To the Graduate Council:

I am submitting herewith a thesis written by Shannon Elizabeth Bennett entitled "Use of a Dynamic Sediment Delivery Model for Watershed Planning in Beaver Creek, Knox County, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

John Schwartz
Major Professor

We have read this thesis
and recommend its acceptance:

Randall Gentry

David Feldman

Accepted for the Council:

Anne Mayhew
Vice Chancellor and
Dean of Graduate Studies

(Original signatures are on file with student's records.)

Use of a Dynamic Sediment Delivery Model for Watershed Planning in Beaver Creek, Knox County, Tennessee

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Shannon Elizabeth Bennett
August 2006

Dedication

I would like to dedicate this thesis to my parents. Without you none of this would have been possible. You both have shown me unconditional love and have supported all of the dreams I have had since I was a little girl. If I had not had your encouragement, I would not have been able to accomplish all of the goals that I have. You both have been such an important part of my life and I know that you still will be while I am starting a new adventure in my life. I appreciate all that you have and continue to do for me. There are no words to express my gratitude and love for you.

I love you Momma and Daddy!

Acknowledgements

I would like to thank my major professor, Dr. John Schwartz for all of his help. He helped me start my graduate education and also provided a lot of guidance on this project. I appreciate all of his effort and time during my schooling at the University at Tennessee. I would also like to thank my committee members, Dr. Randall Gentry and Dr. David Feldman, for taking their time to serve on my thesis committee. I would like to extend my appreciation to Tennessee Department of Environment and Conservation, who provided the funding for this project. The field work for this project could not have been done alone, and I would like to thank Robert Sain and Candice Owen for all of their effort to get the job done. Appreciation is also extended to Brantley Thames, Ron Bingner, and Vance Justice for their help with learning the intricacies involved with AnnAGNPS. It has been a great learning experience to be able to work with the professors at UT and also to work with the Beaver Creek Task Force on this project.

Besides the academic advising I have received, there have been others in my life that have provided a lot of help with finishing my Master's degree by showing their support and unconditional love throughout this entire process. For their love, I would like to especially thank my parents, grandparents, and my whole extended family. My utmost praise and thanksgiving is for my Lord and Savior for blessing me with so much in my life. To Him I will be forever grateful.

Give thanks to the Lord for he is good. His love endures forever.
Psalm 136:1

Abstract

Beaver Creek is located in Knox County, Tennessee and is on the 303d list for impairment due to phosphorus, nitrate, *Escherichia coli*, loss of biological integrity due to siltation, and habitat loss due to impacts from urbanization. The Beaver Creek watershed is rapidly urbanizing, but is still composed primarily of agricultural and forested lands. The watershed also has a large residential area. The purpose of this research is to provide a better understanding to the following questions:

- How does sediment yield change in watersheds as a function of urbanization?
- How do sediment yields change in watersheds as a function of land disturbance coverage and distribution?
- How do sediment yields change in watersheds as a function of Best Management Practices effectiveness, within a framework of land disturbance coverage and distribution?

These questions were explored by performing simulations with the Annualized Agricultural Non-Point Source Pollutant (AnnAGNPS) loading model. AnnAGNPS is a dynamic sediment delivery model that was developed by the United States Department of Agriculture, National Sedimentation Laboratory. There were four experiments that were performed using AnnAGNPS to model different simulation scenarios in the watershed. The experiments are:

- Experiment 1: Effect of increased urbanization on sediment yield with and without bank erosion simulated.
- Experiment 2: Effect of increased disturbed land in the watershed on sediment yield, and its distribution within the watershed.

- Experiment 3: Effect of increased disturbed land on sediment yield distributed on lowland versus hill slope.
- Experiment 4: Effect of BMP effectiveness on sediment yield in the watershed.

The results of this thesis have shown the impacts of urbanization and disturbed lands on sediment yield. Urbanization in Beaver Creek watershed resulted in an increase in the amount or runoff. This increase in runoff resulted in a greater sediment yield when including bank erosion. However, when bank erosion was not included in the calculation of sediment yield, the sediment erosion from the landscape was reduced when urbanization was increased.

A model simulation for sediment yield when the land base was completely undeveloped provides a 'frame of reference' to compare the results of the four experimental simulations. At this point, the sediment yield including bank erosion was 137.47 T/day. This is the natural occurring level of sediment in the watershed mostly consisting of bank eroded sediments.

Increasing the amount of disturbed lands in the watershed has been shown to approximately double the amount of sediment yield. When the spatial location of disturbed lands in the watershed was modeled in AnnAGNPS, the results showed that development concentrated in the lower watershed generated more sediment yield than when concentrated in the mid and upper areas of the watershed.

Experiment 3 simulated the effects of concentrating the disturbed lands on the hillslopes and lowlands. Concentrating the disturbed lands on the hillslopes had the greatest impact on sediment yield. When the disturbed lands were concentrated on the lowlands, the results were near the sediment yield for disturbed lands equally distributed on the lowlands and hillslopes.

Experiment 4 was to determine how BMPs effectiveness would affect sediment yield. The BMPs effectiveness was modeled at increasing amounts of disturbed lands. As the efficiency of the BMPs increased, the sediment yield decreased. Through the effective use of BMPs in Beaver Creek watershed, more development could occur without having a significant increase in sediment yield.

Ultimately, a watershed management plan will be developed by the Beaver Creek Taskforce (BCTF). The BCTF can use the reference point (137.47 T/day) for naturally occurring sediment in the watershed to determine what level of sediment they prefer to manage. Listed below are the recommendations for Beaver Creek to use in establishing the watershed management plan.

- Set the maximum level of development that can occur if it is equally distributed in the watershed.
- Limit development when it is concentrated in either the lower or the upper watershed.
- Limit development on the hillslopes.
- When developing on the hillslopes, strictly enforce the use of BMPs.

- Use BMPs with higher effectiveness if more development is desired in the watershed.

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Chapter 1: Introduction

Increased sedimentation within our nation's waterways has caused a significant impact on water quality and habitat (EPA, 1999; Nelson and Booth, 2002; Ming-Shu and Xiao-yong, 2004; Nietch et al, 2005). Many states have developed biocriteria standards using benthic macroinvertebrate or fish data to identify whether a stream segment is impaired for the same environmental stressors (EPA, 1999). The introduction of excessive fine sediment into the stream is a major environmental stressor (Nietch et al, 2005). Aquatic biota depends on these waterways for their livelihood. Total Maximum Daily Loads (TMDLs) are the maximum allowable loadings for a pollutant into a waterway that does not impair its designated uses (EPA, 1999; EPA, 2002; NSL, 2004). Designated uses include aquatic life, irrigation, domestic water supplies, industry, and navigation (EPA, 1999; EPA, 2002). The implementation of these regulations has created a demand for better tools that can be used to model the amount of sediment coming from the land in the watershed and ways that sedimentation can be reduced (Kuhnle et al, 1996; EPA, 2002; Nietch et al, 2005).

Several studies have researched the effects of disturbed land and urbanization on sediment yield. The watershed for Issaquah Creek in Washington is 73% forested, so the largest contributors to the sediment erosion are forest processes and landslides (Nelson and Booth, 2002). The other major contributors to sediment erosion in the watershed are, from highest to lowest: channel-bank erosion, urban land uses, and road-surface erosion (Nelson and Booth, 2002). Even though forest processes and landslides contribute the most sediment erosion in the watershed, land-clearing activities cause the most sediment erosion on a unit-area relationship, similar to the Beaver Creek watershed situation (Nelson and Booth, 2002). Another study in southeastern Wisconsin was performed on forty-seven watersheds that were composed primarily of agricultural and urban land uses (Wang et al, 2001). This study showed the largest contributors to sediment yield in the waterway were, from best to worst: connected imperviousness, highways-streets-parking lots, commercial land, total urban land, agricultural land, government land, residential land, undisturbed land connected to the stream, woodland, vegetated land, and water-wetland (Wang et al, 2001). This relates to Beaver Creek's situation since it is located in a rapidly urbanizing watershed that results in a lot of development.

There is a lack of understanding about sediment transport in a watershed from a complex assortment of disturbed lands (EPA, 2002; Owens et al, 2005). Because of the spatial variability of land uses in a watershed, sediment modeling provides a useful tool for watershed and land use management. For example, disturbances can occur from residential development on low or high gradient slopes. Disturbances can also be concentrated in the headwaters of the watershed versus the lower end of the watershed. A study was performed on the Redrock Creek watershed in Kansas using AnnAGNPS to estimate runoff and sediment yield (Ming-shu and Ziao-yong, 2004). AnnAGNPS was also used to determine the location the source of sediment. Several scenarios were then modeled in AnnAGNPS to demonstrate the effect Best Management Practices (BMPs) can have on the sediment erosion in the watershed. Another study performed by the National Sedimentation Laboratory used AnnAGNPS to determine the locations of significant sediment erosion in the James Creek watershed (NSL, 2002). The results from AnnAGNPS showed that the majority of sediment came from within the stream channel of the creek and its tributaries. This information was to be used to stabilize eroding reaches and tributaries that were causing the sediment erosion.

Sediment modeling is a useful tool for demonstrating the effect Best Management Practices (BMPs) have on reducing the sediment yield in the watershed (EPA, 2002). BMPs are methods used to reduce the amount of sediment or other pollutants entering the waterways (EPA, 2002; Shepard, 2005; EPA, 2006). There are several BMPs to choose from and each method has its own efficiency rating associated with its use (Nietch et al, 2005). Within the AnnAGNPS model, only BMPs effectiveness is modeled, not specific BMPs methods (NSL, 2001). Once the necessary efficiency is chosen to reach the required TMDL, methods can then be chosen based on their practicality for the site and their efficiency level (Davis, 1991). The efficiency level of various BMPs methods can be found in several sources: government, academic, and individual publications (EPA, 2006).

Watershed planning involves using the information for sediment modeling along with environmental policy and personal values and priorities. Watershed management typically involves stakeholders from various backgrounds in the planning process (Smolko et al, 2002; Smutko et al, 2002). The stakeholders' backgrounds can include: the government, development, agriculture, environmental conservation, forestry, scientists, academia, and residents of the watershed. The goal of the stakeholders is to develop a watershed management plan that will improve the quality of the watershed

(Smolko et al, 2002). This planning can include scientific data and the perspectives of the stakeholders (Smutko et al, 2002). Once information has been analyzed and possible options considered by the stakeholders, a final watershed plan will be agreed upon and typically implemented by the local government (Smolko et al, 2002; Smutko et al, 2002).

The Beaver Creek Watershed Task Force has elected to use AnnAGNPS to model sedimentation that results from different scenarios within the watershed. Beaver Creek is located in Knox County, Tennessee and has been placed on Tennessee Department of Environment and Conservation's 303d list for impaired waterways for sedimentation and other pollutants (TDEC, 2005). Some of the pollutant sources that have been identified include a major municipal point source, pasture grazing, and land development. The TMDL priority for the violations on Beaver Creek is at a medium level. This medium level means that the tools are available to be able to produce the TMDL, but the watershed is not being studied by the state over the next two years (TDEC, 2005). The TMDL will be produced in the next five years and the state needs a better understanding of the sedimentation problems and how to manage BMPs in order to reduce sediment and habitat impairment.

The goal of this research project was to answer the following three questions:

- How does sediment yield change in watersheds as a function of urbanization?
- How do sediment yields change in watersheds as a function of land disturbance coverage and distribution?

- How do sediment yields change in watersheds as a function of Best Management Practices effectiveness, within a framework of land disturbance coverage and distribution?

Answers to these questions will support development of a watershed plan for Beaver Creek. Fundamentally, this research improves our understanding of how different patterns of disturbance on the landscape change the sediment yield in urban watersheds.

Chapter 2: Background

Siltation

Siltation in waterways has become a major cause of poor water quality in the United States. Within Tennessee alone, siltation has impacted over 5,743 miles of streams and rivers (TDEC, 2005). Economically, heavy siltation in a waterway increases the water treatment costs, fills in reservoirs, navigation channels are lost, and there is a greater chance of flooding.

Rivers and streams are affected by siltation biologically, chemically, and physically (Owens et al, 2005; TDEC, 2005). Fish are affected by silt in several ways. The silt can smother their eggs and nests which will reduce the population of species over time (Owens et al, 2005). Their food supply is affected because the substrate that their prey, aquatic insects, use as habitat is covered by silt. Silt can also clog the gills of the fish and other aquatic species. If the gills become clogged, the organism will not receive the necessary dissolved oxygen from the water to survive. Aquatic plants and algae thrive in waters that are heavily laden with silt. If the growth is at an accelerated rate, these plants and algae will force out the other plants in the waterway that the aquatic organisms depend on for food and habitat (Nietch et al, 2005). Siltation will also lead to reducing the biological diversity of a river or stream through altering the habitat to favor burrowing species (TDEC, 2005). Besides the affects siltation has on the species living in the waterways, it can affect humans who consume fish or other aquatic species because pollutants easily attach to silt particles and are then transported throughout the waterway. If these particles are ingested by organisms, the pollutant can become concentrated within the food chain. This problem is seen in several waterways that are listed on the 303(d) list for Tennessee. The fish may not be safe for consumption due to PCBs or Mercury pollution (TDEC, 2004). The main fish that has been seen to have highly concentrated amount of pollutants within their system has been the catfish. This is due to the fact that catfish are bottom feeders and this is where the silt has settled to and the pollution is concentrated.

The chemical properties within rivers and streams are altered when they become heavily concentrated with silt particles, for example, eutrophication is accelerated by the increasing nutrient levels from siltation (Owens et al, 2005). The photosynthesis process is interrupted because siltation increases the water's turbidity and less light can reach to the bottom of the channel. This will lead to the plant species dying off and decreasing the dissolved oxygen levels from the decomposing organic matter (Owens et al, 2005; TDEC, 2005). As mentioned above, pollutants are easily transported by silt particles. This means that there will be more organic chemicals and heavy metals within the waterway.

Physically within the affected waterway, the depths of pools or lakes are decreased (TDEC, 2005). Siltation can also change the temperature patterns and the flow patterns. Each waterway is different in its tolerance of silt. Some waterways are more impacted than others. To determine if a waterway's biological integrity is being affected by silt habitat assessments should be performed over a time series to document the change (Nietch et al, 2005; TDEC, 2005). Other methods to determine the impairment due to siltation include visual observations, total suspended solids analysis, and macroinvertebrate surveys.

Urbanization in a Watershed

When there is an increase in urbanization in the watershed, the amount of sediment yield from the landscape is reduced because of the impervious surfaces that result (Hammer, 1972; Gregory et al, 1992). These impervious surfaces increase the peak flow rate from runoff not being infiltrated by the soil (Roy et al, 2006). Increases in peak flow rate could potentially lead to flooding in the watershed (White and Greer, 2004; Roy et al, 2006). Flooding can increase in the watershed when the floods have a return interval of five years or less (White and Greer, 2004). An increase in flow rates can reduce the amount of vegetation that might be present in the channel. Also, the increase of peak flow rates contributes to increase bank erosion within the channel and channel enlargement (Hammer, 1972; Gregory et al, 1992; Chin and Gregory, 2001, Roy et al, 2006). Bank erosion can potentially lead to bank failures. Bank failures can lead to increase sediment in the waterway and also damage to properties that might be located along the waterway.

Land Use Disturbance

Sediment yield in this thesis will consist of the uplands erosion that typically results from disturbed lands where the soil is stripped of vegetation. The amount of land disturbance affects sediment yield within a watershed (Hammer, 1972). When there is a decrease in the amount of disturbed land, the soil is less easily erodible (Kuhnle et al, 1996). Also, the energy of the runoff is reduced and makes eroding and transporting rates for sediment lower. Along with the amount of disturbance, the spatial distribution of the disturbances has an impact on sediment yield (Lenzi and Luzio, 1997). When the disturbed lands are located on a steep slope there is a greater impact on sediment yield, than when the disturbance is located on the lowlands (Nelson and Booth, 2002).

Case Study: Issaquah Creek

A study was performed on Issaquah Creek to determine the sources of sediment in the watershed. Issaquah Creek is located in King County, Washington. Land use in the watershed is varied, but is primarily forest land at 73% of the watershed (Nelson and Booth, 2002). The Issaquah Creek watershed is rapidly developing in the lowlands and consists of 19% of the total area. The study calculated the sediment yield rates from the land uses within the watershed. Landslides and forest processes caused the greatest contribution of volume of sediment. The other high volume sources of sediment were: channel-bank erosion, urban land uses, and urban road-surface erosion. The greatest sediment yield per area resulted from the steep forested areas of the watershed. The second highest sediment yield per area came from the most urbanized subwatershed. Even though landslides and forest processes contributed the highest volume of sediment in the watershed, construction and land clearing practices had the highest sediment yield when based on the unit-area. Sediment yields from agricultural land uses were low compared to the other land uses because it occurred only on the low-gradient areas of the watershed. Urbanization did not contribute greatly to sediment yield when considering only uplands erosion. However, channel erosion that results from increased runoff due to urbanization accounts for 20% of the total watershed sediment yield.

Sediment Models

Sediment models are tools that can be used to show how possible scenarios could possibly impact a watershed (Choi et al, 2003; He, 2003; Martin et al, 2005). Different "what-if" scenarios can be entered into the model to produce results that can help watershed planning and targeting TMDLs. There are a number of sediment models that have been developed by government agencies, academia, or private practices. Some examples of sediment models include: AnnAGNPS, BASINS with SWAT, USLE, WEPP, and MIKE BASINS (Martin et al, 2005).

AnnAGNPS Model

The Annualized Agricultural Non-Point Source Pollutant (AnnAGNPS) loading model is a watershed model that is used to estimate pollutant loadings from different land use practices (Lenzi and Luzio, 1997; He, 2003; NSL, 2001). The model was developed during a partnership of the United States Department of Agriculture-Agriculture Research Service (USDA-ARS) and the Natural Resources Conservation Service (NRCS). AnnAGNPS was developed to evaluate the impact of BMPs on the total maximum daily loads (TMDLs) to develop cost effective watershed management strategies (NSL, 2001).

In order to run a watershed simulation in AnnAGNPS, the following is needed: daily climate data, watershed topography, soils data, and land use distribution. Once this information is entered into the model, the following continuous daily estimates can be generated: runoff, sediment yield, and chemical (i.e., nutrients, herbicides, pesticides) non-point source pollutant loadings from a watershed (Lenzi and Luzio, 1997; He, 2003; NSL, 2001). Examples of the input data in the Input Editor program can be seen in Appendix A.

The daily climate information is needed to account for the rainfall, temperature, dew point temperature, cloud cover, and wind speed within the model simulation (NSL, 2001). This daily climate data can either be obtained from onsite field data or created by the Generation of weather Elements for Multiple applications (GEM) program. GEM has a NOAA database that uses the nearest weather station to create a time series of weather data. The daily soil-water balance is maintained to determine when runoff would occur during a precipitation event. Only when runoff occurs would sediment or chemical pollutants be transported.

A digital elevation model (DEM) is used to determine the watershed topography (NSL, 2001). AnnAGNPS uses the Topographic Parameterization (TOPAZ) program to delineate drainage areas and stream networks, the slope, slope length, slope-shape factor, and flow direction. The drainage areas are then used with the stream networks to route the runoff, pollutants, and sediment from individual cells to downstream cells. The

Agricultural Watershed Flow-Net (AGFLOW) program formats the TOPAZ output into the form needed by AnnAGNPS.

The soil data that is needed to run simulations in AnnAGNPS can be obtained from the NRCS. In combination with the land use distribution, the model can simulate the hydrology and soil loss programs to determine the sediment yields from erosion (NSL, 2001). The runoff is calculated using the SCS Curve Number method (SCS TR-55 method). This method calculates the time of concentration for each of the drainage areas. The curve numbers (CN) are selected based on the land use classification and which hydrologic soil group the soil is composed of.

To determine the amount of soil loss the Revised Universal Soil Loss Equation (RUSLE) is used by AnnAGNPS (Lenzi and Luzio, 1997; He, 2003; NSL, 2001). RUSLE is explained in great detail in the Agriculture Handbook 703: Predicting Soil Erosion by Water: A Guide to conservation Planning with the Revised Universal Soil Loss Equation (AH703). RUSLE is an empirical equation to calculate the average soil loss rate by water (Haan et al, 1994). The RUSLE equation is in the form below contains the following parameters:

$A = R * K * L * S * C * P$; where,

A = Computed spatial average soil loss and temporal average soil loss per unit area.
R = Rainfall-runoff erosivity factor – the rainfall erosion index plus a factor for any significant runoff from snowmelt.
K = Soil erodibility factor – the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot of 72.6 ft length of uniform 9% slope in continuous clean-tilled fallow.
L = Slope-length factor – the ratio of soil loss from the field slope length to soil loss

from a standard plot.

S = Slope steepness factor – the ratio of soil loss from the field slope length to soil loss from a 9% slope under otherwise identical conditions.

C = Cover-management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P = Support practice factor – the ratio of soil loss with a support practice like erosion control BMPs, detention facilities, etc.

In the calculation for sediment yield, AnnAGNPS uses the RUSLE equation (NSL, 2001). RUSLE has the "LS" factor that accounts for the length and slope of the area being eroded (Haan et al, 1994). The RUSLE equation variables are all linear in relationship. When AnnAGNPS calculates the amount of sediment eroding from the lowlands it uses HUSLE (NSL, 2001). HUSLE accounts for any deposition of the sediment on the landscape based on the length and slope of the area (Haan et al, 1994).

AnnAGNPS can be used to determine the amount of sediment that is eroding from the bank. The model uses the DEM to determine the stream bank's physical characteristics and the Manning's n for the reach and calculates the soil erosion occurring along the banks by using the RUSLE equation (NSL, 2001).

The Conservational Channel Evolution and Pollutant Transport Systems (CONCEPTS) model was developed by the USDA Agricultural Research Service to simulate one-dimensional sediment transport in streams with unsteady flow conditions and bank failures. When using CONCEPTS, cross-sections of the stream must be performed at an acceptable interval longitudinally. At each cross-section, sediment size distributions need to be performed. CONCEPTS is a more physically based model than AnnAGNPS and places more of an emphasis on hydraulics and channel properties. AnnAGNPS places more emphasis on the hydrology of the watershed to determine the sediment yield. CONCEPTS can be coupled with AnnAGNPS and used together to determine the sediment yield for the entire watershed and within the stream bank. However, if there is not sufficient sediment data or stream cross-sections, CONCEPTS cannot be used.

To truly verify output from AnnAGNPS with what is happening at the site-study, the model must be calibrated. AnnAGNPS can be calibrated from flow data at the given site. The flow data can be obtained through personal field measurements or by obtaining data from a USGS gauging station. For the Redrock Creek study, the AnnAGNPS model was calibrated from a USGS gauging station flow data (Ming-Shu and Xiao-yong, 2004). The model was calibrated by adjusting the curve numbers in order to verify the model runoff volume within a ten percent deviation of the USGS flow data. The variables that can be manipulated to calibrate the model are the Manning's n values for sheet, valley, reach, and concentrated flows and the curve numbers.

Case Study: James Creek

The NSL performed a study on James Creek, Mississippi to estimate the current sediment transport rate within the watershed in order to develop a TMDL on sediment for the creek (NSL, 2002). The James Creek Watershed's predominate land use was agricultural land. Thus cultivation and tillage of the land is the major contributor to the amount of sediment found in the creek. There is also the city of Aberdeen and the area's outer residential and business developments that make up an urban portion of the James Creek watershed. This watershed is similar to Beaver Creek watershed in the fact that its main land use type is agricultural.

There were six scenarios modeled and compared to actual values for sediment yield. These values can be seen in Figure 2-1. In order to set the standard, the sediment transport rate from an un-impaired reach was used, along with AnnAGNPS and Conservational Channel Evolution and Pollutant Transport System (CONCEPTS). AnnAGNPS was used to account for uplands erosion and CONCEPTS was used for channel erosion and sediment routing. The total sediment yield calculated from AnnAGNPS and CONCEPTS was consistent with what was measured from James Creek through field collection (NSL, 2002). The combination use of a reference reach and AnnAGNPS coupled with CONCEPTS is a valuable tool in determining sediment yield where no historical data exists. Using the reference reach allowed them to compare the amount of sediment yield in James Creek to a more stable stream to reach a reasonable TMDL level.

Case Study: Shades Creek

Shades Creek is located in Alabama and is on Alabama's list for impaired waterways due to sedimentation (NSL, 2004). The NSL's goal for this project was to determine a quantifiable TMDL for sediment in Shades Creek. A reference reach was

Scenario	Total Sediment (T/y)	Sediment Produced from AnnAGNPS Cells (T/y)	Sediment Produced from the Bed and Bank Contributions of AnnAGNPS (T/y)
Reduced Tillage with Indicated Channel Stability	158,084	24,807	133,277
Reduced Tillage with All Channels Unstable	177,198	24,579	152,620
Reduced Tillage with All Channels Stable	20,053	20,053	0
Conventional Tillage with Indicated Channel Stability	160,677	25,599	135,078
Conventional Tillage with All Channels Unstable	179,960	25,375	154,585
Conventional Tillage with All Channels Stable	26,666	26,666	0

Figure 2-1. Results of James Creek Study: Source of sediment simulated by AnnAGNPS at Darracott Road by simulation totals for 1967-2001 (NSL, 2002).

identified in the area to serve as a comparison level for Shades Creek. The reference reach was located in a different watershed with similar attributes to Shades Creek watershed. AnnAGNPS and CONCEPTS were used to simulate the "actual" sediment yield within Shades Creek. Shades Creek Watershed is composed primarily of two types of land uses: urban and forested land.

There were four different modeling scenarios that were used: past, current, potential, and future conditions of the watershed by changing the land use (NSL, 2004). The current condition was modeled to calibrate the model. Under current conditions for the watershed, the reference reach had a median annual suspended-sediment yield of 24.7 $T/d/km^2$. The result from AnnAGNPS for the suspended-sediment yield of Shades Creek was 52.6 $T/d/km^2$. The only scenario that showed large differences in sediment yield was when the forested areas were converted to urban areas. This increased the runoff rate, which led to a greater sediment yield within the watershed (NSL, 2004). Converting forest land to urban land increased the runoff 53.6%. Also, there was an increase in the average-annual load of suspended sediment of 68%. The fine fraction of the average-annual suspended sediment load increased 70% and the sand fraction increased 67%. From NSL's study on Shades Creek, the majority of sediments in Shades Creek are a result of streambank erosion. Figure 2-2 shows the contributions of the uplands area and the streambanks to the suspended sediment load.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	37.2	62.8	27,200
Sands	27.6	72.4	11,800
Total suspended	34.3	65.7	39,000

Figure 2-2. Relative source contributions of uplands and streambanks to suspended sediment integrated over the study reach for the 2001LUFU scenario (NSL, 2004).

Soil and Water Assessment Tool

The Soil and Water Assessment Tool (SWAT) was designed to simulate long-term processes in a watershed (Kuhnle et al, 1996; Qi and Grunwald, 2002; Martin et al, 2005). These processes could include flow, sediment yield, and nutrient transport. The input data that is required to use SWAT are: hydrology, climate, water quality, soil and plant information, and any management processes (Qi and Grunwald, 2002). The model then can be simulated for a variety of scenarios by changing the input variables to determine what impact those variables will have in the watershed being modeled.

Case Study: Goodwin Creek

Goodwin Creek was chosen to be used to measure the amount of sediment transported in the creek and the effect that the changes in land use has on the amount of sediment located in the creek. Goodwin Creek is located in central northern area of

Mississippi. It is located east of the Mississippi River's floodplain (Kuhnle et al, 1996). The soils along Goodwin Creek are silt loams, which are easily eroded when the surface cover is removed. The Goodwin Creek watershed is composed entirely of agricultural lands. There has not been any urbanization within this watershed, only farm homes and rural residential areas. Most of the cultivated lands are located within the valley bottoms, near the main channel.

This high volume of cultivated lands and its impact on the amount of sediment transport is the focus of this study. The percentage of cultivated lands has decreased from 26% to 12% during the years of 1982 to 1990 (Kuhnle et al, 1996). This decrease in cultivated lands had a drastic impact on the amount of sediment within the creek. The concentration of: fines decreased by 62%, sand decreased by 66%, gravel decreased by 39%. The shift from the cultivated, highly erodible land use to a less erodible land use reduced the amount of runoff leaving the upland areas and reducing the channel erosion and transport.

