED USING SOIL AND WATER ASSESSMENT TOOL (SWAT)

by

Fatma Ulku Karatas

A Thesis submitted to Graduate College
in partial fulfillment of the requirements
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ESTIMATING SEDIMENT AND NUTRIENT LOADING IN THE DAVIS CREEK WATERSHED USING SOIL AND WATER ASSESSMENT TOOL (SWAT)

Fatma Ulku Karatas, M.A.

Western Michigan University, 2015

The Soil and Water Assessment Tool (SWAT) is a physically model to estimate impact of land cover on water, sediment, and agricultural chemical yields in large, complex yields in large, complex watersheds with fluctuating soils, land use, and management conditions for long periods of time. In order to simulate the movement of sediment and nutrients, the Davis Creek Watershed is subdivided into 31 homogenous sub basins, having unique soil and land use properties. The data for each subbasin is grouped into categories of land cover, soil, management within sub basin, draining the sub basin.

The objectives of this study are to classify the most polluted subbasins in the watershed with the aim of determining the most appropriate land uses (e.g., agriculture, industrial, commercial, residential) in this surrounding areas through a 14 years period (1999-2013), examining impact of land use change on runoff sediment load and nutrient yield for 2001 and 2011 and providing recommendations on the best management practices for controlling and reducing source pollution. Through examination of the simulated results, most pollutant subbasins are identified, land cover impacts are examined. This information, while valuable and useful, needs to be further verified in the field for supporting water quality decision making in the Davis Creek Watershed.
ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

Water quality has been a crucial issue in the United States for decades. In 1972, the Clean Water Act (CWA) recognized the increasing importance of the nation’s waterways. This is the part of environmental legislation that brings point source pollution under control. Over the years, the Clean Water Act has been tremendously successful in the abating of chemical in water resources from point source, but reduction of pollutants from nonpoint source (NPS) has not been as successful (Wermuth, 2006).

Most point source pollutants are controlled via regulatory enforcement, capital investment in pollution reduction technology, pollution control standards and better management of municipal and industrial infrastructure (Daniel et al., 2007). Since 1972, the National Pollutant Discharge Elimination System (NPDES) permit program has been responsible for significant improvements to the United States’ water quality. Any point discharge is obligated to get a NPDES permission which corresponds to Clean Water Act provisions.

There are several kinds of nonpoint source pollutants and the difficulty of dealing with them is that they do not enter into waterways from specific or easily identifiable locations like point source pollution.
1.1. Nonpoint Source Pollution

Unlike point source pollution, which involves pollutant discharge from a constant facility, non-point source (NPS) or diffuse pollution is characterized by extensive distribution of a pollution source and by intensely formless rates of delivery (Virginia Department of Environmental Quality, 2015). Nonpoint source pollution happens when precipitation runs off farmland, city streets, construction sites, and sub-urban lawns, roofs and driveways and enters water bodies. Consequently, nonpoint source pollution does not meet legalization of "point source" from Section 502(14) of the Clean Water Act (VDEQ, 2015).

The U.S. Environmental Protection Agency (EPA) now considers NPS pollution to be the major cause of water quality issues in the U.S. The National Water Quality Inventory report for the United States shows that, as of 2004, 44 percent of assessed stream miles, 64 percent of lake acres, and 30 percent of estuary acres are impaired (United States Environmental Protection Agency (USEPA), 2009). However, those values were 39 percent of assessed stream miles, 45 percent of lake acres in 2000 (USEPA, 2003). The changes from 2000 to 2004 indicate how fast water quality can decrease grows in the United States.

Agriculture and unknown/unspecified sources have been identified by USEPA (USEPA, 2009) as top sources of pollutants to lakes, ponds, and reservoirs including pollution attributed to atmospheric deposition by. Leading causes of impairment included: huge amounts of organic nutrients, siltation,
mercury, metals and kinds of pathogens. Carpenter et al (1998) identifies several examples of cause of NPS that are recognized by USEPA as:

- Agricultural runoff, including return flow irrigated farmland
- Runoff from pasture, rangelands, septic tank and sewage systems
- Overuse of fertilizers, herbicides and insecticides in agricultural lands and residential areas
- Sediment from crop and forest land, especially from eroding streambanks
- Atmospheric deposition and hydromodification
- Oil, grease and toxic chemicals
- Salt from irrigation applications
- Acidic drainage from mines

These sources can be transported by rainfall or snowmelt moving over and throughout the ground and carrying natural or anthropomorphic pollutants into lakes, rivers, wetlands, estuaries, other coastal waters, and ground water (Witte and Ross, 2003).

Nonpoint source pollution causes increases in suspended and dissolved sediment, phosphorus, nitrogen, and heavy metals such as cadmium, lead and zinc. When the rate of supply of organic matter to an ecosystem is enhanced, which is defined as eutrophication, nutrient inputs can lead to several negative effects, including overgrowth of aquatic plants, providing good conditions for algal blooms. (Nixon 1995). Roughly 50 percent of impaired lakes and 60 percent of impaired river miles are affected by eutrophication nationwide (Carpenter et al., 1998). Also, enhancement in the total suspended solids which block light are also
harmful to the aquatic vegetation. Point source pollution from urban land such as phosphorus and nitrogen loading in fresh waters has also effects on some coastal regions across the United States and may inhibit recovery from negative changes in geomorphology (DRSC, et al., 2005).

In order to foster the recovery of impaired water sources and increase conditions for to drinkable, swimmable and fishable waters, transporting source of both point and nonpoint source substance through a watershed by hydrological processes should be tracked. (He and Croley, 2007). Numerous simulation models have been developed to assist in the understanding and management of surface runoff, sediment, nutrient leaching, and pollutant transport processes like ANSWERS (Areal Nonpoint Source Watershed Environment Simulation) (Beasley et al. 1980), CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) (Knisel 1980), AGNPS (Agricultural Nonpoint Source Pollution Model) (Young et al. 1989), and SWAT (Soil and Water Assessment Tool) (Arnold et al. 1998; He and Croley, 2007). These models and tools can be used to identify the causes and to minimize impacts of nonpoint source pollution to improve water quality.

1.2. The Clean Water Act

The Clean Water Act (CWA) creates a fundamental structure for directing releases of contaminations into the waters of the United States and controlling quality benchmarks for surface waters. The premise of the CWA was authorized in 1948 and was known as the Federal Water Pollution Control Act, however the Act was fundamentally revamped and extended in 1972. "Clean Water Act"
turned into the Act’s basic name with changes in 1972. Under the CWA, EPA has actualized contamination control projects, for example, setting wastewater principles for industry (USEPA, 2013).

