QUANTIFYING FOREST ROAD EROSION IN THE OUACHITA MOUNTAINS OF OKLAHOMA

By

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CHAPTER I

INTRODUCTION

1.1 Background

A common feature on private and government owned forestlands is roads. It is estimated that there are approximately 1.6 million kilometers of forest roads in the United States (Riiters and Wickham 2003). Roads provide economic and social benefits such as transport of timber products and access for recreation, fire fighting, and residents (inholders).

Along with benefits, there are also adverse impacts that come from forest roads. A road segment can increase flooding and debris flows (Jones et al., 1999). Many roads are built adjacent to streams which can have a serious impact on aquatic ecosystems (Luce 2002). Sediment from roads can increase turbidity in streams which will have a direct effect on visual predators (Eaglin and Hubert 1993). Also, sediment from roads can shorten the life of lakes and reservoirs (Gucinski et al. 2001). Over the years, Best Management Practices (BMP) have been developed to address these concerns of water quality degradation and potential impacts on aquatic ecosystem (Turton et al., 1992).

Research studies have been conducted in many different regions in the United States. An example of long term research on forest road erosion can be found on the

Coweeta experimental forest in Georgia (Swift 1988). Many research projects have been conducted on forest road erosion in the Pacific Northwest (Ketchson and Megahan 1996, Luce and Black 1999, Megahan and Kidd 1972, and Reid and Dunne 1984). However, only two studies on road erosion have been conducted in the Ouachita Mountains.

1.2 Definition of the Problem

Past research on road erosion in the Ouachita Mountains examined how much sediment was attributable to recently constructed and established forest roads. Vowell (1985) and Miller et al. (1985) also examined the potential impact to water quality from roads, and an overall estimate on sediment delivery in an entire watershed. A need has arisen to conduct research on established roads and compare these findings to one or more erosion models. The focus of this paper will be the collection of field data on forest road erosion and the comparison of measured and predicted erosion rates using the computer model called WEPP 2002.700 or Water Erosion Prediction Project 2002.700 (watershed version).

Road segments were identified that represented a typical road segment in the drainage basin. A typical road in the basin has a cutslope, ditch, and a crowned road surface. Then instruments were established to capture and monitor the amount of eroded material from each road segment. The collection devices used in this study will vary from past research in the Ouachita Mountains to accommodate the potential of large amounts of sediment from storm runoff.

A potentially effective way to estimate road erosion over an entire basin is with the use of an erosion model. Commonly used models are the Universal Soil Loss

Equation (USLE), Revised or Modified Universal Soil Loss Equation (RUSLE or MUSLE) and Water Erosion Prediction Project (WEPP). Although their original intention was for croplands, or for some other purpose, the WEPP model has had some success in both forestry practices and road erosion (Elliot et al., 1999a and b). Studies in the past have divided roads up into road segments that included the contributing area that surrounds the road and the road surface itself. Once the roads were defined by their topography, the WEPP model was used to predict erosion from each road segment. The rationale for selecting WEPP over the various different USLE models is the ability of WEPP to model ditch erosion. Also, WEPP is a process based model that takes into account the processes that cause erosion (Alberts et al. 1995).

The results from the model can facilitate further research into estimating the amount of sediment produced in an entire basin. Understanding the amount of sediment produced from a basin can help resource managers gain an idea of how to mitigate the effects a road can have on water quality and aquatic ecosystems in the Ouachita Mountains.

1.3 Objectives

The specific objectives of this study are to:

1) Measure sediment yields from segments of two established industrial forest roads.
2) Compare measured sediment yields to sediment yields predicted by the WEPP model.

CHAPTER II

LITERATURE REVIEW

2.1 Erosion

To understand the different soil erosion models and erosion measurement techniques, we need to first understand the erosion processes. The components of soil erosion are detachment, transport, and deposition of the soil from the forces of water and rainfall (Fetter 2001).

The intensity and depth of rainfall controls the impact of rain drops. The impact of rain drops on the soil surface, or splash erosion, is the single most important factor to the dislodgement of soil on farmland, roads, or rangeland (Ellison 1950). This impact can destroy the soil structure, place particles in suspension, and create a mixture of soil and water at the soil surface. As this muddy mixture infiltrates the soil, the suspended particles are trapped in the pores of the soil and prevent further infiltration of the water. In the case of a road, the soil is compacted which compounds the problem making water infiltration very difficult (Gucinski et al., 2001).

The overland flow of water transports soil material dislodged by rain drops and further dislodges soil particles as the water moves across the soil surface. This sheet erosion leads to increased scour that eventually create concentrated flow that become rills and gullies. This process can be visually seen on many native surface roads across the world. The addition of vehicular traffic will increase erosion by creating ruts which increase the creation of rill and gullies (Ziegler et al., 2000).

The slope of the land or road makes a great difference in the erosion rate. A project conducted by Vowell (1985) in the Ouachita Mountains illustrates this point. He found that an increasing slope was associated with an increase in total sediment yield. In addition to slope, the capacity of running water is dependent on volume and velocity, which are related to intensity and duration of rainfall.

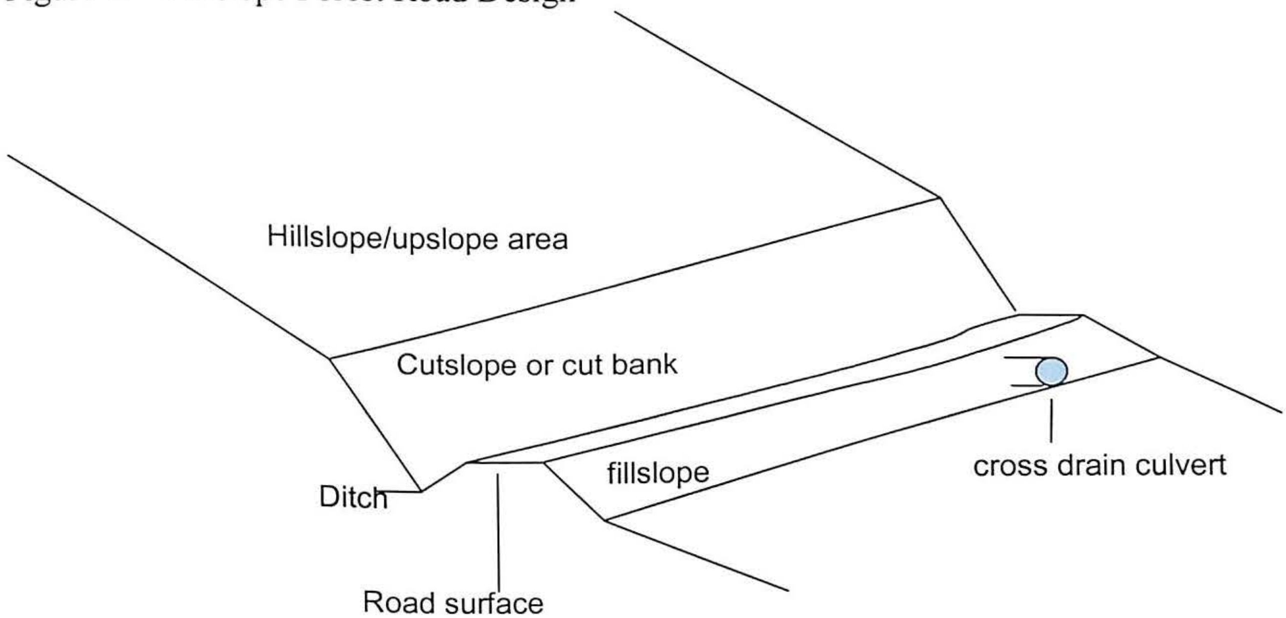
Another set of factors that may lead to increase erosion rates on forest roads is traffic and road grading or blading (Burroughs and King 1989 and Reid and Dunne 1984). Reid and Dunne (1984) reported a 130 times increase in erosion on heavily used roads compared to abandoned roads with similar topography.

2.2 Road Design

The road surface itself is only one aspect of the total area incorporated in a road segment. The total area will include the cutslope, ditch, road surface, and the fillslope (Figure 1) (Brake et al., 1997, Jones et al., 2000, Swift 1988, Turton et al., 1992, and Wemple et al., 2001). All of these areas together comprise what is known as the road prism and each part can play a significant role in the production of sediment. The size and topography of the road prism can vary depending on location.

Midslope roads are built along hillsides that cross any slope. As a result, the major focus of construction is making a surface for vehicular travel. To construct a road surface, the need arises to cut into the hillside. Two common features created from this method are cutslopes and fillslopes (Figure 1).

Figure 1. Midslope Forest Road Design



A cutslope is located on the inside portion of the road prism towards the hillslope region. The age of the road, the gradient of the cutslope, and the presence of vegetation play an important role in erosion. For instance, a cutslope that is recently established with a near vertical cutslope can yield a considerable amount of sediment compared to a well-vegetative cutslope with a flat gradient. A steep cut exposes bare soil and increases the surface area that contributes to erosion and the decreases the establishment of vegetation (Vowell 1985 and Miller et al., 1985). This cutslope can quickly erode during heavy rain events and cause cutslope slides and slumps. Slides and slumps occur when a section of the cutslope is loosened by water flow and a portion slides into a ditch or onto the road surface itself (Jones et al., 2000). This can have many serious consequences such as, blocking the flow of runoff in the ditch and diverting that water onto the road surface. This diverted water can prevent traffic from using that road. In the Ouachita Mountains, it has been estimated that the cutslope can account for nearly half of the total surface area in a road prism (Vowell 1985).

Typically, the sediment and runoff generated from the cutslope is intercepted by a drainage ditch. These ditches run parallel to the road and eventually empty their contents into a cross drain culvert (Figure 1). The purpose of the culvert is to carry ditch water from one side of the road prism to the other. The spacing intervals between the drainage culverts will influence erosion. A smaller spacing interval decreases the velocity and volume of runoff between ditch segments (Jones et al., 2000 and Turton et al., 1992 and Wemple et al., 2001). Spacing of the culvert is dependent on the grade of the road.

The central part of the road prism is the road surface. In some cases, roads can act as a corridor for water (Jones et al., 2000). This flow can eventually develop into mass movement of the road surface or into a debris flow. Through research, guidelines in proper road design have been established to evenly distribute water and properly drain road surfaces (Miller et al., 1980 and Swift 1988). The cross sectional design is an important feature that has been developed to address this problem (Gucinski et al., 2001, Swift 1988, and Turton et al., 1992).

There are three cross sectional designs. They are crowned, inslope, and outslope roads (Swift, 1988 and Turton et al., 1992). A common road design in the Ouachita Mountain region is the crowned road. A cross section of a crowned road reveals a convex shape. The purpose is to distribute water equally on both sides of the road prism.

This particular road design is very versatile and can be used in all terrains but, it requires a drainage system such as a cross drain culvert or wing ditch (Turton et al., 1992).

On the down slope side of the road prism is the fillslope. This portion of the road prism can have a detrimental effect in very steep slopes. However, in the Ouachita Mountains, this aspect of sediment contribution is minimal because fillslopes make up a small portion of the overall road surface area. Past studies in this region have excluded this area from sampling (Vowell 1985). The main focus has been in the measurement of sediment from the cutslopes, road surface, and ditches.

Regardless of the road design, effects from forest roads on water quality and aquatic ecosystems are well documented. These impacts include sediment production and habitat modification. A complete understanding of road design can lead to improved management techniques and research.

2.3 Past Research: Sampling Techniques for Measuring Road Erosion

Monitoring sediment production requires the measurement of the total area for a road segment. The road segment is the region of the road in between drainage outlets and includes the fillslope, cutslope, road surface, and ditch. Once a measurement has been conducted, there are a variety of ways to monitor erosion from roads.

Reid and Dunne, 1984, used a bucket placed at the mouth of a culvert. During rain events volume measurements were taken in 30 second to 5 minute intervals to obtain discharge from the road. To verify the results, replicate samples were taken and shown to be reproducible. At every one to ten minutes, 0.5 to 1 L water samples were collected from the same culvert outlet to measure sediment concentration. Although this method was not precise, it did allow them to measurement road erosion at more sites. This method of sampling yielded sufficient data to demonstrate the effects of forest road erosion in relation to traffic from logging trucks. The drawback to this design is the amount of labor needed for each measurement. In many cases, researchers were unable to be present during each storm event.

Sediment traps are another way to measure erosion from roads without necessarily being present at the time of the storm. Sediment traps can be as simple as a metal tray in a fabric bag. This kind of sediment trap was implemented in a bottomland hardwood forest in Georgia with some success. Five traps were placed in various locations on the downstream side of each road segment. These locations included two traps in a ditch, two on the road bank, and one near the automatic water sampler. These traps collected sediment in the trays which gave the researchers an idea of sediment deposition through settling (Rummers et al., 1997). In the Ouachita Mountains, sluice boxes were used at the mouth of a culvert that served as a sediment trap and standard approach structure to an H-flume. The sluice box captured the large coarse material (rock and sediment larger than 2 mm in diameter) and allowed the suspended sediment and water to pass through the H-flume where water samples were taken and discharge could be measured. A Coshocton water wheel was placed at the mouth of the H-flume to extract an aliquot water sample for measurement of suspended sediment. A wheel sampler will extract approximately 0.5% of the total storm water runoff (Miller et al., 1985). A limitation to this sluice box design is a storm that produces a large volume of sediment. This will cause a build up of sediment in the H-flume which leads to data loss and errors in total discharge and suspended solid measurements (Miller et al., 1985 and Vowell 1985).

To get an accurate measurement of erosion, Luce and Black (1999) placed 1.5 m^3 plastic tanks at the outlet of cross drain culverts. With the use a crane, they measured the weight of the bin with water only and with water and sediment. From these measurements along with the estimate of water and soil density, they were then able to calculate the mass of the sediment. The weight of the tank with water and sediment was subtracted by the weight of the tank with water only. This value was multiplied by the density of the sediment and then divided by the difference between the density of the sediment and the density of water. These tanks had a good trapping efficiency. Luce and Black (1999) reported that an overflowing tank with a third of the volume filled with sediment captures 70 to 80% of the fraction finer than silt and all of the larger fractions during a 12 mm/hr storm event. This is an excellent method for capturing sediment, however, the cost of equipment (e.g. the crane) and the leftover slurry of sediment and water can be limiting factors.

Sediment traps are effective for measuring large sediment samples but they are not efficient in measurement of suspended sediment. An automatic water sampler and a Coshocton water wheel sampler are useful tools for researchers. An automatic water sampler has the ability to take sequential individual water samples throughout a storm event but a Coshocton water wheel will take a single aliquot of the entire storm. The automatic sampler is activated by a data recorder or some other triggering device. Once the sampler is activated, this device can retrieve a water sample at every set time interval or if there is a significant change in flow. Numerous studies have used these samplers to collect data on suspended sediment that a sediment trap is unable to measure (Beasley et al., 1984, Kochenderfer and Helvey 1984, Miller et al., 1985, Rummers et al., 1997, Vose and Riedel 2002, and Vowell 1985).

The location of the samplers varied in each study. Rummers et al., (1997) placed automatic water samplers uphill and downhill of the road segments. This gave the project a comparison of suspended sediment before and after the storm-induced flow passed over the road surface. Researchers in the Conasauga watershed of Georgia installed samplers along a transect that started at the culvert outlet and ended where the surface flow entered the stream or infiltrated in the forest floor. Anywhere from 3 to 5 samplers were installed along these transects. This method served dual purposes, one, to obtain a sediment yield from roads and, secondly, it gave them an idea of sediment transport from the road runoff (Vose and Riedel 2002).

Table 1. Erosion measurements from forest roads throughout the United States.

Site and Region	Erosion rate (kg/ha/yr)	Source
No. McCurtain County, OK (82-83)	91,000	J. Vowell (1985)
No. McCurtain County, OK (82-84)	~79,000	Turton and Vowell (2000)
Alum Creek Watershed, AR	55,000	Miller et al., (1985)
Zena Creek, ID	16,000	Megahan and Kidd (1972)
Ditch Creek, ID	80,600	Ketchson and Megahan (1996)
Fernow NF, WV	42,000	Kochenderfer and Helvey (1984)

2.4 Erosion Models

Soil erosion is a complex interaction between the environment (climate and topography), the vegetation, and the soil. Over the years, a demand grew to have a tool that can simulate this interaction for farms and rangeland. This tool needed to examine alternative conservation practices (i.e. tillage procedures) and their potential effects on erosion rates. The Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1978) became a powerful tool in soil conservation (Heady and Child 1994). Presently, there are many models available that aid in predicting soil loss, such as, the Revised Universal Soil Loss Equation (RUSLE) and Water Erosion Prediction Project (WEPP) (Laflen et al., 1991 and Renard et al., 1991).

USLE is a factor based equation that takes in account five factors to predict erosion for a particular field. The equation and factors are:

- A = RKLSCP
- R = climate erosivity
- K = soil erodibility
- LS = Topography (length and slope)
- CP = Management and Land Use

In short, the R factor takes in account the precipitation and rain intensity. The K is a measure of soil erodibility for a soil series. The LS factor accounts for slope steepness. CP represent two factors of vegetation cover, management (such as tillage of the soil), and surface conditions that affect erosion (Renard et al., 1991).

This equation has been a staple for soil conservationists for many decades. In the last fifteen years, with the increase in knowledge about soil erosion, modifications were made to the model to yield accurate results. These changes came in many forms. The R factor was revised to include new weather stations in the United States and corrected splash erosion by adjusting for flat slopes. Soil erodibility (K) was modified to take into account changes from season to season. Soil is more susceptible to erosion in the spring time due to spring thaw and less likely to erode in the winter when frozen. Modifications were made to the slope steepness. USLE weighted heavily on the factor of slope length in the equation and not as much on slope steepness. It has been found that soil loss is more sensitive to slope steepness than slope length (Renard et al., 1991). The model was revised to account for slope. Finally, the revised equation improved factor values for cover management. The equation was modified to model the effects of different farming and management practices. The final result was called the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991).

Even with these improvements to the USLE, the main purpose of this equation is to measure erosion from cropland and rangeland. There has been successful implementation of this equation to other settings, however, it is difficult to apply this model and obtain satisfactory results (Laflen et al., 1991). In the mid eighties, a project was conceived to develop a model to replace USLE. This project became known as the Water Erosion Prediction Project (WEPP). WEPP steps away from this factor based equation model to a processed based prediction model (Laflen et al., 1991). The WEPP model is a complex computer program that incorporates the processes that cause erosion. These processes include infiltration and runoff, soil detachment and transport, and soil moisture content (Elliot et al., 1999). Unlike the USLE and RUSLE models, WEPP takes in account the time of year to determine the precipitation event (whether it is rain or snow). WEPP can also determine the infiltration rate and surface runoff. WEPP has the ability to include the hillslope region. This model can calculate both the deposition and erosion rates of the hillslope and incorporate it into the overland flow model (Elliott et al., 1999 and Flanagan and Livingston 1995).

A unique aspect of the WEPP model is its flexibility. A great example of this flexibility is in forest road erosion modeling. Elliot et al., (1999a) adapted WEPP for prediction of forest road erosion. This adaptation is called WEPP: Road. Similar to the original WEPP model, WEPP: Road simulates the processes that cause soil erosion. Unlike the USLE and the other modified versions of the USLE, WEPP can take into account erosion that occurs in ditches.

To obtain an accurate output, there are a set of parameters needed in the model. These parameters include:

- regional climate of the study area
- local topography (i.e. slope, area, etc.)
- soil characteristics
- the presence of gravel
- road design
    1) road width
    2) road surface cross section (outsloped, crowned, or inslope)
    3) condition of the road surface (ruts or unrutted)
    4) drainage spacing and the condition of the ditches
- vegetative cover.

After the values of the parameters are entered, the user must specify the number of years to simulate. It is recommended that at least a 30 year model should be simulated to obtain sound results. A series of outputs will be given by WEPP. Included in this output are:

- Average precipitation
- Annual runoff
- Annual sediment yield.

Some studies have been conducted over the past few years that used WEPP and WEPP: Road to predict erosion rates from forest roads (Elliot et al., 1994, Elliot et al., 1999, and Tysdal et al., 1997). Tysdal et al., (1997) used WEPP to predict erosion and transport of sediment. They found that the prediction varied a great deal with several different factors, such as, topography, soil type, and climate. However, the predictions were within the same order of magnitude. They also concluded that further research was needed to accurately predict plume formation or sediment transport.

Many other studies have validated the WEPP model for various different scenarios. For instance, researchers in western Oregon compared observed results to WEPP's predicted values. They found that WEPP tended to over predict sedimentation rates but the values were within the range of error of measured results (Elliot and Tysdal 1999 and Tysdal et al., 1999). Elliot et al., (1999b) summarized observed erosion rates to predictions obtained by WEPP for studies across the United States. His results illustrated WEPP: Road's ability to predict erosion rates within the same order of magnitude as measured results.

In summary, the WEPP model holds promise in predicting forest road erosion. Although the accuracy can vary, the WEPP model can aid in management decisions. WEPP can help resource managers by giving them information about runoff, sediment yield, and sediment delivery, which will enable them to focus their attention on problem areas and act accordingly. This is quickly becoming an issue during times of budget constraints and increasing water quality issues.

2.4 Forest Management and Roads

Knowledge of the road network in any or all forested watersheds are important to effective management of roads. Road inventories are needed to define problem areas and to locate areas that benefit from access (e.g. timber harvesting and recreational facilities) (Gucinski et al., 2001). Many of the forested regions in the United States do not have accurate inventories of their road networks. However, forest managers are conducting inventories with GPS and GIS. These road surveys are currently being conducted in the Ouachita Mountains.

These types of inventories identify road surface types. On most forested roads, there are two main road surface types. They are gravel and native material. Graveled roads usually contain non-native quarry rock material. This type of road surface is common on heavily traveled roads because it armors the surface from traffic. Graveled roads also prevent some erosion by protecting the surface of the road from the impacts by rain drops (Gucinski et al., 2001). Native material surfaces contain no outside source of rock or material. They contain no added rock except for the rock that is already present in the soil. A majority of forest roads in the United States are native material roads (Riiters and Wickham 2003).

