JOHN KIRKWOOD MARTIN
Title: Sediment Flux and Storage in a Southeastern Piedmont River System
(Under the Direction of C. RHETT JACKSON)

A sediment budget was developed for a representative rural southeastern Piedmont watershed to provide information on the relative importance of sediment sources. Sediment is the single most important water quality problem and the largest contributor by volume of Non Point Source Pollution (NPSP) in the United States (Neary et al.), and Georgia is currently required by court order to develop sediment Total Maximum Daily Loads (TMDLs) for several of the states' waterways that are not meeting designated uses. One way to evaluate the relative contribution of various land use activities to total sediment load is to calculate a basin wide sediment budget. This project attempts to evaluate relative contributions of sediment by estimating storage, export and contributions of sediment from various sources. Results indicate, when compared to stored historical sediment, relative contributions of sediment from silvilcultural activities is minimal. To allocate equitable TMDLs for various industries this stored historical sediment must be considered.

INDEX WORDS: Sediment Budget, Total Maximum Daily Loads (TMDL), Non Point Source Pollution (NPSP), Sediment, Historical Sediment

# SEDIMENT FLUX AND STORAGE IN A SOUTHEASTERN PIEDMONT RIVER SYSTEM

by

JOHN KIRKWOOD MARTIN

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JOHN KIRKWOOD MARTIN

Approved:

Major Professor: C. Rhett Jackson

Committee: David S. Leigh
Larry T. West

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
August 2001

# DEDICATION

This project is dedicated to my grandfather, J. Vernon "Swede" Martin, whose guidance in my early life has led me to the route that I now take. Also, I would like thank both of my grandmothers, Judy Martin and Antha C. Kirkwood, for their unlimited support in pursuit of these goals. And finally, I would like to express my deep appreciation to my family, especially my mother and father, without whose tolerance of my extended education accepting and finishing this project would not have been possible.

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# CHAPTER 1

# INTRODUCTION

## PROJECT OBJECTIVES:

One way to evaluate the relative contribution of various land use activities to total sediment load is to calculate a basin-wide sediment budget for a "representative" basin which includes a typical mix of rural land uses. A sediment budget attempts to quantify sediment inputs to a stream system, internal storage volumes, and sediment export from the stream system.

The objective of this project is to formulate a comprehensive sediment budget for Murder Creek located near Eatonton, Georgia. To achieve the goal of quantifying sediment inputs, outputs, storage, and changes in storage, and to put current sediment loadings in perspective with mobile valley sediments deposited by historical agricultural activities, the following sub-objectives must be accomplished:

( 1 ) Analyze the Murder Creek watershed via Geographic Information Systems (GIS) to characterize roads, agriculture, silvicultural activities, and other land use characteristics in the basin,

( 2 ) Estimate sediment production from silvicultural activities,

( 3 ) Estimate sediment production from unpaved county, state and federal roads,

( 4 ) Estimate sediment production from non-forestry activities,

( 5 ) Estimate reservoir accumulation and deposition to estimate bedload production and estimate the export of Total Suspended Solids (TSS),

( 6 ) Estimate current valley sediment storage and past and present sediment accrual rates.

With current regulations and court orders mandating that Total Maximum Daily Loads (TMDLs) for Georgia rivers be formulated, developing a sediment budget will help regulators and land managers prioritize water quality improvement projects. Specifically, this project will attempt to assess the forest industry's sediment input into TMDL allocations by quantifying the amount of sediment inputs, outputs, storage, and changes in storage, and by putting current sediment loadings in perspective with mobile valley sediments deposited by historical deposition. This will be an important step in determining if Best Management Practices (BMPs) are successful in reducing sediment loading when compared to the historical data. The hypothesis is forestry activities with BMPs will yield a small percentage of the total sediment load into Murder Creek in comparison to historical and current sediment loadings.

## BACKGROUND:

In 1972 Congress enacted the Clean Water Act (CWA 1972). The purpose of the CWA was to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. In a section of this provision, Congress recognized the importance of Non Point Source Pollution (NPSP) by stating that, "it is the national policy that programs for the control of nonpoint sources of pollution be developed and implemented in an expeditious manner so as to enable the goals of this chapter [the CWA]" (CWA 1972).

In Title 33, Congress specifically addresses the issue of NPSP in a State. This section says that, "Each State shall identify those waters within its boundaries for which the effluent limitations . . . are not stringent enough to implement any water quality standard applicable to such waters. The State shall establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters" (CWA 1972). These waters are to be identified as Water Quality Limited Segments (WQLS) and the state must prioritize each WQLS according to the amount of pollution in each water body. Then, based upon the ranking of the water body, the State must develop a TMDL for each pollutant degrading a WQLS.

In 1996 the Sierra Club sued the Environmental Protection Agency (EPA) for not enforcing policies set forth under the CWA in the State of Georgia. Georgia had failed to submit their WQLS list to the EPA for approval, as directed by the CWA, for over thirteen years after the deadline. When Georgia finally submitted their WQLS list the EPA refused to approve the list within the mandatory thirty days. The Sierra Club maintained that the States' WQLS list does not include many waters that are affected by NPSP. Specifically, they maintained that these waters are mainly affected by mining, agriculture, and forestry. Later, in 1996, U.S. District Court Judge Shoob ordered that, for the State of Georgia, TMDLs be developed on all of the states' WQLS (Sierra Club vs. John Hankinson 1996). This project is designed to aid in the development of an equitable development of sediment TMDLs for rural basins.

## LOCATION AND SITE DESCRIPTION:

The study site for this project is located in a Piedmont, watershed (Murder Creek) near Eatonton, Georgia (Figure 1.1). This region is confined to the north by the Blue Ridge Province and to the south by the Atlantic Coastal Plain (LeGrand 1988). This area of the Piedmont is characterized by both broad and narrow ridges separated by narrow valleys and ranges with an altitude between 90 and 460 meters. The average yearly precipitation for the Piedmont ranges between 108 and 150 centimeters (Cherry 1961). Currently, the major land disturbing activities in Murder Creek are dominated by forestry and dairy farming. There exists some row-crop agriculture and rural residential land use. The Murder Creek watershed consists of a sixth order stream that drains an area of approximately 538 square kilometers.

### *Geology and Soils:*

The geology of the Piedmont is considered to be old, forming 300 million years ago during the period the Appalachian mountains were rising from uplift and the subsequent erosion of the Appalachians (Miller et al. 2000). The mineralogy of the province consists of basic rocks such as diorite, gabbro, and hornblende and acid metamorphic rocks such as gneiss, and schist (Payne 1976). Closely associated with the geology are the soil series which formed from the geology. The area of interest contains Ultisols (Cecil, Davidson, Pacolet, and Wilkes) Inceptisols (Chewacla and Starr), Alfisols (Wilkes) and Entisols (Toccoa and Congaree) soil orders.

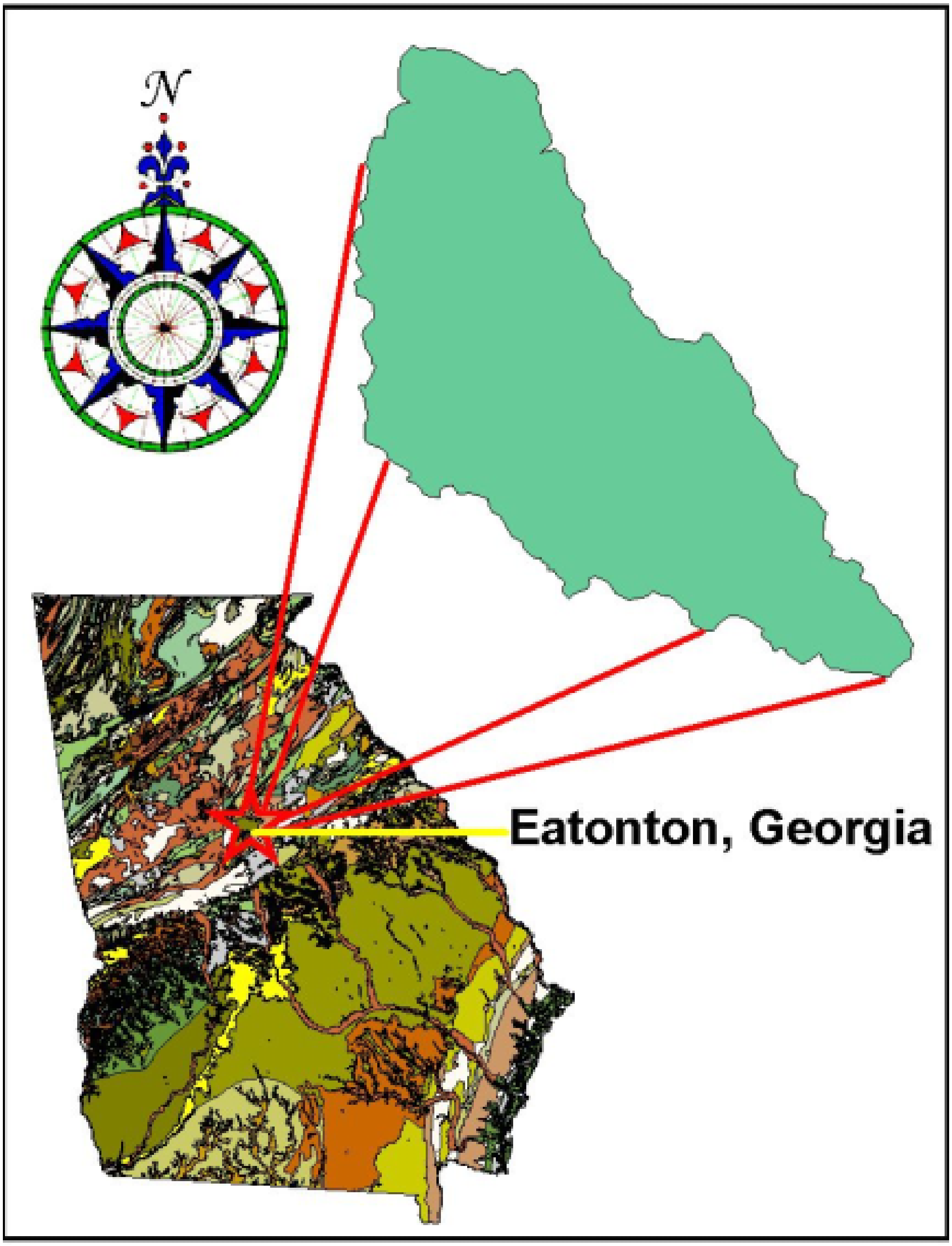


**Figure 1.1** Location of the Murder Creek watershed near Eatonton, Georgia in the Piedmont region of Georgia.

# CHAPTER 2

# LITERATURE REVIEW

## INTRODUCTION:

Sediment is the single most important water quality problem and the largest contributor by volume of Non Point Source Pollution (NPSP) in the U.S. (Neary et. al. 1988). In Georgia, especially in the Piedmont province, there is a past and present problem with NPSP entering the State's waterways. The Clean Water Act (1972) has mandated that States develop a Total Maximum Daily Load (TMDL) program that will protect the nation's water from many specific pollutants, including sediment. Currently, Georgia is required by Federal court order to develop TMDLs for several of the state's waterways that are not meeting designated uses (Sierra Club vs. John Hankinson). It is believed that silvicultural activities are a major contributor of sediment into the state's waters. The objective of this project is to create a sediment budget to determine to what degree, if any, the forest industry may be responsible for the current problem of sediment in the State's waterways and to prioritize water quality improvement efforts.

## HISTORICAL EFFECTS:

The history of agricultural practices in this area of the Piedmont is well documented. Most of the study site was in upland forest until the area was opened to European settlers. Poor farming practices by early settlers may have been the beginning of successive erosion on the area. It was reported that as much as 75% of Putnam County was cleared for agricultural practices (Whitney 1919). The early settlers, reportedly would lay their rows for crops parallel to the slopes of the hills to obtain better drainage for their crops (Whitney 1919). Many of the gullies in this area formed due to these early drainage rows and at the time of the soil survey report many had developed into ravines.

The following excerpt, from an speech by H.H. Bennett (1933), Chief of the Soil Conservation Service, January 31, 1933; describes some of the landscape around the Georgia and South Carolina Piedmont during a soil survey conducted in the year 1911:

> "… 46 thousand acres of stream-bottom, once the most productive soil of the entire state, were classed as Meadow, or land covered with sand and mud washed out of the cultivated hills, and thus made subject to increased overflows due to the choking of channel ways with the debris of erosion. I found on this second trip that the gullies had not stopped with their chiseling away of the fine agricultural lands. They had grown longer, deeper, and wider; they had branched out, forming new canyons. A roadway which I had traveled previously had been moved; it must be moved again. But it can be moved but once more, since yawning ravines are approaching from the opposite direction."

Before settlement by Europeans, it is presumed that the quality of Piedmont streams were clear and non-turbid. William Bartram, in his book *Travels,* noted that the Chattahoochee River "is about three or four hundred yards wide, carries fifteen or twenty feet of water and flows down with an active current; the water is clear, cool and salubrious " (Harper 1998). Bartram also described the soils of the Georgia Piedmont as "a deep, rich, dark mould, on a deep stratum of reddish brown tenacious clay, . . . " (Harper 1998). Years later in 1845, Sir Charles Lyell, an eminent British geologist, described the degraded quality of Georgia Piedmont streams, which had become turbid from the erosion of recently cleared lands in the Piedmont (Trimble 1974). Trimble reported that four to twelve inches of native topsoil were lost during the late 1800's and early 1900's due to poor agricultural practices (Trimble 1974). This resulted in the transport of much sediment into Georgia's Piedmont streams. As a result, current soil surveys by the Natural Resources Conservation Service (NRCS) show that many of the Piedmont soils are highly eroded and have little or no topsoil.

Trimble's research verifies this historical stewardship of Piedmont land. He classified the Piedmont region as having the highest "erosive land use" in the Piedmont area, due to the onset of high cotton prices and cheap available land (Trimble 1974). The geology of the Piedmont is also implicated as a reason for the large amount of sediment leaving the uplands and washing into streams. The soils in the area are residual and overlay a thick mantle of weathered saprolite, sometimes up to 100 feet thick. Saprolite is highly weathered bedrock that has developed in the warm climate of the Southeast. Once a gully was created by poor management practices and extended into the saprolite, large amounts of material moved from the hillslopes and into the stream valley. Glenn (1911) reported that there were many of these gullies forming in the Piedmont region, and that erosional processes and the downcutting through the soil mantle was largely left unchecked. An example of one of these gullies is characterized as the Little Grand Canyon, in Stewart County, Georgia. Georgia's Providence Canyon State Park is now a conservation area that has resulted from the past poor land management practices. Once an agricultural field, lack of land management principles caused this "scenic wonder" to develop into a large gulley that is now hundreds of feet deep and miles long.

The historical influx of sediment into Georgia's streams and the current storage of this sediment was recently illustrated by an Atlanta Journal Constitution article. A Wrightsville native found a 300 - 350 year old canoe that was uncovered from the sediment by a series of water releases from a dam on the Oconee River (Osinski 1999). In addition, Trimble (1974) described a milldam that was once level with the streambed. It was buried under twelve feet of sediment and has only recently become exposed. Clearly, historical sediment storage must be quantified and compared to modern sediment input to accurately determine the effectiveness of silvicultural Best Management Practices (BMPs).

ROAD EFFECTS:

Very little research has focused on the contributions of sediment from roads other than forest roads. The sediment contribution of County, State and Federal unpaved roads has not been adequately evaluated. Most research has focused on sediment effects of logging roads of which there are approximately 369,000 miles in U.S. Forest land in the United States (USDA 1988). It has long been recognized that forest roads are a major contributor of sediment to water systems (Reid and Dunne 1984, Swift 1988, Ketcheson and Megahan 1996, Megahan and Kidd 1972). Sediment production from roads can be attributed to various factors such as road prism and drainage design, aggregate quality and traffic volume (Sturhan et al. 1995 and Foltz 1996). Beasley et al. (1984) found that as the average slope gradient of forest roads increased so did soil loss. As slope increased from one to seven percent the road segments contributed 6.8 to 33.7 tons of sediment per acre. In 1978, Hewlett conducted a field experiment that measured erosion from a silvicultural operation. Two different sites were measured for erosion from clearcut watersheds with first and second order streams. Hewlett (1978) found that outside of normal soil export, 90% of all sediment export could be attributed to road and stream channel damage. This suggests that proper road design and streamside management can prevent much of the soil export due to silvicultural activities.

In the Southern Appalachian Region, Swift (1988) attributed variations in road sediment production on roads with similar traffic volume to differing types of road aggregate. They found that soil loss from a lightly graveled road was similar to the soil loss from an ungraveled road. Similarly, soil loss from a road with grass cover was approximately half the soil loss from a road with bare soil. Foltz (1996) found that “poor” quality aggregate roads produced 4 to 17 times the amount of sediment runoff from roads than the study sections that had “high” quality aggregate. Foltz also reported that traffic volume and weight had a significant impact on the amount of sediment produced from logging roads. Of these roads, those that had “high” quality aggregate produced less sediment even with similar traffic volumes and weights (Foltz 1996). Reid and Dunne (1984) found that forest roads with heavy (loaded log trucks) traffic volumes generated sediment concentrations of up to 31,000 mg/L. In contrast, they found that if traffic is reduced to light vehicular traffic, sediment production may be reduced to 0.8% of the heavy traffic road.

The WEPP:Road model, chosen to estimated sediment production and yield for our watershed, was designed to estimate erosion from forest access and logging roads (USDA 1999). Forest road activities have been implicated in the production of large amounts of sediment (Hewlett 1978, Patric 1976, Swift 1984). These roads are usually the source of much of the sediment that is produced during logging activities (Hewlett 1978, Swift 1984). But much of the sediment production from forest road activities usually decreases, or may even cease, when logging roads or skid trails are properly retired (Patric 1976).

In contrast, unpaved county roads are constantly maintained in order to keep roads accessible to vehicles. To maintain the roads, a road grader is usually employed to grade the road to a level surface and then excess soil is almost always deposited in the drainage ditch. This practice leads to the displacement of large amounts of soil from the surface of the road and into the roadside ditch in a loose unconsolidated form. During a precipitation event, flowing water in the drainage ditch has little problem carrying the displaced sediment into stream or field area where it may settle. Clearly unpaved roads must be accounted for in a sediment budget as a source of sediment production within a watershed.

RESERVOIR STUDIES:

Use of reservoir surveys has been found to be a valuable tool in volumetric analysis of sediment exported from a watershed (Schick 1993). For example, Beach (1992) used reservoir sedimentation to calculate an average rate of soil loss for two watersheds. He combined reservoir survey data with an estimated Sediment Delivery Ratio (SDR) to obtain an average rate of soil loss for the watershed. Similarly, in an arid watershed in Israel, reservoir surveys were used to improve suspended and bedload sediment export from a previous sediment budget created on the same watershed (Schick 1993). Dendy and Bolton (1976) used reservoir sedimentation surveys to evaluate the effect of drainage area and mean annual runoff on sediment yield. They found that as basin size increased sediment yield decreased. This indicates that less sediment is being transported out of the basin and more sediment is going into storage as basin area increases. Therefore, it is apparent that an estimate of sediment erosion, storage, and yield from reservoirs must be included in sediment budget studies.

SEDIMENT BUDGET MODELS:

Physical and empirical models have been created to predict erosion from the landscape. Since, "empirical based models estimate erosion based on field studies of the statistical soil losses that result from specific land uses on specific soils on specific slopes", they are the prevailing type of model for large watershed erosional studies (Beach 1992). Researchers use the Universal Soil Loss Equation (USLE) because it is a predictive model that can be widely used and has been validated to accurately predict soil erosion from the landscape. The USLE has been used to estimate erosion in numerous sediment budget studies (Beach 1992, Trimble 1983, Phillips 1991, USGS 1980). For example, Beach (1992) showed that reservoir sedimentation data and predicted total erosion by the USLE showed strong convergence in two different watersheds. The similarity between these numbers verify the validity of using the USLE in estimating erosion rates from watersheds. The numerous studies and research papers that support the use of the USLE as an predictor of basin wide erosion rates justify using the USLE to estimate erosion for the Murder Creek watershed based on land use activity.

SILVICULTURAL AND BEST MANAGEMENT PRACTICES:

The variety of silvicultural operations necessary to remove timber from the land and to reforest it have been implicated as sources of sediment in Georgia's streams. One study in Eastern Kentucky looked at harvesting effects on streamwater quality with respect to BMPs. Three watersheds were selected: an uncut reference watershed (A), a clearcut watershed with BMPs employed (B), and a clearcut watershed with no regard for BMPs (C). The authors found that "[the] sediment flux from Watershed C was double that of Watershed B during the treatment period, and one and a half times greater than [Watershed B] during the post-harvest period," (Arthur et al. 1998). The higher and persistent sediment yield from Watershed C was attributed to the lack of BMPs on road construction and skid trails (Arthur et. al 1998). Rasmussen and Green (1997) also noted an increase in turbidity from Piedmont ephemeral streams due to improper construction of roads and skid trails, unstabilized stream crossings, rutted streamside management zones, and logging debris left in the stream.

A study of harvesting in Florida focused on the effectiveness of BMPs in controlling erosion on watersheds with different site preparation techniques. Historical land use was observed to determine previous erosion from the land. Although the main objective of the study was to determine biological effects on the streams due to harvesting, the authors found that turbidity was low throughout all test sites. The BMPs appeared successful in controlling sediment input to the stream because there was no smothering of stream habitat (Bureau of Laboratories Division of Administrative and Technical Services 1997).

In a similar study in Mississippi, an experiment was done to predict sediment yields from mixed-cover watersheds. A mixed-cover watershed includes various types of land use characteristics (i.e. agriculture, development, industry, etc. . .). The results suggested that sediment yields from small watersheds, large enough to support a defined channel, may provide a basis for predicting annual sediment yields from large mixed-cover drainage basins (Dendy et al. 1979).

SUMMARY:

Previous studies in the field have attempted to quantify sediment inputs from forestry operations. While the studies have helped quantify NPSP in watersheds, they fail to take into account the resident sediment moving through the system. I suggest that this historical sediment was deposited years ago and may be responsible for the elevated and continued levels of turbidity in some of Georgia's streams. Trimble (1975) estimated that, within the Savannah River watershed, only four percent of the soil eroded from the Piedmont uplands since the 1700's has been carried past Augusta, Georgia.

This project will attempt to quantify the historical and modern flux of sediment through a Piedmont watershed by creating a sediment budget. The information obtained may aid in the development of a sediment TMDLs for rural Georgia Piedmont streams and determine to what degree silvicultural activities may be responsible for sediment entering the state's waters.

CHAPTER 3

RESEARCH METHODOLOGY

INTRODUCTION:

This project will attempt to create a watershed scale sediment budget quantifying sediment contributions, export and storage of sediment. Contributions of sediment for the Murder Creek watershed will be estimated using the Universal Soil Loss Equation (USLE) through the use of Geographic Information Systems (GIS). Additional sediment contributions will be estimated from unpaved roads using the WEPP:Road model developed by the U.S. Forest Service. Sediment export will be estimated by calculating the sediment accumulation in the Murder Creek arm of the Lake Sinclair reservoir and Total Suspended Solid (TSS) export will be estimated from USGS gage station data located on Murder Creek. Historic accumulation of sediment will be estimated through identification of the floodplain that was present before the onset of agricultural practices and calculating the volume of modern sediment that has since accumulated on the floodplain. Site specific measurements of soil properties were not done for this project and therefore certain assumptions in soil properties will be used in calculating the mass and volume of sediment contributions, export and storage. Mass will be calculated in Megagrams (Mg) and volume will be calculated in cubic meters ($m^3$).

CONTRIBUTIONS OF SEDIMENT:

**Gross Watershed Estimated Inputs:**

*Universal Soil Loss Equation:*

The Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (1978), was chosen to estimate gross watershed erosion. The USLE (Equation 1) is a widely used, relatively accurate, and simple model used to estimate gross watershed erosion. The USLE model is comprised of the following parameters:

$$A = R * K * L * S * C * P \quad (1)$$

| | | | |
|---|---|---|---|
| Where | A | = | Annual soil loss (tonnes/hectare/year) |
| | R | = | Rainfall - runoff erosivity factor |
| | K | = | Soil erodibility factor |
| | L | = | Slope - Length factor |
| | S | = | Slope steepness factor |
| | C | = | Cover management factor |
| | P | = | Support practice factor |

The use of Geographic Information Systems (GIS) is the framework within which the USLE model will be run. Each parameter of the USLE model was developed using available databases. When a required database was not available, the necessary data was created using the capabilities of GIS technology. Each parameter was created as a discrete Grid (Raster data) layer for later analysis within the USLE. Once the layers were created they were stacked on top of one another in order to multiply the correct factors together and to obtain discrete erosional outputs for each land cover area in Murder Creek. To run the USLE model the following procedures were completed to develop the necessary inputs for the model.

*Rainfall Runoff Erosivity factor:*

The rainfall runoff erosivity factor (R) was taken from regional values. The rainfall erosivity index for Murder Creek was estimated to be 275 (Figure 3.1) and taken from a USDA Georgia regional handbook of USLE parameters (USDA 1987). This value was used as the rainfall runoff erosivity factor and was later input into the USLE equation to estimate gross watershed erosion.

*Soil Erosivity factor:*

The soil erosivity factor (K) was a necessary database that was created. The availability of a digital soil database was not available, except for a small portion in the northern part of the watershed. The new soil database was created to obtain a spatially distributed coverage of the soils in the watershed. Soil erosivity factors associated with the soils in the Murder Creek watershed were obtained from the Jasper, Newton, and Putnam Counties Soil Surveys (Lathem 1999a, Lathem 1999b, Payne 1976). Large scale (1:20,000), Soil Survey sheets from the Natural Resources Conservation Service (NRCS) were used to create the database.

The soil sheets were scanned into digital format and then imported into ArcView and geo-referenced (UTM Zone 17 NAD 83) using the Spatial Analyst extension. Once the sheets had been given spatial reference, each soil series was digitized into a discrete polygon theme coverage (Figure 3.2). Each soil polygon was then assigned the appropriate attributes of soil series, polygon area and soil erosivity factor (Figure 3.3). Once the soil polygon coverage was created, the coverage was then converted into Grid format, 30meter x 30meter pixel size, with appropriate K factors associated with each cell (Figure 3.4).