EPA’s National Pollutant Discharge Elimination System (NPDES) regulates point source discharges. Point sources are discrete conveyances such as pipes or man-made ditches. Individual homes that are associated with a municipal system, utilize a septic system, or have no a surface release do not need bother with a NPDES grant; however, industrial, municipal, and other facilities must obtain permits if their discharges go straightforwardly to surface waters (USEPA, 2013).

1.3. Total Maximum Daily Loads (TMDL)

A Total Maximum Daily Loads (TMDL) is defined as “the sum of the individual waste load allocations for point sources and load allocations for nonpoint sources and natural background” (40 CFR 130.2) such that the limit of the water body to acclimatize contamination loadings (the Loading Capacity) is not surpassed (DWQ, 2006).

The TMDL calculates the highest amount of pollutant permitted to enter a waterbody so that the waterbody will have stabilized water quality for that specific pollutant. The calculation of TMDL is related with Waste Load Allocation (WLA), Load Allocation (LA) and Margin of Safety (MOS). Waste load allocation is the total amount of pollutant from sources which already exist such as sewage treatment plant, industrial facility, stormwater. Load allocation is estimation of
pollutant from nonpoint source pollution and natural background like, farm runoff, atmospheric mercury. Margin of safety is used to consider lack of knowledge concerning the relationship between residual limitations and water quality. It can be direct factor (e.g., percent of total, such as 8%) or indirect factor (e.g., conservative assumption in modeling) (USEPA, 2012). The relationship between these parameters and TMDL is defined by this basic formula:

\[ \text{TMDL} = \sum WLA_i + \sum LA_i + \text{MOS} \]

A TMDL methodology compels the accounting of all resource of contamination. This aide’s recognition of how additional basin reductions, if necessary, may be achieved. TMDL is moreover expected to be created with periodic mixtures and fuse an edge of wellbeing to address helplessness in the examination. Furthermore, the regulations at 40 CFR 130.6 of the CWA, require states create water quality administration arrangements to directly implement the plan components, including TMDLs. (USEPA, 2013)

EPA has the obligation to estimate and TMDL’s and regulate inputs if a state fails to act (EPA, 1993). States must create TMDLs models for each water body/pollutant in the 303(d) list. Section 303(d) (1) (A) of the Clean Water Act (CWA) obliges that "Each State shall identify those waters within its boundaries for which the effluent limitations...are not stringent enough to implement any water quality standard applicable to such waters." If EPA disapproves of a TMDL plan put together by a state, EPA is obliged to make a TMDL for that waterbody (USEPA, 2013).
1.4. Nonpoint Source Pollution in Michigan

Michigan developed a Nonpoint Pollution Control Management Plan, including a pioneering nonpoint source watershed program. The Best Management Practices component of that contains limitations of nonpoint source pollution of surface water; in 1988 for the first time in the United States. Also, the USGS and MDEQ examined potential phenomena for 28 water quality constituents (physical properties, major ions, nutrients, bacteria, pH and alkalinity, and suspended sediments) for selected National Stream Quality Accounting Network stations in Michigan (Syed and Fogarty, 2005). Data were collected from 1973 to 1995 from the Kalamazoo River. The Kalamazoo River is remarkable nationally as a tragedy of historical industrial pollution. Additionally, accordingly to Kalamazoo River Watershed Council, its valley is one of the most extensively contaminated sediments in the U.S. (Kalamazoo River Watershed Management Plan, 2011).

Pollutants Controlled Calculation and Documentation were prepared and high phosphorus loading have been identified by Michigan Department of Environmental Quality in 1999. Control of this contamination obliges a concerted effort from government, state, and local organizations. This has been fulfilled in a few watersheds through the TMDL implementation, while numerous others stay disregarding federal standards (MDEQ, 2002).

By successfully utilizing Best Management Plan (BMP), there is a high probability of preventing and controlling polluted runoff from reaching a creek, pond, lake, or wetland. The conditions will probably stay within the water quality
regulations for Michigan, if the state prevents or controls nonpoint source pollution. (Larry, 2001).

In addition, Michigan’s NPSP aids state, federal and local partners in the rehabilitation of water bodies impaired by NPS pollution and protects high quality waters from impairments by reason of NPS pollution. (MDEQ, 2013)

1.5. The Problem Statement

Davis Creek watershed is located in the urban and urbanizing core of the Kalamazoo County, Michigan with headwaters in the surrounding agricultural communities. Davis Creek watershed has been identified as the most polluted tributary in Kalamazoo Country. Also this creek has been a major contributor of phosphorus to contiguous lakes. Agriculture as well as runoff from industrial, commercial and residential improvements has been recognized as the main sources of nonpoint source pollution (KCDC, 2002).

One of the recent research projects on this region was completed by Porntip Limlahapun (2002). The study analyzed the impact of land use change on NPS pollution in the Davis Creek Watershed between 1978 and 1996 by using Agricultural Nonpoint Source Pollution (AGNPS). In this study, AGNPS was used to estimate soil erosion and sediment rates, nutrient loading and runoff rates for the entire watershed (He et al., 2001, 2003). However, this original model was not capable of simulating groundwater influences and is a single event model.
Another recent study was completed by Peter Kimosop in 2005. This project attempted similar estimation the project period which was from 1998 to 2004. Recent changes in the watershed create the need for a newer study incorporating more recent data.

This study is intended to examine the impact of land use change from 2001 to 2011 on runoff, sediment load and nutrient loads in the Davis Creek Watershed using the Soil and Water Assessment Tool (SWAT) with the aim of supplying recommendations to have the best management practices to control nonpoint source pollution.