Once an inventory has been conducted, useful information can be extracted. For example, stream crossings and the proximity of roads to streams can be identified (Gucinski et al., 2001). Research indicates that the number of stream crossings relates to an increase in sediment deposited into streams (Reid and Dunne, 1984 and Jones et al., 2000, Wemple et al., 2001). Sedimentation of streams can have a negative effect on the reproduction of certain fish that require a gravel covered stream bottom for spawning (Reid and Dunne 1984, Eaglin and Hubert 1993). BMPs are being developed to limit the effects that forest roads have on streams by limiting the number of stream crossings (if possible) and preventing large road segments from draining directly into streams (Jones et al., 2000). Roads have also been identified as primary suspects for shortening the lives of reservoirs. Over time, this will require management attention (Elliott et al., 1999).

Maintenance activities are another important aspect of forest road management. Roads that receive high traffic inevitably need regular maintenance. Over time, traffic will negatively impact a road surface by creating ruts on the road surface which prevents water on the road to drain into the ditch. Reid and Dunne (1984) found a correlation between increased traffic intensities and erosion on forest roads in the Pacific Northwest. As a result of erosion, roads may become unusable and maintenance would be required to allow the passage of vehicles (e.g. logging trucks). A common road maintenance procedure is re-grading of the road surface with a blade. A road plow will try to flatten a road surface, eliminating the ruts and reshaping the road surface (crowned, insloped or outsloped). Road grading also presents another problem in relation to road erosion. This activity will also introduce loose sediment that can be transported by surface flow during a rain event (Luce 2002, Reid and Dunne, 1984, Reid et al., 1984, and Ziegler et al., 2001).

Recent research on tire pressure for logging trucks have produced promising results in the reduction of erosion from roads with little road maintenance. Moore et al., (1995) noted a reduction of up to 84% in erosion when tire pressure on trucks was low. Tire pressure was reduced from 90 psi to 30 or 50 psi depending on the weight of the truck. They observed an average of 80% reduction in road surface sediment over the three year testing period in Lowell, Oregon. This research has had an impact on management requirements. The U.S. Forest Service has included tire pressure requirements for logging trucks to reduce sediment into streams. Also, heavy-haul vehicles are being equipped with Central Tire Inflation systems. CTI is a simple device located on the dashboard that allows the driver to control tire pressure while the vehicle is in motion.

CHAPTER III

METHODS AND MATERIALS

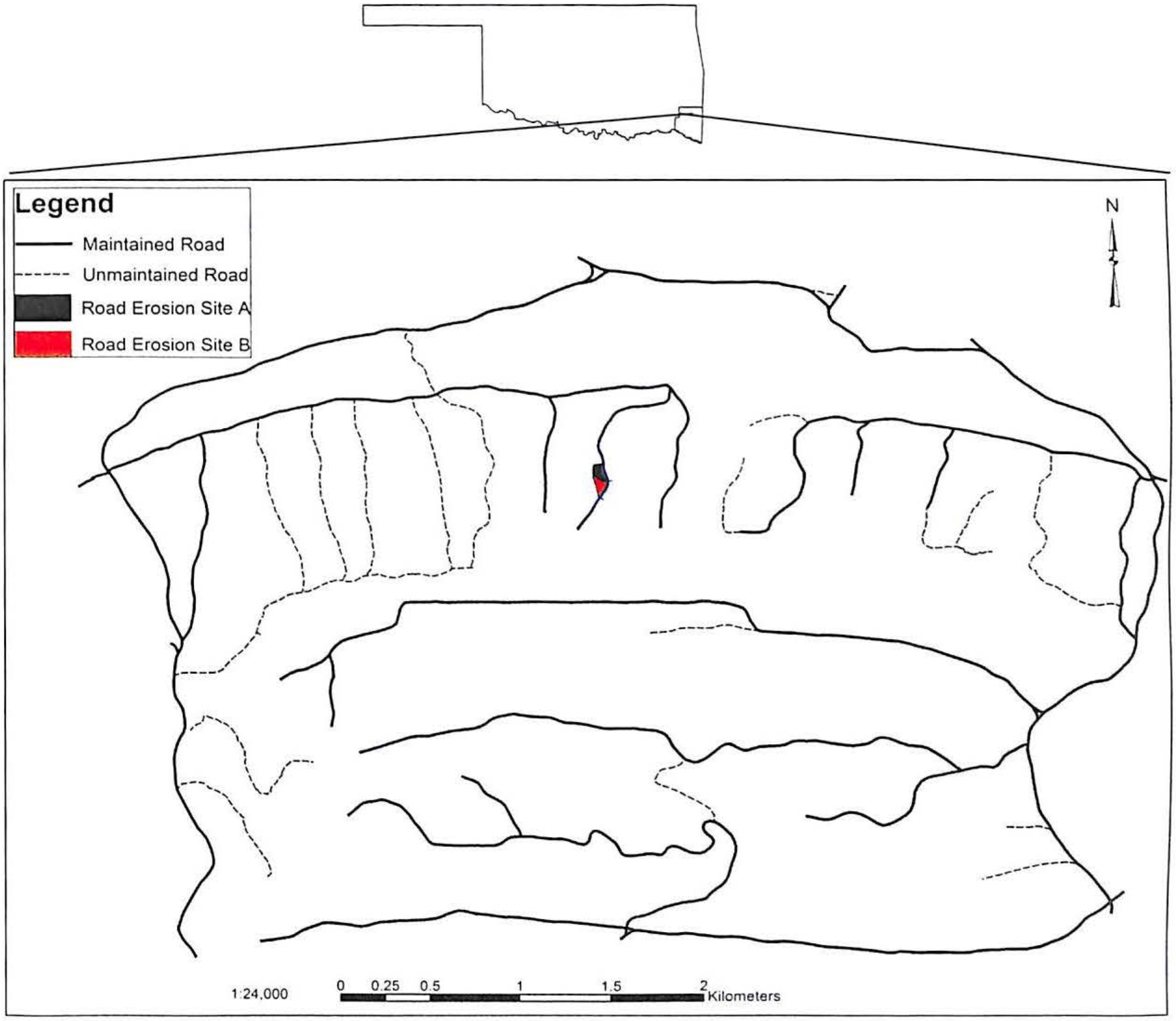
3.1 Study Area

The study area is situated on private (Weyerhaeuser Company), industrial forest land in the Bluff Creek watershed located in northwestern McCurtain County, Oklahoma (34° 27.50'N and 94° 55.20'W) (Figure 2). The approximate elevation is 330 m. The soils in the region are classified as the Goldston-Carnasaw-Sacul association. The soils are well drained and moderately deep upland soils that were derived from the Atoka geologic formations and Jackfork sandstone (Reasoner 1974 and Vowell 1985). The A1 horizon (0 to 102 mm) consists of dark grayish-brown gravelly loam material. The B and C soil horizons are typically yellowish-brown and red silty clays (Reasoner 1974).

This region receives an average of 1270 mm of precipitation annually with the majority of the precipitation in the form of rainfall. The months of April and May combined normally account for over 30% of the annual rainfall (NOAA 2004).

Two adjacent midslope road segments were selected for study. Both segments were crowned, had an inside ditch, and a cross-drain culvert to direct the ditch flow away from the road prism and onto the forest floor. The segments selected in this study were constructed in the late 1970's as an industrial secondary access road. Currently, recreational and ranching traffic is the primary vehicle use although, logging vehicles have used this section in the past and there are plans to use these roads for further logging operations in the future.

Figure 2. Oklahoma and the Bluff Creek road erosion study area.



3.2 Road Segment Measurements and Equipment

Monitoring of these two road segments occurred over an eighteen month period beginning on January 1, 2003 and ending on June 30, 2004. Every storm during this 18-month period was measured to estimate a sediment discharge rate on a storm by storm basis. At the outlet of the cross-drain culvert, two fiberglass fish troughs were placed downstream. These fiberglass fish troughs are similar to troughs found in small fish hatcheries. The troughs were 2.75 m in length and 0.5 m wide. When runoff exited the culvert, it flowed through the first trough. The runoff exited the first trough and entered the lower trough via a 0.25 by 0.25 m hole cut in the base at the downstream end of the upper trough. The runoff traveled through the second trough into a culvert that leads to the approach section to 0.46 m deep H-flume. Each trough contained three or four wire mesh baskets to capture the coarse sediment and material (e.g. large diameter stones, coarse sand, and debris larger than 2mm in diameter) before it reached the H-flume. All baskets were designed to contain 0.3 m^3 of sediment.

The H-flumes in this study were basic 0.46 m deep flumes. A rating table by Brakensick et al. (1979) aided in the calculations for converting the stage height to discharge. A Belfort Instrument portable liquid level recorder (model number 5-FW-1) and stilling well were attached to outside of each H-flume to measure discharge. Each stilling well housed a 4 in diameter metal float, a counterweight, and 9 m of perforated stainless steel tape attached to both the float and counterweight. All of this equipment is connected to the liquid level recorder that converts the movement of the float to a specific change in water level height (in ft). These portable liquid level recorders are modified for potentiometric output for electronic recording by a basic data logger designed for hydrologic studies.

The data loggers (Road segment A and B) used in this study were the Campbell Scientific 21X micrologger. The data logger is a simple module that contains an internal clock and allows several pieces of equipment to be wired electronically via a wiring panel on the front face of the data logger. At road segment A, the liquid level recorder and an automatic water sampler were connected to the 21X. Road segment B contained three different monitoring devices, a liquid level recorder, an automatic water sampler, and a standard tipping bucket rain gauge. The data loggers are designed to log and store readings from each equipment at 5 minute time intervals.

At each five minute interval, the data logger recorded a stage height, the amount of rainfall that occurred during that 5 minute time interval, and prompted the automatic water sampler to collect a water sample when certain criteria were met. A sample was taken if the height of the water level reached 0.02 ft. The sampler would retrieve a sample every thirty minutes unless the water level changed by 0.05 ft (+ or -) during that thirty minute interval. If this occurred then the program would prompt the automatic water sampler to retrieve another sample. This sampling design was selected to obtain samples during rising, falling, and constant flows.

The automatic water sampler used in this study was the Instrumentation Specialties Company (ISCO) 1680 Wastewater Sampler. The ISCO automatic water sampler was set up to extract approximately 250 ml of sediment laden water leaving the H-flume through a copper nozzle located near the outlet of the flume. This nozzle was connected to ¼" vinyl tubing that led to the sampler located two meters from the flume. To correlate the sample with the exact time samples were extracted, the program in the data logger flagged the time by recording a "1" in the data file. If no sample was taken then a "0" was recorded.

Precipitation was recorded by a siphoning (Hydrological Services TB3) tipping bucket rain gauge connected to the data logger at road segment B. Due to the close proximity of the two study segments (~110 m), one rain gauge collected data for both segments.

After each storm, the coarse and suspended sediment for each segment was measured. The coarse materials in the wire mesh baskets were carefully placed into a wheel barrow, thoroughly mixed, and a discrete sample collected. A discrete sample was approximately 1.6 L (~0.5 gallons). This represented 5% of the total volume of a full basket. Each basket held an approximate volume of 32 L. As a check, all coarse material was collected from random storms to determine whether or not this was an accurate sampling method but, due to the lack of coarse sediment movement during the course of the study, all sediment collected in the baskets was collected in a bag, labeled, and brought to the lab for drying and weighting. The suspended sediment samples or water samples were removed from the sampler and properly labeled in both a field notebook and on the sample bottle itself. The samples were then sent to the lab for analysis.

Field measurements or "grab samples" on sediment concentrations were collected to investigate the accuracy of the ISCO water sampler. Samples were taken at the same time as the ISCO water sample and the concentrations were compared to see if there were any differences. The suspended sediment concentrations between the two samples were very similar.

The final step involved in the field work was the cleaning of the sampling equipment. During the course of this study, the only pieces of equipment that required any cleaning were the troughs, baskets, stilling well, and H-flume. The fiberglass fish troughs and the H-flume were cleaned using a simple five-gallon water jug. This was sufficient in all cases due to the small presence of coarse sediment. Most of the equipment stayed relatively clean after each storm event and required little to no maintenance. The stilling well needed to be drained after each event to prevent sediment build up in the well which was easily performed by releasing the drain plug at the base of the well. This action needed to be performed prior to any cleaning with water to prevent a false reading by the water level recorder.

The retrieval of data from the data recorder required the replacement of a SM192 data storage module connected to the data logger. The storage modules were removed from the data logger and replaced with a new module. Software provided by Campbell Scientific (PC208W) enabled the user to extract the data from the module and save that information in a desktop computer.

Maintenance of each site was crucial to successful data collection. A monthly maintenance schedule was implemented to collect data from the data logger, to replace any batteries or desiccant packs on the equipment, and to pump test the automatic water samplers.

It is also important to note that the field equipment only measured a fraction of the road surface. Due to the design of the road (crowned), the sampling equipment only measured one half of the road surface that led into the ditch, the cutslope, and the road ditch. Flow from the other half of the road and the fillslope was not measured. This did not present a serious issue because it was a small part of the road prism. Also, the flow is dispersed and probably is not a major source of sediment.

3.3 Laboratory Procedures

The wet weight of the coarse material collected from the field was determined by weighing. Once the wet weights were determined, the samples were then placed in a drying oven set at 105° C for at least three days to thoroughly dry the sample before the dry weight was recorded. All weights were recorder to the nearest 0.01 gm. The samples were saved for later use in soil texture analysis.

The water samples collected from the automatic water samplers were processed in the lab using the evaporative method described by Guy (1969). Aluminum bread pans were used as evaporation dishes. The clean pans were weighed to the nearest 0.00001 gm on an analytical balance. Sample volume was determined by weighing the sample on a balance to the nearest 0.01 gm. Then, the contents of the sample bottle were emptied into the pre-weighed aluminum bread pan. As a quality control check, a blank sample filled with de-ionized distilled water and a check sample with a known weight of sediment were included with each set of samples being examined. The blank sample gave the user an idea of how much, if any, weight was added to a sample from the de-ionized distilled water. The check was another safeguard in place to give a better understanding on the recovery and accuracy of the evaporative method. A known amount of sediment was placed into a sample bottle and filled with de-ionized distilled water. The sample was mixed and the contents in the bottle were placed into a clean pre-weighed aluminum pan. Both of these samples were treated in the same manner as all of the field samples in the set. After three days in the drying oven, each sample was thoroughly dried and placed into a desiccator for 15 minutes. The dried samples were weighed to the nearest 0.00001 gm on an analytical balance.

Sediment concentrations were calculated using the following equation;

Total solids (mg/L) = [(GW – IW) *1000]/Volume,

where GW is the gross weight (gm) of the sample after three days in the drying oven and IW is the initial weight of the clean aluminum bread pan. This value was recorded for each time increment where a sample was retrieved by the automatic water sampler.

The soil texture of the road surface was determined using the hydrometer method (Gavlak et al. 1994). Twenty random samples were collected from each road segment to give a reasonable composite of the type of soil on each road surface.

All soil samples were placed in a sieve shaker to expedite the separation of soil particles that are greater than or less than 2 millimeters in diameter. A number 10 (2 mm) standard testing sieve with American Society for Testing Materials (ASTM) specifications were used in this procedure (American Society for Testing Materials 1985). The soil sample was placed in the sieve with an enclosed metal bottom to contain all the soil that passed through the 2 mm sieve. The sieve was then situated in the sieve shaker with a metal lid and locked into place. The sieve shaker was operated for at least fifteen to twenty minutes to allow as much soil to pass through the 2 mm sieve as possible. Next, the clods of soil and rock material that was too small to positively identify as either rock or soil were placed into a mortar and pestle for grinding to aid in delineating large rock from soil. Both samples (greater than and less than 2mm samples) were weighed to the nearest 0.01 gm.

The soil that was less than 2 mm in diameter was placed into a weighing tray. It was thoroughly mixed and two 40 gm representative samples were removed from the tray. The first 40 gm soil sample was used in the hydrometer analysis and the second soil sample was used to determine the oven dry soil mass. The oven dry soil mass was used in calculating the percentage of sand, silt, and clay. The soil sample being used for hydrometer analysis was placed into a clean container with 100 ml of 5% Sodium Hexametaphosphate (HMP) dispersing solution. The sample was then placed on a reciprocating horizontal mechanical shaker and agitated overnight. The dispersing solution and shaker ensured that all the consolidated soil particles were broken up for an accurate reading by the hydrometer probe. H_2O_2 was also added to the solution prior to the analysis to remove all organic matter (Gavlak et al. 1994)

Following the overnight agitation, each sample was carefully transferred to a 1 L glass sedimentation cylinder. De-ionized distilled water was added to each cylinder to bring the total volume to one L. The solution in the cylinder was allowed to equilibrate to room temperature before the analysis began. The hydrometers (ASTM 152H) used in this analysis were calibrated on a temperature of 20° C and a particle density of 2.65 g cm^{-3} (Gavlak et al., 1994). A plunger was used to thoroughly mix the sample for at least one minute. The hydrometer was placed in the solution immediately after plunging and then read after thirty seconds. This first reading will indicate the amount of sand in the soil (R_{sand}). For quality control purposes, a glass cylinder tube was filled with de-ionized distilled water and another tube contained a known soil check. This analysis was performed for every sample set. The blank (R_{cl}) is important as a correction factor in the estimation of soil texture. The check insured that the procedures are giving accurate readings.

The second reading was dependant on the temperature of the solution. Gee and Bauder (1986) suggest adjusting the time for the second reading based on the temperature after six hours. The average temperature of solution was 22^{O} C. According to Gee and Bauder (1986), the next reading was taken at seven and a half hours. The hydrometer was placed in the solution to take the reading for clay (R_{clay}) and the blank (R_{c2}). The following equations from Gavlak et al., (1994) were used to estimate the different percentages of sand, clay, and silt:

Sand % = [(oven dry soil mass) – (R_{sand} – R_{c1}) / (oven dry soil mass)] * 100

Clay % = [(R_{clay}-R_{c2}) / (oven dry soil mass)] * 100

Silt % = 100 – (Sand % + Clay %).

The USDA soil triangle was used to determine the textural class (USDA 1951). The percentage of rock in the soil was determined by weight.

3.4 Computer Analysis

When a storm event occurred, all the data during the duration of the storm were saved and used to calculate storm totals. The first procedure that needed to be performed was the conversion of the water level height to discharge. The rating table for 1.5 feet deep H-flumes was used (Brakensick et al. 1979). Stage was converted to discharge for all records that contained a water level of 0.02 feet or higher. A stage of 0.02 feet was chosen because that is when flow occurs out of the H-flume.

Since data collection occurred over an 18 month period, it was important to have each record with its own unique indentification value. The creation of unique date identification is the conversion of the time (in 24 hours) to a decimal. This value was added onto the Julian date. This identification number is especially important for graphing purposes in a spreadsheet because it will allow easy understanding of an x or y axis where the date and time are required.

The last stage in the computer analysis process was correlating the suspended sediment samples to the correct time at which it was collected in order to calculate total sediment yield for each time increment and storm. The first step in this procedure was the examination of each storm event individually. This was done by determining the number of samples collected during the storm and locating the lab and field records that coincide with this event. For one storm, 12 samples were collected by the ISCO water sampler. This is calculated by summing up the number of flagged records in the data file for the ISCO sampler and by the number of samples collected in the field.

There were time periods where there was no collection of suspended water samples. For these time periods, an average sediment concentration was calculated. The average concentration was estimated by taking the concentration of the previous sample and adding together the next sequential sample and dividing by two. The rationale behind this method is that the concentration of the sediment that occurs in between the two known concentrations is most likely somewhere in between those two values. The sediment yield for each time increment was calculated by the summation of the volume of flow that occurred during that time increment and multiplied by the average concentration for that time increment. The total estimation of sediment yield for the entire storm was determined by summing all the incremental sediment yield values calculated for a particular storm.

3.5 Computer Modeling Using Water Erosion Prediction Project (WEPP)

The model selected for this study was the WEPP Windows Interface Version 2002.700. This model was adapted to model erosion from insloped, outsloped, and crowned roads. There are two versions in the WEPP model. One version of WEPP is called the hillslope version and the other is the watershed version. The topography of the road prism will influence which version is selected. The hillslope version will model road erosion as a simple hillslope. This version is appropriate for outsloped roads with no ditch or cutslope. The watershed version incorporates the hillslope portion of the model and allows the user to enter more detail about the topography of the road (e.g. road surface, ditch, and cutslope). The watershed version was implemented in this project because it took into account the cutslope and routed the storm runoff from the road surface and cutslope into the ditch (Brooks et al. 2003 and Tysdal et al. 1997). The climate station (using the CLIGEN weather model version 4.3 and 5.11) used in this model was the Idabel, OK weather station. This model also contains a single storm version to predict sediment yields from a single storm event (Brooks et al. 2003). This single storm option was preferred because it could predict sediment yields from precipitation data collected in this field study.

A Trimble Pro XR Global Positioning Unit and measuring wheel were used to collect many of the road parameters (e.g. the cutslope area, road surface area, road width and length, etc.) that were entered into the model. The upslope area above the cutslope was measured by defining the boundary of the drainage area and the GPS unit was used to collect the area. Since the road was crowned, the insloped option was used in WEPP. WEPP can only estimate sediment yields from insloped or outslope roads. To accommodate this problem, Elliot et al. (1999a) suggests breaking up the road into two halves. This approach is preferred because the sampling equipment could only measure sediment from approximately half of the road surface.

The WEPP watershed version has a template that allows the user to enter this collected data about the physical characteristics and initial conditions of the road. Table 2 summarizes the parameters entered into the model. The initial conditions of the road surface, ditch, and cutslope are very important and can have a direct effect on the sediment yield predicted by WEPP. The initial conditions (e.g. bare soil, vegetated, etc.) selected for the ditch, cutslope, and road surface simulated actual conditions out in the field. The effective lengths, widths, and slopes were used for the road surface. Tysdal et al. (1997) suggested modifying the road surface area in WEPP to better represent the flow of water and sediment off the road. The surface runoff will flow off the road surface and into the ditch along the length of the road and not down the entire length of the road. The effective slope takes into account both the slope of the road and the slope of the crown by using the following equation:

Effective slope = $[(\text{slope of the crown})^2 + (\text{slope of the road})^2]^{0.5}$.

The effective length of the flow path over the road surface is:

Effective length = road width * (effective slope/slope of the crown).

The effective width is used to maintain the correct road surface area and it is calculated as

Effective width = (road length* road width)/effective length.