To determine the contribution of the upland sources to the fine sediment, the SWAT model was used instead of AnnAGNPS. This model takes into account soil moisture and crop growth. To predict the sediment yield, SWAT uses the Modified Universal Soil Loss Equation (MUSLE). The sediment yield calculation only included sources of sediment that were not within the channel. Therefore, channel erosion was not included in the sediment yield output. Within the given time period of 1982 to 1990, fine sediment from agricultural lands were accountable for 42% of the decrease in the total fine sediment concentration (Kuhnle et al, 1996). Although the SWAT model does not take into account channel erosion, it was inferred that 64% of fines at the watershed outlet was from channel erosion. This is due to the overland and rill flows on the cultivated fields are not capable of entraining the particles.

The results from this study showed that the changes in the land use reduced the discharge rate and amount (Kuhnle et al, 1996). This reduction, in turn, affected the sediment yield for all particle sizes. The shift in the watershed from cultivated land to nonerodible land benefited the watershed because of the runoff leaving the upland areas and reducing the amount of channel erosion and sediment transport.

Watershed Management

A watershed management plan looks holistically at the entire watershed to determine the best measures to use to improve the waterways located within. The plan will take into account point and non-point sources of pollution and looks at short and long-term strategies to protect the waterway. Watershed management has involved stakeholders from various backgrounds in the planning process (Rhoads et al, 1999; Smolko et al, 2002; Smutko et al, 2002; Manring and Pearsall, 2006). The stakeholders' backgrounds can include: the government, development, agriculture, environmental conservation, forestry, scientists, academia, and residents of the watershed. These stakeholders come together to accomplish common goals to improve the quality of the watershed by addressing policy and regulatory issues (Smolko et al, 2002; Manring and Pearsall, 2006). Scientific data can also be used in the planning process to make decisions

(Rhoads et al, 1999; Smutko et al, 2002; Manring and Pearsall, 2006). A large portion of the success of the watershed management plan depends on the effectiveness of the stakeholder involvement (Smolko et al, 2002). Since stakeholder involvement is generally voluntary, the process to develop the management plan should maximize agreement, involvement, and ownership, although the process can be different in each case (Smolko et al, 2002; Manring and Pearsall, 2006). Once information has been analyzed and possible options considered by the stakeholders, a final watershed plan will be agreed upon and typically implemented by the local government (Smolko et al, 2002; Smutko et al, 2002; Manring and Pearsall, 2006).

The Beaver Creek Task Force (BCTF) was established in 1998 to improve water quality in the watershed. A goal of the BCTF was to develop a watershed management plan for Beaver Creek watershed. The BCTF is composed of members of the community, local government officials, Tennessee Valley Authority employees, scientists, and utility district employees. The members have presently accomplished the following matters: updated the FEMA flood study for Beaver Creek, completed an initial watershed assessment, started a watershed education program, completed a Green Infrastructure Plan, and updated the GIS land use map. Currently, bacteria, nitrogen, dissolved oxygen, phosphorous, and sediment are pollutants that are being modeled and monitored by the BCTF. After the completion of the modeling, the members will analyze the data and determine possible measures to improve the quality of water in Beaver Creek.

Best Management Practices

Best Management Practices (BMPs) are both structural or nonstructural methods to prevent or reduce the amount of sediment, nutrients, and other pollutants entering a waterway (Owens et al, 2005; Shepard, 2005; EPA, 2006). BMPs are a method to reduce non-point source pollution. States have typically enforced the regulations on BMPs in order to comply with federal regulations (Shepard, 2005).

There are several BMPs to choose from and each method has its own efficiency rating associated with its use (Haan et al, 1994; Nietch et al, 2005). Some examples of BMPs include: land grading, check dams, preserving natural vegetation, sodding, protecting steep slopes, vegetative buffer, silt fence, sediment basins and filters, and storm drain inlet protection (Haan et al, 1994; Shepard, 2005). There are efficiency ratings for BMPs that can be used to determine the reduction in sediment coming off of the landscape (Haan et al, 1994). For example, vegetated swales have an efficiency range of 40% to 75%, with an average efficiency of 60% (Davis, 1991). Riparian filters have a range of 50% to 80%, with an average of 65%. Trapped catch basins have a range of 20% to 40%, with an average of 30% efficiency. Extended detention basins have a range of 50% to 90%, with an average of 60%. With these tools, developers can choose the best methods for their site and can use a variety of methods to achieve the level of efficiency required (Table 2-1).

Table 2-1. BMP Effectiveness Ratings (Davis, 1991).

BMP Effectiveness Ratings			
BMP Method	**Low End Efficiency**	**High End Efficiency**	**Average Efficiency**
Vegetated Swales	40%	75%	60%
Riparian Filters	50%	80%	65%
Trapped Catch Basins	20%	40%	30%
Extended Detention Basins	50%	90%	60%

Chapter 3: Methods

Study Area

The Beaver Creek watershed is located in northwestern portion of Knox County, Tennessee. The watershed is contained entirely in the county boundary and comprises 86 square miles. Figure 3-1 shows the location of Beaver Creek within Knox County, Tennessee. Figure 3-2 shows a map of the watershed. Beaver Creek drains into the Clinch River, which is a tributary for the Tennessee River. The communities of Gibbs, Halls, Powell, Karns, and Harden Valley are located within the Beaver Creek watershed.

Within the watershed different land use classifications were used for this research. The percentage of the watershed that each land use occupies is shown in Figure 3-3. The watershed is composed mainly of urban land, woods, agricultural land, and low density residential land.

Beaver Creek watershed was divided into 23 subsheds for management purposes. The subsheds were delineated by BCTF to manage water resources more locally. Each of these subsheds has their own characteristics and some have major tributaries into Beaver Creek. The size of the subsheds is shown in Table 3-1.

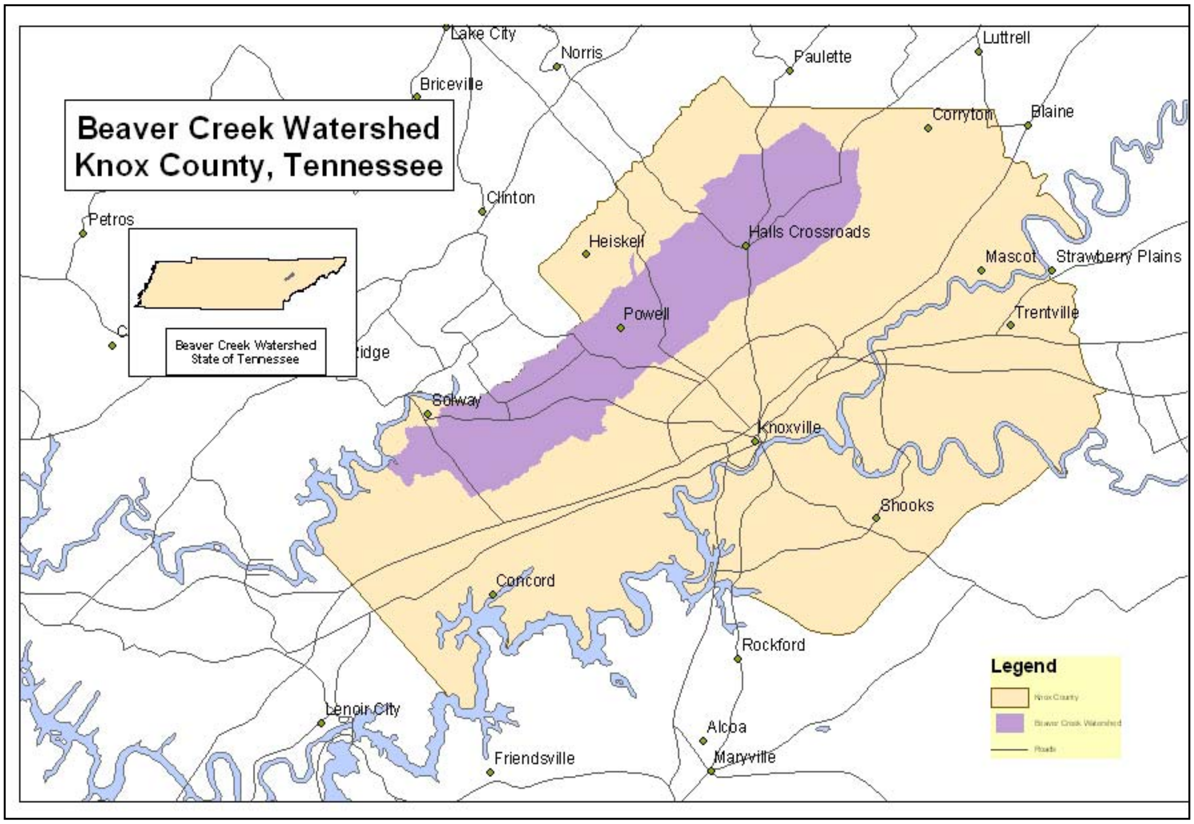

Figure 3-1. Location of Beaver Creek Watershed in Knox County, Tennessee

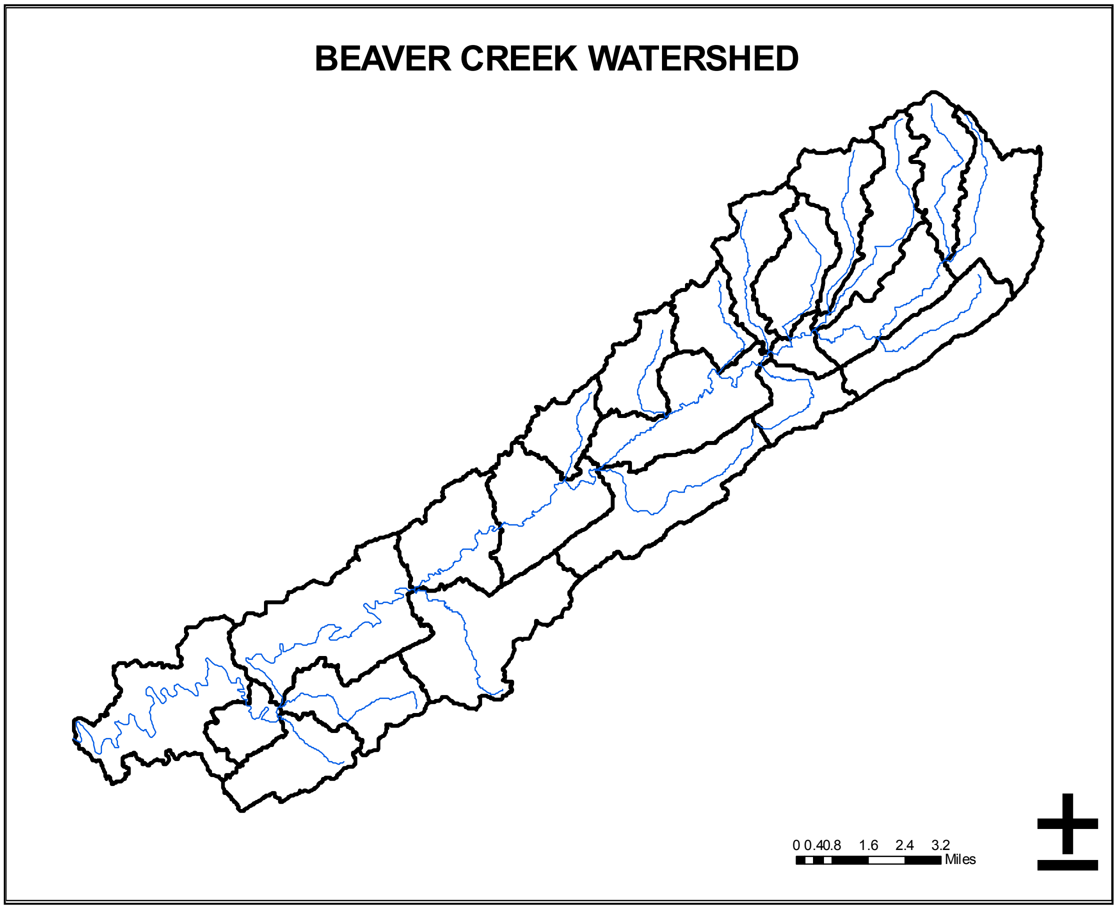

Figure 3-2. Beaver Creek Watershed

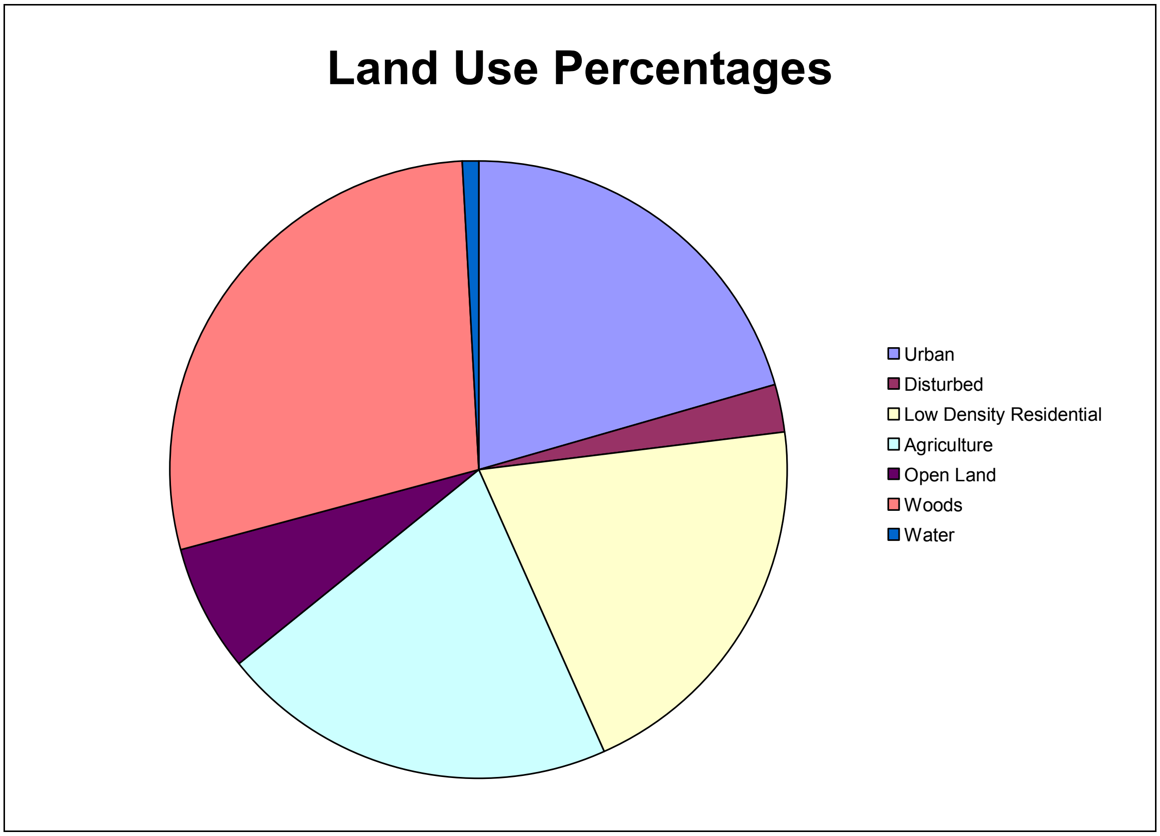

Figure 3-3. Distribution of Land Use Classifications in Beaver Creek Watershed for August 2003.

Table 3-1. Size of Beaver Creek Subsheds

Beaver Creek Subsheds		
Subshed	**Acres**	**% of WS**
1) Gibbs	417.04	5.33
2) Kerns Branch	267.82	3.42
3) Upper Section of BC	330.52	4.23
4) Halls	116.56	1.49
5) North Fork	279.68	3.58
6) Allen Branch	260.85	3.34
7) Mill Branch	265.67	3.40
8) Willow Fork	359.61	4.60
9) Cox Creek	313.26	4.01
10) Brickey	525.84	6.72
11) Bishop Road	242.39	3.10
12) Cardwell Lake	228.23	2.92
13) Hines Branch	278.75	3.56
14) Knob Fork	493.36	6.31
15) Powell	422.45	5.40
16) Collier Road	159.64	2.04
17) Bell's Bridge	381.17	4.87
18) Karns	615.51	7.87
19) Westbridge	185.06	2.37
20) Grassy Creek	564.44	7.22
21) Meadow Creek	342.95	4.39
22) Plumb Creek	275.78	3.53
23) Lower Section BC	493.40	6.31

Study Design

A dynamic sediment yield model was used, AnnAGNPS, to answer the questions about how sediment yields change in a watershed as a function of land disturbance coverage and distribution and how sediment yields change as a function of best management practices (BMPs) effectiveness. Land disturbance is where the soil has been stripped of all vegetation and the soil is exposed to rainfall.

The following modeling experiments were performed in order to be able to answer the three questions posed for my thesis:

- Experiment 1: Effect of increased urbanization on sediment yield with and without bank erosion simulated.
- Experiment 2: Effect of increased disturbed land in the watershed on sediment yield, and its distribution within the watershed.
- Experiment 3: Effect of increased disturbed land on sediment yield distributed on lowland versus hill slope.
- Experiment 4: Effect of BMP effectiveness on sediment yield in the watershed.

Experiment 1 was used to show the impact on sediment yield after the disturbed lands were converted to urbanized areas. Experiments 2 and 3 were performed to best answer the question "How do sediment yields change in watersheds as a function of land disturbance coverage and distribution?" The question "How do sediment yields change in watersheds as a function of BMPs effectiveness, within a framework of land disturbance coverage and distribution?" was addressed through Experiment 4.

AnnAGNPS

Input Data

To run a simulation in AnnAGNPS, the following information is needed: the watershed topography, daily climate data, soil data, and the land use designations of the watershed. The watershed topography is used by the model to determine the drainage areas and the stream network. The digital elevation model (DEM) is required for AnnAGNPS to determine the topography of the watershed. The DEM for the Beaver Creek Watershed was provided by Knoxville Geographic Information Systems (KGIS). It is shown in Figure 3-4. The soil data is used by AnnAGNPS to predict the amount of erosion that will occur from the given daily climate data. The soil data for Beaver Creek watershed was obtained by the NRCS.

The AnnAGNPS model requires either measured or simulated weather data to be able to generate precipitation. The daily climate data contains: the maximum and minimum air temperatures, dew point temperature, precipitation, sky cover, and wind speed. In order to calibrate the model with flow data, historical weather data was used. The historical weather data from January 1, 2000 to July 1, 2003 was from the National Oceanic and Atmospheric Administration's Knoxville McGhee Tyson Airport (WBAN # 13891, Coop ID #404950) and Oakridge Atdd. (WBAN # 03841, coop id # 406750) sites. From July 1, 2003 to March 31, 2005, the weather data was obtained from Hallsdale Powell Utility District. The compilation of the two weather data sections was performed by Jim Hagermann with the Tennessee Valley Authority.

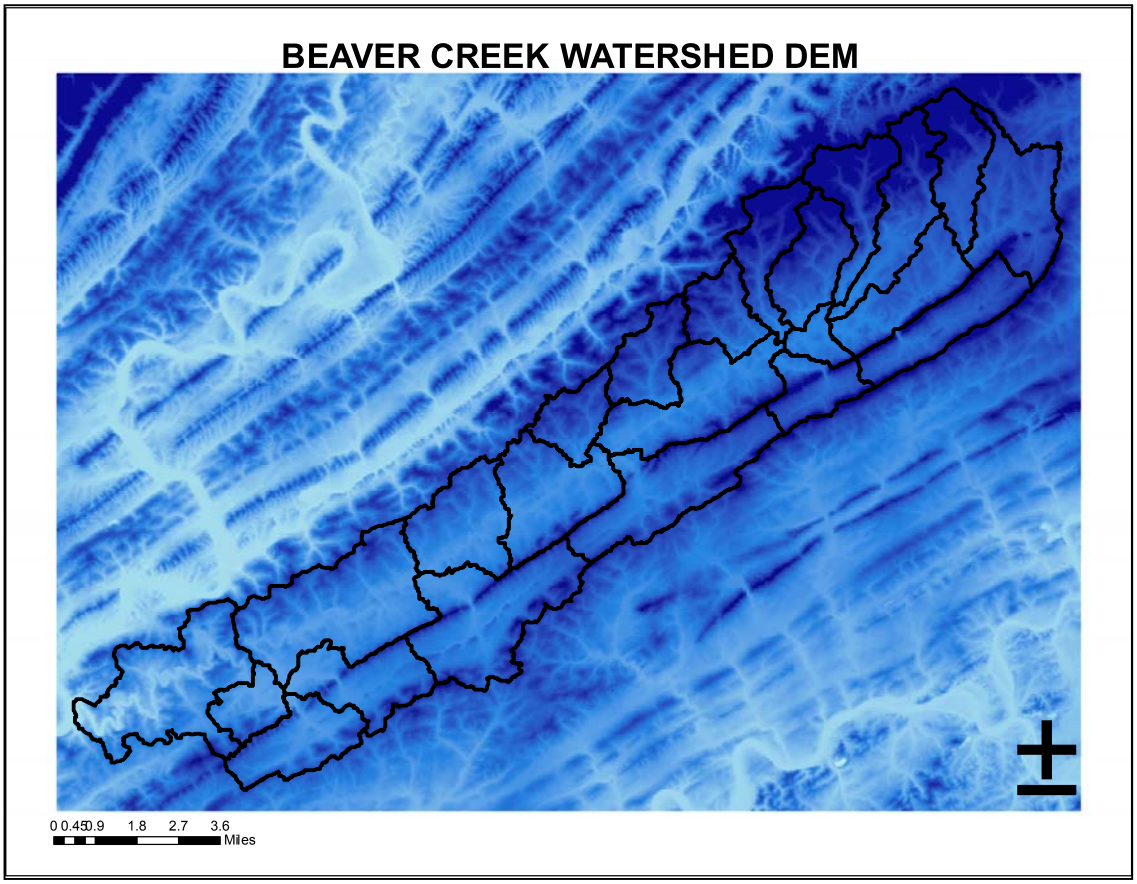

Figure 3-4. Digital Elevation Model of Beaver Creek Watershed

The land use designations were obtained from KGIS aerial photographs that were taken of the Beaver Creek watershed in August of 2003. The University of Tennessee (UT) Geography Department used these aerial photographs to generate a GIS land use shapefile. This land use layer contained thirty-eight classifications for the land use. These classifications were combined based on their similarities into thirteen broader categories for the AnnAGNPS modeling effort. The final classification used for the modeling effort is shown in Table 3-2. The land use distribution is shown in Figure 3-5.

Model Calibration

After the needed input for AnnAGNPS was obtained, the model was run for several locations where there was previous flow data. The flow data was obtained from TDEC Contract No. z-02008760-00. Thirteen stations had flow data recorded from March 2004 to January 2005. The location of these stations is shown in Table 3-3. The flow data for each of the stations is contained in Table 3-4. Continuous flow data was obtained for two locations from USGS; one where Beaver Creek is crossed by Solway Road and the other at Beaver Creek near Willow Fork. After the model was run for each of these locations, the output from AnnAGNPS was compared to the actual data points. From here, the curve numbers and Manning's n values were changed by hand within the program accordingly to calibrate the model with respect to peak runoff and runoff volume. The Manning's n value controlled the peak runoff and the curve numbers control the amount of runoff. The amount of runoff from the USGS gage at Solway was 8020.65 Tonnes. The amount of runoff from AnnAGNPS was 7221.72 Tonnes, which is within a 10%

Table 3-2. Land Use Classifications

Final Land Use Classification	Original Land Use Classification
1) Residential (High Density)	Single family, high density (more than 6/acre) Apartment/condominium complex
2) Residential (Medium Density)	Single family, medium density (2-5/acre)
3) Residential (Low Density)	Single family, low density (fewer than 2/acre)
4) Commercial	Central business district; Strip development; Shopping center; Service areas; Community complex; Water treatment plant; Institutional-other; Airport; Major highway right of way
5) Industrial	Light industry; Heavy industry
6) Disturbed/Transitional	Quarry; Disturbed area without sediment control structures/practices; Disturbed area with sediment control structures/practices
7) Agricultural	Cropland; Good pasture, well maintained; Fair pasture, uneven growth and condition with minimal maintenance; Heavily overgrazed pasture; Poor pasture, sparse cover, shallow soils, steep slopes, often gullies; Feedlot of loafing areas; Specialty crops; Hay land
9) Open Land (Good)	Golf course; Park; Medium brush (10'-20'); High brush (greater than 20'); Shrub and brush
10) Meadow	Meadow
11) Woods (Thick)	Woods (Thick)
12) Woods (Thin)	Woods (Thin)
13) Impervious	Impervious surfaces
14) Water	Streams and canals; Reservoirs; Detention Ponds

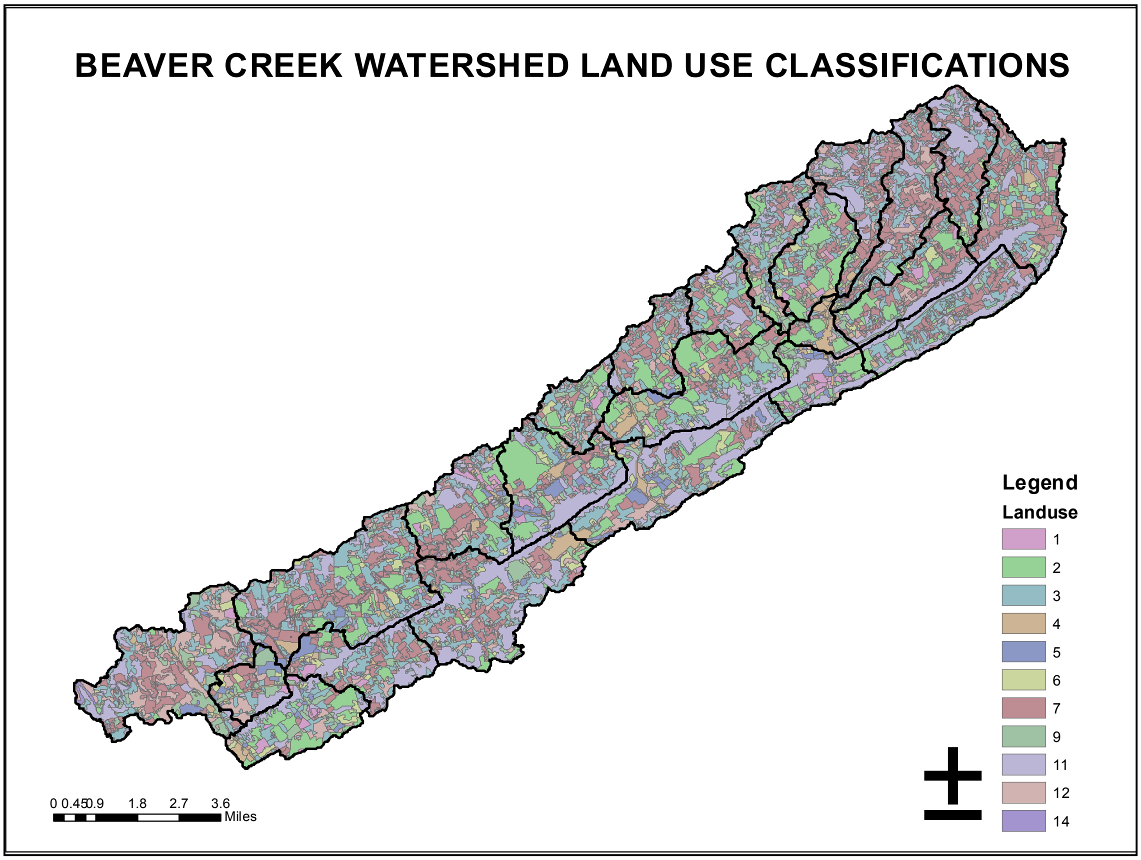

Figure 3-5. Distribution of Land Use Classifications

Table 3-3. Location of Flow Data Stations

Station No.	GPS Coordinates (DMS)	Station Description
COX000.2KN	Lat 36 04 43 Long 83 53 54	Cox Creek, 100 m upstream of Brown Gap Rd
BEAVE038.7KN	Lat 36 04 53 Long 83 53 55	Beaver Creek, 100 m upstream of Brown Gap Rd
WILLO000.5KN	Lat 36 05 07 Long 83 55 14	Willow Fork, 100 m downstream of Emory Road
HINES000.2KN	Lat 36 04 09 Long 83 56 36	Hines Branch, 150 m upstream of Cunningham Road
BEAVE031.8KN	Lat 36 03 32 Long 83 58 24	Beaver Creek, 100 m upstream of Dry Gap Pk
KNOBF000.3KN	Lat 36 02 15 Long 84 00 13	Knob Fork, 50 m upstream of E. Beaver Cr. Dr
BEAVE024.7KN	Lat 36 01 06 Long 84 03 04	Beaver Creek, 150 m upstream of Clinton Hwy.
BEAVE020.9KN BEAVE021.0KN	Lat 35 59 46 Long 84 05 06	Beaver Creek, 300 m upstream of Harrell Road
GRASS000.9KN	Lat 35 59 39 Long 84 04 04	Grassy Creek, at T. Graham private driveway
PLUMB000.3KN	Lat 35 57 28 Long 84 07 42	Plumb Creek, backyard from Highgate Circle
MEADO000.2KN	Lat 35 57 50 Long 84 07 48	Meadow Creek, 5 m upstream of Cross Lane
BEAVE012.5KN	Lat 35 57 26 Long 84 08 08	Beaver Creek, downstream of West Cott Blvd.
BEAVE003.5KN	Lat 35 57 22 Long 84 11 24	Beaver Creek, 150 m upstream of Swafford Rd

Table 3-4. Flow Data from TDEC Contract Stations
Asterisk (*) indicates an estimate of discharge derived by measured discharge-drainage area relationships because velocity measurements were unattainable from deep flow or equipment malfunction.

