4-2002

Assessment of Land Use/Land Cover Change Impact on Water Quality in the Davis Creek Watershed, Southwestern Michigan

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ASSESSMENT OF LAND USE/LAND COVER CHANGE IMPACT ON WATER QUALITY IN THE DAVIS CREEK WATERSHED, SOUTHWESTERN MICHIGAN

by

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A Thesis
Submitted to The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Arts
Department of Geography

Western Michigan University
Kalamazoo, Michigan
April 2002

ACKNOWLEDGEMENTS

I would like to express my greatest appreciation to my advisor Dr. Chansheng He for all his support, help and encouragement during my education at Western Michigan University. This research would not have been possible without his guidance. I would also like to thank to Dr. Charles Emerson and Dr. Gregory Veeck for their reviews and constructive comments to this thesis.

I would particularly like to thank Dr. David Dickason and Greg Anderson for a great opportunity and experience for training at the GIS Research Center. My thanks are also extended to Faculty members and staff who have been helping me over years.

I appreciate the concern, encouragement and stimulation of my good friends. For some friends were far apart, you are always being indeed.

A very special thank to my parents and my family. I am much indebted to their comfort and everlasting support, without them, I would never be like today.

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Western Michigan University, 2002

This study uses ArcView Nonpoint Source Modeling (AVNPSM), an interface between Agricultural Nonpoint Source Pollution Model and ArcView GIS to assess the impact of land use/land cover change between 1978 and 1996 on water quality in the Davis Creek watershed, southwestern Michigan. The distribution of land use/land cover changes is identified by geographic analysis. Compared to 1978, agricultural land decreased by more than 60 percent while residential land increased by over 170 percent in the watershed in 1996. The hydrologic impact of the urbanization is evaluated by the AGNPS model. AVNPSM is used to derive required input parameters to the AGNPS model. Runoff, soil erosion, sedimentation, and nutrient (nitrogen and phosphorus) loading were simulated by AGNPS in the entire watershed. The results indicate that urbanization of the watershed significantly increased the peak flow rate, making the watershed more vulnerable to flooding. Through examination of the simulated results, erosion prone areas are identified. This information enables planners and/or decision makers to target the problem areas for best management practice.

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CHAPTER I

INTRODUCTION

Background

Nonpoint source (NPS) pollution generally results from land surface runoff, atmospheric deposition, and transport of contaminants from diverse areas. Major sources of nonpoint pollution include runoff from agricultural, forest, urban and industrial areas. These diffuse sources are often more difficult to identify, isolate, and control than point sources of pollution (USEPA, 1995). NPS pollution is caused by rainfall or snowmelt moving over and through the ground. During this transport process, the surface runoff transports natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and underground sources of drinking water. The pollutants include: fertilizer, herbicide, and insecticide runoff from agricultural lands and residential areas; oil, grease, and toxic chemicals from urban transport runoff and energy production; sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks; salt from winter road treatment, irrigation practices and acid drainage from abandoned mines; bacteria and nutrients from livestock, pet wastes, and faulty septic systems; and atmospheric deposition. Due to the great variation of NPS pollution dispersal, content and sources (Agosti, 1998), NPS cannot be monitored at its points of origin, and the precise sources of the final depositions are difficult, if not impossible, to trace (Mostaghimi et al., 1997).

NPS water pollution results from a wide variety of human activities on the land and has been identified as a significant source of water quality pollution in the United States (USEPA, 2001) (http://www.epa.gov/region4/water/nps/). Urban sprawl, the expansion of residential, commercial, industrial and service land uses to rural or agricultural land, is one of the causes of water pollution. Urban sprawl has been expanding rapidly in the past fifty years all over the world. In the United States, urban sprawl has sparked a national debate over land-use policy (Samuel, 1999). The debate over sprawl is driven primarily by general concerns that low-density residential development threatens farmland and open space, increases public-service costs, encourages people and wealth to leave central cities, and degrades the environment (Samuel, 1999).

Human activities on the land, including farming and land development, change the natural landscape, especially the land adjacent to water resources. The altered landscape results in “the built-up” environment, reduces infiltration capacity and produces a greater volume of run off into rivers, lakes or creeks. In the “porous”, natural landscapes such as forests, wetlands, and grasslands, runoff tends to reach receiving waters gradually. In contrast, the effluents and runoff from nonporous urban landscapes such as roads, bridges, parking lots, and buildings have little or no infiltration into the soil. Water remains above the surface, accumulates, and flows in greater intensities to move over limited area (USEPA, 2001). In the mean time, the increased runoff often carries larger load of pollutants in water (Kieser & Association, 1999).

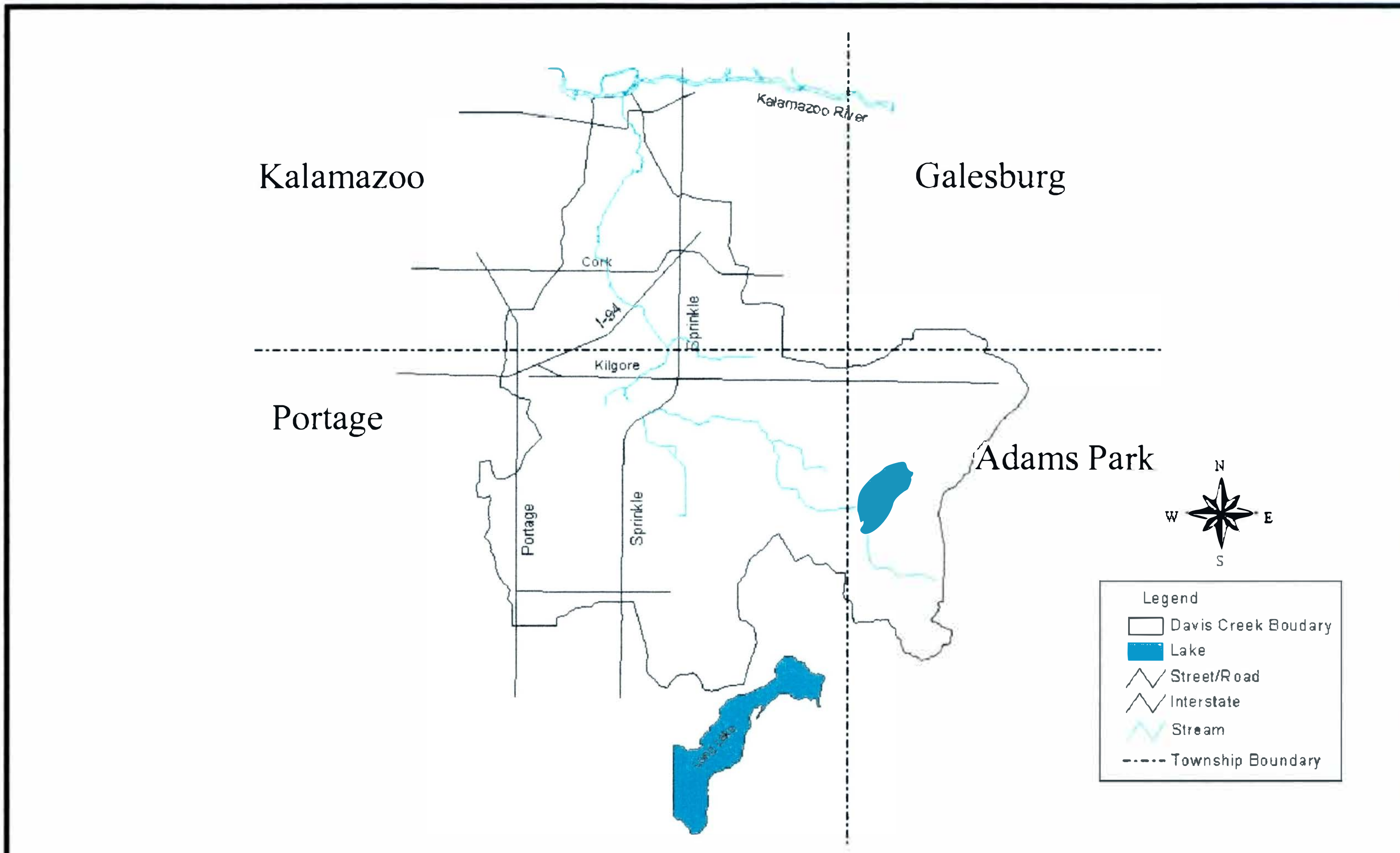
Clearly, NPS water pollution has a significant impact on human health. Runoff from agricultural lands, intensive livestock feeding and other NPS operations may be contributing unacceptable levels of organic matter, sediment, chemicals and bacteria to surface and groundwater supplies. This could result in eutrophication and depletion of oxygen in surface waters, leading to acidity and toxicity in surface and groundwaters, and adversely affecting water uses for human and the entire ecosystem (Harker, 1997). The effect of toxic contaminants on human health can be either acute or chronic.

The reaction to a substance causing serious illness or death in an individual within 48 hours after exposure is considered acute toxicity (Willmitzer, 2001). Chronic toxicity is a long term effect on health due to frequent exposures to small amounts of a toxic substance. Chronic reactions to chemicals are difficult to study and our knowledge of the chronic toxic effects of nearly all chemicals is very poor. Examples of chronic health effects would be kidney and liver disease, cancer, mental illness, etc. (Willmitzer, 2001). Since water supplies, either surface water or groundwater, are essential to meet domestic, agricultural, industrial and recreational demands, NPS impacts on human health and ecosystem need to be promptly addressed.

This study assesses the impacts of land use/land cover change on water quality by identifying critical areas in the study watershed and providing such information to management agencies for development of management programs.

Study Area

The study area of this research is the Davis Creek watershed (Figure 1). It is located along the eastern portions of the cities of Kalamazoo and Portage, within the core of Kalamazoo County, Michigan. The Davis Creek watershed covers a drainage area of about 9,311 acres and is home to approximately 13,000 people. The length of Davis Creek is approximately 6 miles (Kieser & Associates, 2000). Davis Creek is one of the tributaries of the Kalamazoo River and has received tremendous public attention during the past ten years as a valuable and shared resource for community economic growth and quality of life enhancements (The River Partners Program, 1996). However, water quality of Davis Creek changed significantly during the past century, and this change is expected to continue (Kieser & Association, 1999). Such changes include increased flooding from urban runoff, intensified surface water contamination by toxic chemicals, and elevated soil erosion and sedimentation. As a result, Davis Creek has been identified as the most polluted tributary to the Kalamazoo River in Kalamazoo County (The Forum of Greater Kalamazoo, 1998). Since Davis Creek has no sources of direct industrial or municipal discharge to the creek, its water quality problems are mainly caused by past and present nonpoint sources (The Forum of Greater Kalamazoo, 1998).



Source: GIS Research Center, Western Michigan University

Figure 1. The boundary of the Davis Creek watershed

Problem Statement

The Davis Creek watershed has been a focal point of several management programs in recent years. A number of projects were initiated to tackle environment problems within the watershed. Still there has been no systematic research done in the Creek to examine the causes of and impacts of NPS. As land use practices often are the main causes of NPS pollution, it is critical to assess the impact of land use on NPS and to identify the critical problem areas in order to support water resource planners and program managers to better manage the Davis Creek watershed.

This study analyses the impact of land use on NPS pollution in the Davis Creek watershed by examining land cover changes between 1978 and 1996, and assessing the impact of these changes to nonpoint source pollution. Aerial photographic interpretation is used to identify the spatial and temporal changes of land cover. Separate land mosaics are compared to determine types and magnitude of land cover change between 1978 and 1996. The study uses ArcView Nonpoint Source Modeling (AVNPSM), an interface between Agricultural Nonpoint Source Pollution Model (AGNPS) and ArcView GIS to evaluate non-point source pollution in the Davis Creek watershed (He et al., 2001). AGNPS is used to estimate soil erosion and sediment rates, nutrient (nitrogen and phosphorus) loading potential, and runoff rates across the entire watershed. The results of the simulation help identify the critical problem areas to support water resource decision-making.

Objectives

Land use change has a significant impact on the nonpoint source pollution. Since the leading cause of degraded water quality in the Davis Creek watershed is NPS pollution, identification and assessment of land use impact on water quality is essential for NPS management. The results, including critical areas of nutrient levels and sedimentation, will provide important information to resource managers and planners for protection, planning and management of Davis Creek. The objectives of this study are: 1) to analyze the types and magnitude of land use change between 1978 and 1996; 2) to simulate the impact of land use on water quality using AGNPS and AVNPSM; and 3) to identify the critical nonpoint source areas in the watershed to support targeted NPS management in Davis Creek.

CHAPTER II

LITERATURE REVIEW

Land use is a series of human activities undertaken to produce one or more goods or services (Gregorio and Jansen, 1996). The United Nation's Food and Agricultural Organization (FAO, 2001) defines land use as "based upon function, the purpose for which the land is being used". Land cover, on the other hand, is "the observed physical cover, as seen from the ground or through remote sensing, including the vegetation (natural or planted) and human constructions (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock or sand surfaces count as land cover" (FAO, 2001).