*Slope-Length and Slope Steepness factor:*

The slope length and slope steepness factors (LS) were created using Digital Elevation Models (DEM). DEM data were obtained from the Georgia Spatial Data Clearinghouse (Georgia GIS Data Clearinghouse 2000). Two separate county 30m x 30m DEMs (Jasper and Putnam Counties) were obtained to cover the extent of the watershed. The DEMs were combined using the MERGE command in ArcInfo to eliminate No Data values. Next, a polygon mask was created, which was large enough in area to cover the extent of the watershed. Using ArcInfo, the GRIDCLIP command was used to clip the DEMs to reduce file size and allow for faster processing of data values.

Calculation of slope for each cell of the merged DEMs had to be determined. Percent slope was calculated in ArcInfo using the SLOPE command. Once slope was determined for each cell in the watershed, LS factors were then assigned to each grid cell. The appropriate LS factors, determined from the calculated percent slope values, were taken from the Length-Slope lookup table in Agriculture Handbook 537 (Wischmeier and Smith 1978). Each cell in the watershed was then assigned the correct LS factor using a CONDITIONAL statement command in ArcInfo (Figure 3.5). Once the necessary data had been created the data was then converted into a Grid, 30meter x 30meter, with the associated LS factors (Figure 3.6).

*Cover Management factor:*

The Murder Creek land cover was determined from 1998 LANDSAT Imagery. The cover management factor (C) was taken from given values from the Georgia USLE Resource area handbook (USDA 1987). The C factors that were used were compared to values that were provided by the Georgaia Environment Protection Division to assure consistency in calculating erosion as compared to other management agencies (Table 3.1). Using ERDAS Imagine 8.4 Interpretation Software, land use was classified and separated into nine different categories (Figure 3.7). Agricultural land from 1988 Multi-Resolutional Land Characteristics (MRLC) data was used to subset the 1998 LANDSAT Image. The 1988 classified agricultural land was used to separate pixel data from the 1998 LANDSAT Image. Once separated, the 1998 pixel data was processed into 30 classes with a maximum of 20 iterations with a 99 percent convergence threshold using an unsupervised classification procedure (Figure 3.8). The image was reclassified to further refine the agricultural land use. This was done because some of the agricultural land from the 1988 data has since been converted into pine plantation or it has been kept in pasture or agriculture.

An unsupervised classification procedure was used to determine the remaining land use category clusters that were not separated from the 1988 MRLC data. During field sampling the land use of much of the Murder Creek watershed was observed and located. Therefore, for much of the watershed, the identified land use was compared to the 1998 classified image to ensure that the classification was accurate. The image was processed into 40 classes, with a maximum of 30 iterations and a 99 percent convergence threshold (Figure 3.8). All 40 of the classes were then classified based upon the LANDSAT image reflectance and aerial Digital Orthophoto Quarter-Quadrangles (DOQQ). Land use classifications were then separated into the following nine categories: Open water, Urban, Clear Cut, Mixed Deciduous/Evergreen, Planted Pine, Pasture, Row crop agriculture, Wetlands, and Mixed Re-Growth for later erosion analysis (Figure 3.9). Next, the two classified images were mosaiced together into one discrete land use coverage. Then the classified land use image was converted into raster data in ArcInfo. Once in Grid format, each individual cell was assigned the appropriate land use cover management (C) factor that was taken from Agricultural Handbook 537 (Wischmeier and Smith 1978). A cover management factor for clear cut areas was taken from a Dissertation in which C factors were developed for clear cut sites as compared to the amount of bare soil exposed in the Georgia Piedmont (Burns 1978).

*Support Practice factor:*

The support practice factor (P) was obtained from a lookup table in the Georgia USLE Resource area handbook (USDA 1987). Each cell that had been classified as row crop from the image classification was then assigned a P factor. The P factors ranged from 1.0 to 0.80 and were dependant upon slope and row grade percentage (Figure 3.10). The P values were based upon an assumption of a row grade of two percent and the slope determined from the DEMs. To obtain the necessary support practice numbers for agricultural land, the grid with the cover management factors was multiplied by the grid with the support practice factors to obtain a grid coverage of a discrete CP value that was associated with the agricultural land.

*Calculation of Gross Watershed Erosion:*

Once all of the appropriate factors (LS, K and CP) had been assigned to each cell in the different layers, the nine different land use classes were converted from an Imagine IMAGE format into Grid format in ArcInfo. Once in raster format the land use was converted into an ArcInfo coverage. From this, the land use coverage was then converted into an ArcView shapefile.

Once the land use shapefile had been created, they were copied and edited to create nine different shapefiles each of which represented a separate land use category. Once the nine shapefiles were created they were converted back into nine separate ArcInfo coverages. Then each individual land use coverage was converted into an individual land use in Grid format. Once in Grid format, each land use grid was assigned an value of 1 and all data outside of that specific land use was assigned a value of No Data. The next step was to multiply each land use grid cell with a value of 1 by the classified cover management land use grid to obtain an discrete C value for each land use classification (Figure 3.10).

To run the model, each land use grid was multiplied by the rainfall erosivity factor (R factor), soils grid (K factor), the slope-steepness grid (LS factor), and the land use and support practice factor (C and P factors) to obtain erosional values specific to each land use category. Once erosional values had been obtained for the nine different land uses, they were multiplied by a conversion factor of 2.47105 (Figure 3.10). This factor converted estimated erosion from English units of tons per acre into an estimate of erosion in metric tonnes per hectare. The grids were then imported into ERDAS Imagine to obtain erosional values on a pixel by pixel basis for each individual land use. These values were then imported into a spreadsheet and the total amount of estimated erosion for each land use was calculated.

Total erosional values were then multiplied by 0.09 to obtain a weighted factor of tonnes per hectare. This was done because each individual cell had an estimate of erosion in tonnes per hectare but each cell only occupies nine percent of one Hectare. Volumetric analysis of the estimated individual land use and gross watershed erosion was then calculated. The estimated amount of erosion for each land use was recorded in metric tonnes per hectare. The estimated erosion in metric tonnes per hectare converted directly into Megagrams per hectare. Once the amount of estimated erosion in Megagrams per hectare was calculated, an estimated volume of erosion could be calculated. The total land use erosion, in Megagrams per hectare, was divided by the amount of grams in one cubic meter of soil. An average bulk density of 1.50 g/cm$^3$ was used to calculate the number of grams in a cubic meter. An equivalent depth of erosion, in centimeters, was estimated by dividing total volume by the areal extent of the Murder Creek watershed. An estimated volume of erosion from each classified land use was also calculated, in

Megagrams, cubic meters and Megagrams per hectare to help obtain a relative amount of sediment contribution from each land use category.

**County Road Estimated Inputs:**

*WEPP:Road Erosion Model:*

Roads that have an exposed or dirt surface may be a large source area of sediment. Unpaved county roads needed to be assessed to estimate relative contribution of sediment to the total budget. Inputs of sediment from county roads were estimated using WEPP:Road (USDA 1999), a model developed by the USDA Forest Service.

The spatial extent of the road network was downloaded from the Georgia GIS Data Clearinghouse and then was clipped to fit within the Murder Creek watershed. The county DEMs were filled and an ArcInfo CONDITIONAL statement was used to generate a stream coverage within the Murder Creek watershed (Figure 3.11). The created road network was placed on top of the stream network generated from the DEMs. The stream network was then buffered by 100 meters to identify all the roads that contributed directly or crossed a stream path (Figure 3.12).

Once the intersections had been identified, field excursions to Murder Creek were conducted to collect the necessary parameters for use in the WEPP:Road model. Parameters of the WEPP:Road model included climate, road surface cover, slope, ditch condition, road design, contributing length, and buffer length. Also, during field reconnaissance, all roads in the area were identified as either unpaved or paved and entered into the road network spatial database. This information was added into ArcView and converted into a coverage which allowed for estimating the total amount of unpaved county road length and area contributing to the watershed.

Qualitative data for the WEPP:Road parameters were collected from a total of 86 road segments that contributed directly to a waterway. Using the file generator from the USFS web site (USDA 1999 http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/wr/wepproad.pl), estimated road contribution, in kilograms of sediment, was recorded for each contributing unpaved road segment. A climate generator for the model allowed the user to select a custom climate that most approximates rainfall distributions for a particular area. The available climate information from the WEPP:Road database was chosen, which was the Macon Airport near Macon, Georgia. Outputs were generated for each contributing road segment based upon 30 year mean annual average precipitation amounts determined by the custom climate generator.

The WEPP:Road model allows for only one of the four following soil textures to be entered into the model: Clay loam, silt loam, sandy loam and loam. For each contributing road segment soil texture was determined from the digitized soil series maps. Soil texture inputs for all of the contributing road segments in the WEPP:Road model were classified as sandy loam. There are four road design features from which the Forest Service model allows the user to choose. For the purposes of this project the road design feature of an insloped, vegetated or rocked ditched was chosen because this allows an estimation of sediment production and yield from one side of a crowned roadway. To estimate sediment delivery for both ditches, the user is advised to multiply the result by two. Ditch condition was recorded and the information was then entered into the WEPP:Road model. Information regarding surface cover was also recorded. The WEPP:Road model allows the user to enter one of three following types of surface cover: graveled, native (bare surface) or paved. The type of surface condition for each contributing road segment was recorded and then input into the model. On each contributing unpaved road segment the slope of the segment was obtained. To estimate slope, a clinometer was used to record the gradient of each road segment in percent. Also, for each contributing road segment the average road width was estimated and recorded. The final parameter that was collected was the buffer length that exists between the stream and where the ditch may or may not empty directly into a stream. For example, if there is a road turnout (where a road ditch is directed into a forest or field) that is 30 meters before it reaches a stream, the buffer length that was recorded would be 30 meters. Once all the data had been collected for each contributing road segment the climate, road design, soil texture, slope, road width, ditch condition, and buffer length were entered into the WEPP:Road model.

*Contributing Unpaved Roads:*

The estimated amount of erosion, for all of the contributing unpaved road segments, was calculated in kilograms of delivered sediment. This number was then converted into Megagrams of delivered sediment. Once the estimated weight of the delivered sediment was calculated, an estimate of delivered sediment volume was obtained. An average bulk density of 1.50 g/cm$^3$ was used to convert Megagrams into cubic meters in order to obtain an estimated volume of delivered sediment. The volumetric estimate of the sediment eroded and delivered from the surface of the unpaved roads was used to calculated an average depth of erosion for all the contributing road segments. This was accomplished by dividing the estimated volume (m$^3$) of eroded sediment by the surface area (m$^2$) of the contributing road segments. The surface area of the contributing road segments was calculated by multiplying the average width and the total length of all 86 contributing road lengths. Also, estimated delivery of sediment was calculated in Megagrams per hectare per year. In addition to estimating sediment delivery, the WEPP:Road model also predicts the total amount of eroded sediment from the given road segments. The estimated total erosion for all of the contributing segments was calculated and was reported as a depth of erosion in centimeters per year, cubic meters, Megagrams and Megagrams per hectare per year.

*Total Unpaved Road Estimated Contribution:*

Once the average depth of erosion for the contributing road lengths was calculated, total unpaved road contributions of sediment for the whole watershed were calculated. This was done to obtain the relative contribution of unpaved road segments to the total sediment budget for the entire watershed. The length of all the unpaved county roads identified during field reconnaissance was calculated through the use of ArcView. A unpaved road coverage was created in ArcView and the total length, in meters, was obtained (Figure 3.13). This total length was then multiplied by the average width of the contributing road segments to obtain the total contributing area of unpaved roads within the watershed. Once total area of all the unpaved roads was calculated an volumetric estimate of the contribution sediment was calculated for all of the unpaved roads. This was done by multiplying the estimated depth of erosion from the contributing unpaved road segments by the total area of all unpaved roads. The volumetric estimate was then converted into an estimate of Megagram contribution per year for all unpaved roads within the Murder Creek watershed. In addition to estimating sediment delivery, the total length of all of the unpaved roads was used to estimate total erosional values. The estimated total erosion for all of the unpaved roads was calculated and was reported in a depth of erosion in centimeters per year, cubic meters, Megagrams and Megagrams per hectare per year.

EXPORT OF SEDIMENT:

**Lake Sinclair Sediment Storage:**

*Pre – 1950 Lake Sinclair Volumetric Analysis:*

Two of the original survey sheets of the Murder Creek arm of Lake Sinclair, before dam closure, were obtained from Georgia Power. The survey sheets (Georgia State Plane East NAD 27) were digitally scanned and imported into ArcView using the Spatial Analyst extension. Geo-referenced (UTM Zone 17 NAD 27) United States Geological Survey (USGS) Digital Raster Graphic (DRG) topographic maps were obtained and imported into ArcView. Using the State plane coordinates on the USGS DRG, a shape file was constructed to match the state plane coordinates on the original survey sheet. The State plane coordinates on the original survey sheets were then linked to the matching state plane grid coordinates on the USGS DRG to geo-reference the original survey into the proper coordinate system (UTM Zone 17 NAD 27).

Using the original survey map, now geo-referenced (UTM Zone 17 NAD27), the 330 and 340 foot contour lines were digitized in ArcView into separate elevation themes (Figure 3.14). The 350 foot contour line was omitted from this process due to the fact that the level of the lake rarely exceeds 340 feet in elevation and there were no obvious signs of sediment accumulation above the 340 foot mark. These contour themes were then merged into one theme using the GeoProcessing Wizard extension in ArcView. The contour lines were then edited to convert them from elevation in feet to elevation in meters. This was done to match the projection of the

USGS DRG and so that the estimate of sediment elevations used to calculate reservoir volume would be calculated in cubic meters. Using the 3D Analyst extension in ArcView, a Triangulated Irregular Network (TIN) model was created from the digitized contour elevation values for the Murder Creek arm of Lake Sinclair (Figure 3.15). TINs store z coordinates, in addition to x and y, for every point used to define a feature (ESRI 1999). Next, in ArcView, the TIN model was converted into Grid format which had a 2.5 m x 2.5 meter resolution (Figure 3.16).

*Current Lake Sinclair Volumetric Analysis:*

Locations of sediment elevations in the Murder Creek arm of Lake Sinclair were collected with a Trimble Geo-Explorer II GPS unit. Elevation locations were logged in UTM Zone 17 NAD 83 and then differentially corrected using Trimble Pathfinder Software. Figure 3.17 shows the elevation points that were collected and then projected into the proper coordinate system (UTM Zone 17 NAD 27) to match the digitized contour features of the original lake survey.

Sediment elevations were determined and recorded using the following method. Sediment elevations were obtained by lowering a weighted meter tape towards the bottom of the reservoir until the weight reached the top of the stored sediment in the Murder Creek arm of Lake Sinclair. The depth to sediment was recorded in meters and then was assigned to the proper GPS point at a later time. Lake Sinclair pool elevations are recorded at the Georgia Power dam office on an hourly basis and were obtained to match the time of sediment elevation data collection. Sediment elevations relative to this Georgia Power bench mark were calculated by subtracting the depth to sediment from the pool elevation. Once all the data had been collected, all of the GPS points were merged into one theme using the GeoProcessing Wizard in ArcView.

Using Inverse Distance Weighted (IDW) interpolation, sediment elevation contours were created from GPS sediment attribute data (Figure 3.18). The IDW contours were then merged with the elevation contours from the geo-referenced original survey. This process gave an areal extent of current sediment elevations across the Murder Creek arm of Lake Sinclair. From this theme, a TIN model was created using the 3D Analysit, in ArcView, to represent current sediment elevations in the Murder Creek arm of Lake Sinclair (Figure 3.19). The sediment elevation TIN model was converted into Grid format with a cell size of 2.5meters x 2.5meters (Figure 3.20).

*Volumetric Analysis of Stored Bedload Sediment in Lake Sinclair:*

Using the constructed pre-dam closure and post-dam closure sediment Grids (Figure 3.16 and Figure 3.20), the files were imported into ArcInfo. In the ArcInfo GRID prompt, the CUTFILL command was used to determine change in sediment elevations between the two time periods (Figure 3.21). CUTFILL analysis calculates cut and fill volume between an "after" grid and a "before" grid for each contiguous cut or fill area (ESRI 1999). The "before" grid was constructed from the TIN model that was created from the original survey map prior to dam closure. The "after" grid was the constructed grid created from the TIN built from the reservoir contours and GPS sediment elevation points.

Volume of sediment in storage in the Murder Creek arm of Lake Sinclair was taken from the volume analysis of the ArcInfo CUTFILL output. The specific weight for sediment in the Murder Creek arm of Lake Sinclair was taken from a table (Julien and Shen 1992) in which the average bulk density of sediment for this type of reservoir, for which sediment is nearly always submerged, is calculated to be 1.28 g/cm$^3$. This is based on the assumption that the particle size distribution of the sediment in the reservoir is 70% sand, 20% clay and 10% silt. Total export of bedload sediment, in kilograms, was calculated by multiplying the volume of sediment by the number of calculated grams per cubic meter. This weight of sediment was then converted into an total export of sediment in Megagrams. Average yearly bedload export, in Megagrams, was calculated by dividing total sediment in storage by the 47 years since the Lake Sinclair dam was closed.

**Estimation of Total Suspended Solids (TSS) Export:**

*USGS Data for Murder Creek:*

Long term historical flow data from the USGS Murder Creek station was obtained to estimate total sediment export from the watershed. Information from the station included gage height (ft), discharge (cfs), and TSS (NTUs) data. The gage on Murder Creek is located at Latitude 33°15'08", longitude 83°28'53", Putnam County, Georgia, Hydrologic Unit 03070101, in left bank 300 ft upstream from bridge on county road S-777, 3.0 miles downstream from Beaverdam Creek, 5.8 miles upstream from mouth, and 7.5 miles southwest of Eatonton (USGS 2001).

A sediment rating curve was developed, from the USGS data, to estimate TSS export as compared to discharge (Figure 3.22). Then the long term flow data (22 years) for Murder Creek was obtained from the USGS web site. The long term flow data (cfs) was sequentially ordered from lowest to highest average daily flow. The long term flow data was then converted from cubic feet per second and then into liters per day. Daily TSS (L/day) export was estimated by multiplying total daily flow (L/sec) by total turbidity (mg/L) estimated from the equation developed from the USGS sediment rating curve (Figure 3.22). Once a value for turbidity (mg/sec) was obtained, it was multiplied by the number of seconds in a day to calculate total discharge in mg/day. From this value an average TSS export in Megagrams per year was obtained. Total volumetric export per year was calculated by dividing the export of Megagrams per year by using an average bulk density of 1.50 g/cm$^3$. This resulted in an calculated average yearly export in cubic meters of sediment.

<u>STORAGE OF SEDIMENT:</u>

**Dendro-geomorphology:**

*Current Floodplain Activity:*

The use of dendro-geomorphology techniques were employed to estimate whether the Murder Creek floodplain was aggrading, degrading or in a state of equilibrium (Sigafoos 1964).

Several sites were selected to observe the presence of active floodplain aggradation or degradation. Tree boles were excavated to where the root crown was present below the soil surface (Figure 3.23). Once excavated, the depth to the buried root crown was measured and recorded. To determine an average annual value of floodplain aggradation or degradation the excavated trees were bored to obtain a ring core. Tree rings were to be counted to determine age and divided by the depth to root crown to obtain an average rate of aggradation or degradation in centimeters per year.

**Historical Floodplain Storage:**

*Storage of Historical Sediment:*

Natural Resources Conservation Service (NRCS) soil survey maps were obtained and scanned into digital format. Using ArcView Spatial Analyst, the Soil Survey maps were geo-referenced (UTM Zone 17 NAD 83). Once geo-referenced, the floodplain soils in the watershed were digitized into polygons and assigned appropriate attributes. Digitizing the soil series allowed for a determination of an areal extent of the floodplain soil series. Only soil series that were classified as Entisols or Inceptisols were included in the digitized floodplain soil series (Figure 3.24).

A soil auger was used to measure the depth to the Pre Historic Floodplain (PHFP), the floodplain surface which existed before the onset of European agriculture, at various locations. Depths to the PHFP were identified by locating the contact point between the PHFP and the Historical Floodplain (HFP) which is comprised of a stratigraphic layer of sand over a boundary of reduced high clay texture and low mica content (Figure 3.25). Depths to the PHFP were compared against an instream bank estimation of the Historical Floodplain (HFP) where the historical soil horizons were visible (Figure 3.25). This was done to verify that the recorded auger depths to the PHFP were similar to the depth of the HFP that was measured from the bank. Auger hole locations were selected based upon access and stream order.

Once a site had been measured and recorded, the auger hole locations were added to the digitized floodplain soil series theme (Figure 3.26). In order to use an average depth to the PHFP, observed HFP accumulated depths were compared against elevation, slope, Strahler stream order, and drainage area to determine if these variables may have any affect upon the depth of the HFP. Linear regression analysis was conducted to determine if any of these variables affected the depth to the PHFP.

For each auger site the drainage area was delineated, Strahler stream order determined, slope calculated, and elevation recorded. Elevation values for each auger location were obtained from USGS Digital Elevation Models. In ArcInfo, the stream network that was created for the road survey was used and then assigned Strahler stream order values. Drainage areas for each auger location, based upon the DEMs, were digitized in ArcView. Slope values were obtained by recording the elevation in each auger drainage area from which the longest stream section started. Slope was calculated as the change in elevation divided by the length of the longest stream reach for each drainage area.

*Calculation of Historical Sediment Storage:*

Once the areal extent of the floodplain was determined, volume of the sediment in floodplain storage was calculated. Average depth to the PHFP was used to calculate the total volume of the sediment in storage. Once historical sediment volume in storage was calculated, depth of erosion that the stored sediment accounted for was calculated. This was done by dividing the total stored volume of sediment by the number of square meters in the watershed. Stored sediment volume was then converted into Megagrams by using an average bulk density of 1.50 $g/cm^3$.

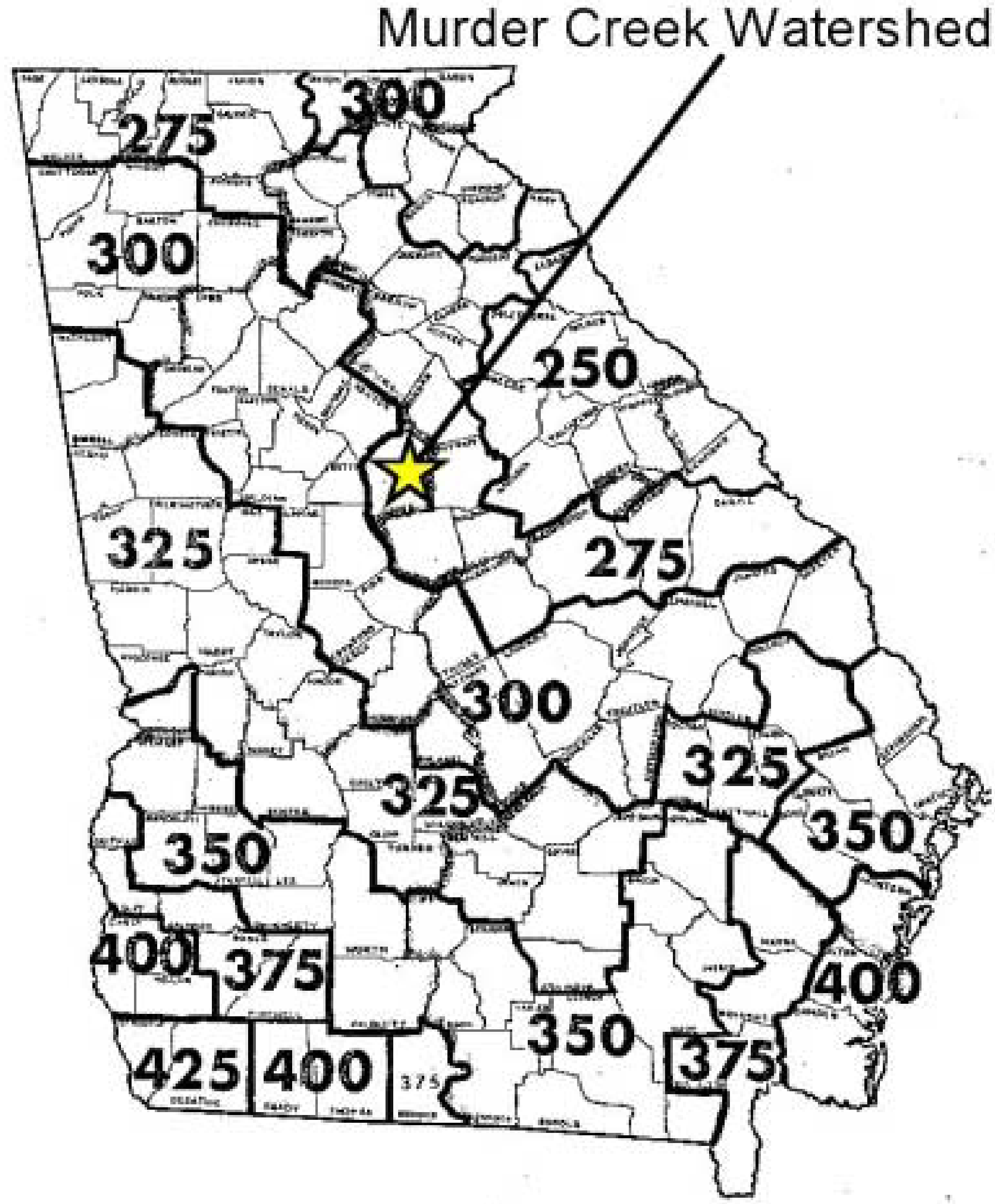


**Figure 3.1** Map of the Rainfall Erosivity factors throughout the State of Georgia. The area that Murder Creek occupies is shown with its associated Rainfall Erosivity factor.