Table 2. Values of parameters used in the WEPP watershed version for the road surfaces, cutslopes, and ditches at Bluff Creek, OK.

Road site	Topography	Initial Conditions	Soil type	Slope (%)	Length (meters)	Width (meters)
A	Road Surface	Bare (no ruts)	Clay Loam	5 (effective)	3.33 (effective)	67.20 (effective)
A	Cutslope	5 year disturbed forest	Clay Loam	50	113	4
A	Ditch	vegetative or rocked	Clay Loam	4 (uniform profile)	113	0.8
B	Road Surface	Bare (no ruts)	Clay Loam	6.7 (effective)	4.47 (effective)	45.62 (effective)
B	Cutslope	5 year disturbed forest	Clay Loam	50	102	4
B	Ditch	vegetative or rocked	Clay Loam	6 (uniform profile)	102	1

The length of the ditch and the area of the cutslope were not modified. This information along with the Idabel, OK climate data selected for these sites provided WEPP with the necessary data to estimate a sediment yield on an annual basis. For a single storm event, the tipping bucket precipitation data collected by the data recorder was used to simulate an individual storm. The required information needed for this prediction is the total rainfall amount (depth), the storm duration (in hours), the maximum intensity of the storm, and the percent of the total duration to peak intensity. Upon completion of the calculations, WEPP predicted the sediment yield, runoff, and soil loss for each storm. This was performed on all measured storms for both sites.

It is important to note that there are many other parameters in WEPP. Most of these parameters can be changed to better reflect the conditions of the road prism. However, many of these parameters can be extremely difficult to measure without proper equipment. Some of the parameters include critical shear stress of the soil and soil erodibilty (rill and interill). The critical shear stress and soil erodibility represent the soil detachment parameters. The critical shear stress is the shear stress below which no soil detachment will occur from overland flow. The interill erodibility is a measure of the sediment delivery rate to rills which is a function of rainfall intensity and the runoff rate (Alberts et al., 1995 and Elliot et al., 1999c). The rill erodibility is a measure of the soil susceptibility to detachment by concentrated flow (Alberts et al., 1995). These soil detachment parameters can be reduced by 75% to reflect a low traffic regime. For this project, the soil detachment parameters were left at default values. There are many more parameters in WEPP; however, changes in these values have little to no effect on road erosion (Elliot 2004, personal communication).

If a goal of this project was calibration of the model, I could have either measured or estimated antecedent soil moisture conditions for each storm event. This was not performed for each storm due to the uncertainty in estimating this parameter and the lack of equipment and time to measure soil moisture content prior to each storm. Also, the model could have been calibrated based on storm water runoff however, uncertainty in the amount of runoff contributed from the upslope area above the cutslope would present a problem in calibrating. Researchers have found that the upslope area can contribute as much as 80% of the total storm water runoff (Wemple 1998).

CHAPTER IV

RESULTS

4.1 Physical characteristics for each road

The physical characteristics for both road segments are given in table 3. The majority of the area incorporated in the road prism includes the cutslope. The road surface itself accounted for less than half of the total area.

Table 3. Physical characteristics of road segments in Bluff Creek, Oklahoma.

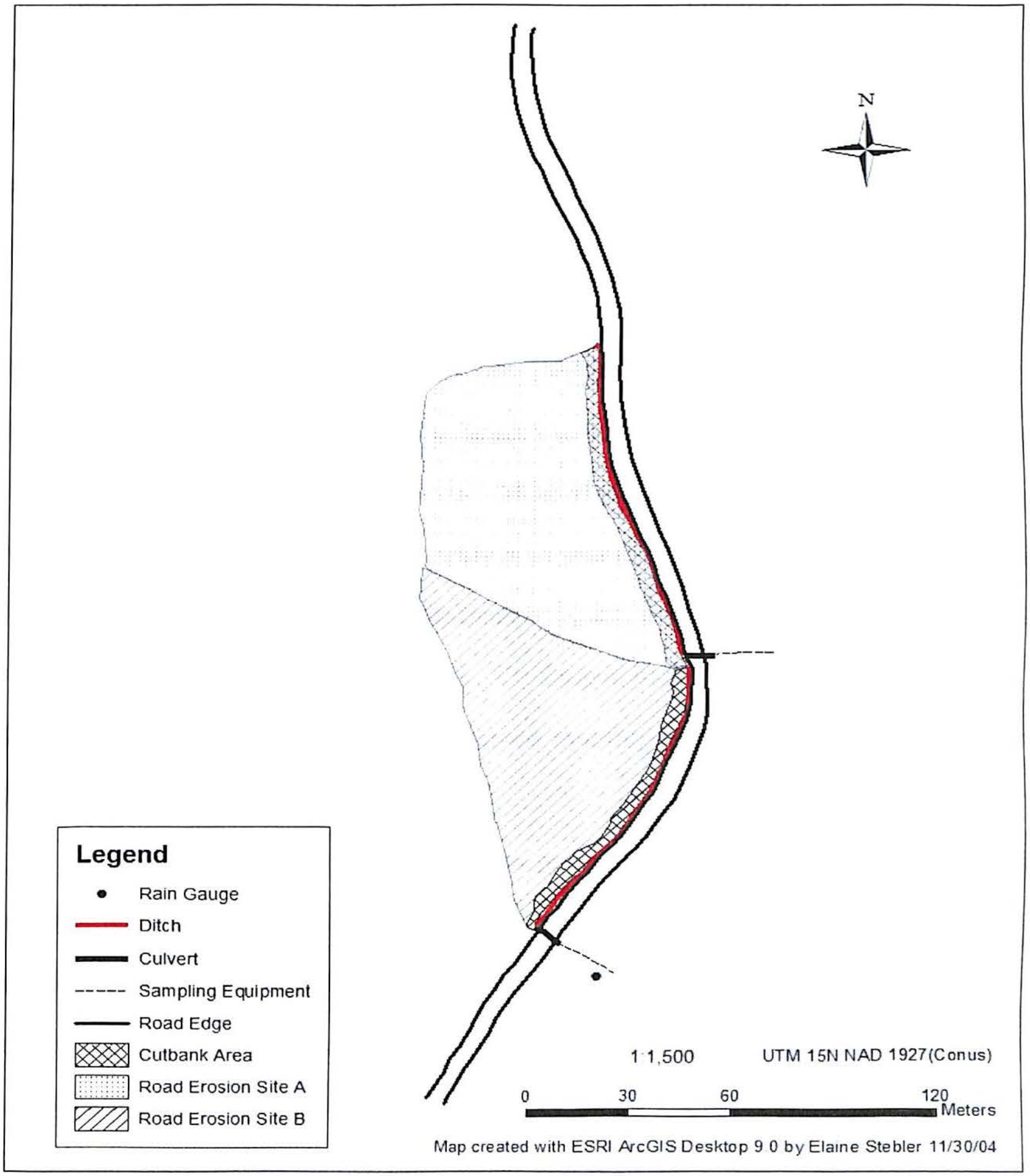
Road Segment	Length (meters)	Width (meters)	Slope (%)	AREA ESTIMATES (m^2) ½ Road Surface	Ditch	Cutslope	Total Area
A (Upland Site)	113	3.5	4	320	62	448	830
B (Lower Site)	102	4.4	6	395	82	350	827

On road segment A, nearly all of the cutslope and ditch were covered with dense vegetation and litter. The types of vegetation that inhabited this area were Loblolly pine seedlings (*Pinus taeda*), blackberry bushes (*Rubus* spp.), Virginia Creeper (*Parthenocissus quinquefolia*), and various grasses. The litter found in the ditches and cutslope mainly consisted of dead grass and pine needles. The vegetation on road segment B was the same vegetation as found on road segment A. However, road segment B had slightly more exposed bare soil in the road ditch due to the heavy scouring that occurred over the life of the road. This scouring not only exposed bare soil but also exposed large deposits of sandstone. The sandstone outcrops protruded out of the soil acting as small impoundments along the length of the ditch. Over time, the ditch has become lined with rocks and vegetation.

Both road segments had native surface roads constructed from clay loam soils. However, road segment A contained less rock (33%) on the road surface than road segment B (44%). Due to the remote location of each site coupled with the lack of logging in the area, both sites received a small amount of traffic. This was clearly evident because of the large amount of vegetation that grew on the road surface itself (i.e. grasses, blackberry bushes, etc.) and the lack of rutting on the road.

Area estimates were also performed on the upslope contributing area above each road segment (Figure 3). Each midslope road segment is a small watershed. Midslope roads intercept both surface and subsurface flow from the hillslope above the road cut. Road segment A had an upslope contributing area of 5358 m^2. Road segment B had an upslope area of 4754 m^2.

Figure 3. Map of both road segments at Bluff Creek, Oklahoma.



4.2 Precipitation and storm runoff

Seventy-six storms (Appendix 1) occurred over the eighteen month period from January 1st of 2003 to June 30th of 2004. Those storms yielded 1,571 mm of precipitation. During the first twelve months of the study, only 765 mm of precipitation accumulated. The last six months of the study yielded approximately 806 mm of precipitation. Storm events ranged in size from 3 mm to 76 mm. The average annual precipitation from the Broken Bow, Oklahoma National Oceanic Atmospheric Administration's weather station is 1,270 mm (NOAA 2004). During a normal continuous eighteen month period from January to June of the following year, an average of 1,940 mm of precipitation would occur. Most of the precipitation is in the form of rainfall. Comparisons of observed monthly precipitation totals to the monthly averages at the Broken Bow weather station (approximately 40 km from the study sites) are given in the series of figures below (Figure 4 to 6). The largest monthly precipitation total was 247 mm in June of 2004 (Figure 6). The lowest monthly precipitation total was 0.0 mm in January of 2003 (Figure 4).

Depth-duration-frequency analysis was performed on the measured precipitation. Three storms met the 1 year return period depth-duration-frequency set forth by Hershfield (1964). On July 10th of 2003, 48 mm of precipitation accumulated in two hours which exceeded the 1 year 2 hour precipitation total of 47 mm. A 1 year 1 hour event occurred the following month on August 29th where, 45 mm of precipitation accumulated in approximately one hour which exceeded the 1 year 1 hour total of 41 mm. The third storm classified under this frequency analysis occurred on April 21st of 2004. In twelve hours, 75 mm of precipitation accumulated which exceeded the 1 year 12 hour precipitation total of 74 mm.

The measured storm runoff for road segment A was 1,353,346 L. The storm runoff from segment B was slightly lower at 812,351 L.

Figure 4. Average monthly precipitation and the actual measured precipitation during the first six months of this study.

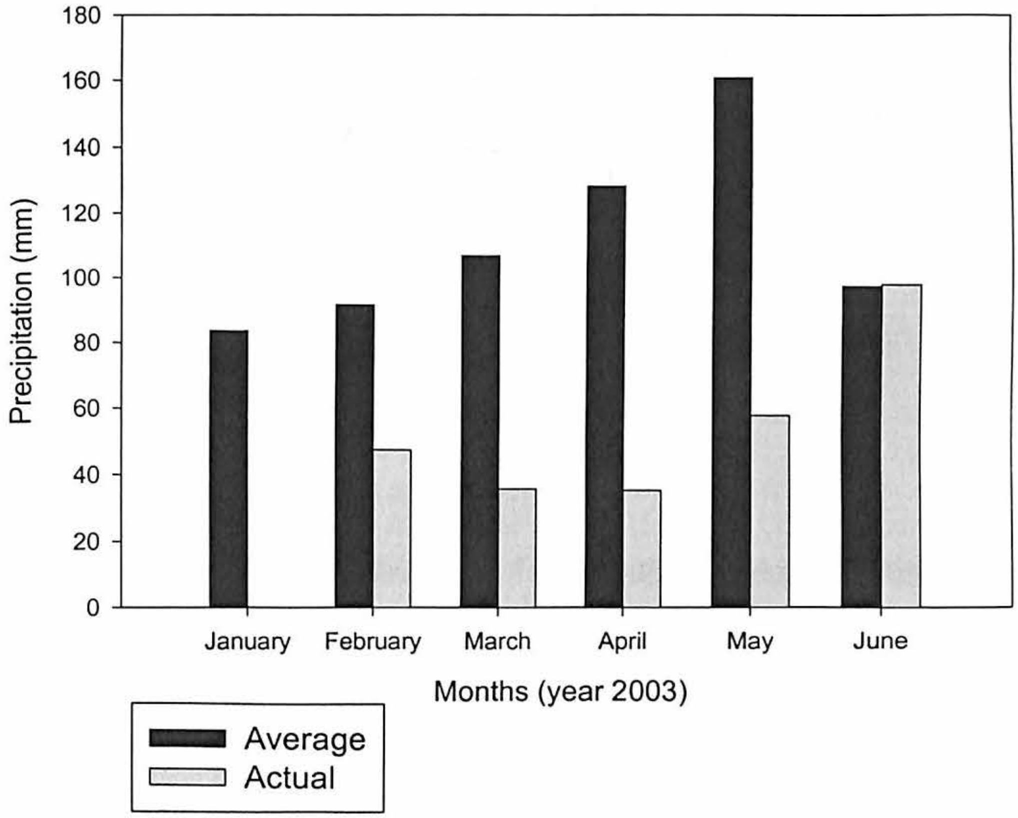


Figure 5. Average monthly precipitation and the actual measured precipitation during the last six months of 2003.

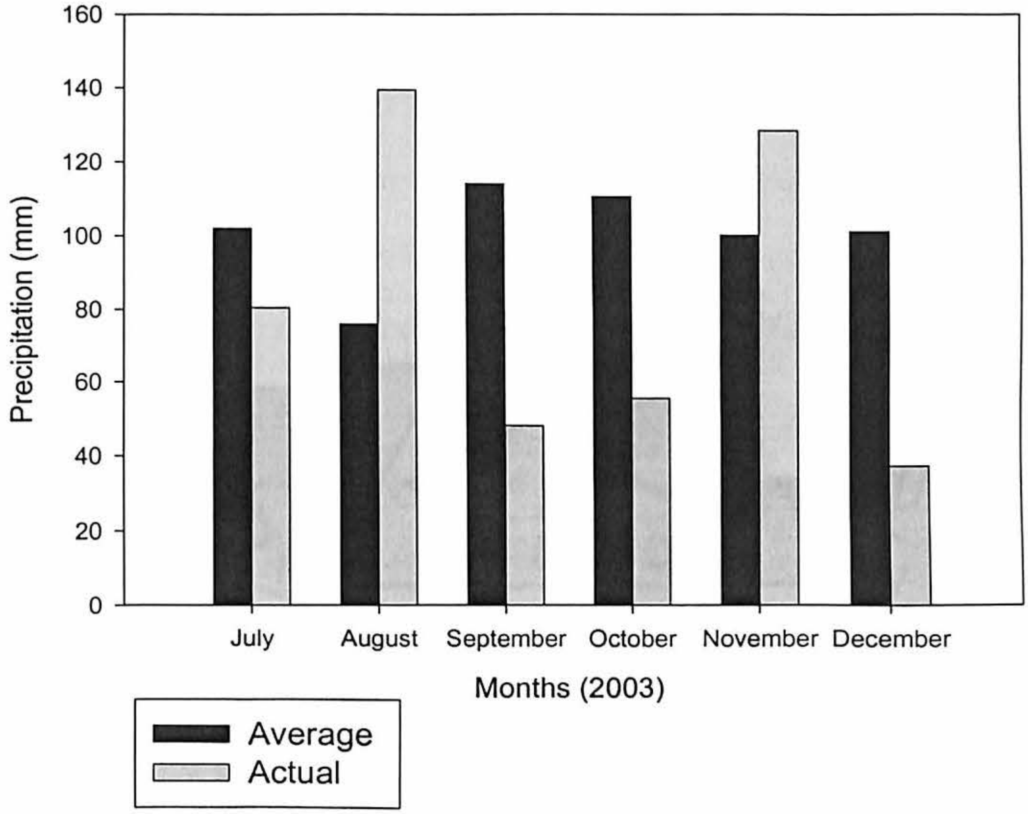
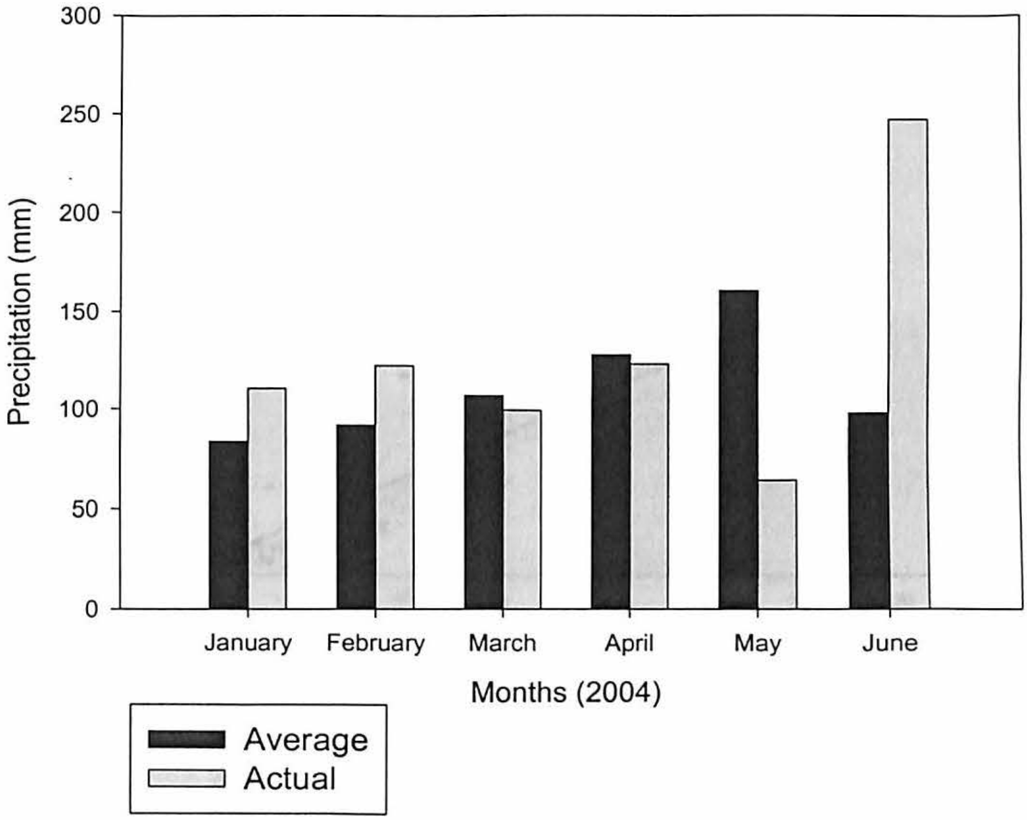


Figure 6. Average monthly precipitation and the actual measured precipitation during the first six months of 2004.



The linear regression analysis of storm runoff to rainfall depth yielded a high correlation for both study segments. At road segment A, the correlation coefficient (r) was equal to 0.79 ($P = 2.89 \times 10^{-12}$) (Figure 7). At road segment B, the correlation coefficient is 0.75 ($P = 9.07 \times 10^{-10}$) (Figure 8). The storm runoff on road segment A was a good predictor of storm runoff from road segment B with a coefficient of determination (r^2) of 0.87 ($P = 8.52 \times 10^{-26}$) (Figure 9).

Figure 7. Regression of storm runoff (Y variable) on rainfall depth (X variable) for 76 storms at road segment A.

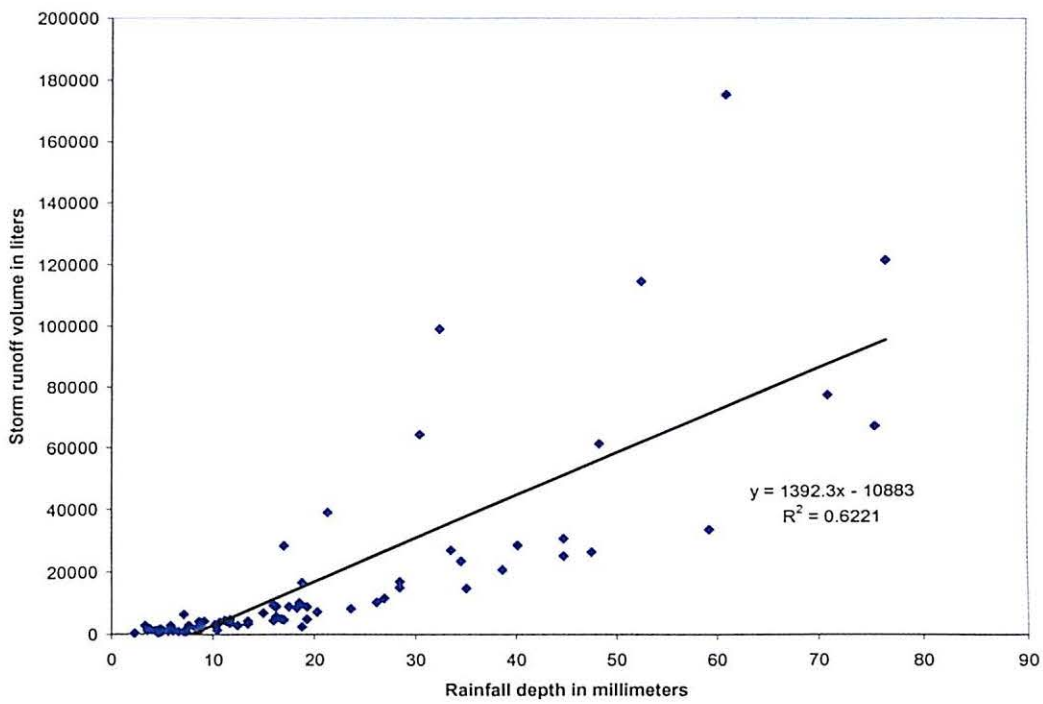


Figure 8. Regression of storm runoff (Y variable) on rainfall depth (X variable) for 76 storms at road segment B.