Briassoulis (2001) recognizes that land is used to fit a majority and variety of human needs and to serve various purposes. When the users of land decide to employ its resources for different purposes, land use change occurs, producing both desirable and undesirable impacts. The analysis of land use change is basically the analysis of the relationship between people and land. Consequently, the significant cause of change on land use is from increasing human population. A 1997 Public Sector Consultants, Inc. (1998) survey revealed that 65 percent of farmland in Michigan is being rehabilitated to commercial and residential development. Once agricultural land has been converted to other uses, such as residential or commercial areas, it usually cannot be converted back to agricultural land due to difficulty of aggregating small parcels and rehabilitation. Land use has significant impacts on both quantity and quality of water resources. Surface runoff is a function of the soil type, topography, climate and land use. Land development without recognizing the conservation needs of a watershed leads to reduction of groundwater recharge, degradation of streams, and loss of aquatic life (Purdue University, 2001). Since the land use/land cover information could be very beneficial for resource planners and managers, the measurement and investigation of land use changes are for better evaluation of land use policies and management.

Different approaches have been used to assess the effect of land use/land cover change on landscape. Lambin et al. (2000) evaluated different agricultural land use models for prediction of changes in land use intensification. The study identified five types of land use models.

(1) Empirical-statistical models attempted to identify the causes of land cover changes using multivariate regression techniques. These models are suitable to predict changes in land use concentration where such changes have been measured.

(2) Stochastic models consisting principally of transition probability models, defining changes from one land cover category to another. This type of models addressed the issue of land use intensification.

(3) Optimization models develop land use scenarios for highest benefits, while subject to certain resource constraints.

(4) Dynamic (process-based) simulation models mimic the interactions of biophysical and socio-economic processes that result in patterns of land cover changes in time and space. Being process-based, this type of models is better suited to develop land use change scenarios for decision-makers than the more common empirical, stochastic or optimization models.

(5) Integrated modeling approaches refer to the combined use of the four modeling techniques to get the best solution. For example, the combination of dynamic, process based models, with optimization techniques to predict European land use (IMPEL; Rounsevell et al.; 1997 Lambin et al., 2000).

"Modeling, especially if done in a spatially explicit, integrated and multi-scale manner, is an important technique for the projection of alternative pathways into the future, for conducting experiments that test our understanding of key processes in land use changes" (Veldkamp and Lambin, 2001). Verberg et al. (1999) used a multi-scale approach to the pattern of land use change for different development pathways. Faul (1995) studied land use change by comparing aerial photography between 1938 and 1988 in Van Buren County, Michigan to provide information for township planning commission to implement growth management policies and monitor the effectiveness of their comprehensive master plan.

A Geographic Information System (GIS) is a useful tool for applications in land use/land cover change studies. Kristensen (1999) used GIS to analyze the spatial aspects of the landscape changes in Rostrup, Denmark. The author surveyed 30 farmers, and compared land use change between 1973 and 1995 using GIS analysis.

The results show that change in farm type between 1973 and 1995 was mainly attributable to development economics.

Other studies have also used simulation models to assess the impact of land use on water quality. Agricultural Nonpoint Source Pollution Model (AGNPS) was developed for agricultural watershed analysis and has been applied to studies of land use change and its effects on water resources in many studies. For example, the model was used to determine the sediment and nutrient loads delivered to the trout stream in the Garvin Brook watershed in southeastern Minnesota. It was used to identify critical areas for controlling pollutants to the trout stream (Young et al., 1989). Rode and Frede (1999) linked AGNPS to GIS (SPANS), to investigate erosion and nutrient transport in agricultural catchments in Germany. Kao et al., (1998) integrated the AGNPS model with the WASP model (a dynamic model that simulates the water quality of a water column and underlying benthos for an aquatic system) to determine phosphorus loading in Posan reservoir, China. Pekarova et al. (1999) tested the AGNPS model in Rybarik and Lesny subbasins in Slovakia.

Another study by He et al. (1993) used AGNPS and GRASS through GRASS WATERWORKS (a hydrological modeling tool box) to evaluate the impact of agricultural runoff on water quality in the Cass River, a subwatershed of Saginaw Bay. The results identified the amount and locations of nitrogen, phosphorus, and sediment loading into the Saginaw Bay watershed, and also identified critical erosion areas within the Cass River watershed. The study also explored management practices for reducing soil erosion and sedimentation.

This study assesses the impact of land use/land cover change to the water quality in the Davis Creek watershed. Aerial photographic interpretation and a GIS are used to spatially analyze land cover changes in the Davis Creek watershed between 1978 and 1996 to aid in the identification of the spatial variations and temporal changes of urban sprawl patterns. AGNPS is used to evaluate the impact of land use/land cover change on water quality because the model considers the effect of management practices in the entire watershed, i.e., the effect of land use in upper reaches to the water quality of lower reaches (Agosti, 1998). However, this study will not consider point source inputs since Davis Creek has no sources of industrial or municipal discharges and the water quality problems of Davis Creek are caused by nonpoint sources (The Forum of Greater Kalamazoo, 1998).

CHAPTER III

METHODOLOGY

The purpose of this study is to evaluate the impacts of land use change on nonpoint source (NPS) pollution in the Davis Creek watershed. Aerial photography is used to assess changes in land use between the 1978 and 1996. AGNPS and GIS are used to estimate soil erosion and nutrient loading in the watershed and to identify the critical areas for management of NPS. Procedures for assessment of land cover changes and for identification of critical areas are discussed in the following sections.

A Brief Description of the AGNPS Model

AGNPS is a single storm-event based simulation model for evaluating soil erosion and nutrient transport from agricultural watersheds (Young et al., 1987; 1989; USDA Agricultural Research Service, 1995; He et al., 2001). It was developed by the U.S. Department of Agriculture. Agriculture Research Service (Young et al., 1989) to serve as a land management tool for estimating sediment and nutrient yields in surface water runoff from agricultural lands and to compare the potential impacts of various land management strategies on the quality of surface water runoff (Panuska and Moore, 1991). The model operates on a cell-by-cell basis so that the spatial variation in parameters of each cell can be accounted for in the analysis throughout the whole watershed (Lenzi and Luzio, 1995). Subsequently the "problem areas" of extreme runoff within the watershed can be indicated (He et al., 1993). The model includes three basic components: hydrology, erosion and sediment, and nutrient transport (nitrogen, phosphorus, and chemical oxygen demand) (He et al., 2001). The model is also capable of dealing with point sources of sediment, water, nutrients and chemical oxygen demand (COD) from animal feedlots, ponds and other point sources (Young et al., 1989a; Mostaghimi et al., 1997).

The hydrologic component calculates surface runoff (in inches) and peak flow rate (in cubic feet per second) based on the SCS (Soil Conservation Service) curve number equation and an empirical formula embedded within the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model. Soil erosion and sedimentation is computed based on a modified Universal Soil Loss Equation (USLE) and the sediment delivery ratio (Young et al., 1989; He et al., 2001).

AGNPS divides nutrient transport into the major soluble nutrients from agricultural activities (the amount of initial soluble nitrogen and phosphorus in the top half inch (1.2 cm) of soil prior to the rainfall event in lbs/acre), which are transported in the runoff, and the sediment nutrients (the amount of nitrogen or phosphorus contained in the sediment), which are transported in the sediment (He et al., 2001). In the case of point sources, inputs are accounted for by entering inflow rates and chemical concentrations to the cells where the point sources are located. Sediment from stream bank, streambed and gully erosion is also treated as a point source and is added to upland sediment (Mostaghimi et al., 1997). However, this study will not consider point source inputs since Davis Creek has no sources of industrial or municipal discharge to it and the water quality problems of Davis Creek are mainly attributable to the impacts of nonpoint sources (The Forum of Greater Kalamazoo, 1998). AGNPS needs 22 input parameters as shown in Table 1.

The outputs of the AGNPS model include estimates of surface runoff volume (inches/acre), peak flow rate (in cubic feet per second), sediment yield (tons), mass of sediment-attached and soluble N in runoff (lbs/acre), mass of sediment-attached and soluble P in runoff (lbs/acre), and soluble COD (lbs/acre) (He et al., 2001).

ArcView Nonpoint Source Modeling (AVNPSM)

AGNPS operates on a cell-by-cell basis and requires 22 input parameters for each cell. Determining cell size was 5 acre (total cells equal 2006 cells) regarding the Davis Creek watershed area. Since manual manipulation of the input data for each cell would be very difficult and time consuming, efforts have been made to automate the input process for AGNPS (Arnold et al., 1991; Kang et al., 1992; He et al., 1993). He et al. (2001) developed an ArcView Nonpoint Source Modeling (AVNPSM) interface to link ArcView GIS and AGNPS to facilitate the application of AGNPS to watershed scale analysis. The AVNPSM consists of seven modules: 1) AGNPS Utilility, 2) Parameter Generator, 3) Input File Processor, 4) Model Executor, 5) Output Visualizer, 6) Statistical Analyzer, and 7) Land Use Simulator (He et al., 2001). Model requires soil database, digital elevation, land use/land cover, watershed

Table 1

Input parameters for AGNPS model

Parameters	
1. Cell number	14. Surface condition (adjustment for time it takes for channelization of surface runoff)
2. Cell division	15. Chemical Oxygen Demand (COD) factor
3. Receiving cell number	16. Soil texture
4. Receiving cell division	17. Fertilizer indicator
5. Flow direction	18. Pesticide indicator
6. Soil Conservation Service (SCS) curve number	19. Point source indicator
7. Slope	20. Additional erosion
8. Slope length	21. Impoundment indicator (number of ponds in impoundment terrace system)
9. Slope shape	22. Channel indicator (number of channels in a cell)
10. Soil erodibility factor (K)	
11. Manning's coefficient	
12. Crop management (C)	
13. Support practice (P)	

Source: He et al. (2001)

boundary and water features, climate, and crop management information (He et al., 2001).

This study uses AVNPSM for watershed modeling and analysis. A soil database, soil survey database from the U.S. Department of Agriculture Natural Resource Conservation Service, is used to attain information on soil texture, hydrologic groups, and soil erodibility factor (K).

A digital elevation model (DEM), obtained from the United States Geological Survey (USGS), at scale 1:24,000, is used to determine slope, slope length, slope shape, and flow direction parameters (Figure 2). The watershed boundary and water resource features were obtained from the Western Michigan University GIS Research Center based on the source of the USDA Natural Resources Conservation Service draft 14 digits by hydrological units (1999).

Davis Creek crosses parts of four U.S.G.S. Quadrangles (Figure 1). The land use/land cover files for Kalamazoo, Portage, Galesburg, and Adams Park were merged together to form one contiguous file before cutting the file down to the watershed. After merging, all new files were checked for any duplication and mismatches of polygons and common boundaries. These files were then processed either to an Arc/Info coverage or ArcView shape format to be compatible with the format requirement of the AVNPSM interface. Aerial photo interpretation for 1978 land use/land cover map was done by Michigan Department of Natural Resources (1985). For 1996 land use/land cover data was done by GIS Research Center, Western Michigan University as part of Kalamazoo River Watershed project (GIS Researh Center, 1997). This land use/land cover data were obtained from the GIS Research Center, Western Michigan University for 1978 and 1996. Land cover was

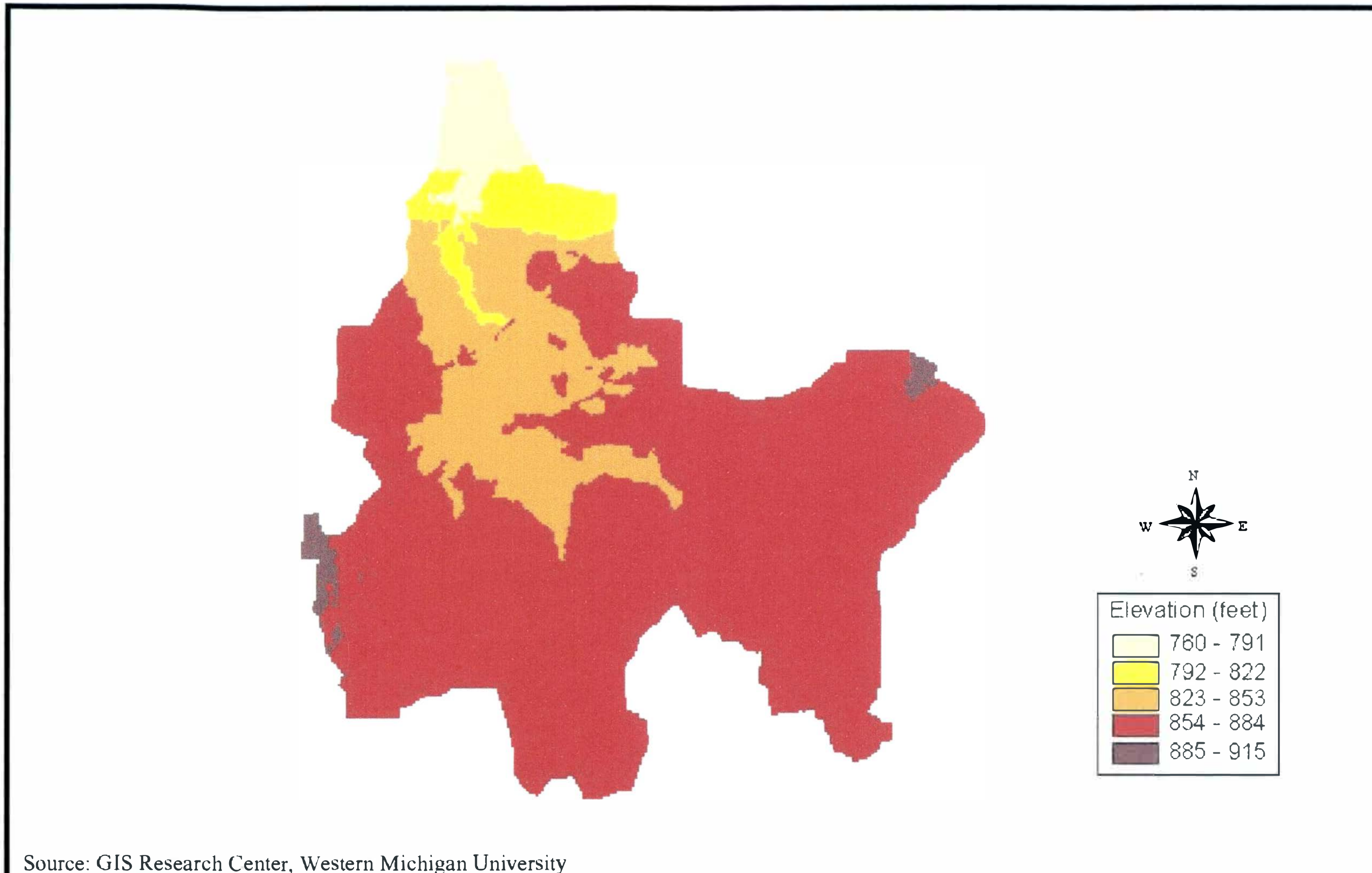


Figure 2. Elevation of the the Davis Creek watershed

classified using a modified version of the U.S.G.S. Land Use Classification System (Anderson et al., 1976).