1.6. Study Area

The Davis Creek watershed is located along the eastern part of the cities of Kalamazoo and Portage, within the core of Kalamazoo County, Michigan (Figure 1). Davis Creek flows roughly 8.7 miles and covers a 9,424 acre watershed. The watershed home to approximately 15,300 people (KCDC, 2011). According to Kalamazoo County Drain Commissioner, the main sources of sediment, phosphorus and other pollutants within the Davis Creek are stream bank erosion and urban land use practices. Also, the Watershed Management Plan further identified known water quality problems within the watershed, including oil, and toxic chemical releases from near industrial properties, trash, sediment bars and algal blooms (Kalamazoo County Drain Commissioner, 2011).
Figure 1. Location of the Davis Creek Watershed in Kalamazoo County, Michigan (Source: Michigan Geographic Information Library)
The Davis Creek Watershed ranges in elevation between 230 and 280m above sea level. The watershed has been facing significant land use changes since the late 1970s. According to the 2011 National Landcover Data (NLCD), the major land use of the watershed are shown in Figure 2. Below Table_1 shows percentage of land cover use in the Davis Creek Watershed.

*Table1*. Percentage of land cover use in the Davis Creek Watershed.

<table>
<thead>
<tr>
<th>Land use</th>
<th>Description</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban and-low density</td>
<td>Single-family housing</td>
<td>14%</td>
</tr>
<tr>
<td>Urban land-medium density</td>
<td>Multi-family housing</td>
<td>14%</td>
</tr>
<tr>
<td>Urban land-high density</td>
<td>Apartment complexes, Row houses</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>Shopping center, Parks Recreation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rail transportation</td>
<td></td>
</tr>
<tr>
<td>Commercial/Transportation</td>
<td>transportation</td>
<td>9%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Cultivated Crops</td>
<td>21%</td>
</tr>
<tr>
<td></td>
<td>Grassland/Herbaceous</td>
<td></td>
</tr>
<tr>
<td>Rangeland</td>
<td>Sedge/Herbaceous Lichens</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Deciduous Forest Evergreen Forest</td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>Mixed Forest</td>
<td>6%</td>
</tr>
<tr>
<td>Hay</td>
<td>Pasture Hay</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>Woody Wetlands Emergent</td>
<td></td>
</tr>
<tr>
<td>Wetland</td>
<td>Herbaceous Wetlands</td>
<td>8%</td>
</tr>
<tr>
<td>Water</td>
<td>Open Water</td>
<td>1%</td>
</tr>
</tbody>
</table>
The watershed is historically associated with mostly glacial till plains and ponded areas resulting from past activities. The Davis Creek watershed soils range from poorly drained Adrian mucks, Brady, Gilford sand loams, Houghton, Sebewa and Glendora sandy loams, well-drained Kalamazoo loams and Oshtemo sandy loams, Sleeth, Udipsamments level to steep, Urban land, Urban land-Glendora complex, Urban land-Kalamazoo complex, Urban land-Oshtemo complex, Water as shown in Figure 3. Dominant hydrologic soil group is B as shown Figure 4. Soils in this group have low runoff potential in a certain extent when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10% and 20% clay and 50 % to 90% sand and have loamy sand or sandy loam textures (United States Soil Conservation Service, 1922).
**Figure 2.** 2011 Land use map of the Davis Creek Watershed
(Source: NLCD National Landcover Characterization Data, 2011)
Figure 3. 2011 Soil class map of the Davis Creek Watershed (Source: SSURGO-Soil Survey Geographic Data Base)
Figure 4. Hydrologic Soil Group map of the Davis Creek Watershed (Source: SSURGO-Soil Survey Geographic Data Base)
1.7. Objectives of the Study

The objectives of this study are:

1. Estimating the nutrient and sediment loading using SWAT to recognize the most polluted sub-basins in the watershed with the aim of determining the most appropriate land uses (e.g., agriculture, industrial, commercial, residential) in this surrounding areas through a 14 years period (1999-2013).


3. Evaluating the uncertainty of the SWAT model in the Davis creek by comparing the observed (actual) data with simulated yield and nutrients loading to prove sensitivity analysis and their default values for future studies.

4. Assessing the best management practices (BMPs) scenarios for controlling and reducing nonpoint source pollution in the watershed.
Nonpoint source pollution has received much attention by federal agencies, academic studies, research institutes and private entities that have been involved to develop methods to estimate and mitigate its impacts. Various studies have been conducted all through the United States to investigate the relationship between water quality and explanatory variables, where a wide range of methods have been used and numerous logical variables have been analyzed. There are three primary techniques used in the attempt to research deeply and analyze water quality issues, including statistical analysis, the use of a Geographical Information System (GIS), or some combination of statistical analysis and a GIS (Wermuth, 2006). In this chapter, these primary techniques will be discussed based on previous studies.

2.1. Nonpoint Source Pollution

Nonpoint source pollution has been characterized as the consequences of diffuse processes that bring pollutants into water bodies. In the 1970s, the control of point source pollution discharges was supported by regulatory action on the part of the Clean Water Act of 1972 in the United States. Since then, controlling nonpoint source pollution has become the most important step in water quality improvement (Novotny, 1999).
Point source pollution is produced from a source which is identifiable and manageable, for instance, metropolitan or modern wastewater treatment plants. But nonpoint source pollution management is a great challenge because of the unstable origin of diffusion (Limbrunner, 2008). Phosphorus, for example, is one common pollutant originating a nonpoint source.

Phosphorus sorbs emphatically to fine-grained particles (Chapra, 1997) and most agricultural and suburban soils display a consistent amassing of phosphorus (Novotny, 2003). The erosion of phosphorus-containing soils can bring about nonpoint source conveyance to water bodies. Moreover, adjusting the amount of phosphorous discharge, urbanization seems to assume an essential part in the timing of phosphorus delivery. Burton et al. (1977) found that 98% of the aggregate phosphorus burden was traded in streamflow from the urban watershed in their study, while 53% of aggregate phosphorus burden sent out in streamflow on a forested-agrarian watershed they studied. Nonpoint source toxins also are produced by diffuse process and are regularly subject to complicated transport, change, and interference forms along the way to a target water body.

2.2. Management of Nonpoint Source of Pollution

Management techniques for nonpoint source pollution (NPS) have been needed to link numerous complicated approaches, theory and models where the best choices are not always clear. Scientists have begun to consider differences
between storm water runoff and other nonpoint sources when they try to find best way for land use surface management (Limbrunner, 2008). This highly complex structure has been investigated formally since the 1940s and 1950s by research group (Hillier and Lieberman, 2001), and started to be the foundation for water quality management in the 1960s and 1970s (Haith, 2003). A brief history is given below.

Revelle et al. (1968) applied a management system to minimize the expense of removal of biological oxygen demand (BOD) from waste water treatment plants. This method was based on cost effectiveness, ideal configuration and operation of a wastewater discharge plant. Then, this approach was connected to watershed drainage systems to optimize detention pond operation.

