MODELING WATER QUALITY IMPACTS OF OFF-ROAD VEHICLES IN FORESTED WATERSHEDS

Christian John Brodbeck

A Thesis

Submitted to

The Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
August 8, 2005

MODELING WATER QUALITY IMPACTS OF OFF-ROAD VEHICLES IN FORESTED WATERSHEDS

Christian John Brodbeck

Signature of Author

Date

VITA

Christian John Brodbeck, son of Martin and Diane Brodbeck, was born on September 7, 1979 in Reutalhuleu, Guatemala. He grew up in Santa Maria de Jesus, Guatemala, with his brothers Beau and Michael. After graduating from the Inter-American School in June of 1997, he entered Faulkner State Community College in Bay Minnette, Alabama. In June of 1999 he entered Auburn University in Auburn, Alabama. He graduated cum laude with a Bachelors of Biosystems Engineering on December 15, 2002. He then entered Auburn University's graduate program in Civil Engineering in August of 2003, and worked as a graduate research assistant and graduate teaching assistant in the Biosystems Engineering Department. He is currently employed as a Research Associate in the Biosystems Engineering department of Auburn University.

THESIS ABSTRACT

MODELING WATER QUALITY IMPACTS OF OFF-ROAD VEHICLES IN FORESTED WATERSHEDS

Christian John Brodbeck

Master of Science, August 8, 2005
(B.B.S.E., Auburn University, 2002)

140 Typed Pages

Directed by Timothy P. McDonald and Dan A. Brown

Erosion from off-road vehicles can cause negative effects on water quality by impairing fish habitat and shortening reservoir life. Due to an increasing level of off-road vehicle use throughout the country, this impact has risen to a level that has become a cause for concern. Interest has been raised by the USDA Forest Service to quantify sediment loads and determine management practices that may aid in reducing the current sediment delivery rates.

A bridged stream trail crossing on the Kentuck ORV trail system in the Talladega National Forest was equipped with water sampling equipment to measure total suspended sediment and flow rates. Equipment was also installed to measure rainfall and traffic volumes. From this data, sediment loads were calculated and used to calibrate the Water

Erosion Prediction Project (WEPP) model. The model was then utilized to simulate sediment yields for varying management practices.

A total sediment load of 120.9 kg was calculated for the entire data collection period. Sediment yield proved to be only significant from storm events that had a one year return interval or longer. During peak season, traffic volumes reached 180 passes per day with an average throughout the riding season of 25 passes per day. During calibration of the WEPP model, a Nash-Sutcliffe R^2 of 0.92 was achieved. Using the WEPP model, it was determined that in order to achieve target sediment loads, management practices should have a minimum forest buffer length of 20 m with a minimum water bar spacing of 6 m for slopes between 13 and 20%. The use of proper BMPs , such as water bar spacing, slope grade, and buffer lengths, can aid in minimizing the degradation of water quality.

ACKNOWLEDGEMENTS

The author would like to thank his parents for their economic and moral support throughout his educational career. The author would also like to thank Dr. Tim McDonald for providing the opportunity for this project and also for his continuing support and encouragement through it all. The author would also like to thank Dr. John Fulton and Dr. Puneet Srivastava for their guidance in accomplishing various tasks throughout the project. The author would also like to recognize fellow students Layne Owen and Corey Kichler who helped with the collecting and processing of field data. The author would also like to thank Dennis Block and Upton Hatch of the Auburn University Environmental Institute for the funding to conduct the research project. Finally and most importantly, the author would like to thank God for everything He has given us and done for us.

Style manual used Auburn University Graduate School Guide to Preparation and Submission of Theses and Dissertations

Computer software used Microsoft Office 2000 --- Microsoft Word 2000, Microsoft Excel 2000 ---- Water Erosion Prediction Project (WEPP) model

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Problem Statement

The use of Off-Road Vehicle (ORV) trails as a form of outdoor recreation is rapidly becoming more popular and is one of the fastest growing forms of recreation in the United States. All-terrain vehicles (ATV's) and 2-wheel motorcycles provide entertainment for outdoor enthusiasts seeking the thrill and excitement of challenging trails not traversable by ordinary vehicles. The use of ORV's has increased dramatically in the last three decades. According to the USDA Forest Service, the use of ORV's has increased from 5 million in 1972 to 36 million in 2002. In 2003, 5 percent of the visitors to National Forests and Grasslands consisted of ORV users (USDA Forest Service, Office of Communication). An increase in use, such as this, leads to the need for management in order to protect the land and its natural resources for the benefit of all users.

In 2003, the USDA Forest Service identified four threats to the Nation's Forests and Grasslands. The threats were as follows: fuel and fire, invasive species, fragmentation, and unmanaged recreation (USDA Forest Service, Office of Communication). Since ORV trails fit under the category of unmanaged recreation, significant strategic changes must take place with the intent of refocusing attention. Due to the identification of these threats, the USDA Forest Service has changed its approach on some management issues, but their mission remains the same, "to sustain the health, diversity, productivity of the Nation’s forests and grasslands to meet the needs of present and future generations” (USDA Forest Service, Office of Communication).

ORV trails that are unmanaged have the potential to have various adverse impacts on the environment. Factors that affect the level of degradation include soil erosion potential, terrain, and type of vegetation. The two most common types of adverse impacts are severe soil erosion and damage of riparian areas and species. Through site specific management and maintenance techniques, these impacts may be greatly reduced to meet the Forest Service’s mission of sustainability.

The delivery of sediment into a stream system is always a cause of concern due to the environmental impact that it may cause. In areas where salmonid species are present, stream bottoms covered in gravel are required for spawning, so sedimentation can be a serious problem. Also, water supply systems and reservoirs dependent on quality water from surface sources are also affected due to a shortened life (Elliot et. al. 1999). Because these types of impacts may occur, managing a trail system to reduce erosion becomes a very important, but challenging task

Site-specific management of ORV trails is applicable all over the nation, but of particular interest is the Kentuck ORV trail system, located in the Talladega National Forest of Alabama. The Kentuck ORV is of particular interest because of some concerns occurring downstream in relation to water quality degradation. The first step in trail management is proper trail location, layout, and construction. According to Strom and Wilkins (1990) a list of criteria were set forth before construction could begin on the trail with the intention of reducing any environmental impacts, in particular erosion and water quality degradation, that the trail may cause. This list of criteria included the following:

riding loops would be created using existing closed roads and newly constructed trails, archeological survey needed to be completed prior to any soil disturbance, highly erodible soils were to be evaluated by soil scientists and proper actions taken, degradation of water quality would be avoided by use of proper stream crossings, avoid areas for wildlife habitat improvement, areas known to have red-cockaded wood pecker were also avoided, and timber management will be modified as is deemed appropriate. Following this list of criteria during trail construction helped reduce some adverse impacts an ORV trail produces, but did not eliminate them.

Although the Forest Service has attempted many different maintenance techniques, problems still arise that are not only causing some environmental impacts, but are economically costly as well. The foremost problem is erosion which is magnified by puddling of water and the formation of ruts. On the Kentuck ORV, the use of water bars, broad based dips, and water turn-outs have been used in an attempt to shed water from the trails. Some maintenance techniques used, with the intent of increasing infiltration rates, involved the use of gravel and ‘geoblock’ on the running surface. Due to high traffic volumes during both wet and dry conditions, elevated levels of tire slip, and the presence of steep slopes, maintenance practices and techniques are short lived. These conditions also lead to the formation of ruts. The formation of ruts disregards the usefulness any maintenance technique may have had as well as making conditions unsafe for riders. The presence of ruts also magnifies erosion levels because of increased energy as a result of channelized flow. Effective maintenance techniques for use, particularly on ORV trails, are necessary because of current techniques not withstanding the wear and tear caused by trafficking.

The development of new maintenance techniques requires background information on which to base management and maintenance decisions. Since documentation of sediment yield and delivery from ORV trails in the Eastern United States is limited, the collection of field data is necessary. The most obvious location for data collection to determine sediment delivery would be at stream crossings. Collecting water samples for lab analysis of total suspended solids (TSS) levels at the stream crossing would allow for the documentation of sediment delivery rates as a result of ORV trail use. As a manager, knowing the levels of sediment yield and delivery are very useful in determining the effectiveness of certain maintenance practices.

Another tool that proves to be useful in making management decisions is the ability to predict the levels of soil yield and delivery. The ability to predict erosion accurately from a trail system, or particular sections of a trail system, allows the manager to simulate maintenance techniques or trail rerouting. Basing management decisions on erosion prediction simulations generally will lead to a better outcome that will aide in reducing environmental impact due to sediment production and delivery. Another benefit of modeling sediment yield is, that by predicting erosion, the placement of various management and maintenance techniques and designs can be better cited. Sediment yield and delivery modeling can have numerous applications that may be utilized by managers and road designers for the layout and upkeep of low-volume roads or trails.

The use of chemical amendments applied to the soil for the maintaining of ORV trails is an area that has limited research but is believed to be a viable method for the reduction of maintenance. The use of the three soil amendments for trail stabilization was studied by Davis (Unpublished thesis. 2004). Davis (2004) found, through traffic and rainfall simulation, that the soil amendment known as Envirotac® had superior performance compared to lignin and control plots. Davis (2004) also found that Envirotac® was useful in reducing rutting and TSS levels. The use of Envirotac® still requires additional research to determine its applicability and usefulness in conditions that involve extended wet periods along with high traffic levels.

The need for research on ORV trails and their impact on water quality in the Eastern U.S. is the reason for conducting this project. Design and maintenance techniques currently used on trails tend to follow those set forth for low-volume roads but are not always applicable. Due to the increase of ORV use, the need for management of ORV trail systems has become essential. The goal of this project is to develop Best Management Practices for Off-Road Vehicle trails. The goal of this project will be accomplished by addressing the following objectives.

Objectives

1. Quantify sediment delivery at a stream crossing and meter traffic volume levels from an Off-Road Vehicle trail system.
2. Calibrate the WEPP model using field data to simulate and predict sediment yield and delivery for ORV trails.
3. Use calibrated WEPP model to recommend Best Management Practices for ORV trails.
4. Conduct an assessment on the application and testing of the soil amendment, known as Envirotac®, to directly reduce trail maintenance and indirectly reduce erosion.

REVIEW OF LITERATURE

Introduction

Studies involving erosion from low-volume roads have been conducted throughout the entire United States, whereas, studies involving the effects of Off-Road Vehicles (ORV's) have been conducted mainly in the Western United States. The principles and theories resulting from multiple research projects are applicable to the Southeastern United States, but due to soil variation is difficult to account for in determining if similar results would be attained in different locations across the country. ORV's affect many aspects of the environment including infiltration rate and sediment production (Eckert, et. al. 1979), damage to soils and vegetation (Sparrow, et. al. 1978), soil compaction and trail width (Weaver and Dale, 1978) and water pollution. Water pollution is generally classified as point source, arising from a distinct outlet, or non-point source, arriving in streams from diffuse areas. Point source pollution is easier to identify whereas non-point source pollution is not. Land activities that create runoff are a source for water contamination. Non-point source pollution has many "sources", including agriculture, mining, forestry operations, landfills, and runoff (Liban, 1998). Erosion from roads and road construction has been shown to yield 95 tons/hectare/year (Brooks et al., 2003) of sediment. Erosion from roads and trails may be reduced through the use of soil amendments.