Twelve land cover categories (Table 2) were used in analyzing land use/land cover change. These categories were used to determine values of the SCS curve number, Manning's coefficient, crop management (C), support practice (P), surface condition, and fertilizer indicator parameters of the AGNPS model. Crop management information, including crop types and rotation, fertilization level, and tillage practices, is used to infer fertilizing and erosion control practices in the watershed area. The distributions of the land cover changes from 1978 to 1996 were identified by GIS analysis. Once the 1978 and 1996 were created, land use/land cover in 1978 subtracted 1996 land use/land cover file (land cover codes in 1978 minus land cover codes in 1996, if the values in new item equal zero, determining as no change, otherwise, the area was identified as changes) to indicate the magnitude, types, and locations of changes during the study periods.

Processing of Input Parameters

Once the required databases for soils, DEM, land cover, watershed boundaries and features were compiled and processed, the AVNPSM model is used to process the input parameters step by step. The AGNPS Utility module is used to create a grid file of the watershed, FISHNET (file name for dividing the study watershed into grid cells (output grid cell size: 131.37 ft. 250 rows and 313 columns)

Table 2

Modified Anderson land use classification system

Categories	Code	Key Interpretation
Residential	111	Multi-family high-rise
	112	Multi-family low-rise
	113	Single family
	115	Mobile home park
Commercial	121	Primary/central business district
	122	Shopping center mall
	124	Secondary/strip mall
	126	Institutional
Industrial	138	Industrial park
Transport	141	Air transportation
	142	Rail transportation
	144	Road transportation
Utilities	143	Water (sewage and treatment)
	145	Communications
	146	Utilities (power station, water tank/storage)
	147	Well fields
Open Land	193	Golf courses, parks, and campgrounds
	194	Cemeteries
Agriculture	210	Cropland
	220	Orchard, greenhouse, nurseries/ornamental horticulture and confined feeding
	240	Pasture
	290	Farmsted and outbuilding storage
Nonforested	310	Herbaceous openland
	320	Shrubland
Forestland	410	Deciduous forest
	420	Evergreen Forest

Table 2-(Continued)

Categories	Code	Key Interpretration
Water	520	Lakes
Wetlands	611	Forested wetlands
	612	Shrub-scrub wetlands
	621	Aquatic bed wetlands
	622	Emergent wetlands
	623	Wetland (mud) flats
Barren	730	Sand dunes
	750	Surface excavations

Source: GIS Research Center, Western Michigan University

Once FISHNET was created, other parameters were generated using the pull down menu of the Parameter generator module. For the topographically based parameters (from Flow Direction to Slope Shape), the AVNPSM interface uses ArcView Spatial Analyst's built-in functions: flow direction, slope, aspect, etc. to extract flow direction, slope, and slope shape (He et al, 2001). Flow direction, one of the most critical parameters for AGNPS, was checked and edited to ensure no loops exist in the input file. Receiving cell number, which is related to the flow direction of each cell, was assigned the cell number that the water flowed into the Kalamazoo River. The K-factor (soil erodibility) and soil texture variables were generated from the soil survey database. The soil texture in the AGNPS model includes sand, clay, loam, and peat. The other land cover related parameters such as SCS curve number, Manning's coefficient, crop management (C) etc. were determined by land cover category based on values from literature (He et al. 2001).

Execution of AGNPS

After generating all parameters, the Input File Processor module of AVNPSM was used to produce a single input file for the AGNPS model. A 25-year, 24-hour storm event of 4.5 inches was used in the simulation. The model was run in the DOS mode to produce output files (Output.NPS and Output.GIS). The Output Visualizer module of the AVNPSM was then used to generate thematic maps of chosen parameters such as soil erosion, or peak runoff. A thematic map of the selected variable was automatically created in ArcView Layout. These data can be shown in either tabular or map format. The results (e.g. peak flow, erosion, sedimentation, nitrogen, phosphorus, etc.) can be used by decision makers to prioritize the entire watershed for implementation of best management practices to minimize the nonpoint source pollution problems (He et al., 1993). The Statistical Analyzer module was used to conduct statistical analysis of the relationship between the land cover and the simulated NPS pollution results.

CHAPTER IV

RESULTS AND DISCUSSION

Different land uses affect water quality in different ways. For example, the application of pesticides and fertilizers to agricultural land, or the disposal of hazardous chemicals from industrial sources, if not properly managed, can lead to different types of water pollution. In the Davis Creek watershed, land use has changed dramatically during the past two decades. This study assesses land use change between 1978 and 1996, then estimates the amount of sediment, erosion and nutrients produced in the watershed for the two periods. Finally, based on this analysis, the chapter discusses the relationship between land use/land cover change and nonpoint source pollution in the watershed.

Analysis of Land Cover Change between 1978 and 1996

Davis Creek Land Cover in 1978

The 1978 land use/cover of the Davis Creek watershed is shown in Table 3 and graphically as Figure 3. The dominant type of land cover was agriculture, with 3,850 acres, accounting for 41% of the total watershed. Agricultural land use is concentrated in the south and southeast portion of the watershed. Nonforested area (including herbaceous and shrubland) was the second most common class and

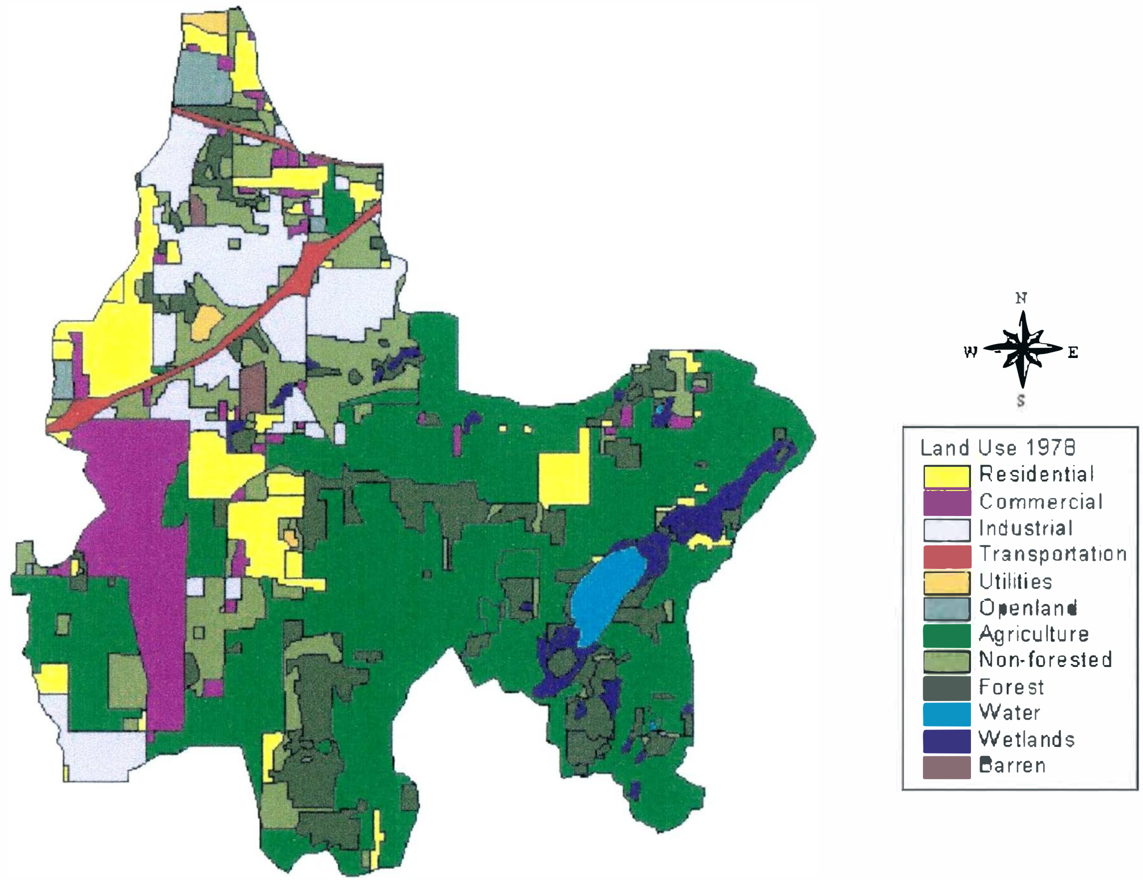
Table 3

The 1978 land cover in the Davis Creek watershed

Land Cover	Area (acres)	Percentage
Residential	865.0	9.3
Commercial	756.3	8.1
Industrial	902.0	9.7
Transport	146.0	1.6
Utilities	48.8	0.5
Open Land	99.7	1.1
Agriculture	3,854.6	41.4
Non-forested	1,138.0	12.2
Forestland	1,073.6	11.5
Water	118.0	1.3
Wetlands	264.0	2.8
Barren	45.0	0.5
Total	9,311	100

Source: Calculated by author

accounted for 1,140 acres. This was approximately 12% of the watershed area. Non-forested land was mainly distributed in the western portion of the watershed. Forest lands, industrial, residential and commercial areas accounted for about 11, 9.7, 9.3, and 8 percent of the total areas, respectively. Forested areas were mostly found adjacent to wetlands. Wetlands were mainly located near the East Lake. In contrast



Source: Calculated by author

Figure 3. Distribution of the 1978 land use/land cover in the Davis Creek watershed

residential areas were mainly situated along either highways or along the river.

Davis Creek Land Cover in 1996

The 1996 land use/cover of the Davis Creek watershed is shown in Table 4 and Figure 4. In contrast to 1978, main land cover type in 1996 was residential area with approximately 2,350 acres, or about 25% of the total. Other land use/cover types ranked in descending order were: non-forested, 18%; agriculture, 16%; industrial, 14%; forested, 9%; and commercial area, 7% of the total watershed.

Land Cover Change between 1978 and 1996

Significant changes took place in land use/cover in the Davis Creek watershed between 1978 and 1996. Agricultural land decreased from 3,850 acres in 1978 to about 1,500 acres in 1996, a 61 percent reduction. The majority of the reduction was due to residential development in the middle portions of the watershed. Forestland declined by 200 acres (18%) because of conversion to non-forest land. Other land cover types that decreased as well included: commercial land, barren land (such as beach, sand dunes, and surface excavations) and utilities lands, which land uses for water sewage/treatment, communications and well fields, due to development for residential and industrial uses. As a result, residential area increased by 1,500 acres (170%). This is primarily attributable to increases in population growth. The U.S. Bureau of Census statistics indicates population in Kalamazoo county increased from 212,000 in 1980 to 239,000 in 2000 (http://quickfacts.census.gov). Associated with