STATION NO.	March 04, '04	April 13, '04	May 03, '04	May 25, '04	June 29, '04	July 14, '04	August 03, '04	Sept 13, '04	Oct 27, '04	Nov 17, '04	Dec 14, '04	Jan 11, '05
COX000.2KN	5.90	41.69	4.0*	1.70	5.97	2.41	1.9*	1.92	1.73	3.88	8.60	6.50
BEAVE038.7KN	14.43	82.22	9.3*	2.38	10.66	3.75	1.67	1.58	1.76	7.58	24.37	13.84
WILLO000.5KN	14.30	59.32	4.9*	4.67	14.36	4.61	4.1*	3.74	4.54	10.08	33.04	18.02
HINES000.2KN	3.07	24.74	3.4*	1.36	3.00	1.59	1.06	0.80	0.71	1.63	5.21	3.03
BEAVE031.8KN	60.36	197.7*	31.66	16.14	60.89	10.84	18.64	13.62	18.42	38.91	105.5*	88.9*
KNOBF000.3KN	11.30	88.32	5.63	2.70	8.46	4.65	4.37	2.62	3.19	4.75	18.01	13.54
BEAVE024.7KN	94.64	227.3*	56.14	23.92	93.96	45.91	35.16	25.93	26.80	64.44	153.8*	137.5*
BEAVE021.0KN	133.3*	318.0*	65.07	27.9*	116.74	54.86	43.56	28.66	38.19	85.63	184.4*	166.2*
GRASS000.9KN	11.61	60.98	5.18	3.9*	7.37	4.09	2.95	1.57	5.65	6.93	18.23	22.14
PLUMB000.3KN	6.30	17.74	3.13	3.4*	4.41	4.48	3.29	3.24	5.33	5.50	11.29	10.08
MEADO000.2KN	4.74	24.88	2.29	2.4*	2.64	4.08	1.73	1.14	4.01	3.08	7.65	10.6*
BEAVE013.5KN	148.0*	340.9*	76.19	39.9*	132.63	59.69	69.69	45.96	51.10	101.47	225.1*	184.0*
BEAVE003.5KN	192.26	382.68	119.55	74.2*	156.91	96.38	97.43	64.99	81.33	168.58	267.6*	223.78

difference from the historical data. The final values for the Manning's n and curve numbers are shown in Tables 3-5 and 3-6.

Stream flow was verified by using a discharge frequency curve. The verification that was performed using AnnAGNPS output and the USGS data is shown in Figure 3-6. During the low and high frequency discharges, the actual flow data and AnnAGNPS data were very well correlated. This range is from 0 to 1.7 cms and 55 to 100 cms. However, the frequency discharges from 1.7 to 55 cms were not as well correlated, but were still within a reasonable correlation. The average discharge from the AnnAGNPS output was 4.295 cms. The average discharge that was measured was 4.385 cms.

Model Simulations Using AnnAGNPS

Experiment 1: Effect of increased urbanization on sediment yield with and without bank erosion simulated.

The percentage of urbanized land was modeled at 0%, 23.7%, 35%, and 60%. The current level of urbanization in the watershed is 23.7%. The increase was distributed evenly across the entire Beaver Creek watershed. The distribution for each layer can be seen in Figures B-1 and B-2. From the land use layer provided from UT's Geography Department, meadow, open land, forest- thick and thin, agriculture, and low density residential land uses were converted to high-density residential.

Table 3-5. Manning's n Values

Manning's n Values	
Sheet Flow Manning's n	1.00
Concentrated Flow Manning's n	0.90
Reach Manning's n	0.90
Valley Manning's n	0.90

Table 3-6. Curve Numbers

Curve Numbers				
Hydrologic Soil Group	**A**	**B**	**C**	**D**
Residential (High Density)	81	95	98	98
Residential (Medium Density)	74	90	98	98
Residential (Low Density)	65	85	97	98
Commercial	98	98	98	98
Industrial	98	98	98	98
Disturbed/Transitional	98	98	98	98
Agricultural	86	97	98	98
Open Land- Good	50	68	85	93
Meadow	50	78	91	98
Woods (Thick Cover)	50	75	90	97
Woods (Thin Cover)	52	78	92	99
Impervious	98	98	98	98
Water	30	30	30	30

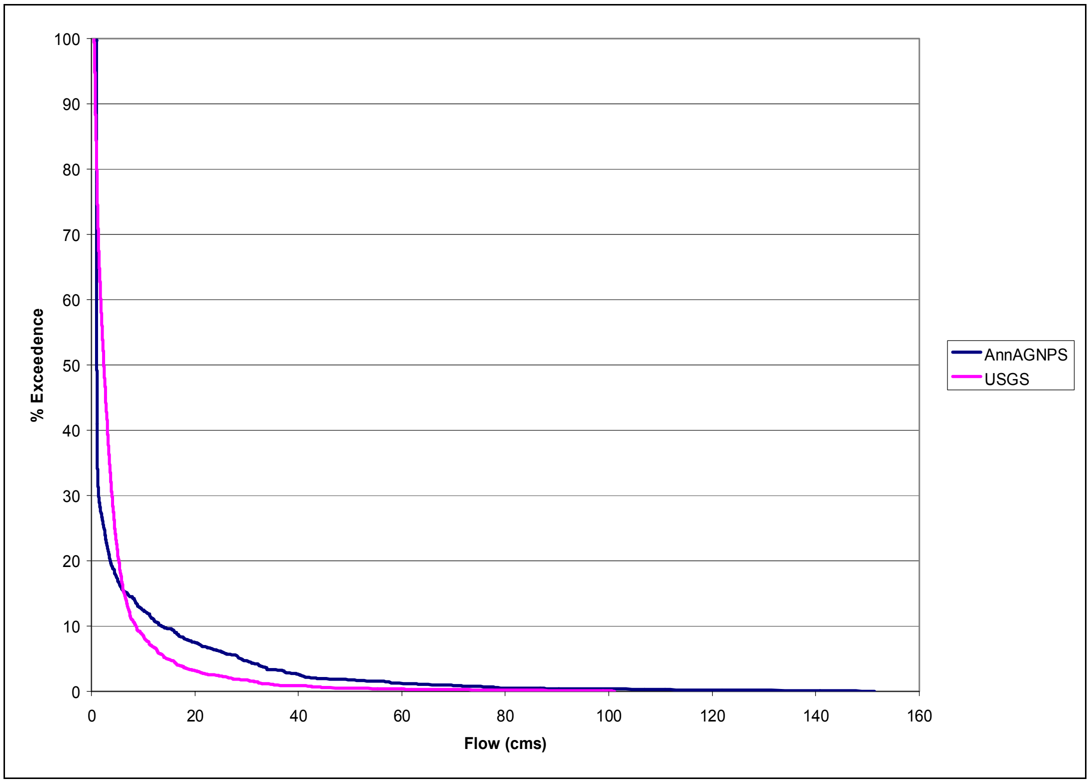

Figure 3-6. Discharge Frequency Curve of AnnAGNPS Output vs. USGS Flow Data

There was one scenario that demonstrated the natural level of sediment that occurs in the watershed with no human impacts on the landscape. The current urban lands were converted to forest and meadow land uses. The model simulations were performed twice for each of the above scenarios with and without bank erosion in the calculation of total sediment yield.

Experiment 2: Effect of increased disturbed land in the watershed on sediment yield, and its distribution within the watershed.

Different land use layers were created for four scenarios of disturbed lands equally distributed disturbed lands on the hillslopes and lowlands in the Beaver Creek Watershed. The four scenarios are as follows:

- Equally distributed across the entire watershed (Figures B-3, B-9, B-15).
- Concentrated in the upper watershed (Figures B-4, B-10, B-16).
- Concentrated in the middle watershed (Figures B-5, B-11, B-17).
- Concentrated in the lower watershed (Figures B-6, B-12, B-18).

These scenarios were varied by increasing the percentage of lands disturbed on previously un-developed lands. The current level of disturbed land within the watershed is at 2.16%. The percentage was increased to 5%, then to 8% and finally to12%. These model simulations did not include bank erosion in the annual sediment yield value.

The upper watershed included ten subsheds. Figure 3-7 shows which subsheds make up the upper watershed. The middle watershed contained eight subsheds and is

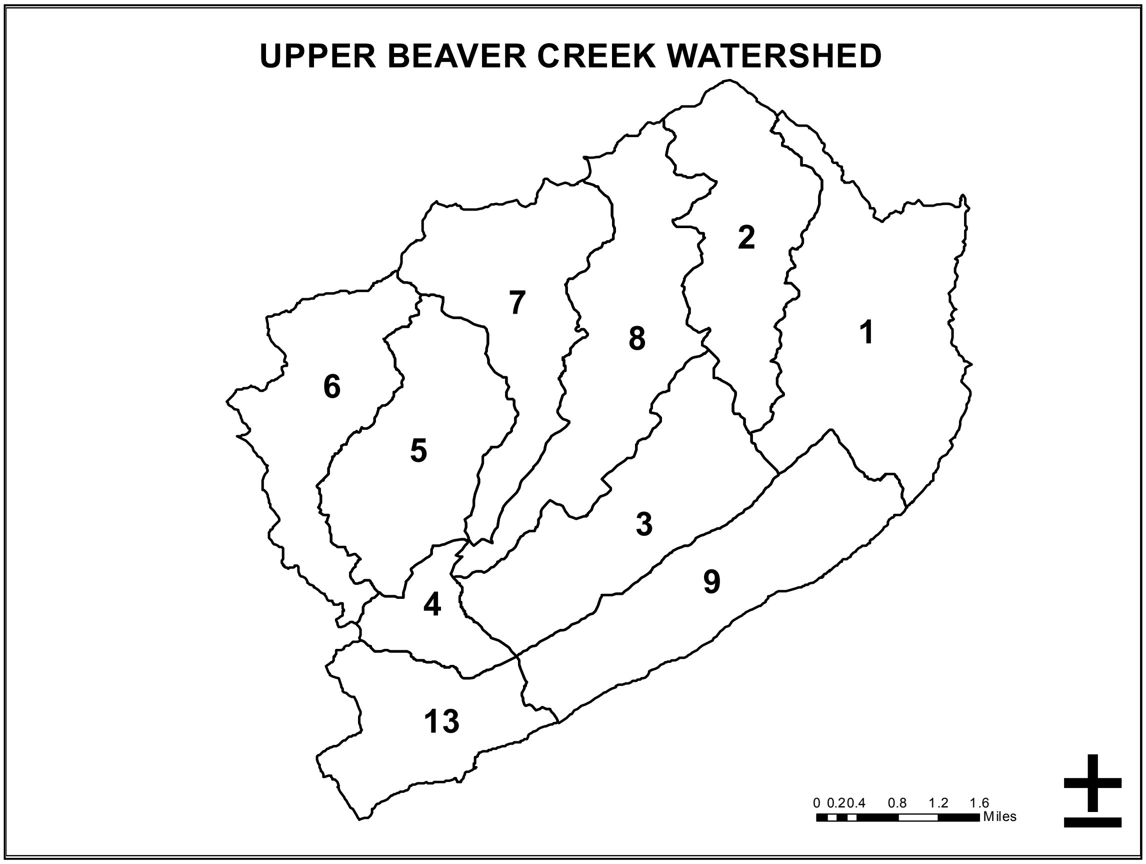

Figure 3-7. Upper Beaver Creek Watershed

shown in Figure 3-8. The lower watershed was made up of five subsheds and is shown in Figure 3-9.

Experiment 3: Effect of increased disturbed land on sediment yield distributed on lowland versus hillslope.

This modeling experiment involved three scenarios of disturbed land location. The first equally distributed the land between the hillslope and lowlands through the entire watershed. The other two scenarios concentrated the disturbed land on the hillslope and the lowlands. The percentage of disturbed lands was increased from the existing level at 2.16%, to 5% to 8% to 12%. The distribution of the disturbed lands all located in the lowlands can be seen in
Figures B-7, B-13, and B-19. The distribution for all disturbed lands located on the hillslopes can be seen in Figures B-8, B-14, and B-20.

Experiment 4: Effect of BMP effectiveness on sediment yield in the watershed.

This modeling experiment used the scenarios of the disturbed land being equally distributed throughout the watershed and equally on the hillslopes and lowlands. The amount of disturbed land increases from 5%, to 8%, to 12%. From these levels of disturbance, the different levels of effectiveness of the BMPs were modeled at 50%, 75%, and 100% effectiveness by changing the P factor in AnnAGNPS. The P factor accounts for the BMP effectiveness within the model.

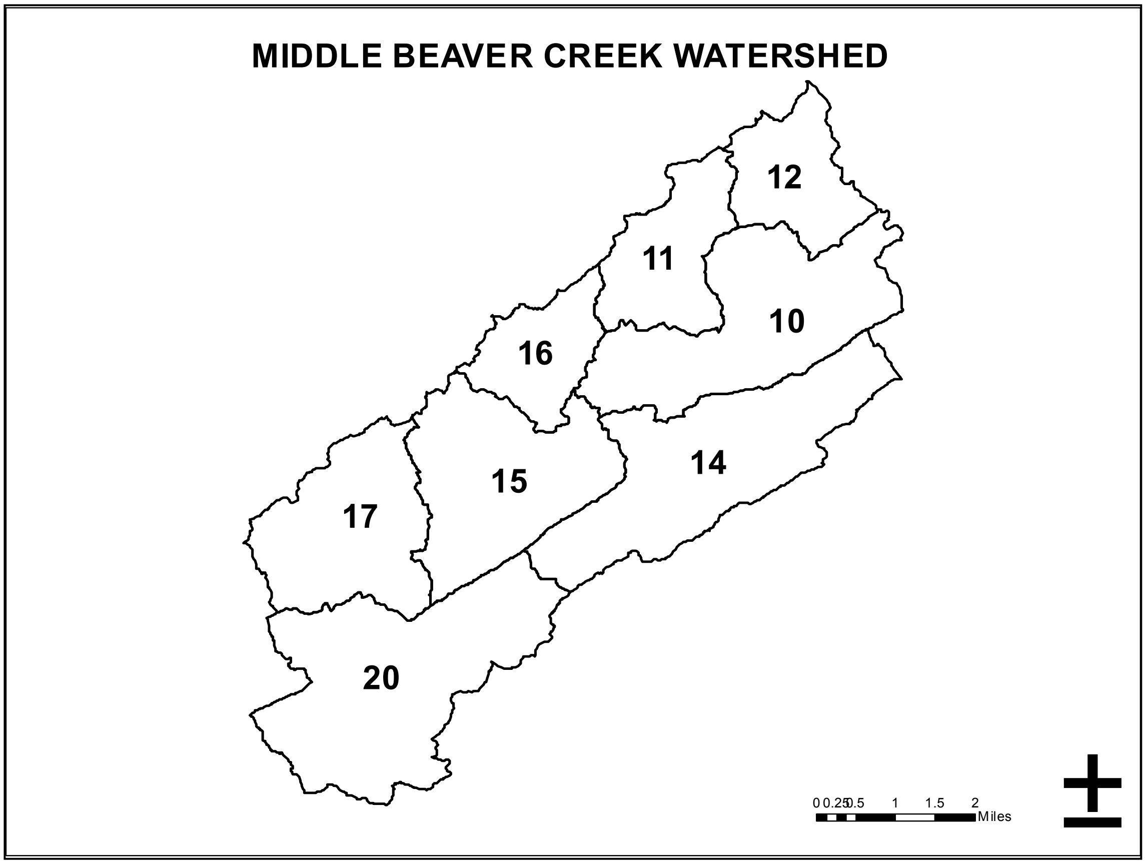

Figure 3-8. Middle Beaver Creek Watershed

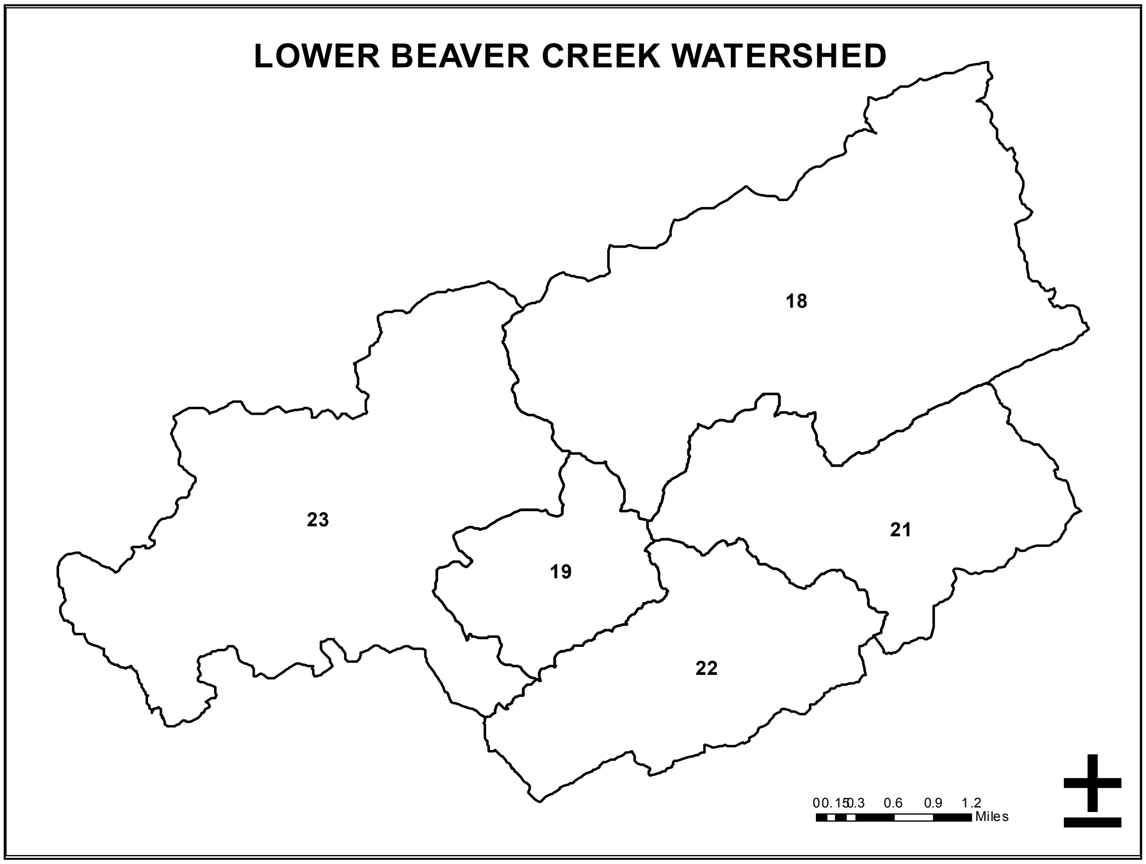

Figure 3-9. Lower Beaver Creek Watershed

Chapter 4: AnnAGNPS Model Simulations: Results and Discussion

Experiment 1: Effect of increased urbanization on sediment yield with and without bank erosion simulated.

Results

The first model simulation that was performed in AnnAGNPS looked at the effect of increasing urbanization on sediment yield. The sediment yield was calculated for: 1) upland erosion and no bank erosion, and 2) upland erosion and bank erosion. At a level with no urbanized lands, sediment yield is 3.84 Tonnes (T)/day for just upland erosion. When including bank erosion, sediment yield is 137.47 T/day (Figure 4-1). This data point that includes bank erosion can be used as a reference point for the amount of sediment yield that occurs naturally in the watershed.

From the reference point, the sediment yield increases drastically for 23.7% of urbanized lands (Figure 4-1). The sediment yield for no bank erosion and bank erosion is 75.33 T/day and 374.01 T/day, respectively. Between the values of 35% to 60% urbanized lands, the sediment yield levels off. The values for sediment yield for 30% urbanized lands are 3.91 T/day for no bank erosion and 362.34 T/day with bank erosion. The values for the 60% urbanized lands are 0.88 T/day for no bank erosion sediment yield and 381.12 T/day including bank erosion in the sediment yield.

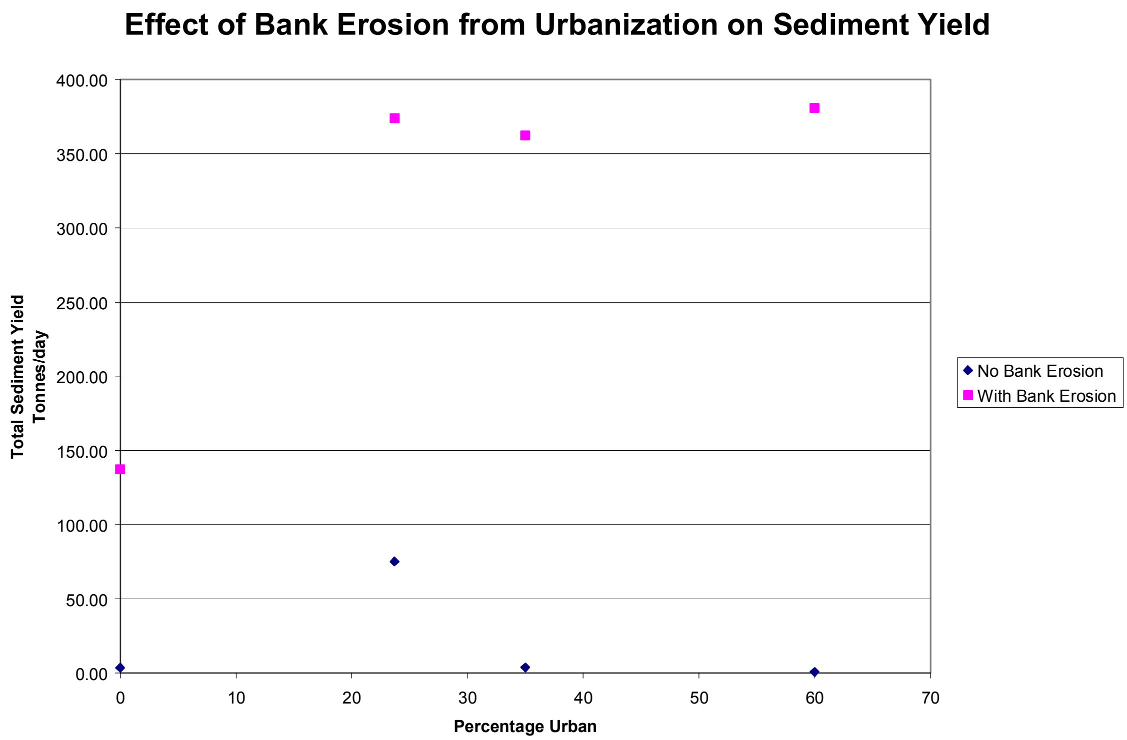

Figure 4-1. Effect of Bank Erosion from Urbanization on Sediment Yield

The amount of runoff increases as more land becomes urbanized. The increase in runoff volume as urbanized land increases is shown in Figure 4-2. The volume of runoff for 23.7% urbanized lands is at 630089 T/day. The values for 35% and 60% are 746028 T/day and 787170 T/day, respectively.

Discussion

The drastic increase in sediment yield from 0% urban lands to 23.7%, with and without bank erosion, shows evidence that there might be a threshold with regards to sediment yield relating to urbanized lands. The level of sediment yield reaches a plateau when the urbanization is greater than 23.7%. After lands have become urbanized, the model shows there is not going to be a significant amount of upland erosion coming off of the surface due to the impervious surface covering.

When there are no urbanized lands in the watershed, there is minimal erosion on the landscape. However, bank erosion is an ongoing process in the watershed. With the watershed being in a natural state, the sediment yield is at 137.47 T/day when including bank erosion. This natural level of sediment yield can be used as a frame of reference to understand how sediment increases once urbanization occurs within the watershed.

The data points at 23.7% shows a greater difference in sediment yield for both bank erosion and uplands erosion. This is due to the inclusion of 2.16% disturbed lands in

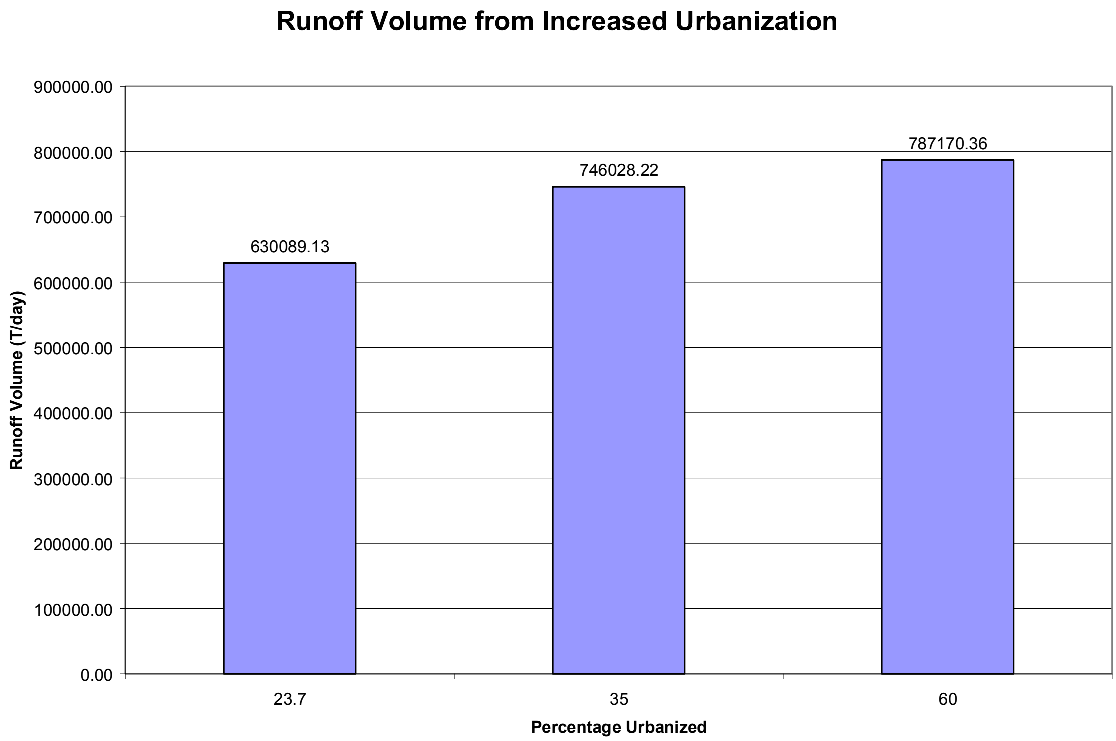

Figure 4-2. Runoff from Increased Urbanization

the model simulation. The high level of sediment yield relative to the other data points demonstrates the affect that disturbed lands has on the sediment yield.