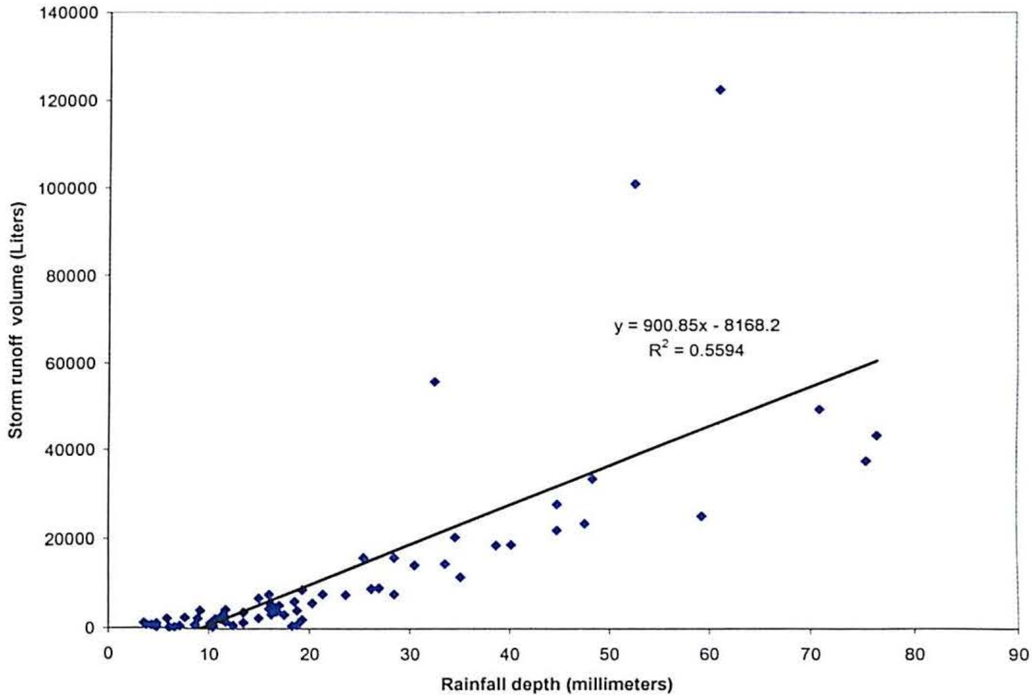
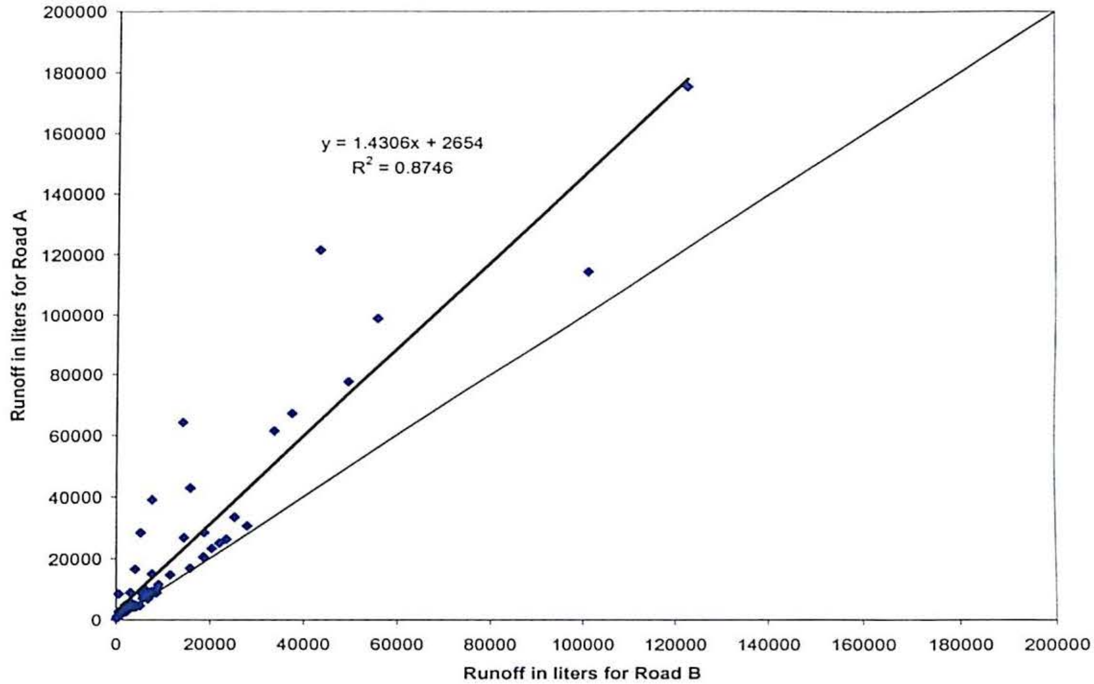


Figure 9. Regression of storm runoff from road segment A (Y variable) on storm runoff from road segment B (X variable) for all storm events. Included in the graph are the 1:1 line, linear line (bold), and the coefficient of determination.



4.3 Sediment Yields

The annualized sediment yields for road segments A and B were 7,600 and 6,500 kg/ha/yr, respectively. These calculations were based on the total area measured which is half the road surface, the ditch, and cutslope. Also, there were certain months during the duration of the study that lack measurable sediment data due to uncontrollable circumstances (e.g. battery failure, vandalism, and equipment breakdown) that led to an adjustment of the total annual estimate. For instance, on road segment B, an equipment malfunction prevented the sampling of two months worth of data in March of 2003 and May-June of 2004 (Figures 10 to 12). As a result of this loss, two months were excluded from the estimate. In other words, instead of adjusting the prediction by one and a half years or eighteen months, the prediction was adjusted by sixteen months. The same procedure was implemented for road segment A where, the month of October was excluded due to the malfunction of the ISCO water sampler.

The highest monthly sediment yield was June of 2003 with a yield of 108 kg for road segment A and 86 kg for road segment B (Figure 10). Similar to the monthly precipitation totals, the lowest monthly sediment yield total was January of 2003 with 0.0 kg (Figure 10). Individual sediment yields for road segment A ranged from 0.0 to 84 kg (Appendix 1). For road segment B, individual sediment yields ranged from 0.0 to 74 kg (Appendix 1).

Figure 10. Monthly sediment yields for the first six months of 2003. It is important to note that due to the malfunctioning of the ISCO water sampler at road segment B, the month of March yielded no sediment data.

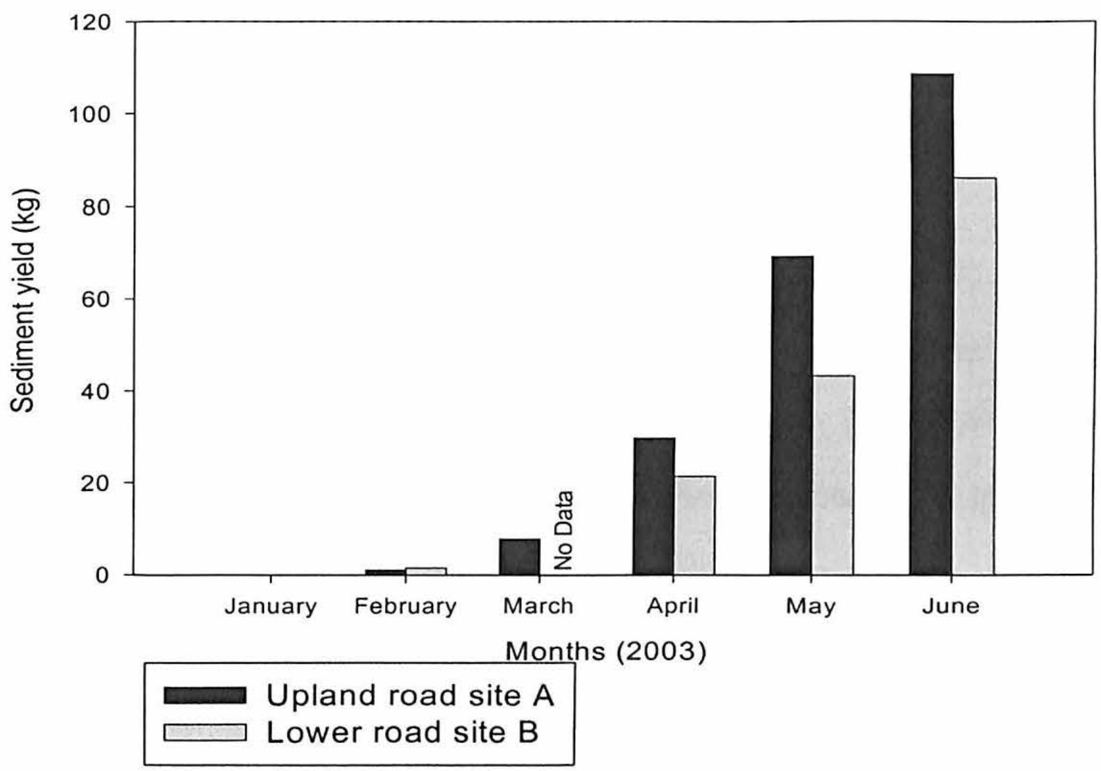


Figure 11. Monthly sediment yields for the last six months of 2003. It is important to note that due to the malfunctioning of the ISCO water sampler at road segment A, the month of October yielded no sediment data.

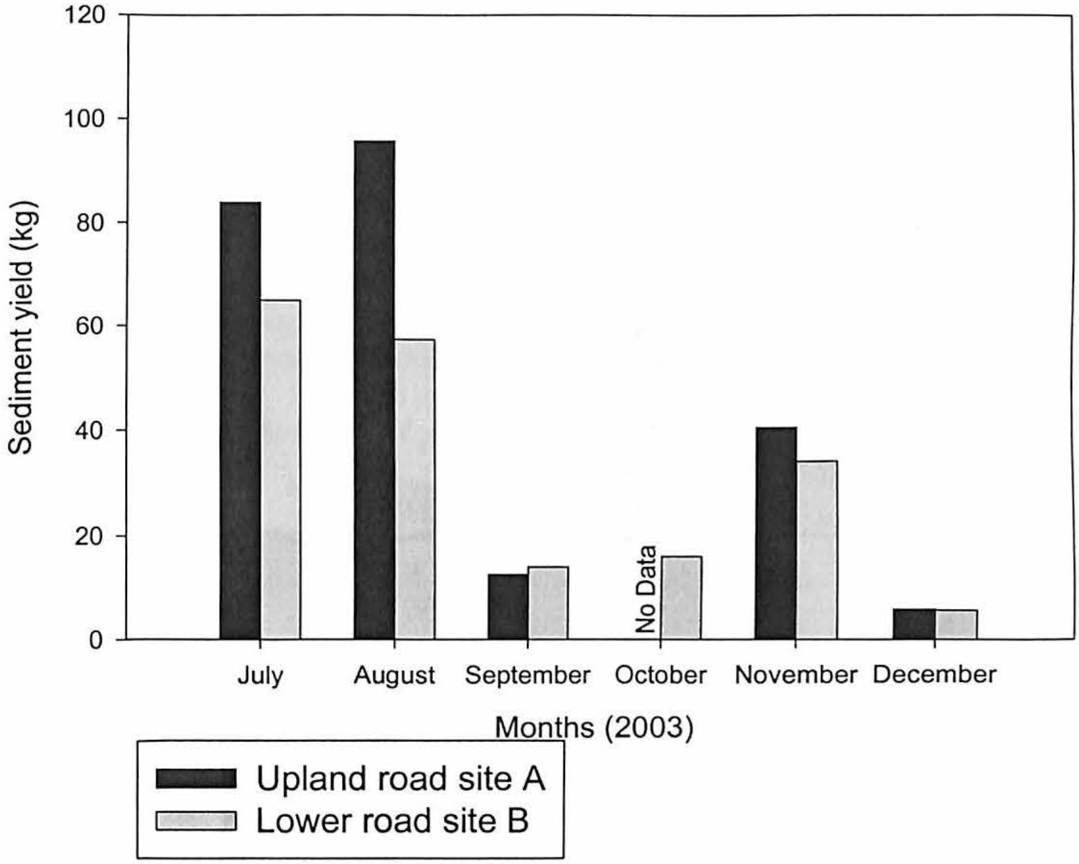
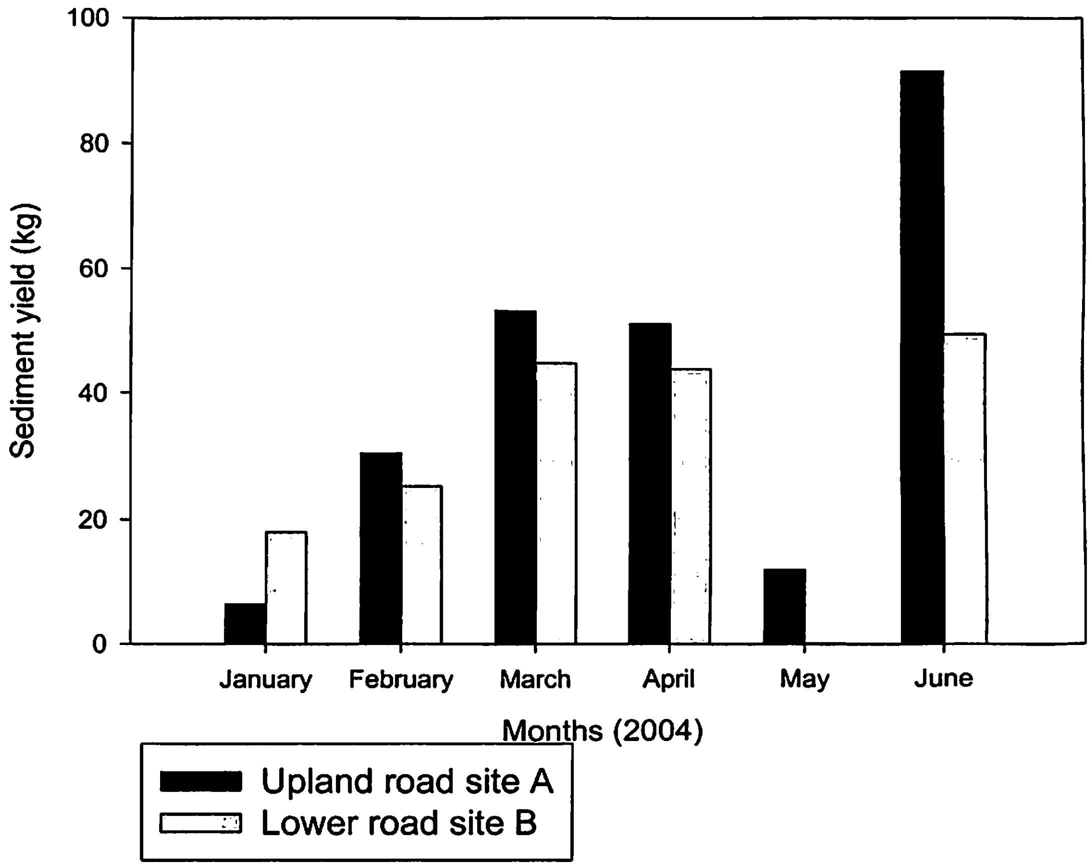


Figure 12. Monthly sediment yields for the first six months of 2004. It is important to note that due to the malfunctioning of the ISCO water sampler at road segment B, half the month of May and half of June yielded no sediment data.



Regression analysis was performed on physical factors that control erosion to see how well these physical factors predict sediment yields. Four physical factors were used in this regression analysis. These physical factors were rainfall depth, rainfall intensity, maximum rainfall intensity, and storm runoff.

At road segment A, only 35% of the variation in sediment yield was explained by the variation in rainfall depth ($P = 1.29 \times 10^{-06}$) (Figure 13). The same was true for rainfall intensity at road segment A (Figure 14). Thirty-four percent of the variation in sediment yield was explained by the variation in rainfall intensity ($P = 4.99x10^{-06}$). The next regression analysis was performed on maximum rainfall intensity and sediment yield. Only 16% of the variation in sediment yield was explained by the variation in maximum rainfall intensity ($P = 0.001$) (Figure 15). Finally, the last regression analysis on storm runoff and sediment yield showed that the variation in storm runoff only explained 28% of the variations in sediment yield ($P = 0.0004$) (Figure 16).

Figure 13. Regression of sediment yield (Y variable) on rainfall depth (X variable) for 76 storms at road segment A.

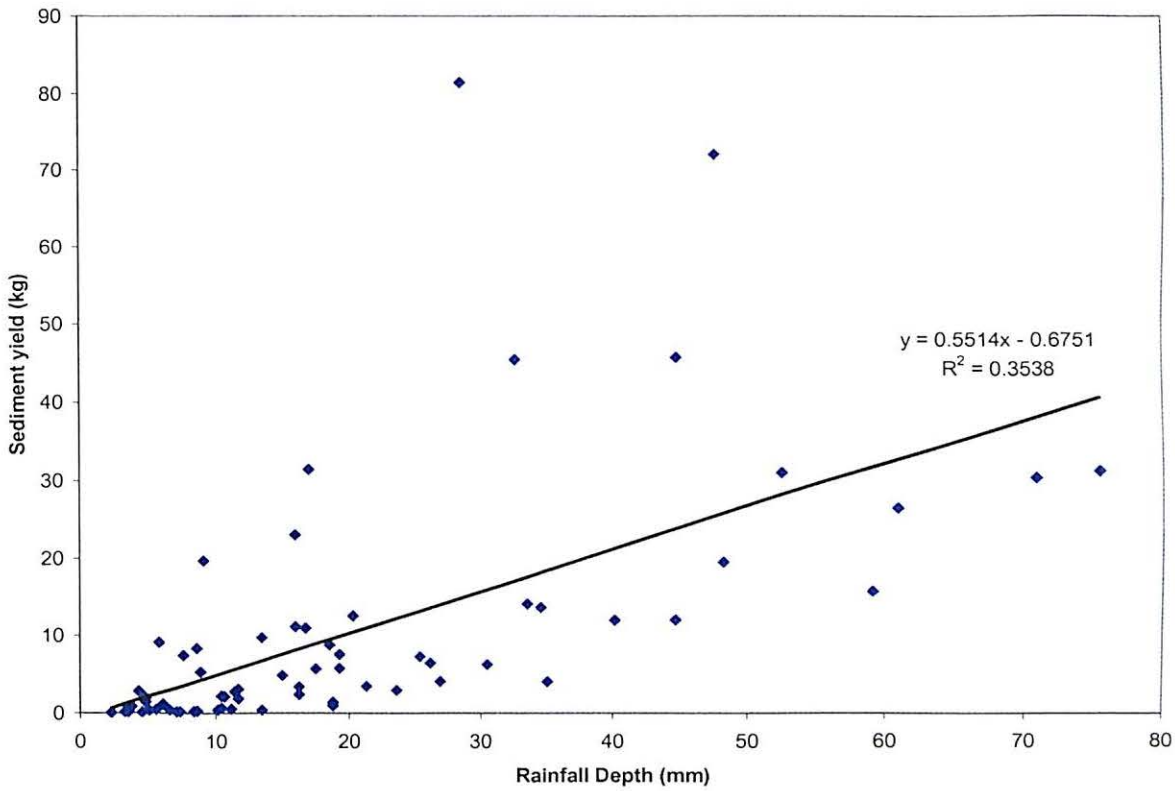


Figure 14. Regression of rainfall intensity (Y variable) on sediment yield (X variable) for 76 storms at road segment A.

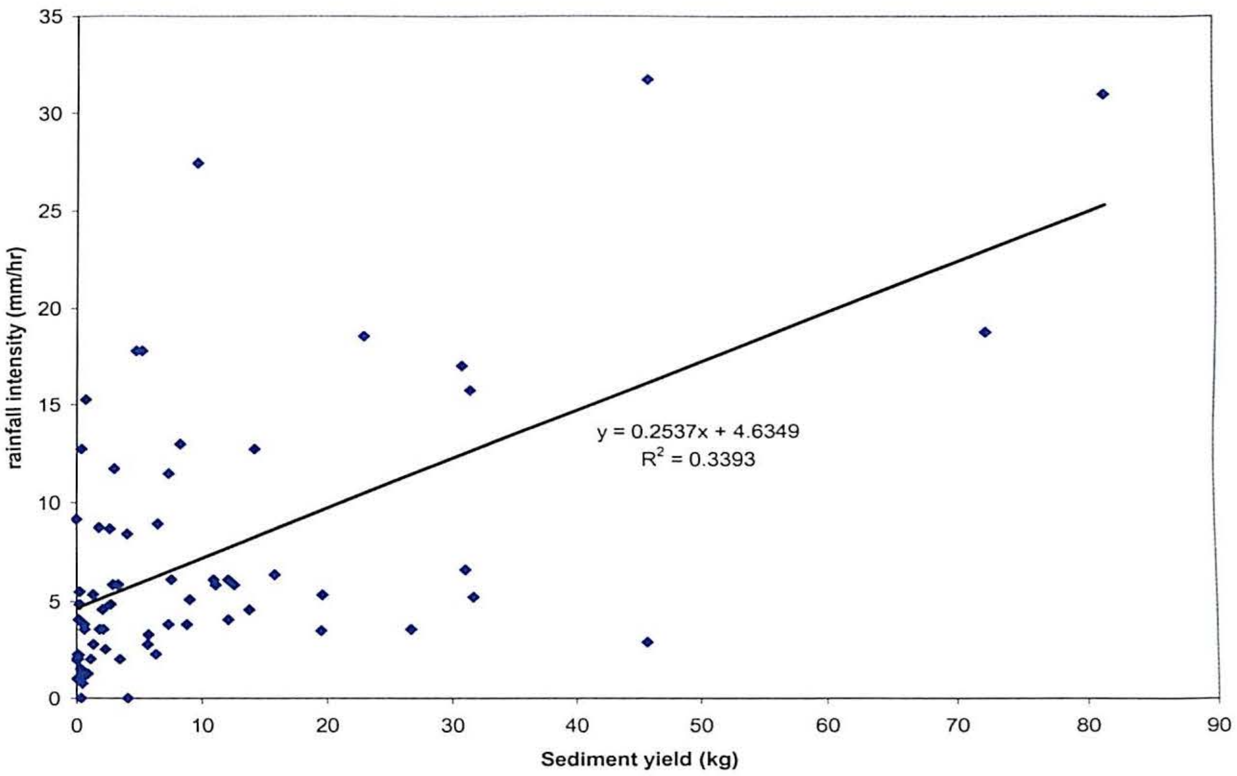


Figure 15. Regression of sediment yield (Y variable) on maximum rainfall intensity (X variable) for 76 storms at road segment A.