Weaver and Dale (1978) conducted a study on the effects of hikers, motorcycles, and horses in forests and meadows. They noted that the trail width increased linearly with increasing roughness, wetness, slope, and number of users. Sparrow et. al. (1978) noted that trail width increased in relation to wetness and that in areas where soils became easily saturated, water would pond resulting in the formation of a quagmire. Rider attempts to circumvent these wet areas, led to a gradual widening of the trail. In Weaver and Dale's (1978) study, they also discovered that on level ground, horses were more destructive than hikers or motorcycles, but this did not hold true on steeper slopes. Damage during uphill climbs was much higher for motorcycles than horses or hikers. In general, when the motorcycles were ridden at conservative speeds (less than 20 kph), they caused more damage than hikers, but less than horses. Problems occur when outdoor enthusiasts enjoy riding on steep slopes at non-conservative speeds causing trail damage which can lead to escalated erosion levels.

A study conducted by Eckert et al. (1979) draws the same conclusions found by Elliot et al. (1999). In their paper titled "Impacts of Off-Road Vehicles on Infiltration and Sediment Production of Two Desert Soils", they simulated traffic and rainfall on sites in southern Nevada. Traffic simulation was conducted using motorcycles and 4-wheel drive trucks traveling at 30 kph. Motorcycles were trail-bikes, with knobby tires and weighing approximately 155 kg, and trucks were ¾ ton pickup operated in 4-wheel drive. Results indicated that infiltration and sediment production was mostly due to the type of surface soil. Infiltration rates, or hydraulic conductivities, for coppice soils were 3 to 13 times greater than that of interspace soils. Alternatively, sediment production for interspace soils were10 to 20 times greater than coppice soils. Coppice soils consist of a rocky structure that is well-aggregated and rapidly transmits water. With interspace soils, not only is the structure weak and unstable, saturation occurs quickly which leads to the susceptibility of particle dispersion in the form of runoff. Elliot et al. (1999) stated that erosion rates were affected by hydraulic conductivity and soil erodibility and it backs the conclusions reported by Eckert et al. (1979). Soils with higher hydraulic conductivities will be able to drain water at a higher rate, leading to reduced runoff, which in turn reduces sediment production. Eckert et al. (1999) discovered that after ORV traffic, soil properties are altered, leading to varying results. Negative results due to vehicular traffic include shear damage, fine soil material being powdered and compaction. In general, Eckert et al. (1999) found that infiltration rates were reduced and sediment production increased after soil disturbance due to vehicular traffic.

Other effects of vehicular traffic are soil shearing and compaction (Eckert et al., 1979) resulting in soil damage and destruction of vegetation (Sparrow et al., 1978). The shearing of soil is a physical disturbance that causes an increase in both water and wind erosion in more arid regions. In the more arid regions, shear damage causes the protective soil pavement to be destroyed, powdering fine soils, and finally filling in cracks in the surface polygons (Eckert et al., 1979). Eckert et al. (1979) also discussed the role that motorcycle and other vehicular traffic have in soil compaction. Several studies (Lull, 1959; Wilshire and Nakata, 1976; Davidson and Fox, 1974) demonstrated how compaction caused a decrease in pore space and an increase in bulk density. In these studies, intense motorcycle use as well as traffic by other off-road vehicles was directly correlated to increased soil compaction. A study conducted by Sparrow et al. (1978) in Alaska investigated the effect that ORV's had on soils and vegetation. They discussed that the degree of vegetative destruction was related to the reported traffic volumes. Soil impact was influenced mainly by soil depth and drainage. The presence of gravelly or cobbly soils, whether shallow or deep, were less susceptible to erosion than soils that were deep, but gravel free. Other studies (Egan, 1999; Patric, 1978; Brinker, 1995) emphasize the findings of Sparrow et al. (1978), regarding the negative impacts that wet soil conditions have on roads and trails.

Researchers agree that it is best to avoid wet areas and/or areas containing steep terrain for the location of low-volume roads or trails because of the increased probability of runoff and sediment production. Sometimes the designer does not have the liberty to avoid such areas, so specific design and maintenance techniques can be followed to help reduce the level of sedimentation and therefore potential negative environmental impacts. Numerous studies have been conducted through the years on the measuring of sedimentation from forest roads. Several different types of road designs exist that aid in reducing the levels of sediment transport. Croke and Hairsine (2001) stated that in a forestry environment, a major sediment source is unsealed or low-volume roads. Specific road designs are necessary to help reduce sediment production. Generally, low-volume roads are designed to be either insloped, outsloped, or crowned (Tysdal et al., 1999). The purpose of any one of these road designs is to shed water off the road surface. With an insloped road, water flows into a ditch running parallel to the road, and then into a cross-drain or water bar. Flow in this ditch is described as concentrated. On an outsloped road, water is drained evenly across the road prism and down the hillslope without the development of concentrated water flow.

A crowned road is a combination of both insloped and outsloped roads. Crowned roads will shed water into a channel on one side while evenly draining water across the road prism on the other side. Some crowned roads may drain water into ditches on both side of the road. The effect of insloping, outsloping or a crowned road is overshadowed when the formation of ruts commences (Elliot et al., 1999). Once ruts begin to form, water is no longer shed across the road prism into a ditch or down a hillslope in the manner of the designed flow for the road. The high level of erosion from roads, reported by many researchers, is due to the concentrated flow of water in the ruts causing an increase in rut size, thus sediment transport.

Brinker (1995) discussed the erosive potential that water with high kinetic energy can have. He stated that the kinetic energy of water is controlled by mass, or volume, of water and its velocity. Water velocity and volume are controlled by slope steepness on which the road or trail is built and the ability to move water off the road or trail (Brinker, 1995). In order to remove water from the road's traveled surface, Brinker (1995) suggests four diversion devices: water turn-outs, cross-drain culverts, broad-based dips, and water bars. The use of water diversion devices that are properly spaced along with suitable road prism shape can greatly aide in the reduction of sediment yield from low volume roads or ORV trails. By minimizing water volume and velocity, the kinetic energy possessed by the water is reduced, thereby reducing its erosive potential.

Limited research has been conducted on specific trail maintenance techniques for ORV trail systems. The Soil Ecology and Research Group (2002) installed five types of erosion control devices on the San Clemente Island ATV trail system. These were installed for research and demonstration and to test the compatibility with ATV's. The erosion control methods that were installed were: “wood trail drain, rubber water bar, rock water bar, rolling dip, and Soil Sement.” Wood trail drains consisted of ditches with boards on the sides to prevent the ditch from collapsing in on itself. Rubber water bars utilize strips of conveyer belt placed perpendicular to the trail to divert flow from the running surface. Rock water bars function in the same manner as the rubber water bar, but rocks are used rather than rubber stripping. A rolling dip consists of a rock-lined drain perpendicular to the trail which also aides in removing water from the trail surface. Soil Sement is a soil coagulant similar to Envirotac II. The only preliminary results from this study consisted of erosion-control cost analysis. The costs per 100 m of trail for each erosion control type are as follows: wood trail drain is $2245, rubber water bar is $1267, rock water bar is $1225, rolling dip is $900, and soil sement has an estimated cost of $1050. Results on the effectiveness of each device for erosion control are yet to be reported. On ORV trails, the spinning of tires causes rutting to occur more readily, making erosion control a difficult task as well as making it a challenge to keep water diversion devices intact. The use of soil stabilizers, such as Soil Sement used by the Soil Ecology and Research Group (2002), may provide a good alternative for minimizing the formation of ruts and destruction of water diversion devices.

Soil Erosion Amendments

Fly ash, a type of soil stabilizer, is a by-product of pulverized coal combustion and has been tested for its shear strength when mixed with soils (Porbaha, et al., 2000). Porbaha et al. (2000) reported that the shear strength parameters of soils treated with fly ash were higher than soils without any form of soil stabilization, making it useful in areas with soft grounds. The effectiveness of fly ash is a contradictory issue. Some research has reported increases in permeability for soils with a maximum ash content of 10% while other research has reported large decreases in permeability for soils with 5 to 10% fly ash content (Porbaha et. al., 2000). Further research should be conducted to determine if fly ash may be a viable alternative for ORV trails in the southeast.

Additional forms of soil stabilization include the use of cement kiln dust, polyacrylamide, and acrylic copolymers. Research has been conducted on cement kiln dust to determine its effectiveness as a soil stabilizer (Miller and Azad, 2000). Cement kiln dust is a by-product of cement manufacturing. It is collected from kiln exhaust gases and is unsuitable for recycling by cement manufactures, so it is disposed of as an unusable byproduct. Cement kiln dust stabilizes soil and it increases the potential strength of the soil while decreasing the soil plasticity index. It is thought that by measuring soil pH, one can rapidly determine the potential increase in soil strength.

Miller and Azad (2000) conducted a study on cement kiln dust and its effectiveness on soil stabilization and their results are used in the following discussion. In regular cement, such as Portland cement, there are four phases that govern the strength and curing time. The four phases are alite (Ca_3SiO_5), belite (Ca_2SiO_4), aluminate ($Ca_3Al_2O_6$), and ferrite ($Ca_2(Al_xFe_{1-x})_2O_5$). Aluminate and ferrite are fast reacting but do not yield high strengths, whereas alite and belite are slower reactors but yield high strengths (Portland Cement Clinker, 2004). From this, one can gather that it would be important for cement kiln dust to have high percentages of alite and belite. These two phases when reacting with soil and water would yield a higher-strength soil. Data on the chemical composition of cement kiln dust showed that it was primarily composed of

Silicon dioxide and calcium oxide. Silicon dioxide and calcium oxide are important components in forming alite and belite.

Polyacrylamide (PAM) is a synthetic organic polymer that was developed for the clarification of drinking water. PAM has a high molecular weight and, depending on its molecular composition, it is classified as either a linear or cross-linked polymer. PAM with a linear molecular structure is effective in controlling erosion by stabilizing soils and removing the fine suspended sediment found in storm water runoff. Cross-linked PAM, usually a granular crystal, can absorb hundreds of times its weight in water. There are many applications for PAM, but erosion control is of primary interest. PAM is a long chain organic polymer. Its effectiveness is influenced by soil structure, texture, and salinity. Surface attraction of PAM to soil particles during irrigation by Van der Waals and coulombic forces make it effective in forming floccules thereby preventing erosion (Wu, 2001). The surface attractions, due to these forces, helps soil particles resist detachment by shear-inducing forces, preventing the transport of particles in runoff thus stabilizing the soil. PAM also enhances infiltration by improving pore continuity. Linear PAMs used in erosion control are generally anionic and water soluble. Cross-linked PAMs are generally anionic as well, but cross-linked in order to minimize solubility and maximize water adsorption. The use of linear PAM as a soil amendment has been tested primarily on erosion caused by irrigation in an agricultural application (Sojka et al., 1998). In agriculture, PAM is applied to fields through furrow irrigation. It was also discovered that while helping reduce erosion, PAM also aided in increasing the infiltration rate of water. The Washington State Department of Transportation tested the usefulness of PAM in reducing erosion from highway construction sites (WSDOT).

Cross-linked PAM has proven unsuccessful in gardens and houseplants for conservation of water (Wu, 2001). Due to evapotranspiration, the same amount of water is used with and without cross-linked PAM. The difference is that with cross-linked PAM, higher volumes of water are required at longer intervals, rather than smaller volumes of water at shorter intervals.