Mays and Bendient (1982) built up a dynamic program for spotting and estimating lakes for dendritic confinement frameworks with drainage channels interfacing the detainment basins. Jenq et al. (1983) applied a linear program to examine reduction of nonpoint source pollution by following principles of Revelle et al. (1968). In their examination, Jenq et al. (1983) lumped nonpoint source pollutant producing zones, and treated areas as point source of pollution to a stream.

Schleich and White (1997) utilized a linear program and a lumped model to discover the minimum expense management method to meet phosphorus and aggregate suspended solids lessening for a watershed containing point sources
and nonpoint sources. Elliot (1998) applied algorithm and a spreadsheet model to
discover best frameworks of detainment for multi-target objectives.

Sample et al. (2001) analyzed a combination of best management plan
(BMP) controls and minimum cost of land use choice using linear programming.
Burn et al. (2001) utilized a genetic algorithm to reanalyze the optimization
problem as analyzed by Revelle et al. (1968) of load reduction allocation for
oxygen demanding wastes. They enlarged the first definition to consider a
measure of value in the removal fraction allocated to each waste discharger.

Roesner et al. (2001) specified that stream control is a crucial step to
succeeding in attaining water quality targets in urban watersheds and that urban
runoff management projects ought to organize the management of flow. Veith et
al. (2003) applied an evolutionary algorithm to reposition BMP to agricultural
fields. They added to a watershed-scale, appropriated sediment routing model,
utilizing the USLE for sediment generation, and simulating down slope sediment
capture along flow paths.

Srivastava et al. (2003) explored the issue utilizing a genetic algorithm and
the watershed model AnnAGNPS to gauge the consequences of BMP with
applying design storms and continuous simulation. It shows up the determination
of methodology is more useful for specific pollutant and management practices
(Larson et al., 1997).

Zhen et al. (2004) updated AnnAGNPS and utilized the model to discover
optimal plans of detention ponds. They applied an evolutionary algorithm, scatter
pursuit, to investigate the tradeoff between storm water pond framework cost and

Bekele and Nicklow (2005) investigated the tradeoffs between environmental quality and agricultural productivity using a multi-objective evolutionary algorithm. Arabi et al. (2006) utilized SWAT and represented BMP by altering corresponding SWAT parameters. They optimized the use of best administration hones at the watershed scale utilizing a genetic algorithm.

Contemporary solution techniques have been applied more frequently to nonpoint source pollution management. These techniques, including genetic algorithms, are powerful tools for analyzing the large and complex decision spaces often associated with nonpoint source pollution management problems (Limbrunner, 2008). The scientific and engineering community can provide help to overcoming these barriers through developed communication of exploratory thoughts and by giving decision makers enhanced access to investigative information and examination tools.

2.3. Total Maximum Daily Load

The Total Maximum Daily Load (TMDL) procedure provides a system for reacting to and reducing nonpoint source pollution, and has been central to endeavors to increase the condition of surface waters that are not achieving water quality benchmarks pertinent to their assigned use. TMDL came into
existence in 1972 with the proclamation of the Clean Water Act that particularly described point sources of pollution as not quite the same as nonpoint source of pollution.

The separation of point and nonpoint source pollution was a key decision by the U.S. Congress in framing a national way to pollution control with consequences for contemporary nonpoint source pollution control strategy (Ice, 2004). There was little action identified with the decrease of nonpoint source pollution under the TMDL program in the years promptly following the approval of the Clean Water Act. Amid the 1970s and 1980s, states concentrated on point source pollution regulation (NRC, 2001) under another branch of the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES).

This work is ongoing, considering the final requirement of more than forty thousand TMDLs to be created in the United States to address the impaired condition of the water bodies recorded under Section 303(d) of the Clean Water Act (NRC, 2001).

The TMDL procedure gives a system in which to oversee nonpoint source pollution, and contains three general exercises. The primary is the recognizable proof of water bodies which are unimpaired for its assigned utilization. The second part of the TMDL procedure includes deciding the acceptable load of a pollutant that could be released to a water body from all sources. The last significant part of the TMDL structure includes assignment of the allowable load among all potential sources in a basin. These procedures were outlined briefly in the introduction.
TMDL computations are provided and applied by the USEPA and state offices to gauge the amount of pollution that a watershed can receive and still meet water quality standards (USEPA, 2000). The TMDL calculations are the premise for a significant part of the permitting and water quality rules as to sediment and nutrient loading. These distinctions focus the viability, restrictions, and suitability of the models for different applications. In expansion to having the capacity to reproduce this real conditions of waterbody, these mathematical statements can likewise capacity to figure out TMDLs and predict and non-point and point source pollution transport inside a watershed. So, each state must develop a TMDL for each of the impaired watersheds.

2.4. Modeling Nonpoint Source Pollution at the Watershed Scale

Soil erosion, sediment and nutrient loading are the issues have been enhanced to understand, manage and mitigate soil erosion and pollution. The issues which are connected with nonpoint source pollution are regularly best approached by considering management choices on a basin-wide scale (Haith, 2003). Several researchers have noticed the potential for autonomously composed, a site-scale detention system to expand watershed-scale storm water crest mitigation including Yeh and Labadie (1997). Emerson et al. (2005) also utilized a hydrologic model of a watershed in Pennsylvania to demonstrate that a current detention basin framework is equipped for expanding watershed peak flow rates. Their outcomes propose a requirement for composed arranging and operation of site-scale detainment basins.
Soil erosion, pollution transfer, sediment and nutrient models have regularly been used to comprehend and oversee soil erosion and pollution at all types of scales. Both USEPA and the USDA have contributed financially and towards the development and implementation of these transport models (Merritt et al., 2003).

Smith and Whitt (1948) were credited by Renard et al. (1996) with displaying a "rational" erosion assessing equation that began with a settled amount of erosion for a chosen base case and altered the base erosion utilizing components for rainfall erosivity, soil erodibility, slope steepness, slope length, cover and management and support practices. Upgrades and changes to the USLE (Universal Soil Loss Equation) have happened through the last several decades, and right now it exists as the generally connected Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1996). The USLE and RUSLE are empirically- based models for forecast of erosion at the hill slope scale. The consolidated use of the soil conservation service curve number system for overflow estimation and the USLE or RUSLE strategy for erosion estimation is the basis to numerous nonpoint source pollution models. An alternate way to forecast erosion on the hill slope scale is the Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995), a physically based slope incline scale erosion demonstrate that is expected as a substitution to the more general Universal Soil Loss Equation (Laflen, 1997).