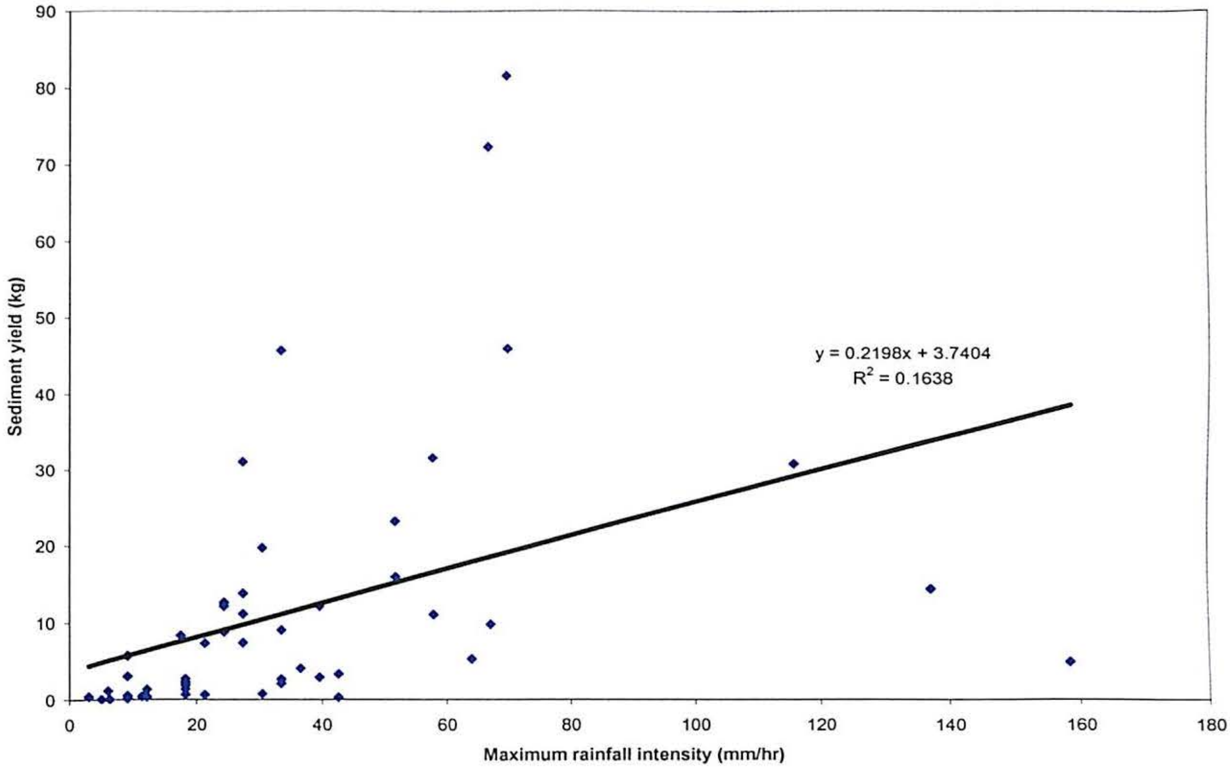
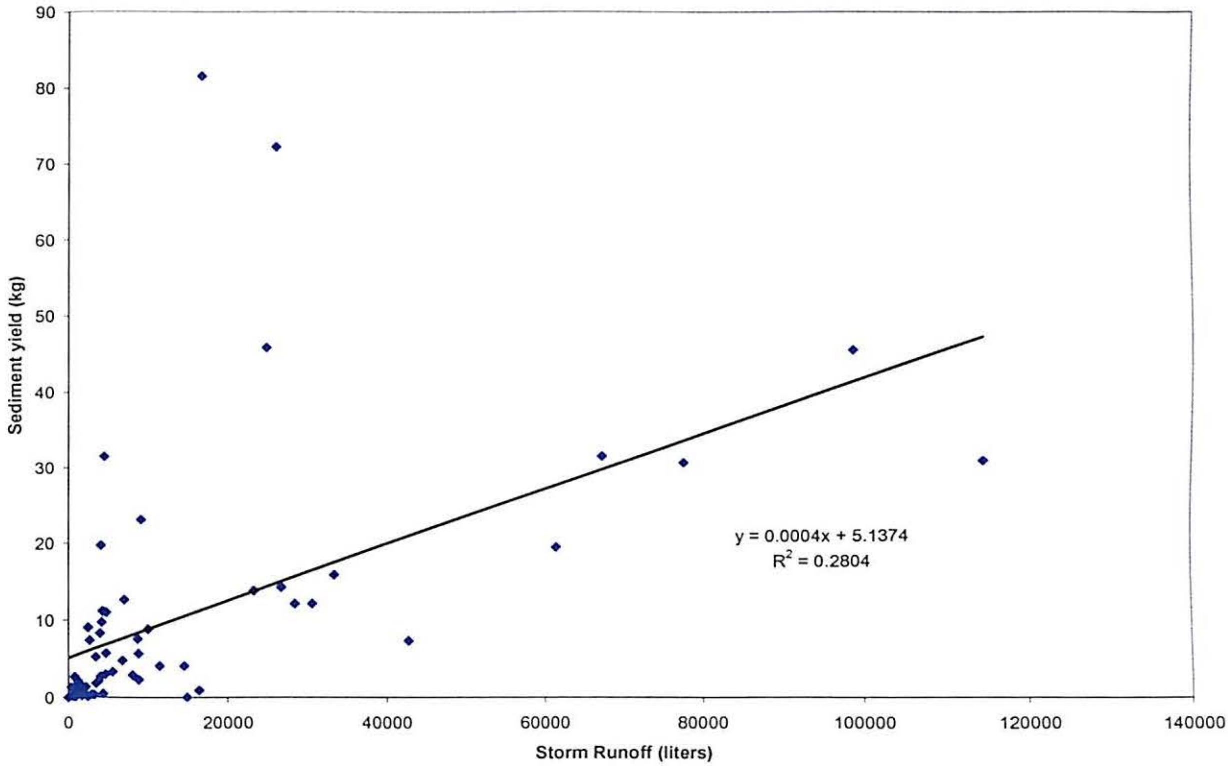


Figure 16. Regression of sediment yield (Y variable) on storm runoff (X variable) for 76 storms at road segment A.



This same pattern was observed on road segment B. Regression analysis of rainfall depth and sediment yield indicated that 32% of the variation in sediment yield was explained by the variation in rainfall depth ($P = 2.07x10^{-05}$) (Figure 17). A slightly lower coefficient of determination was observed between rainfall intensity and sediment yield (Figure 18). 23% of the variation in sediment yield was explained by the variation in rainfall intensity (P = 0.0002). In Figure 19, only 11% of the variation in sediment yield was explained by the variation in maximum rainfall intensity (P = 0.006). The last regression analysis between storm runoff and sediment yield indicated that 26% of the variation in sediment yield was explained by the variation in storm runoff (P = 0.0002) (Figure 20).

Figure 17. Regression of sediment yield (Y variable) on rainfall depth (X variable) for 76 storms at road segment B.

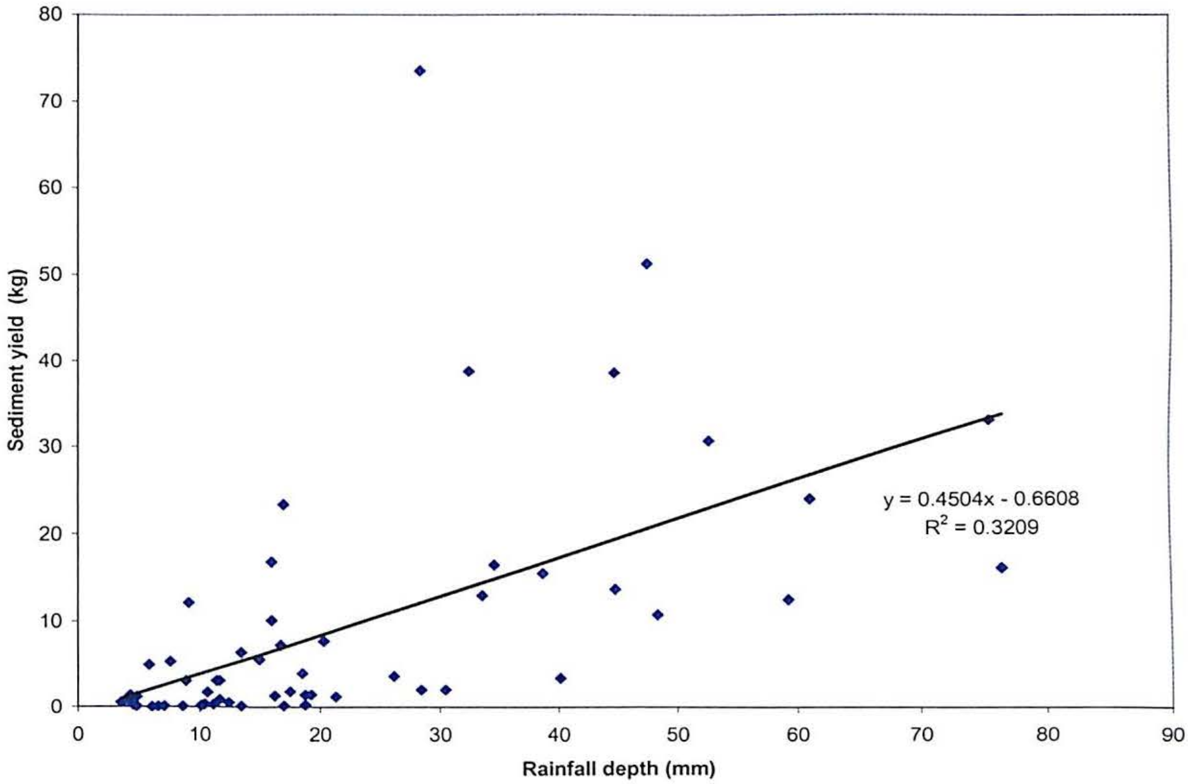


Figure 18. Regression of sediment yield (Y variable) on rainfall intensity (X variable) for 76 storms at road segment B.

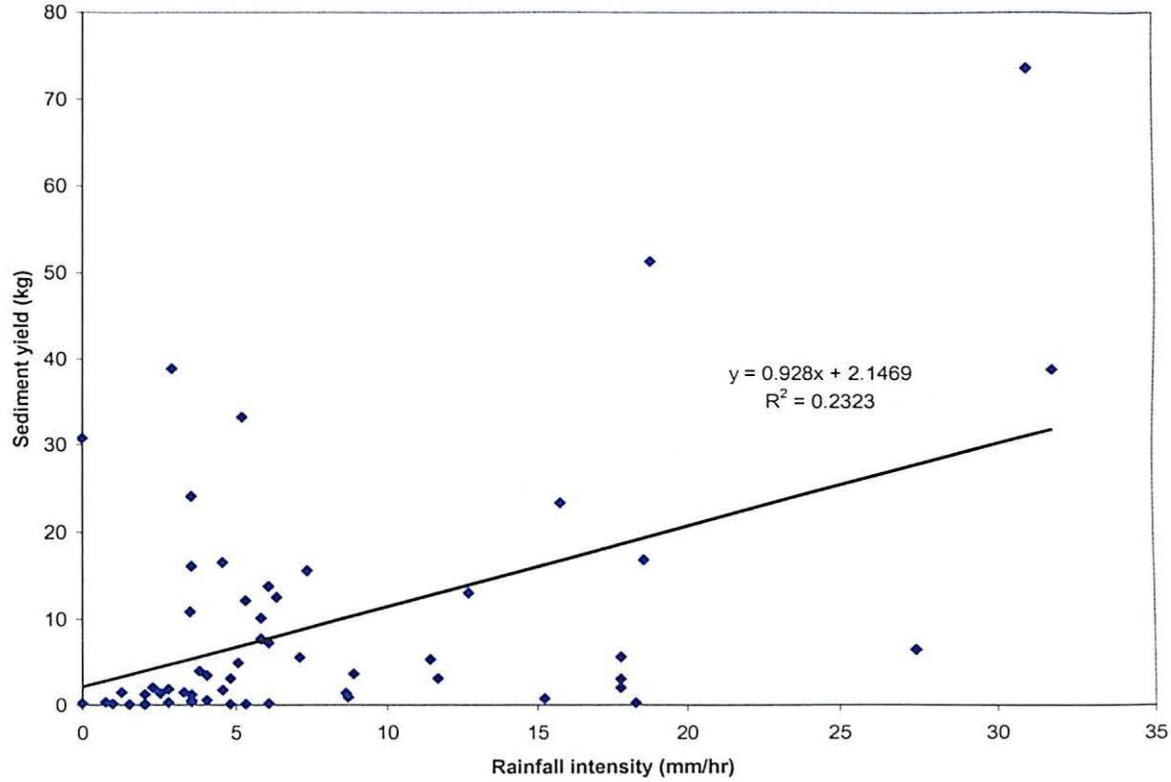


Figure 19. Regression of sediment yield (Y variable) on maximum rainfall intensity (X variable) for 76 storms at road segment B.

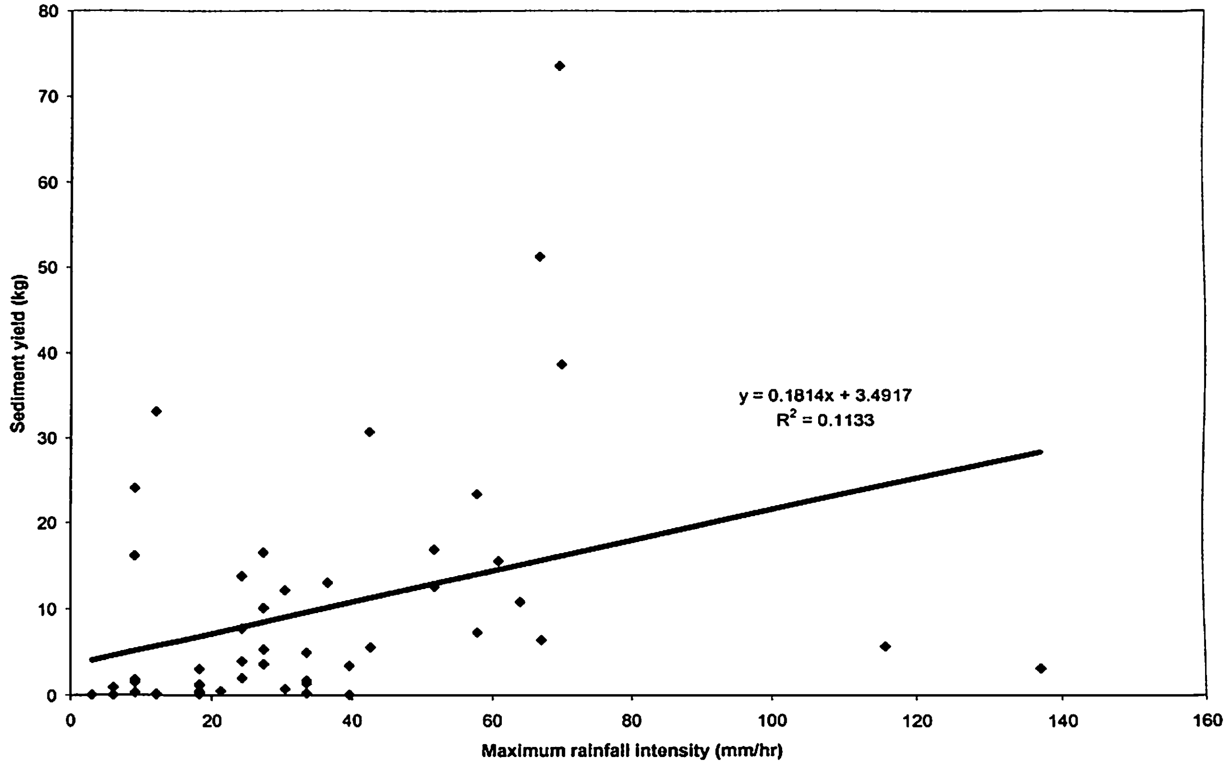
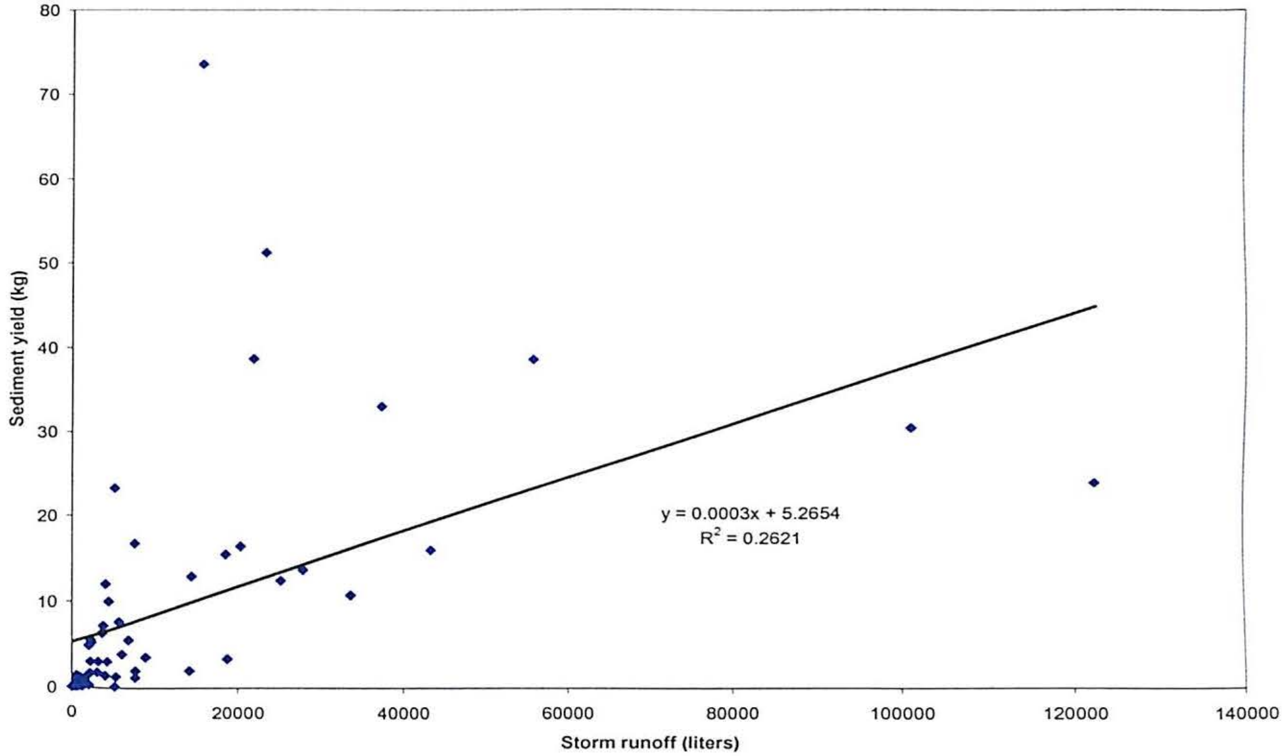


Figure 20. Regression of sediment yield (Y variable) on storm runoff (X variable) for 76 storms at road segment B.



A unique aspect of the suspended sediment sampling technique is the ability to examine changes in sediment yields during a storm event. Previous research on forest road erosion used devices such as a Coshocton wheel sampler (Kochenderfer and Helvey 1984, Miller et al., 1985, and Vowell 1985) or a sediment bin (Luce and Black 1999), which retrieved a composite sample of the entire storm. With the use of an automatic water sampler, I was able to observe changes in sediment yields and concentrations throughout a storm event. Example of two storm events from road segment A are given in figures 21 and 22. As expected, the highest sediment concentrations were in conjunction with the highest rainfall amount. This pattern was observed on all storms regardless of the depth or duration of rainfall.

Figure 21. A rainfall hyetograph, storm runoff hydrograph, and 5 to 30 minute incremental sediment concentrations for a storm event that occurred on June 30, 2003.