Many types and uses of acrylic copolymers exist ranging from glues, fire retardants, carpet backings, to erosion control. Envirotac is a specific type of acrylic copolymer that is used as a soil stabilizer. Some of the applications of Envirotac are unpaved road stabilization, erosion and dust control, and landfill stabilizer (Envirotac, 2005). Other types of acrylic copolymers include Soil-Sement, Soiltac, and PennzSuppress D. These types of acrylic copolymers generally are used on construction sites and other unpaved surfaces. They are not used for erosion control on agricultural lands.

The use of acrylic copolymers such as Envirotac for erosion control is a new concept. These acrylic copolymers create a hard layer, or crust, on the surface that binds the soil particles together to prevent erosion. The use of the polymer for erosion control in areas with little or no traffic, such as on stream banks or hillsides, and dust control need only a light application that still permits water and air penetration. Heavier applications of polymer are used to create an impervious, durable layer on unpaved surfaces experiencing traffic. The soil particles are bound together by resins resistant to breakdown by water, alkaline, and UV (Envirotac, 2005). US Troops at Camp Rhino, Afghanistan were experiencing trouble due to the formation of dust clouds generated during helicopter landings along with the development of rutting on aircraft runways.

Dust was being produced from a clayless 3 ft deep soil underlain with a clay soil (Sawyer, 2002). Envirotac diluted in water was applied to the surface to create a hardpan layer for aircraft landings. The acrylic copolymer created a hard plastic type resin bond with the soil particles. Due to the bond between the particles, the development of dust was suppressed and the runway surface was stronger minimizing rutting. Minimal studies have been conducted on Envirotac and its chemical reactivity with soils, its relation to soil pH, and the surface attraction to sediment. Davis (unpublished thesis) reported that research plots treated with Envirotac and then compacted had an increase in California Bearing Ratio from 5.1 to 11.2. The same study also reported significantly lower total suspended sediment (TSS) values for plots with Envirotac compared to control plots. It was concluded that Envirotac II performed better than lignin treated plots and control plots with respect to TSS levels, bearing ratio, and presence of rutting.

Erosion Modeling

Methods for quantifying erosion from roads have been studied by engineers for years. Recent research has involved using computer models to predict sediment yield within a watershed. The application of erosion prediction models varies depending upon the area of focus such as agriculture, forestry, or road construction (Elliot, et al., 1999). One of the most popular erosion prediction models is the Universal Soil Loss Equation (USLE) (Elliot, et. al., 1999). This model was developed for application in modeling agriculture practices but has been applied towards forest harvesting conditions with little success in predicting sediment yield from forest roads. An alternative to the USLE is the Modified Universal Soil Loss Equation (MUSLE). The MUSLE provides an advantage over the USLE due to its ability to account for sediment delivery and downslope deposition (Elliot, et. al., 1999). A problem with both the USLE and MUSLE is that they were designed to average or smooth out ecological and natural variability. Since the USLE and MUSLE are not event models, peak storm events are averaged with smaller events, therefore reducing the natural variability. The USLE and MUSLE are not representative of the naturally occurring variability in the ecosystem (Baffaut, et. al., 1998). Another type of erosion prediction models are cumulative effect models, in particular the WATSED model. The WATSED model was developed by the USDA Forest Service in the Northwestern United States. It is useful for predicting erosion from roads in all or part of a defined watershed. The drawback with the WATSED model, is its inaccuracy when used for areas outside of the Northwest US (Elliot et al., 1999). Another model used for water surface profiles in both subcritical and supercritical flow is the Hydrologic Engineering Center's River Analysis System (HECRAS), but is not applicable to water erosion modeling (NRCS, 2005). Another widely used model, which is not applicable on a small-scale watershed, is the Soil and Water Assessment Tool (SWAT) which is used on large-scale, ungaged river basins to predict the effect of management decisions on nutrients, pesticides, and water yields (Blackland Research Center, 2005).

Another erosion prediction model that is becoming popular is the Water Erosion Prediction Model (WEPP). As described by Tysdal et. al. (1999), it is "a physically based erosion and sedimentation model used for prediction of erosion from forest roads that can be described as hillslopes." The WEPP model continuously simulates daily soil loss due to irrigation, snowmelt, or rainfall but requires many input parameters for accurate sediment yield prediction. Parameters include rainfall amounts and intensities, soil textural characteristics, soil erodibility, land management practices, plant growth, and topography (Baffaut, et. al. 1998). The WEPP model was created with the idea that it could be parameterized and usable for crops, soils, management practices and topographies to which it is applied (Laflen, et. al. 1991). Because of the required inputs, the WEPP model appears most suited and applicable for modeling soil erosion from ORV trails.

The WEPP model requires the input of several parameters as well as the use of other models for applications such as weather simulations. One of the models WEPP utilizes for climate simulation is known as the CLIGEN Model. The CLIGEN model uses statistical weather data from more than 1400 weather stations across the United States to generate weather simulations for the desired number of years (Baffaut, et. al. 1998). In order for WEPP to predict sediment yield and deposition, it uses six different processes: erosion processes, hydrologic processes, plant growth and residue processes, water use processes, hydraulic processes, and soil processes (Laflen, et. al. 1991). By looking independently at the role and impact each process has on the overall sediment production and deposition, WEPP can be applied to a wider range of natural conditions as well as management activities.

Inputting various parameters into the WEPP model may prove to be lengthy as well as difficult. A study conducted by Flanagan et. al. (2000) focused on using digital geographic information to facilitate the input of parameters. Flanagan et. al. (2000) attempted to build a Geographic Information System (GIS) and utilized Digital Elevation Models (DEM) for delineation of watershed boundaries, channel delineation by means of flow accumulation, hillslope locations, and use the myriad flowpath data to determine hillslope profiles that were identified as “representative”. Multiple automatic WEPP simulations were run for both the Hillslope method and Flowpath method. They predicted comparable runoff and sediment losses and produced similar results from the manual application of WEPP. Flanagan et al. (2000) concluded that there was no significant difference between the two automatic simulations or between the automatic and manual simulations. Attempts to model soil erosion dynamically through the use of WEPP have also been conducted (Wu et al. 1992). They encountered difficulties similar to Flanagan et. al. (2000) in handling and inputting large amounts of data containing temporal and spatial variability. Through the use of GIS, the process of inputting large-scale spatial and temporal data is simplified and the visualization capabilities of a GIS allow for making decisions based on model result displays (Wu et al. 1992). Studies, such as these, lead to the development of GeoWEPP which incorporates a GIS interface to WEPP using ArcView.

Sediment prediction associated with erosion using WEPP has been applied to several areas, including timber harvest areas (Elliot, et. al. 1996), disturbed forests (Elliot, et. al. 1993), rangeland and croplands (Laflen, et. al. 1991), and erosion from various road designs (Morfin, et. al. 1996; Tysdal, et. al. 1999; Elliot, et. al. 1999). Laflen et. al. (1991) set up experimental plots to determine soil erodibility values for rangeland and cropland soils. It was determined that important variables for soil erodibility were organic matter content, particle size distribution, rill presence and spacing, and slope gradient. WEPP predicted some extremely high erosion rates in rills that were realistic on freshly tilled soils, especially if the slopes were steep and high flow rates existed (Laflen, et. al. 1991). Another study conducted by Elliot et. al. (1994) aimed at modifying the WEPP model used for rangeland and cropland and applying it to timber harvest areas, including forest roads. Various model components required change, such as forest soil estimation and parameters, management techniques, hydrology, and the introduction of roads. In this study, they were able to complete some of the model components, but stated that other components such as rainfall causing sediment detachment, runoff, overland sheet flow, residue composition, and plant growth were still under development. Elliot et. al. (1999) conducted a study focusing on sediment prediction from forest roads. Some factors discussed in this study were the difficulty in distinguishing erosion from only forest roads versus sediment within the watershed that generated from other sources. They stated that if the road erosion rates and sediment plume length predictions are acceptable, then the predicted sediment reaching the stream will also be an acceptable value. This is following the assumption that if you accurately predict the amount of sediment leaving the road and how far it travels, then it would be expected that the predicted amount of sediment reaching the stream will also be accurate. When modeling forest road erosion, surface conditions generally overshadow the effect of soil properties. As discussed by Elliot et al. (1999), once the soil on a road surface is compacted the infiltration rate approaches zero, in which case the surface cover dominates the soil properties.

As discussed earlier various types of road designs exist aiding in shedding water from the road prism. When using WEPP, the user must specify the road design type, including parameters such as outsloping or insloping, cross-drain spacing, and if rutting exists. WEPP can be calibrated to help predict erosion under various conditions. Elliot et al. (1999) suggests using WEPP to determine erosion from bike trails or footpaths, by simply narrowing the width, or sediment yield prediction from parking lots, log landings, or other cleared areas that are less than 30 m wide and in a state of erosion.

Some more specific studies have also been conducted on modeling and prediction of erosion with the aide of WEPP. Tysdal et al. (1999) conducted a study where WEPP watershed model was only used to predict erosion from low-volume insloping roads. As described earlier, with an insloping road, water flows across the road prism, into a ditch parallel to the road, and then across the road by means of a water bar or culvert. An insloping road incorporates complex topography making it better to model as a small watershed, rather than a hillslope (Tysdal et al. 1999). The fact that observed sediment yield data is highly variable demonstrates why modeling an insloping road is very complex and challenging. They stated that "WEPP predictions fall in the range of 24 to 74 percent of the maximum measured values." In this study, field measurements and WEPP predictions were very similar in showing that longer, steeper roads produce higher levels of sediment, as well as higher sediment production when grading within the road ditch occurs. WEPP also predicted that on long, steep slopes higher sediment yields were predicted due to a larger contribution area. Therefore, they concluded that the WEPP watershed model can be useful for road engineers and managers in predicting sediment yield and runoff when used correctly with the use of appropriate variables.

Determining the level of detail for input into the WEPP model for a realistic output and prediction is an area of study addressed by Rhee et al. (2004). In this study, buffer geometry, hillslope topography, and road geometry of an outsloped road for sediment yield prediction using WEPP was explored using methods consisting of low, intermediate, and high detail. A 4.4-km road network was analyzed by dividing it into segments of different lengths with data detail for each length varied from low to high. High detail consisted of dividing the road into segments based on azimuth and grade with buffer length and slopes measured along a curvilinear path. Low detail divided the road into segments only at road grade reversals, and buffer length and slope measured using a straight-line path to the stream channel. Intermediate detail segments utilized a combination of high and low detail data analysis methods. Comparison between simulations for the three levels of detail showed very little difference when predicting road-generated sediment. On the other hand, when predicting sediment reaching the stream channel, significant differences were observed between the high level of detail compared to the intermediate and low levels. They concluded that for sediment production from the traveled way, low levels of detail will provide adequate information for reasonable results. If the desired output is sediment delivery, it is suggested that a high level of detail be used and the road network divided based on buffer geometry rather than the geometry of the road traveled way.