The Shades Creek study yielded similar results to Experiment 1. The forested areas in Shades Creek watershed were converted to urban lands in AnnAGNPS (NSL, 2004). The watershed was at a level of 98% urban lands. The amount of runoff was increased by 53.6% due to the impervious areas. This is similar to the increase in runoff that occurred in Beaver Creek. The runoff increased by 20% when going from 23.7% urbanized to 60%. The sediment yield in Shades Creek increased by 68% (NSL, 2004). However, most of the sedimentation was due to bank erosion. The bank erosion sediment yield was twice the amount of the landscape sediment yield. The study on James Creek also determined that bank erosion contributed to 89% of the total sediment yield (NSL, 2002). In Beaver Creek, the sediment yield decreased when urbanization increased. However, sediment yield including bank erosion increased as urbanization increased. The amount of sediment in Beaver Creek from this experiment resulted mostly from bank erosion, as it did in the studies on James Creek and Shades Creek.

Experiment 2: Effect of increased disturbed land in the watershed on sediment yield, and its distribution within the watershed.

Results

As shown in Figure 4-3, the increased percentage of land that is disturbed evenly throughout the watershed and equally on the hillslopes and lowlands increases the amount of sediment yield. These model simulations do not include bank erosion in the sediment yield calculation. When there is no disturbed land the sediment yield is at 3.87

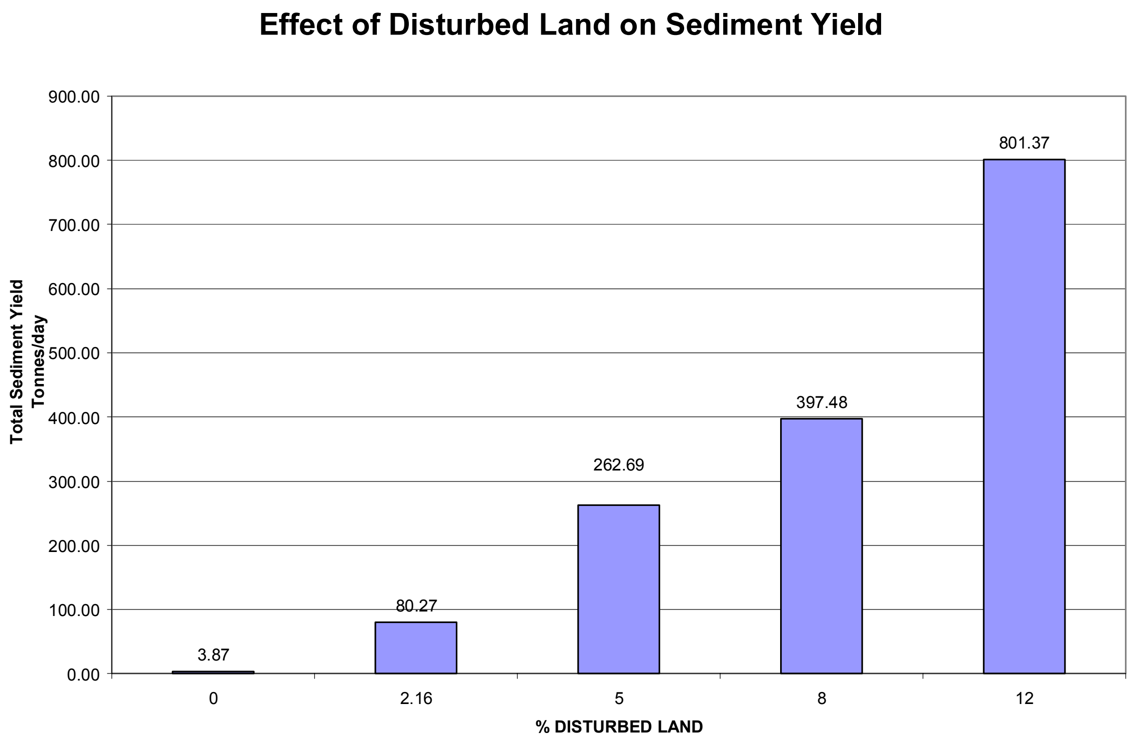

Figure 4-3. Effect of Disturbed Land on Sediment Yield

T/day and increases almost linearly to 801.37 T/day when the disturbed land is at 12%. This linear relationship seen when the disturbed land is evenly distributed throughout the watershed is also seen when the disturbed lands are concentrated in the upper, middle, and lower watersheds.

The sediment yield for each scenario at varying percentages of disturbed lands within the watershed is shown in Figure 4-4. When the disturbed lands are at 5%, the sediment yield rates going from highest to lowest are: lower watershed (436 T/day), upper watershed (298 T/day), equally distributed (262 T/day), and middle watershed (213 T/day). For 8%, from highest to lowest: lower watershed (900 T/day), upper watershed (669 T/day), middle watershed (499 T/day), and equally distributed (397 T/day). For 12%, from highest to lowest: lower watershed (1362 T/day), upper watershed (1102 T/day), middle watershed (992 T/day), and equally distributed (801 T/day).

Discussion

The increase in sediment yield with an increase in disturbed lands occurs since disturbed land is more easily eroded because of no grass or other rooted plants to hold the soil in place (Kuhnle et al, 1996). The amount of disturbed land will increase with an increase in the amount of development within the watershed. This increase in the disturbed land and sediment yield calls for better field practices and planned development throughout the watershed.

It should be noted that the values in Figure 4-3 do not include bank erosion in the calculation, while the reference point does include bank erosion. By using the point of

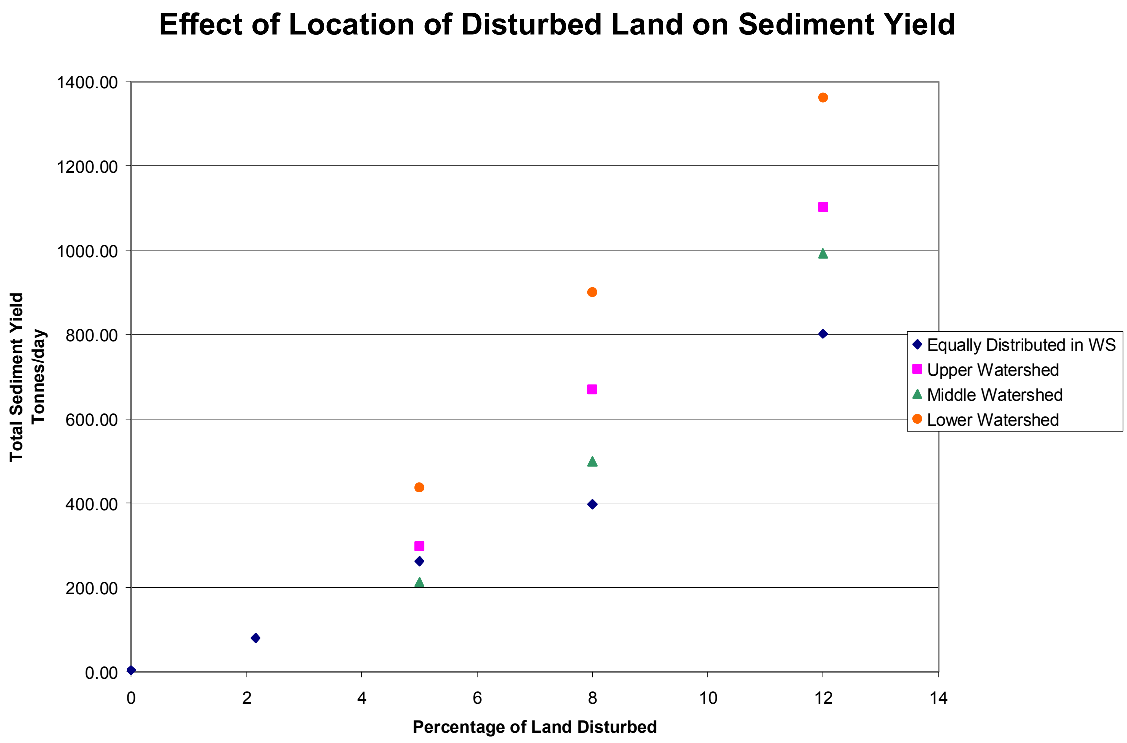

Figure 4-4. Effect of Location of Disturbed Land on Sediment Yield

reference for the natural amount of sediment yield from Figure 4-1, the sediment yield on the landscape is below 137.47 T/day for land disturbances less than approximately 3.8% when distributed equally across the watershed. For any amount of disturbed land over 3.8%, the sediment yield will be greater than the reference level.

Location of the disturbed lands plays a major role in the amount of sediment yield that occurs within the watershed along with the amount of disturbed lands. Figure 4-4 shows that the location of the disturbed lands affects the sediment yield. Concentrating all of the disturbed lands in the lower end of the watershed has the greatest impact on the sediment yield. Similarly, all of the disturbed land being concentrated in the upper watershed has a large impact on the sediment yield. There is an average difference of 210 T/day between the lower and upper watersheds' sediment yield values. The location of the lower watershed with respect to the outlet is the reason for the sediment yield in the lower watershed to be higher than any of the other simulations. The sediment in the lower watershed does not have the same amount of time to settle out in the waterway as it would have in the remaining watershed. The reason that concentrating the disturbed lands in the upper watershed has the second highest level of sediment yield can be attributed to the topography of the area. The upper watershed contains more hillslopes and higher gradients than the other sections of the watershed. Because the disturbed land is not as close to the outlet of the watershed the sediment yield is not as high as it is for disturbed land in the lower watershed.

When the land disturbances are distributed evenly throughout the watershed, the values for sediment yield are the lowest for the simulations equal and greater than 8%. At 5%, the sediment yield for equally distributed disturbed lands is only 50 T/day greater than the same percentage concentrated in the middle watershed. Because the disturbed land is not concentrated heavily in one area of the watershed, the effects of disturbance are minimized. From these results, evenly distributing the disturbed land across the watershed has the least impact on sediment yield relative to the other simulations.

When comparing the values for the simulation found in Figure 4-4 with the point of reference for the natural sediment yield in the watershed, the only values that would be below 137.47 T/day would be when the disturbances are equally distributed in the watershed and are less than 3.8%. However, even these values would be above the reference level if bank erosion was included in the sediment yield. Concentrating the disturbed land within an area of the watershed creates a significantly higher level of sediment relative to the natural state of the watershed.

The results of this experiment are comparable with the results from a study on the spatial location of detention ponds within a watershed. The study results showed that any amount of development in the lower watershed had a great impact on peak flow rate in the watershed (Goff and Gentry, In Press). This can be compared to the amount of disturbed land on any level in the lower Beaver Creek watershed has a greater impact on sediment yield than the other areas of the watershed. The second highest impact on peak flow rate from the study on detention ponds was cited in the upper watershed. This is also the case for sediment yield in Beaver Creek for disturbed lands. Even though the two studies involve two different variables, they are comparable because sediment is transported by water runoff.

Experiment 3: Effect of increased disturbed land on sediment yield distributed on lowland versus hill slope.

Results

The relation between sediment yield and location of disturbed lands on lowland or hillslope is shown in Figure 4-5. When the percentage of disturbed lands is at 5%, the sediment yield rates from highest to lowest are: all hillslopes (546 T/day), equally distributed (262 T/day), and all lowlands (225 T/day). At 8% disturbed lands, from highest to lowest, the sediment yields are: all hillslopes (882 T/day), all lowlands (414 T/day), and equally distributed (397 T/day). At 12% disturbed lands, from highest to lowest, the sediment yields are: all hillslopes (1366 T/day), equally distributed (801 T/day), and all lowlands (649 T/day).

Discussion

When the disturbed lands are distributed evenly throughout the watershed, the location of the disturbed land on the lowlands or the hillslopes has an impact on sediment yield. When the disturbed lands are located on the hillslopes, there is a significantly greater sediment yield. This is because the slope of the soil is at a higher incline, making it more easily erodible, whereas the lowlands have a gradual slope. During a rain event, the precipitation has more kinetic energy on a higher gradient than it would on a gradual

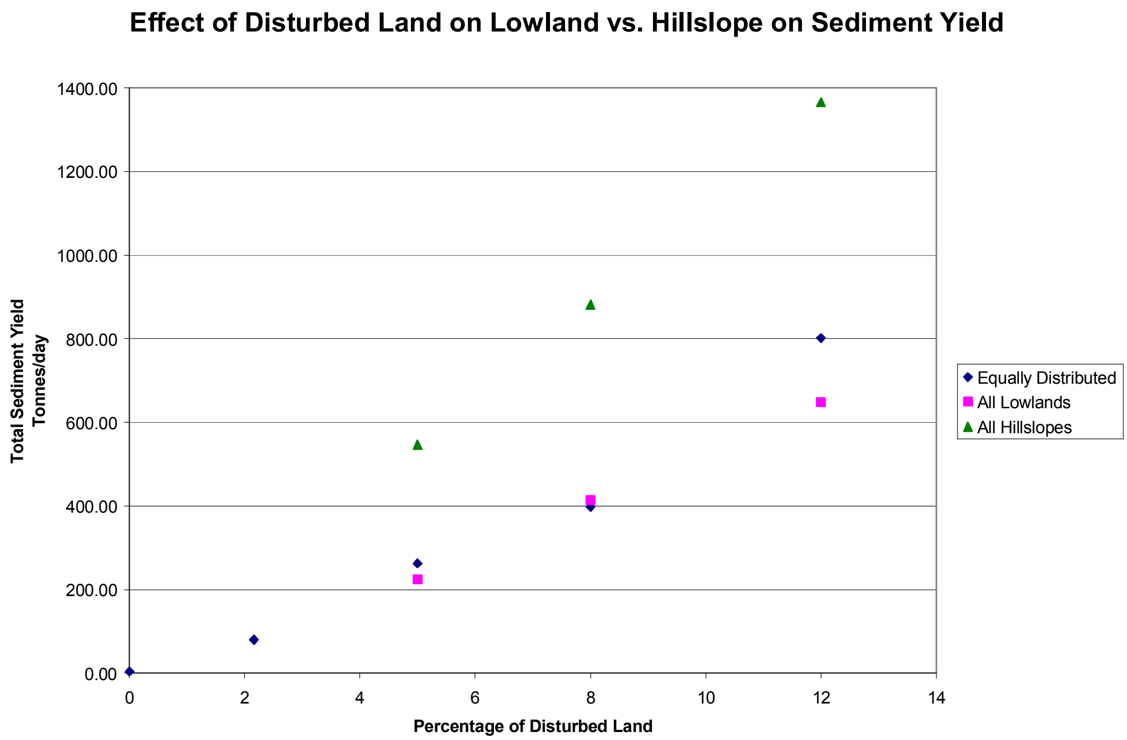

Figure 4-5. Effect of Disturbed Land on Lowland vs. Hillslope on Sediment Yield

slope. In the study on Issaquah Creek, the greatest sediment yields came from the steep forested subwatersheds (Nelson and Booth, 2002).

The RUSLE equation variables that AnnAGNPS uses are all linear in relationship. This linear equation would account for the nearly linear relationship for all three of the scenarios. Figure 4-5 also shows that there is not a significant difference in whether the disturbed land is on all lowlands or is equally distributed between the lowlands and hillslopes until reaching 12% disturbed. HUSLE accounts for any deposition of the sediment on the landscape based on the length and slope of the area (Haan et al, 1994). Deposition would occur more frequently on the lowlands due to the low gradient of the landscape, thus disturbed land in the lowlands has the least impact on sediment yield relative to the other scenarios.

Concentrating the disturbed lands on the hillslopes or on the lowlands results in the sediment yield being significantly higher than the reference point from Figure 4-1. Even without including bank erosion in the values for Figure 4-5, the values are still above this reference level of 137.47 T/day.

Experiment 4: Effect of BMP effectiveness on sediment yield in the watershed.

Results

BMPs have a significant effect on the sediment yield. The effect that BMPs have on the sediment yield is shown in Figure 4-6. There is a linear relationship with BMPs

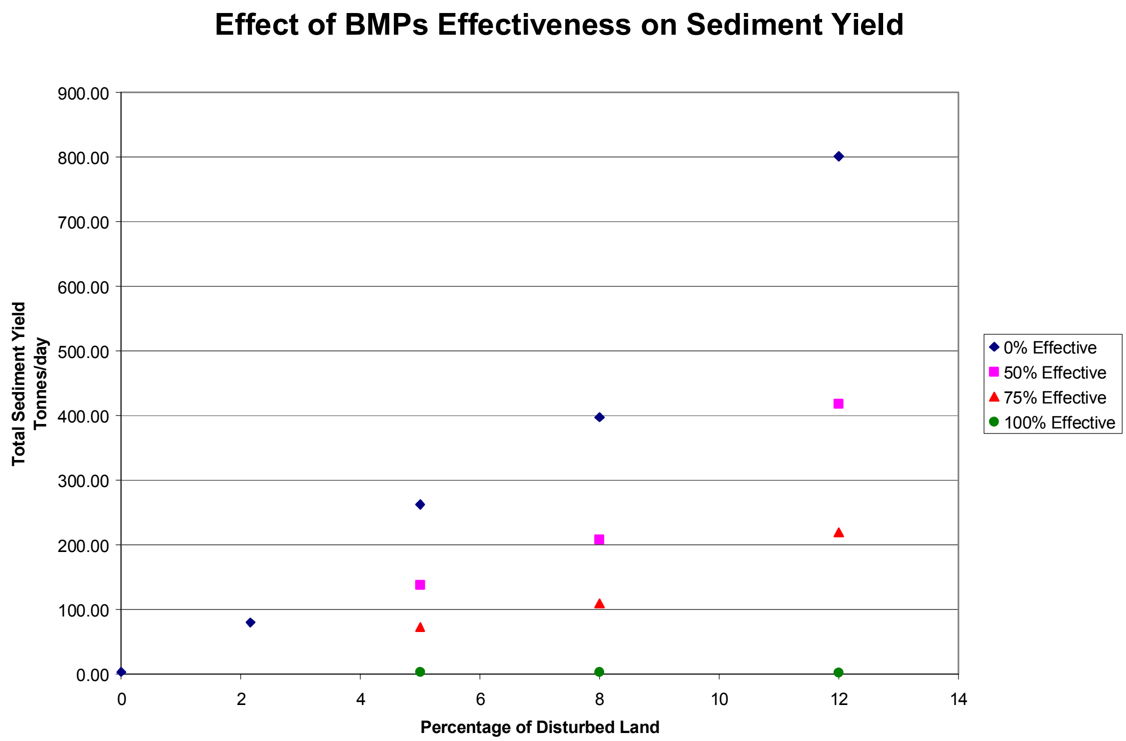

Figure 4-6. Effect of BMPs Effectiveness on Sediment Yield

effectiveness and sediment yield until reaching a level of disturbance greater than 8%. When the percentage of disturbed lands was at 5% the sediment yield values from highest to lowest were: 0% effective (262 T/day), 50% effective (138 T/day), 75% effective (73 T/day), and 100% effective (4 T/day). At 8% disturbed lands, the sediment yield values from highest to lowest were: 0% effective (397 T/day), 50% effective (209 T/day), 75% effective (109 T/day), and 100% effective (3 T/day). At 12% disturbed lands, the sediment yield values from highest to lowest were: 0% effective (801 T/day), 50% effective (419 T/day), 75% effective (220 T/day), and 100% effective (3 T/day).

Discussion

The effectiveness of BMPs can greatly reduce the sediment yield within the watershed. With more effective BMPs, the watershed can tolerate more disturbed land without having a major increase in sediment yield. A study in the Cache River watershed demonstrated how effective BMPs can decrease the sediment yield (Schoonover et al, 2006). Giant cane buffer was used as a BMP method along the river and reduced the sediment yield by 94%. A forest buffer along Cache River reduced the sediment yield by 86%. Each BMP method has an average effectiveness and maximum effectiveness associated with its use (EPA, 2006). By determining BMP methods on a case-by-case basis high levels of effectiveness could be obtained, especially when using multiple BMPs on each site. AnnAGNPS does not model specific BMPs methods, but rather, the effectiveness level of the BMPs. The methods for BMPs will be decided on by the BCTF in their final consideration of the watershed management plan. Possibilities for BMPs that could be used are silt fences, sedimentation ponds, check dams, and erosion control blankets. The erosion control blankets and check dams could mainly be used on the steep slopes to reduce the impact of erosion on the hillslopes.

Comparing the reference level for sediment yield in the natural watershed to Figure 4-6 shows that using BMPs can drastically reduce the amount of sediment coming from the landscape. Using the value of 137.47 T/day as the reference point, when there is 5% disturbed lands, BMPs with 50% or higher efficiency fall below this level. At 8% disturbed lands, BMPs with 75% or higher efficiency fall below the reference level. BMPs with effectiveness of approximately 80% or greater will bring the sediment level below the reference level.

According to Figure 4-6, there is approximately the same amount of sediment yield if there is 8% disturbed land with no BMPs as there is for 12% disturbed land with 50% effective BMPs. When more effective BMPs are used in development, the sediment yield can be reduced and more development can occur at the same time without harming the water quality in the watershed.

Chapter 5: Implications for Improved Urban Watershed Management

The first step to improve watershed management is to identify the problems affecting sediment yield (Rhoads et al, 1999). Only by recognizing a problem can anything be done about it. Federal regulations have resulted in states assessing the condition of their waterways. This assessment has included water, habitat, and wildlife quality of the waterway and its surrounding watershed (EPA, 1999; Scholz and Booth, 2000; TDEC, 2005). In all states the assessment of the waterways in that state are published in the 303d report (TDEC, 2005). The 303d report tells which waterways are impaired and the causes of the impairment.

After specific problems have been identified, methods to correct these problems will need to be addressed. In order to analyze the causes of impairments of a waterway and determine appropriate solutions, watershed management plans are initiated (Smutko et al, 2002). A watershed management plan will outline the regulations and methods needed to reach the goal of improving the quality of the waterway and watershed. This plan is typically established through the work of stakeholders (Smolko et al, 2002; Smutko et al, 2002). Stakeholders can consist of various members of the community of all professions and education levels. Generally, stakeholders consist of: government officials, land developers, farmers, environmental stewards, forestry workers, business owners, representatives of the utility districts, scientists, and residents of the watershed.

To start the process of developing a watershed management plan, goals should be established, assess what data analysis should be performed, and a timeline implemented (Smolko et al, 2002; Smutko et al, 2002). Because stakeholder involvement is voluntary, it is important to maximize agreement and the efficiency of meetings (Smutko et al, 2002). The key to developing a watershed plan is to engage the stakeholders and make sure they all feel that they have a part in the process to voice their concerns.

Developing a watershed management plan involves the integration of scientific data and policy decisions (Rhoads et al, 1999; Manring and Pearsall, 2006). In order to not hinder the decision making process, great care should be taken by both sides to not place their knowledge in a position above the other's knowledge. Scientists need to understand the values and culture of the stakeholders in order to be able to effectively communicate with them (Rhoads et al, 1999). When presenting the technical data to the stakeholders, it should be explained in easily understood terms and demonstrate the implications of the findings. The non-technical stakeholders are more likely to be responsive to the technical findings when the data is presented in a respectful and informative manner (Rhoads et al, 1999; Manring and Pearsall, 2006). The non-technical stakeholders also need to effectively communicate with the technical stakeholders. The non-technical stakeholders should not dismiss scientific data under the assumption it does not follow with their values or because they do not fully understand the findings. Communication from both sides should be a top priority in watershed management planning (Rhoads et al, 1999, Smolko et al, 2002; Smutko et al, 2002).

This thesis develops the technical side of watershed planning for the Beaver Creek watershed. Before the research was performed, the BCTF determined which model would be best suited for the needed data and also the time and financial constraints of the committee. The AnnAGNPS model was chosen because it involves hydrology, topography, soil characteristics, and weather data in its calculation of sediment yield. Currently, TDEC has used a non-dynamic model, Watershed Characterization System (WCS) Sediment Tool (v. 2.6), to determine sediment yield (TDEC DWPC, 2005). Within WCS, the sediment erosion is calculated for a "cell" of the watershed. The erosion from all of the cells is then summed without routing the sediment through the drainage network to produce the total sediment yield. AnnAGNPS uses the hydrology and topography functions in the Geographic Information Systems (GIS) interface to route the sediment through the watershed. Through routing the sediment, there will be less error in the final calculation for total sediment yield. The use of AnnAGNPS will improve the data found from the TDEC study by providing more reliable results that includes more variables in the sediment calculations than from the WCS model.

The results of this thesis has shown the impacts of urbanization and disturbed lands on sediment yield. Urbanization in Beaver Creek watershed resulted in an increase in the amount or runoff. This increase in runoff resulted in a greater sediment yield when including bank erosion. However, when bank erosion was not included in the calculation of sediment yield, the sediment erosion from the landscape was reduced when urbanization was increased. The results of this experiment are supported by the similar findings of the Shades Creek (NSL, 2004) study and the James Creek (NSL, 2002) study.

A frame of reference was determined from the model simulation where there was no human impact in the watershed. This is the natural occurring level of sediment in the watershed. At this level with no development on the landscape, the sediment yield including bank erosion was 137.47 T/day.

Increasing the amount of disturbed lands in the watershed has been shown to directly increase the amount of sediment yield. When the soil is bare of plants or trees to hold the soil in place, it is more easily eroded (Kuhnle et al, 1996). When the spatial location of disturbed lands in the watershed was modeled in AnnAGNPS, the results showed that development concentrated in the lower watershed had the greatest impact on sediment yield. The effects of spatial location of disturbed lands are similar to the results found by Goff and Gentry (In Press). Goff and Gentry studied the effect of the spatial location of detention ponds in a watershed and found that concentrating the ponds in an area of the watershed greatly increased the amount of runoff that was not captured when the ponds were equally distributed.

The other experiment on disturbed lands simulated the effects of concentrating the disturbed lands on the hillslopes and lowlands. Concentrating the disturbed lands on the hillslopes had the greatest impact on sediment yield. The study performed on Issaquah Creek had similar findings (Nelson and Booth, 2002). The amount of sediment yield increased more when development occurred on the hillslope than when it was located anywhere else in the watershed. When the disturbed lands were concentrated on the lowlands, the results were near the sediment yield for disturbed lands equally distributed on the lowlands and hillslopes.

The other objective of this thesis was to determine how BMPs effectiveness would affect sediment yield. The BMPs effectiveness was modeled at increasing amounts of disturbed lands. As the efficiency of the BMPs increased, the sediment yield decreased. Through the effective use of BMPs in Beaver Creek watershed, more development could occur without having a significant increase in sediment yield (Owens et al, 2005). The research performed on the Cache River demonstrated this principle by implementing BMPs near the waterway (Schoonover et al, 2006). These BMPs had up to 94% effectiveness at reducing the sediment entering the waterway.

Through modeling the various scenarios described in the previous chapters with AnnAGNPS, recommendations can be made for potential options to use in the Beaver Creek watershed management plan. In order to implement the options provided from this study, a level for sediment in Beaver Creek must first be established by the stakeholders. The sediment level can be based on the maximum amount of sediment that can be in the waterway before impacting the biological integrity of Beaver Creek. However, if data on the biological integrity is not available in a sufficient amount of time, the stakeholders can determine a percentage to lower the overall sediment yield. For example, the goal could be to reduce the amount of sediment yield by 50% for the value when disturbed lands are distributed equally across the watershed at 5%. This would result in the sediment level being at ½ of 262.69 T/day, which equals to 131.35 T/day.

Once the sediment level has been decided upon by the BCTF, the following options can be considered in the final watershed management plan:

- Set the maximum level of development that can occur if it is equally distributed in the watershed.
- Limit development when it is concentrated in either the lower or the upper watershed.
- Limit development on the hillslopes.
- When developing on the hillslopes, strictly enforce the use of BMPs.
- Use BMPs with higher effectiveness if more development is desired in the watershed.