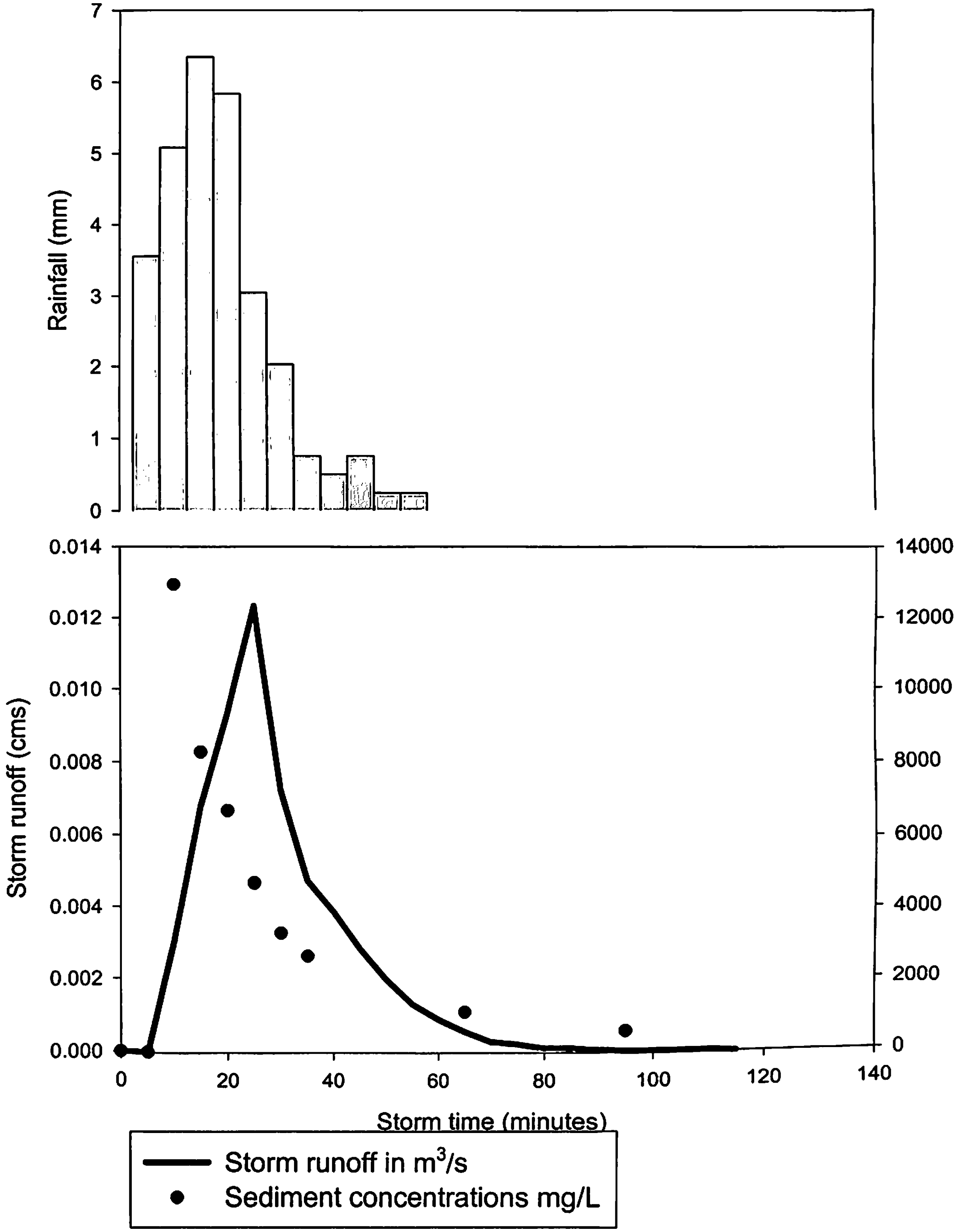
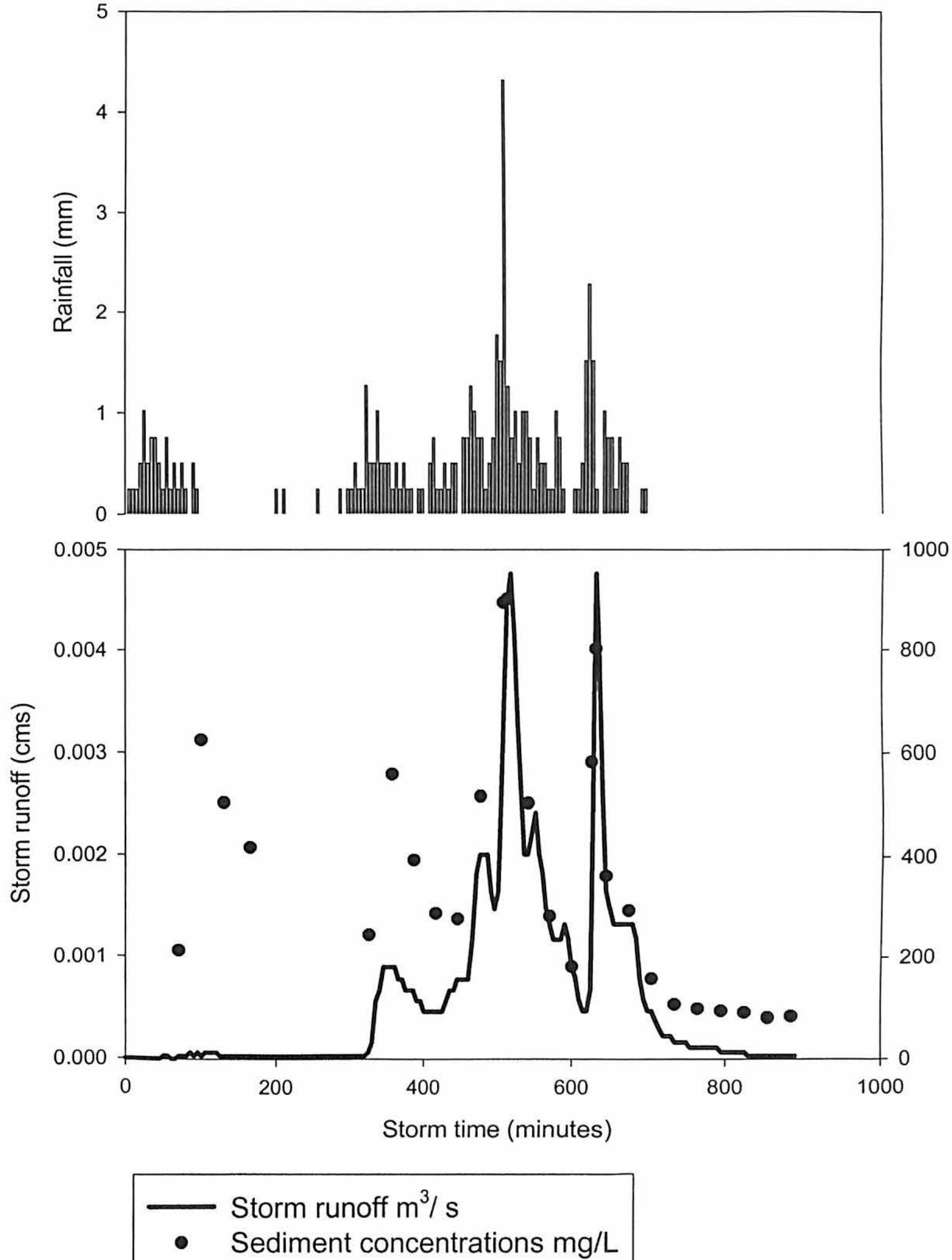


Figure 22. A rainfall hyetograph, storm runoff hydrograph, and 5 to 30 minute incremental sediment concentrations for a storm event that occurred on November 5, 2003.



4.4 WEPP model predictions

The WEPP model (Watershed version) was used to predict sediment yields and runoff from all measured storms during the course of the eighteen month study period (Figures 25 to 28 and Appendix 1). WEPP had the tendency to under-predict sediment yields on storms less than 30 mm. WEPP did over-predict sediment yields on certain storms that were greater than 30 mm. However, WEPP did give reasonable estimates of sediment yields for storms greater than 30 mm.

Regression analysis was performed on the predicted and observed results. WEPP was good at predicting sediment yields with a coefficient of determination (r^2) of 0.47 (P = 2.65×10^{-08}) for road segment A and 0.45 (P = 2.32×10^{-08}) for road segment B (Table 4 and Figures 23 and 24).

The WEPP model made reasonable predictions of annual sediment yields for both sites. For road segment A, WEPP predicted a sediment yield of 6,500 kg/ha/year. This prediction was slightly lower than the observed measurement of 7,600 kg/ha/yr. Road segment B annual sediment yield prediction by WEPP was almost the same as the observed measurement. For road segment B, WEPP predicted a sediment yield of 6,500 kg/ha/yr. This prediction was the same as the observed sediment yield of 6,500 kg/ha/yr.

Table 4. Comparison of measured and predicted sediment yields.

Road	Measured sediment yield kg/ha/yr	Predicted sediment yield kg/ha/yr	Coefficient of Detemination R^2	Relative Error	Nash-Sutcliffe Efficiency
A	7600	6500	0.47	0.14	0.4
B	6500	6500	0.45	0	0.4

Table 5. Comparison of measured and predicted runoff volumes.

Road	Measured runoff volume L	Predicted runoff volume L	Coefficient of Detemination R^2	Relative Error	Nash-Sutcliffe Efficiency
A	1353346	469000	0.42	0.65	0.15
B	812351	479000	0.45	0.41	0.33

Figure 23. Regression analysis of WEPP's predicted sediment yields to observed sediment yields for road segment A.

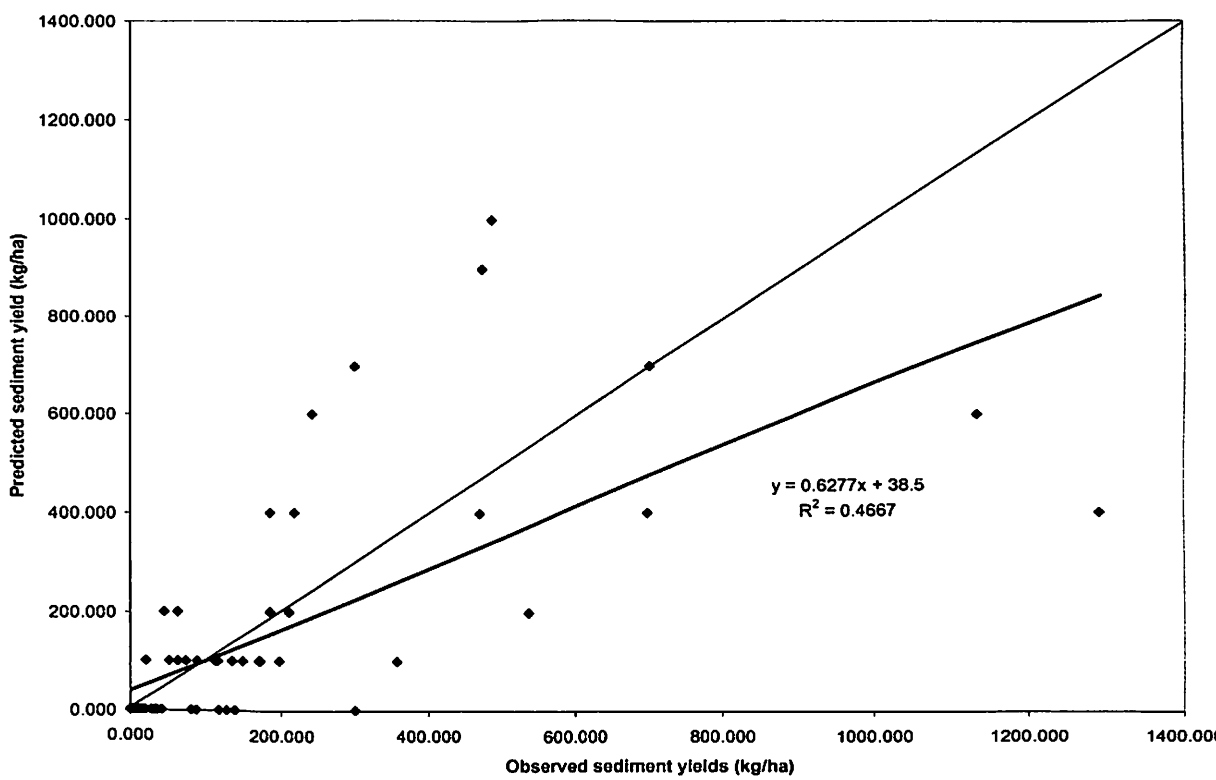


Figure 24. Regression analysis of WEPP's predicted sediment yields (y –axis) to observed sediment yields (x-axis) for road segment B.

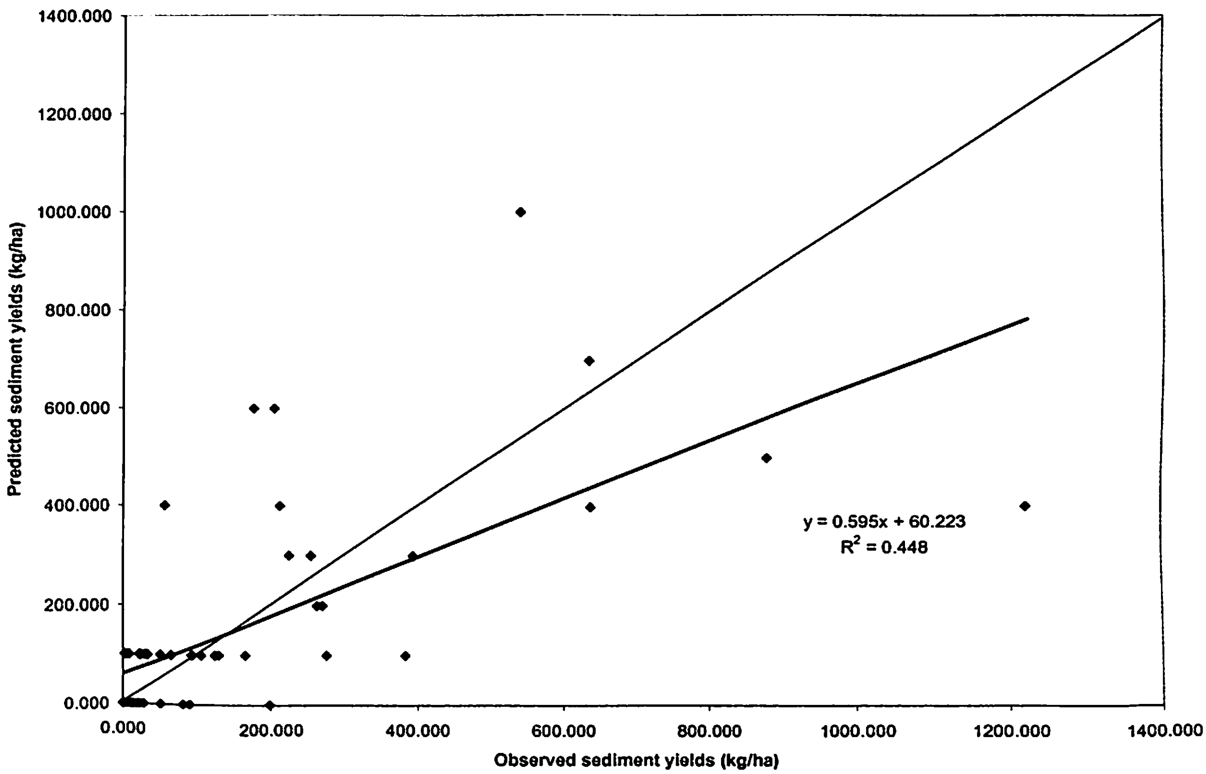


Figure 25. Time series of predicted minus observed sediment yields for road segment A.

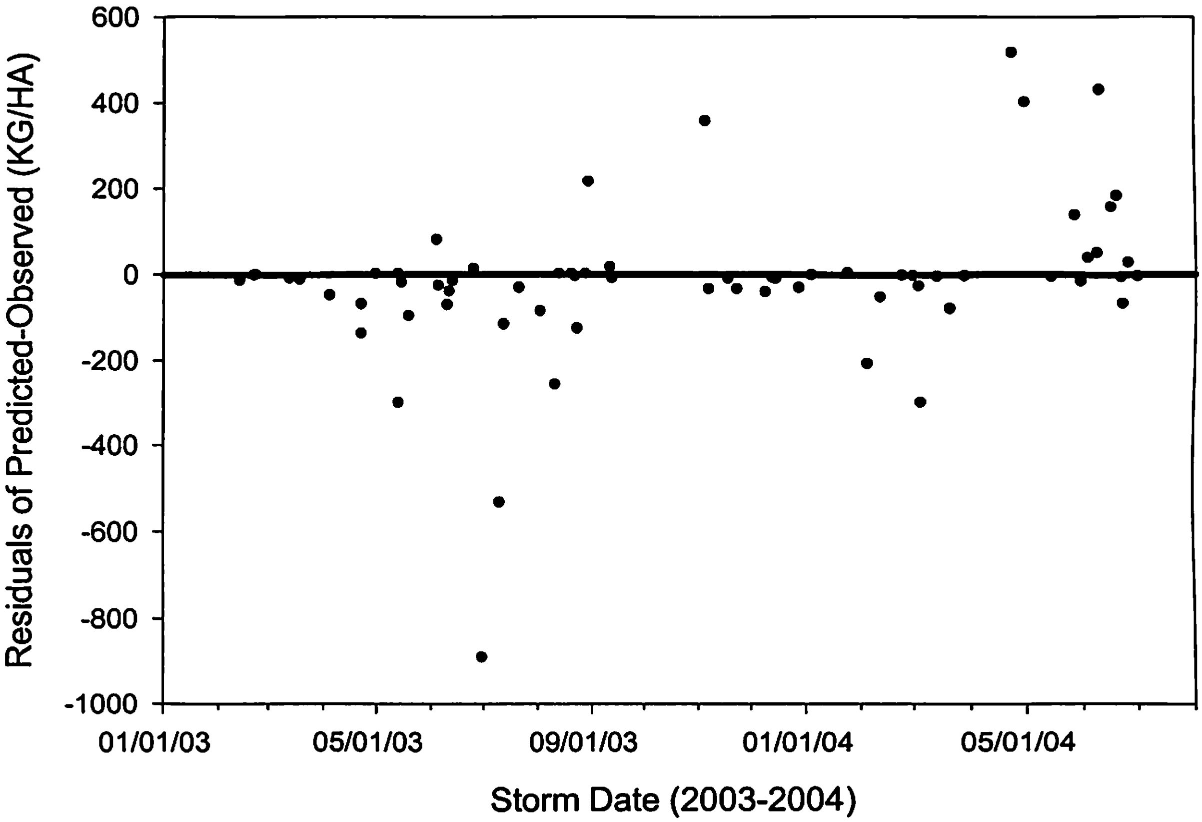


Figure 26. Time series of predicted minus observed sediment yields for road segment B.

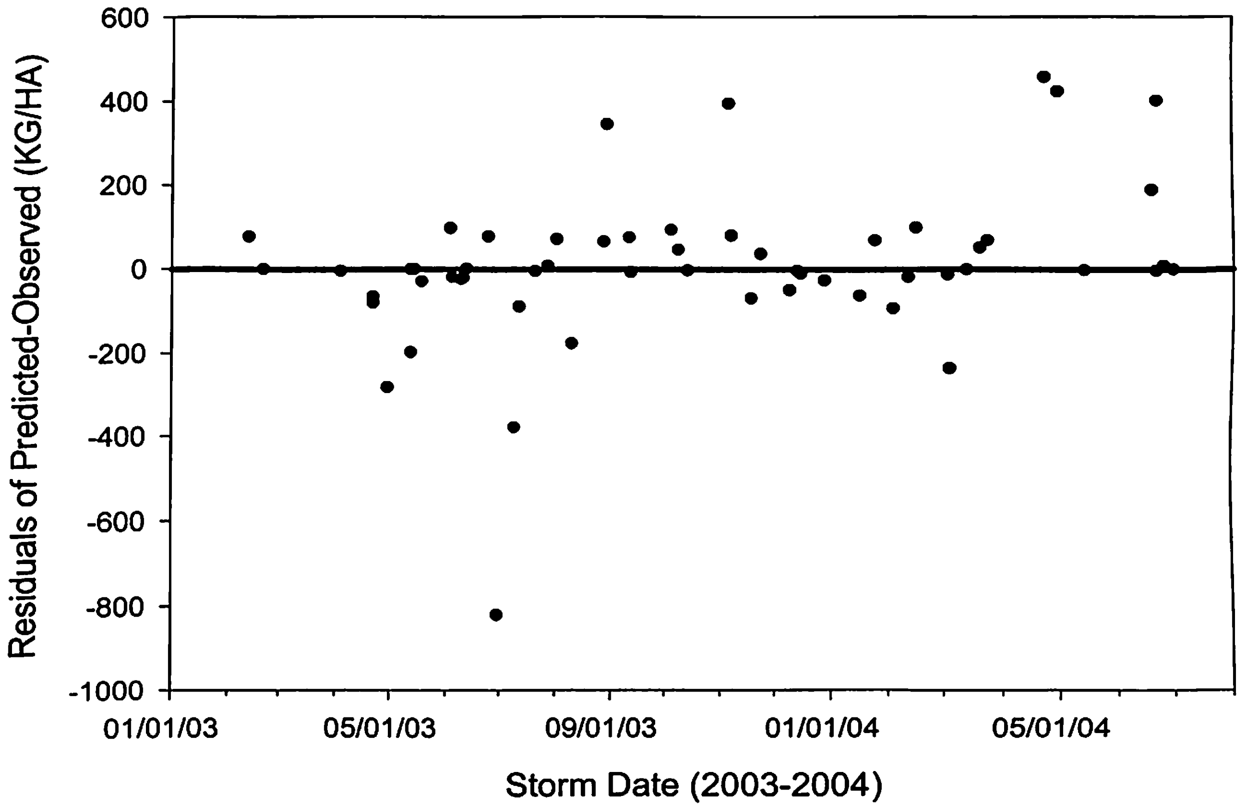


Figure 27. Time series of predicted minus observed runoff volumes for road segment A.