Sometimes it may seem practical to use Global Positioning System (GPS) as a method for data input when modeling using WEPP in conjunction with GIS-based road erosion models. Brooks et al. (2003) used WEPP to model erosion from a large road network, where GPS was used to survey the road and road attributes, and GIS used to analyze and manipulate the data. The area of study was a watershed that ranged from 277 to 2706 m in elevation, encompassing 3040 km^2 and included 1017 km of roads. The roads were divided into 6955 segments and surveyed using GPS and with the use of a data dictionary. The following attributes of road data were collected: high points, delivery points, insloped design, outsloped design, crowned design with one ditch, crowned design with two ditches, road width, road cover type, the presence of ruts, and the road gradient. They concluded that using GPS as a form of data input through a GIS can be very useful, although, on a road network of this magnitude the field data collection does prove to be very time consuming. Further, results indicated that accurate predictions are possible on a scale this large, but heavily dependent on how well the true system is represented by the input parameters.

Summary

Research or literature on applying the WEPP or GeoWEPP model to ORV trails has not been conducted, or found, at the time of this review. The use of GPS for spatial data input and GIS for data analyses and manipulation, as was conducted by Brooks et al. (2003), appears to be the best way to calibrate the WEPP model to predict sediment yield and delivery for a watershed containing 3.2 km of ORV trails. There is limited research, especially in the Southeast, on calibrating and testing the WEPP model using individual storm event field data. Using the conclusions by Rhee et al. (2004) to predict sediment delivery, a high level of detail should be used in order to achieve reliable results. Through the review of literature it appears that limited information is available on maintenance techniques and sediment yield and delivery predictions for ORV trails exist. The National Off-Highway Vehicle Conservation Council (NOHVCC) outlines park guidelines for ORV's, but does not delineate any Best Management Practices (2002). A set of Best Management Practices (BMPs) does not currently exist for ORV's and ORV trail systems. BMPs need to be created and used as guidelines during trail design and maintenance. There is also limited research on the use of soil amendments, such as Envirotac II, as a stabilizer for ORV trails. It is apparent that research is required to quantify erosion from ORV trails, calibrating and testing the WEPP model using field data, and testing soil amendments for their ability to reduce erosion and maintenance.

RESEARCH PROCEDURES

Introduction

This project was a joint study between the USDA Forest Service, Talladega Ranger District in Talladega, Alabama and the Biosystems Engineering Department of Auburn University in Auburn, Alabama. The project was funded by the Auburn University Environmental Institute. The overall goal of this research project was to establish some Best Management Practices for ORV trails, in particular the Kentuck ORV trail system. The project sought to quantify total suspended sediment loads of streams influenced by the ORV trails, conduct soil erosion prediction modeling to identify the results of different management practices and perform an initial assessment on the use of soil amendments to reduce trail maintenance. The project provides data that can be utilized by trail designers to reduce sediment yield and deposition based on field data and a calibrated erosion prediction model.

Site Description

The study site is located on the Kentuck ORV trail in Talladega County, Alabama in the Talladega National Forest as shown in Figure 3.1. The Kentuck ORV trail is a recreation area for use of All-Terrain Vehicles (ATVs) and motorcycles. The trail system has a length of about 48 km and an average width of 3.0 m. The trails are broken down into 4 loops of varying lengths. The inner loop, known as the Blue Trail, is about 3.3 km long and is located within the watershed that this study focused on. The Blue Trail, along with the study site, is shown in Figure 3.2. The trails are all unpaved with exposed soil in most areas and some small sections with a gravel running surface. Maintenance practices used on the trails are primarily broad-based dips, water bars, and water turn-outs with timber bridges and culverts used at stream crossings. The stream monitored was a second-order unnamed tributary to Silver Run Creek. The size

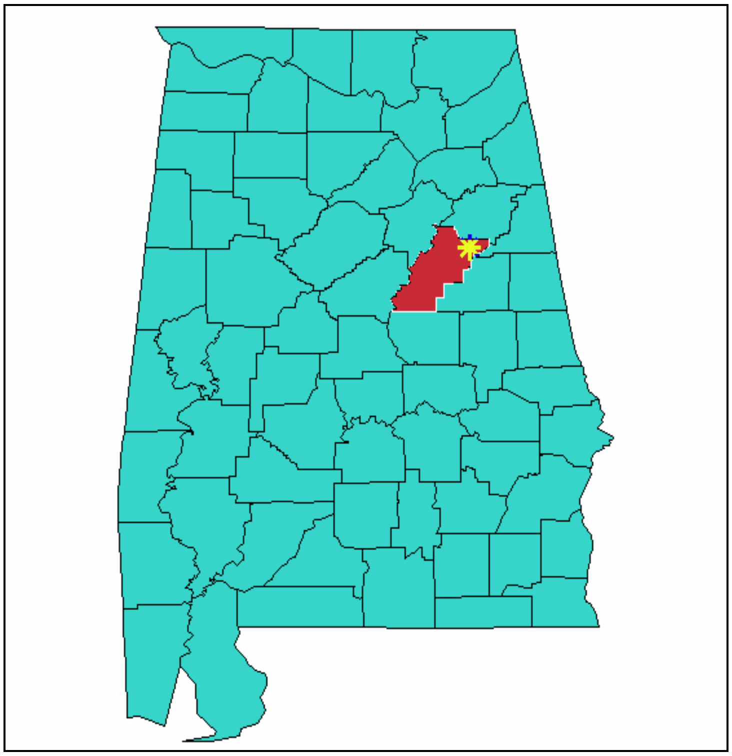


Figure 3.1 – Site Location

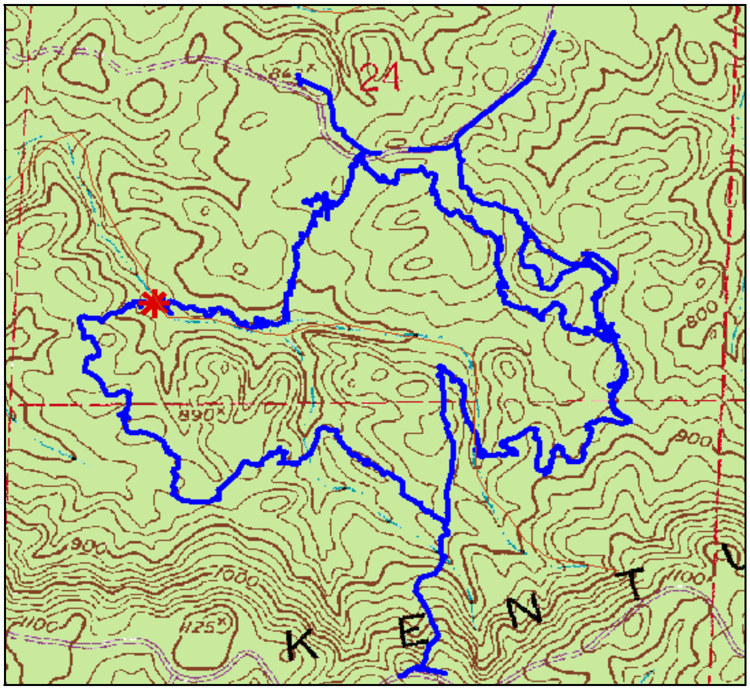


Figure 3.2 – Blue Trail with and Study Site

of the watershed, with the pour point at the crossing, is about 119 ha with an average flow of 2.5 l/s. The average flow was calculated from the flowrate data that was collected. Flowrate data included flow for storm events as well as base flow. The soil description at the site, according to the NRCS Soil Interpretation Record, fit into the Fruithurst Chewacla series with 50% being Fruithurst and 30% being Chewacla. The Fruithurst soil consists of well drained upland soils with a 12 cm thick dark yellowish brown loam surface layer, and a subsoil red clay loam with a depth of about 86 cm. Average slopes are between 6 and 35%.The Chewacla soil is a poorly drained soil found on the flood plains with a brown surface layer about 20 cm thick. Under the surface layer there is a yellowish brown silt loam and loam. Average slopes are between 0 and 2%.

The trail approach to the stream crossing is broken into three sections, the trail section, forest buffer section, and the section on the opposite side of the stream. On both sides of the stream, the trail sections consist of slopes between 0-2 % for a distance of 31 m. On the west side of the stream, there is a water bar at 31 m from the stream channel that diverts flow into a forest buffer that is 60 m long with 0-2 % slopes. On the east side of the trail, there is also a water bar at 31 m diverting the flow through a 20 m forest buffer with a 2 % slope. Above the water bar on the east side of the trail, four more water bars are present at varying distances from the stream. The trail section on the east side, above the water bar is 88 m long with slopes ranging from 2 to 18%.

Equipment Description

Stream Water Sampling

Stream water sampling was conducted in a fully automated fashion. Two ISCO 6700 automated water samplers were used at two separate points in the stream. The first ISCO 6700 was located 16 m upstream from the bridge crossing and the other was placed 60 m downstream from the crossing. The downstream distance to the sampler was large because there was an intrusion of sediment from a trail turnout just below the crossing. This sampler was placed in order to capture this trail runoff.

The ISCO 6700 contains 24 one liter bottles that are filled during storm events (see Figure 3.3). ISCO, or other commercial products, are available at the ISCO website, http://www.isco.com. Both ISCO 6700's were connected to an ISCO 674 Tipping Bucket rain gauge for the purpose of triggering the sampler to start data collection. When storm intensity reached 0.26 cm/hr, both samplers would turn on and commence sampling. Every 15 minutes, one 250 ml sample was taken for a 24 hour period. Each one liter bottle represented one hour of the storm event. The intake hose for each sampler was mounted in the stream roughly 7 to 8 cm from the stream bottom and secured with steel rods. To try and reduce sample contamination, the sampler would purge with air before and after each sample was taken. Also, to collect more accurate samples, the ISCO Water Sampler was calibrated using the intake hose length and the hydraulic head that the sampler had to pump. To lengthen the time the sampler could stay in the field, 12-V automotive and marine batteries were used rather than the supplied ISCO batteries. The data, which included time of trigger and time each sample was collected, was downloaded using an ISCO 524 Rapid Transfer Device for each sampler.

Figure 3.3 – 24 1 liter ISCO Water Bottles

Stream Flow Rate

Stream flow rate was monitored at the upstream site during this study. Flow rates were collected using a Starflow Ultrasonic Doppler Instrument 6526C. The Starflow was bolted to a steel plate and then mounted in the stream bottom using steel rods to secure it. For use in a natural stream, the cross-sectional area must be programmed into the instrument, in millimeters, so that it can conduct all calculations and output a final stream flow rate. The Starflow measures water depth and an average water velocity in order to compute flow rate. The stream cross-section was surveyed using a Topcon 720 Total Station. Figure 3.4 illustrates the stream profile programmed into the Starflow instrument. The Starflow was also powered using a 12-V battery and the downloaded data was collected via a RS 232 serial cable and a laptop computer.