The Soil and Water Assessment Tool (SWAT) is a semi-disseminated watershed model produced by the USDA's Agricultural Research Service to
address the issue of non-point source pollution. It has the ability to model substantial zones with differing land uses, and incorporates algorithms to test the impacts of best management systems, including vegetative filter strips. It runs on daily time step producing long-term impacts or short time estimation. (Arnold et al. 2011). SWAT is a direct adjustment of the Simulator for Water Resources in Rural Basins (SWRRB) model (Williams et al., 1985). SWAT was created because SWRRB model was restricted to little watershed stretching out to a couple of hundred square kilometers.

SWAT is the most capable nonpoint source simulation model when compared with the Agricultural Nonpoint Source Pollution (AGNPS) model- an event-based model used to simulate sediment, runoff, nitrogen and phosphorus transport, and chemical oxygen demand for single rainfall events; the Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWER) model - models runoff, infiltration soil loss and subsurface drainage for a single event; the Annualized Agricultural Nonpoint Source Pollution (AnnAGNPS) model - a continuous simulation model used to assess pollutant loadings and the Chemical, Runoff and Erosion from Agricultural Management Systems (CREAMS) (Borah et al., 2003 and Merritt et al., 2003)

SWAT has been used for a number of applications at various scales. Francos et al (2000) connected the model to survey the effect of climate changes and agricultural management activities on nitrogen and phosphorus loading in a medium-sized watershed in Finland. Pruillet al (2000) used SWAT to depict month by month and day by day stream flows from watershed in Kentucky.
CHAPTER 3

METHODOLOGY

This project applies the SWAT model to simulate runoff, sediment yields and nutrient loadings in the main channels of each subbasin taking into account of the effect of several physical processes that influence the hydrology of Davis Creek. SWAT requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the watershed (Neitsch et al., 2002). Each of these inputs is explained below.

3.1. Description of Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) is a physically based model to simulate landscape hydrology at a catchment scale (Arnold et al., 1998; Neitsch et al., 2005). SWAT is the most capable nonpoint source simulation model that builds upon several past models. These include: the Agricultural Nonpoint Source Pollution (AGNPS) model - an event-based model used to simulate sediment, runoff, nitrogen and phosphorus transport, and chemical oxygen demand for single rainfall events; the Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWER) model that computes runoff, infiltration soil loss and subsurface drainage for a single event; and the Annualized Agricultural Nonpoint Source Pollution (AnnAGNPS) model - a continuous simulation model used to assess pollutant loadings and the
Chemical, Runoff and Erosion from Agricultural Management Systems (CREAMS) (Borah et al., 2003 and Merritt et al., 2003).

Each sub-basin has a set of Hydrologic Response Units (HRU) which comprise of pixels with comparable soil, land use, and soil characteristics (Psaris, 2013). Every HRU can be conceptualized as a field with consistent slope, bordering the stream reach. SWAT computes the flow, sediment and nutrient yields from a HRU, adds it to what was conveyed from the upstream reach, and after that figures in-stream forms.

In this study ArcSWAT 2012.10.2.16 is applied as an extension to ArcGIS 10.2.

3.2. SWAT Input

Topographic Variables

A 30 meter resolution Digital Elevation Model (DEM) for Davis Creek watershed was downloaded into SWAT from Geo Community website http://www.geocomm.com. The first step was to delineate subwatersheds from the DEM. The interface allows for import of a map that masks out part of the DEM grid but in this case the main outlet point cloud slightly outside of the outlet of watershed. So, shapefile of the Davis Creek watershed was imported to ArcMap to draw a more accurate polygon mask manually in order to specify watershed area. After that, all data were defined as project NAD_1983_UTM_Zone_16N on ArcCatalog. The watershed drainage covers
about 9400 acres. In this project, the watershed was divided into 31 subbasins as shown in Figure 1.

Land Use Data

SWAT requires land use data to determine the area of each land category to be simulated within each subbasin. For this project, the most recent 30-meter, seamless, land cover database land cover data NLCD 2011 land cover map is applied for land use grid data from National Land Cover Database website http://www.mrlc.gov/. Also SWAT provides legend information for NLCD database. Land use type is summarized in Figure 2.

Soil Data

Soil type Soil data were downloaded from Soil Survey Geographic Database (SSURGO). The data were imported to SWAT and its soil types (MUID) were first matched with the SWAT_US_SSURGO_Soils, and then were reclassified within the SWAT.

Climate Data

This model has a good advantage for users for all around the world because the weather data which is needed for this tool is available at the Global Weather Data for SWAT at the http://globalweather.tamu.edu/ website.

The watershed location was used to query the global weather data website and 4 weather stations were found for that area. Weather data was requested
from 1/1/1990 to 12/31/2013 for the four stations; Battle Creek, Kalamazoo River at Comstock, Austin Lake Near Kalamazoo and West Fork Portage Creek at Kalamazoo.

Input weather variables including: Temperature (C), Precipitation (mm), Wind (m/s), Relative Humidity (fraction), and Solar (MJ/m²) were used in the SWAT.

**Management Information**

Fertilizer application for common crops grown in the watershed was obtained after having some interviews with local farmers (*personal communication, Bak-Ayr Farms, Nov. 2013*). They provided fertilizer application recommendations supported by Michigan State University extension documents for the most common crops: corn and soybeans. Also, the chisel plow was identified as the main tillage operation in both corn and soybeans within the watershed area (Buckham, 2004).

### 3.3. SWAT Calibration and Simulation

The model was run for 23 years; from 1/1/1990 to 12/30/2013 for the Davis Creek Watershed. At least 4 warm up years are recommended and in this study the eight years from 1990-1998 were used for warm up time. Normally, parameter sensitivity analysis could have been performed by the SWAT Calibration and Uncertainty Program (SWAT-CUP) to learn most sensitive parameters. SWAT-CUP could not be used in this study because of the
insufficient of observed flow, sediment and nutrient data. Thus the most sensitive parameters were identified based on the previous studies which are either for the Davis Creek Watershed or for the larger Kalamazoo River Watershed (Serfas, 2012). Similarity in land types, soil type and slope between the two studies makes it reasonable to take his study as a reference for sensitivity analysis.