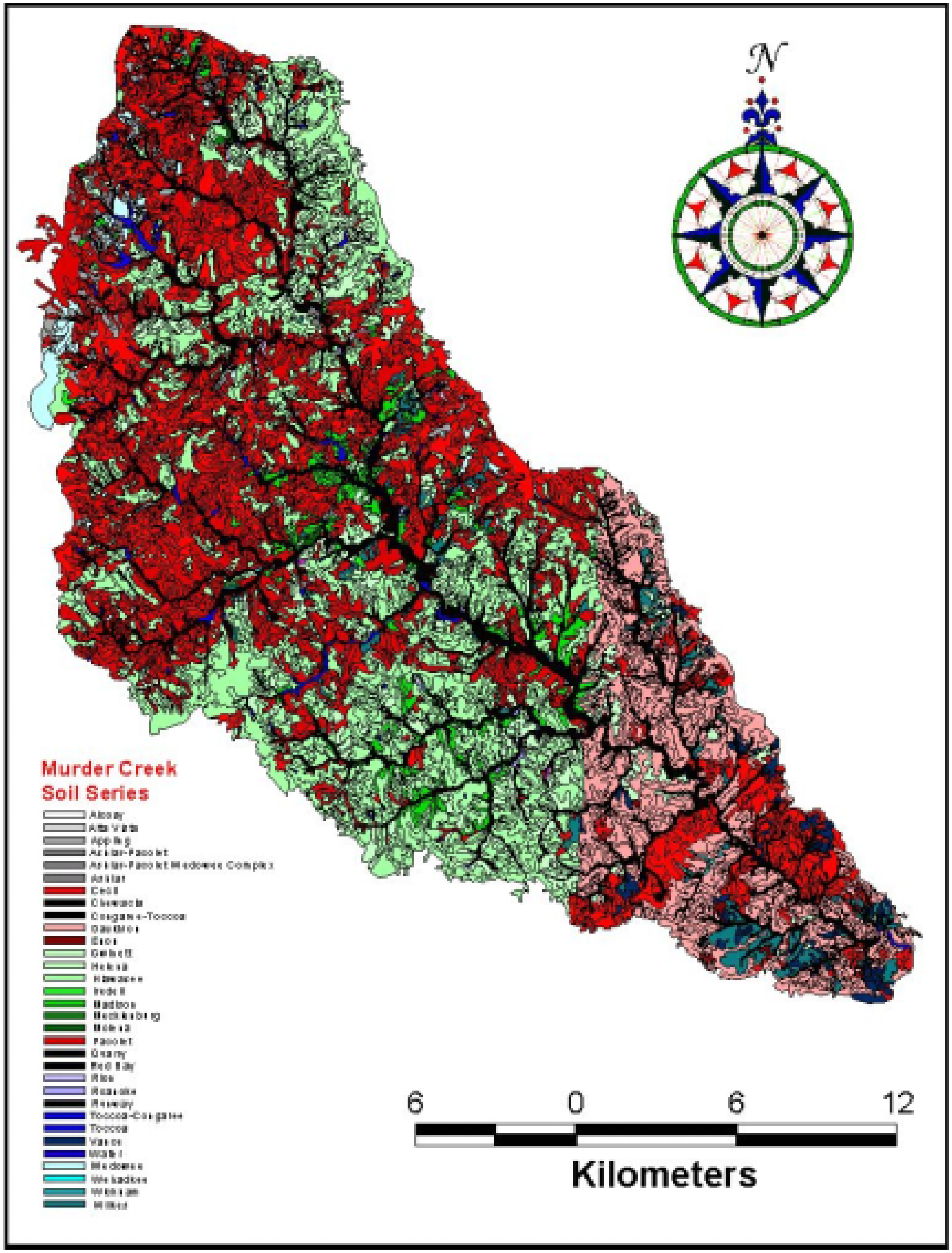


**Figure 3.2** Map showing the distribution of the soil series in the Murder Creek watershed. The map was created by digitizing NRCS soil survey maps at the 1:20,000 scale.

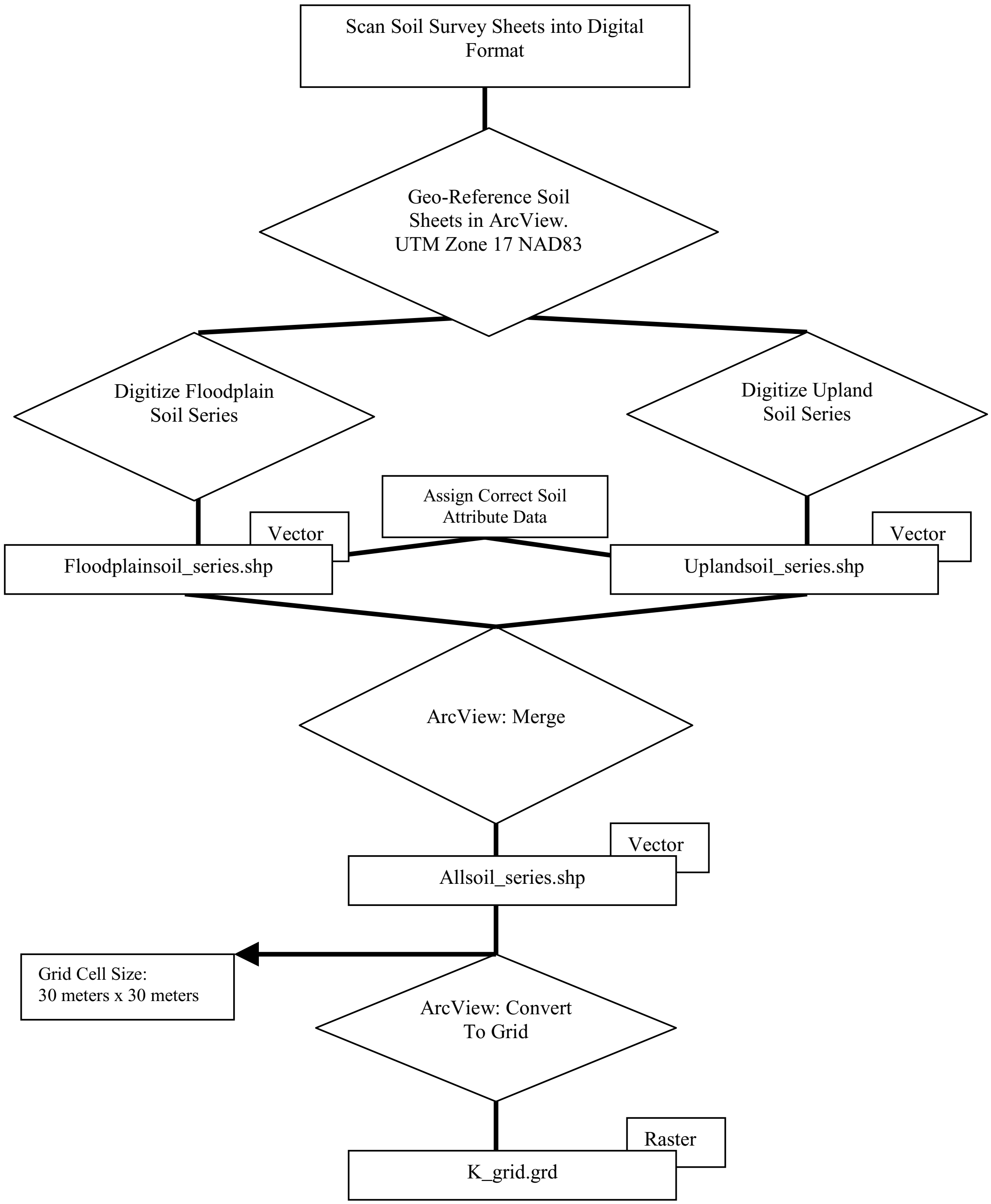


**Figure 3.3** Flow chart representing the process of digitizing and creating the soil coverage and soil erosivity Grid files.

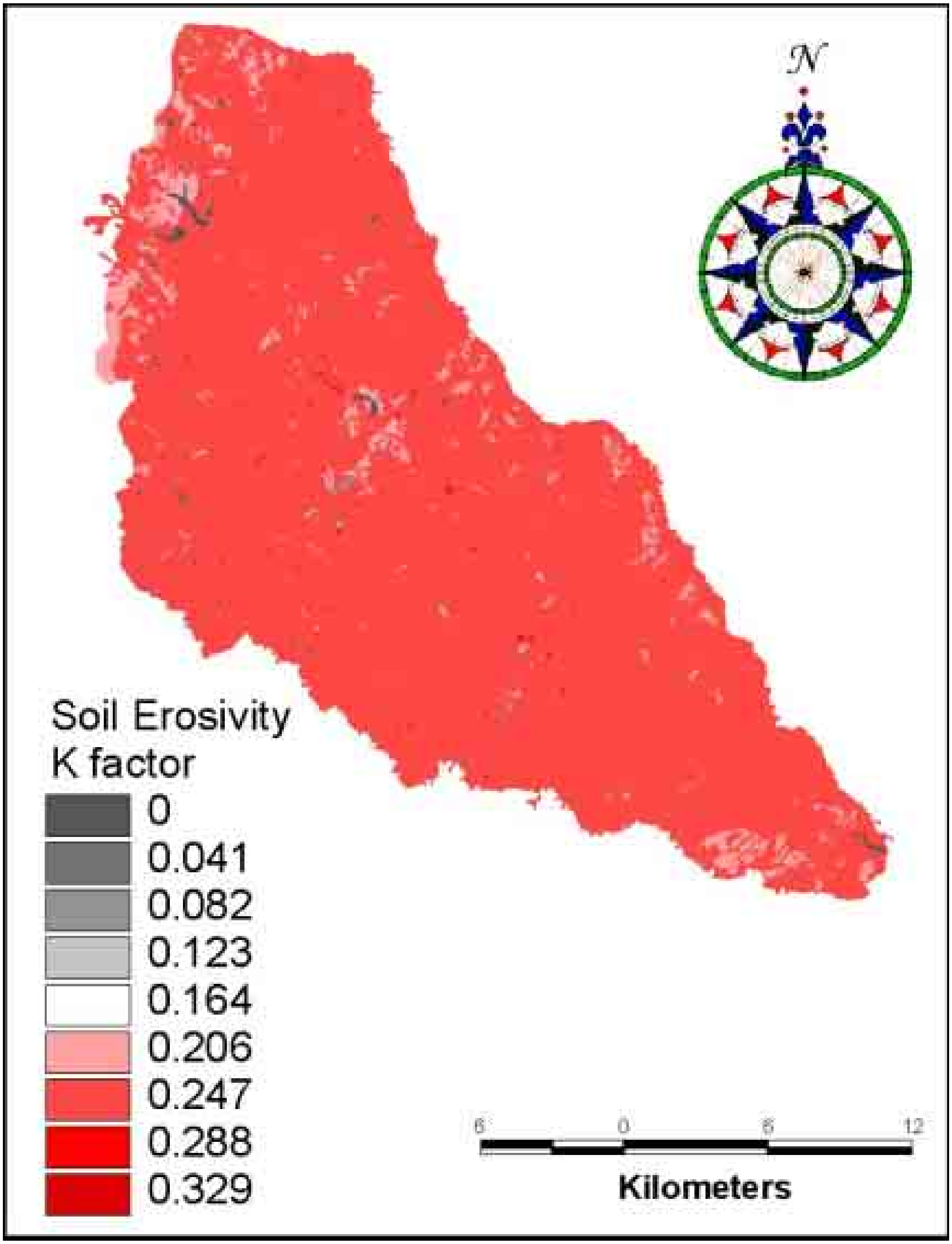


**Figure 3.4** Map depicting the K factors determined from the digitized soil series (Figure 3.2). An increas K factor means that a soil is more susceptible to erosion.

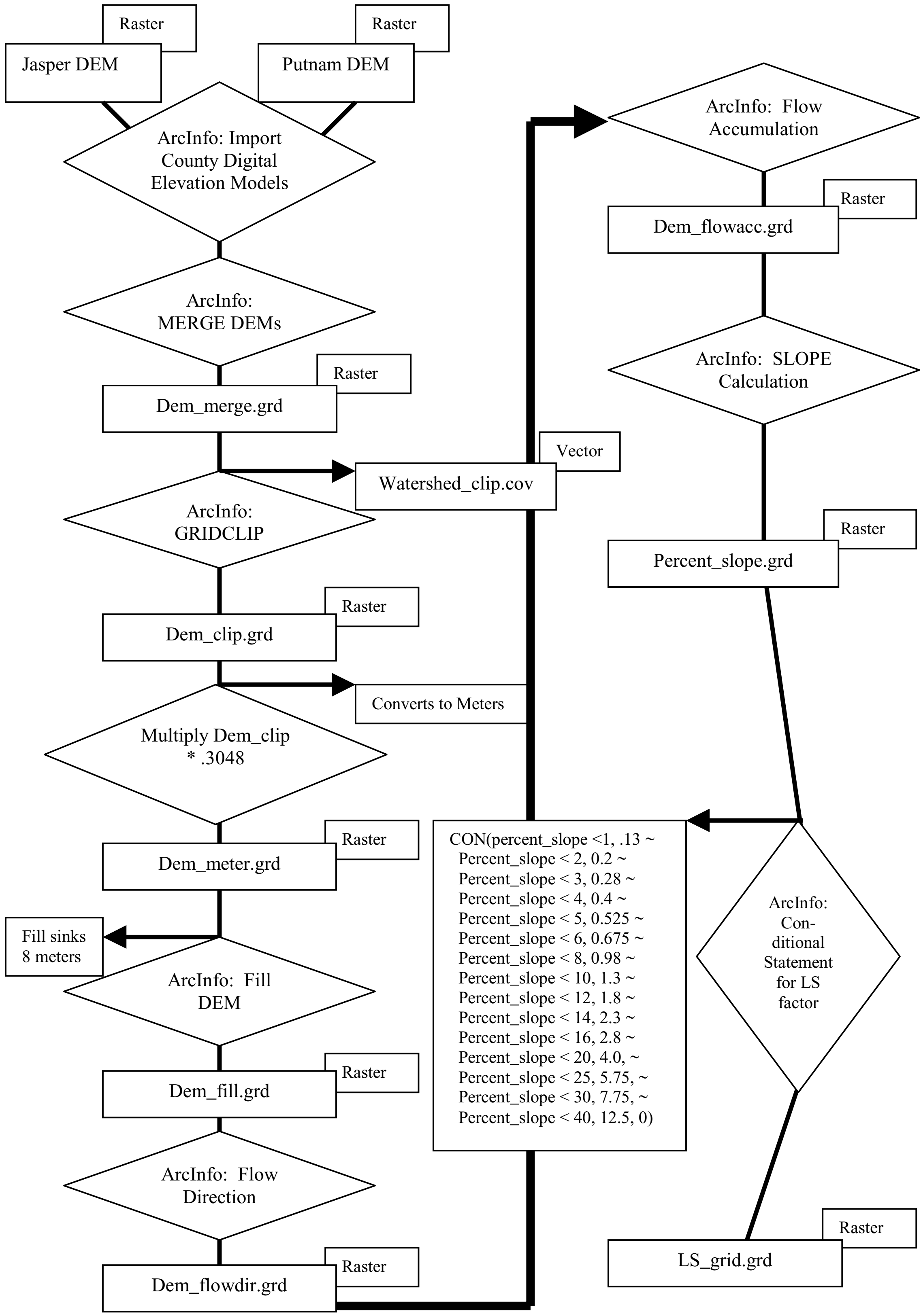


**Figure 3.5** Flowchart showing methodology used to create the Slope Length (LS) Steepness factors for input into the USLE model.

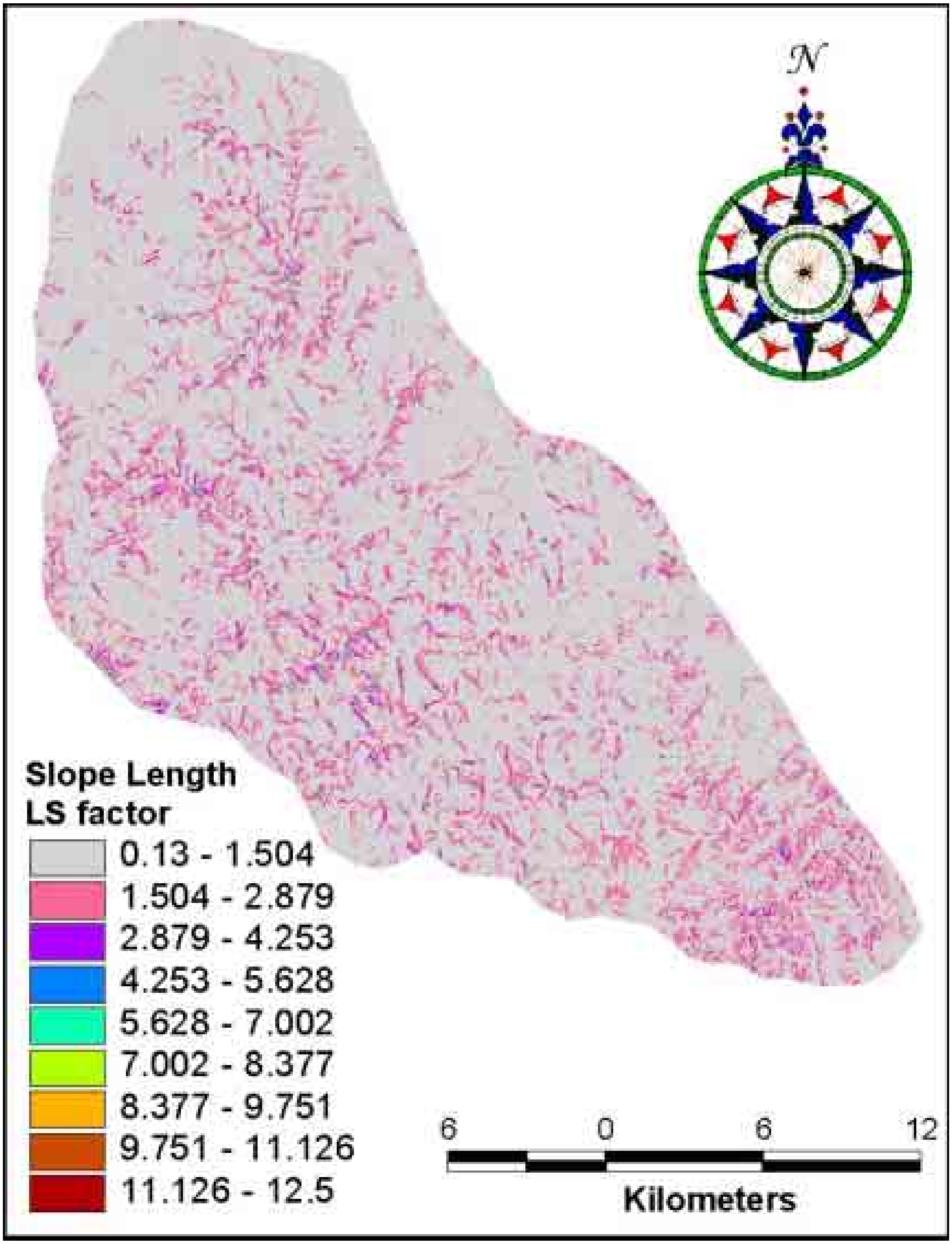


**Figure 3.6** Map showing the spatial distribution of the assigned LS factor. The higher the LS factor the greater the slope of the land and susceptibility to erosion. LS values were obtained from a lookup table in Ag. Handbook 538 (Wischmeier and Smith 1978).

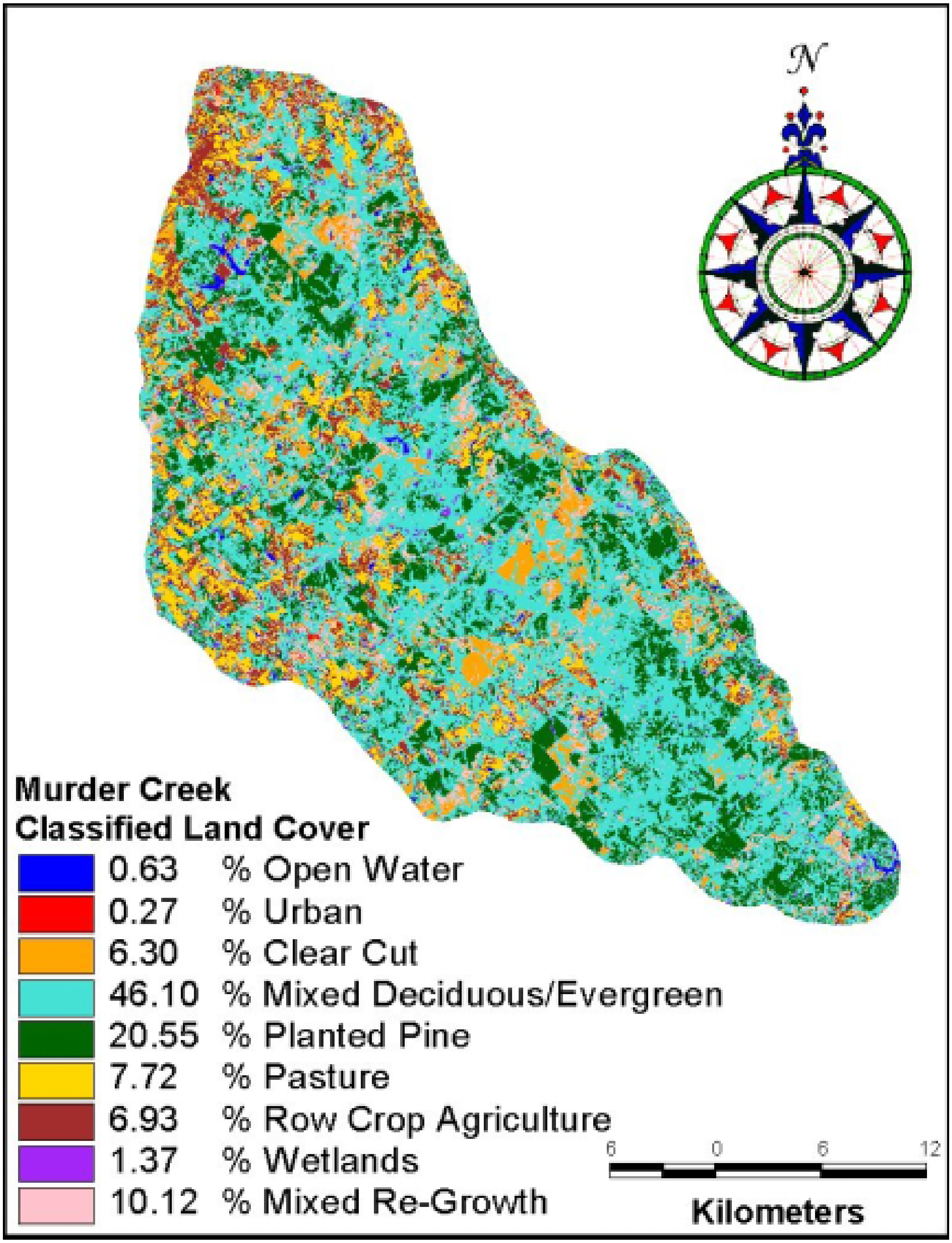


**Figure 3.7** Map showing the major land cover classifications determined from 1998 LANDSAT Image classification in the Murder Creek watershed. Land cover is also shown as a percentage of total area.

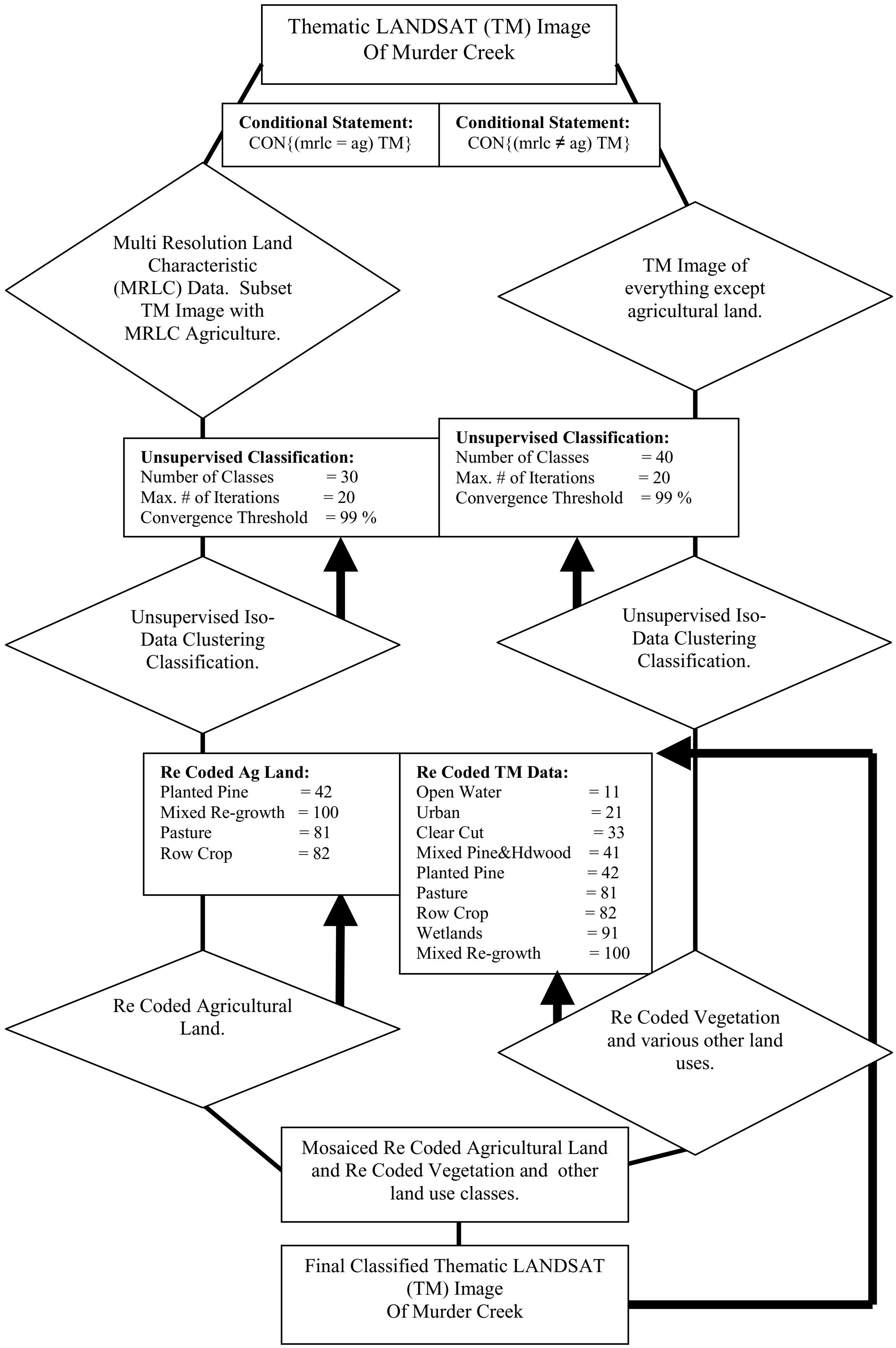


**Figure 3.8** Flowchart outlining the methodology used to create the land cover classifications for the Murder Creek watershed.