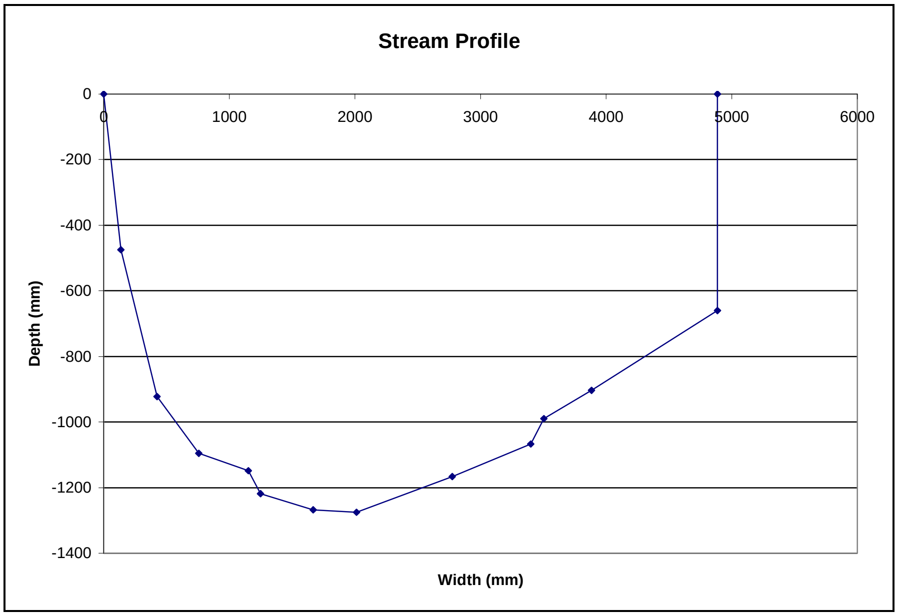


Figure 3.4 – Stream Profile

Rainfall Measurement

Rainfall was measured using an ISCO 674 Tipping Bucket rain gauge. This was the same rain gauge that was used to trigger the ISCO 6700 water samplers. The rain gauge measured both intensity and total rainfall. The sampler was placed in the largest canopy opening available and connected to the ISCO 6700 water sampler. The data was stored directly on the ISCO 6700 water samplers and was downloaded simultaneously with the water sample data. Rainfall amounts were compared to those of a nearby weather station to determine accuracy. The cumulative rainfall data collected with the ISCO rain gauge was typically within 20 % of that measured 5.5 km away in Anniston, AL.

Traffic Measurement

Traffic measurements were conducted in a fashion that allowed for the separation of vehicle types. A waterproof video camera with LED lights for night data collection was mounted to a tree next to the trail 25 m past the bridge crossing. The video camera was wired into a 12-V Video Camera Recorder (VCR) with both video and sound inputs. A motion sensor, mounted adjacent to the bridge crossing, was connected to the VCR and used to trigger the video camera. Each time the motion sensor was 'tripped', the VCR would record a 5 second video clip with a time and date stamp. This allowed for the computation of monthly averages and the separation of ATV's and motorcycles. Figure 3.5 demonstrates the initial video capture setup. The initial setup was only able to record for a 3 to 4 day period before the 12-V marine battery was drained, so it was modified in order to allow for an increased traffic data collection time. Two solar panels were mounted above the video house, wired into a 12-V converter and connected to two 12-V marine batteries that were wired in parallel. Depending on traffic levels, video data collection time was extended to about 10 days. Figure 3.6 is a view from the traffic monitoring station of the bridge approach and departure. Traffic volumes were measured in number of passes per day.

Figure 3.5 – Initial Video Housing Setup

Figure 3.6 – View from Traffic Monitoring Station

Laboratory Analysis

All laboratory analyses were conducted at the Biosystems Engineering Wet Lab at the Auburn University Swine Research Unit. Collected water samples were analyzed for sediment concentration by measuring Total Suspended Sediment (TSS). TSS measurements were conducted according to standard 209C, described in the APHA Standard Methods book (Franson, 1985). Glass fiber filters were washed using 60 ml of distilled water, dried for one hour at temperatures between 103-105 ºC, and weighed twice. Filters were weighed using a Denver Instruments A-200D analytical balance accurate to 0.1 mg with a taring range of 0-200 g and a repeatability of 0.1 mg (Denver Instruments web page). One liter sample bottles were shaken thoroughly to evenly distribute sediment throughout. Next, 200 mL of each water sample were pulled by vacuum through the glass fiber filter and dried. Before weighing, the filters were allowed to cool to the balance temperature in a desiccator and then weighed as before. Sediment concentration was calculated using the following formula:

$$\text{mg total suspended sediment / L} = \frac{(A - B) \times 1000}{\text{sample volume, mL}}$$

where:

A = weight of filter + dried residue, mg, and

B = weight of filter, mg.

In some instances, the sample volumes were decreased because high sediment concentrations would clog the filter, not allowing the remaining sample to pass through.

Soil Amendments

Soil amendments were tested by carefully selecting four plots. Two of the plots were to be control plots, while the other two were treated with the soil amendment known as Envirotac. Curved sections of trail tend to be more readily disturbed, so four trail sections consisting of curves were chosen and paired. Prior to treatment it was determined that the paired curves had similar ruts, same soils, and the same traffic volumes. Data analysis on the plots was conducted by measuring cross-sectional profiles to determine sediment loss or deposition.

Control Plots

Two control plots were used for comparison purposes with the two treated plots. The plots were first drained because of puddling due to the formation of large ruts. With the aid of the Forest Service, the plots were reshaped and bladed using a small dozer and left in what is considered ‘ideal’ conditions, that is a smooth running surface free of ruts, outsloped in order to shed water from the trail prism, and minimize the presence of rock formations for rider safety. Figure 3.7 shows control plot White-A in ideal conditions. The plot was named ‘White-A’ because it was the first plot measured and it was on the section of trail called the White Trail. Steel rods were placed in concrete along the side of the trail so that multiple trail profiles could be collected for cross-sectional area computations. With trails closed, the plots were allowed to sit for 48 hours before the first set of trail profile measurements were collected. Profile measurements were collected using a string pulled tight between the steel posts. A leveled meter stick was used to take vertical measurements from the trail surface to the string at 30 cm intervals along the cross-section. Trail profile measurements were collected between mid-October, 2004 and mid-January 2005.

Figure 3.7 – Control plot White-A in ideal condition

Treated Plots

Two plots, identified as problem areas, were used for the application of treatment. Initial preparation of the plots was the same as occurred on the control plots. The puddles were drained and the plots then reshaped. After reshaping, the plots were scarified with a set of pull-behind discs to a depth of about 10 cm. With the plots scarified, Envirotac II was applied at the manufacturer's recommended dilution rate of four parts water to one part chemical. The application of the chemical was conducted in two ways. First, after dilution, the solution was streamed through a PTO pump and into 5 nozzles with 0.3 cm orifices. The large nozzle orifice was used because of the thick consistency of the solution. The nozzles became clogged, forcing the use of a second application technique which was to spray the solution on the plot directly from the PTO pump. Figure 3.8 shows the method in which the solution was applied to the plots. The solution was applied evenly throughout the entire plot and allowed to soak in thoroughly. Figure 3.9 demonstrates one plot with the Envirotac II application. Once the Envirotac II had been absorbed by the soil, the plots were compacted using a 'Sheep's Foot' trench compacter. The compacter was a Wacker 36-in wide, 3000-lb radio controlled machine with the option of using vibration. Due to the soil type that was being compacted, vibration was not used. Figure 3.10 shows the plot with the compacter near the end of the compaction process. The manufacturer recommended 24 hours for the Envirotac II to dry, however, the plots were allowed to 'set-up' for 48 hours before treated trail sections were opened to traffic. Data collected on the plot consisted of profile measurements which were collected on the treated plots in the same manner as on the control plots.

Figure 3.8 – Application of Envirotac II

Figure 3.9 – Plot soaked in
Envirotac II

Figure 3.10 – Compaction of treated plot

Data Analysis

Data analysis consisted of determining total and average soil loss for each cross-sectional profile and the complete plot itself. The initial and final cross-sectional profile of each plot was graphed on the same chart. The area between the curves was calculated in order to determine the amount of soil loss or deposition. By plotting the initial and final cross-sectional measurement, it was determined visually where soil was being detached and deposited.

Erosion Prediction Modeling

Erosion prediction modeling was conducted using the Watershed Erosion Prediction Project (WEPP) as the driver along with three different interfaces. The WEPP driver uses ANSI FORTRAN 77 as the source code and is capable of running on any computer that utilizes MS DOS 5.0+. The three interfaces that WEPP utilizes allow for a user-friendly data and parameter input as well as various outputs for easy interpretation. The first interface was the ArcView 3.2a GIS interface, known as GeoWEPP, used to delineate the watershed and various subcatchments. The second interface used was web-based, known as Rock: Clime, and was a weather generator model interface. The final interface used was the more popular windows interface known as WEPP:Windows. The three interfaces were used to calibrate and run the model to predict erosion for various management practices.

Watershed and Subcatchment Delineation

The ArcView 3.2a GIS interface, GeoWEPP, was used to delineate the watershed and subcatchments within the watershed. Digital Elevation Models (DEM) and topographic images were downloaded in ASCII format from the NRCS Data Gateway web page for use in GeoWEPP. The DEM were used in GeoWEPP to determine the topography of the area of interest. GeoWEPP allows the user to adjust the critical source area and minimum channel length, in order to accurately identify the number of channels in which the flow is allowed to accumulate. In order to create accurate stream channel delineation, the critical source area and minimum channel length were adjusted to 10 ha and 200 m, respectively. Using GeoWEPP, flow accumulation and direction were identified and checked by ground truthing. Using collected GPS data projected into the UTM 1983 datum, the pour point for the watershed was identified and used to delineate the watershed. With the pour point identified, GeoWEPP delineated the watershed and 8 subcatchments within. Figure 3.11 identifies the 119 ha watershed with the 8 subcatchments with the 3.3 km, Blue Trail, as the top layer in the image. The watershed and subcatchments were saved for later modification using the WEPP: Windows interface.