It is important to note that the disturbances that were modeled in AnnAGNPS were considered to be simultaneously occurring. The maximum level of development that is chosen would not be for the limit for the year, but rather, would limit the number of developments that could be occurring within the same time frame. Another note of importance is that only BMPs effectiveness was modeled in AnnAGNPS, not the BMPs methods. These methods can be determined by the BCTF and the land developers in order to reach the sediment level chosen. Some possibilities for BMPs methods in Beaver Creek would be silt fences, check dams, and vegetative filter strips. Consideration should also be given to providing a riparian buffer for Beaver Creek and its tributaries. This would act as a non-structural BMP method to reduce sediment and would also promote habitat.

The options listed above are only addressing erosion from the landscape. They do not include bank erosion. Further studies would need to be performed to determine the amount of sediment yield resulting from bank erosion with increased disturbed lands. The AnnAGNPS model can be used to determine the bank erosion, but CONCEPTS would be a more accurate model to predict the bank erosion in Beaver Creek. Cross-sections of Beaver Creek would have to be surveyed in order to run the model. AnnAGNPS and CONCEPTS can be used together to more precisely determine the sediment yield from the landscape and from bank erosion. This is another option that the BCTF should consider for future investigation due to the watershed rapidly urbanizing. As shown in Experiment 1, bank erosion does increase with more urbanization. The increase in bank erosion may lead to more bank failures or incisions in the stream. In order to protect habitat, water quality, and personal property, the bank erosion issue will eventually need to be addressed.

Further research on determining the sediment level in Beaver Creek, habitat surveys should be performed in the watershed. The habitat surveys would determine the current condition of aquatic organisms in the watershed. The process of determining what species are present and their location in the watershed will help determine the tolerance of those species to the sediment when compared with previous sediment data from other studies. The sediment level to be monitored to can then be set based on the tolerance level of the aquatic species to not cause detriment to their habitat.

Once these options, along with others, have been analyzed by the BCTF, a final decision will be made by the stakeholders. Their final decisions will result in a watershed management plan that will then be presented to the local government for approval and implementation (Manring and Pearsall, 2006). After implementation, the local government will be responsible for monitoring the proposed regulations and their enforcement. In order for the Beaver Creek watershed management plan to be successful, proper implementation and enforcement must occur. Unless this last part of the process is followed through, the watershed management plan will have no impact on Beaver Creek.

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Appendices

Appendix A

AnnAGNPS

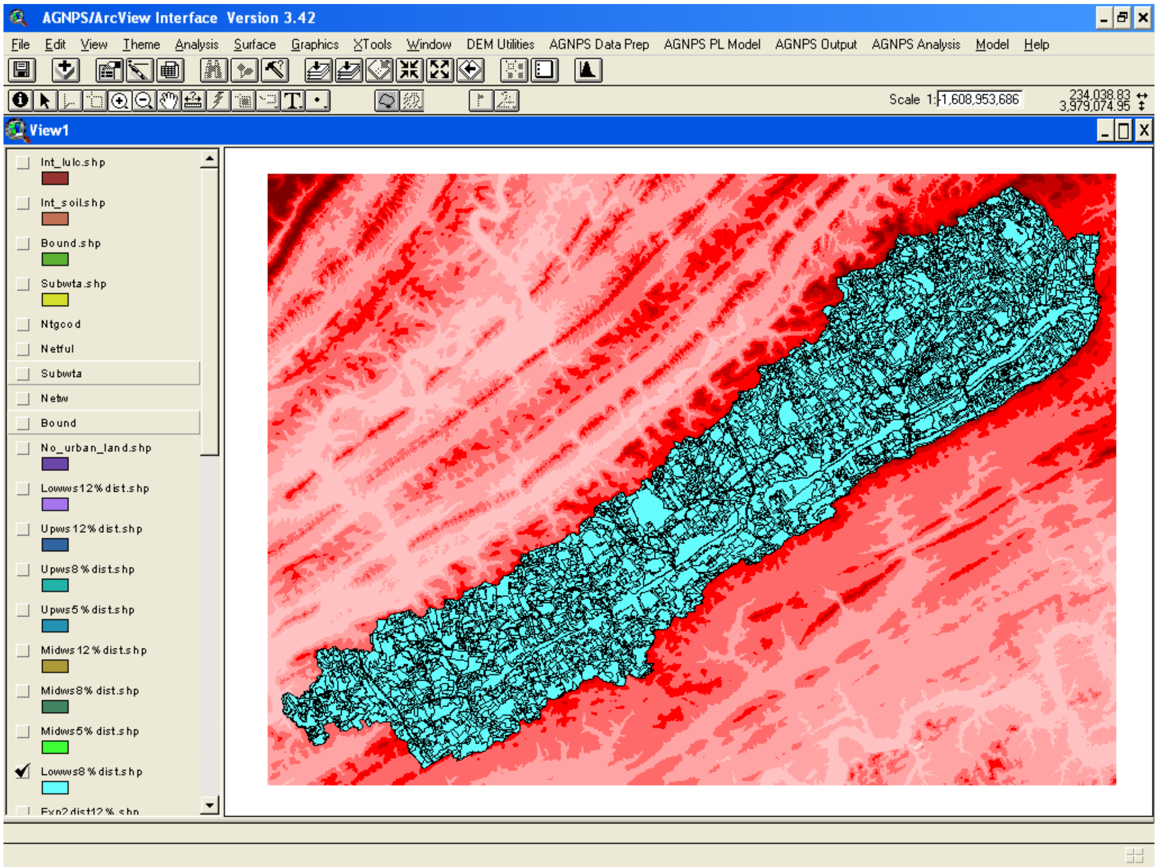


Figure A-1. AnnAGNPS ArcView Interface

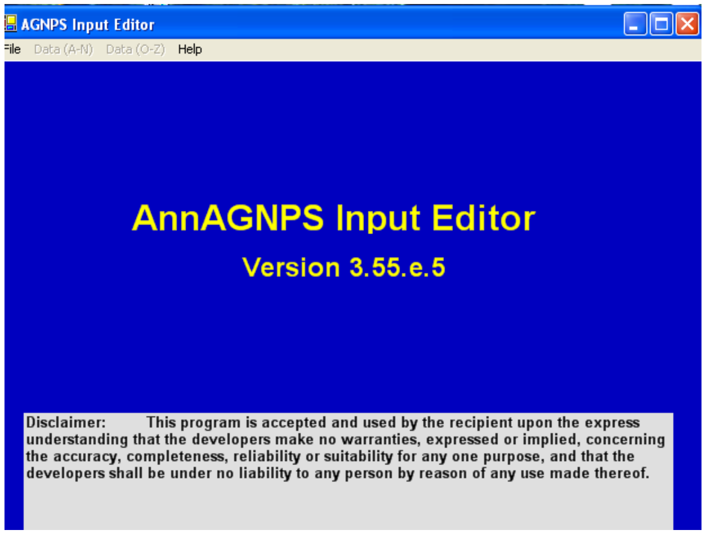


Figure A-2. Input Editor Welcome Screen

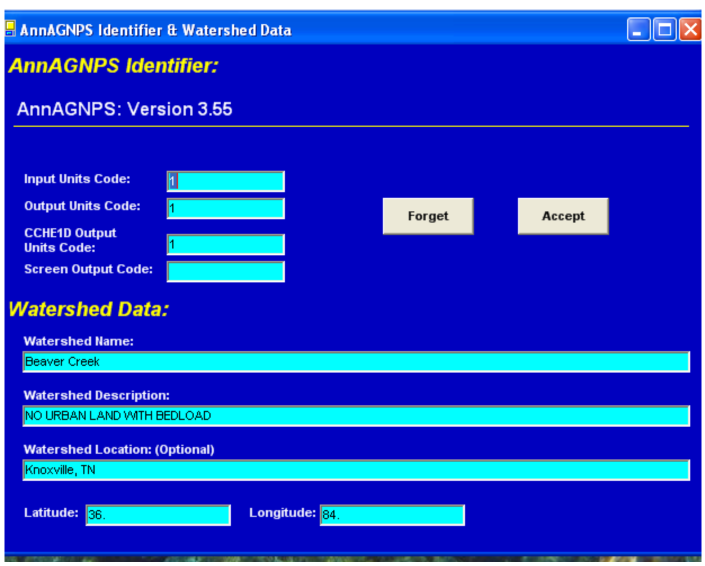


Figure A-3. Project Setup and Identifier Screen

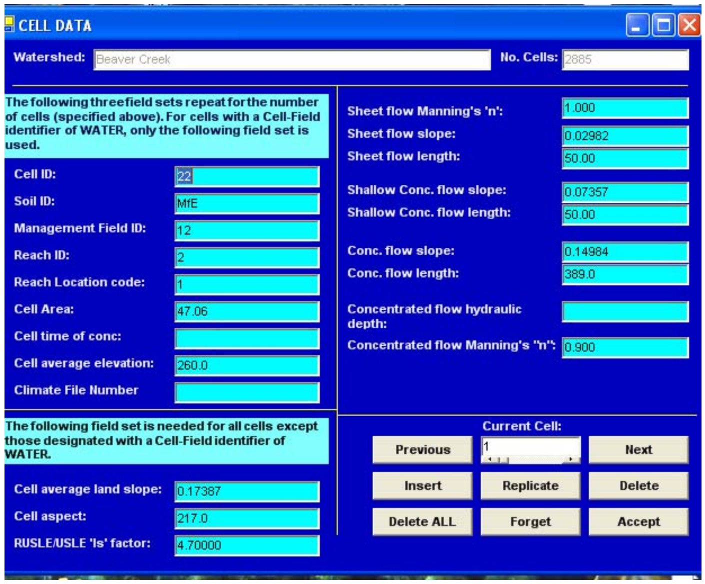


Figure A-4. Cell Data Screen

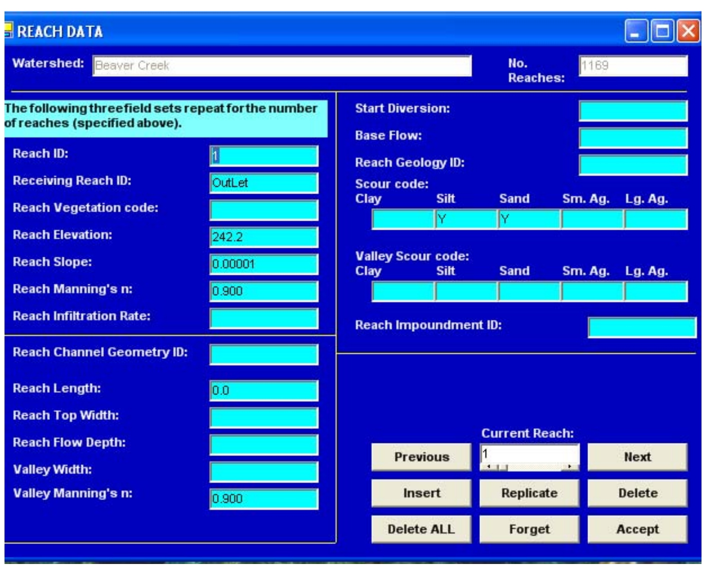


Figure A-5. Reach Data Screen

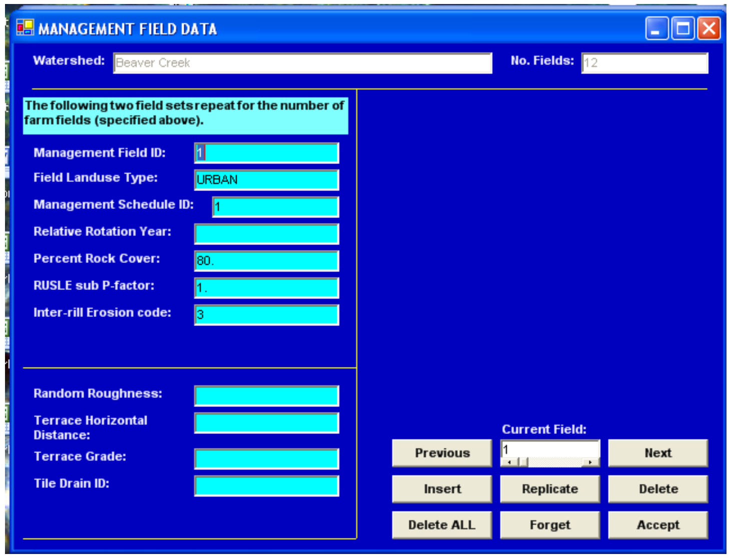


Figure A-6. Management Field Data Screen

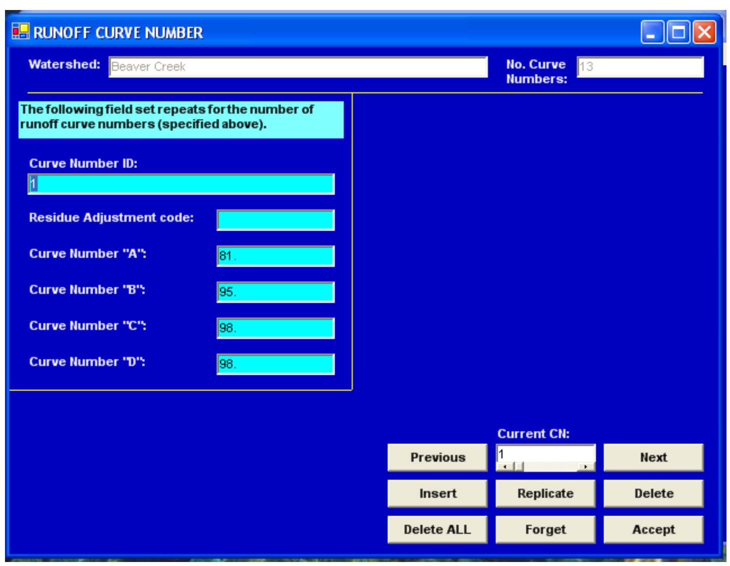


Figure A-7. Runoff Curve Number Screen

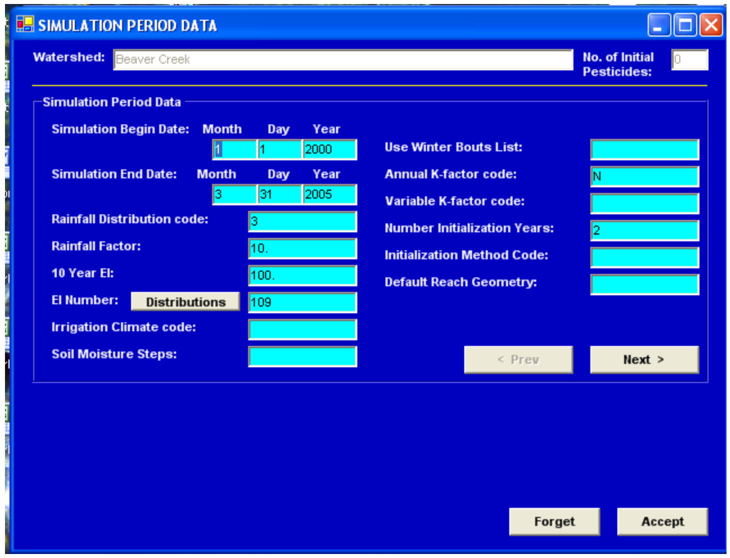


Figure A-8. Simulation Period Data Screen

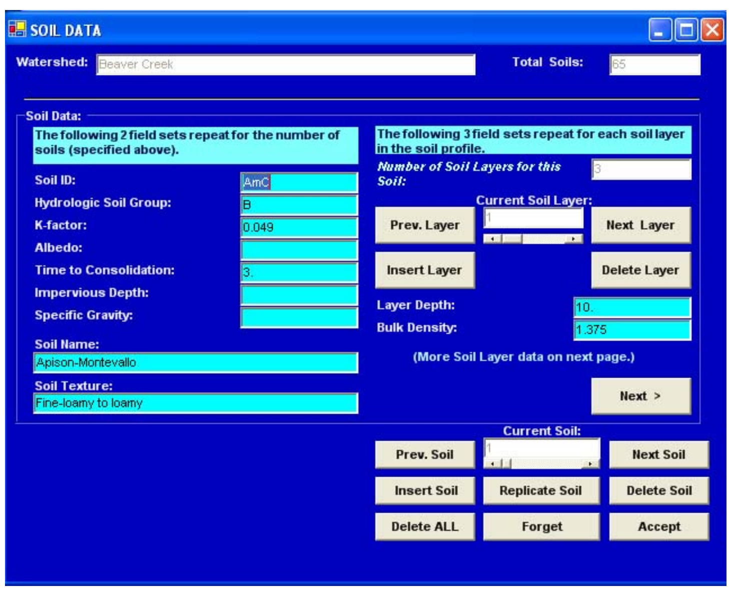


Figure A-9. Soil Data Screen

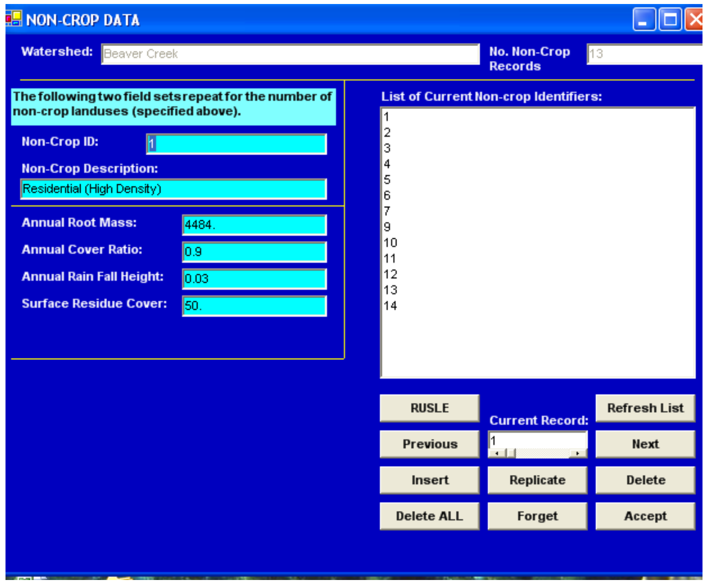


Figure A-10. Non-Crop Data Screen

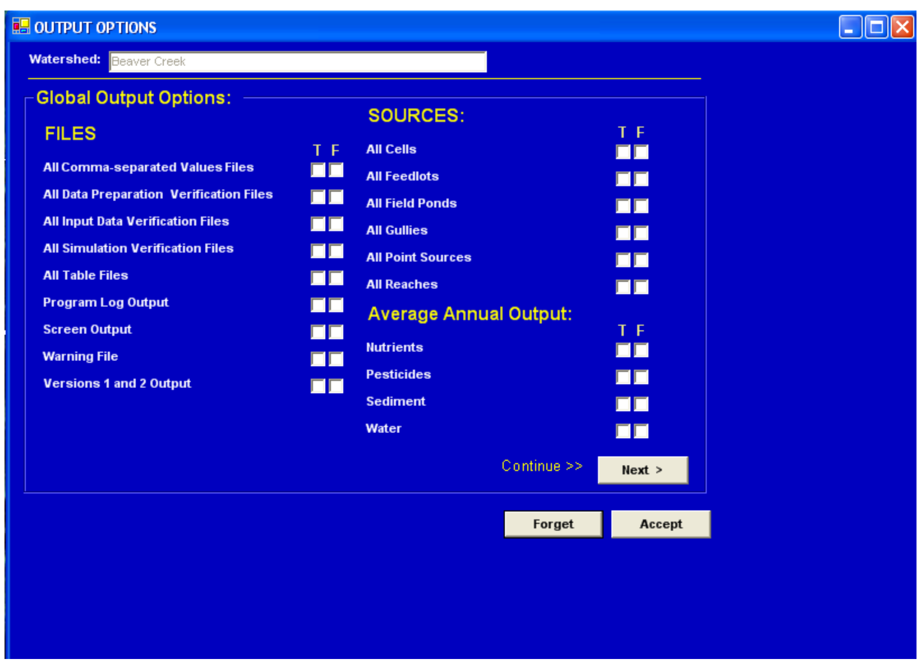
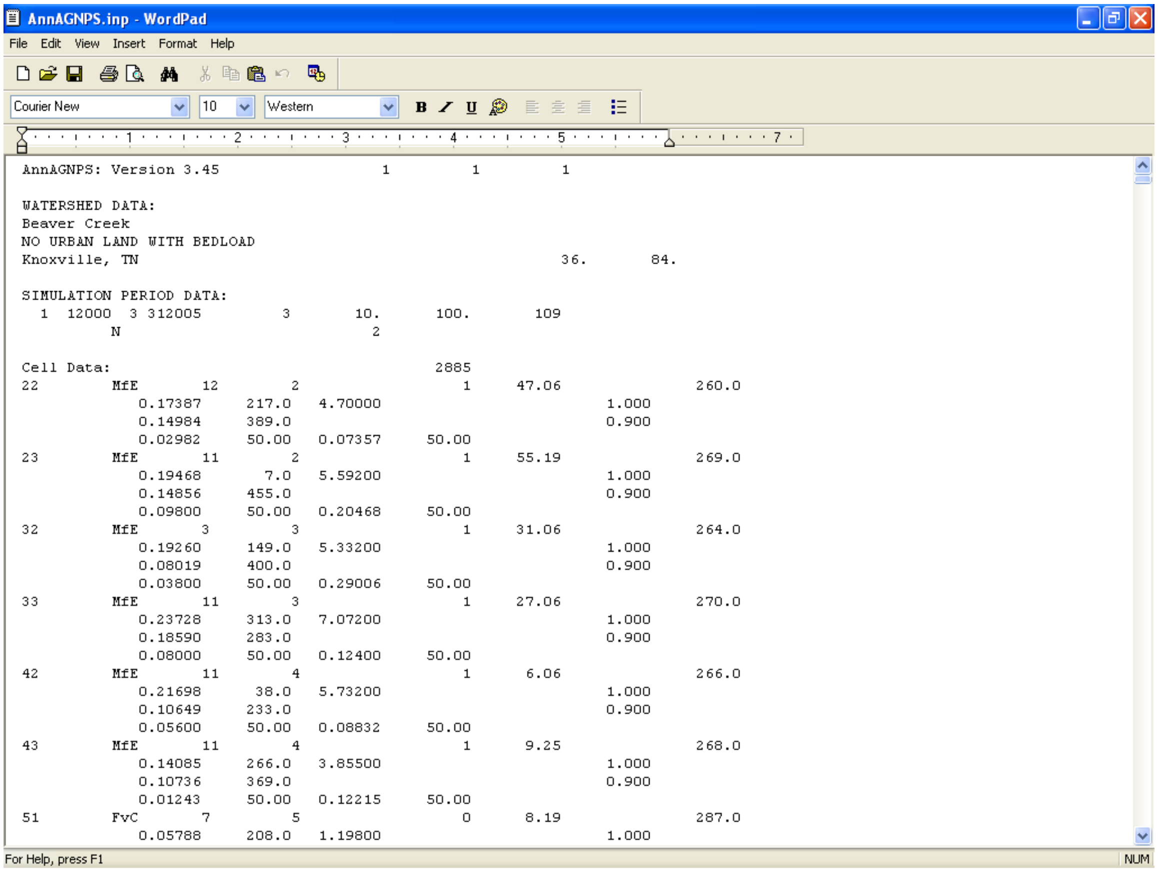


Figure A-11. Output Options Screen



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AnnAGNPS: Version 3.45                  1         1         1

WATERSHED DATA:
Beaver Creek
NO URBAN LAND WITH BEDLOAD
Knoxville, TN                                                 36.       84.

SIMULATION PERIOD DATA:
  1  12000  3 312005         3       10.      100.       109
          N                             2

Cell Data:                                    2885
22        MfE       12         2                 1      47.06                   260.0
             0.17387     217.0   4.70000                          1.000
             0.14984     389.0                                    0.900
             0.02982     50.00   0.07357     50.00
23        MfE       11         2                 1      55.19                   269.0
             0.19468       7.0   5.59200                          1.000
             0.14856     455.0                                    0.900
             0.09800     50.00   0.20468     50.00
32        MfE        3         3                 1      31.06                   264.0
             0.19260     149.0   5.33200                          1.000
             0.08019     400.0                                    0.900
             0.03800     50.00   0.29006     50.00
33        MfE       11         3                 1      27.06                   270.0
             0.23728     313.0   7.07200                          1.000
             0.18590     283.0                                    0.900
             0.08000     50.00   0.12400     50.00
42        MfE       11         4                 1       6.06                   266.0
             0.21698      38.0   5.73200                          1.000
             0.10649     233.0                                    0.900
             0.05600     50.00   0.08832     50.00
43        MfE       11         4                 1       9.25                   268.0
             0.14085     266.0   3.85500                          1.000
             0.10736     369.0                                    0.900
             0.01243     50.00   0.12215     50.00
51        FvC        7         5                 0       8.19                   287.0
             0.05788     208.0   1.19800                          1.000
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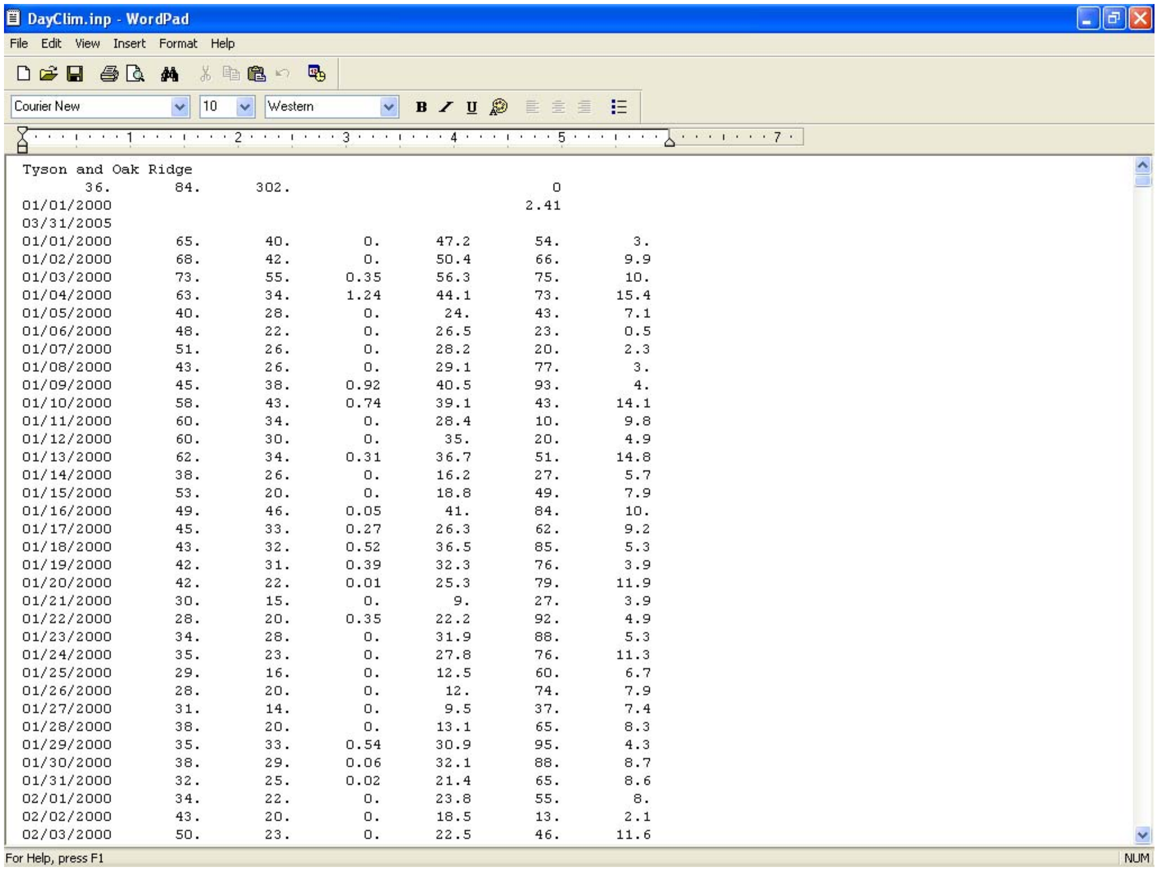
Figure A-12. AnnAGNPS input file (AnnAGNPS.inp)




```
Tyson and Oak Ridge
       36.      84.       302.                              0
01/01/2000                                               2.41
03/31/2005
01/01/2000      65.       40.       0.      47.2        54.        3.
01/02/2000      68.       42.       0.      50.4        66.        9.9
01/03/2000      73.       55.     0.35      56.3        75.       10.
01/04/2000      63.       34.     1.24      44.1        73.       15.4
01/05/2000      40.       28.       0.       24.        43.        7.1
01/06/2000      48.       22.       0.      26.5        23.        0.5
01/07/2000      51.       26.       0.      28.2        20.        2.3
01/08/2000      43.       26.       0.      29.1        77.        3.
01/09/2000      45.       38.     0.92      40.5        93.        4.
01/10/2000      58.       43.     0.74      39.1        43.       14.1
01/11/2000      60.       34.       0.      28.4        10.        9.8
01/12/2000      60.       30.       0.       35.        20.        4.9
01/13/2000      62.       34.     0.31      36.7        51.       14.8
01/14/2000      38.       26.       0.      16.2        27.        5.7
01/15/2000      53.       20.       0.      18.8        49.        7.9
01/16/2000      49.       46.     0.05       41.        84.       10.
01/17/2000      45.       33.     0.27      26.3        62.        9.2
01/18/2000      43.       32.     0.52      36.5        85.        5.3
01/19/2000      42.       31.     0.39      32.3        76.        3.9
01/20/2000      42.       22.     0.01      25.3        79.       11.9
01/21/2000      30.       15.       0.        9.        27.        3.9
01/22/2000      28.       20.     0.35      22.2        92.        4.9
01/23/2000      34.       28.       0.      31.9        88.        5.3
01/24/2000      35.       23.       0.      27.8        76.       11.3
01/25/2000      29.       16.       0.      12.5        60.        6.7
01/26/2000      28.       20.       0.       12.        74.        7.9
01/27/2000      31.       14.       0.       9.5        37.        7.4
01/28/2000      38.       20.       0.      13.1        65.        8.3
01/29/2000      35.       33.     0.54      30.9        95.        4.3
01/30/2000      38.       29.     0.06      32.1        88.        8.7
01/31/2000      32.       25.     0.02      21.4        65.        8.6
02/01/2000      34.       22.       0.      23.8        55.        8.
02/02/2000      43.       20.       0.      18.5        13.        2.1
02/03/2000      50.       23.       0.      22.5        46.       11.6
```