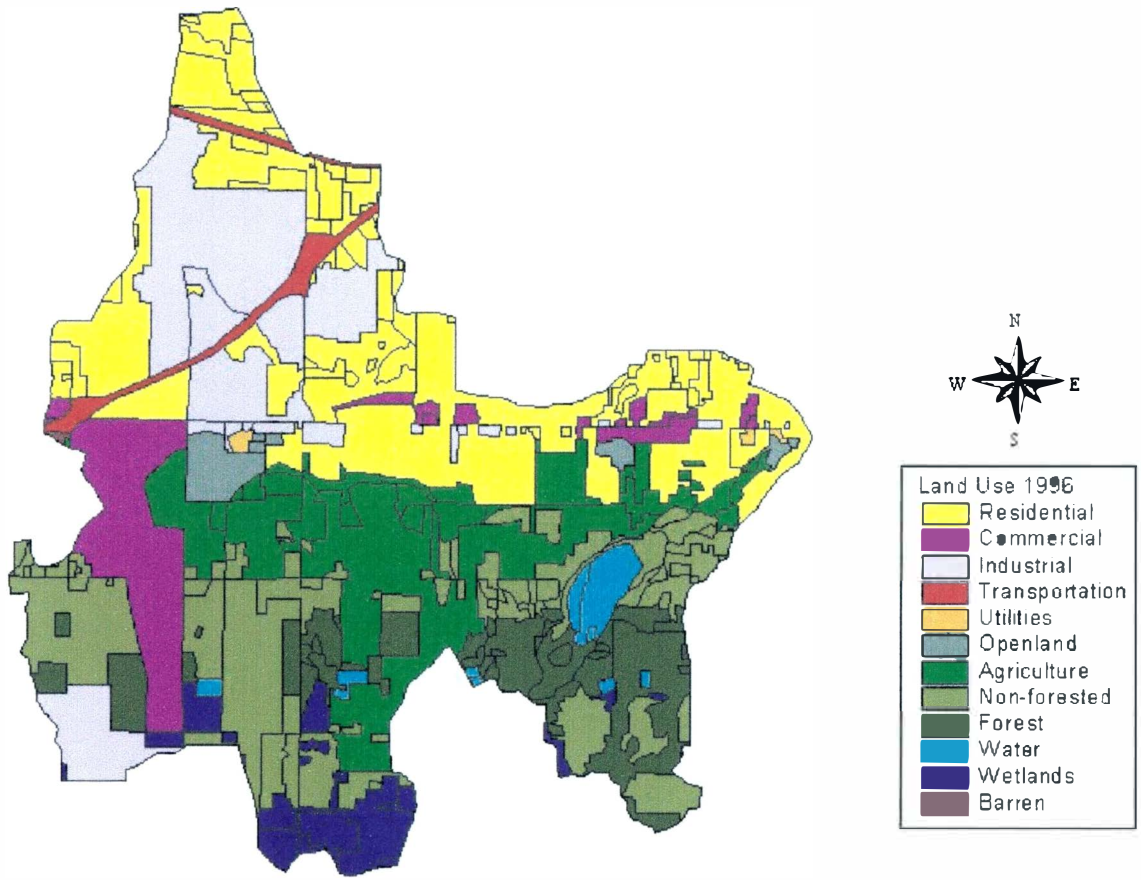
Table 4

The 1996 land cover in the Davis Creek watershed

Land Cover	Area (acres)	Percentage
Residential	2,351.0	25.2
Commercial	680.0	7.3
Industrial	1,319.0	14.2
Transport	160.	1.7
Utilities	20.5	0.2
Open Land	158.0	1.7
Agriculture	1,500.0	16.1
Non-forested	1,681.7	18.1
Forestland	877.6	9.4
Water	159.4	1.7
Wetlands	399.6	4.3
Barren	4.8	0.1
Total	9,311.0	100.0

Source: Calculated by author

this population growth, the need for residential and commercial services also increased. Thus residential land had an over 170 percent increase in the watershed during the study period from 1978 to 1996. Non-forested land, in the form of herbaceous shrubland, increased by 540 acres (48%) due to the development of



Source: Calculated by author

Figure 4. Distribution of the 1996 land use/land cover in the Davis Creek watershed

residential area with increasing lawns: planted with many herbaceous species. Compared to 1978, industrial land also significantly increased by 420 acres (46%). These new industrial areas are mainly in the west and middle portions of the watershed. The amount of wetland increased by 135 acres, largely distributed along ponds, within the Pharmacia Inc. properties, and around Long Lake at the southern part of the watershed. Water area was also slightly increased due to addition of some ponds. Table 5 and Figure 5 show the areas of the change between 1978 and 1996.

The Simulation of Land Use Effect on Nonpoint Source Pollution

Land use/land cover change has significant impacts on water quality. This study uses AGNPS and GIS to model the effects of the identified land use/cover changes between 1978 and 1996 on changes in nonpoint source pollution in the Davis Creek watershed. The input parameters for AGNPS were derived by using the ArcView Nonpoint Source Modeling Routine (AVNPSM), an interface between the ArcView GIS and AGNPS to facilitate watershed analysis developed by He et al. (2001). A 25-year, 24-hour storm event of 4.5 inches was used in the simulation for both 1978 and 1996. Since the Davis Creek is a small watershed, a uniform distribution of precipitation was assumed in the study. The simulated results for the entire watershed are shown in Table 6.

Table 5

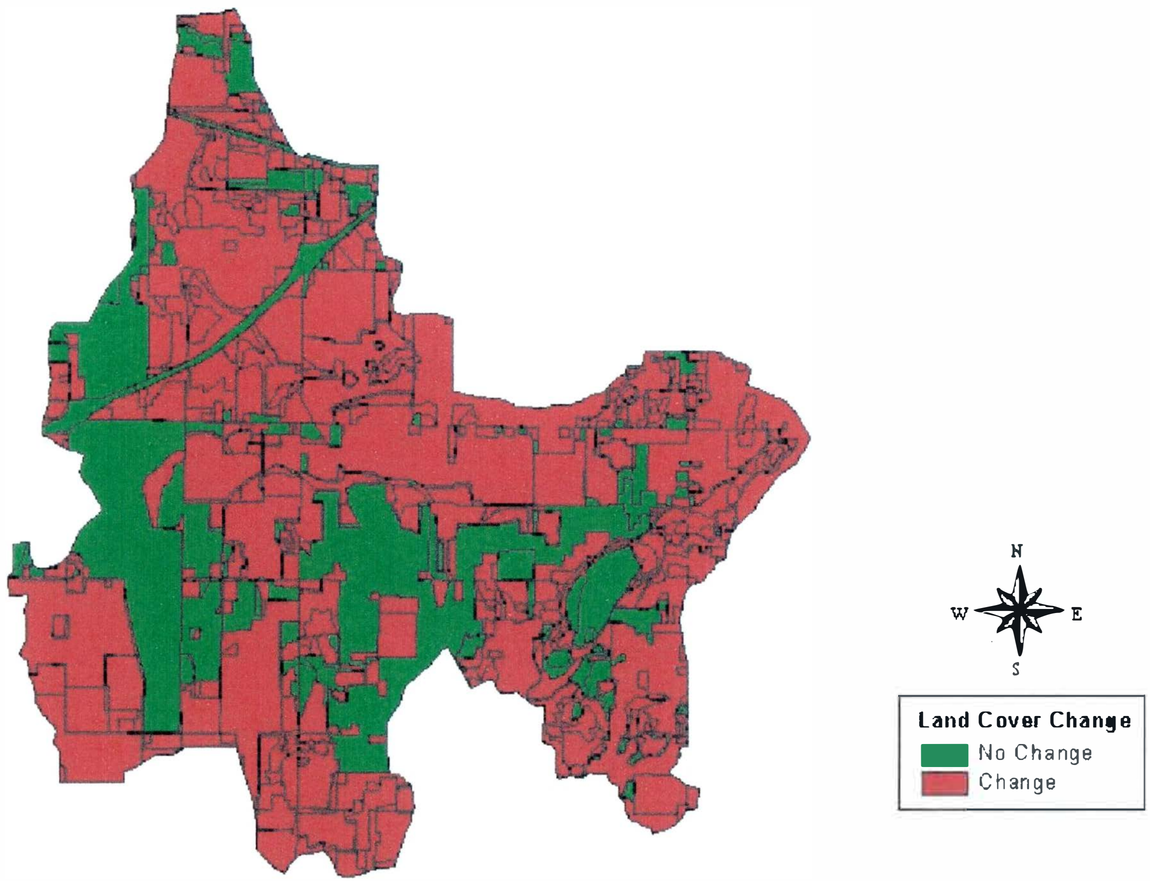
Land cover change between 1978 and 1996 in the Davis Creek watershed

Land Cover	Area Change (acres)	Percentage change
Residential	1,486.0	172.0
Commercial	-76.0	-10.0
Industrial	417.2	46.3
Transport	14.2	9.7
Utilities	-28.2	-58.0
Open Land	58.2	58.3
Agriculture	-2,355.7	-61.0
Non-forested	543.7	47.8
Forestland	-196.0	-18.3
Water	41.4	35.0
Wetlands	135.8	51.5
Barren	-40.3	-89.3

Source: Calculated by author

Simulation of 1978 Land Use Effect on NPS Pollution

Results of a simulation of a 25-year, 24-hour storm of 4.5 inches in the Davis Creek watershed for 1978 is shown in Tables 6 and 7. Peak flow rate at the outlet of the watershed was 507 cfs. in 1978. Utilities areas and barren land had the highest peak flow rates of 136-145 cfs due to a lack of vegetation and low precipitation



Source: Calculated by author

Figure 5. Land use/land cover change between 1978-1996 in the Davis Creek watershed

Table 6

Summary of simulation results by AGNPS from a 25-year, 24-hour storm event of 4.5 inches in the Davis Creek watershed for both 1978 and 1996

Variables	Results	
	1978	1996
Storm Event (inches)	4.5	4.5
Surface Runoff (inches)	1.02	1.05
Peak Runoff Rate (cubic feet per second)	507	1,421
Total Sediment Yield (tons)	529	387
Total Nitrogen in Sediment (lbs/acre)	0.38	0.31
Total Phosphorus in Sediment (lbs/acre)	0.19	0.15

Source: Calculated from the AGNPS model

infiltration during and immediately after the simulated storm. Similarly, residential, commercial, open land, and transportation areas also had higher peak flow rates as land surfaces in these areas also had little infiltration. Spatially, downstream areas where urban, residential, commercial and industrial areas were concentrated had a relatively high peak flow rate. Agricultural areas exhibited lower peak flow rates (Figure 6). This is because large storms usually take place in the summer months (June to August) when the agricultural land is well-covered by the two most common crops, corn and soybeans. An analysis of variance (ANOVA) in 1978 (Table 8 and 9) show that there is significant differences in peak runoff rates between different land cover types ($\alpha = 0.01$). The largest difference amount was found in residential and

Table 7

Simulated runoff, erosion, sediment and nutrients from a 25-year, 24-hour storm event of 4.5 inches in the Davis Creek watershed in 1978

Categories	Area (acres)	Peak Flow (cfs)	Surface Runoff (in)	Soil Erosion (tons/acre)	Sediment Yield (tons)	Sediment Attached N in cell (lb/acre)	Sediment Attached P in cell (lb/acre)
1. Residential	865.0	78	0.96	0.05	64	0.26	0.13
2. Commercial	756.3	69	1.82	0.06	39	0.31	0.16
3. Industrial	902.1	43	1.82	0.09	19	0.44	0.22
4. Transportation	146.0	57	1.82	0.13	40	0.56	0.28
5. Utilities	48.8	145	0.96	0.04	96	0.21	0.11
6. Openland	99.7	61	1.82	0.33	26	1.20	0.60
7. Agriculture	3,854.6	20	0.90	0.08	7	0.42	0.21
8. Nonforested	1,138.0	28	0.11	0.04	13	0.23	0.12
9. Forestland	1,073.6	36	0.00	0.01	27	0.08	0.04
10. Water	118.0	19	4.50	0.00	2	0.00	0.00
11. Wetlands	264.0	34	2.91	0.01	26	0.06	0.03
12. Barren	45.0	136	1.82	0.72	135	2.16	1.08

Source: Calculated by author

* Significant level at $\alpha = 0.01$ level by analysis of variance for all variables

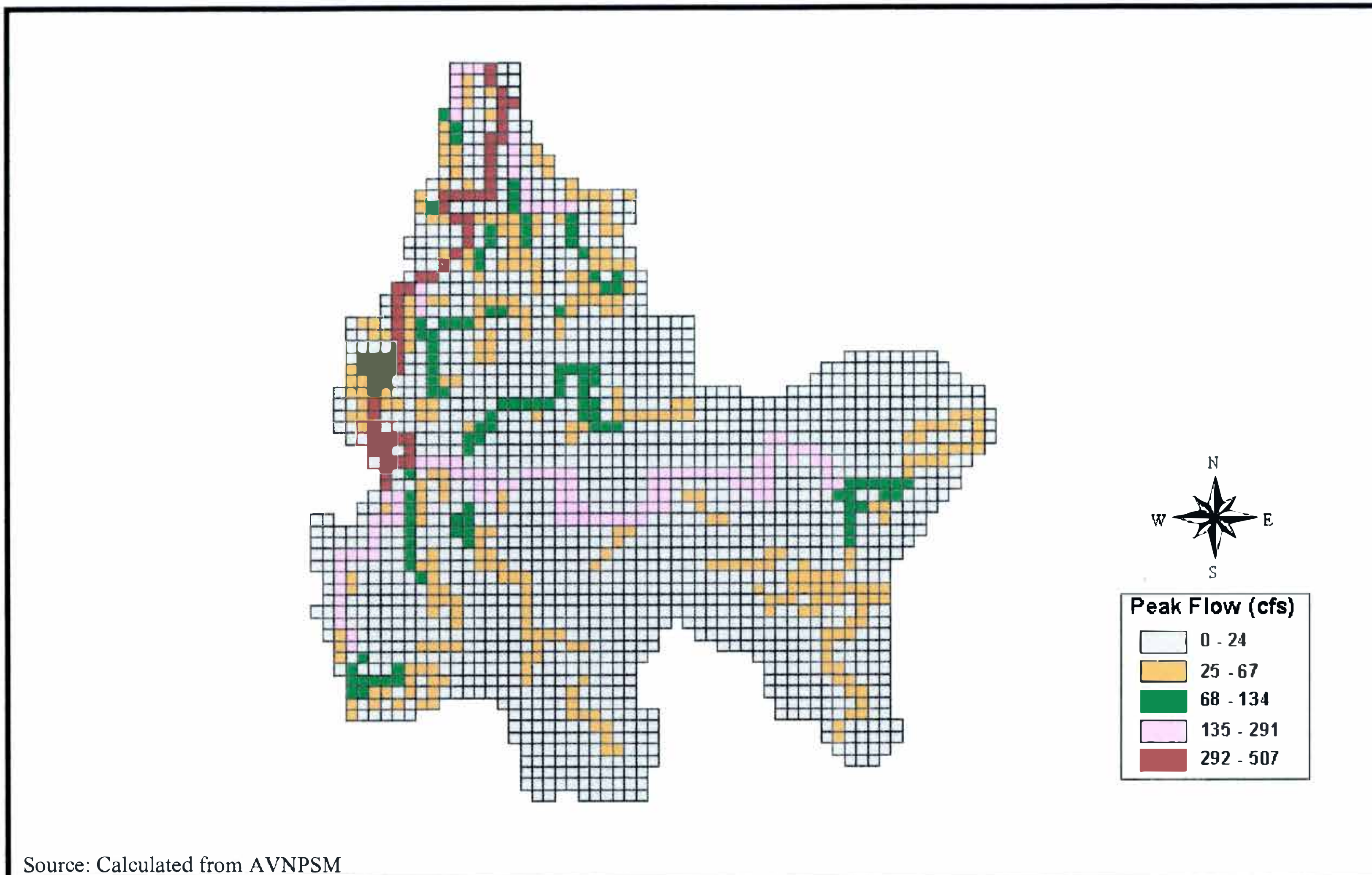


Figure 6. Simulated peak flow (cfs) in the Davis Creek watershed, 1978

Table 8

The Analysis of Variance of the simulated results for 1978 land cover types

Categories	f (1978)
Peak Flow	18.40
Surface Runoff	23,606.04
Soil Erosion	82.47
Sediment Yield	12.82
Sediment Attached N	179.06
Sediment Attached P	169.86