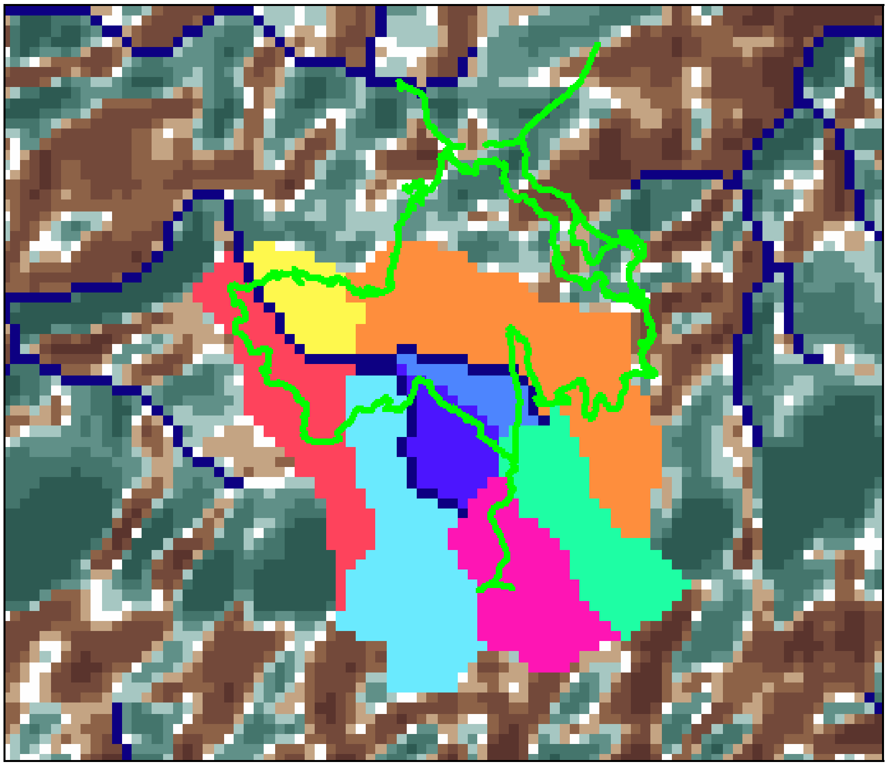


Figure 3.11 – Watershed and subcatchments

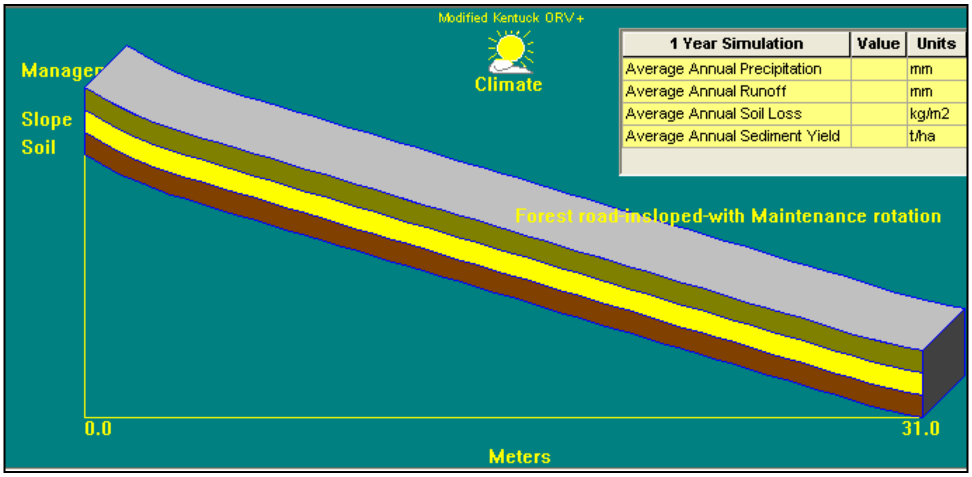
Weather Generator

WEPP uses a stochastic weather generator called CLIGEN. It is accessible through WEPP: Windows or the internet interface known as ROCK: CLIME. The ROCK: CLIME interface was used because of its ease of modification. The ROCK: CLIME weather station of Anniston, AL was used because of its proximity to the trail system. The Anniston weather station is about 5.5 km from the trail system. Using PRISM (Parameter-Regression on Independent Slopes Model), the climate parameters were modified for the exact latitude, longitude, and elevation of the Kentuck Trail System. These parameters were used to generate one year of simulated weather and then saved and downloaded. The generated weather was next modified to match the actual precipitation amounts and dates recorded during field collection. This was accomplished by zeroing out precipitation amount, precipitation duration, time to peak intensity, and peak intensity. These four values were calculated using field data for every storm event and input into the generated weather file for its respective date. The weather data is generated on a daily basis over a one year period. With the weather file modified, it was ready to be imported into WEPP: Windows. A second weather file was also created using same process as above, except this file was generated to simulate 30 years of weather. This file was saved and not modified.

Subcatchment Modification and Model Calibration

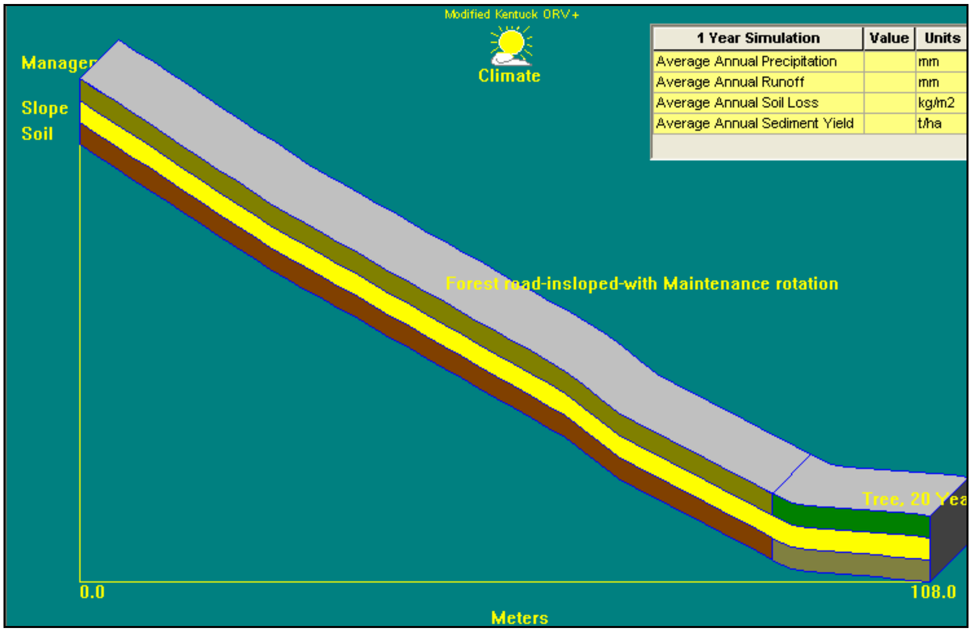
Once the subcatchments were delineated with the aide of GeoWEPP and the weather modified using ROCK: CLIME, a new project was created with WEPP: Windows in order to conduct final modifications and model calibration. Using a clinometer and meter tape, slope length and percents were recorded for sections of the trail that intersected streams. These values were recorded and used to modify the model of subcatchments that included stream/trail intersects. Since all trail approaches to the stream included waterbars, it was assumed that the last waterbar before the stream diverted 100% of the flow into the forest. Therefore, the forest acted as a buffer for flow of water and sediment traveling along the trail above the final waterbar. WEPP represents terrain in a three layer fashion. The top layer is used to input the current management practice. The second layer is used to input the slope length and steepness. The third layer is used to input the soil types that are found on the particular hillslope. By inputting breaks in any of the layers, the user can create different overland flow elements (OFE) to better represent the hillslope. Breaks were used within the model to separate trail sections and soils from forest buffer sections and soils. Also, on sections of trail that were directed straight down the slope, it was assumed that all flow remained on trail, either in ruts or bare ditches. These sections of trail were modeled as insloped roads with a bare ditch, or outsloped road with the presence of ruts. Both parameters yield similar results because they both conduct flow down the trail rather than shedding water from the road prism. The final section of trail below the last water bar was also considered and it was modeled as an insloped trail with all sediment loss being delivered directly into the stream. The section of trail on the other side of the stream was modeled in this same manner. Figures 3.12 and 3.13 represent the insloped trail leading directly into the stream and the insloped trail with the forest buffer, respectively. These figures demonstrate the data input screen that WEPP uses. Figure 3.12 shows a hillslope representing a 1 m wide section of the hillslope on which the trail is located. Figure 3.13 is similar except that it includes a 20 m section of forest buffer at the hill bottom. The different color at the bottom of the hillslope represents the forest buffer with its associated soils.

For subcatchments containing trails but not crossing any stream channels, the distance between the trail and the stream was measured using ArcView. These sections of trail were modeled as outsloping with sediment flowing across the road prism and the distance between the trail and the stream was considered to be a forest buffer. Figure 3.14 represents this.



1 Year Simulation	Value	Units
Average Annual Precipitation		mm
Average Annual Runoff		mm
Average Annual Soil Loss		kg/m2
Average Annual Sediment Yield		t/ha

Figure 3.12 – Insloped Trail Leading into Stream



1 Year Simulation	Value	Units
Average Annual Precipitation		mm
Average Annual Runoff		mm
Average Annual Soil Loss		kg/m2
Average Annual Sediment Yield		t/ha

Figure 3.13 – Insloped Trail with 20 m Forest Buffer

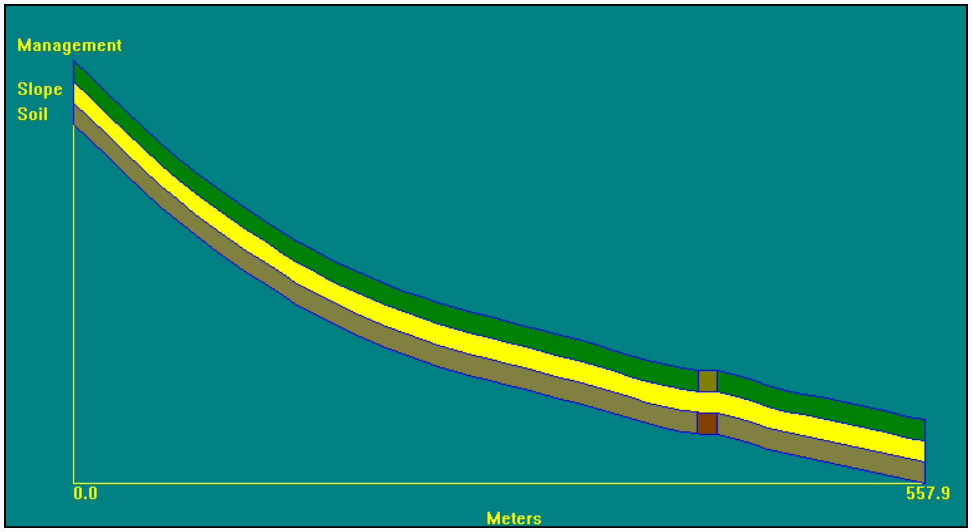


Figure 3.14 – Outsloped Trail with Forest Buffer

Once all the subcatchments were modified with the proper slope parameters, the soil parameters had to be adjusted. To ensure proper soil parameters, field samples were collected and analyzed by the USDA Forest Service and the Auburn Soils Testing Laboratory for percent sand, silt, and clay. These values were then compared to data collected by both the USDA Forest Service and the NRCS. From the WEPP literature, it was determined that the four most important and sensitive soil parameters used to determine sediment yield and deposition were the following: interrill erodibility, rill erodibility, critical shear, and effective hydraulic conductivity. Because of the importance of these values, the soil parameters determined from the field data were used along with the following formulas taken from the WEPP Application Help:

<u>Interrill Erodibility (kg*s/m^4)</u>

$$K_i = 2728000 + 192100 * VFS$$

<u>Rill Erodibility (s/m)</u>

$$K_r = 0.00197 + 0.0003 * VFS + 0.03863 * e(-1.84) * ORGMAT$$

Critical Shear (N/m^2)

$$T_c = 2.67 + .065 * Clay - 0.058 * VFS$$

Effective Hydraulic Conductivity (mm/h)

$$K_b = -0.265 + 0.0086 * Sand\ \hat{}(1.8) + 11.46 * CEC\hat{}(-0.75)$$

where:

VFS = percent very fine sand in the surface soil

ORGMAT = percent organic matter in the surface soil

Clay = percent clay in the surface soil

Sand = percent sand in the surface soil

CEC = Cation Exchange Change

The interrill erodibility, rill erodibility, critical shear, and effective hydraulic conductivity were input as model parameters and multiple simulations were conducted. The model was set to output event-by-event storm data so as to make a direct comparison with the event-by-event field data. The effective hydraulic conductivity was reduced because the calculated value represented an undisturbed soil and, due to the compaction on the trail surface, the actual hydraulic conductivity was much lower. The reduced value that was used was similar to the default WEPP value for a loam road surface. After each simulation, the storm-by-storm output was recorded and compared to the field data. Numerous simulations were carried out in which the four parameters defined above were systematically changed and model outputs were compared to the measured sediment yield values. When the highest correlation between measured and modeled values was achieved it was assumed that the model calibration was complete.