Figure A-13. Daily Climate Data File (DayClim.inp)

Appendix B

Model Simulations

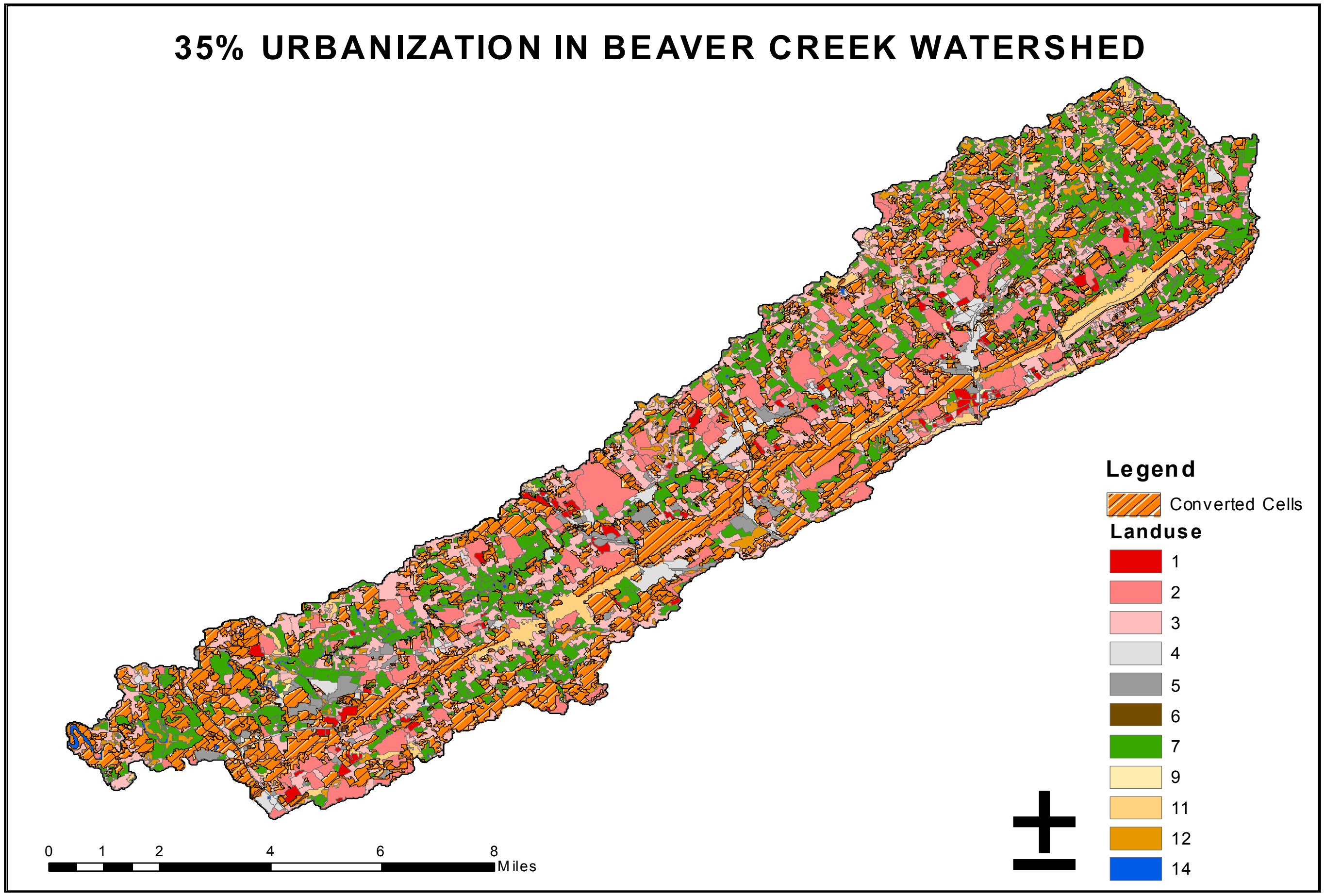


Figure B-1. 35% Urbanized Land in Beaver Creek Watershed

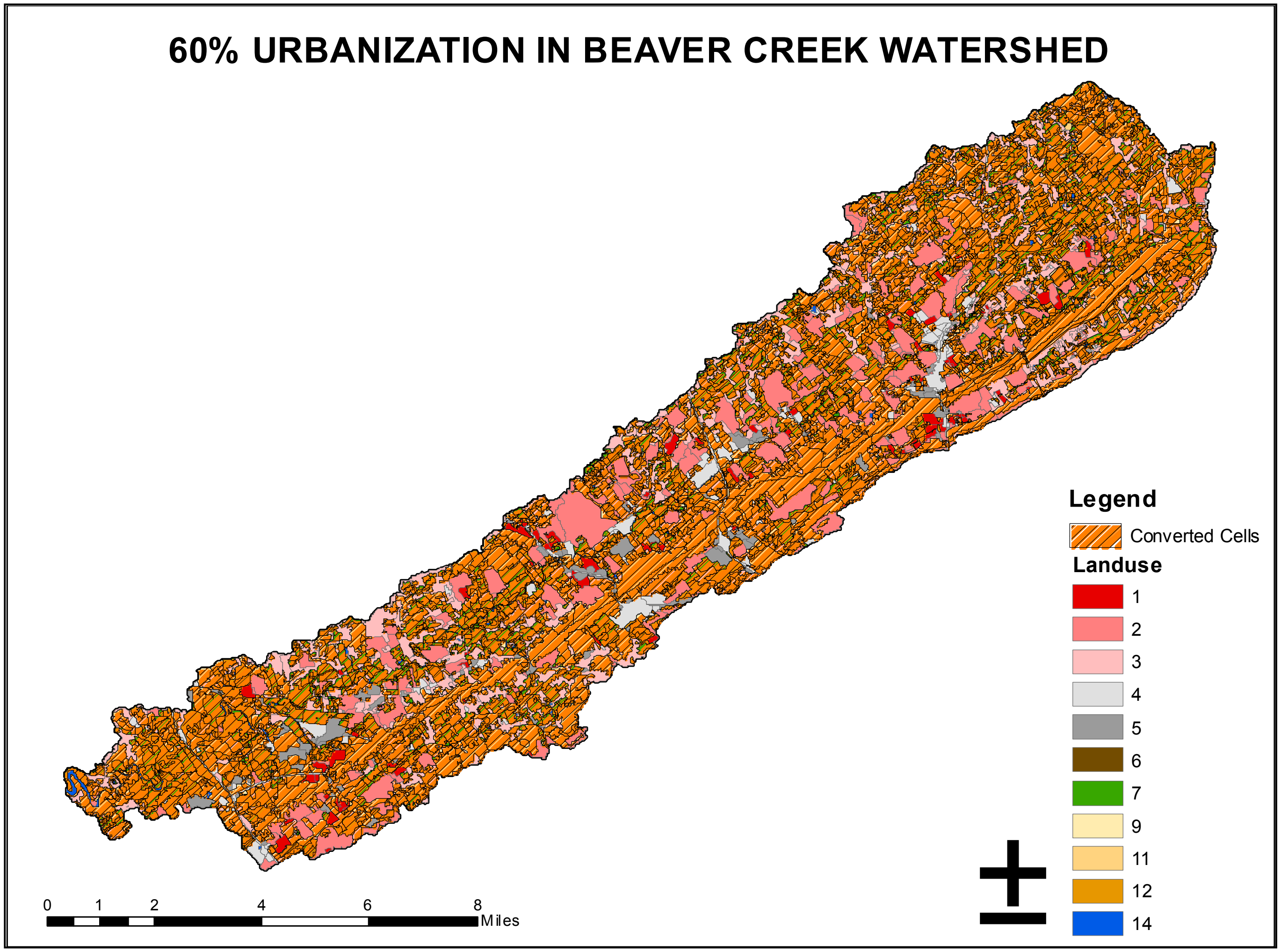


Figure B-2. 60% Urbanized Land in Beaver Creek Watershed

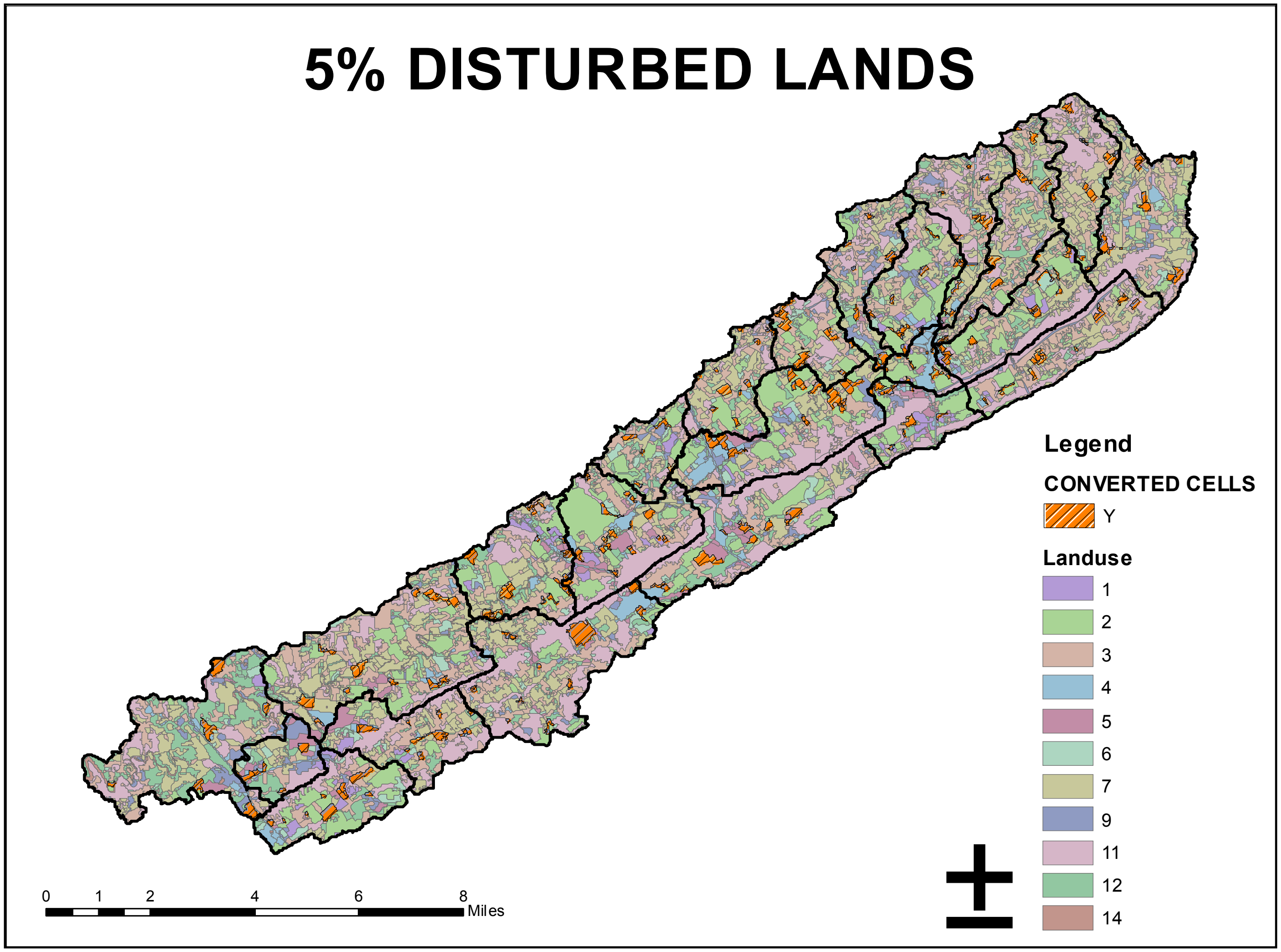


Figure B-3. 5% Disturbed Land Equally Distributed in the Watershed

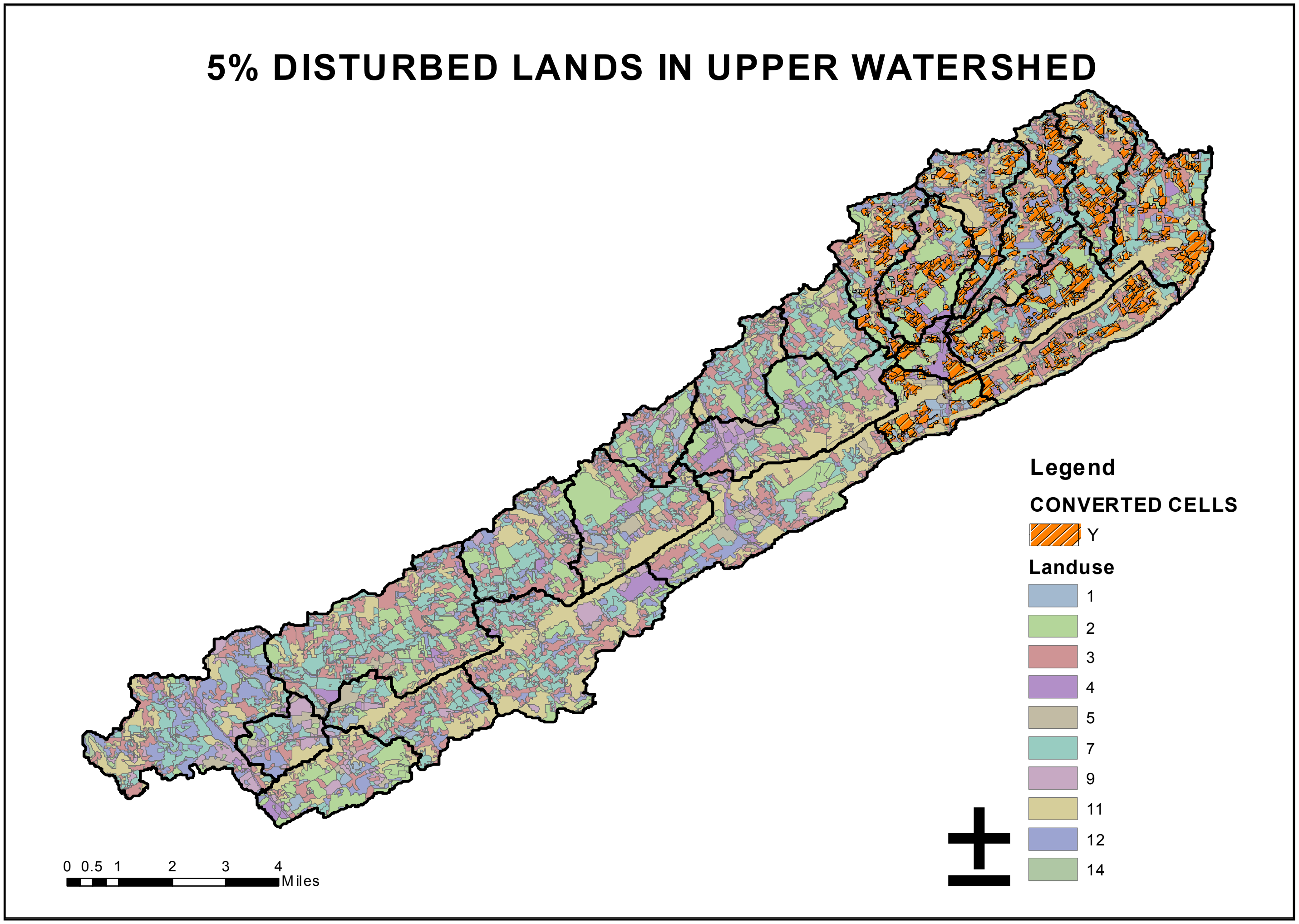


Figure B-4. 5% Disturbed Land Concentrated in the Upper Watershed

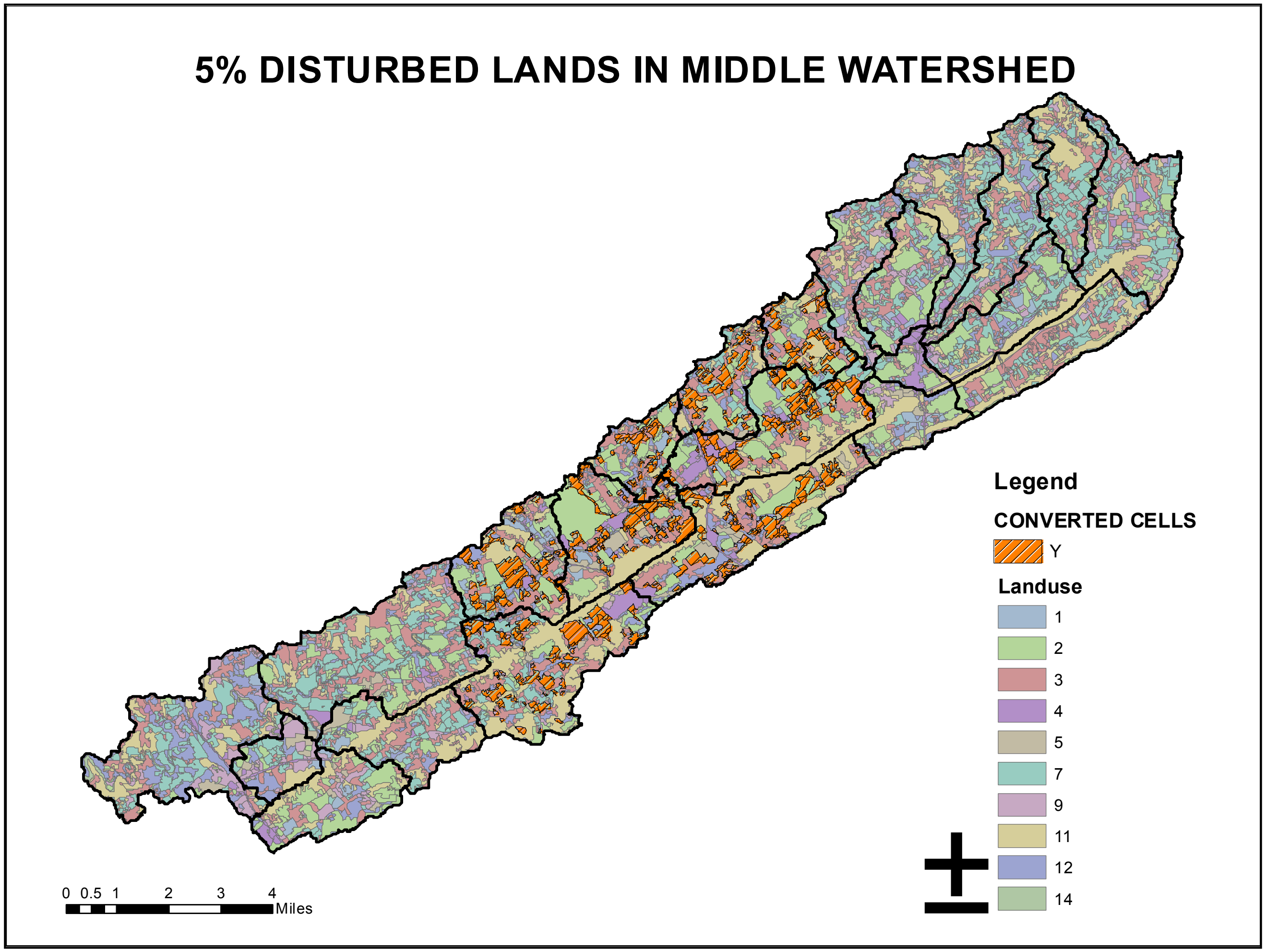


Figure B-5. 5% Disturbed Lands Concentrated in the Middle Watershed

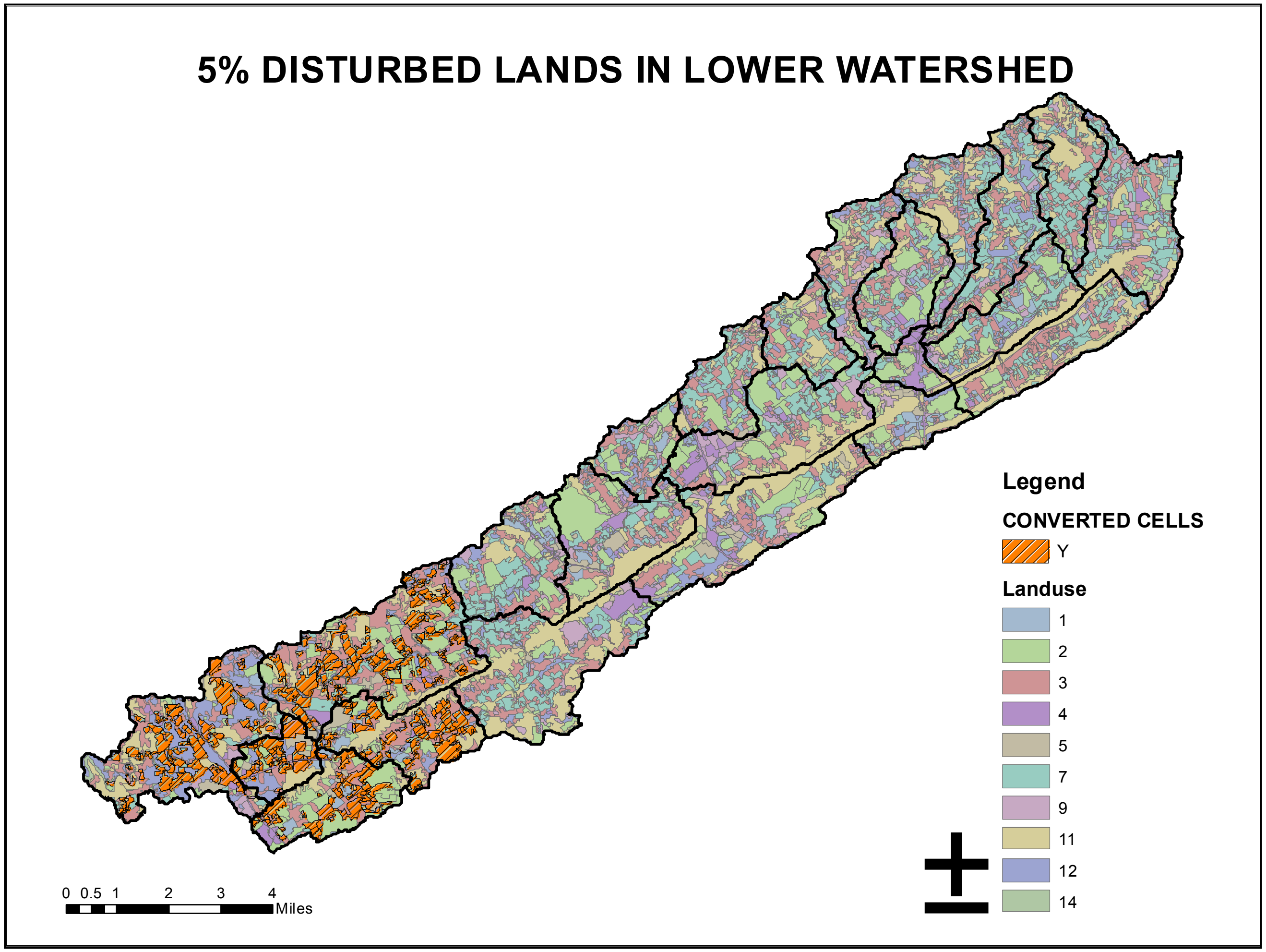


Figure B-6. 5% Disturbed Lands Concentrated in the Lower Watershed

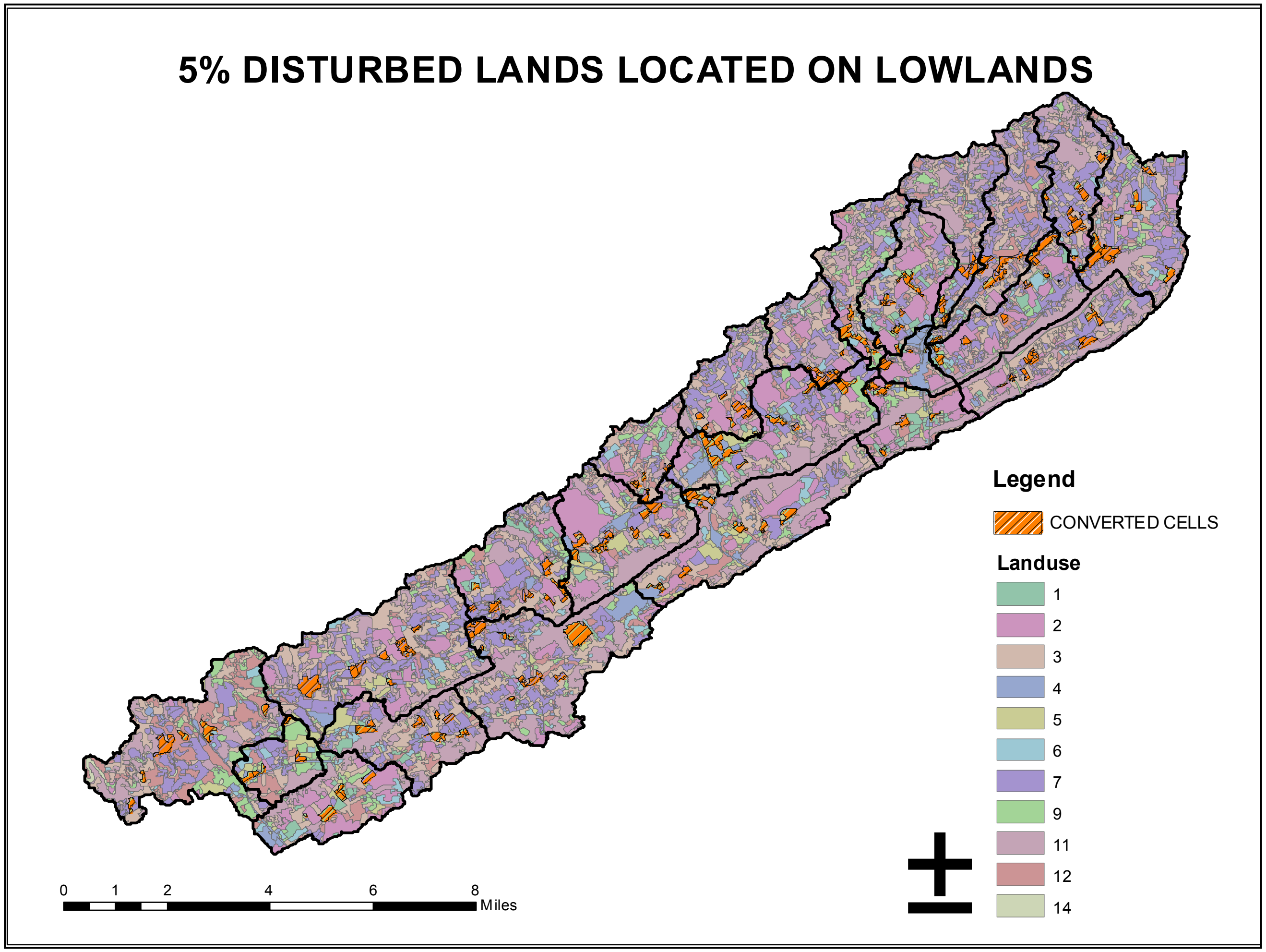


Figure B-7. 5% Disturbed Land Concentrated on Lowlands

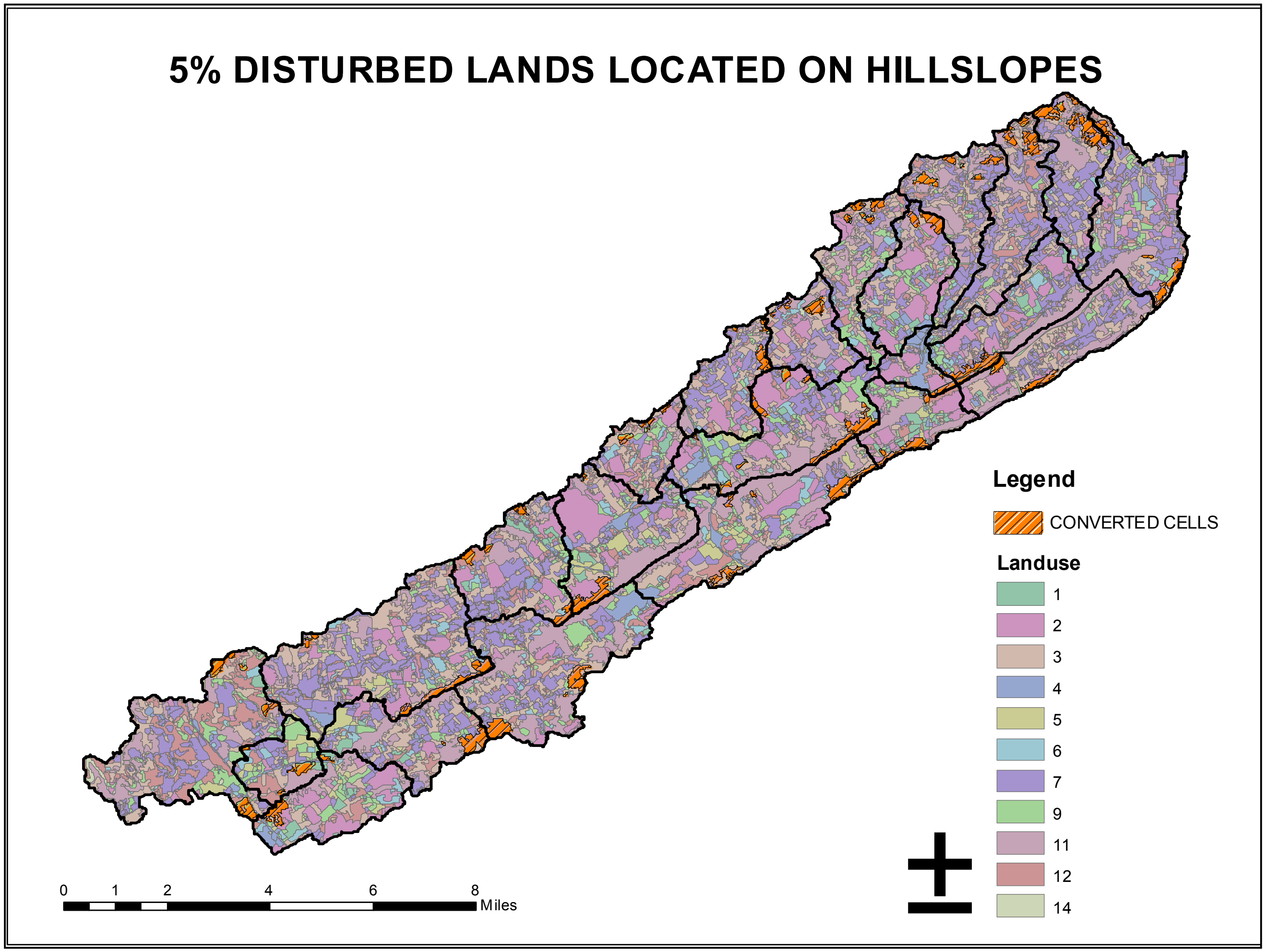


Figure B-8. 5% Disturbed Land Concentrated on Hillslopes

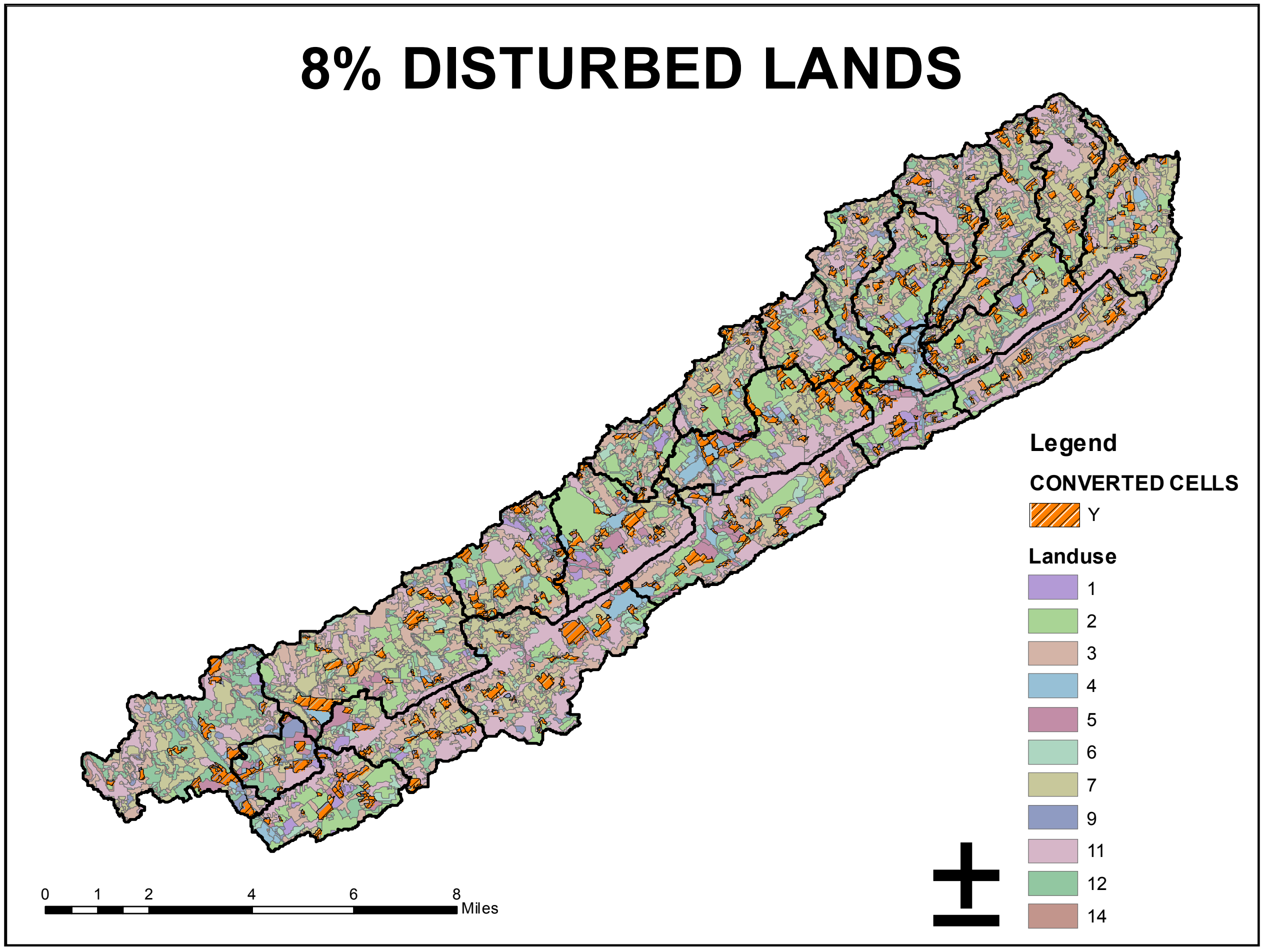


Figure B-9. 8% Disturbed Lands Evenly Distributed Through Watershed

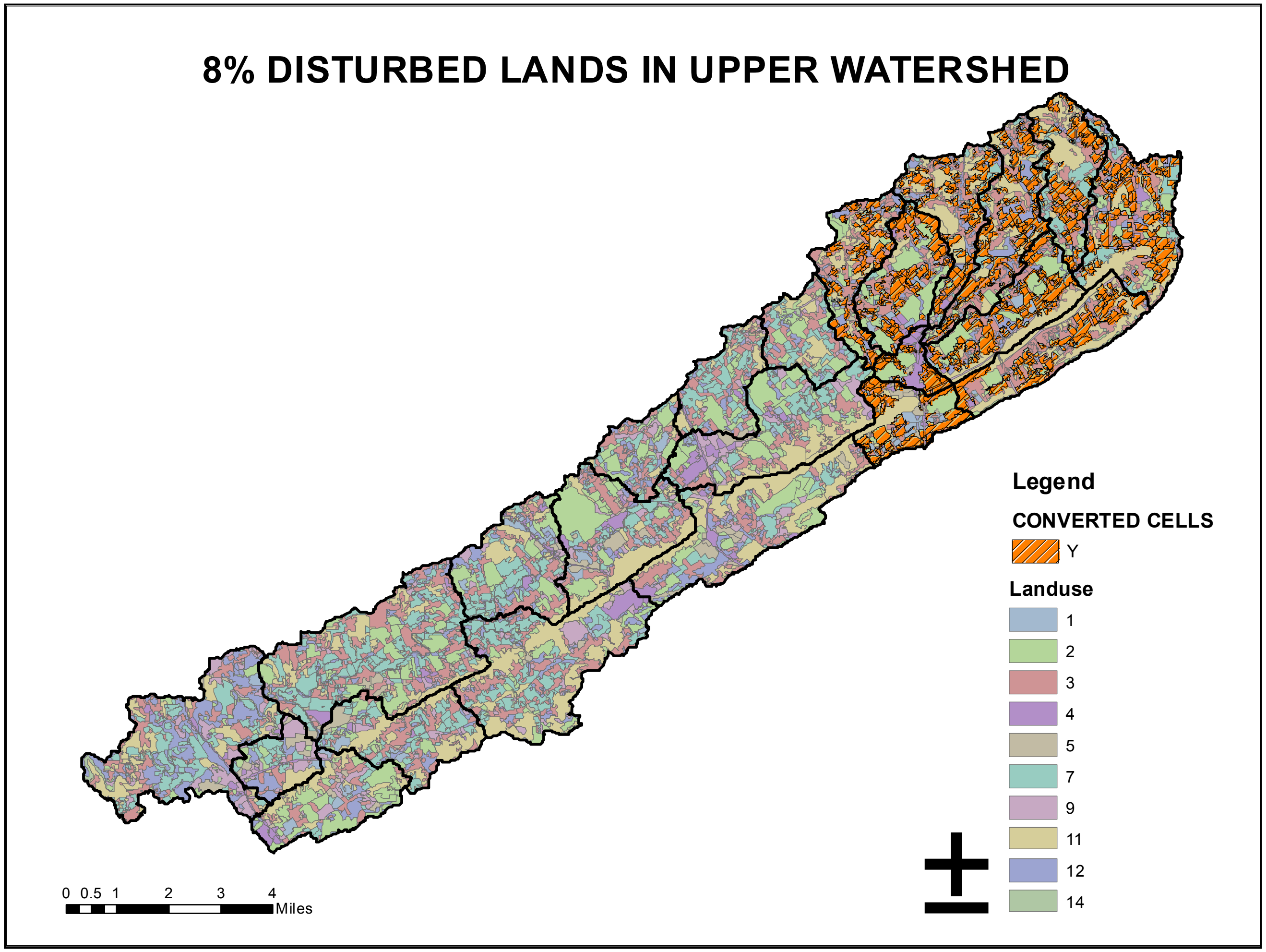


Figure B-10. 8% Disturbed Lands Concentrated in Upper Watershed

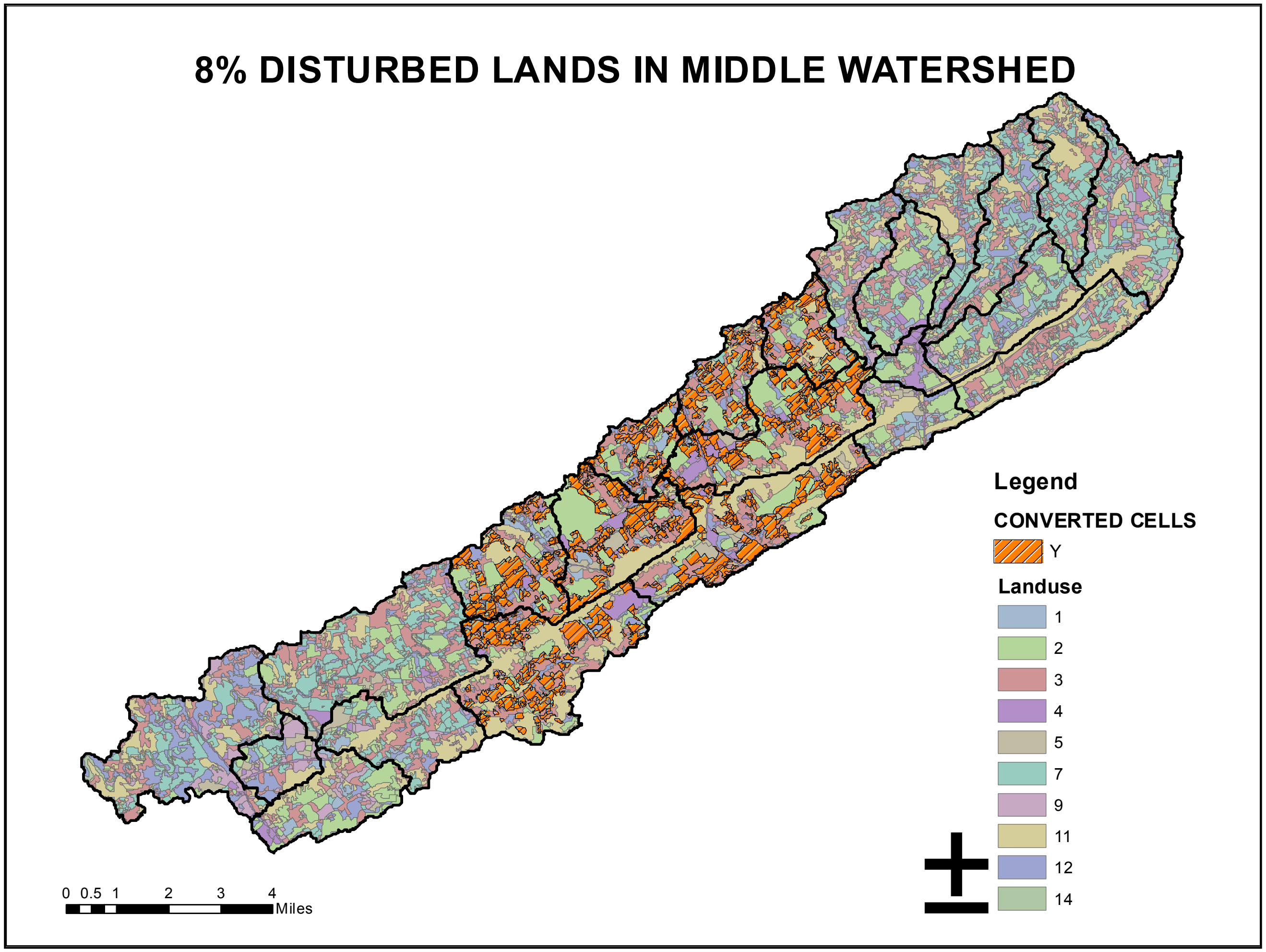


Figure B-11. 8% Disturbed Lands Concentrated in Middle Watershed

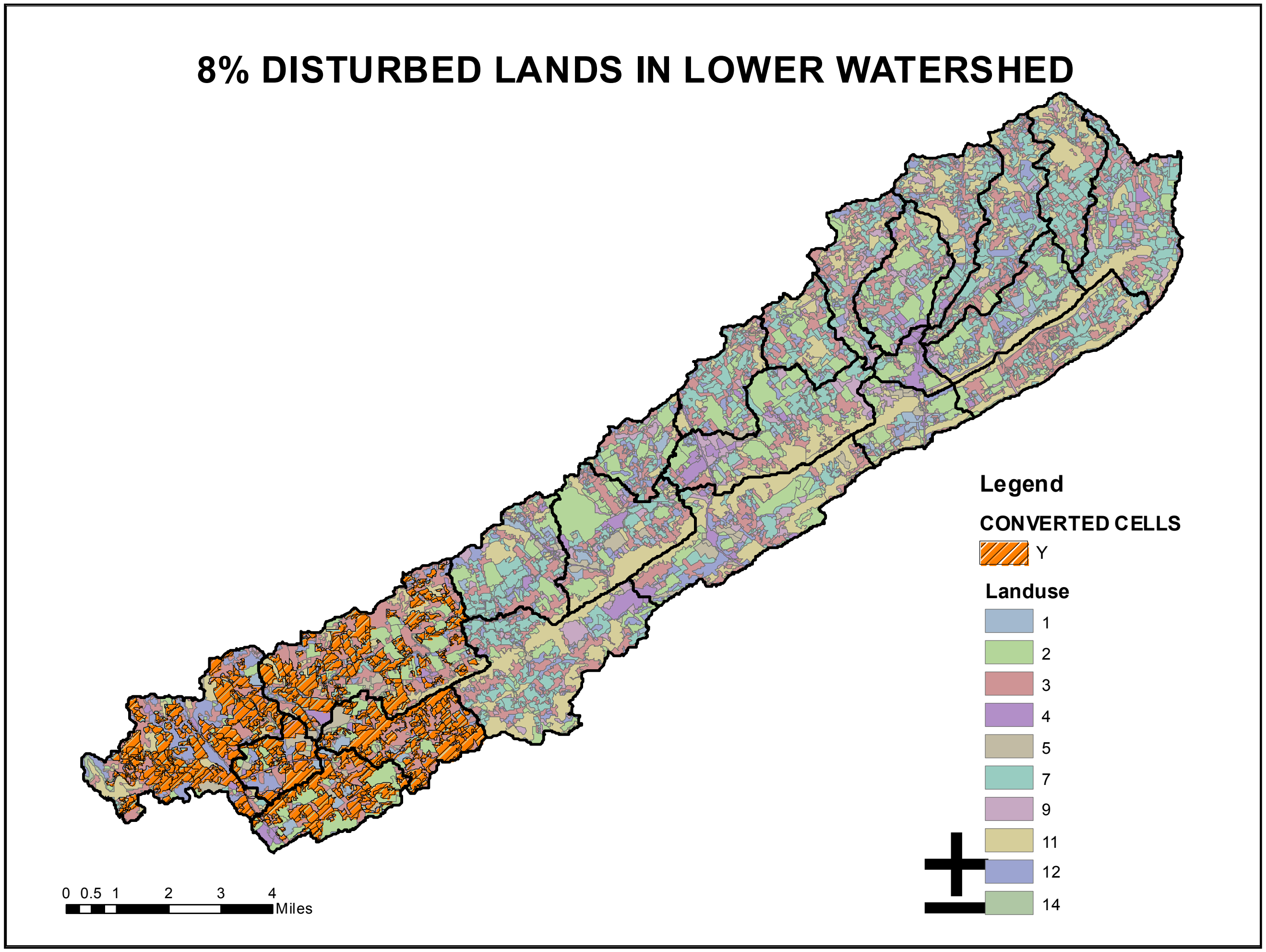


Figure B-12. 8% Disturbed Lands Concentrated in the Lower Watershed

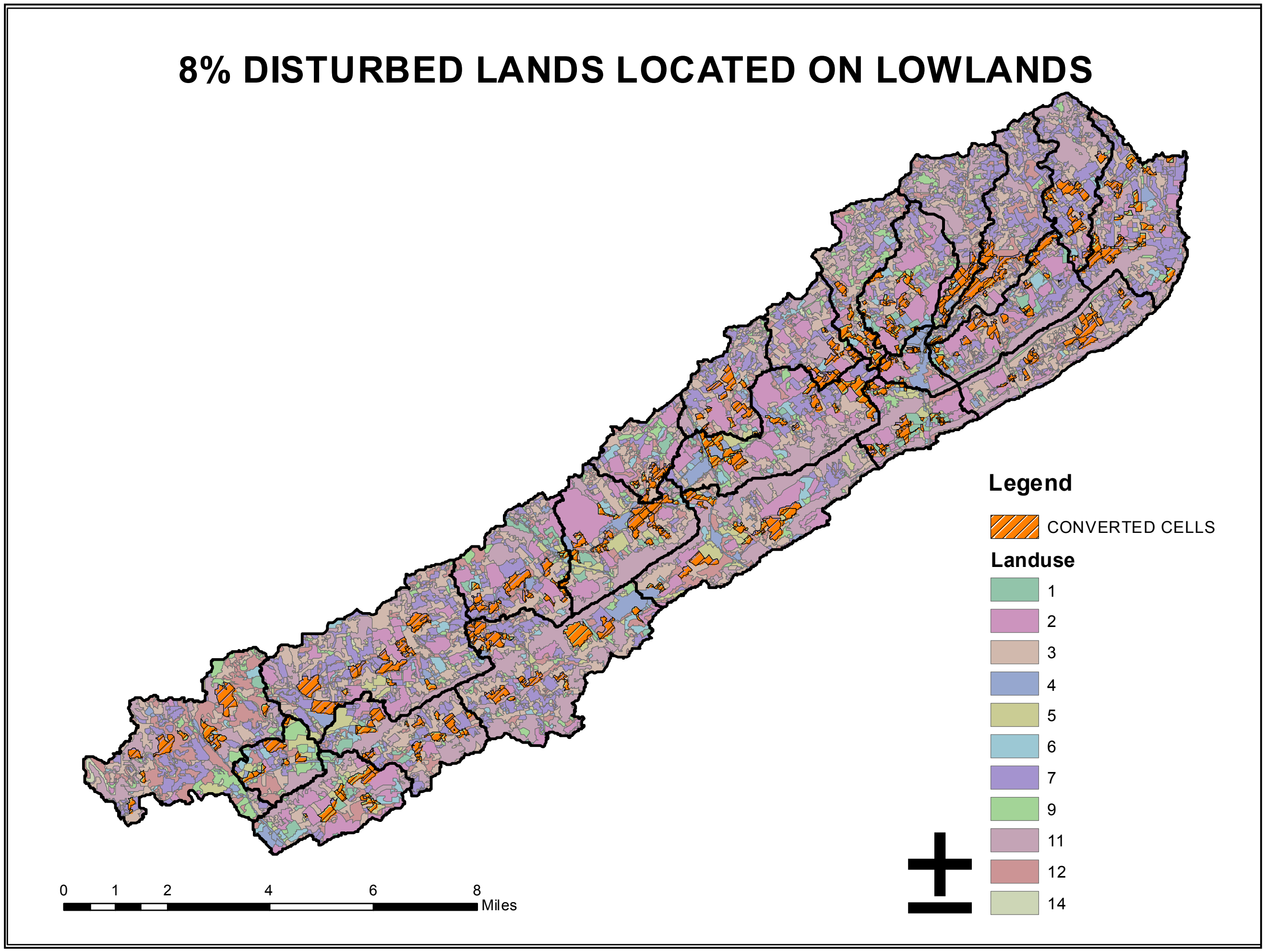


Figure B-13. 8% Disturbed Lands Concentrated on Lowlands

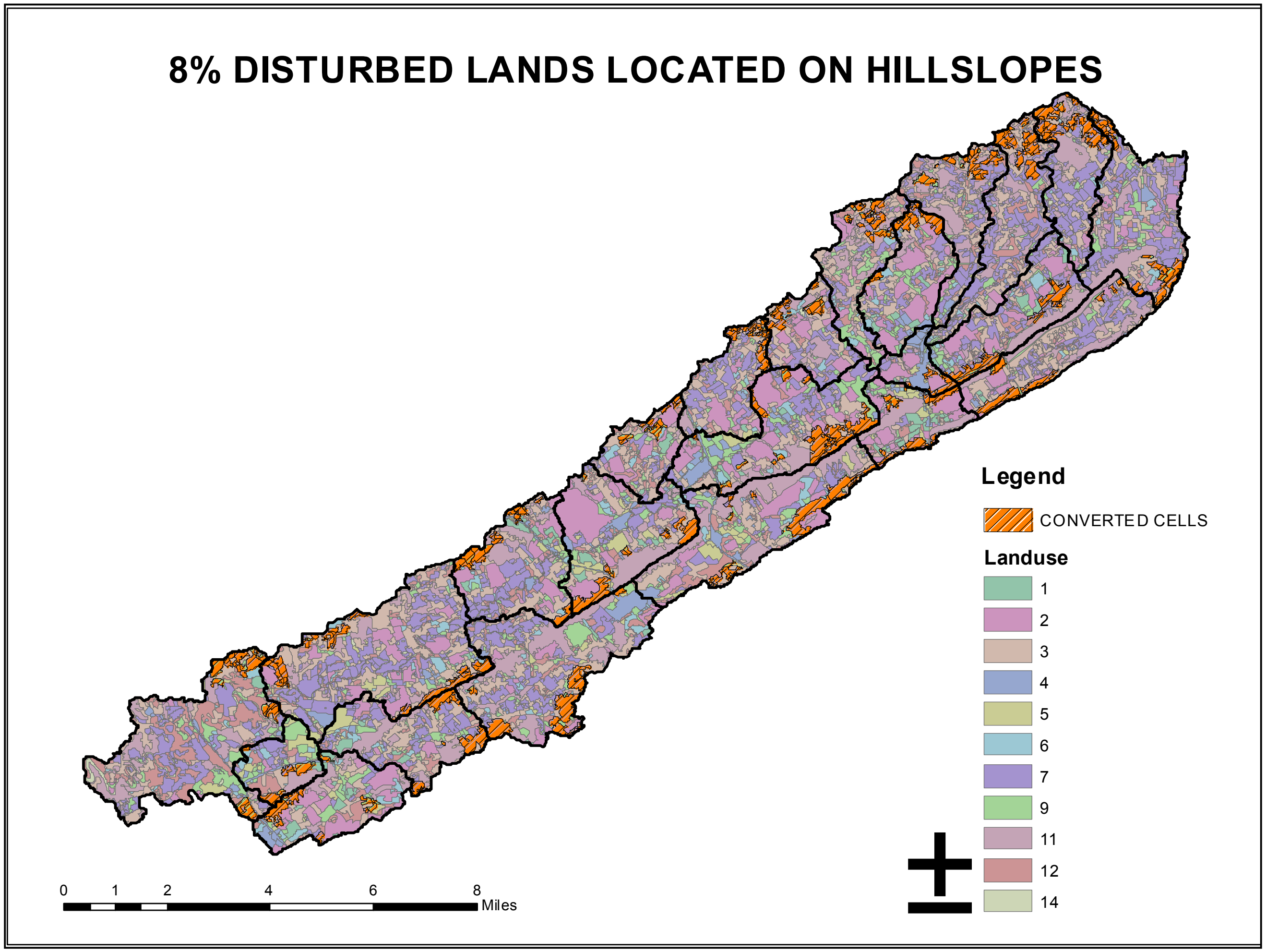


Figure B-14. 8% Disturbed Lands Concentrated on Hillslopes

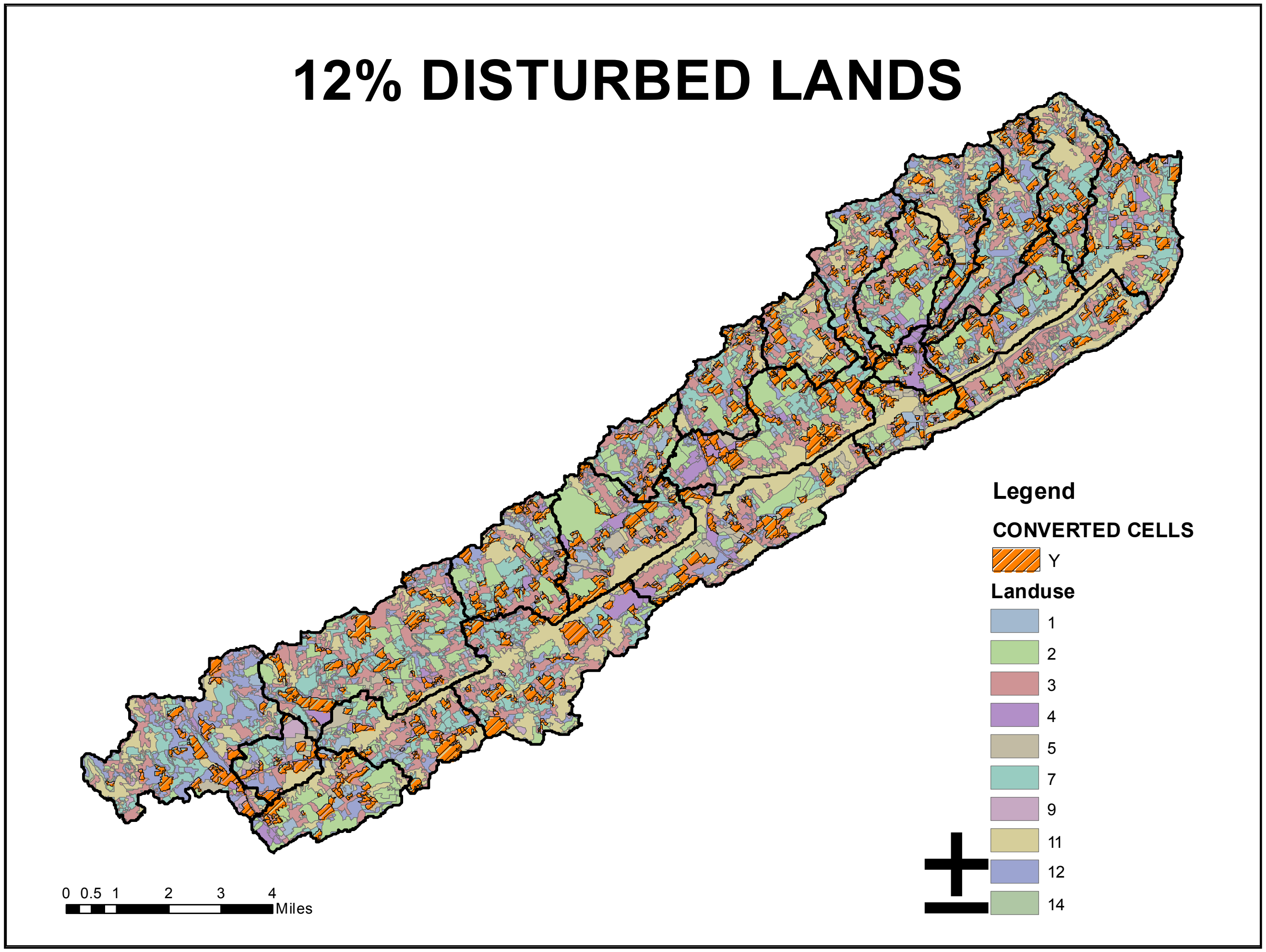


Figure B-15. 12% Disturbed Land Equally Distributed in the Watershed

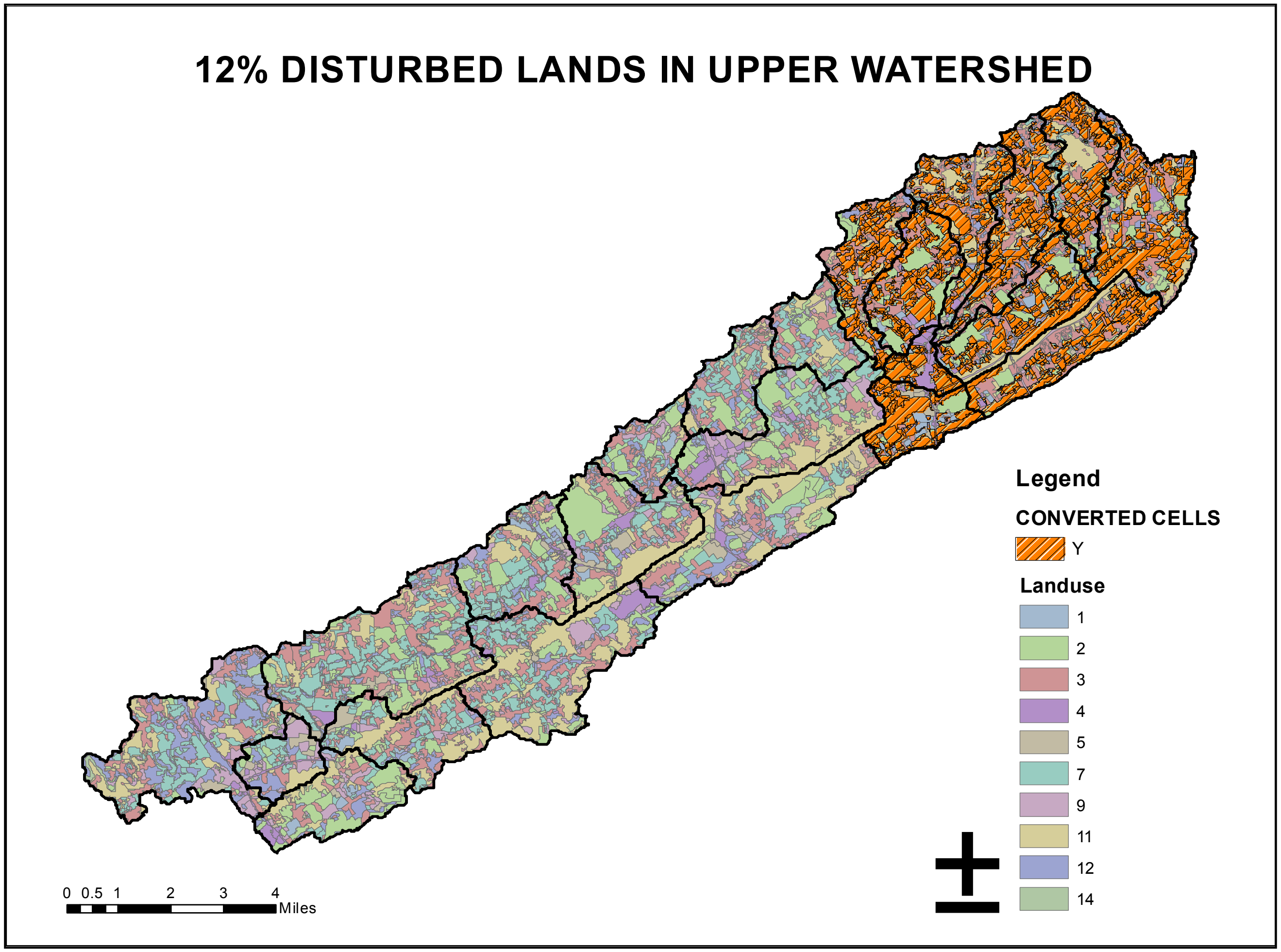


Figure B-16. 12% Disturbed Lands Concentrated in Upper Watershed

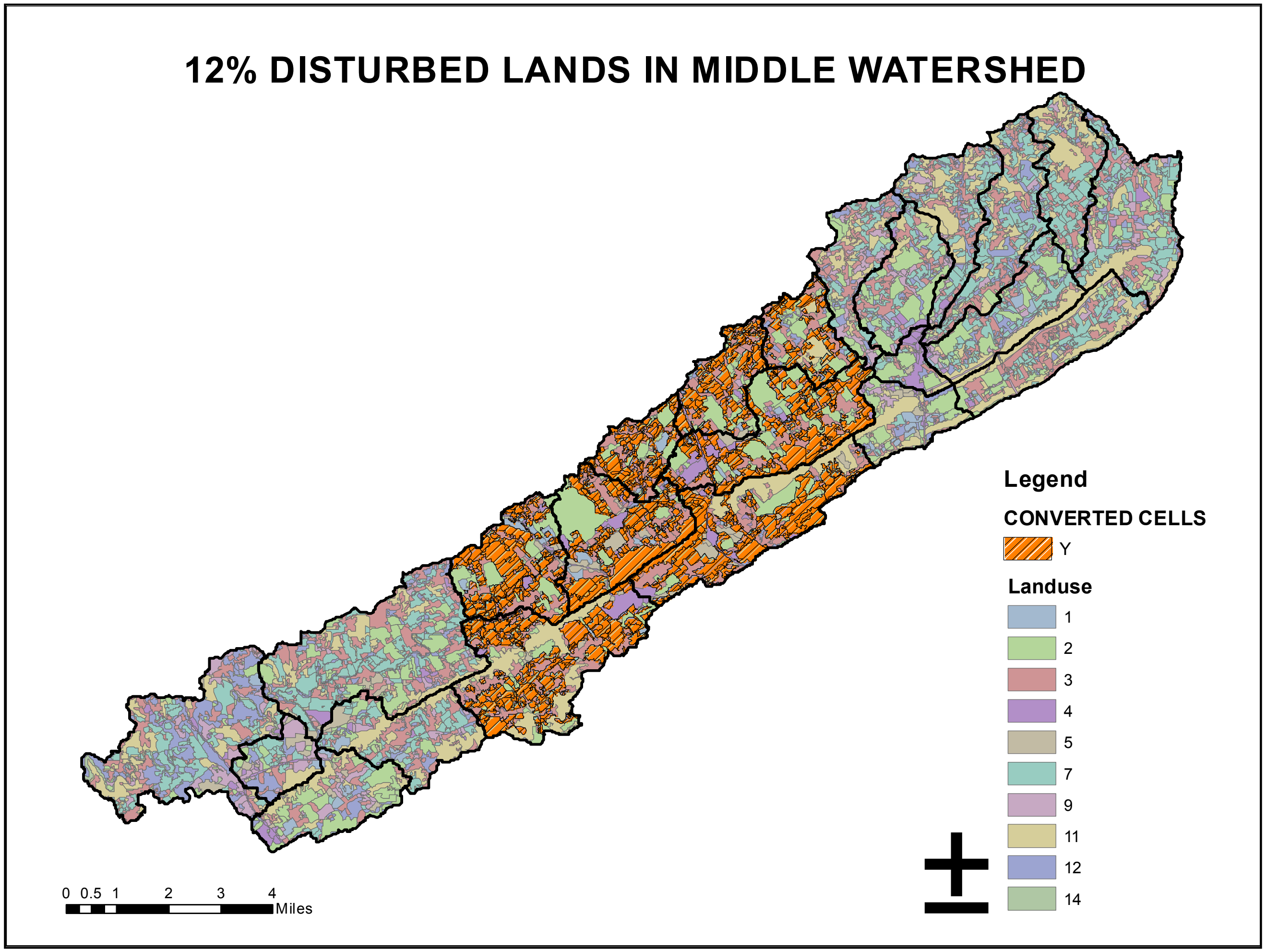


Figure B-17. 12% Disturbed Lands Concentrated in Middle Watershed

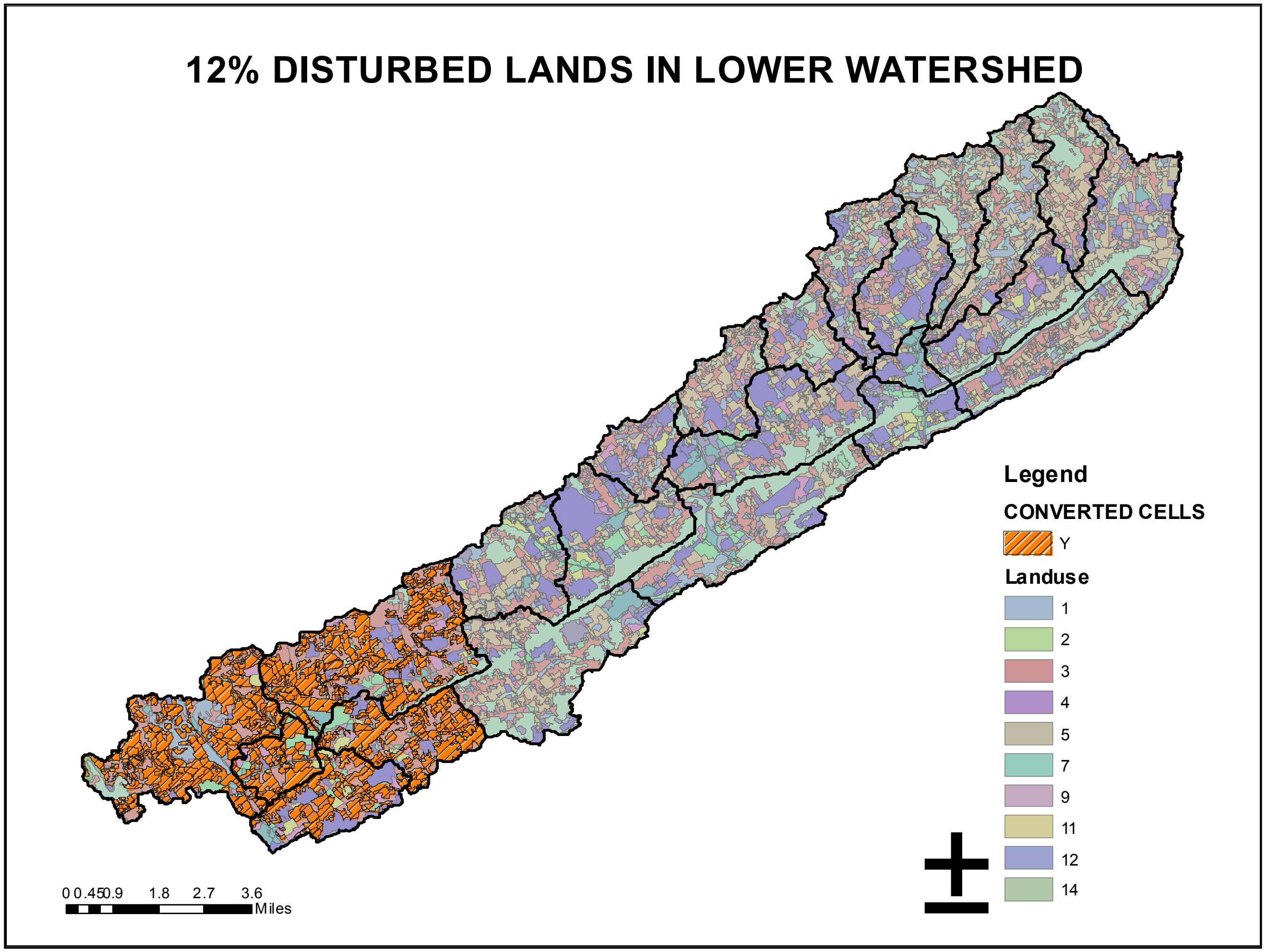