* Calculated from AVNPSM, an interface between the ArcView GIS and AGNPS developed by He et al. (2001)

Table 9

The Largest differences in selected variables between 1978 land cover types

Categories	The largest difference amount between land cover types
Peak Flow	Residential and agriculture
Surface Runoff	Water and forest
Soil Erosion	Barren and forest
Sediment Yield	Residential and agriculture
Sediment Attached N	Commercial and agriculture
Sediment Attached P	Commercial and agriculture

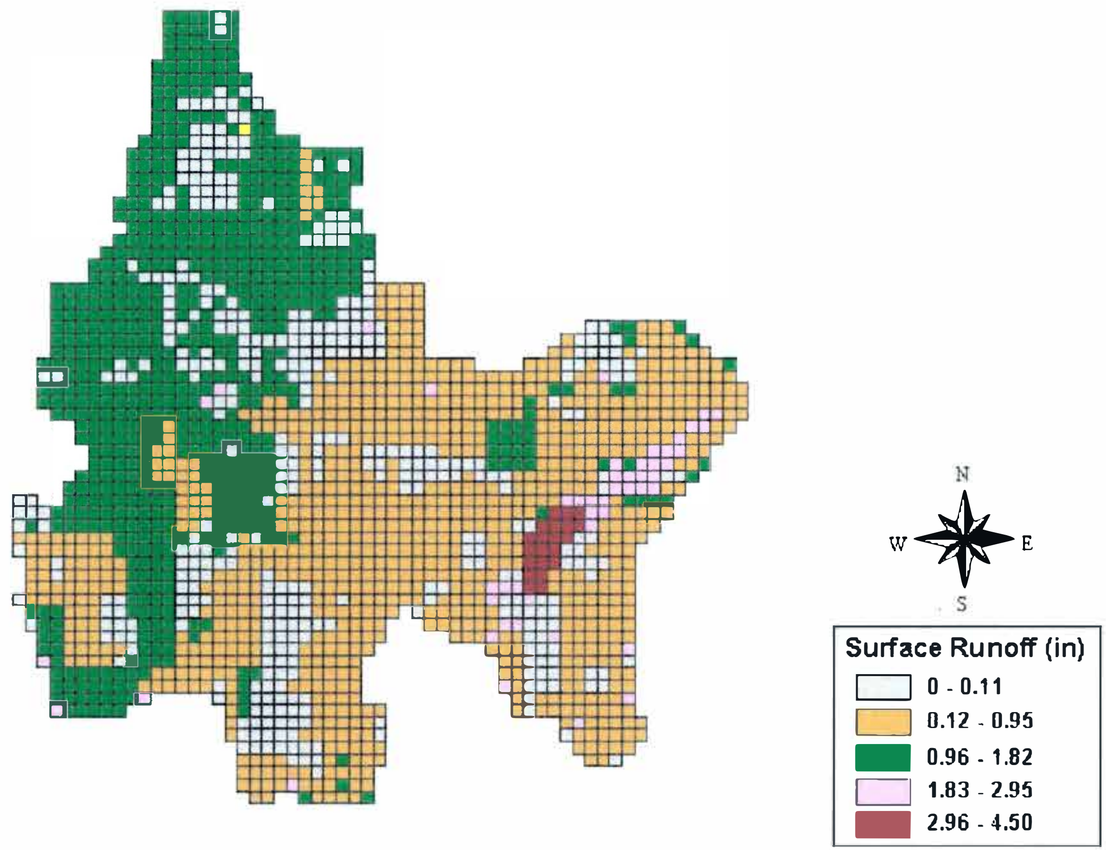
* Calculated from AVNPSM

agricultural lands.

The average surface runoff rate for the entire watershed was 1.02 inches. The highest runoff rates obviously occurred in open water and wetland areas where little or no infiltration could occur. The highest amount of surface runoff was found in land classified as commercial, industrial, transportation, open land and barren areas where there was little or no vegetation. Similarly, residential and agricultural lands had a lower surface runoff rate of less than 1 inch due to extensive vegetation coverage. Forested and non-forested, lands covered with herbaceous shrubs, land produced little or no surface runoff (Figure 7).

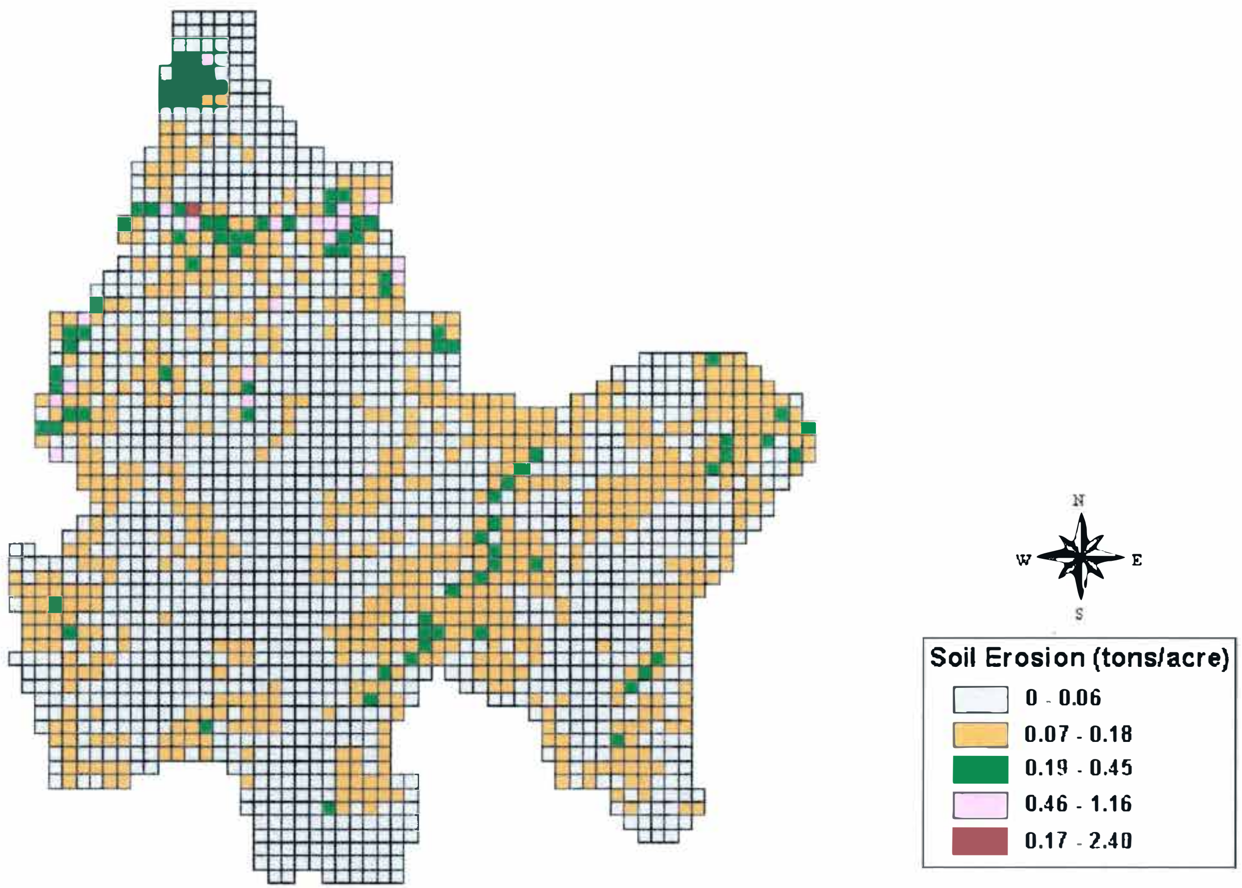
The soil erosion rates for each land use is shown in Figure 8. Barren and open lands had the highest erosion rate of 0.33 ton/acre due to the lack of vegetation. Agriculture and other land uses had a low erosion rate. Forested land produced little erosion.

Total sediment yield at the outlet of the watershed in 1978 was 529 tons, which represents the accumulated sediment runoff contribution (slope parameter was considered as discussed in chapter III) for the entire watershed (Table 6). Based on the model, barren, utility, and residential lands typically generated high amount of sediments (64 to 135 tons) probably due to construction or little vegetation. Commercial, transportation, and industrial areas had a sediment yield of between 19 to 40 tons. Agricultural areas had a low sediment yield of 7 tons because of crop coverage (Figure 9). (ANOVA statistics (Table 8 and 9) shows that the differences in sediment yield between land covers were significant at $\alpha = 0.01$. The largest



Source: Calculated from AVNPSM

Figure 7. Simulated surface runoff (inch) in the Davis Creek watershed, 1978



Source: Calculated from AVNPSM

Figure 8. Simulated soil erosion (tons/acre) in the Davis Creek watershed, 1978

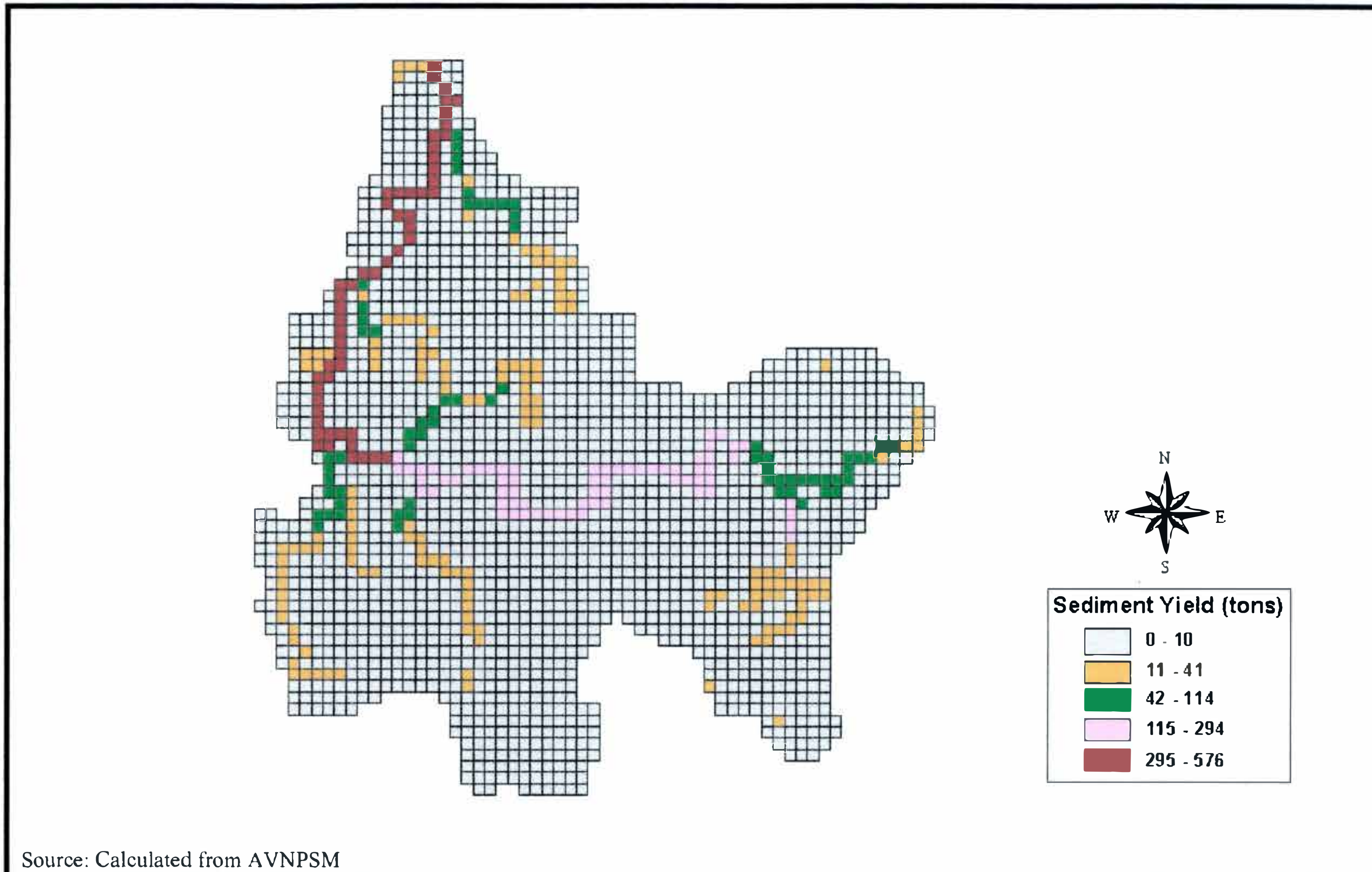


Figure 9. Simulated accumulative sediment yield (tons) in the Davis Creek watershed, 1978