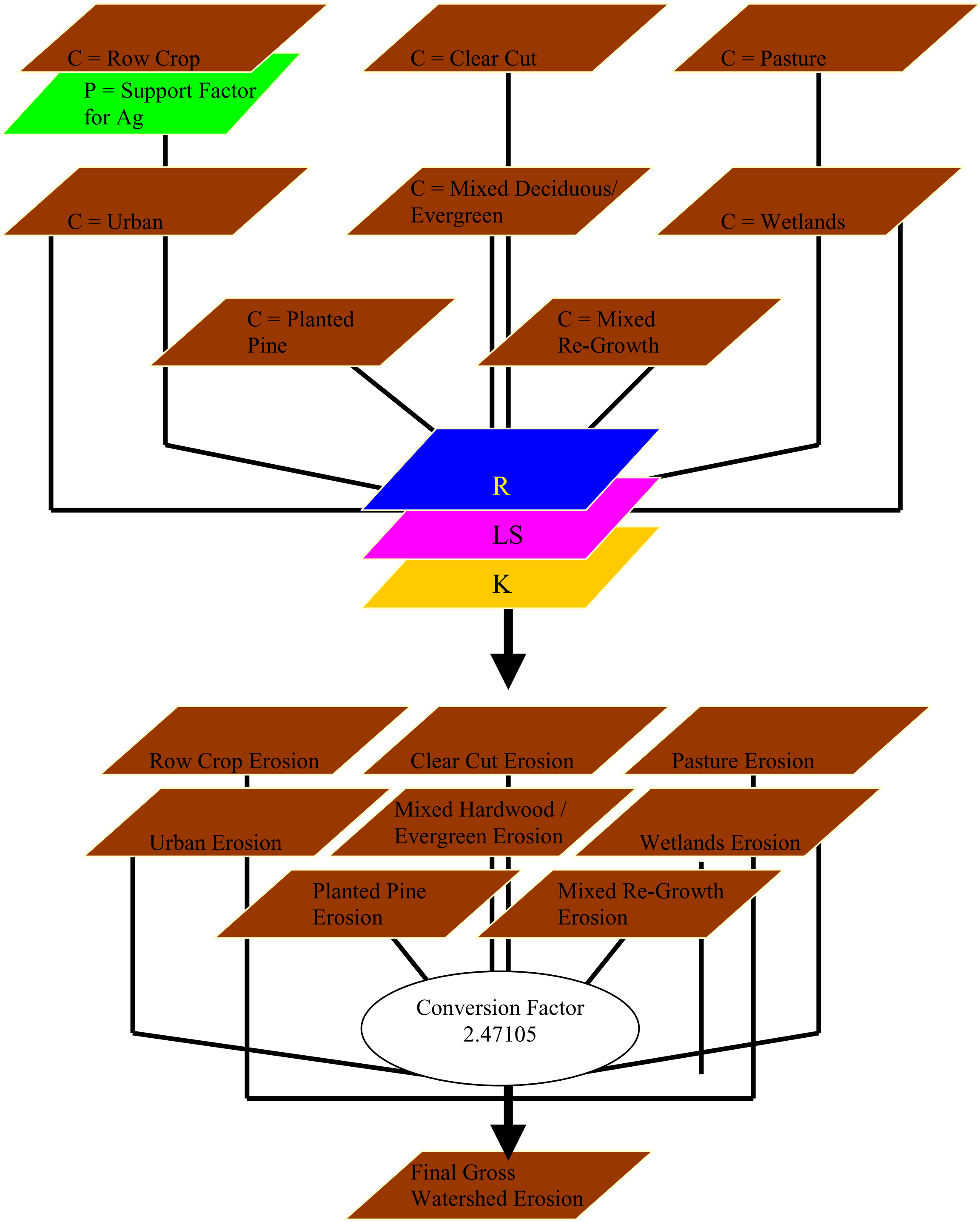


**Figure 3.9** Graphic illustrating how gross erosion was calculated in tonnes per hectare for the Murder Creek watershed.

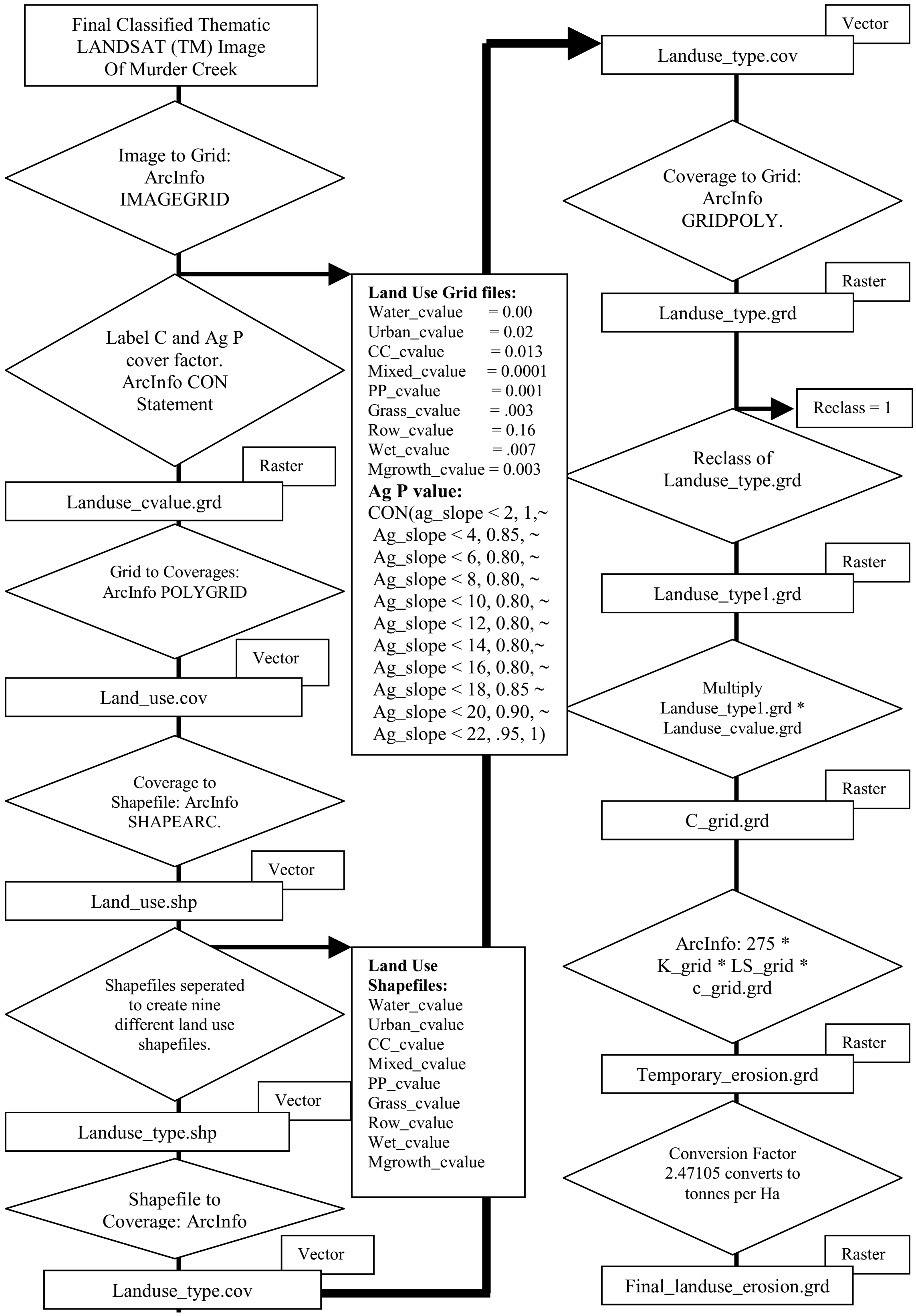


**Figure 3.10** Flowchart outlining the methodology to calculate gross watershed erosion using the USLE equation.

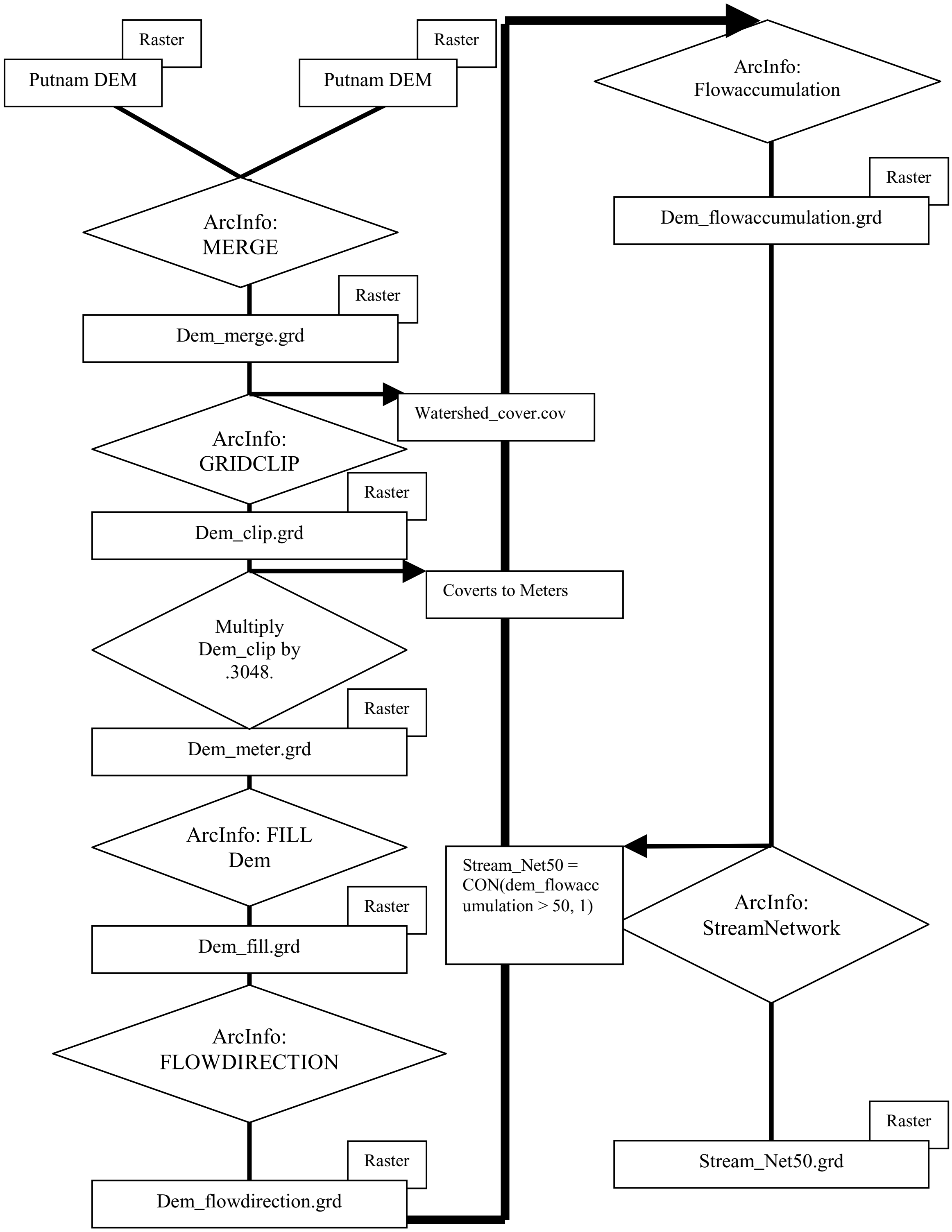


**Figure 3.11** Flow chart depicting methodology to generate a stream coverage for the Murder Creek watershed.

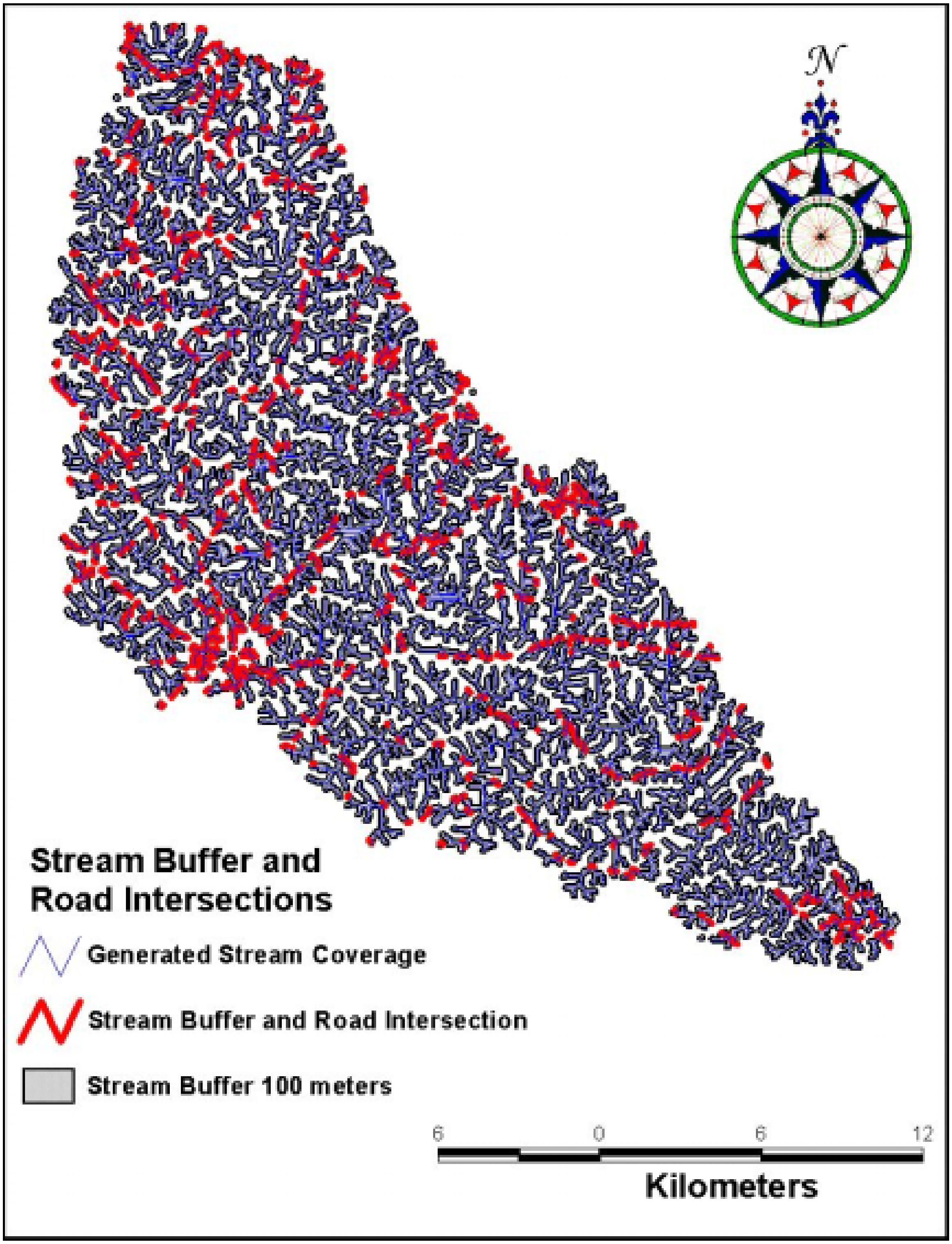


**Figure 3.12** Map showing the intersection of streams that are within 100 meters of any road in the watershed. Excursions to the watershed were performed to identify which stream and road intersections were paved or unpaved.

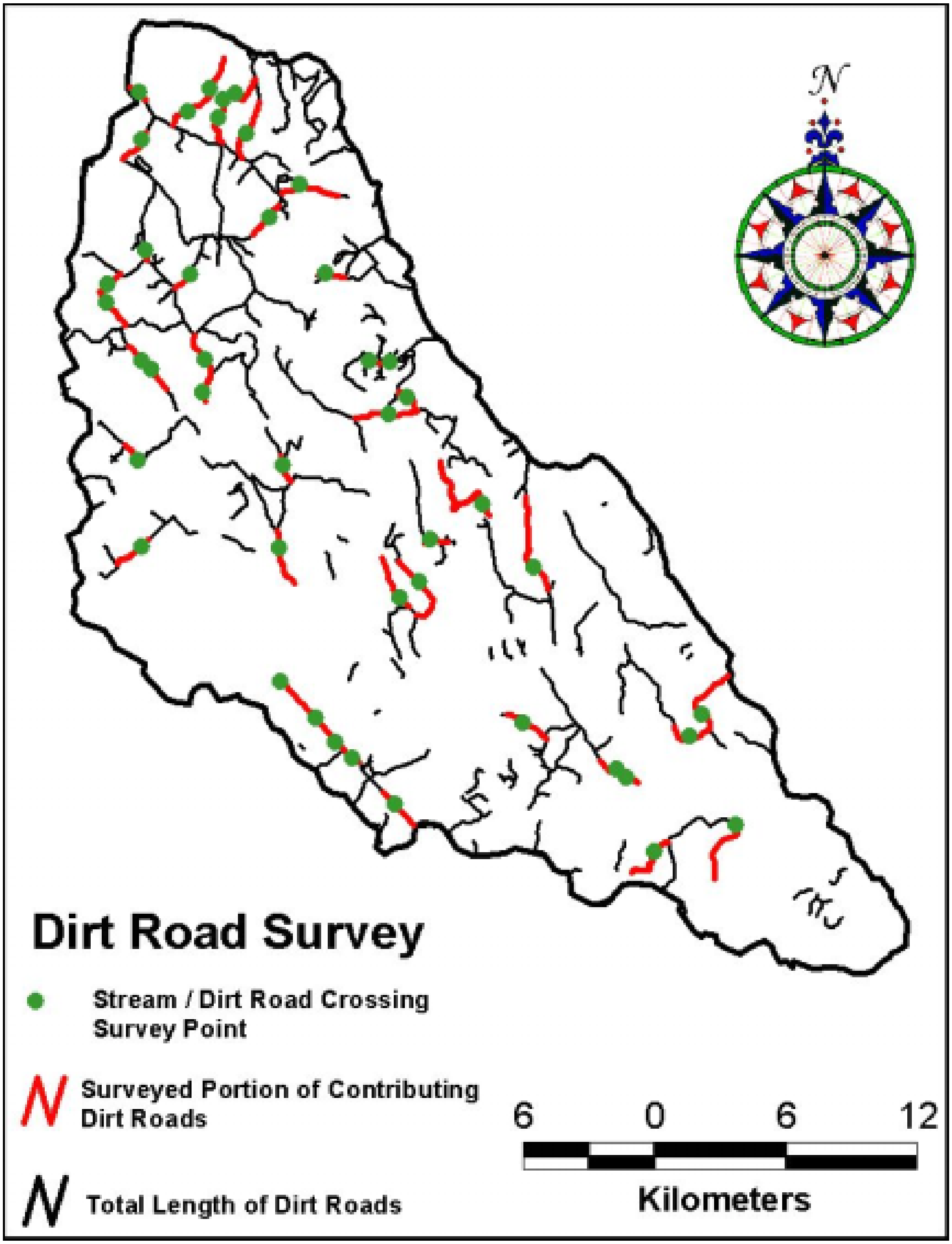


**Figure 3.13** Map showing the locations of the surveyed contributing segments of unpaved roads and the total extent of unpaved roads within the Murder Creek watershed.

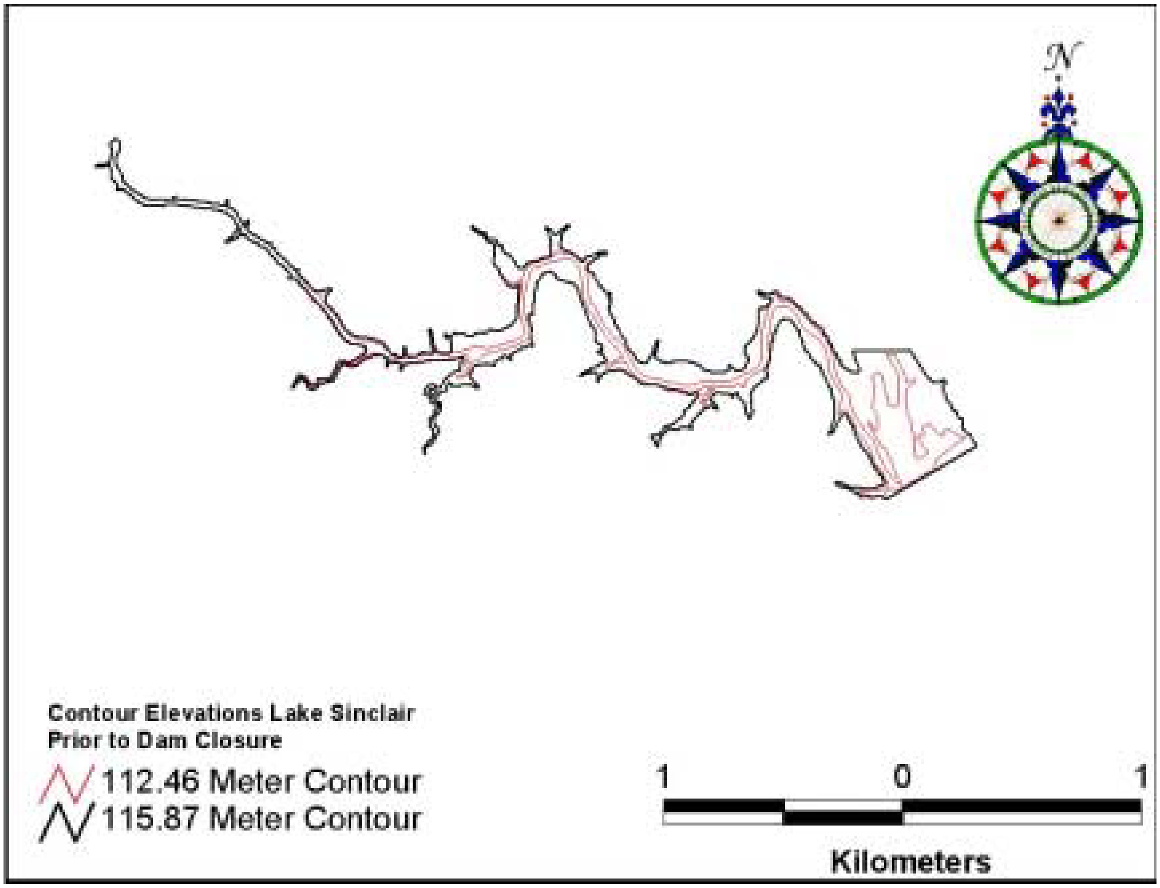


**Figure 3.14** Map showing contour elevations of the Murder Creek arm of Lake Sinclair prior to closure of Sinclair Dam. Contour elevations were created from a geo-referenced survey sheet of the Murder Creek arm of Lake Sinclair prior to dam closure.

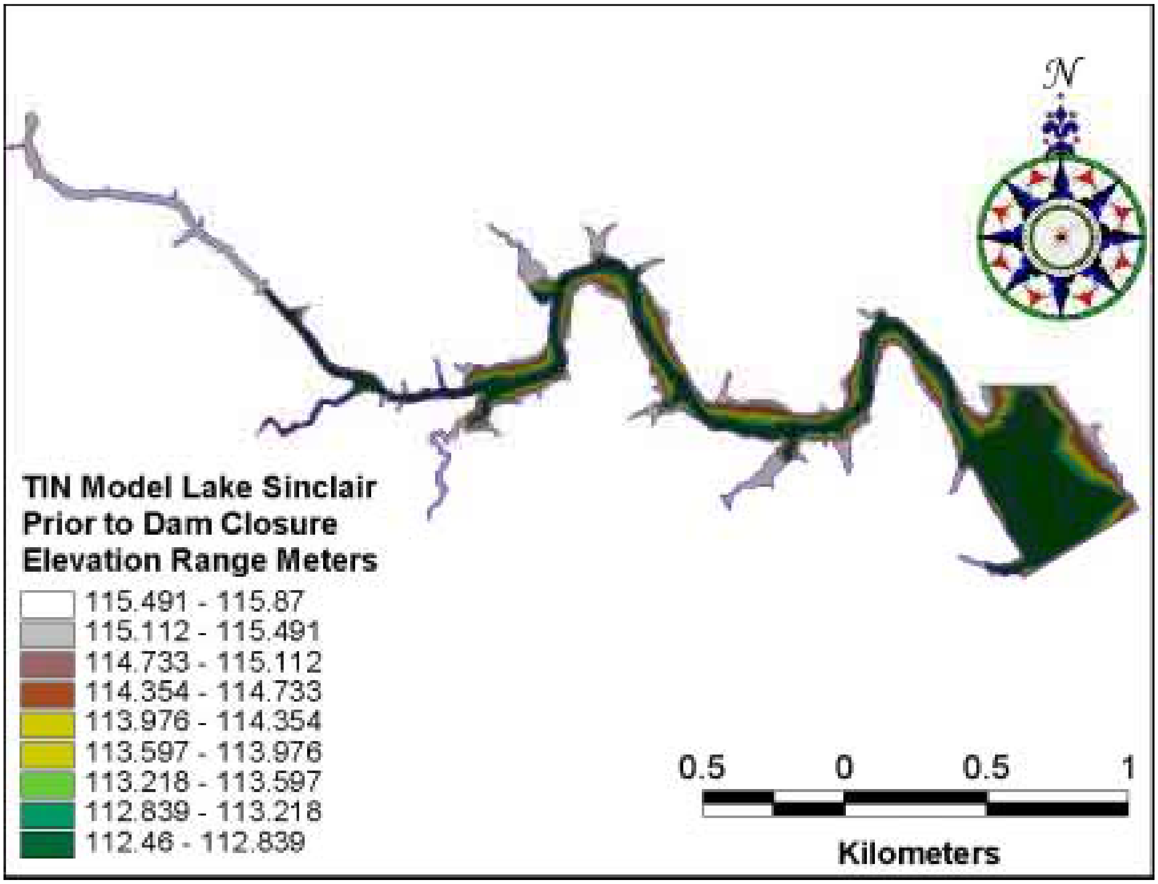


**Figure 3.15** Triangular Irregular Network (TIN) model depicting a three dimensional view of sediment elevations present in the Murder Creek arm of Lake Sinclair prior to closure of Sinclair Dam. The TIN model was created from digitized sediment elevation contours created from a geo-referenced survey of the Murder Creek arm of Lake Sinclair (Figure 3.15).