In this study, those sensitivity parameters were applied as calibration parameters. Then the model was run for the selection of time period 1999-2001 because of the availability of observed streamflow data at the outlet of watershed for this time allowed for calibration. Streamflow (discharge) was the only variable that was capable of being calibrated. Those parameters were manually adjusted depending on soil type and land cover uses in order to obtain reasonable match between observations and model simulations. Below Table 2 shows the parameters and fitted values.

The results of 1999-2001 simulation shows that calibrated parameters are reasonable to use for whole time period simulation. The simulation output is similar to observed data, especially 2000 and 2001. The output from SWAT during calibration is shown below Table 3. The flow data for May 1999 to June 2001 were collected and provided from Dr. Chansheng He and his research team. However, the available observed data does not cover the whole simulated period. Those are the only and insufficient data that is available to be used for calibration since Davis Creek Watershed is an ungauged watershed.
Table 1. Parameter values for flow and sediment calibration used in the Davis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter name</th>
<th>Description</th>
<th>Fitted parameter values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>r_CN2.mtg*</td>
<td>Curve Number</td>
<td>66-88</td>
</tr>
<tr>
<td></td>
<td>r_SOL_AWC.sol**</td>
<td>Available water capacity</td>
<td>+0.04</td>
</tr>
<tr>
<td></td>
<td>v_GW_REVAP gw***</td>
<td>Ground water revap co-efficient</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>v_REVAPMN gw</td>
<td>Threshold water depth in the shallow aquifer for revap</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>v_ESCO hru</td>
<td>Soil evaporation compensation</td>
<td>0.80</td>
</tr>
<tr>
<td>Sediment</td>
<td>v_USLE_P</td>
<td>Universal Soil Equation practice factor</td>
<td>0.48</td>
</tr>
<tr>
<td>N</td>
<td>v_USLE_P</td>
<td>Universal Soil Equation practice factor</td>
<td>0.48</td>
</tr>
<tr>
<td>P</td>
<td>v_USLE_P</td>
<td>Universal Soil Equation practice factor</td>
<td>0.48</td>
</tr>
</tbody>
</table>

*The extensions; mtg, sol, gw and hru refers to the SWAT input file where the parameter occurs.
**The qualifier "v_" refers to the substitution of a parameter by a value from the given range.
*** The qualifier "r_" refers to relative change in the parameter where the value from the SWAT database is multiplied by 1 plus a factor in the given range.
Table 2. Comparison of the simulated and observed flow for Davis Creek for the period of 1999 - 2001

<table>
<thead>
<tr>
<th>Year</th>
<th>Simulated (m3/sec)</th>
<th>Observed (m3/sec)</th>
<th>Sediment (tons/ha/yr)</th>
<th>Nitrogen (kg/ha/yr)</th>
<th>Phosphorus (kg/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>0.2</td>
<td>0.1</td>
<td>10.614</td>
<td>31.71</td>
<td>6.56</td>
</tr>
<tr>
<td>2000</td>
<td>0.1</td>
<td>0.1</td>
<td>5.95</td>
<td>19.75</td>
<td>3.49</td>
</tr>
<tr>
<td>2001</td>
<td>0.2</td>
<td>0.2</td>
<td>9.728</td>
<td>31.99</td>
<td>5.87</td>
</tr>
</tbody>
</table>

Results of the 1999-2001 simulation shows that 2001 has almost same flow rate but sediment and nitrogen loads are lower than 1999. Differences of sediment, nitrogen and phosphorus loading between two years is around one ton per hectare but considering the whole watershed this difference becomes more significant, around 4000 tons total. Precipitation and surface runoff values of these two years were very similar except the timing of storm events. In 2001, storm events occurred mostly August, September, October and November as shown below Figure 5. On the contrary, storm events ensued frequently January, February, May, and July in 1999. This could be explain that sediment and nutrient loading were less in 2001. The time when storm events happened in 2001 is the time when harvested crop left on the ground which reduces sediment and nutrient loads. This reason can support that changed value parameters are appropriate.
After having examined similarities and differences in simulated and observed data, the parameters were considered adequately calibrated and used for all further simulation runs up to 2011. Additional data were used for comparison to model results from later time periods.

To that end, the Kalamazoo Drain Commission released a report titled “Engineering Report for Davis Creek Phosphorus Reduction Study in 2011”. It provides sediment, nitrogen and phosphorus loading which gives an opportunity to validate the simulation result. This report provides amount of sediment, nutrient and phosphorus loading for 7 selected areas which match some subbasins in this study area as shown Figure 6. Comparing the results of the report and the final simulations results shows similar relationship. Numbers are not exactly match as shown below in Table 4 and Table 5. But it has same relationship as 2011.
simulated results. These numbers do not exactly match because they just
selected small location on reach but mu numbers for whole match subbasin.

*Table 3. Kalamazoo Drain Commission engineering report 7 selected areas*

<table>
<thead>
<tr>
<th>Area</th>
<th>Sediment (tons/year)</th>
<th>Nitrogen (kg/year)</th>
<th>Phosphorus (kg/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area-1 Springfield to Brookfield</td>
<td>75</td>
<td>58</td>
<td>30</td>
</tr>
<tr>
<td>Area-2 Stewart Drive to Market Street</td>
<td>60</td>
<td>46</td>
<td>23</td>
</tr>
<tr>
<td>Area-3 Twin Culverts</td>
<td>90</td>
<td>70</td>
<td>35</td>
</tr>
<tr>
<td>Area-4 Canadian National Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road to Twin Culverts</td>
<td>270</td>
<td>208</td>
<td>104</td>
</tr>
<tr>
<td>Area-5 Canadian National Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>216</td>
<td>166</td>
<td>83</td>
</tr>
<tr>
<td>Area-6 East Cork Street</td>
<td>85</td>
<td>65</td>
<td>33</td>
</tr>
<tr>
<td>Area-7 Colonial Acres</td>
<td>2</td>
<td>80</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>798</td>
<td>693</td>
<td>333</td>
</tr>
</tbody>
</table>
Table 4. Simulated results of 7 selected areas’ subbasin