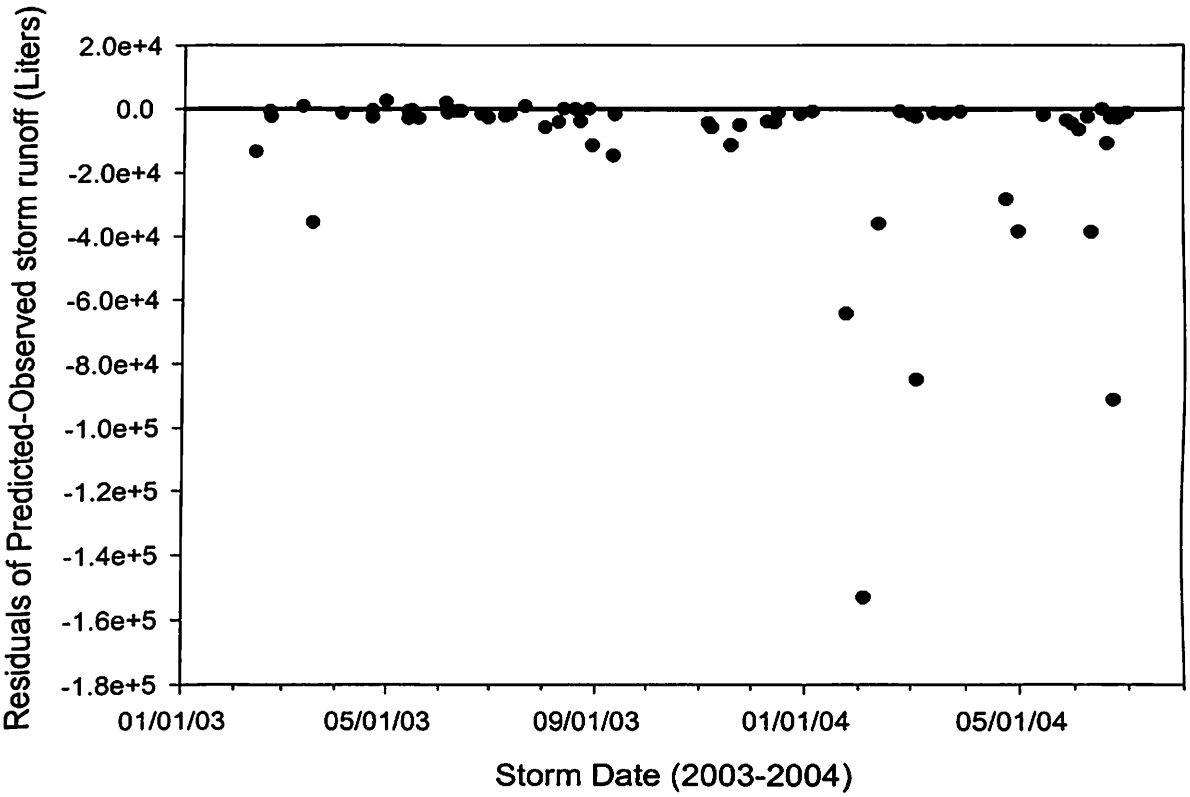
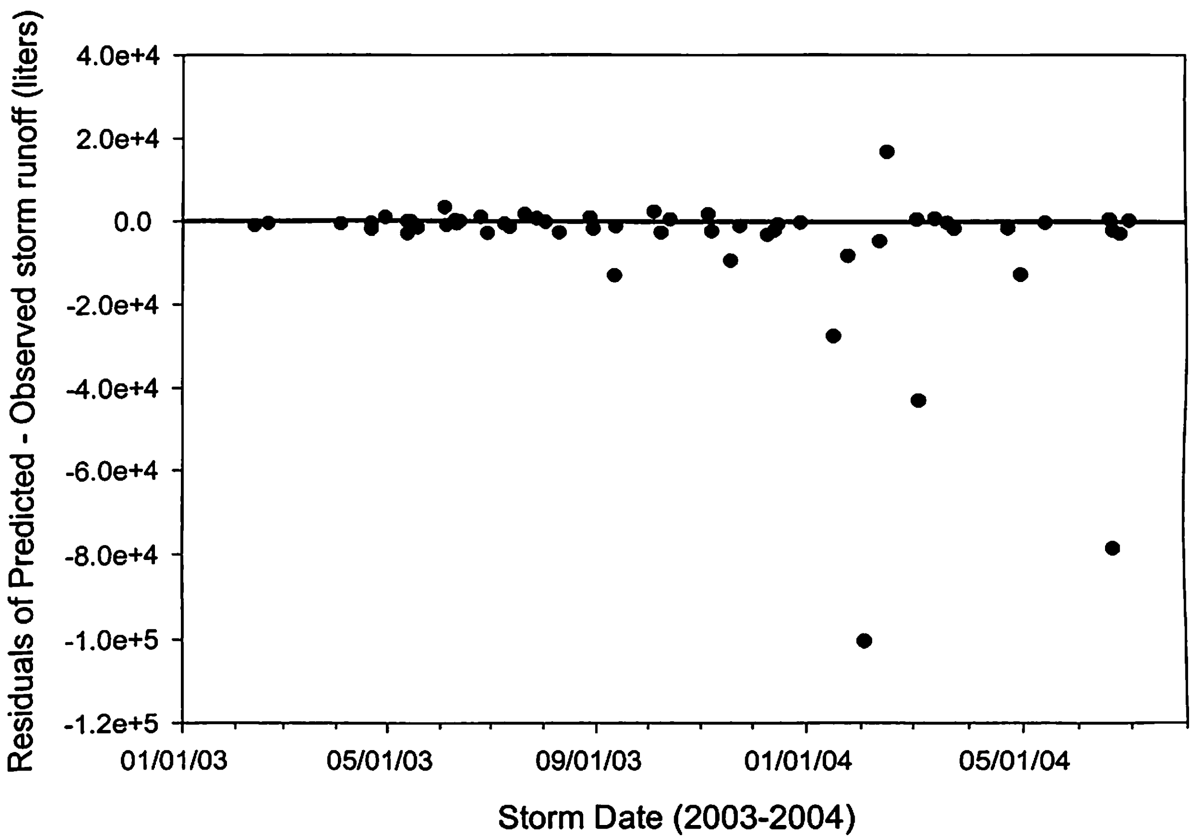


Figure 28. Time series of predicted minus observed runoff volumes for road segment B.



CHAPTER V

DISCUSSION

5.1 Comparison to previous studies in the Ouachita Mountains

As was expected, the totals were lower than measurements by Vowell (1985) and Miller et al., (1985) (Table 6). There are a variety of different factors that could explain this lower road erosion rate. Differences in road age, precipitation, and the amount of vegetation present could have influenced changes in the erosion rates.

Table 6. Comparison of Ouachita Mountain forest road erosion measurements documented in past and current studies.

Site and Region	Erosion rate (kg/ha/yr)	Source
No. McCurtain County, OK (82-83)	91,000	J. Vowell (1985)
No. McCurtain County, OK (82-84)	~79,000	Turton and Vowell (2000)
Alum Creek Watershed, AR	55,000	Miller et al., (1985) and Beasley et al., (1984)
Bluff Creek Watershed, OK	7,000	2003-2004 study period

The age of the road system is a potential influence on erosion rates. Vowell (1985) conducted his study on a recently established road in the Ouachita Mountains. In the process of road construction, the soil erosivity does change resulting in increased erosion. For instance, a great deal of soil is exposed with no vegetation when road grading equipment and backhoes create a new road. Bare soil on recently constructed roads is more susceptible to erosion due to the lack of vegetation holding the soil together and the increase of loose soil and rock made available to storm runoff by the construction process. However, sediment yields change over time as a new road ages. Turton and Vowell (2000) reported a gradual decrease in sediment yields from a new road in the Ouachita Mountains over a three year period. This sounds reasonable because over time the road should begin to slowly stabilize or yield lower sediment rates as the availability of loose soil and rock decreases.

The road system in the Bluff Creek area was constructed in the late 1970's. After twenty five years, it might be safe to assume that the sediment yield would decline over time. This is clearly evident when examining the road and cutslope of the lower road segment B in this study. At some point after construction, large storm events resulted in the scouring of the ditch that ultimately caused the exposure of large deposits of sandstone and rock. This large rock material can prevent further ditch erosion by limiting the amount of surface area prone to erosion (e.g. bare soil) and impounding the storm runoff allowing sediment to settle out of the water and reducing the velocity of water running through the ditch. Although the cutslope indicated heavy erosion due to mass wasting in the past, the cutslopes seemed to stabilize over time and allowed the growth of grasses and seedlings which added further stability to the cutslope.

In previous studies, researchers found that steeper gradients yielded larger erosion rates compared to roads with flat gradients and similar topography (Miller et al., 1985 and Vowell 1985). I found that gradient did not influence road erosion of both suspended and coarse sediment. This could be influenced by the age of the road. As mentioned earlier, road segment B had the steeper gradient but yielded the lower sediment total.

Evidence would indicate heavy erosion in the past but stabilization of the ditch has prevented this segment from producing large amounts of sediment. Road segment B contains a ditch that was inundated with large deposits of rock and vegetation which could have resulted in the lack of sediment in storm runoff due to filtering and settling. Road segment A lacked these large rock obstructions which could have allowed water to flow through the ditch without impoundments.

Another potential indication of stability resulting from time is the texture of the sediment captured after each storm event. Both Miller et al. (1985) and Vowell (1985) reported that their midslope roads produced large quantities of coarse sediment (rock and soil > 2mm in diameter). In some cases, almost half their annual estimate of sediment was coarse sediment. This was not observed on either of the midslope roads in my study. At both study segments, one percent or less of the total sediment captured was coarse sediment. There could be a myriad of reasons for this change in the sediment yield. Age of the road could potentially be a factor that influenced this change. Over time, less coarse sediment is made available to storm water runoff due to the lack of recent construction activities or maintenance that would cause large soil particles to become dislodged. Both roads could have "armored" themselves from some of the effects of erosion and prevented the movement of coarse sediment.

When discussing the age of the road, vegetation is the next logical factor involved in the reduction of erosion. On the new roads studied by Vowell (1985), the cutslopes had little to no vegetation. This is a stark contrast to my study segments where most if not all of the cutslopes and ditches were completely covered in various types of vegetation and forest litter. Also, the road surface was partially covered with various grasses and bushes. This vegetation serves dual purposes by retarding the flow of runoff, thereby causing sediment to settle out of the water and the vegetation will acts as a filter to catch sediment in the runoff (Haan et al., 1994). The vegetation prevents erosion by reducing the surface area exposed to the impact of rain drops.

Another potential factor that could have influenced the reduction in erosion is precipitation. Over the course of the 2003 sampling period, southeastern Oklahoma received 765 mm of rainfall which is 40% below an average or normal year of 1270 mm. 1571 mm of precipitation was recorded during the entire eighteen months. On average, 1940 mm of precipitation can be expected during the same time period of January to June of the following year (NOAA 2004). This lack of precipitation could have influenced the sediment yields. Miller et al. (1985) reported 2602 mm of precipitation during their study. They also measured 508 mm of precipitation in October of 1984 which set a record of that month. On December 2-3 of 1982, they measured a storm event that exceeded the 100 year 24 hour storm event (Hershfield 1964 and Miller et al., 1985). This storm produced over 228 mm of precipitation and nearly half of their annual total sediment yield.

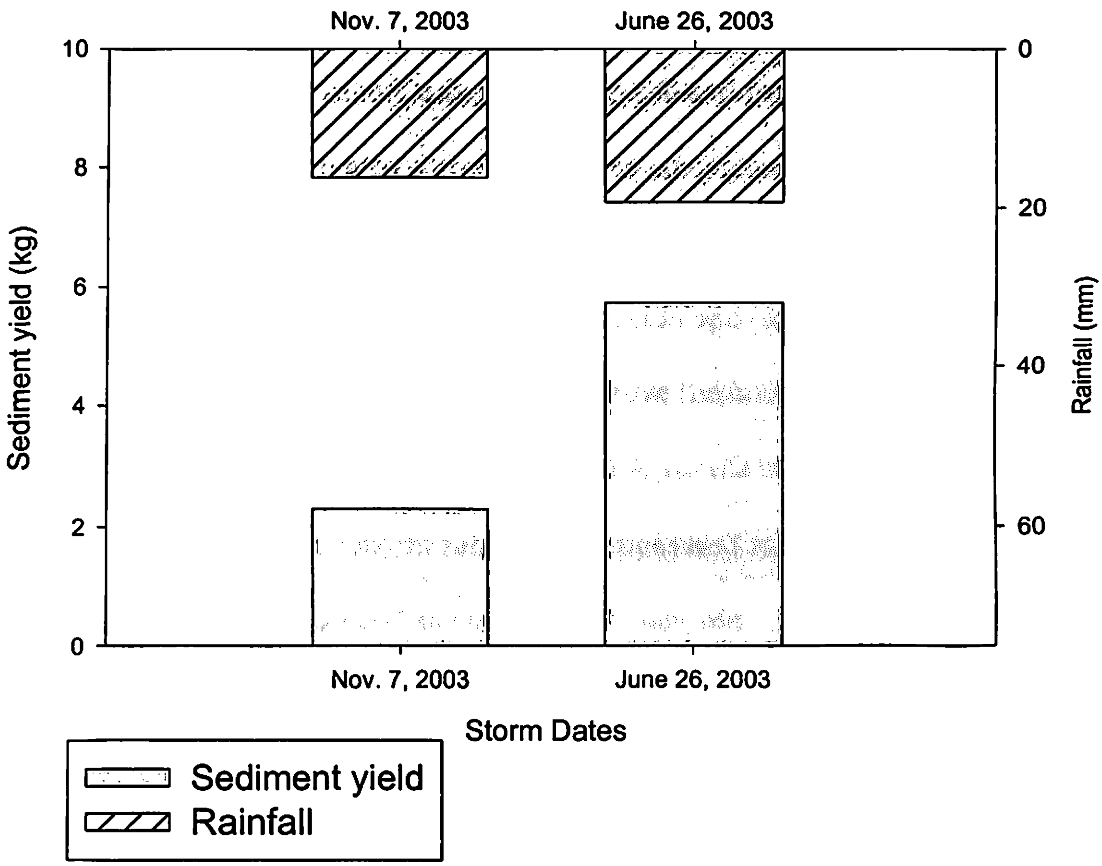
Vowell (1985) also reported a larger precipitation total than my study. He recorded a precipitation total that was 5% (1352 mm) higher than the annual average. Vowell's average depth per storm of 41 mm is nearly twice the Bluff Creek average of 21 mm. Although this offers a reasonable explanation, it is one of a series of factors that may have caused a lower sediment yield.

Along with differences between these studies, there were also many similarities. Both studies by Vowell (1985) and Miller et al. (1985) documented the effects of antecedent soil moisture conditions, rainfall depth, rainfall intensity, and upslope contribution on forest road erosion. Many of the same patterns reported in the previous two projects appear in this study.

Vowell (1985) discussed the increase in sediment yields from periods of low antecedent soil moisture compared to periods with high antecedent soil moisture content prior to the storm event. This was something that was noticed throughout the duration of the study on my road segments. Storms with similar rainfall amounts and intensities but with different antecedent soil moisture conditions were compared to see if this pattern developed (Figure 29). Although only one example is shown, many of the different storm comparisons yielded similar results.

An explanation for this phenomenon could be the soil texture of the road. The Bluff Creek road segments were constructed from clay loam soils. Under mesic or wet conditions, clays are cohesive and prevent the detachment of soil particles that can be made available to storm runoff. Another explanation for this observation is the soil cracking and separating during periods of hot and dry weather. The separation of the soil surface loosens rock and soil particles which can make them available to surface runoff from storms. This was observed during the last half of June (2003) when there was approximately two weeks of dry conditions preceded by a spring that produced little precipitation.

Figure 29. The effects of antecedent soil moisture conditions on sediment yields at road segment A. Both storms had nearly identical rainfall intensities of 3 mm/hr; however, the June 26th storm was preceded by two weeks of hot and dry weather and the storm on November 7th was preceded by cooler temperatures and a storm two days earlier that yielded 59 mm of precipitation.

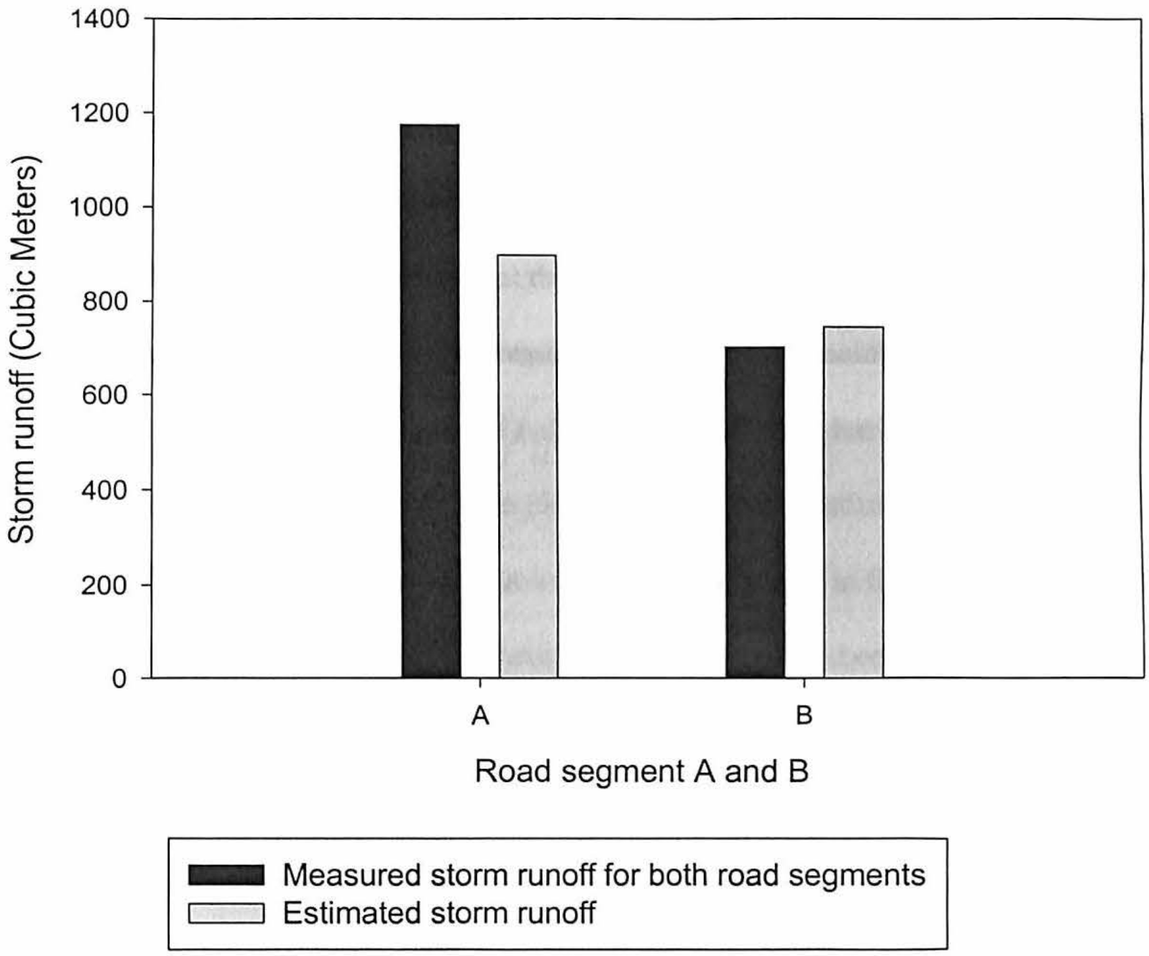


According to Miller et al. (1985) and Vowell (1985), rainfall depth and intensity played an important role in the sediment yield. In fact, they observed that relatively few storms produced the majority of the annual sediment yield. This was observed during the course of this study. Three storms during the 2003 study period produced 45% of the total annual sediment yield for that year. These storms were characterized by both high rainfall intensities and depth. During the last six months of this study (2004), a majority of the monthly sediment yields came from one or two storms that occurred each month.

Midslope roads are built along hillsides. As a result, midslope roads intercept surface and subsurface flow from the area above the road segment. The contributing upslope area above the road segment will influence storm runoff. An observation noted by Vowell (1985) during his study. He compared measured annual storm runoff to estimated annual storm runoff using rainfall depth and road segment area. He reported that the higher than estimated storm runoff was attributable to flow from the upslope area above the road prism.

The road segments on my study were midslope roads. These roads have the potential to be affected by the upslope area above the cutslope. This influence was evident on road segment A, where the measured annual storm runoff was slightly larger than the estimated annual storm runoff. The measured runoff from road segment B was less than the estimated annual storm runoff (Figure 30). The estimated storm runoff is calculated from the precipitation (depth) and area of the road prism (i.e. the road surface, cutslope, and ditch). The assumption in this calculated is that no infiltration will occur.

Figure 30. The total measured storm runoff compared to the maximum road prism estimated storm runoff calculated for both road segments.



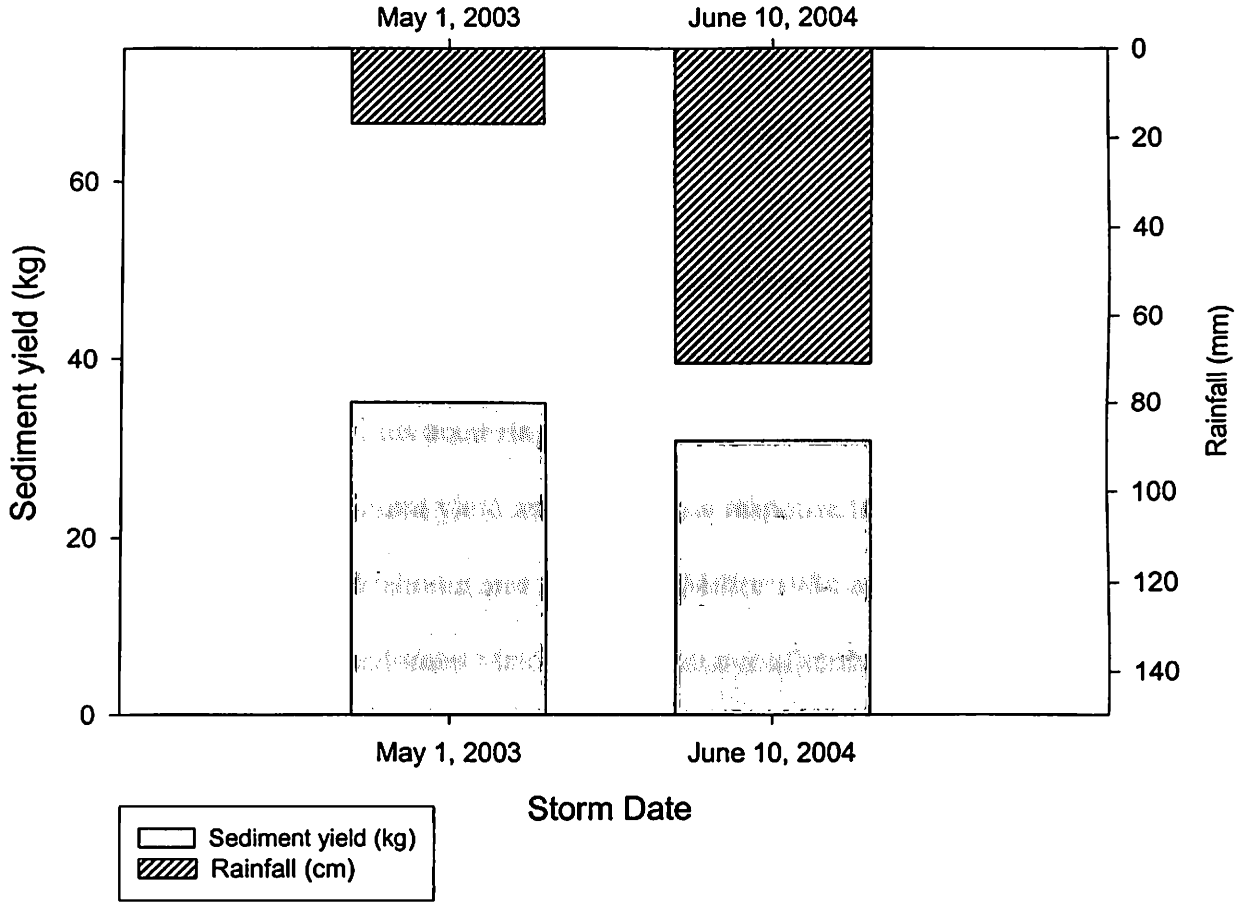
It is important to keep in mind that all of these projects have different elements that have direct and/or indirect effects on road erosion rates. This brings up the issue of why further research was needed in this region. If a forest manager in the Ouachita Mountain region only had Vowell's study as a reference on road erosion, he could conclude that all roads in this area are a serious issue. That may not be necessarily true. This study indicates that there are roads in the Ouachita Mountains that yield much smaller amounts of sediment. This needs to be taken into account when management decisions are being made. This could save money and energy by allowing forest managers to focus on areas that might be potential problem areas.