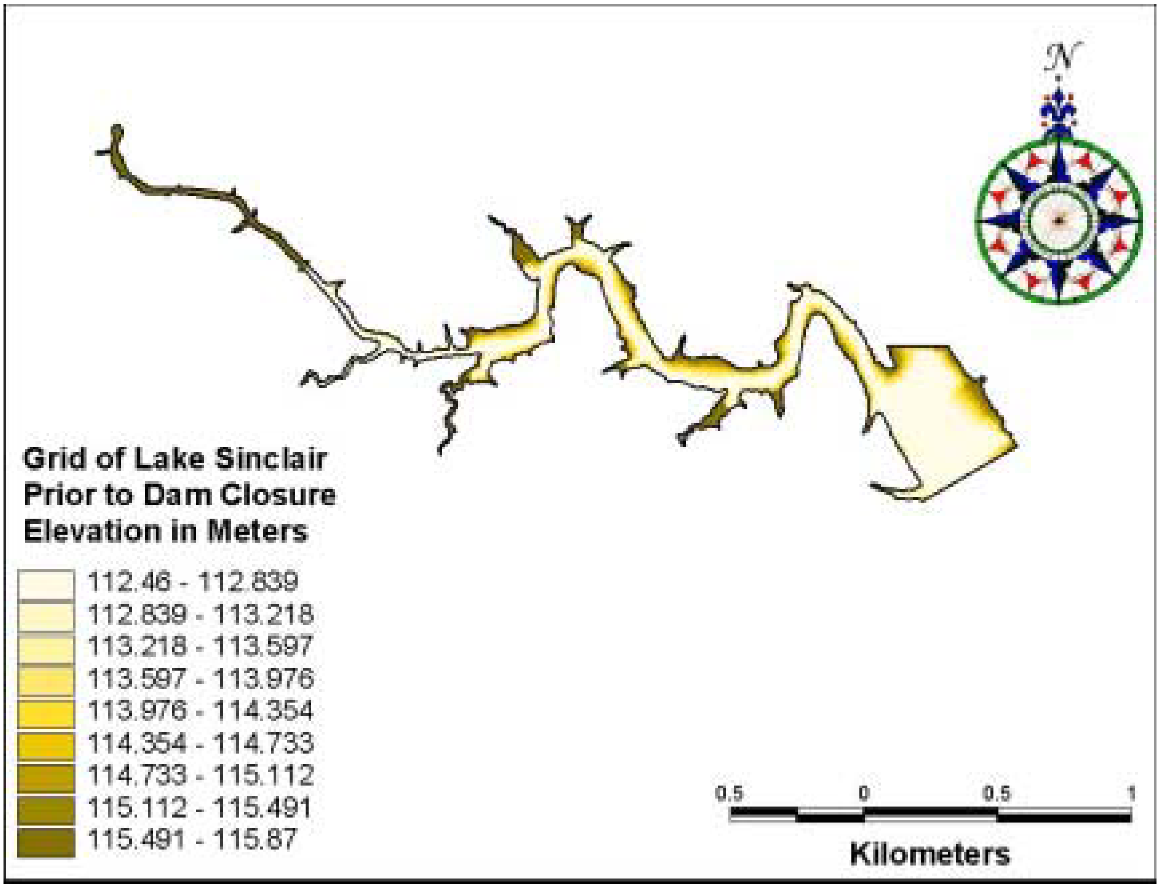


**Figure 3.16** Grid coverage depicting sediment elevation values in raster format. Values were converted into raster format from a TIN model created from digitized sediment contour elevations (Figure 3.15). Contour elevations were created from a geo-referenced survey sheet of the Murder Creek arm of Lake Sinclair prior to dam closure (Figure 3.14).

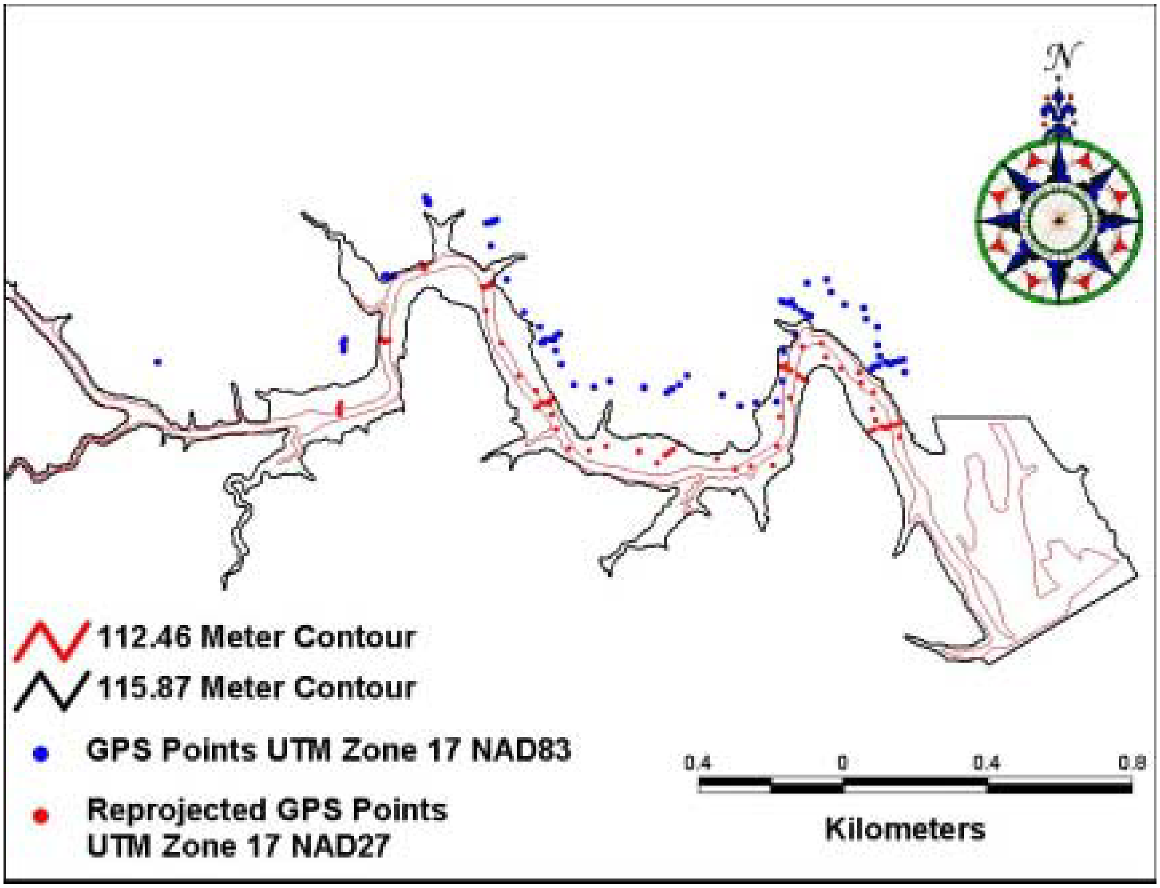


**Figure 3.17** Map showing the re-projection of GPS points into the same coordinate system in which the digitized contours of the Murder Creek arm of Lake Sinclair were created. Observed sediment elevations were associated with each collected GPS point.

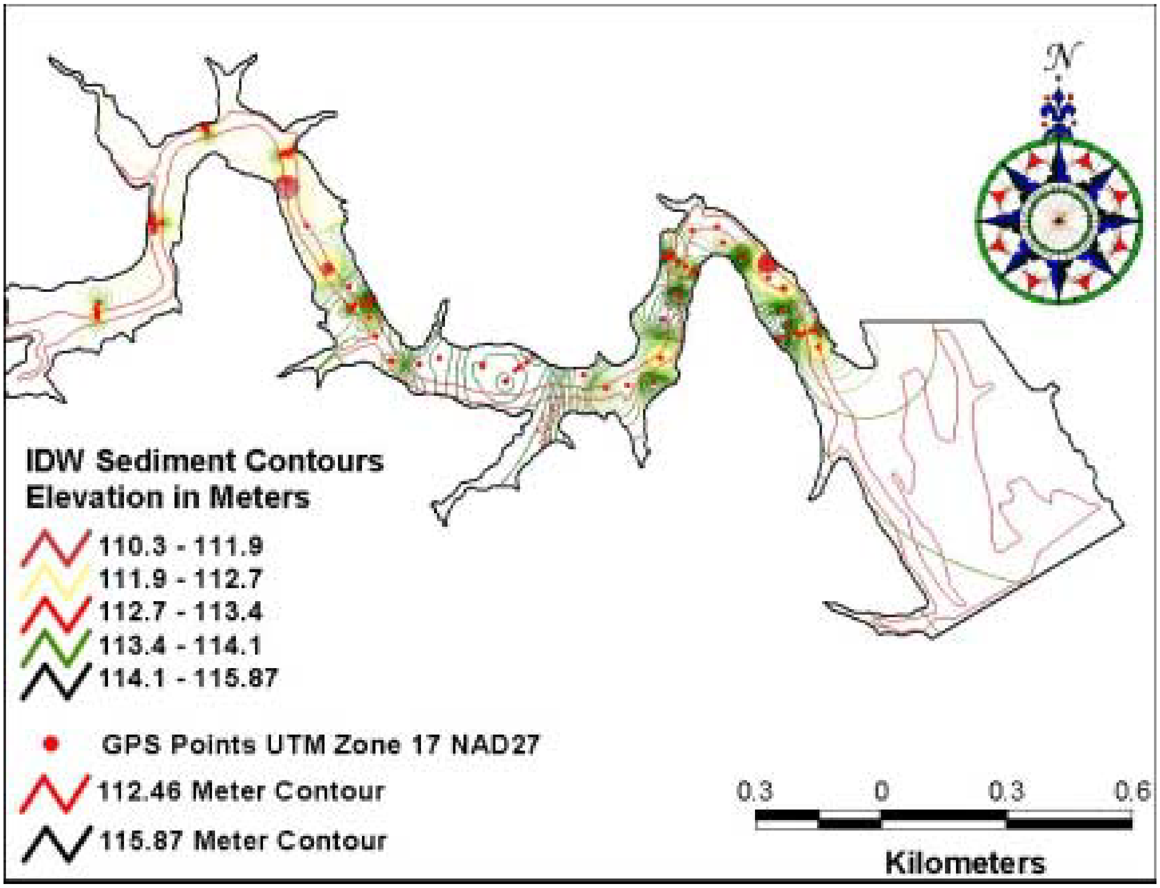


**Figure 3.18** Map showing the elevation contours generated using the Inverse Distance Weighting (IDW) method in ArcView. Sediment elevation points were created by collecting sediment elevation data with a GPS unit (Figure 3.17).

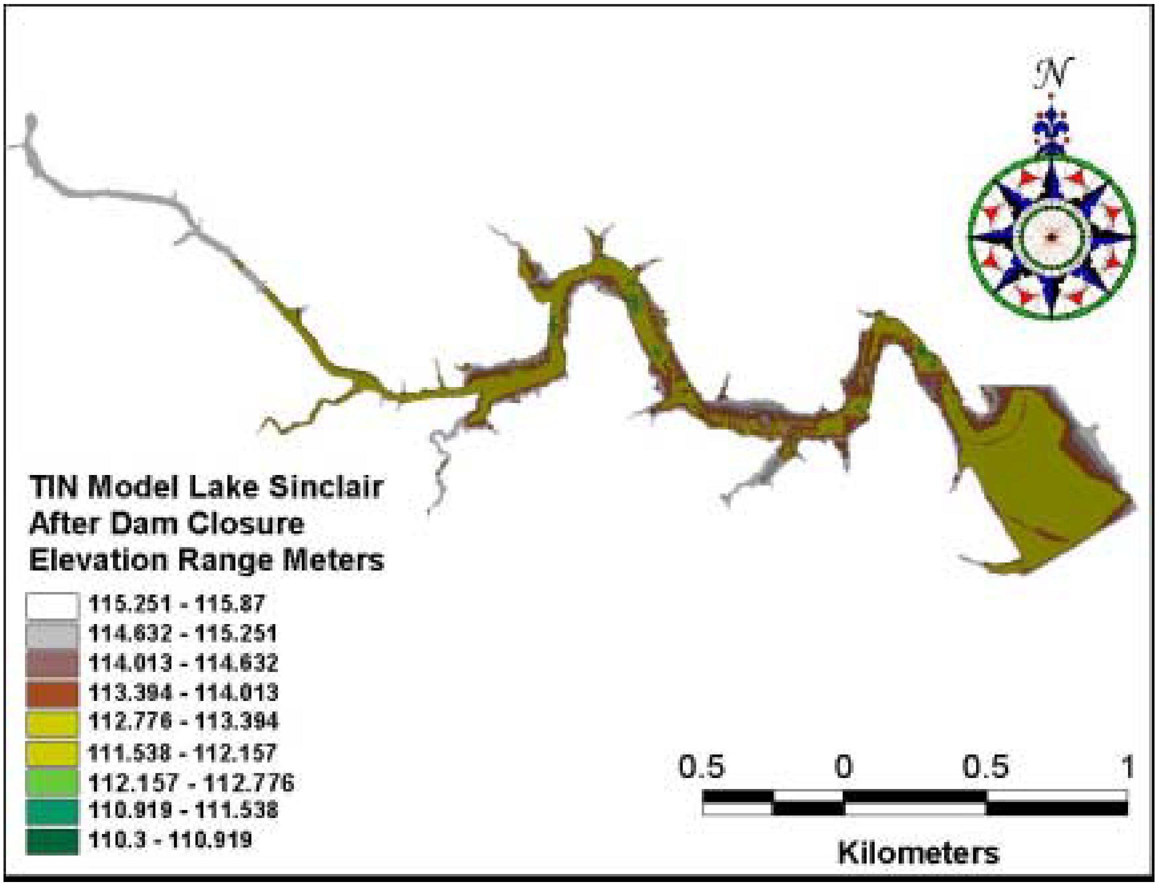


**Figure 3.19** TIN model depicting the current sediment elevation values in the Murder Creek arm of Lake Sinclair. The TIN model was created in ArcView based upon the sediment elevation contours created using Inverse Distance Weighting (IDW) method (Figure 3.18).

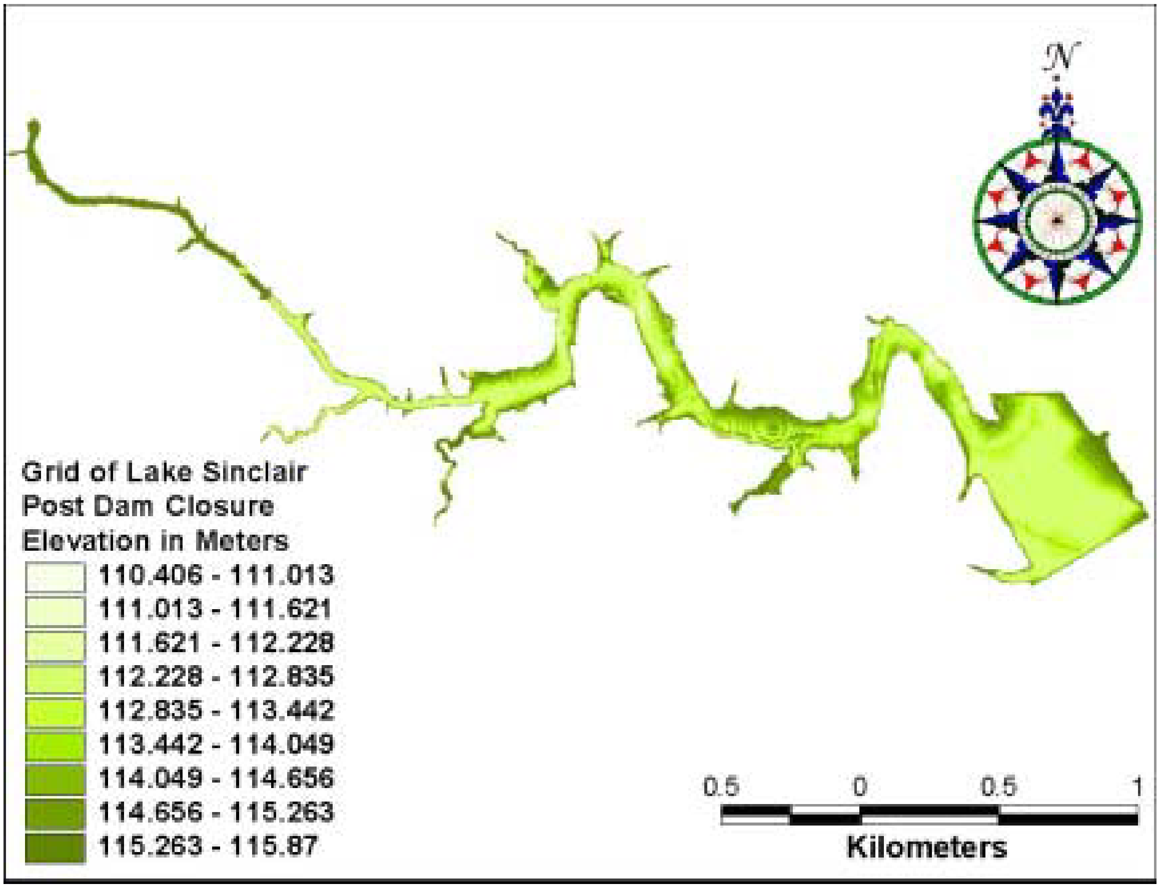


**Figure 3.20** Map showing sediment elevation values that were converted from the TIN model (Figure 3.19) into raster format. The TIN model was generated from sediment contour elevations (Figure 3.18). Sediment contour elevation values were created from collected sediment elevation values on the Murder Creek arm of Lake Sinclair (Figure 3.17).

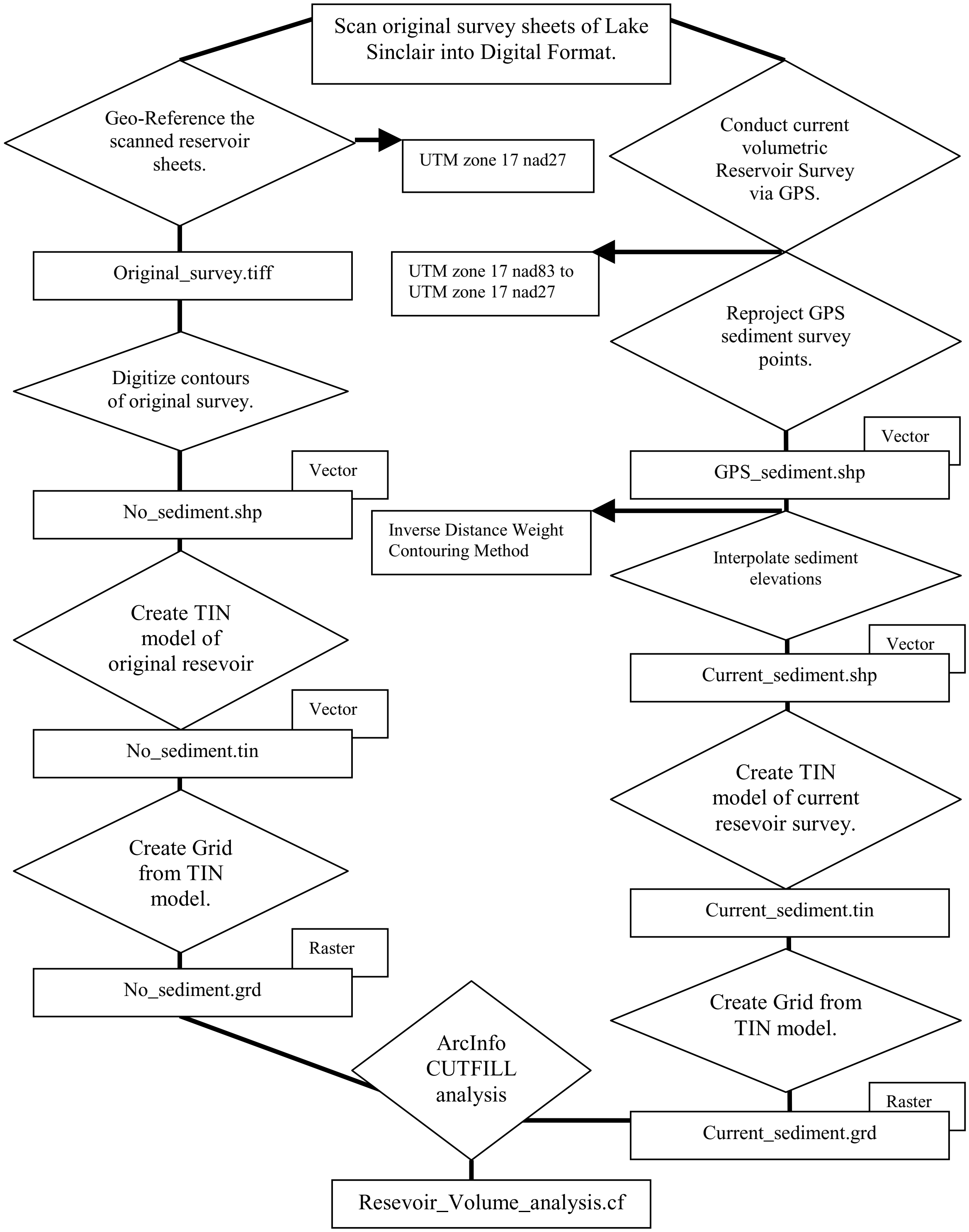


**Figure 3.21** Flow Chart showing methodology used to calculate sediment in storage of the Murder Creek arm of Lake Sinclair. ArcInfo was used to calculate the volume of sediment in reservoir storage using CUTFILL analysis.

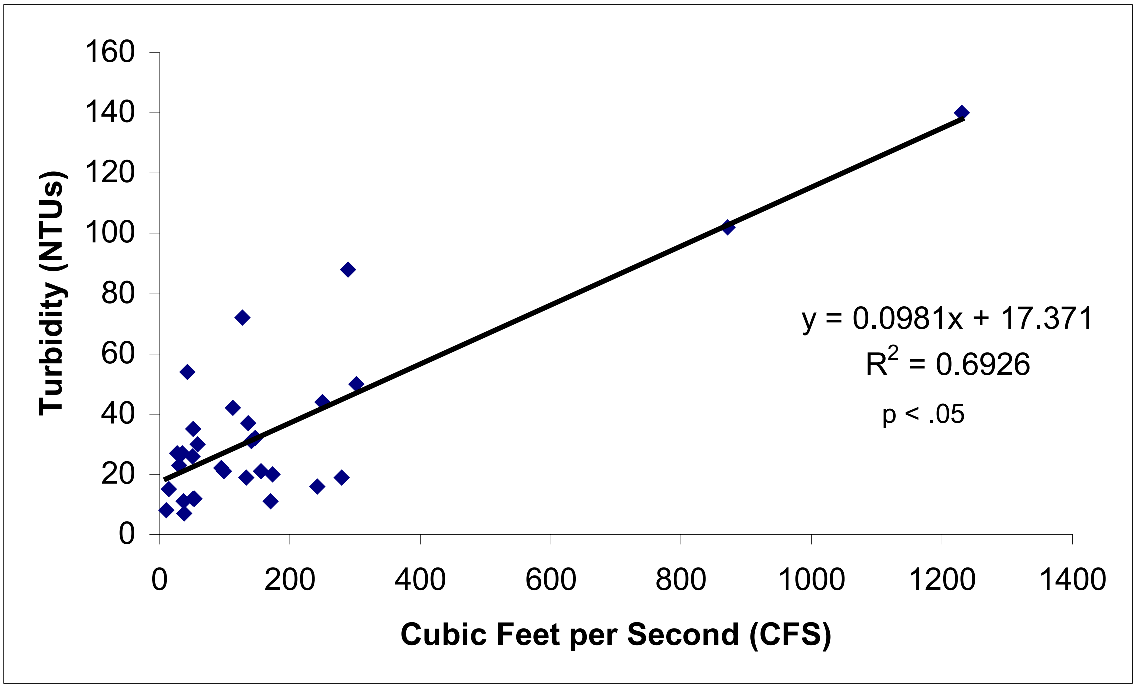


**Figure 3.22** Sediment rating curve developed from long term USGS stream data on Murder Creek.

**Figure 3.23** Example of an excavated tree within the Murder Creek watershed. Trees that appeared to have sediment accumulation around their tree boles were excavated and cored. Depths from the sediment accumulation around the tree bole to the top of the root crown were measured and recorded.