Management Simulations

Using the non-calibrated model, multiple simulations were conducted to simulate various management activities. Simulations were conducted on waterbar spacing, minimum forest buffer lengths, and acceptable slope steepness. The simulations were conducted using an unmodified 30 year weather file. Simulations were also conducted to demonstrate the importance of proper maintenance including functioning waterbars, reducing rut formation, and forested buffers.

Statistical Analysis

Statistical analysis was conducted to test the goodness-of-fit between the measured and predicted event-by-event sediment losses (Spruill et. al., 2000). The Nash-Sutcliffe coefficient, R^2, was used to measure the goodness-of-fit. The equation used was the following:

$$R^2 = 1 - \frac{\sum (Q_m - Q_p)^2}{\sum (Q_m - Q_{avg})^2}$$

where:

Q_m = measured soil loss (kg)
Q_p = predicted soil loss (kg)
Q_{avg} = average soil loss (kg)

By comparing R^2 values for each simulation, individual predicted storm events were used and compared to the measured of the same storm events. This allowed for accurate model calibration and reasonable erosion prediction results for varying management activities.

RESULTS AND DISCUSSION

Stream Water Sampling

Stream water sampling data collection was conducted between December of 2003 and July of 2004. The data collection time was separated into three periods. The first period was during the winter months when the ORV trails were closed, the second period was in the early spring when trail maintenance was conducted, and the third period was during spring and summer when the trails were opened and ATV and off-road motorcycle trafficking allowed. Data were collected during these three periods and the results are separated accordingly. Three example storm events with similar cumulative rainfall will be discussed in the next three sections along with maximum sediment producing storm events and total sediment production during each period.

Trails Closed Period

Data collected in this period was from January through February 2004. During this period, the ORV trails were closed, therefore there was no trafficking taking place. Four storm events were monitored during this period with cumulative rainfall for each storm ranging from 1.12 cm to 4.88 cm. Data for each storm event is separated into Site A and Site B, representing the sampler upstream from the bridge crossing and the sampler downstream from the bridge crossing, respectively. Figures 4.1 through 4.4 exemplify a single storm event that took place February 12, 2004. These figures represent cumulative rainfall, stream flowrate, total suspended sediment (TSS), and sediment loading. In Appendix A, plots for all storm events during the trail closed period are represented.