<table>
<thead>
<tr>
<th>Subbasin</th>
<th>Sediment (tons/year)</th>
<th>Nitrogen (kg/year)</th>
<th>Phosphorus (kg/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(Area1,2,3,4)</td>
<td>1872</td>
<td>227</td>
<td>75</td>
</tr>
<tr>
<td>2(Area4)</td>
<td>123</td>
<td>69</td>
<td>45</td>
</tr>
<tr>
<td>3(Area4,5)</td>
<td>1720</td>
<td>201</td>
<td>59</td>
</tr>
<tr>
<td>4(Area6)</td>
<td>470</td>
<td>135</td>
<td>38</td>
</tr>
<tr>
<td>5(Area6)</td>
<td>88</td>
<td>39</td>
<td>30</td>
</tr>
<tr>
<td>6(Area6)</td>
<td>316</td>
<td>62</td>
<td>17</td>
</tr>
<tr>
<td>11(Area7)</td>
<td>60</td>
<td>22</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td>4649</td>
<td>755</td>
<td>280</td>
</tr>
</tbody>
</table>
Figure 6. Davis Creek Phosphorus Reduction Study 7 selected areas (Source: KDC, 2011)
CHAPTER 4

RESULTS AND DISCUSSION

The simulated model output, land cover impacts on sediment and nutrient loading are presented and discussed in this chapter.

4.1. Validation of Simulated Results

Twelve years of simulation show that 2008 has the highest sediment, nitrogen and phosphorus loading values as shown in Table 6. This seems quite reasonable because, as shown below Figure 7, 2008 has the highest precipitation as well. Also, 2002, 2003, 2007, 2008, 2009 and 2013 are the highest loading years during the simulation period. The flow of sediments and nutrients in the watershed is highly influenced by ground water flow and surface runoff. Also, model output show higher surface runoff rates in the residential, commercial and transportation areas. These land uses mainly located in the northern and southwestern part of the watershed. Subbasin 1, 4, 6, 11 and 14 have higher runoff rates compared to other subbasin. Agricultural areas located in the eastern and southeastern portions of the watershed where have low runoff and loading rates compared to whole watershed.
Table 5. Simulated sediment, nitrogen and phosphorus loading at the Davis

<table>
<thead>
<tr>
<th>Year</th>
<th>Simulated</th>
<th>Sediment (tons/ha/year)</th>
<th>Nitrogen (kg/ha/year)</th>
<th>Phosphorus (kg/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>0.3</td>
<td>12.937</td>
<td>36.31</td>
<td>7.49</td>
</tr>
<tr>
<td>2003</td>
<td>0.3</td>
<td>12.906</td>
<td>35.06</td>
<td>6.96</td>
</tr>
<tr>
<td>2004</td>
<td>0.3</td>
<td>8.802</td>
<td>31.54</td>
<td>5.54</td>
</tr>
<tr>
<td>2005</td>
<td>0.2</td>
<td>9.162</td>
<td>32.9</td>
<td>6.52</td>
</tr>
<tr>
<td>2006</td>
<td>0.2</td>
<td>7.608</td>
<td>25.75</td>
<td>4.09</td>
</tr>
<tr>
<td>2007</td>
<td>0.3</td>
<td>12.702</td>
<td>39.75</td>
<td>8.08</td>
</tr>
<tr>
<td>2008</td>
<td>0.5</td>
<td>18.926</td>
<td>54.17</td>
<td>11.51</td>
</tr>
<tr>
<td>2009</td>
<td>0.4</td>
<td>17.277</td>
<td>46.01</td>
<td>8.96</td>
</tr>
<tr>
<td>2010</td>
<td>0.3</td>
<td>7.513</td>
<td>26.61</td>
<td>4.72</td>
</tr>
<tr>
<td>2011</td>
<td>0.2</td>
<td>8.702</td>
<td>29.42</td>
<td>5.08</td>
</tr>
<tr>
<td>2012</td>
<td>0.1</td>
<td>4.326</td>
<td>16.26</td>
<td>2.18</td>
</tr>
<tr>
<td>2013</td>
<td>0.4</td>
<td>17.321</td>
<td>48.18</td>
<td>10.02</td>
</tr>
</tbody>
</table>
4.2. Sediment Loading

The calibrated results show sediment loading is higher in residential medium and high density areas where there are mostly single and multiple family housing units than in commercial and industrial areas. These areas are mostly vegetation planted in develop setting for recreation erosion control or aesthetic purposes. By the total sediment load per year, erosion from subbasins 1, 4, 6, 11, 14 and also 3, 16, 17, as shown in Figure 8, are highest. Besides residential and industrial nonpoint pollution, agricultural practices are another major source of sediments.

Figure 7. Precipitation and simulated runoff for the Davis Creek Watershed from 1999 to 2013
Figure 8. Sediment loading in Davis Creek for period of 2002 - 2013
4.3. Phosphorus Loading

Phosphorus loading in Davis Creek is higher in the same subbasins with higher sediment loading. The subbasins 1, 4, 6, 11 and 14 have the high phosphorus loading per hectare for the entire watershed as shown in Figure 9. Though phosphorus loading happens in residential and industrial areas primarily, another standing out feature is soil type. Because those subbasins soil types are urban land - Glendora, Kalamazoo, Oshtemo complex. Simulated result shows that agricultural areas contributes lower amount of phosphorus loading than residential areas.
Figure 9. Total Phosphorus loading in Davis Creek for period of 2002 - 2013
4.4. Nitrogen Loading

Nitrogen loading unlike phosphorus and sediment loading do load on subbasin 3 more. Also, subbasin 1, 4, 6 has highest rate of Nitrogen loading as shown in Figure 10. Agricultural areas where are located southeastern has high amount of nitrogen loading because of overuse fertilizer and land cover management.
Figure 10. Total Nitrogen loading in Davis Creek for period of 2002 - 2013
As a summary, consequences of this study show that sediment and nutrient loading rates are related to each other. If subbasin has high sediment loading experience, this subbasin has a higher probability of an increased rate of nutrient loading. These tables, figures and results help understand where the loading of sediment, nitrogen and phosphorus is in Davis Creek Watershed and support mitigating and controlling nonpoint source pollution problem to have drinkable, swimmable and fishable watershed.