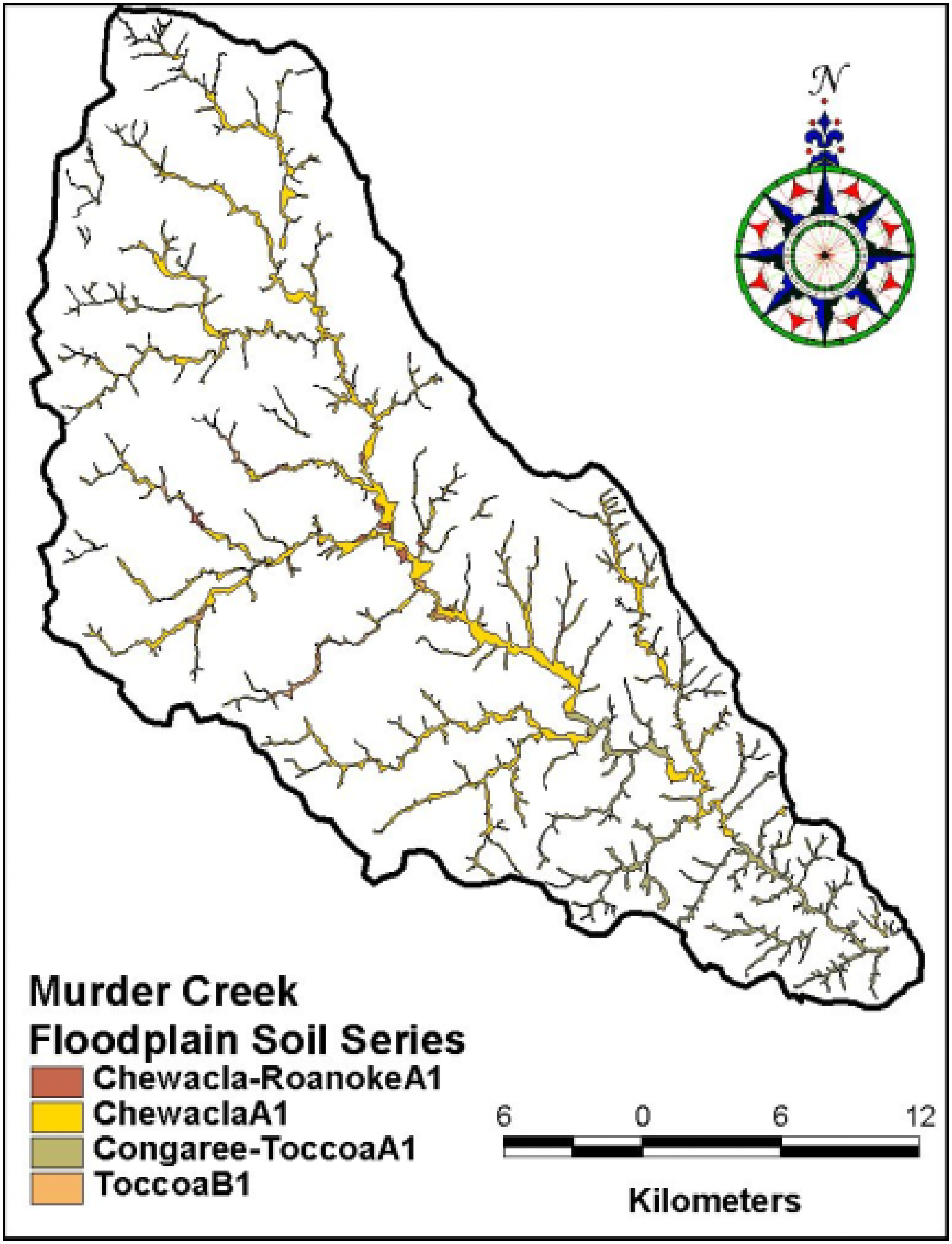


**Figure 3.24** Map showing the spatial extent of the NRCS mapped floodplain Entisol and Inceptisol soil series in the Murder Creek watershed. Only Entisols and Inceptisols were in the floodplain were included. Gaps in the digitized soil series represent bodies of open water.

**Figure 3.25** Picture of the Pre Historical Floodplain (PHFP) underlying the modern accumulation of the Historical Floodplain (HFP). The gray area represents reduced clay where the contact layer is high in clay content and there is little to no mica present in this horizon.

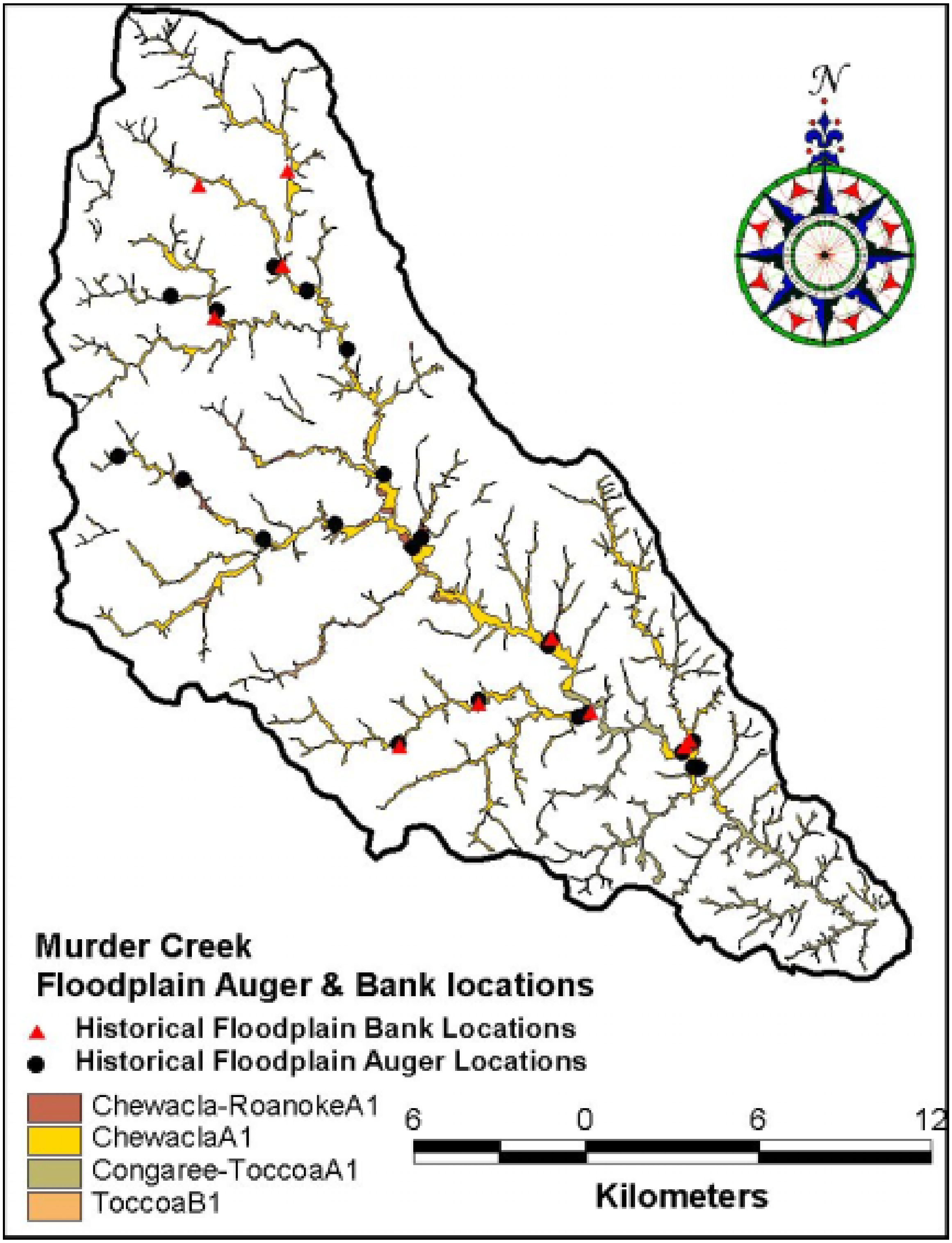


**Figure 3.26** Map showing locations where measurements of depths to the PHFP were recorded. A soil auger was used to measure the depth of the Historical Floodplain at each location. An instream bank estimate was used to compare measured HFP depths with the soil auger to ensure that the measurements were accurate.

**Table 3.1** Land cover classification (C) factors used in the Universal Soil Loss Equation in calculating gross watershed erosion. C factor values that Georgia EPD has used for other regions in the state were taken into consideration for consistency in erosion estimates.

| Ga. EPD Land Cover Classifications | Georgia Environmental Protection Division C factor | Our 1998 Land Cover Classifications | Our C factor | Notes |
|---|---|---|---|---|
| **Open Water** | 0.00 | **Open Water** | 0.00 | No erosion from open water. |
| **Urban** | | **Urban** | 0.02 | |
| Low Intensity Residential | 0.02 | | | Low Intensity Residential C factor was used because the watershed contains little active urbanization. The largest municipality in the watershed is Monticello. Also, there is no classification of commercial/industrial in the watershed. |
| High Intensity Residential | 0.005 | | | |
| Commercial/ Industrial | 0.003 | | | |
| **Clear Cut** | 0.0018 | **Clear Cut** | 0.013 | Our C factor taken from values calculated on clear cuts in the Ga. Piedmont (Burns 1978). |
| **Mixed Deciduous/Evergreen** | 0.001 | **Mixed Deciduous/Evergreen** | 0.0001 | Our C factor taken from the NRCS regional based values for Georgia (USDA 1987). |
| **Planted Pine** | 0.001 | **Planted Pine** | 0.001 | Our C factor taken from the NRCS regional based values for Georgia (USDA 1987). |
| **Pasture** | 0.0033 | **Pasture** | 0.003 | Our C factor taken from the NRCS regional based values for Georgia (USDA 1987). |
| **Row Crop Agriculture** | 0.15824 | **Row Crop Agriculture** | 0.16 | Our C factor based on corn and small grain agriculture with 30% conservation tillage employed. Taken from the NRCS regional based values for Georgia (USDA 1987). |
| **Supprot Practice Factor for Ag. Sites** | ???? | **Supprot Practice Factor for Ag. Sites** | Varied b/w 1.0 and 0.85 | Our C factor taken from the NRCS regional based values for Georgia. Based upon a average of a 2% row grade and dependant on site specific slope (USDA 1987). |
| **Wetlands** | | **Wetlands** | 0.007 | The average of the Ga. EPD wetland values was taken to use for our wetland C value. |
| Emergent Herbaceous/ Wetlands | 0.003 | | | |
| Woody Wetlands | 0.011 | | | |
| **Mixed Re-Growth** | | **Mixed Re-Growth** | 0.003 | Mixed Re-Growth was classified as land that was either abandoned fields/pasture or silvicultural sites greater than 3 years. Taken from the NRCS regional based values for Georgia (USDA 1987). |
| Transitional | 0.002 | | | |
| Other Grasses | 0.003 | | | |

CHAPTER 4

# RESULTS AND DISCUSSION

## INTRODUCTION:

Results for a sediment budget created for the Murder Creek watershed near Eatonton, Georgia are reported. Estimated contributions of sediment from unpaved roads and land cover classifications are reported for gross erosion and estimated sediment yield. Sediment export results for Total Suspended Solids (TSS) and bedload are reported as total estimated sediment export and sediment export per year. Floodplain storage and other calculations of sediment are reported in Megagrams (Mg), cubic meters ($m^3$) and a relative depth of erosion (cm) for total and average annual values. Historical sediment in storage is compared against estimated current land surface erosion rates. Bank erosion was calculated as a residual to balance the sediment budget.

## CONTRIBUTIONS OF SEDIMENT:

### *Contributing Unpaved Roads:*

The output of the WEPP:Road model indicates there were approximately 20 kilometers of unpaved roads leading directly to waterways in the watershed. The exposed surface of the contributing roads had an area of approximately 139,587 $m^2$, calculated from the average road width, 6.87 meters, from the surveyed roads. Erosional depth of the contributing unpaved road segments was estimated to be 0.17 centimeters per year. Total estimated yield from the contributing county, state and federal unpaved roads was 361 Mg/year (240 $m^3$/year) of delivered sediment (Table 4.1). Total amount of sediment eroded from the contributing roads was estimated to be 819 Mg/year (546 $m^3$/year) of sediment. This resulted in an erosional depth of 0.39 cm per year (Table 4.1). Erosional sediment yields for the contributing unpaved roads was estimated to be approximately 26 Megagrams per Hectare per year (Mg/Ha/Yr) and total eroded sediment was estimated to be 59 Mg/Ha/Yr (Table 4.1).

*Total Unpaved Road Estimated Contribution:*

The total length of unpaved roads in the Murder Creek watershed was calculated from Figure 3.13 to be approximately 340 kilometers. The total length of all the unpaved roads (340 km) in the watershed was multiplied by the average width of the contributing road lengths and an area of 2,341,920 $m^2$ (234 Ha) was obtained. When the calculated erosional depth for the contributing road lengths, 0.17 cm/Yr, is multiplied by the total county unpaved road area, the average annual sediment yield is estimated to be 6,031 Mg/Yr (4,021 $m^3$/Yr) to the watershed. The total estimated sediment yield from all of the watershed's unpaved roads was calculated to be 26 Mg/Ha/Yr. An estimate of gross erosion from all the unpaved roads, based upon the 0.39 cm/Yr of gross erosion from the surveyed unpaved roads in the watershed, was calculated to be 13,743 Mg/Yr (9,162 $m^3$/Yr) to the watershed. Estimated sediment production values, for all the unpaved roads, was calculated to be 59 Mg/Ha/Yr (Table 4.1).

*USLE Estimates of Land Surface Erosion:*

Estimated gross erosion for each land use was calculated. The greatest contributors by volume were row crop agriculture and clear cuts (Table 4.2). These two categories accounted for more than 90 percent of the estimated gross erosion generated within the watershed. Also, these two land use classifications occupied only 13 percent of the land in the watershed and therefore it is to be expected that they should account for a smaller fraction of the gross annual erosion in the watershed. On a per unit basis (Mg/Ha/Yr) an estimate of gross erosion found that unpaved roads, row crop agriculture, wetlands, urban areas and clear cuts contributed the most sediment. Total gross annual watershed erosion for the Murder Creek watershed, including unpaved roads, was estimated to be 101,518 Mg/Yr (67,678 $m^3$/Yr). Average annual volume of gross erosion was estimated to be 1.88 Mg/Ha/year (Table 4.2).

It has been shown that as basin area increases sediment delivery will decrease (Dendy and Bolton 1976). Although row crop agriculture and clear cut land cover classifications are estimated to generate the majority of gross erosion in the watershed, an estimate of the sediment yield to Murder Creek was calculated to determine which one, if any, of the land cover classifications may be responsible for yielding a disproportionate amount of sediment. A Sediment Delivery Ratio (SDR) was calculated to determine an estimate of sediment yield for each land use. The SDR was based upon the land area each land cover classification occupied in the Murder Creek watershed.

*Estimated Sediment Delivery:*

A SDR for each individual land use categories was calculated using the following equation from Julien and Shen (1992):

$$SDR = 0.41 A_t^{-0.3} \quad (2)$$

Where

SDR = Sediment Delivery Ratio

$A_t$ = Drainage area in $km^2$

A SDR was calculated for each land cover and an individual delivery ratio was obtained. The areal extent that each land use occupied affected sediment yield. The major contributors of sediment, based upon calculated sediment yield, were those of row crop agriculture and clear cuts (Table 4.2). Combined these two land use categories were responsible for approximately 89 percent of the estimated sediment yield in the Murder Creek watershed. Therefore, it is apparent that these two land cover classifications contribute a disproportionate amount of the total sediment load to Murder Creek based upon land area. Although these categories were estimated to contribute the majority of the sediment yield to the watershed, the delivery per unit area (Mg/Ha/Yr) was calculated to normalize sediment delivery for each land use. This resulted in the land cover classifications of row crop agriculture, wetlands and urban areas yielding the greatest amount of sediment per unit area (Table 4.2).

EXPORT OF SEDIMENT:

*Lake Sinclair Volumetric Analysis:*

The total volume of storage in the Murder Creek arm of Lake Sinclair was estimated to be 160,091 $m^3$ of stored sediment. The average annual rate of sediment accumulation for the 47 years since dam closure was estimated to be 3,406 $m^3$/Yr (Table 4.3). An average bulk density of 1.28 $g/cm^3$ was taken from an equation to estimated the specific weight of sediment deposits (Julien and Shen 1992). It was estimated that there were 204,948 Megagrams of sediment in storage. This resulted in an average annual value of 4,360 Mg/Yr of sediment export for the 47 years of record since dam closure. Total erosional depth for which bedload accounts is $2.97 \times 10^{-2}$ cm ($6.32 \times 10^{-4}$ cm/Yr) for the whole watershed (Table 4.3).

*USGS Estimation of Total Suspended Solids (TSS) Export:*

USGS long term stream data was used to calculate the total export of TSS from the Murder Creek watershed (Figure 3.22). An average bulk density of 1.50 $g/cm^3$ was used to calculate volumetric export of TSS sediment. Total volumetric export of sediment was calculated to be 336,113 Mg (224,075 $m^3$). For the 22 years of record, average yearly export was calculated to be 14,978 Mg/Yr (9,985 $m^3$/Yr). An estimated depth of erosion for the Murder Creek watershed was calculated to be $4.16 \times 10^{-2}$ cm ($1.85 \times 10^{-3}$ cm/yr) and is shown in Table 4.3.

STORAGE OF SEDIMENT:

*Dendro-geomorphology:*

Examinations along floodplain areas occurred near bridges along small-order streams and in several areas along the main stem of Murder Creek. Although some trees showed signs of accumulation above the tree boles, a majority of the trees in these areas exhibited little or no signs of recent alluvial accumulation above the root crown to warrant further investigation. All of the selected sites along lower order streams exhibited no visual accumulation of floodplain sediment around tree boles. From the sites selected along the larger stream orders, there were a few scattered trees in each area that were dug out and exhumed for alluvial accumulation. Lack of approved access to portions of the floodplain along the larger order streams is the reason only a few sites were selected and examined for recent floodplain alluvial accumulation.

An indication as to why there is little or no activity occurring in the floodplain, along smaller order stream systems, may be seen from geo-referenced historical photographs of Howard's Branch, located in Jasper County, on Bullard Road near State Road 16. In the first aerial photo, taken in 1938, it is obvious that agriculture had a pronounced affect upon stream systems (Figure 4.1). The area around this stream had no riparian zone or buffer. It is also apparent from this photo that, even in the late 1930's, contouring of the land was not commonly practiced to deter soil erosion. Much of the agricultural operations in this area practiced methods similar to this photo. Figure 4.2, from 1950, shows that there was some reclamation of the landscape by successional forest stage and that some of the farmed areas were then practicing conservation techniques such as contouring. The 1958 (Figure 4.3) aerial photo shows that the land around this stream had a pronounced riparian zone and that the successional forest had increased in size. It appears from the 1966 photo (Figure 4.4) that much of the watershed was in some sort of vegetative cover. The 1972 (Figure 4.5) aerial photograph demonstrates the apex of the typical progression from agriculture to either forestry or some type of forested situation. This progression occurred across much of the Murder Creek watershed due to the fact that soil erosion had been so severe and the land could no longer sustain widespread agricultural practices.

This watershed was one of the locations for which access to examine floodplain accumulation was granted. The 1950 (Figure 4.2) photo reveals that a riparian zone had begun and that by 1958 the riparian zone had become well established in this stream. The trees on this stream were, at the time of examination (1999), mature hardwoods that probably became established sometime between 1938 and 1950. This third order stream exhibited no recent or active accumulation of sediment in the riparian zone that had been growing sometime between

1938 and 1950. Howard's Branch is also a deeply incised channel which indicates that the channel is downcutting which is an indicator that import of sediment is less than the export of sediment. Many of the lower order channels in the Murder Creek watershed are deeply incised. This suggests that the alluvial floodplain and stream channel in this area has stabilized and the channel may be downcutting since the inception of the riparian zone, sometime after 1938. This may explain why, in the smaller order streams examined, there was no apparent recent alluvial accumulation. If there is alluvial sedimentation occurring, a more accurate method may be needed to quantify the amount of floodplain accumulation occurring.

*Historical Floodplain Storage:*

To determine a relative amount of the historic sediment in storage to current sediment loads, a calculation of historical sediment in storage needed to be determined. Identification between the Pre Historical Floodplain (PHFP) and the modern Historical Floodplain (HFP) boundary was necessary in determining a volumetric analysis of sediment in storage. The HFP is comprised of a stratigraphic layer of sand/sediment over a boundary of reduced high clay texture and low mica content (Figure 3.25). This boundary layer is presumed to be the contact point between the modern HFP and the PHFP and was created due to low overland erosion and floodplain deposition rates prior to European settlement (West and Leigh pers. comm.).

For the 20 sample sites, depths of the HFP were compared against the following four variables: drainage area, watershed slope, stream order and elevation of each sample site (Table 4.4). The data showed that there was a slight increasing relationship with depth to the PHFP that occurred with drainage area. Linear regression analysis produced an $R^2$ value of 0.07 which showed that there was little explanation in the variance between the depth to the PHFP and drainage area (Figure 4.6). The regression analysis was not statistically significant and therefore these data suggest that the depth to the PHFP is not affected by the size of the drainage area above a sample point.

Watershed slope for each sample site was calculated to determine if slope had an affect on the depth to the PHFP. A decrease in depth to the PHFP was expected with an increase in slope. Calculation of the watershed slope for each drainage area showed a general decrease in the depth to the PHFP when slope increased (Figure 4.7). Regression analysis data showed only a four percent explanation in the variance of the depth to the PHFP and therefore slope may not be a controlling factor on the depth to the PHFP.

Elevation for each location was compared against the depth to the PFHP (Figure 4.8). A relationship exists with depth and elevation, however, the explanation in variance is minimal. Strahler stream order for each sample site was also compared with depth to the PHFP. It was thought that the Strahler stream order may have an affect on the depth to the PHFP (Figure 4.9). But the relationship between stream order and depth to the PHFP was slight and there was little explanation in the variance for the data set. Both of the variables, elevation and stream order, were calculated as not having a statistically significant relationship with the depth of the HFP.

It was apparent there were no strong relationships between depth to the PHFP and the measured variables, drainage area, slope, elevation and Strahler stream order. Therefore an average depth of 1.58 meters to the PHFP was calculated (Table 4.4). Knox (1977) and Lecce (1996) have shown that modern floodplain sediment accumulation is relatively uniform. They determined this by locating and mapping the location of the PHFP with valley cross sections. Happ (1945) has also shown that the modern sediment accumulation is uniform in the South Carolina Piedmont. Happ located the PHFP with floodplain borings and mapped the PHFP valley cross sections. In essence, the authors found that sediment accumulation along the PHFP may be assumed to be uniform. This is because the PHFP was a level surface and when sediment loading from agricultural practices began to accumulate, sediment accumulation did so in an uniform manner. Therefore the modern accumulation of sediment should increase vertically with little lateral increase along valley walls. An average depth of the HFP was chosen and there should be little error in the calculation of sediment in storage that is associated with sloping valley walls.

The HFP analysis resulted in 65,919,085 $m^3$ of stored sediment. Total mass for the stored historical alluvial sediment is estimated to be 98,818,627 Mg. This resulted in at least 12 centimeters (4.8 inches) of soil eroded and currently in storage for the Murder Creek watershed (Table 4.5).

SUMMARY:

*Past and Present Sediment Contributions:*

Past average annual erosion rates were calculated to estimate an average rate of erosion for approximately 140 years of past agriculture practices. Comparing average annual past sediment yield currently in HFP storage ($8.74 \times 10^{-2}$ cm/Yr) to the estimated rates of land cover sediment yield, it was found that historical average annual sediment yields were much greater than the estimated annual modern sediment yield ($1.75 \times 10^{-3}$ cm/Yr). Total modern annual sediment yield from land use activities, including contributions of sediment from unpaved roads, were an order of magnitude less than estimated past sediment yield rates. Individual land cover annual sediment yields were much less than that of estimated annual past sediment yield with the exception of row crop agriculture ($2.02 \times 10^{-2}$ cm/Yr), which was slightly less than the annual past erosion rates. Average annual export of sediment was found to be an order of magnitude less than those of the estimated past erosion rates (Table 4.6). Therefore, average annual past estimated sediment yields were much greater than the estimated annual modern sediment yields.

*Comparisons of HFP Sediment in Storage:*

It is well known that forested areas produce or contribute relatively small amounts of sediment to a watershed (Patric 1976). However, the process of harvesting, removing trees and site preparation during a silvicultural operation are likely to lead to a significant increase in the amount of sediment produced. The results from the USLE model show that areas classified as row crop agriculture and clear cut in 1998 were estimated to yield a significant amount of erosion (Table 4.7).

From the 1998 land cover classification there were approximately 34 $km^2$, 54 $km^2$ and 110 $km^2$ classified as clear cut, mixed re-growth and pine plantation, respectively. Therefore there was about 198 $km^2$ (36 %) of the Murder Creek watershed in some type of silvicultural operation. Row crop agriculture and pasture land occupied 37 $km^2$ and 41 $km^2$ (14 %) of the classified land cover within the Murder Creek watershed. The other land cover classifications, mixed deciduous/evergreen, wetlands and urban, occupied approximately 248 $km^2$, 7 $km^2$ and 1 $km^2$ respectively (Table 4.7). The open water land cover classification occupied the rest of the area (3.4 $km^2$) in the Murder Creek watershed.

Forested lands, agricultural lands and the other land use classifications were individually aggregated to create a more representative estimation of sediment yield based upon land use area. Silvicultural operations in the Murder Creek watershed were aggregated and an average rate of sediment yield was calculated. It was estimated that, on average, sediment yield from silvicultural land was $8.3 \times 10^{-2}$ Mg/Ha/Yr. Average annual agricultural land use was estimated to yield 1.46 Mg/Ha/Yr. The other land cover classifications were estimated to yield $3.8 \times 10^{-2}$ Mg/Ha/Yr of sediment. Unpaved road sediment contributions were estimated to contribute a large amount of sediment (26 Mg/Ha/Yr) per unit area. Sediment in reservoir storage accounted for an average annual export of 4,360 Mg/Yr ($8.1 \times 10^{-2}$ Mg/Ha/Yr) and TSS export was estimated to account for 14,978 Mg/Ha (0.27 Mg/Ha/Yr). Although unpaved roads, agricultural activities (row crops), urban areas and wetlands were estimated to yield the greatest amount of sediment to the Murder Creek watershed individually, the estimated sediment yield is only a fraction of the estimated sediment in storage from past land use activities (Table 4.7).

There is a positive net export of sediment from the Murder Creek watershed. To account for the sediment budget balance difference between export and contributions of sediment, an estimation of bank erosion was calculated. Using the generated stream network, a total length of the streams was obtained. An average annual rate of bank erosion of 0.17 cm/Yr was calculated to account for the disparity between contributions and export of sediment.