Figure B-18. 12% Disturbed Lands Concentrated in the Lower Watershed

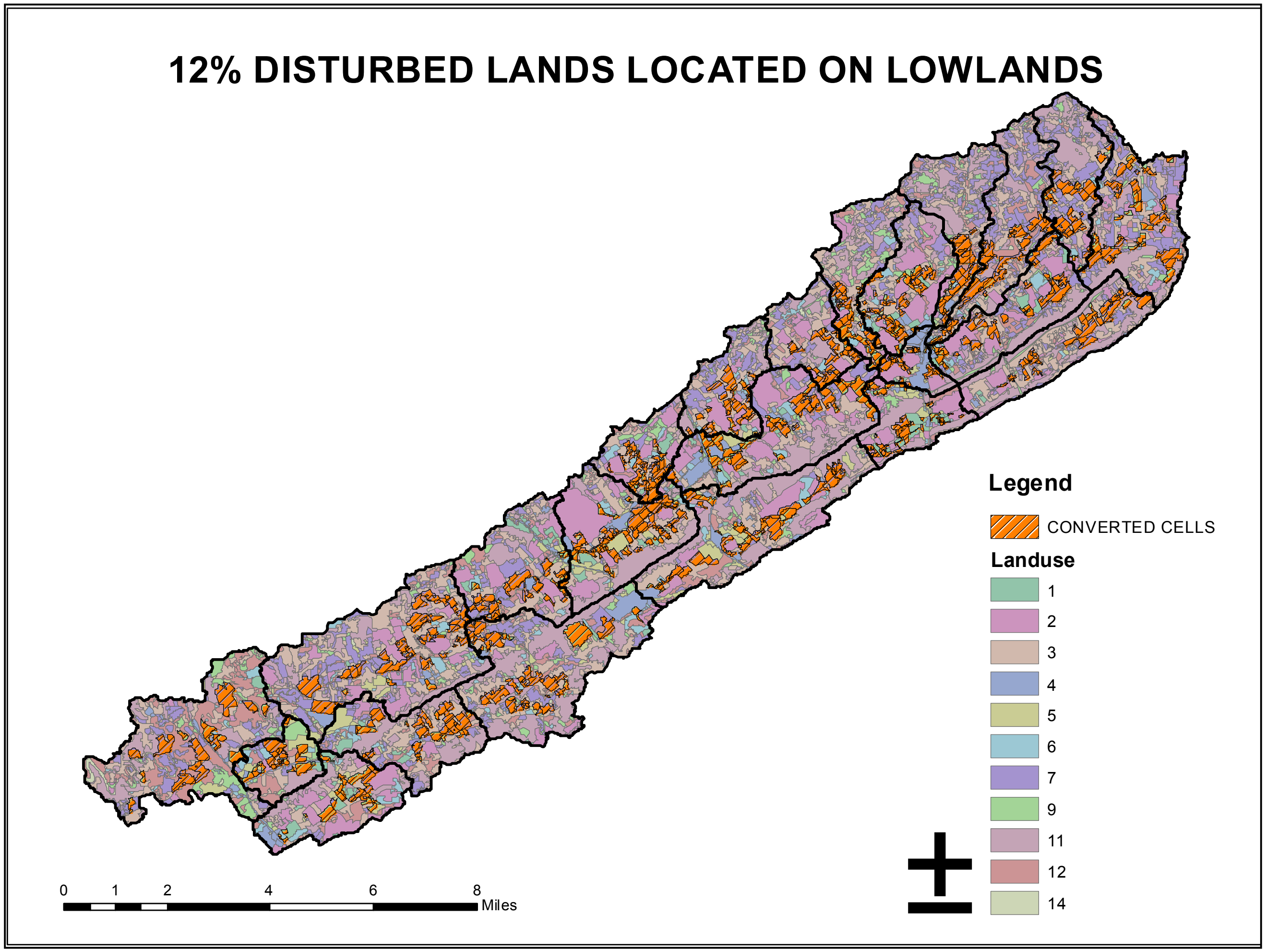


Figure B-19. 12% Disturbed Lands Concentrated on Lowlands

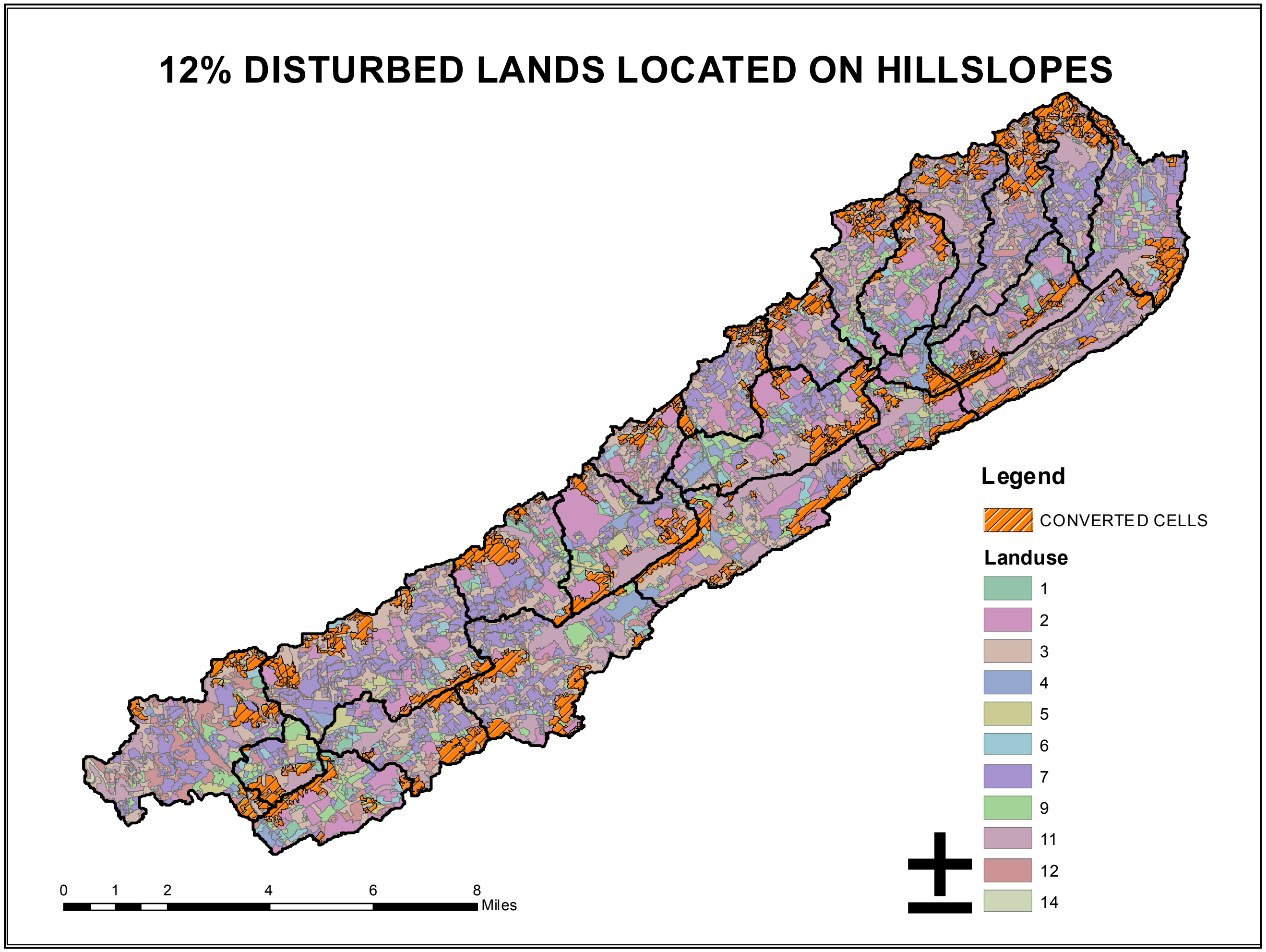


Figure B-20. 12% Disturbed Lands Concentrated on Hillslopes

Table B-1. Results from all Experiments

Scenarios	Runoff Tonnes	Clay Tonnes/day	Silt Tonnes/day	Sand Tonnes/day	Total Tonnes/day
No Urban Land	849870105.64	3.25	0.55	0.04	3.84
No Urban Land with BedLoad	849870105.64	3.25	134.18	0.04	137.47
23.7% Urban Land	859441579.93	64.31	10.91	0.11	75.33
23.7% Urban Land with BedLoad	859441579.93	70.45	272.91	30.64	374.01
35% Urban Land	916122659.57	3.10	0.67	0.14	3.91
35% Urban Land with BedLoad	916122659.57	3.10	322.51	36.73	362.34
60% of Urban Land	928861030.22	0.64	0.19	0.05	0.88
60% of Urban Land with BedLoad	928861030.22	0.64	341.53	38.95	381.12
No Disturbed Land	882583431.51	3.26	0.57	0.04	3.87
Equally Distributed 2.16% Disturbed Land	886356667.43	70.63	9.59	0.04	80.27
Equally Distributed 5% Disturbed Land	897218820.28	230.83	31.82	0.04	262.69
Equally Distributed 8% Disturbed Land	901698493.65	355.95	41.48	0.04	397.48
Equally Distributed 12% Disturbed Land	917025298.90	732.82	68.51	0.04	801.37
Upper Watershed 5% Disturbed Land	893552729.23	294.91	3.07	0.04	298.02
Upper Watershed 8% Disturbed Land	906318239.83	584.57	84.55	0.28	669.39
Upper Watershed 12% Disturbed Land	927679112.17	1095.43	6.75	0.04	1102.22
Middle Watershed 5% Disturbed Land	890115608.46	204.13	8.82	0.04	212.99
Middle Watershed 8% Disturbed Land	906958083.81	483.08	16.24	0.04	499.36
Middle Watershed 12% Disturbed Land	932063878.01	965.64	26.74	0.04	992.43
Lower Watershed 5% Disturbed Land	898220828.00	345.64	91.17	0.04	436.86

Table B-1 continued.

Scenarios	Runoff Tonnes	Clay Tonnes/day	Silt Tonnes/day	Sand Tonnes/day	Total Tonnes/day
Lower Watershed 8% Disturbed Land	919348243.23	708.33	192.04	0.04	900.41
Lower Watershed 12% Disturbed Land	938182750.18	1016.36	302.70	43.72	1362.78