4.5. Management Scenarios

Numerous scenarios were developed in this study to measure the impact of nonpoint source pollution on sediment and nutrient loading in Davis Creek in order to support nonpoint source pollution management. As a difference from previous studies, land cover changes were examined as scenarios. In this study, the same simulation process was applied for 2001 land cover data to compare with impact of land cover changes on sediment and nutrient loading in 2011. The following bar chart, Figure 11, shows the land cover change ratio for this 10 year span.
Figure 11. Comparison of Percentage of Land Cover Types between 2001 and 2011

(Source: NLCD-National Landcover Characterization Data, 2011)
Table 6. 1992 Land Cover / Land Use Ratio in Davis Creek Watershed
(Source: NLCD-National Landcover Characterization Data, 2011)

<table>
<thead>
<tr>
<th>Code</th>
<th>Land use</th>
<th>2001 (%)</th>
<th>2011 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTR</td>
<td>Water</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>URLD</td>
<td>Urban land-low density</td>
<td>15.3</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>Urban land-medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>URMD</td>
<td>density</td>
<td>12.6</td>
<td>13.7</td>
</tr>
<tr>
<td>URHD</td>
<td>Urban land-high density</td>
<td>9.7</td>
<td>11.6</td>
</tr>
<tr>
<td>UIDU</td>
<td>Commercial/Transportation</td>
<td>7.8</td>
<td>8.7</td>
</tr>
<tr>
<td>RGNB</td>
<td>Rangeland</td>
<td>4.2</td>
<td>4.1</td>
</tr>
<tr>
<td>FRST</td>
<td>Forest</td>
<td>5.6</td>
<td>6.0</td>
</tr>
<tr>
<td>HAY</td>
<td>Hay</td>
<td>12.5</td>
<td>11.3</td>
</tr>
<tr>
<td>AGRR</td>
<td>Agriculture</td>
<td>22.4</td>
<td>20.8</td>
</tr>
<tr>
<td>WETN</td>
<td>Wetland</td>
<td>8.3</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

As shown in Table 7 above, hay and agricultural areas decreased. In 2001, 22.4 percent of the whole watershed was agricultural area. In 2011, agricultural area was reduced by 1.6 percent which is almost equivalent to 60 hectares. Although agricultural areas can increase loadings of phosphorus and nitrogen to the discharge area, agricultural area can also reduce sediment loads and reducing runoff if fertilizer is not overused. Also hay/pasture area has been decreasing since 2001. In 2001, 12.5 percent of whole watershed was hay area
and then it has become 11.3 percent in 2011. The one and most important increasing is on residential areas. All reduction of urban land-low density, agricultural area, hay area, rangeland return has been replaced by urban land medium- high, commercial and transportation areas.

Increasing of developed urban land involves the production of new buildings, roads and parking - all of which create non-permeable surface, that both decrease infiltration and can speed up the delivery and amount of stormwater runoff to the watershed. Also, increasing of impervious land can also reduce ground water levels due to a decrease in infiltration capacity. As a result, increment of residential areas increase sediment and nutrient loading directly thereby augmentation of surface runoff.
CHAPTER 5

SUMMARY AND CONCLUSIONS

This study assessed sediment and nutrient loading in Davis Creek Watershed for period of 1999 to 2013. Additionally, impact of land use changes between 2001 and 2011 were examined. The soil and water assessment tool (SWAT model) was used to: 1) simulate the sediment and nutrient loading and 2) examine impact of land use change on resulting changes runoff sediment load and nutrient yield and 3) identify critical nonpoint source areas in the watershed to support targeted and NPS pollution management in Davis Creek watershed.

5.1. Research Funding from the Simulation

This study used Soil and Water Assessment Tool (SWAT) to simulate the movement of sediment and nutrients in the watershed. Databases of the digital elevation model (DEM), weather data, soil types, land use and management practices were used as inputs to run the SWAT. Run period was 23 years from 1990 to 2013, although years up to 2002 were used for calibration. Result from 12 years of simulation shows that; firstly, subbasin 1, 2, 6, 11, 14 are where most
loading occurs. These subbasins should be considered the most pollutant subbasins where officials should step in to remediate by local or non-profit organization. Secondly, increasing residential, commercial and transportation areas affects sediment and nutrient loading directly during this time period. Thirdly, twelve years of simulations shows, how variability of climate effects on pollutant loading. This is remarkable. For example, in 2009, precipitation was 1362.9 mm and sediment loads were 17.277 tons per hectare. Next year, precipitation declined from 1362.9 to 891.7. This changes reduced sediment loads almost 10 tons per hectare in 2010. The other way round, precipitation of Davis Creek area remained approximately 300 mm in 2011 and it cost 3tons more sediment loads for per hectare. Davis Creek watershed is a small watershed, even 3% of 9.424 acres small area can increase sediment loading up to one ton per hectare, nitrogen loading up to 4 kilograms per hectare and phosphorus loading up to 2 kilograms per hectare. Even though it is a small watershed, similar results over a larger area should be considered as causing significant differences in this region of the country.

5.2. Limitation of the Study

SWAT model requires a considerable amount of input data, nutrient and phosphorus observed data for some parameters to run SWAT-CUP to have calibrated and validated reasonable results. It was really hard to determine default values for the watershed. Kalamazoo County Drain Commissioner has broadcasted a Davis Creek Phosphorus Reduction Study Report. I provide peak
flow and sediment and nutrient pollution data but calculation of peak flow data were not explained in the study. Also, estimating sediment, phosphorus and nitrogen loading were calculated for 7 selected areas in that report, not the whole watershed. Otherwise, it could be a great reference for calibration and validation.

5.3. Recommendations

The current proportion of land covers in the Davis Creek watershed, the changes over the last decade, and the relationship among these land covers with sediment and nutrient loading all point to the need to reducing the effects of urbanization and promote afforestation throughout the watershed. Over the past several years, there have been several studies trying to describe the pollutants involved in the Kalamazoo River’s problems. None of the studies have made marked change because there is no gauge to have observed data. The fact is that having gauge is quite expensive and it is not preferable to construct gauge in every small watersheds. However, if we consider that this watershed is the most polluted watershed in Kalamazoo River and major phosphorus tributary to Allegan County according to 1999 Michigan Department of Environmental Quality Report, there must be a gauge in Davis Creek Watershed to control and mitigate the pollution.
REFERENCES


Limlahapun P.,(2002). Assessment of Land Use/ Land Cover Change Impact On Water Quality In The Davis Creek Watershed , Southeastern,Michigan Using Arcview Nonpoint Source Modeling (AVNPSM)


Rathburn, Sara L., and Ellen E. Wohl. "One-dimensional sediment transport modeling of pool recovery along a mountain channel after a reservoir sediment release."