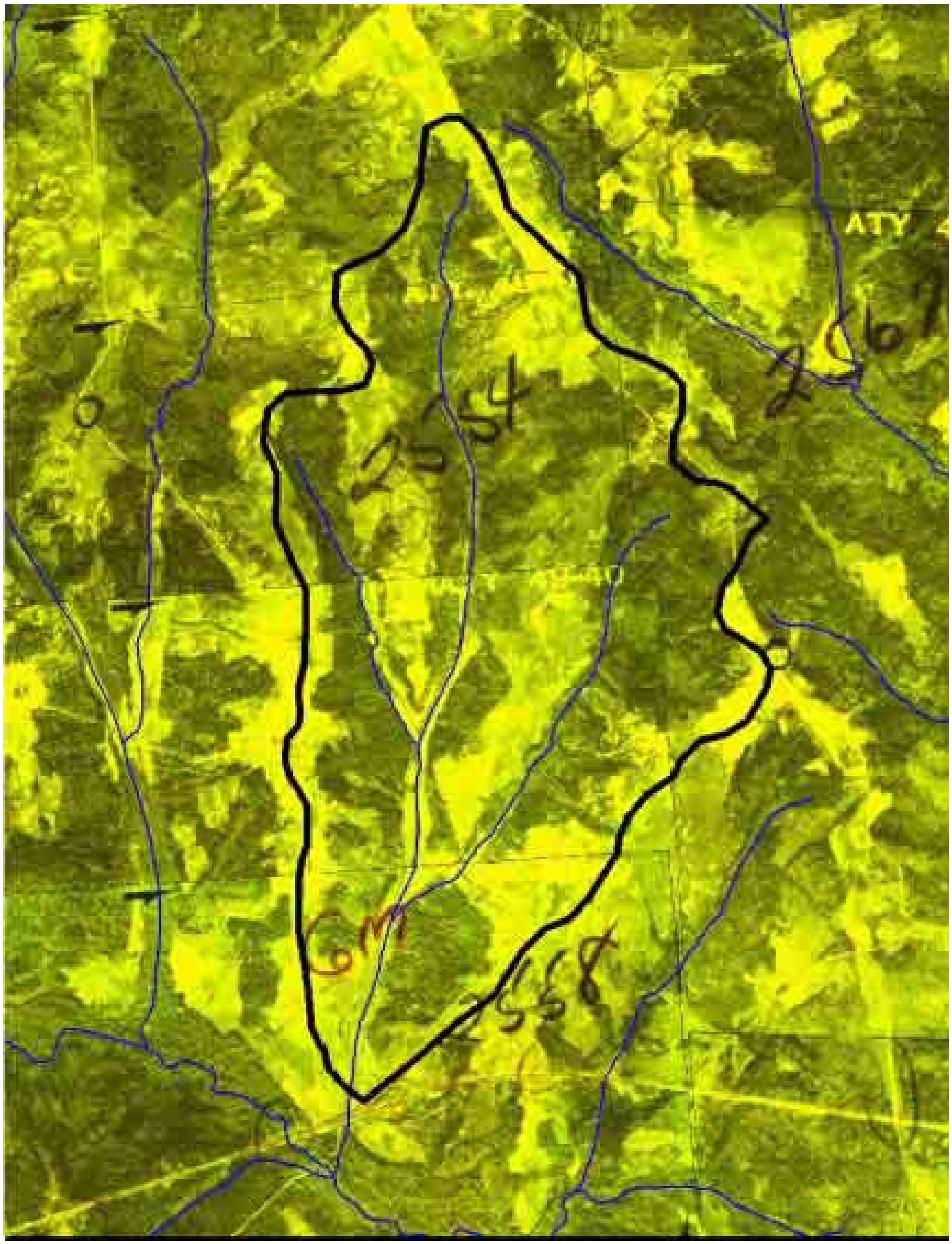


**Figure 4.1** Image of Howard's Branch watershed from 1938. This aerial photograph shows the effects that agriculture had upon the land.

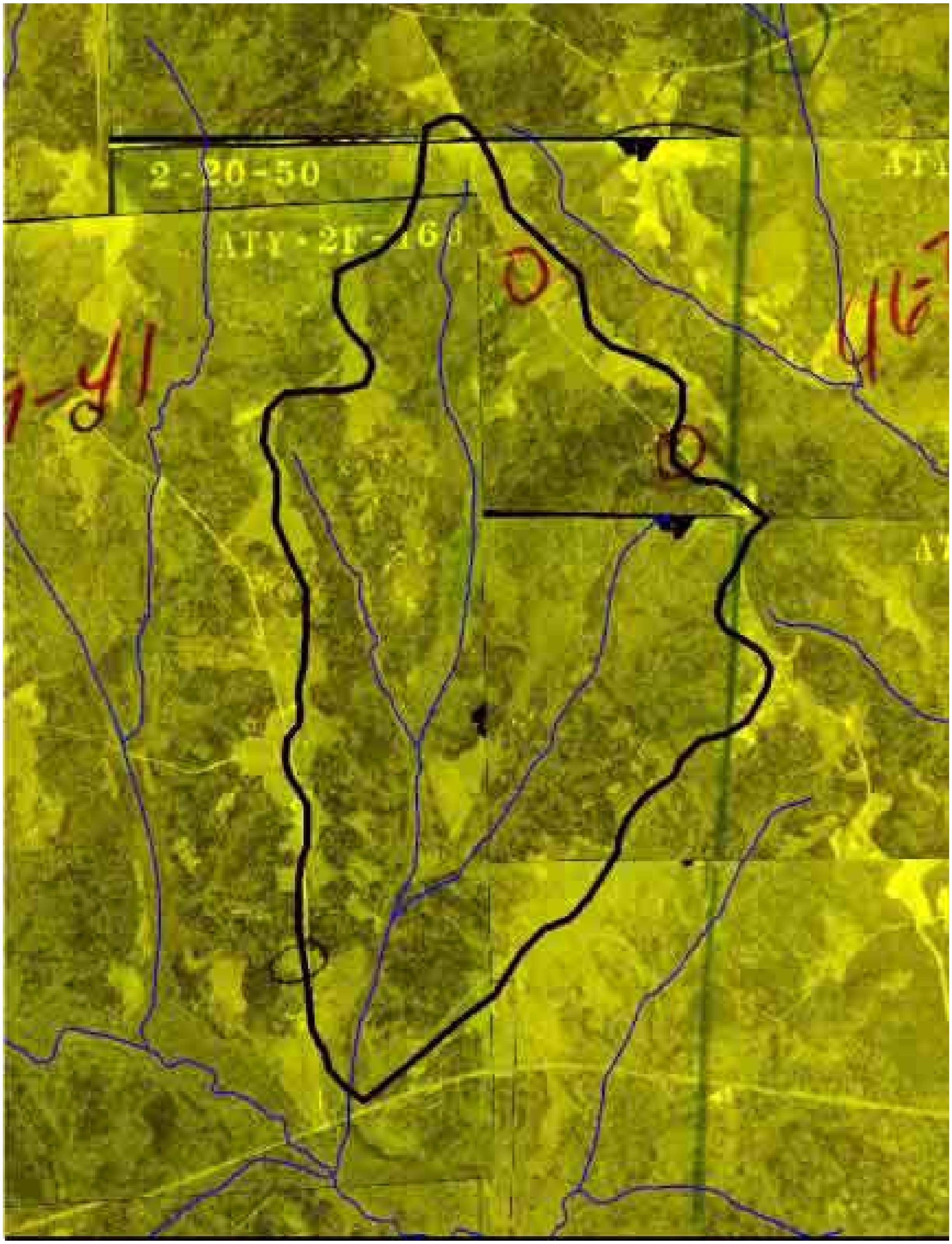


**Figure 4.2** Image of Howard's Branch watershed taken in 1950. This aerial photograph shows some reclamation of the land by successional forest stage. It is apparent that a riparian zone along the stream had become established.

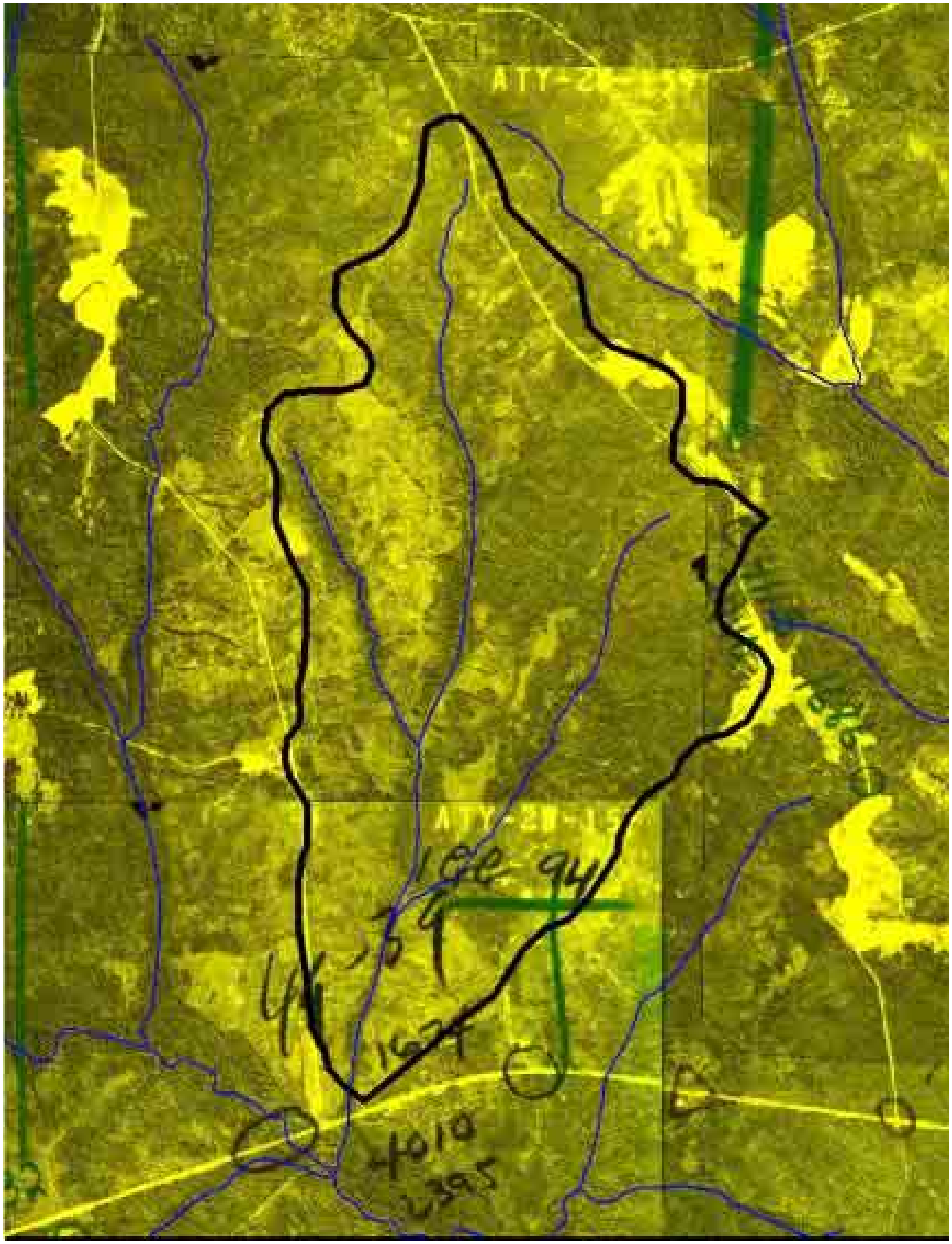

**Figure 4.3** Image of Howard's Branch watershed taken in 1958. Much of the watershed at this time has reverted to some type of vegetative cover or successional forest.

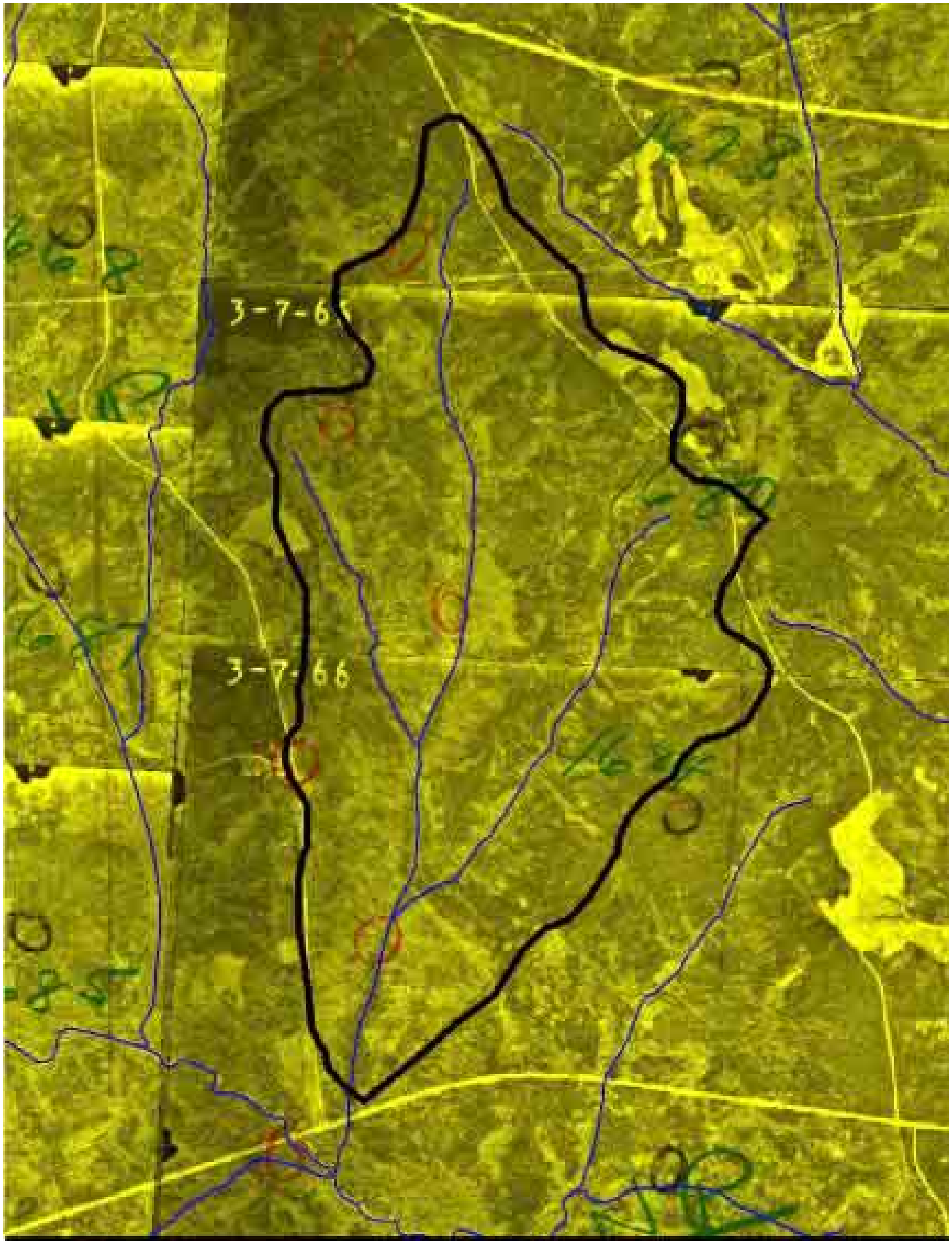


**Figure 4.4** Picture of Howard's Branch taken in 1966. Almost the entire watershed is now in forested cover.

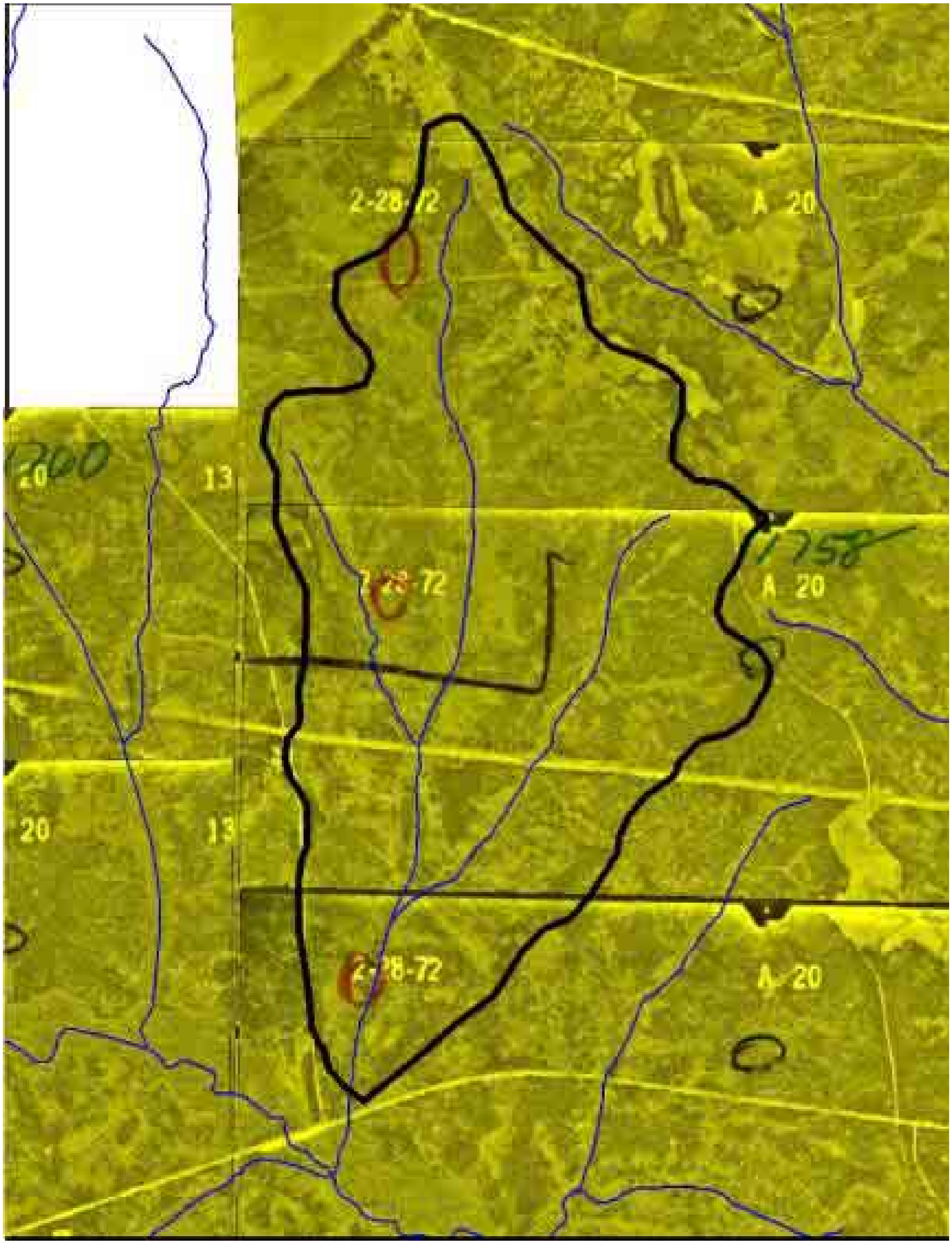


**Figure 4.5** Image of Howard's Branch watershed taken in 1972. The watershed now appears to be in mature forested growth. This progression of agriculture to forest was typical for much of the area in the Murder Creek watershed.

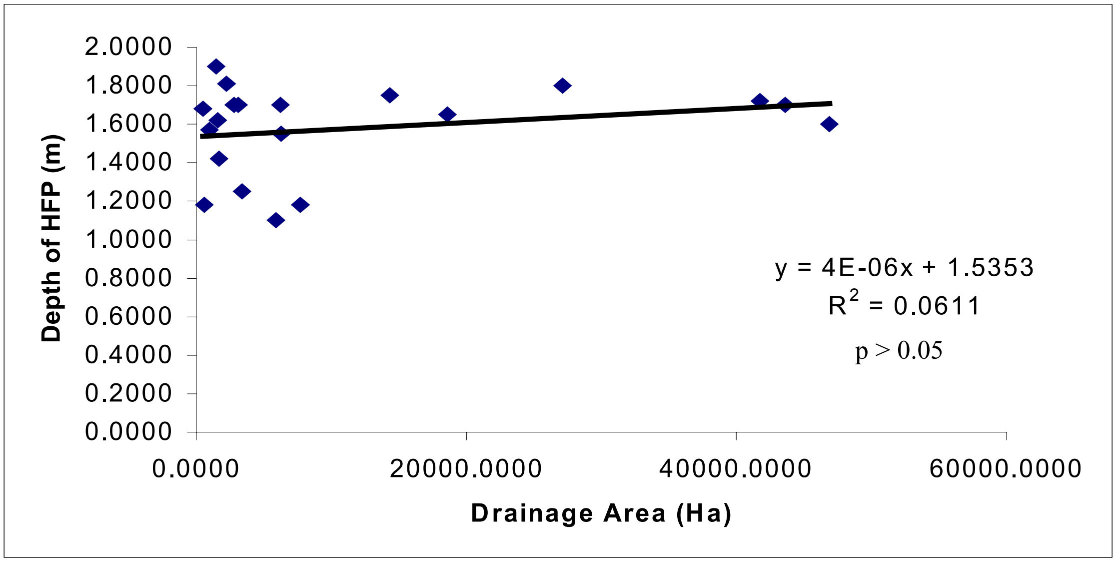


**Figure 4.6** Linear relationship between the drainage area of each sample site and associated depth of the HFP. No relationship exists between drainage area and the measured depth of the Historical Floodplain.

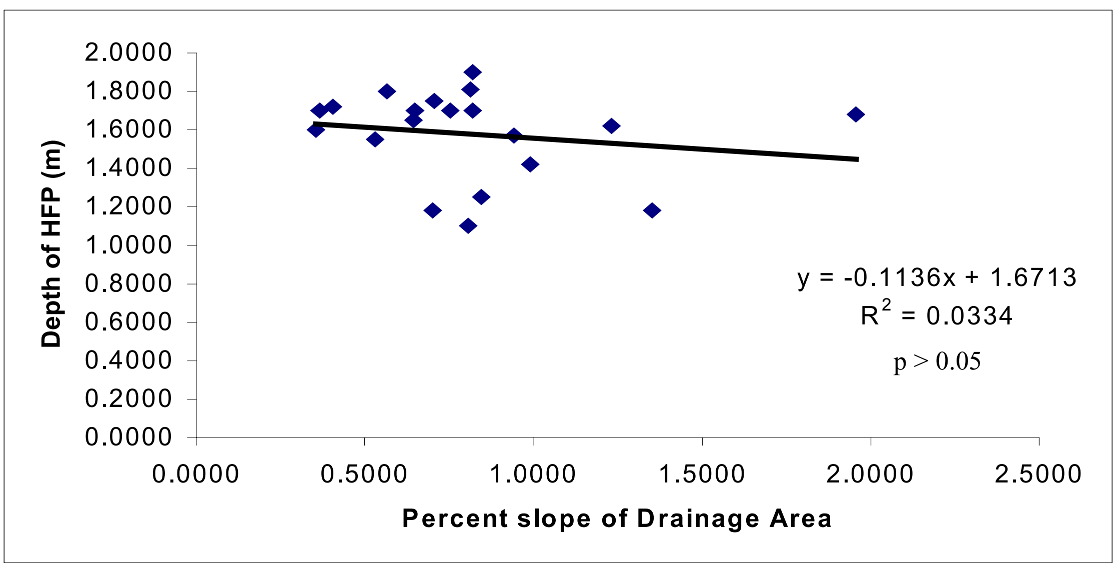


**Figure 4.7** Relationship between the slope for each drainage area and the depth of the HFP. There is a slight relationship between slope and depth of the HFP, but the explanation in variance is minimal and is not statistically significant.

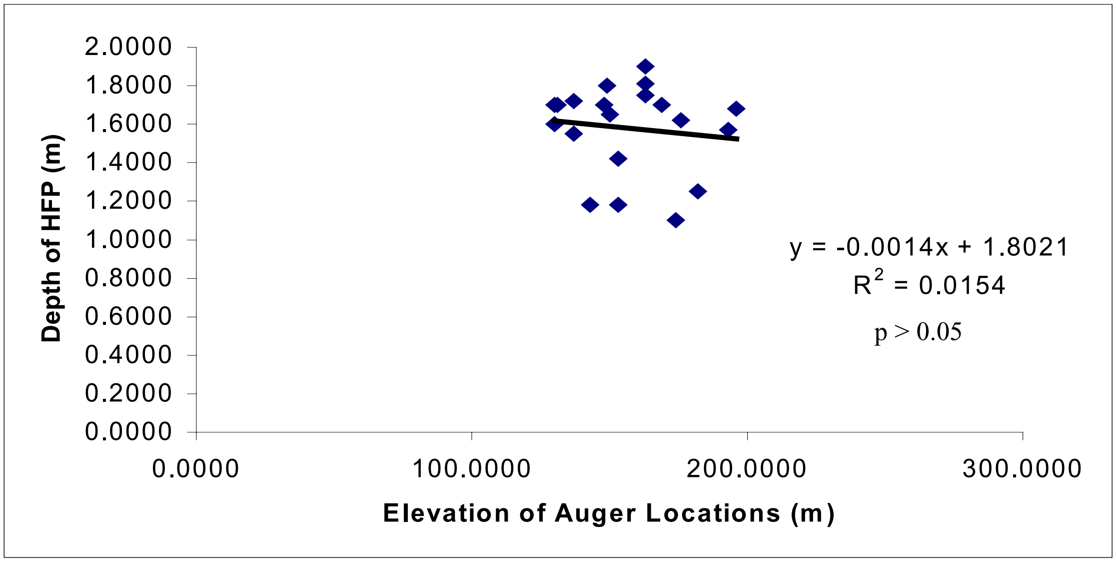


**Figure 4.8** Relationship between the elevation and depth of the HFP. An increase in elevation shows a slight relationship with the measured depth of the HFP, but is not significant.