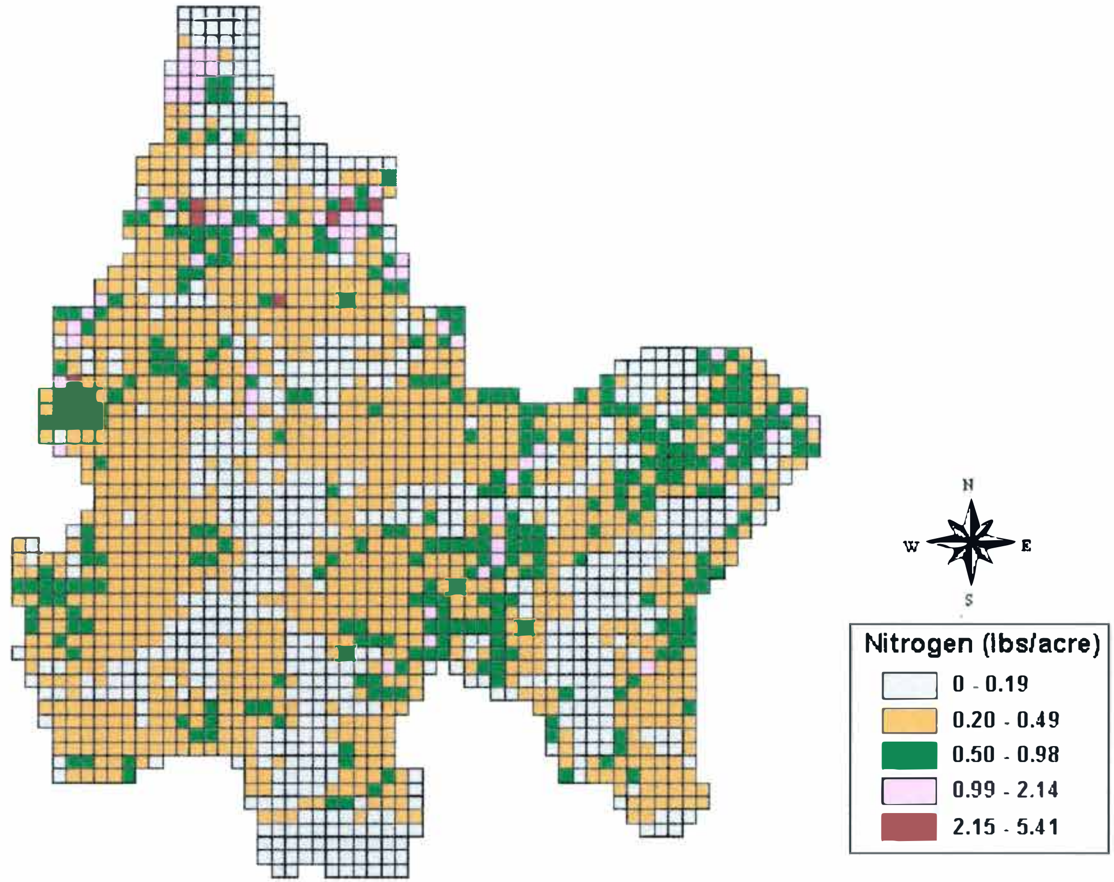
difference amount was found in water and forest lands). Of course seasonally results would differ but given that most extreme precipitation event were in summer, the results are reasonable.

Nutrient rates for nitrogen (N) and phosphorus (P) are shown in Table 7 and Figure 10 and 11. Sediment-attached nutrients are nutrients that are attached to the soil and transported in the sediment (Agosti, 1998). Weighted average nitrogen loading rate in sediment for the entire watershed was 0.38 lb/acre. Agricultural areas had a high nitrogen loading in cell runoff of 0.42 lb/acre due to crop utilization of applied fertilizers. Urban uses, including industrial, transportation, commercial and residential areas had a nitrogen loading between 0.26 to 0.56 lb/acre due to debris and contaminant such as metals, industrial organic chemicals, nutrients and pesticides from roads, industrial areas, and golf course (Figure 10).

Sediment attached phosphorus levels had a similar distribution pattern to that of nitrogen. Weighted average phosphorus loading rate in sediment for the entire watershed was 0.19 lb/acre. Agricultural land had a high phosphorus loading in cell runoff of 0.21 lb/acre. Urban uses, including industrial, commercial and residential areas had a rate between 0.13 to 0.22 lb/acre.

Simulation of 1996 Land Use Effect on NPS Pollution

The simulation results of a 25-year, 24-hour storm of 4.5 inches in the Davis Creek watershed for 1996 are shown in Tables 6 and 10. Peak flow rate at the outlet of the watershed was 1,421 cfs. in 1996. Urban uses such as residential and



Source: Calculated from AVNPSM

Figure 10. Simulated sediment attached N (in cell runoff) in the Davis Creek watershed, 1978

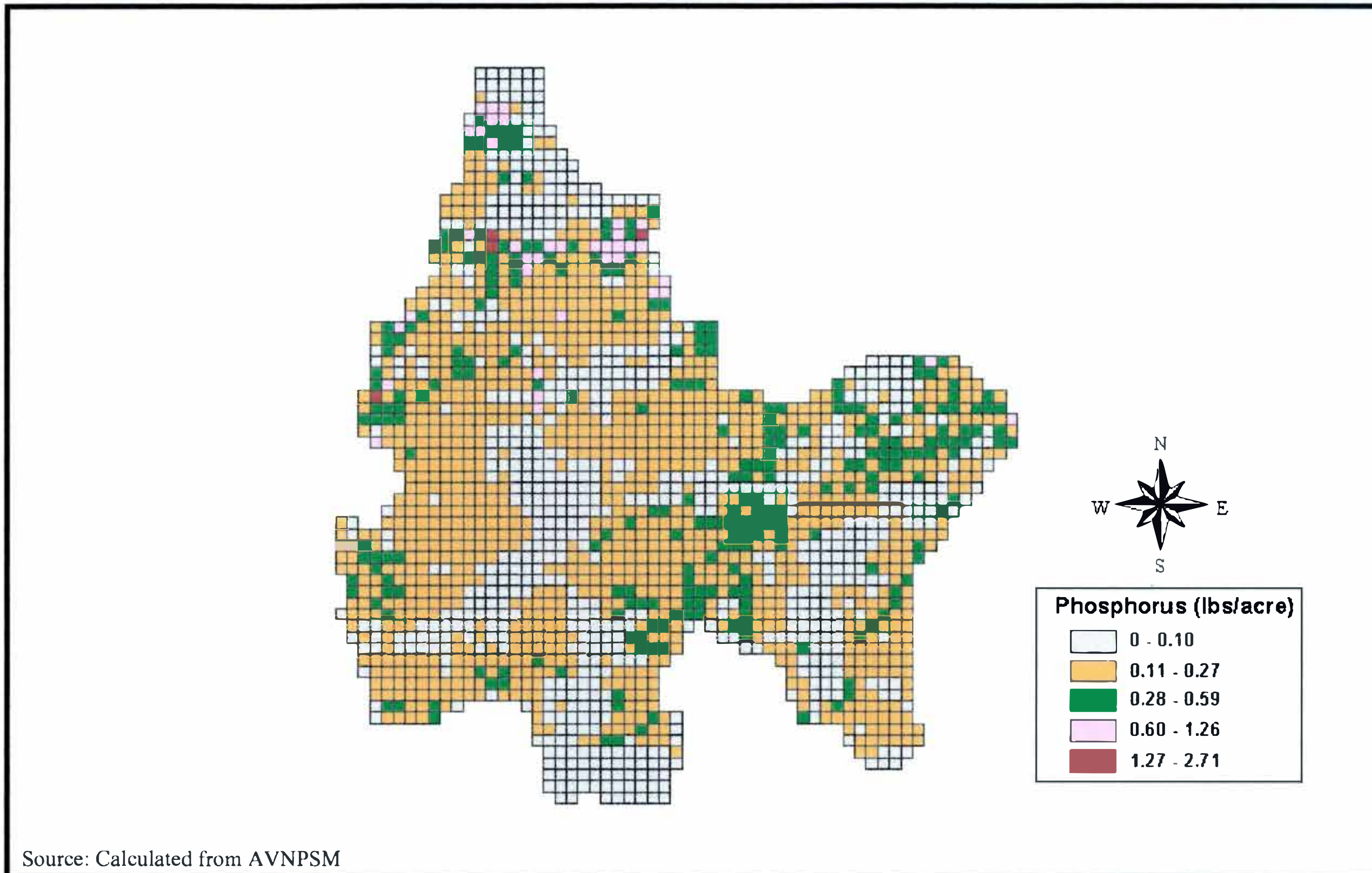


Figure 11. Simulated sediment attached P (in cell runoff) in the Davis Creek watershed, 1978

Table 10

Simulated runoff, erosion, sediment and nutrients from a 25-year, 24-hour storm event of 4.5 inches in the Davis Creek Watershed in 1996

Categories	Area (acres)	Peak Flow (cfs)	Surface Runoff (in)	Soil Erosion (tons/acre)	Sediment Yield (tons)	Sediment Attached N in cell (lb/acre)	Sediment Attached P in cell (lb/acre)
1. Residential	2,351.0	125	0.96	0.04	25	0.23	0.11
2. Commercial	680.0	138	1.82	0.06	31	0.33	0.16
3. Industrial	1,319.0	102	1.82	0.10	20	0.46	0.23
4. Transportation	160.0	83	1.82	0.15	15	0.65	0.33
5. Utilities	20.5	22	0.96	0.12	1	0.57	0.29
6. Openland	158.0	133	1.82	0.00	20	1.40	0.70
7. Agriculture	1,500.0	110	0.90	0.08	9	0.44	0.22
8. Nonforested	1,681.7	48	0.11	0.03	3	0.18	0.09
9. Forestland	877.6	25	0.00	0.00	2	0.03	0.02
10. Water	159.4	52	4.50	0.00	0.12	0.00	0
11. Wetlands	399.6	56	2.91	0.00	6	0.00	0
12. Barren	4.8	29	1.82	0.45	2	1.67	0.83

Source: Calculated by author

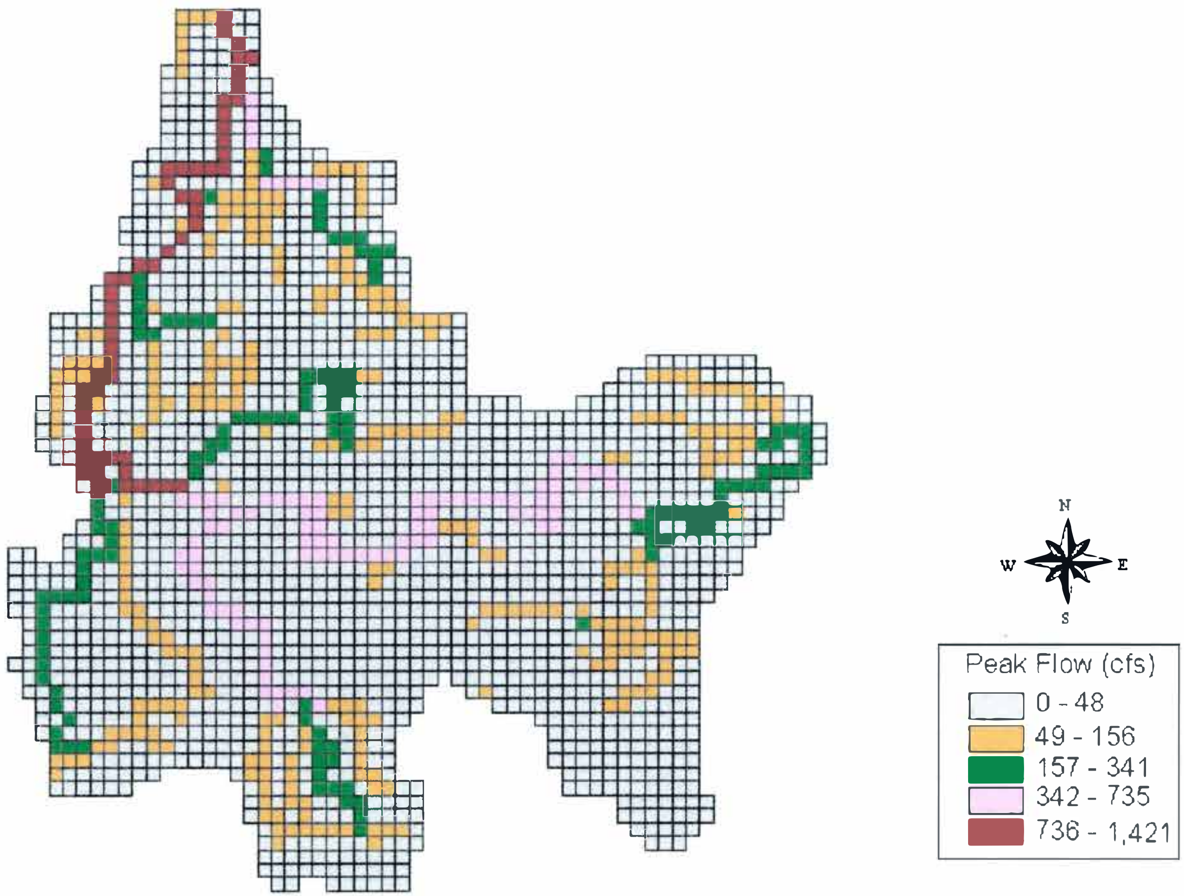
* Significant level at $\alpha = 0.01$ level by analysis of variance for all variables

commercial areas, had high peak flow rate of 125 and 138 cfs due to low infiltration. Agricultural land had a high peak flow rate of 110 cfs. Spatially, the urban land concentrated in the north and south eastern portions of the Davis Creek watershed had a relatively high peak flow rate. Agricultural areas in the central of the watershed had a second highest peak flow rate (Figure 12). ANOVA statistical analysis in 1996 (Table 11 and 12) shows that there are significant differences in peak runoff rates between different land cover types ($\alpha = 0.01$).