All Lowlands 5% Disturbed Land	892578778.21	201.46	23.45	0.04	224.96
All Lowlands 8% Disturbed Land	900961829.28	378.96	35.29	0.04	414.29
All Lowlands 12% Disturbed Land	912161544.54	590.30	58.54	0.04	648.88
All Hillslopes 5% Disturbed Land	904165340.22	505.36	41.08	0.04	546.48
All Hillslopes 8% Disturbed Land	919806597.74	821.06	60.82	0.04	881.92
All Hillslopes 12% Disturbed Land	944014734.89	1265.30	101.13	0.04	1366.47
BMP 50% Effective 5% Disturbed Land	897218820.28	119.47	18.82	0.04	138.34
BMP 50% Effective 8% Disturbed Land	901698493.65	184.23	24.51	0.04	208.78
BMP 50% Effective 12% Disturbed Land	917025298.90	377.31	41.42	0.04	418.77
BMP 75% Effective 5% Disturbed Land	897218820.28	61.94	10.83	0.04	72.82
BMP 75% Effective 8% Disturbed Land	901698493.65	95.35	14.07	0.04	109.46
BMP 75% Effective 12% Disturbed Land	917025298.90	195.15	24.53	0.04	219.72
BMP 100% Effective 5% Disturbed Land	897218820.28	3.12	0.56	0.04	3.72
BMP 100% Effective 8% Disturbed Land	901698493.65	2.85	0.52	0.04	3.41
BMP 100% Effective 12% Disturbed Land	917025298.90	2.44	0.48	0.04	2.96

Vita

Shannon Elizabeth Bennett was born on November 25, 1981 in Chattanooga, Tennessee. She grew up in Jasper, Tennessee where she went to school at Jasper Elementary, Jasper Middle, and Marion County High School. She graduated high school in May, 2000 as the Valedictorian of her class. After graduating from high school she attended Tennessee Technological University in Cookeville, Tennessee. During her summers while in college, she worked for the Tennessee Valley Authority in the Surveying Services Department. She earned her Bachelor's Degree in Civil and Environmental Engineering in December, 2004. After graduation, Shannon moved to Knoxville, Tennessee to begin pursuing her graduate education at the University of Tennessee in January, 2005. She completed the requirements for her Master of Science degree in Environmental Engineering with a minor in Environmental Policy in May, 2006.