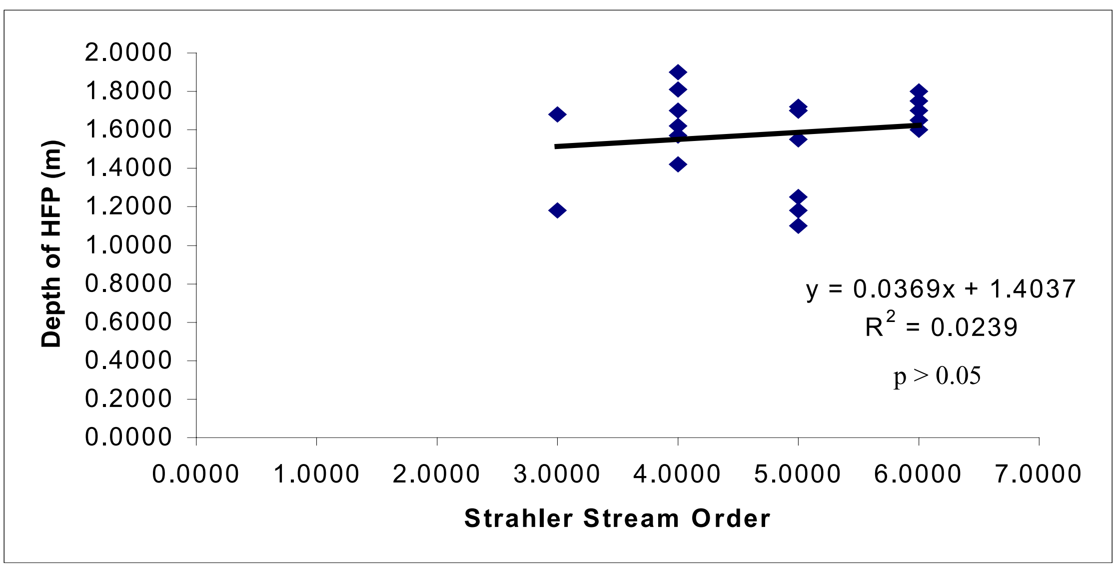


**Figure 4.9** Relationship between Strahler stream order for each sample location and depth of the HFP. An increase in Strahler stream order shows a general relationship with an increase in depth of the HFP, but is not significant.

**Table 4.1** Estimated delivery of sediment for the surveyed unpaved roads produced from the WEPP:Road model. The directly contributing unpaved roads were estimated to contribute a significant amount of sediment to the overall sediment budget. The estimated total unpaved road sediment contributions show that unpaved roads may contribute large amounts of sediment to a watershed.

| | Contributing Unpaved Roads Estimated Delivery | Contributing Unpaved Roads Erosion Estimate | Total Unpaved Roads Estimated Delivery | Total Unpaved Roads Estimated Erosion |
|---|---|---|---|---|
| Total Length (m) | 20,307 | 20,307 | 340,699 | 340,699 |
| Average Width ($m^2$) | 6.87 | 6.87 | 6.87 | 6.87 |
| Average Contributing Area ($m^2$) | 139,587 | 139,587 | 2,341,920 | 2,341,92 |
| Sediment Contribution Megagrams/year | 361 | 819 | 6,031 | 13,743 |
| Sediment Contribution Volume ($m^3$/year) | 240 | 546 | 4,021 | 9,162 |
| Erosion (Mg/Ha/year) | 26 | 59 | 26 | 59 |
| Average Depth of Erosion (cm/yr) | 0.17 | 0.39 | 0.17 | 0.39 |

**Table 4.2** Land cover estimates of gross watershed erosion calculated from the USLE. Row crop agriculture and clear cut classifications were estimated to contribute the greatest amount of gross erosion. An estimated SDR for each land cover class was calculated from Equation 2. Row crops and clear cuts were estimated to yield the most erosion but on an areal basis row crops, wetlands and urban areas were estimated to yield the highest amounts (Mg/Ha/Yr). Total gross watershed erosion, including unpaved road contributions, was estimated to be 1.88 Mg/Ha/Yr and watershed yield was estimated to be 0.27 Mg/Ha.Yr.

| Land Cover Type | Hectares | (%) | Estimated Gross Erosion (Mg/Yr) | Estimated Gross Erosion ($m^3$/Yr) | Estimated Gross Erosion (Mg/Ha/Yr) | *Estimated SDR | Estimated Sediment Yield (Mg/Yr) | Estimated Sediment Yield (Mg/Ha/Yr) | Estimated Sediment Yield ($m^3$/Yr) | Equivalent Depth of Erosion (cm/yr) |
|---|---|---|---|---|---|---|---|---|---|---|
| Open Water | 340 | (0.63) | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.00 | 0.00 |
| Urban | 146 | (0.27) | 454 | 303 | 3.10 | 0.365 | 165 | 1.14 | 110 | $7.6 \times 10^{-3}$ |
| Clear Cut | 3,397 | (6.30) | 8,958 | 5,972 | 2.64 | 0.142 | 1,272 | 0.37 | 848 | $2.5 \times 10^{-3}$ |
| Mixed Deciduous/ Evergreen | 24,842 | (46.11) | 610 | 407 | 0.02 | 0.078 | 48 | 0.0019 | 32 | $1.2 \times 10^{-5}$ |
| Planted Pine | 11,073 | (20.55) | 2,255 | 1,503 | 0.20 | 0.099 | 223 | 0.02 | 149 | $1.3 \times 10^{-4}$ |
| Pasture | 4,160 | (7.72) | 1,700 | 1,133 | 0.41 | 0.133 | 226 | 0.05 | 151 | $3.6 \times 10^{-4}$ |
| Row Crop Agriculture | 3,733 | (6.93) | 82,023 | 54,682 | 21.97 | 0.138 | 11,319 | 3.03 | 7,546 | $2.0 \times 10^{-2}$ |
| Wetlands | 736 | (1.37) | 3,394 | 2,263 | 4.60 | 0.225 | 764 | 1.04 | 509 | $6.9 \times 10^{-3}$ |
| Mixed Re-Growth | 5,452 | (10.12) | 1,305 | 870 | 0.24 | 0.123 | 161 | 0.03 | 107 | $1.9 \times 10^{-4}$ |
| Roads: Summarized from Table 4.1 | 13.9 | | 819 | 546 | 59 | NA | 361 | 26 | 240 | 0.17 |
| **TOTALS** | 53,884 | (100) | 101,518 | 67,678 | 1.88 | NA | 14,539 | 0.27 | 9,692 | $1.8 \times 10^{-3}$ |

SDR Calculated from Equation 2

**Table 4.3** Estimation of export volumes for Total Suspended Solids (TSS) and bedload sediment for the Murder Creek watershed. Total volume analysis for the 47 years of sediment in reservoir storage was estimated and total TSS export (22 years) was calculated. Average annual values for sediment in reservoir storage and TSS were calculated and an equivalent depth of erosion is reported.

| | Total Lake Sinclair Reservoir Data (47 years) | Average Annual Lake Sinclair Reservoir Data | Total Estimated TSS Export (22 years) | Average Annual Total TSS Export |
|---|---|---|---|---|
| Volume $m^3$ | 160,091 | 3,406 | 224,075 | 9,985 |
| Megagrams | 204,948 | 4,360 | 336,113 | 14,978 |
| Equivalent Depth of Erosion (cm) | $2.97 \times 10^{-2}$ | $6.32 \times 10^{-4}$ | $4.16 \times 10^{-2}$ | $1.85 \times 10^{-3}$ |

**Table 4.4** Locations of each sample site where depths of the Historical Floodplain (HFP) were identified. For each sample site several variables were calculated to determine if there may be an affect upon the depth of the HFP. Watershed slope, drainage area, stream order and sample elevation were calculated for the 20 sample sites and are listed below.

| Auger Location | Depth to HFP (cm) | Slope Percent | HFP Area (Ha) | Drainage Area (Ha) | Stream Order | Elevation (m) |
|---|---|---|---|---|---|---|
| BarBridge Road | 175 | 0.7052 | 931.17 | 14,332.91 | 6 | 163 |
| Beaverdam Road | 170 | 0.8196 | 309.77 | 3,096.36 | 5 | 131 |
| Calvin Road | 162 | 1.2305 | 56.47 | 1,561.66 | 4 | 176 |
| County Road 23 | 181 | 0.8121 | 110.88 | 2,244.17 | 4 | 163 |
| Howard’s Branch | 118 | 1.3520 | 34.55 | 598.68 | 3 | 143 |
| Jacks Creek and River Road | 142 | 0.9909 | 77.22 | 1,699.53 | 4 | 153 |
| Murder Creek & Aldridge Road | 125 | 0.8461 | 173.67 | 3,379.05 | 5 | 182 |
| Murder Creek & State Road 300 | 180 | 0.5645 | 1695.13 | 27,116.15 | 6 | 149 |
| Murder Creek & State Road 83 | 165 | 0.6452 | 1123.37 | 18,600.04 | 6 | 150 |
| Murder Creek & Wolf Creek | 172 | 0.4051 | 2860.31 | 41,742.69 | 5 | 137 |
| Murder Creek Church Road | 157 | 0.9418 | 40.50 | 967.60 | 4 | 193 |
| Murder Creek & Forest Service Road 1068 | 170 | 0.3663 | 3079.68 | 43,586.23 | 6 | 130 |
| Murder Creek & Hillsboro Road | 160 | 0.3542 | 3422.57 | 46,859.69 | 6 | 130 |
| North Fork of Wolf Creek | 190 | 0.8198 | 84.49 | 1,464.11 | 4 | 163 |
| Palo Alto Road | 168 | 1.9563 | 7.93 | 512.47 | 3 | 196 |
| Pittman Branch | 110 | 0.8072 | 347.93 | 5,928.52 | 5 | 174 |
| Post Road | 170 | 0.7529 | 386.54 | 6,248.32 | 5 | 169 |
| Smithboro Road | 170 | 0.6489 | 167.69 | 2,766.93 | 4 | 148 |
| State Road 83 | 118 | 0.7006 | 401.85 | 7,689.30 | 5 | 153 |
| Wolf Creek | 155 | 0.5305 | 451.29 | 6,289.07 | 5 | 137 |
| Average Depth | 158 | | | | | |

**Table 4.5** Volume of sediment in storage was calculated from an average depth of 1.58 meters (Table 4.4) to the Historical Floodplain (HFP). HFP area was estimated from NRCS soil series maps for floodplain soils classified as either Inceptisols or Entisols (Figure 3.24). An equivalent depth of erosion was calculated by dividing the volume of sediment in storage ($m^3$) by the total area of the watershed ($m^2$). The total erosional value in Mg/Ha was calculated by dividing the Mg in storage by watershed area.

| Estimated Sediment Volume ($m^3$) | Estimated Megagrams in Storage | Equivalent Depth of Erosion (cm) | Total Estimated Erosion (Mg/Ha) |
|---|---|---|---|
| 65,919,085 | 98,818,627 | 12.2 | 1,835 |

**Table 4.6** Historical estimate of average annual depth of erosion (cm/Yr) for 140 years of past agricultural practices. Sediment yield for land cover classes is reported as the estimated average annual yield. Total contributions of sediment are calculated to include unpaved road sediment contributions. Current sediment contributions and export is much less than the average annual input from the past 140 years of agriculture sediment inputs.

| | Estimated Sediment Yield ($m^3$/Yr) | Hectares | Delivered Erosion Rate (cm/Yr) | NOTES |
|---|---|---|---|---|
| **CONTRIBUTIONS** | | | | |
| Open Water | 0.00 | 340 | 0.00 | |
| Urban | 110 | 146 | $7.48 \times 10^{-3}$ | |
| Clear Cut | 848 | 3,397 | $2.49 \times 10^{-3}$ | |
| Mixed Deciduous/ Evergreen | 32 | 24,842 | $1.28 \times 10^{-5}$ | |
| Planted Pine | 149 | 11,073 | $1.34 \times 10^{-4}$ | |
| Pasture | 151 | 4,160 | $3.63 \times 10^{-4}$ | |
| Row Crop Agriculture | 7,546 | 3,733 | $2.02 \times 10^{-2}$ | |
| Wetlands | 509 | 736 | $6.82 \times 10^{-3}$ | |
| Mixed Re-Growth | 107 | 5,452 | $1.96 \times 10^{-4}$ | |
| **Totals** | 9,446 | 53,884 | $1.75 \times 10^{-3}$ | |
| **Roads** | | | | |
| Contributing Unpaved Roads | 240 | 13.9 | $1.71 \times 10^{-1}$ | Assumes that only unpaved roads leading to flowing waterways are contributing sediment on a yearly basis. |
| **TOTALS (Including Roads)** | 9,686 | 53,884 | $1.79 \times 10^{-3}$ | |
| **EXPORT** | | | | |
| Bedload (47 Years) | 3,406 | 53,884 | $6.32 \times 10^{-4}$ | Does not account for the amount of stored sediment that has been dredged from the Murder Creek arm of Lake Sinclair. |
| TSS (22 Years) | 9,985 | 53,884 | $1.85 \times 10^{-3}$ | Data obtained from USGS resulted in a poorly defined sediment rating curve that is strongly affected by two data points. |
| **Totals** | 13,391 | 53,884 | $2.48 \times 10^{-3}$ | |
| **Cotton-Era Average Input Rate** | | | | |
| Historical Floodplain Storage (Approximately 140 years of past agricultural practices) | 470,850 | 53,884 | $8.74 \times 10^{-2}$ | Results obtained by dividing current mass of sediment in storage by an estimated 140 years of farming practices. Does not account for export that may have occurred during this time period. |

**Table 4.7** Sediment yield values estimated for individual land cover classifications, unpaved roads, and sediment export. Sediment yield values are compared as a percentage to the historical sediment in storage. Estimated values for bedload and TSS are compared to the historical sediment in storage. Total estimated sediment contributions, estimated sediment yield from individual land uses and estimated export of sediment values are a small percentage of the sediment that is estimated to be in floodplain storage from past agriculture practices.

| | $m^3$/Yr | Mg/Yr | Hectares | Mg/Ha/Yr | Percent of Sediment in Storage |
|---|---|---|---|---|---|
| **CONTRIBUTIONS** | | | | | |
| **USLE** | | | | | |
| **- Forest Activities** | | | | | |
| Mixed Re-Growth | 107 | 161 | 5,452 | $2.9 \times 10^{-2}$ | $1.63 \times 10^{-4}$ |
| Planted Pine | 149 | 223 | 11,073 | $2.0 \times 10^{-2}$ | $2.26 \times 10^{-4}$ |
| Clear Cut | 848 | 1,272 | 3,397 | $3.7 \times 10^{-1}$ | $1.28 \times 10^{-3}$ |
| **Total** | **1,104** | **1,656** | **19,922** | **$8.3 \times 10^{-2}$** | **$1.67 \times 10^{-4}$** |
| **- Agricultural Activities** | | | | | |
| Row Crop | 7,546 | 11,319 | 3,733 | 3.03 | $1.14 \times 10^{-2}$ |
| Pasture | 151 | 226 | 4,160 | $5.4 \times 10^{-1}$ | $2.29 \times 10^{-4}$ |
| **Total** | **7,697** | **11,545** | **7,893** | **1.46** | **$1.17 \times 10^{-2}$** |
| **- Other Land Uses** | | | | | |
| Mixed Deciduous/Evergreen | 32 | 48 | 24,842 | $1.9 \times 10^{-3}$ | $4.90 \times 10^{-5}$ |
| Urban | 110 | 165 | 146 | 1.13 | $1.67 \times 10^{-4}$ |
| Wetlands | 509 | 764 | 736 | 1.03 | $7.73 \times 10^{-4}$ |
| **Total** | **651** | **977** | **25,724** | **$3.8 \times 10^{-2}$** | **$9.89 \times 10^{-4}$** |
| **- Roads** | | | | | |
| Contributing Unpaved Roads | 240 | 361 | 13.9 | 26 | $3.65 \times 10^{-4}$ |
| **CONTRIBUTION TOTALS** | **9,692** | **14,539** | **53,539** | **0.27** | **$1.47 \times 10^{-2}$** |
| **EXPORT** | | | | | |
| **Bedload** | | | | | |
| Average Yearly | 3,406 | 4,360 | 53,884 | $8.1 \times 10^{-2}$ | $4.41 \times 10^{-3}$ |
| **TSS** | | | | | |
| Average Yearly | 9,985 | 14,978 | 53,884 | 0.27 | $1.51 \times 10^{-2}$ |
| **STORAGE** | **Total $m^3$** | **Total Mg** | **Hectares** | | |
| Historical Floodplain Storage (140 years of past agricultural practices) | 65,919,085 | 98,818,627 | 53,884 | NA | NA |

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

Individual land uses contributed varying amounts of sediment. When land uses were aggregated it was determined that row crop agriculture, silvicultural activities and the other land uses classifications contributed 1.46 Mg/Ha/Yr, $8.3 \times 10^{-2}$ Mg/Ha/Yr and $3.8 \times 10^{-2}$ Mg/Ha/Yr respectively. Unpaved road segments were estimated to yield the greatest amounts of sediment to the watershed. However, these modern average annual sediment yields, for the combined land uses and road contributions, are small when compared as a percentage of the sediment in storage.

A stream system in equilibrium will have the same amount of sediment entering the system as is leaving. The historical influx of sediment into Murder Creek has been shown. Historically there was more sediment entering the Murder Creek watershed than the stream could carry. Therefore excess sediment went into storage on top of the Pre Historical Floodplain (PHFP). Currently, the average annual estimated sediment yield from land cover classifications and contributing unpaved road segments is less than the estimated average annual sediment export from the Murder Creek watershed. This suggests that there is less sediment entering the system than is exiting the watershed and therefore the system may be degrading or downcutting. When there is less sediment entering a system than it may be able to transport the system may begin to "grab" sediment from storage because it can carry more sediment than it is currently. This difference in the sediment budget may be attributed to the historical sediment in storage where historical valley sediment deposits are being re-mobilized due to downcutting. An estimation of bank erosion that may account for the difference in the contributions and export of sediment was calculated. An average annual rate of 0.17 cm/Yr of bank erosion was calculated to account for this discrepancy in the sediment budget. Therefore bank erosion that may be originating from the sediment in storage within the Murder Creek watershed may be responsible for some of the elevated turbidity levels found in rural watershed basins in the Piedmont of Georgia.

Unpaved roads within the Murder Creek watershed contributed the greatest amount of erosion on a per unit area. These unpaved roads need to be considered in future TMDLs and better soil erosion controls on these roads need to be implemented. More research is needed in determining actual sediment yield from various land uses and developing models for site specific land uses. These models may be integrated with Geographic Information Systems to aid in the development of allocating equitable sediment TMDLs for industry and land owners. Hydrologic models may be needed to aid in determining if and when volumes of historical sediment in storage may be re-mobilized. These models may aid in separating land use sediment contributions to a waterway from sediment that is mobilized from storage.

REFERENCES

Arthur, M.A., G.B. Coltharp., and D.L. Brown. 1998. Effects of Best Management Practices on Forest Streamwater Quality in Eastern Kentucky. JAWRA 34:481-495.

Beach, Timothy. 1992. Estimating Soil Loss from Medium-Sized Drainage Basins. *Physical Geography.* Vol. 13, No. 3. pg. 206-224.

Beasley, R.S., E.L. Miller and S.C. Gough. 1984. Forest Road Erosion in the Ouichita Mountain. Pp. 203-212. In: Peters, P.A. and J. Luchok, eds., Proceddings from Mountain Logging Symposium, West Virginia University, Charleston, WV.

Bennett, H.H. 1933. Speech. http://www.nhq.nrcs.usda.gov/CCS/history/01_31_33.html.

Bureau of Laboratories Division of Administrative and Technical Services. 1997. Effectiveness of Forestry Best Management Practices. Florida Dept. of Env. Protection.

Burns, Richard Garwood 1978. An Improved Sediment Delivery Model for Piedmont Forests. PhD Dissertation, University of Georgia, Athens, GA.

Cherry, Rodney N. 1961. Chemical Quality of Water of Georgia Streams, 1957-1958. United States Geological Survey 1961. Bulletin No. 69.

Clean Water Act 1972. Section 303(d).

Dendy, F.E. and G.C. Bolton. 1976. Sediment yield-runoff-drainage area relationships in theUnited States. *Journal of Soil and Water Conservation.* Nov-Dec.

Dendy, F.E., S.J. Ursic,. And A.J. Bowie 1979. Sediment Sources and Yields from Upland Watersheds in North Mississippi. In: Proceedings: Mississippi Water Resources Conference.

ESRI. 1999. Environmental Systems Research Institute, Inc. ArcView 3.2. Online Help Manual.

Foltz, Randy B. 1996. Traffic and No-Traffic on an Aggregate Surfaced Road: Sediment Production Differences. USDA Food and Agriculture Seminar: Environmentally Sound Forest Road and Wood Transport. Sinaia, Romania., June 17-22.

Georgia GIS Data Clearinghouse. 2000. http://gis1.state.ga.us.

Glenn, L.C. 1911. Denudation and Erosion in the Southern Appalachian Region and the Monongahela Basin. Dept. of the Interior, USGS Professional Paper 72. GPO.

Happ, Stafford C. 1945. Sedimentation in South Carolina Piedmont Valleys. American Journal of Science. Vol. 243, No. 3. pp. 113-126.

Harper, Francis (ed.) 1998, The Travels of William Bartram: Naturalist Edition, University of Georgia Press.

Hewlett, John D. 1978. Forest Water Quality: An Experiment in Harvesting and Regenerating a Piedmont Forest. School of Forest Resources, University of Georgia. Athens, Georgia.

Julien, Pierre Y. and Hsieh Wen Shen. 1992. Erosion and Sediment Transport. Handbook of Hydrology. Chapter 12, Ed. David R. Maidment. McGraw-Hill, Inc. New York, N.Y.

Ketcheson, G.L. and Walter Megahan. 1996. Sediment Production and Downslope Sediment Transport from Forest Roads in Granitic Watersheds. USDA Forest Service Research Paper. INT-RP-486.

Knox, James C. 1977. Human Impacts on Wisconsin Stream Channels. Annals of the Association of American Geographers. Vol. 67, No. 3. pp. 323-342.

Lathem, James. 1999a. Soil Survey of Jasper County, Georgia. USDA.

Lathem, James. 1999b. Soil Survey of Newton and Rockdale Counties, Georgia. USDA.

Lecce, Scott A. 1996. Spatial Patterns of Historical Overbank Sedimentation and Floodplain Evolution, Blue River, Wisconsin. Geomorphology 18. pp. 265-277.

LeGrand, Harry E. 1988. Region 21 Piedmont and Blue Ridge. Hydrogeology: Boulder, Colorado. Geological Society of America. The Geology of North America, v. O-2.

Miller, W., R. Jackson, and T. C. Rasmussen. 2000. Readings in Soils and Hydrology. University of Georgia Press, Athens, Georgia.

Megahan, W.F. and Walter J. Kidd. 1972. Effect of Logging Roads on Sediment Production Rates in the Idaho Batholith. USDA Forest Service Research Paper. INT-123.

Neary, D.G., W.T. Swank, and H. Riekerk. 1988. An overview of non-point source pollution in the Southern United States. In: *Proceedings of the symposium The Forested Wetlands of the Southern United States*. Orlando, FL, July 12 -15, 1988. Forest Service General Technical Report SE-50.

Osinki, Bill. *Fisherman's tale may recast history of Georgia Indians*. Atlanta Journal Constitution, September 12, 1999.

Patric, J.H. 1976. Soil Erosion in the Eastern Forest. Journal of Forestry.

Payne, H. H. Et al. 1976. Soil Survey of Baldwin, Jones, and Putnam Counties, Georgia. USDA Soil Conservation Service and Forest Service. In Coop. with University of Georgia, College of Agriculture Experiment Station.

Phillips, Jonathan D. 1991. Fluvial sediment budgets in the North Caroling Piedmont. *Geomorphology* Vol. 4. 231-241.

Rasmussen, T.C. and F. Green. 1997. A Study of Stream Turbidity Following Forest Harvesting in Georgia. Georgia Environmental Protection Division.

Reid, Leslie and T. Dunne. 1984. Sediment Production from Forest Road Surfaces. *Water Resources Research*. Vol. 20. No. 11:1753-1761.

Sierra Club vs. John Hankinson 1996. Civil Action 1:94-cv-2501-MHS. United States District Court for the Northern District of Georgia, Atlanta Division.

Sigafoos, R.S. 1964. Botanical Evidence of Floods and Flood-Plain Deposits. USGS Professional Paper 485-A.

Schick, Asher P. and Judith Lekach. 1993. An Evaluation of Two Ten-Year Sediment Budgets, Nahal Yael, Israel. Physical Geography Vol. 14, No. 3. pg. 225-238.

Sturhan, N., Walt Megahan, Kate Sullivan, Curt Veldhuisen and Steven Toth. 1995. Watershed Analysis Appendices B Surface Erosion.

Swift, L.W. 1984. Gravel and Grass Surfacing Reduces Soil Loss from Mountain Roads. Forest Science. Vol. 30, No. 3. pp. 657-670.

Swift, L.W. 1988. *Forest Access Roads: Design, Maintenance, and Soil Loss in Forest Hydrology and Ecology at Coweeta*. ed. W.T. Swank and D.A. Crossley, Jr. Springer-Verlag. New York.

Trimble, Stanley W. 1974. *Man induced soil erosion on the southern Piedmont; 1700 - 1970.* Soil Science Society of America.

Trimble, Stanley W. 1975. A Volumetric Estimate of Man - Induced Soil Erosion on the Southern Piedmont Plateau, in Present and Prospective Technology for Predicting Sediment Yields and Sources: U.S. Dept. Agriculture, Agr. Res. Serv. Ars-S-40.

Trimble, Stanley W. 1983. A Sediment Budget for Coon Creek Basin in the Driftless Area, Wisconsin, 1853-1977. *Am. Journal of Science*. Vol. 283. Pg. 454-474.

USDA. 1987. All Resource Areas Georgia.

USDA. 1988. Roads in the National Forests, FS 414. Washington, D.C.: United States Department of Agriculture, Forest Service.

USDA. 1999. WEPP:Road. WEPP Interface for Predicting Forest Road Runoff, Erosion and Sediment Delivery. USDA Forest Service Lab. http://forest.moscowfsl.wsu.edu/fswepp/docs/wepproaddoc.html

USGS. 1980. Erosion, Sediment Discharge, and Channel Morphology in the Upper Chattahoochee River Basin, Georgia. USGS Professional Paper 1107.

USGS. 2001. Georgia Real Time Water Data. http://ga.water.usgs.gov/rt-cgi/gen_stn_pg?station=02221525.

West, Larry T and David S. Leigh. 2000. Personal Communication.

Whitney, Milton. 1919. Field Operations of the Bureau of Soils. USDA Washington Government Printing Office, 1925.

Wischmeier, Walter H. and Dwight D. Smith. 1978. Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. USDA Agricultural Handbook 537, Washington, D.C.