5.2 The Potential Effects of Road Maintenance on Road Erosion

At the start of this research, I was fortuitous enough to have the Weyerhaeuser Company road crew come out and re-grade the road surface. The goal was to examine an established road beginning at its most disturbed state. The construction of news roads are not planned in the near future. The results found that road maintenance can produce changes in sediment yield (Figure 31). On May 1st of 2003, ten days after the maintenance, a relatively small storm (17 mm) produced a sediment yield of 32 kg. This was one of only three times when coarse sediment collected in the metal baskets situated in the collection troughs. Of those three storms that collected coarse sediment, this storm event had the largest volume of coarse sediment collected. On June 10th of 2004, a larger storm (71 mm) with a similar rainfall intensity of 16 mm/hr produced an identical sediment yield of 31 kg as the May 1st storm (Figure 31).

Recovery from this maintenance was difficult to clearly define. It seemed as though both roads began to produce lower sediment concentrations in the suspended water samples within two months after the road maintenance. This observation was also true with coarse sediment. After July, which was approximately two months after maintenance, no coarse sediment was collected in the collection troughs.

Figure 31. The effects of road maintenance on sediment yield from roads. Both storms had similar rainfall intensities of ~ 16 mm/hr but each storm had different rainfall totals. The June 10th storm produced 4 times more precipitation than the May 1st storm but they both produced somewhat similar sediment yields.



5.3 Deflation Rates for these Study Segments

Annual deflation rates are a good way to visualize the effects that erosion can have on a forest road. The deflation rate is the amount of soil surface lost (in cm) to erosion in the road prism (cutslope, road surface, and ditch) assuming that the erosion is uniform over the road segment. In order to convert weight to depth of soil surface, assumptions were made on the soil bulk density. A soil bulk density of 1.6 g/cm^3 was used in the calculations of deflation rates (Miller et al., 1985). The deflation rates for road surface A and B were 0.12 cm/yr and 0.07 cm/yr, respectively. The deflation rates for road prism A and B (including the cutslope and ditch) were 0.03 cm/yr and 0.05 cm/yr, respectively.

5.4 Comparisons of Road Erosion to Erosion from other Silvicultural Activities in the Ouachita Mountains

Roads have long been viewed as a major contributor to sediment yield and to the degradation of water quality in forest settings. It is important to compare these findings to other silvicultural activities occurring in the area. Two studies were conducted in the mid to late 1980's on sediment yield and storm flow response to clear-cutting in the Ouachita Mountains of Oklahoma and Arkansas (Miller 1984 and Miller et al., 1988). Miller (1984) reported a sediment yield of 282 kg/ha/yr after the first year of the clear-cut. An uncut watershed produced a sediment yield of 36 kg/ha/yr. The clear-cut watersheds recovered to near pretreatment levels in 3-4 years. Miller et al. (1988) found that the sediment yield from a 3-year post harvest clear-cut ranged from 50 to 510 kg/ha/yr. The uncut control watershed in this study produced 1 to 120 kg/ha/year of sediment over the same period (Miller et al., 1988).

In contrast, sediment yields measured on my road segments were 14 times larger than the first year clear-cut treatment and almost 200 times larger than the uncut forested watershed. Also, forest roads would take much longer to return to erosion levels prior to construction. Vowell's study examined roads that were around two years of age and he measured large sediment yields. Turton and Vowell (2000) estimated sediment yields (on the White Rock Creek road segments) over a three year collection period that suggested a slight decrease in sediment yields but it never returned to pre-construction levels.

Although this seems to be a large difference in sediment yields, scale needs to be kept in mind. Most of these harvested watersheds are much larger in area than these road segments and they may yield more sediment overall as a result. It is reported that only 4.5% of forestland is occupied by forest roads (Riiters and Wickham 2003). However, roads have the potential to directly input sediment into streams at crossings which can have a serious impact to the water quality of streams.

5.5 WEPP predictions

One of the objectives in this project was to test the applicability of the WEPP model on forest roads in the Ouachita Mountains. If the results are favorable then a future step could be the prediction of road erosion on the entire watershed in Bluff Creek and possibly the entire forest road network in the Ouachita Mountains.

The results from WEPP's predictions on my two road segments produced favorable results for sediment yields. In both cases, WEPP predicted sediment yields that were close to observed measurements. However, the predicted storm water runoff was approximately half of the observed measurement.

For road segment A, WEPP predicted a sediment yield of 6,500 kg/ha/yr. This is slightly lower than the observed sediment yield of 7,600 kg/ha/yr. Due to the natural variability of road erosion from year to year, users of the WEPP model should not place too much emphasis on slight differences in observed and predicted values (Elliot et al. 1999c and Foltz 1996). Elliot et al. (1999c) and Tysdal et al. (1997) suggested a margin of error of plus or minus 50% of the observed measurement. WEPP's predicted sediment yield was well within that margin of error for observed measurements. Although this sediment yield predicted by WEPP is reasonable, the storm water runoff prediction from WEPP was less than half of the observed runoff. WEPP predicted 469,000 liters of storm water runoff would occur over the year and a half period of data collection from road segment A. The actual storm water runoff measured at segment A was over 2.9 times greater at 1,353,346 liters. This may indicate that WEPP is not accounting for the subsurface flow from the upslope area above the cutslope. This research and past studies suggest that the upslope area above the cutslope can contribute a large amount of runoff to the road prism (Miller et al., 1985 and Vowell 1985). If the model predicted a storm runoff that was closer to the observed measurements then the sediment yield predictions may be somewhat different.

At road segment B, WEPP predicted a sediment yield of 6,500 kg/ha/yr which is very similar to the measured sediment yield of 6,500 kg/ha/yr. Again, WEPP underestimated the runoff by 41%. WEPP predicted a runoff of 479,000 liters and the measure storm runoff was 812,351 liters for the entire study period of eighteen months.

Ultimately, this aspect of the research brought up the issue of the natural variability of sediment yields by roads and the many obstacles those modelers face when attempting to predict sediment yields. Both computers models and natural variability of erosion are complex entities. It can be extremely difficult to accurately estimate sediment yields without physically measuring each road segment in a watershed.

5.6 Suggestions for Further Research

Throughout this chapter, there have been suggestions for further research on this topic. One suggestion included the re-visitation of past road erosion study sites to measure the change in the sediment yields after twenty years. Another research topic is the measurement of sediment yield rates from various different traffic regimes. Traffic and maintenance are considered two influential activities that have a direct affect on sediment yield (Burroughs and King 1989 and Luce and Black 1999). It is important to fully research this issue to comprehend the affects of traffic on sediment yield on Oklahoma forest roads.

A more detailed examination of the upslope contributing area is another point of interest. Currently, there is a lack of knowledge about how this area affects sediment and water yields (Luce 2002). Collection devices similar to previous subsurface flow studies could be implemented along the cutslopes of the road (Navar et al., 1996 and Turton et al., 1992). At certain heights along the cutslope, collection troughs can be set in place to measure this subsurface flow exiting the cutslope and entering the road prism. Measurement of the upslope contribution may give a detailed understanding of forest road erosion by allowing the separation of storm flow from different parts of the road prism. Past studies in the Pacific Northwest noted that over 80% of the total storm runoff came from subsurface flow intercepted by the cutslope (Burroughs et al., 1972, and Luce 2002, and Wemple 1998). This type of research can open many doors into quantifying storm flow response, water pathways, and residence times (Luce 2002). Also, a better understanding of the cutslope and upslope area above the road may influence future management and construction decisions.

The monitoring of traffic is another topic for further research into forest road erosion. A study conducted by Reid and Dunne (1984) reported traffic as a major influence on sediment yields. They noticed sediment yields that were 130 times higher on heavily used roads compared to abandoned roads. Although the road segments studied in this project were not closed to the public, traffic on them was minimal. The lack of silvicultural activities in the region and large amounts of vegetation developing on the road surface (i.e. blackberry bushes, seedlings, and grass) seem to support that the lack of traffic could have been another factor in a low sediment yields observed on these two segments.

The examination of different erosion models may be another aspect that can be explored. The National Council for Air and Stream Improvement (NCASI) and the Boise Cascade Corporation worked in cooperation to develop the computer model called SEDMODL2 for road erosion and sediment delivery. This model could potentially be more accurate than the WEPP computer model because of the numerous road attributes needed to predict sediment yield. These attributes include:

- Construction year
- Cutslope height
- Percent cutslope cover
- Slope
- Road use
- Road width
- Surface type.

This model has the ability to measure changes in sediment yield with various different road erosion control methods (Megahan 2003).

Finally, the next phase in this study could be the measurement of sediment delivery. This topic has been covered with some success in the past but there are many aspects of sediment movement to streams that is still unknown (Miller et al., 1985 and Vowell 1985). Further research into this area can help in determining the impact of road erosion to the aquatic ecosystem and overall water quality.

Research into road erosion in the South is limited. The best way to develop and to show the effectiveness of Best Management Practices (BMPs) for the southern region of the United States is through detailed studies about the various different aspects of forest road erosion. This increased knowledge will lead to improved management techniques that will ultimately protect the nation's water quality.

CHAPTER VI

CONCLUSIONS

Seventy-six individual rainfall events occurred over the 2003 to 2004 study period. Storm precipitation ranged in depth from 3 mm to 76 mm. Individual storm sediment yields ranged from 0 kg/ha to 1291 kg/ha. During the course of the eighteen month study period, both road segments A and B produced a sediment yield of 7600 kg/ha/yr and 6500 kg/ha/yr, respectively. The WEPP (watershed version) model predicted sediment yields of 6500 kg/ha/yr and 6500 kg/ha/yr for road segments A and B, respectively. WEPP's predicted values fell within the margin of error for observed results. When used correctly, The WEPP model may be a useful tool for forest managers in predicting sediment yields for forest roads in the Ouachita Mountains.

Another point of interest includes the effects of road maintenance and antecedent soil moisture conditions on forest road erosion. My study indicated that road blading may increase the total sediment yield for individual storm events that occur after the disturbance. Antecedent soil moisture may influence forest road erosion. This study found that sediment yields from roads were higher during storms with low antecedent soil moisture compared to storms with high antecedent soil moisture content.

The storm runoff measured at road segment A exceeded precipitation inputs to this segment. On road segment B, the measured storm runoff was slightly lower than precipitation input but the values were very similar. The upslope area above the cutslope had an influence on the storm runoff. This contribution to storm runoff by the upslope area can be a serious issue if the cutslope and ditch are built on non-vegetative highly erodible soils.

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APPENDIX I:
OBSERVED AND PREDICTED SUMMARY DATA FOR BOTH ROAD SEGMENTS

Summary data for road segment A

Road site	Storm date 2003-2004	precip. (mm)	observed volume (Liters)	sediment load (kg)	Observed Sediment yield (T/ha)	WEPP Estimated Sediment yield (T/ha)	WEPP estimated runoff (liters)
a	Feb. 13 and 14	18.80	16449	0.91	0.014	0.000	3000
a	21-Feb	7.11	703	0.15	0.002	0.000	0
a	22-Feb	3.30	2477	0.05	0.001	0.000	0
a*	Feb 27 to Mar 1	18.29	8423			0.000	3000
a	13-Mar	10.41	1223	0.60	0.009	0.000	2000
a	19-Mar	25.40	42786	7.34	0.112	0.100	7000
a	5-Apr	13.46	4215	9.72	0.149	0.100	3000
a	23-Apr	16.00	4313	11.12	0.170	0.100	4000
a	23-Apr	5.84	2496	9.04	0.138	0.000	0
a	1-May	17.02	4512	35.02	0.535	0.200	7000
a	14-May	6.60	650	0.35	0.005	0.000	0
a	14-May	9.14	4123	19.66	0.301	0.000	1000
a	16-May	4.83	401	1.32	0.020	0.000	0
a	20-May	20.32	7059	12.93	0.198	0.100	4000
a	5-Jun	18.80	2238	1.35	0.021	0.100	4000
a	6-Jun	4.83	1352	1.84	0.028	0.000	0
a	11-Jun	16.76	4818	11.27	0.172	0.100	4000
a	12-Jun	4.32	814	2.68	0.041	0.000	0
a	14-Jun	6.10	867	1.14	0.017	0.000	0
a	26-Jun	19.30	4757	5.75	0.088	0.100	3000
a	30-Jun	28.45	16812	84.40	1.291	0.400	14000
a	10-Jul	47.50	26294	74.09	1.133	0.600	24000
a	13-Jul	7.62	2688	7.65	0.117	0.000	1000
a	22-Jul	10.41	1222	2.16	0.033	0.000	2000
a*	29-Jul	14.99				0.100	3000
a	3-Aug	17.53	8835	5.69	0.087	0.000	3000
a	11-Aug	16.00	9192	23.36	0.357	0.100	5000
a	14-Aug	2.29	47	0.00	0.000	0.000	0
a	21-Aug	4.57	92	0.01	0.000	0.000	0
a	23-Aug	5.59	695	0.39	0.006	0.000	0
a	24-Aug	8.64	4019	8.31	0.127	0.000	0
a	29-Aug	44.70	25040	45.79	0.700	0.700	25000
a	Aug 3	40.13	28478	12.11	0.185	0.400	17000

a	12-Sep	44.70	30685	12.13	0.185	0.200	16000
a	13-Sep	3.56	1804	0.64	0.010	0.000	0
a*	5-Oct	12.45	2803			0.000	2000
a*	9-Oct	38.61	20560			0.400	18000
a*	14-Oct	4.57	967			0.000	1000
a	5-Nov	59.18	33482	15.83	0.242	0.600	29000
a	7-Nov	16.26	8864	2.31	0.035	0.000	3000
a	18-Nov	34.54	23344	13.79	0.211	0.200	12000
a	23-Nov	18.54	10034	8.80	0.135	0.100	5000
a	9-Dec	11.43	4084	2.73	0.042	0.000	0
a	13-Dec	11.18	4396	0.49	0.008	0.000	0
a	15-Dec	3.81	1436	0.74	0.011	0.000	0
a	28-Dec	10.67	3778	2.07	0.032	0.000	2000
a	4-Jan	3.56	963	0.11	0.002	0.000	0
a*	16-Jan	76.45	121362			0.100	15000
a	Jan 24-28, 2004	30.48	64061	6.33	0.097	0.100	0
a*	3-Feb	7.11	6302			0.000	0
a	4-Feb	60.96	175104	26.70	0.408	0.200	22000
a	11-Feb	21.34	38912	3.45	0.053	0.000	3000
a*	15-Feb	17.02	28354			0.000	3000
a	23-Feb	7.37	692	0.16	0.002	0.000	0
a	29-Feb	8.38	1743	0.22	0.003	0.000	0
a	3-Mar	11.68	3504	1.80	0.027	0.000	1000
a	4-Mar	32.51	98660	45.64	0.698	0.400	14000
a	13-Mar	13.46	3275	0.34	0.005	0.000	2000
a	20-Mar	8.89	3451	5.25	0.080	0.000	2000
a*	24-Mar	28.45	14953			0.100	6000
a	28-Mar	5.08	889	0.25	0.004	0.000	0
a	23-Apr	75.44	67232	31.67	0.484	1.000	39000
a	30-Apr	48.26	61440	19.55	0.299	0.700	23000
a	14-May	10.16	2955	0.39	0.006	0.000	1000
a	27-May	35.05	14571	4.09	0.063	0.200	11000
a	30-May	19.30	8735	7.57	0.116	0.100	4000
a	3-Jun	26.92	11477	4.08	0.062	0.100	5000
a	8-Jun	16.26	5599	3.34	0.051	0.100	3000
a	10-Jun	70.87	77539	30.81	0.471	0.900	39000
a	16-Jun	23.62	8107	2.91	0.044	0.200	8000
a	19-Jun	33.53	26791	14.26	0.218	0.400	16000
a	21-Jun	7.60	2737	0.40	0.006	0.000	0
a	22-Jun	45.50	111717	30.63	0.468	0.400	21000
a	25-Jun	14.99	6804	4.78	0.073	0.100	4000

a	30-Jun	8.64	1090	0.25	0.004	0.000	0
total		1533	1353346	700.690	10.714	9.800	469000
total excluding loss data		**1315**	**1149623**	**700.69**	**10.714**	**9.100**	**439000**
Corrected value to reflect approximately one and a half years worth of data (T/ha/yr)					**7.563**	**6.500**	

* data lost due to various circumstances and not included in final estimates for both the observed and WEPP predicted values.

Summary data for road segment B

Road site	Storm date 2003-2004	precip. (mm)	observed volume (Liters)	sediment load (kg)	Observed Sediment yield (T/ha)	WEPP Estimated Sediment yield (T/ha)	WEPP estimated runoff (liters)
b	Feb. 13 and 14	18.80	4039	1.44	0.024	0.100	3000
b	21-Feb	7.11	462	0.07	0.001	0.000	0
b*	22-Feb	3.30	0	0.00		0.000	0
b*	Feb 27 to March 1	18.29	589	0.00		0.100	3000
b*	13-Mar	10.41	720	0.00		0.000	2000
b*	19-Mar	25.40	15800	0.00		0.100	7000
b	5-Apr	13.46	3668	6.41	0.105	0.100	3000
b	23-Apr	16.00	4473	10.08	0.166	0.100	4000
b	23-Apr	5.84	2055	4.94	0.081	0.000	0
b	1-May	17.02	5188	23.35	0.383	0.100	6000
b	14-May	6.60	163	0.03	0.001	0.000	0
b	14-May	9.14	4078	12.10	0.199	0.000	1000
b	16-May	4.83	161	0.08	0.001	0.000	0
b	20-May	20.32	5703	7.89	0.130	0.100	4000
b	5-Jun	18.80	740	0.26	0.004	0.100	4000
b	6-Jun	4.83	983	1.19	0.020	0.000	0
b	11-Jun	16.76	3825	7.57	0.124	0.100	4000
b	12-Jun	4.32	600	1.36	0.022	0.000	0
b	14-Jun	6.10	84	0.00	0.000	0.000	0
b	26-Jun	19.30	1998	1.47	0.024	0.100	3000
b	30-Jun	28.45	15848	74.33	1.221	0.400	13000
b	10-Jul	47.50	23573	53.50	0.879	0.500	23000
b	13-Jul	7.62	2360	5.48	0.090	0.000	1000
b	22-Jul	10.41	352	0.34	0.006	0.000	2000
b	29-Jul	14.99	2309	5.68	0.093	0.100	3000
b	3-Aug	17.53	3098	1.81	0.030	0.100	3000
b	11-Aug	16.00	7629	16.84	0.277	0.100	5000
b*	14-Aug	2.29	0	0.00		0.000	0
b*	21-Aug	4.57	0	0.00		0.000	0
b*	23-Aug	5.59	0	0.00		0.000	0
b*	24-Aug	8.64	0	0.00		0.000	0
b	29-Aug	44.70	22091	38.73	0.636	0.700	23000
b	August 31 to Sept 2	40.13	18777	3.44	0.056	0.400	17000
b	12-Sep	44.70	27963	13.75	0.226	0.300	15000
b	13-Sep	3.56	1115	0.51	0.008	0.000	0
b	5-Oct	12.45	712	0.51	0.008	0.100	3000
b	9-Oct	38.61	18616	15.54	0.255	0.300	16000
b	14-Oct	4.57	452	0.23	0.004	0.000	1000
b	5-Nov	59.18	25275	12.52	0.206	0.600	27000

b	7-Nov	16.26	5350	1.32	0.022	0.100	3000
b	18-Nov	34.54	20411	16.49	0.271	0.200	11000
b	23-Nov	18.54	6057	3.95	0.065	0.100	5000
b	9-Dec	11.43	3213	3.09	0.051	0.000	0
b	13-Dec	11.18	2114	0.29	0.005	0.000	0
b	15-Dec	3.81	676	0.73	0.012	0.000	0
b	28-Dec	10.67	2213	1.71	0.028	0.000	2000
b	16-Jan	76.45	43435	16.05	0.264	0.200	16000
b	Jan 24-28, 2004	30.48	14210	2.01	0.033	0.100	6000
b	3-Feb	60.96	122440	24.01	0.394	0.300	22000
b	11-Feb	21.34	7678	1.21	0.020	0.000	3000
b	15-Feb	17.02	5216	0.14	0.002	0.100	22000
b	3-Mar	11.68	1502	0.88	0.014	0.000	2000
b	4-Mar	32.51	55838	38.78	0.637	0.400	13000
b	13-Mar	13.46	1286	0.10	0.002	0.000	2000
b	20-Mar	8.89	2273	3.05	0.050	0.100	2000
b	24-Mar	28.45	7704	2.01	0.033	0.100	6000
b*	28-Mar	5.08				0.000	0
b	23-Apr	75.44	37563	33.11	0.544	1.000	36000
b	30-Apr	48.26	33719	10.82	0.178	0.600	21000
b	14-May	10.16	1240	0.15	0.003	0.000	1000
b*	27-May	35.05	11554			0.200	11000
b*	30-May	19.30	8679			0.100	4000
b*	3-Jun	26.92	9056			0.200	9000
b*	8-Jun	16.26	3115			0.100	3000
b*	10-Jun	70.87	49625			0.900	36000
b*	16-Jun	23.62	7554			0.200	7000
b	19-Jun	33.53	14499	12.99	0.213	0.400	15000
b	21-Jun	7.60	2132	0.25	0.004	0.000	0
b	22-Jun	45.50	98907	30.45		0.400	20000
b	25-Jun	14.99	6843	5.62	0.092	0.100	4000
b	30-Jun	8.64	751	0.05	0.001	0.000	1000
total		1507	812351	531	8.215	8.200	479000
total excluding loss data		**1191**	**686883**	**527.30**	**8.215**	**8.200**	**38000**
Corrected value to reflect approximately one and a half years worth of data					**6.490**	**6.480**	

* data lost due to various circumstances and not included in final estimates for both the observed and WEPP predicted values.

VITA (1)

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