The surface runoff rate for the entire watershed was estimated to be 1.05 inches. Similar to 1978, the highest amount of surface runoff was found in commercial and industrial areas at 1.82 in. Residential and agricultural lands had a surface runoff rate of 0.96 and 0.90 in., respectively. Forestland had the lowest rate of runoff because of high infiltration rate (Figure 13).

The highest erosion rate was 0.45 ton/acre in barren land due to a lack of vegetation. Industrial, transportation, and utility areas had an erosion rate of between 0.1-0.15 ton/acre. Other areas had a rate less than 0.1 ton/acre (Figure 14).

Total sediment yield at the outlet of watershed was estimated by the model to be 387 tons, which represents the accumulative eroded soil contribution of the entire watershed (Figure 15). Land diverted to urban uses including residential, industrial, commercial areas, and open land, had a high average sediment yield of 20 to 30 tons per cell (5 acre area) due to construction or little vegetation. Agricultural areas produced an average sediment yield of 9 tons per cell (5 acre area).



Source: Calculated from AVNPSM

Figure 12. Simulated peak flow (cfs) in the Davis Creek watershed, 1996

Table 11

The Analysis of Variance of the simulated results for 1996 land cover types

Categories	f (1996)
Peak Flow	5.86
Surface Runoff	56,220.00
Soil Erosion	73.58
Sediment Yield	6.72
Sediment Attached N	305.11
Sediment Attached P	301.11

* Calculated from AVNPSM

Table 12

The Largest differences in selected variables between 1996 land cover types, 1996

Categories	The largest difference amount between land cover types
Peak Flow	Residential and Forest
Surface Runoff	Wetland and Non-forest
Soil Erosion	Industrial and Forest
Sediment Yield	Residential and Forest
Sediment Attached N	Commercial and Forest
Sediment Attached P	Commercial and Forest

* Calculated from AVNPSM

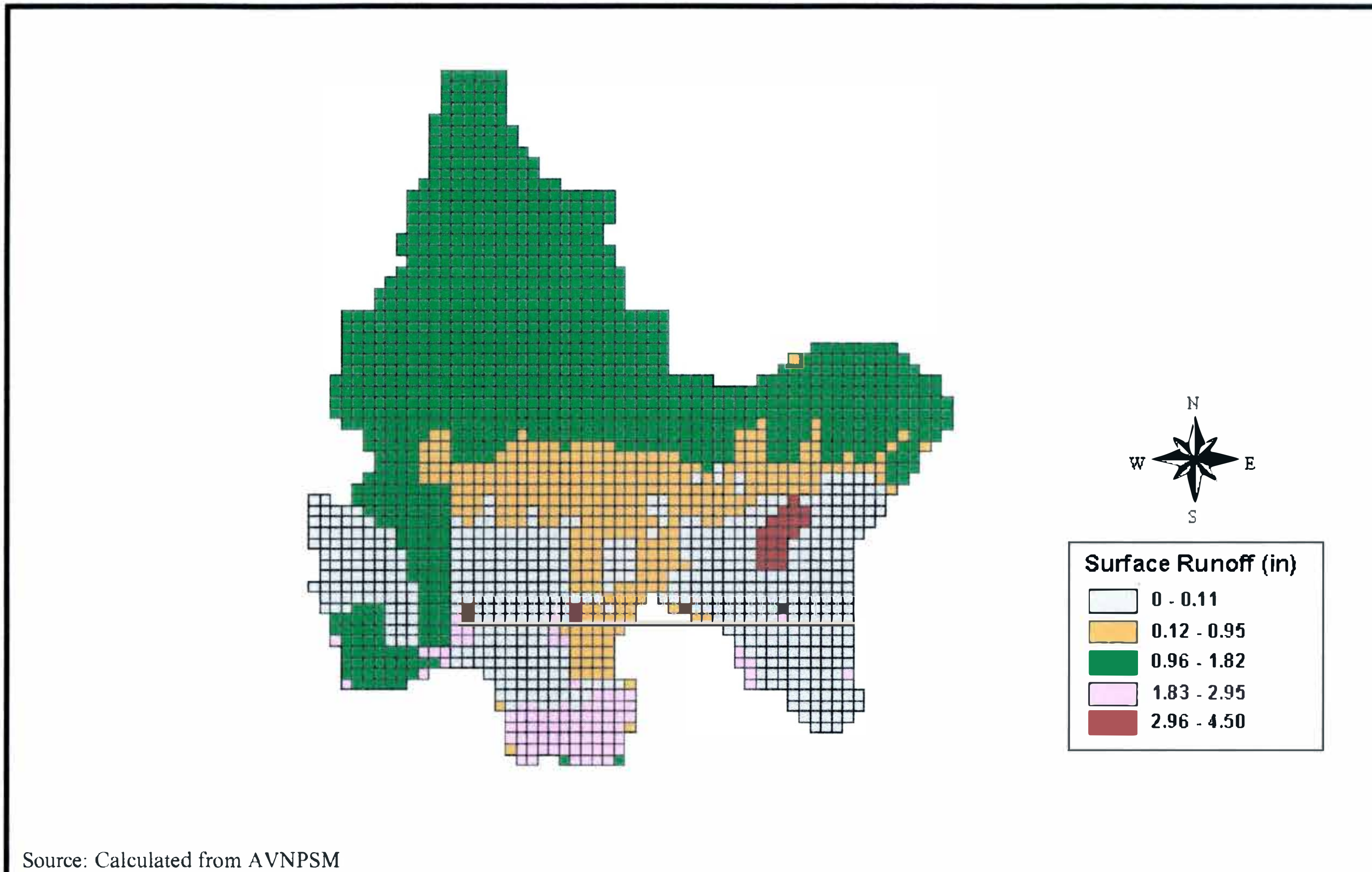
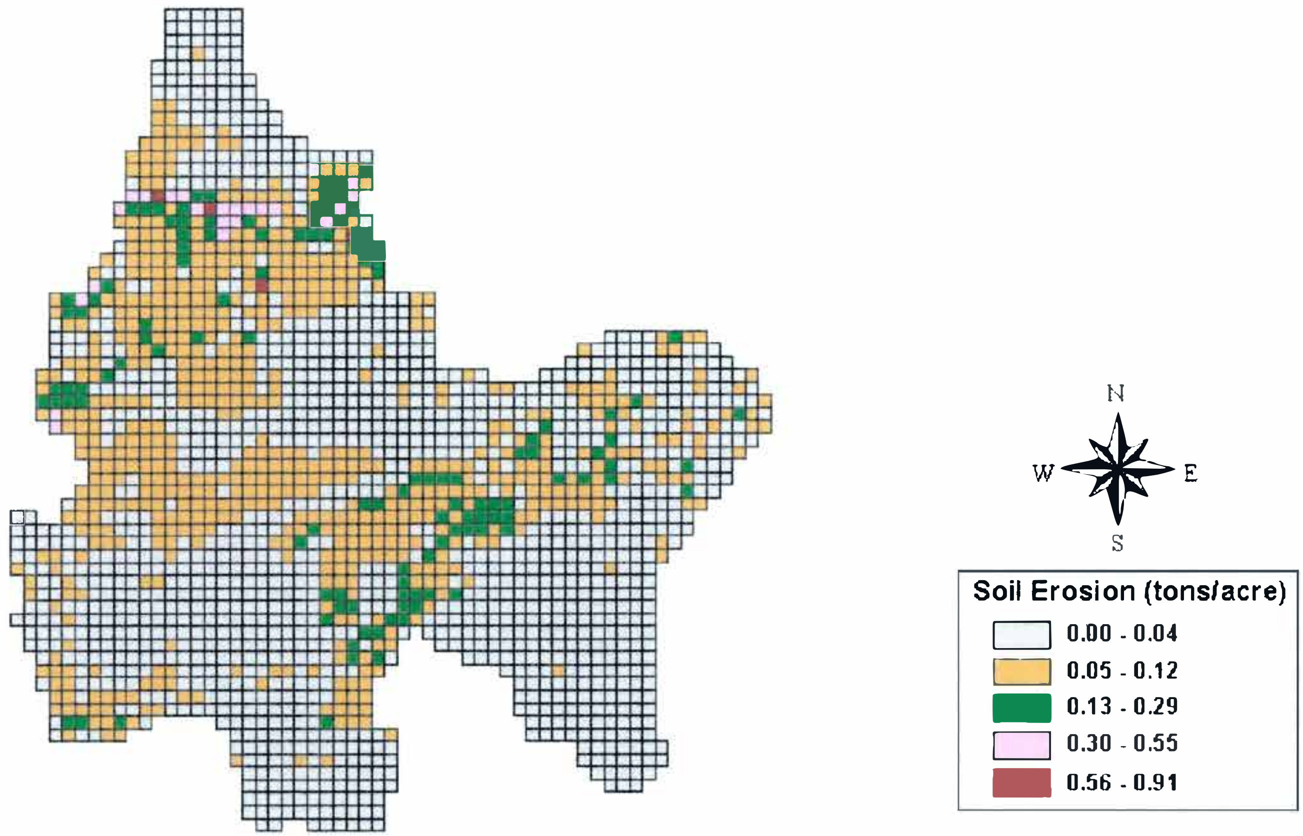
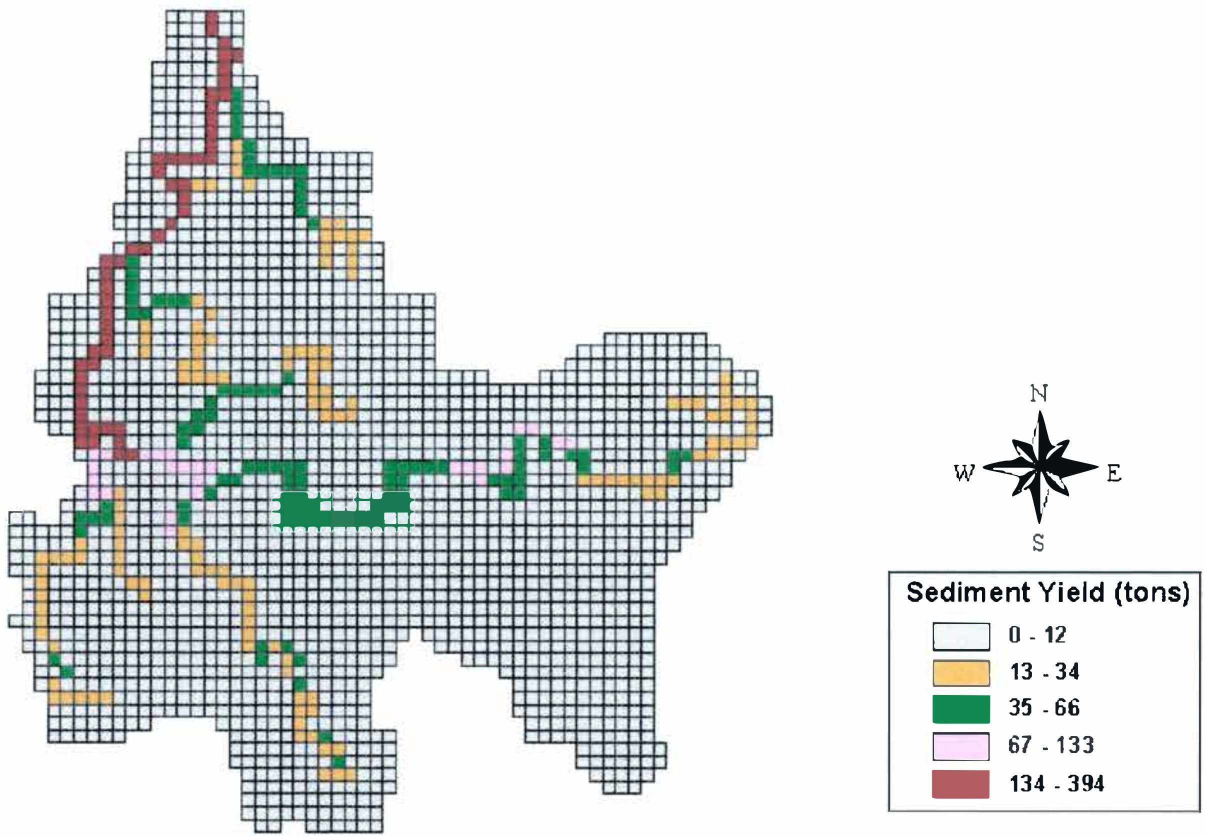


Figure 13. Simulated surface runoff (inch) in the Davis Creek watershed, 1996



Source: Calculated from AVNPSM

Figure 14. Simulated soil erosion (tons/acre) in the Davis Creek watershed, 1996



Source: Calculated from AVNPSM

Figure 15. Simulated accumulative sediment yield (tons) in the Davis Creek watershed, 1996

The weighted average nitrogen loading rate in the sediment for the entire watershed in 1996 was estimated to be 0.31 lb/acre. Agricultural areas had a high rate of sediment-attached nitrogen in cell runoff of 0.44 lb/acre Industrial, commercial, and residential areas had an average amount of nitrogen loading in cell runoff between 0.23 to 0.46 lb/acre (Figure 16).

The weighted average phosphorus loading rate in sediment for the entire watershed was at 0.15 lb/acre. Agricultural areas produced a high rate of phosphorus in sediment in cell runoff at 0.22 lb/acre Urban land uses produced an average amount of phosphorus loading in cell runoff between 0.11 to 0.23 lb/acre (Figure 17).

A Simulation of the Effect of Land Use Change between 1978 and 1996 on NPS Pollution

Land use had changed significantly between 1978 and 1996. Compared to 1978, residential areas increased by more than 172 percent in 1996. Industrial areas, transportation areas, open land, and wetlands also increased by 10 to 50 percent. On the other hand, agricultural areas decreased by more than 60 percent from 1978 to 1996. Therefore, the conversion of forest and agricultural land to urban uses was a major change in the Davis Creek watershed between 1978 and 1996.

The urbanization/suburbanization (sprawl) of Davis Creek produced a significant impact on the hydrology of the watershed. Compared to 1978, the peak flow rate of runoff increased by 180 percent while the total sediment and nutrient loads decreased in 1996. This is mainly due to the fact that residential land create

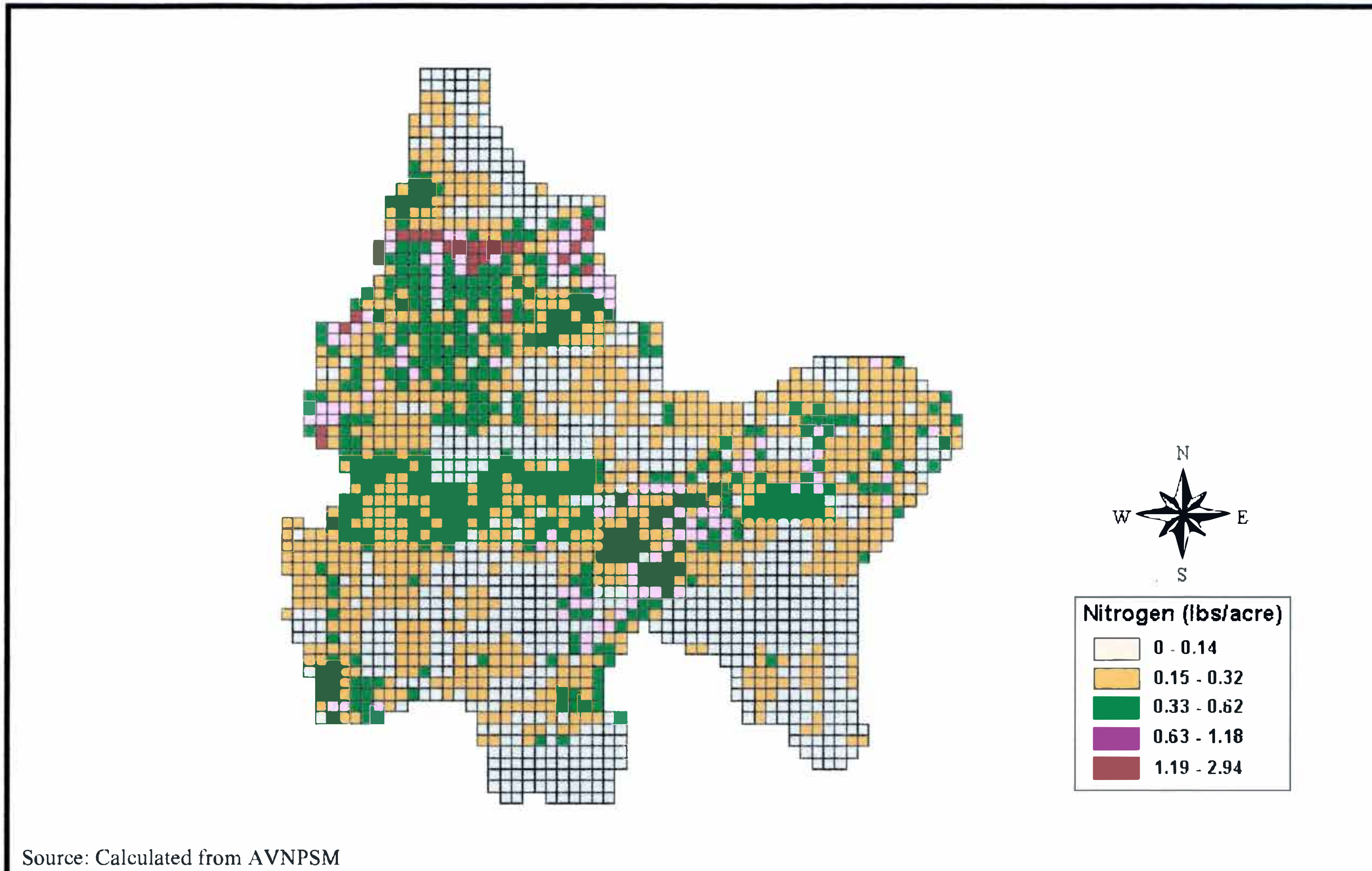


Figure 16. Simulated sediment attached N (in cell runoff) in the Davis Creek watershed, 1996

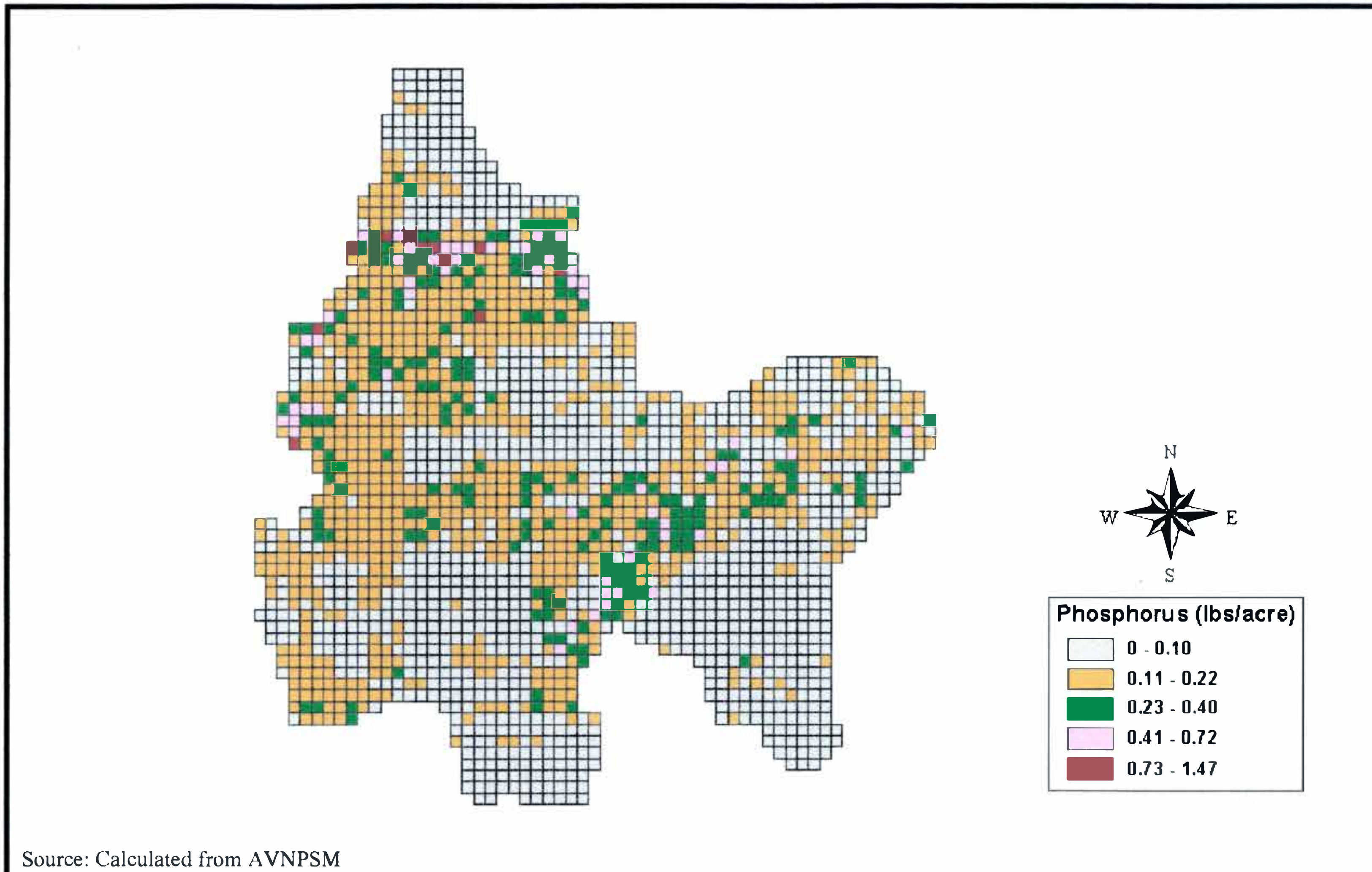


Figure 17. Simulated sediment attached P (in cell runoff) in the Davis Creek watershed, 1996

many areas of near total runoff such as roofs, roads, sidewalks, and parking lots. These areas, or the increase as noted previously, had very low infiltration rate. Much of the precipitation striking those surfaces becomes runoff, flowing to the river. Thus, compared to 1978, the Davis Creek was more vulnerable to flooding in 1996.

Compared to 1978, erosion and sedimentation decreased by 140 tons (27%) in 1996. This is again due to the conversion of agricultural land to urban uses that had a great portion of paved surfaces. In addition, changes between urban uses also would lead to focal differences in erosion and sediment yield. In the west-central areas of the watershed, many commercial areas in 1978 changed to industrial areas by 1996. As a result, sediment yield also declined in these areas.

Nutrient yields (sediment attached nitrogen and phosphorus) in the Davis Creek decreased slightly in 1996 compared to those in 1978. This is probably a result of reduced sediment from declined agricultural and commercial lands in the watershed.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This study assesses the impact of land use change on nonpoint source pollution in the Davis Creek watershed. Land use change between 1978 and 1996 was assessed using remote sensed data used in conjunction with GIS. The ArcView Nonpoint Source Modeling (AVNPSM) was used to: 1) simulate the impact of land use change on resulting changes in runoff, soil erosion, sediment load and nutrient yields; and 2) identify the critical nonpoint source areas in the watershed to support targeted NPS pollution management in the Davis Creek watershed.

Land Use/Cover Change between 1978 and 1996

Land use changed dramatically during past two decades in the Davis Creek watershed. Compared to 1978, residential land increased by more than 170 percent in 1996, while industrial, open land, and wetlands increased by 46 to 58 percent, respectively. Agricultural and forested lands declined by 61 and 18 percent respectively due to their conversion to urban uses in 1996. Barren land also declined by about 90 percent in 1996. Largely, the results are predictable in that the retirement of agriculture land uses and its conversion to urban uses such as residential, commercial, and industrial land resulted in significant changes in drainage and water quality. Residential land increased significantly throughout watershed. These changes were attributable mainly to the population growth and the associated demands for residential development and urban services in the Davis Creek watershed.

The Effect of Land Use/Cover Change between 1978 and 1996 on NPS Pollution

The effects of land cover changes on nonpoint source pollution in the Davis Creek were simulated using the AVNPSM for the period of 1978 and 1996. Compared to 1978, the conversion of agricultural and forested lands to urban uses resulted in a more than 180 percent increase in the peak flow rate in the Davis Creek in 1996. That is, the Creek became more vulnerable to flash flooding. Sediment yields and associated sediment attached nitrogen and phosphorous in 1996 also decreased slightly due to urbanization of the watershed as land was taken from crop production.

Land cover changed is more than 70 percent of the watershed between 1978 and 1996. A faster rate of urbanization also took place throughout the watershed. This led to an increased flooding rate in the Creek. Best management practices can be used to minimize the impacts of urbanization on water resources. Rather, it is cleared that more integrated water management in urban/suburban areas is needed to limit the effects of flooding in these areas. For example, cluster development, the grouping of a particular development's residential structures on a portion of the available land and reserving a significant amount of the site as protected open space (Mega et. al, 1998), can be used to control subdivision expansion. Conservation tillage can be used to reduce soil disturbance and water loss by retaining crop residues on the land and leaving the surface rough.

Recommendations for Further Studies

This study uses AVNPSM and AGNPS to assess the impacts of land use change on nonpoint source pollution and to identify critical areas for implementation of best management practices. The AVNPSM interface significantly improves the efficiency and accuracy of the watershed modeling process, which concurs the similar findings by others (He et al., 1993; Liao and Tim, 1997; He et al., 2001). The use of these models allows easy visualization of spatial distribution of simulated results in map format, and thus enabling examination of critical areas for application of management practices. An overlay of roael/rail system and incorporated areas in vector to identify areas of greatest potential problem is also recommended for further study.

Field measurements of streamflow and water quality should be used to calibrate the simulation results. Additionally, best management practices should also be explored using AVNPSM to provide information to resource planners for reducing magnitude of flooding in the Davis Creek watershed.

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