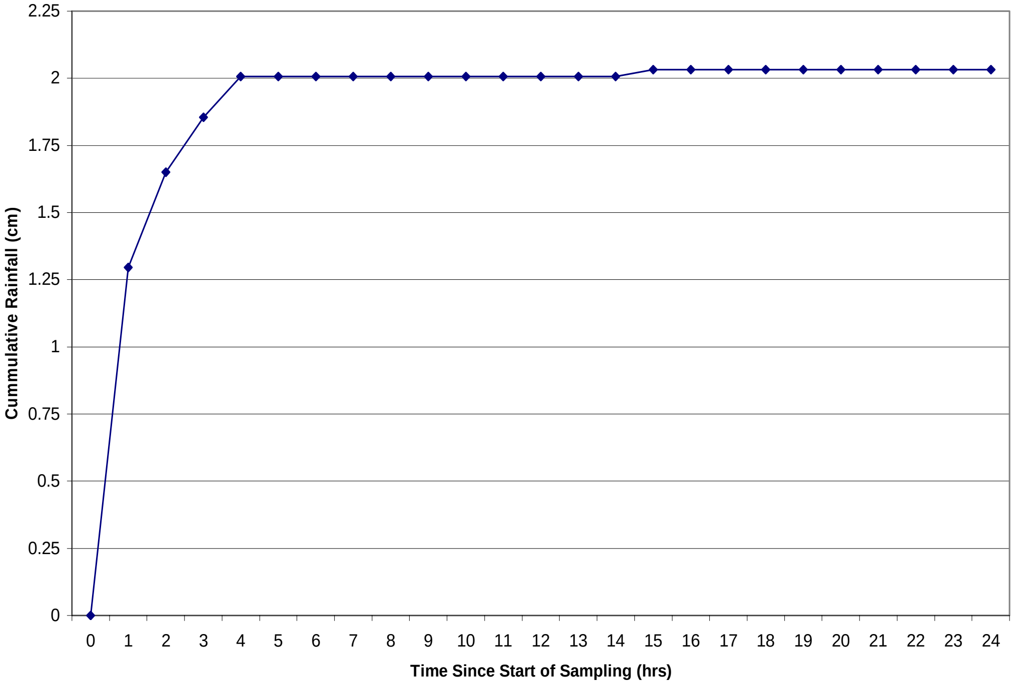


Figure 4.1 – Cumulative Rainfall for February 12, 2004 storm event

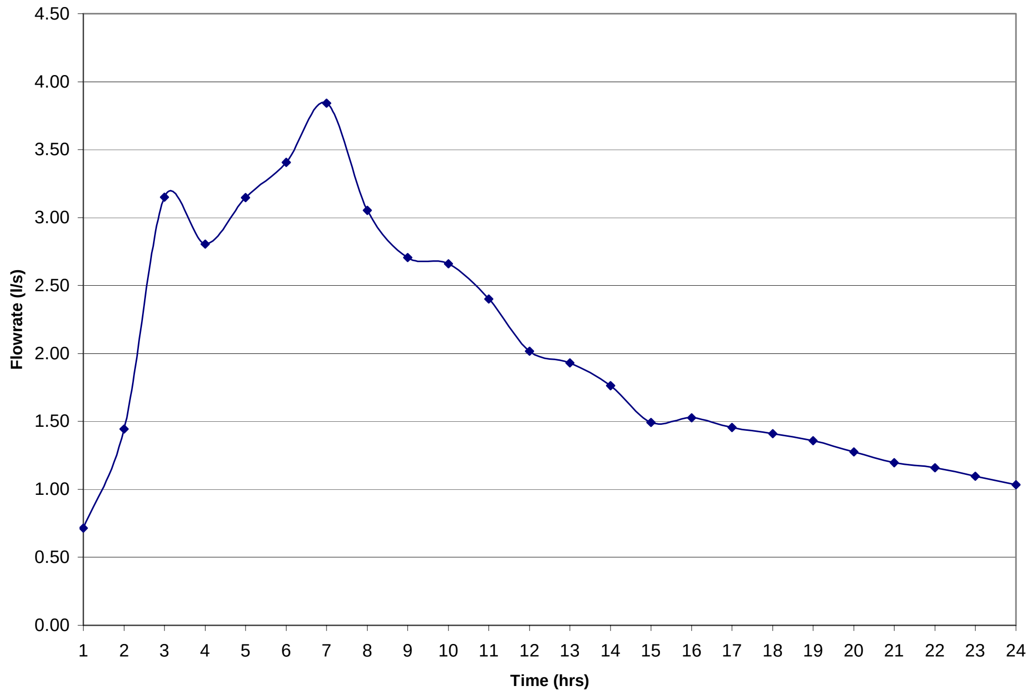


Figure 4.2 – Hydrograph for February 12, 2004 storm event

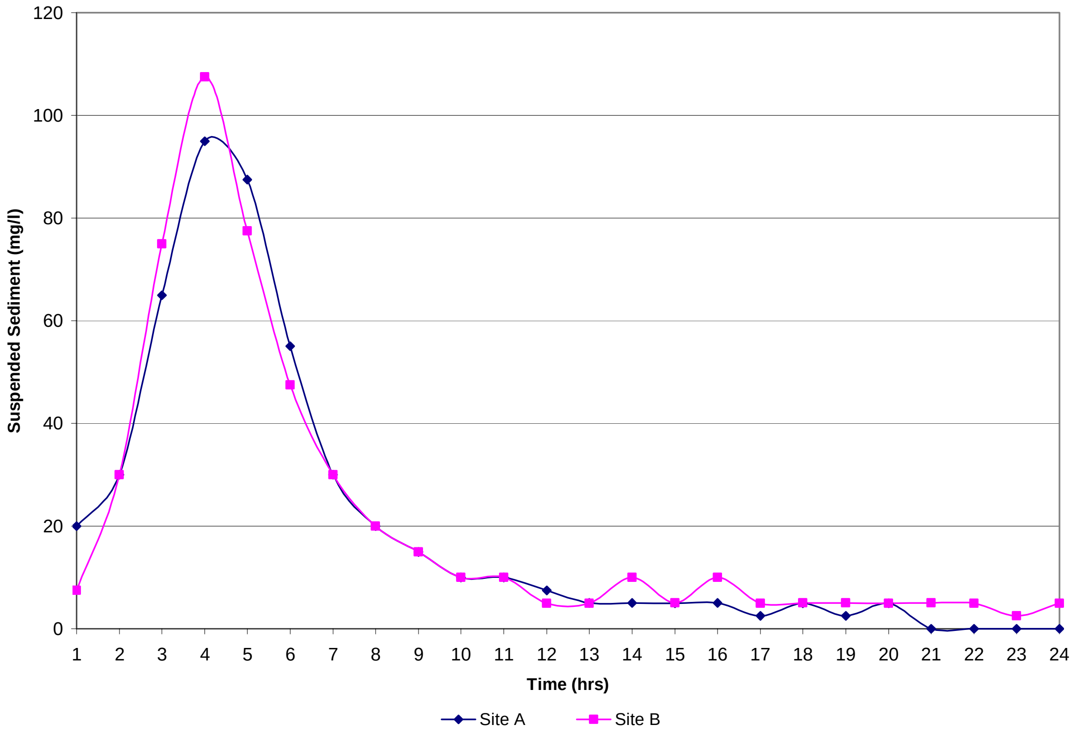


Figure 4.3 – TSS for February 12, 2004 storm event

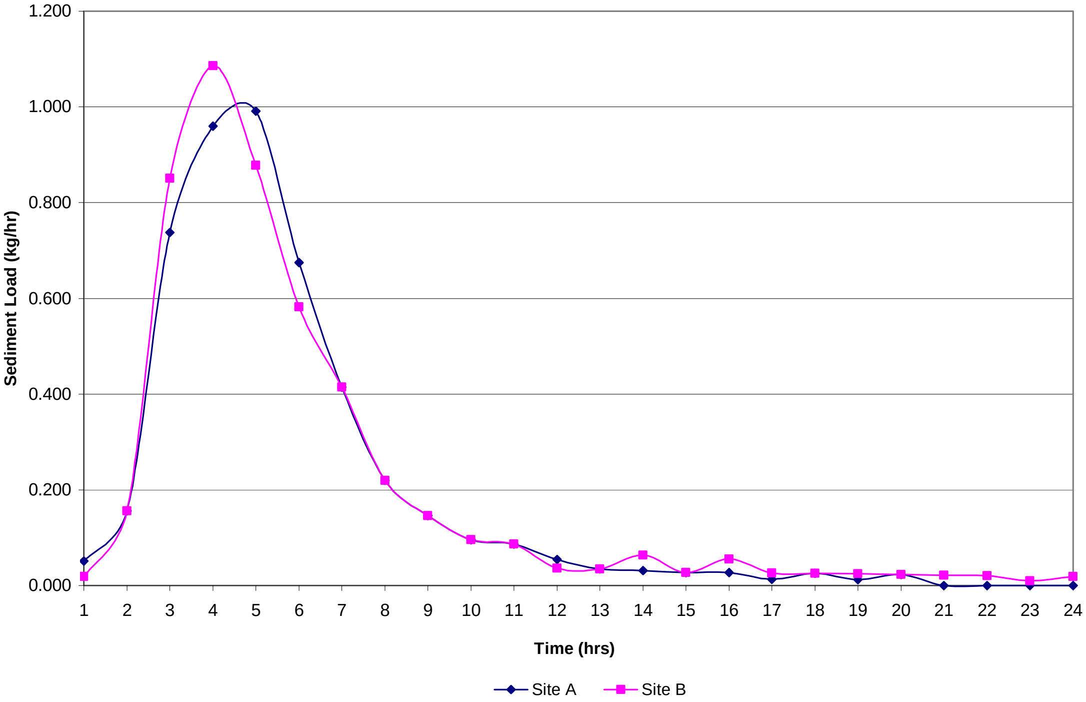


Figure 4.4 – Sediment Load for February 12, 2004 storm event

The cumulative rainfall for this storm event was 2.0 cm. The maximum TSS level measured at the upstream sampler was 95 mg/l while the maximum measured at the downstream sampler was 108 mg/l for this storm event. These peaks were only reported for a one hour period before a significant drop was noticed. Sediment load was calculated by multiplying TSS values with flowrate values. The maximum sediment loads calculated for this storm event were 0.96 kg/hr and 1.09 kg/ hr for Site A and Site B, respectively. By integrating under the curve for each sediment load and then taking the difference between Site A and Site B, total sediment introduced at the crossing was calculated. From Figures 4.3 and 4.4, it is noted that at the 5th and 6th hour, the upstream concentration and sediment load is higher than that of the downstream site. It is difficult to determine what caused this situation to occur. Possibilities for this include measurement error, channel overflow causing deposition, or bank sloughing just upstream of the Site A sampler. Table 4.1 summarizes sediment loads for the February 12, 2004 storm event and for all four storm events that occurred during the period when the trails were closed.

Table 4.1 – Sediment Load summary for storm event on February 12, 2004 and the trail closed period (Jan – Feb, 2004)

	Storm Event	
Location	**12-Feb-04 Storm (kg)**	**Entire Closed Period 4 - storm events (kg)**
Site A	4.8	177.6
Site B	4.9	286.9
Sediment Introduced	***0.1***	***109.4***
% of Total	**2.8**	**38.1**

The storm of February 12, 2004 did not contribute a significant sediment load to stream channel. This is shown in Table 4.1. The percent of total value represents the amount of sediment introduced into the stream at the crossing compared to the total sediment in the stream. The maximum TSS and sediment load during this period occurred on February 6, 2004 with a cumulative rainfall of 4.9 cm. The TSS level peaked at 1715 mg/l resulting in 108.9 kg of sediment introduced at the crossing. This explains why the total sediment load value for the closed period in Table 4.1 is rather large. This storm is shown in Appendix A, but not here because comparisons were made only between storms with similar cumulative rainfall.

Trail Maintenance Period

The trail maintenance period occurred during the month of March 2004. During this period, the USDA Forest Service conducted their standard annual trail maintenance in preparation for the opening of the trail on April 1, 2004. Four storm events were recorded with cumulative rainfall during maintenance ranging from 0.51 cm to 2.032 cm. Figures 4.5 through 4.8 demonstrate a single storm event that occurred on March 6, 2004. The figures represent cumulative rainfall, stream flowrate, TSS, and sediment loading. The cumulative rainfall for this storm event was 2.03 cm with a peak intensity of 2.24 cm/hr. Other storm events recorded during this period can be found in Appendix B.

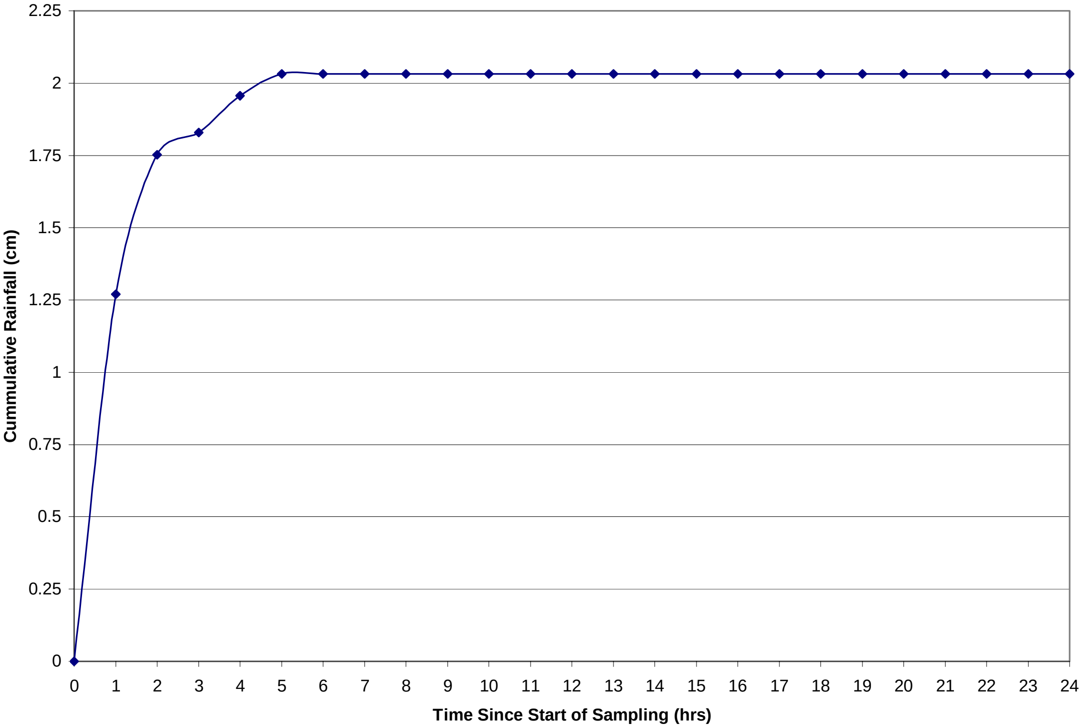


Figure 4.5 – Cumulative Rainfall for March 6, 2004 Storm Event

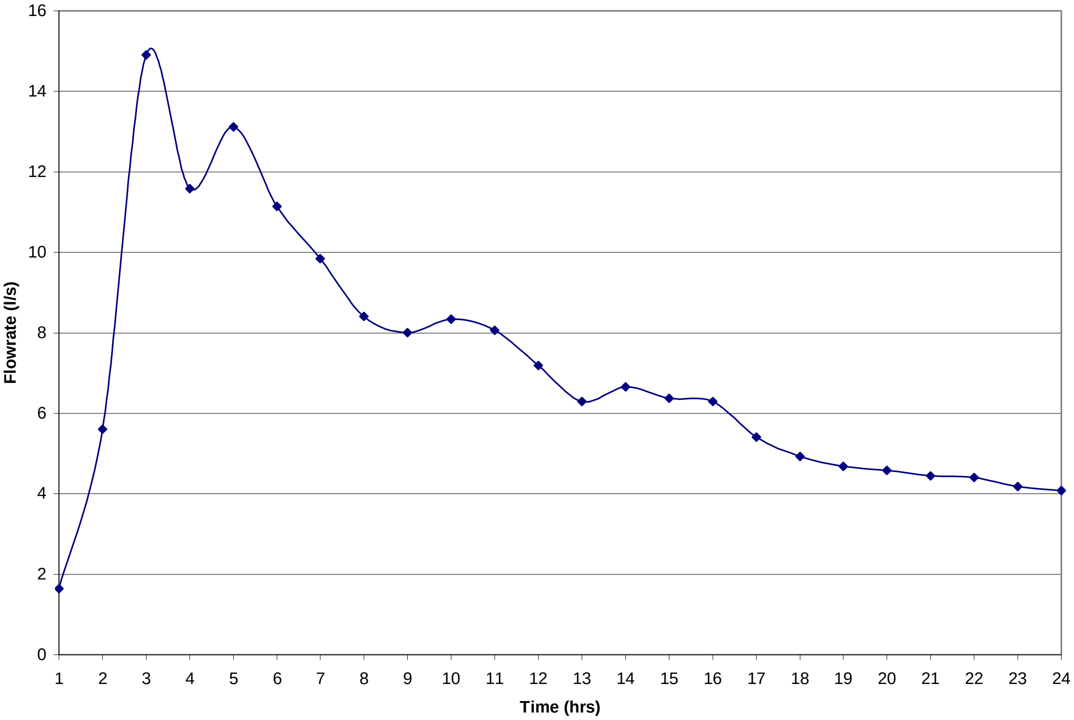


Figure 4.6 – Hydrograph for March 6, 2004 Storm Event

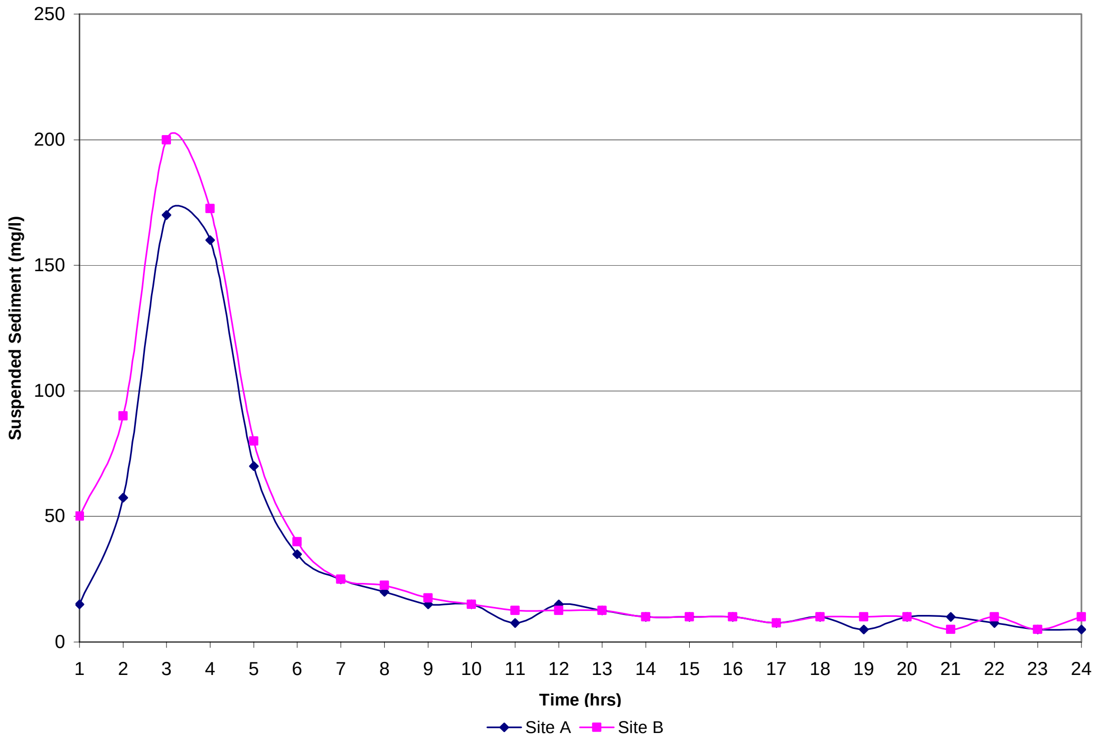


Figure 4.7 – TSS for March 6, 2004 Storm Event

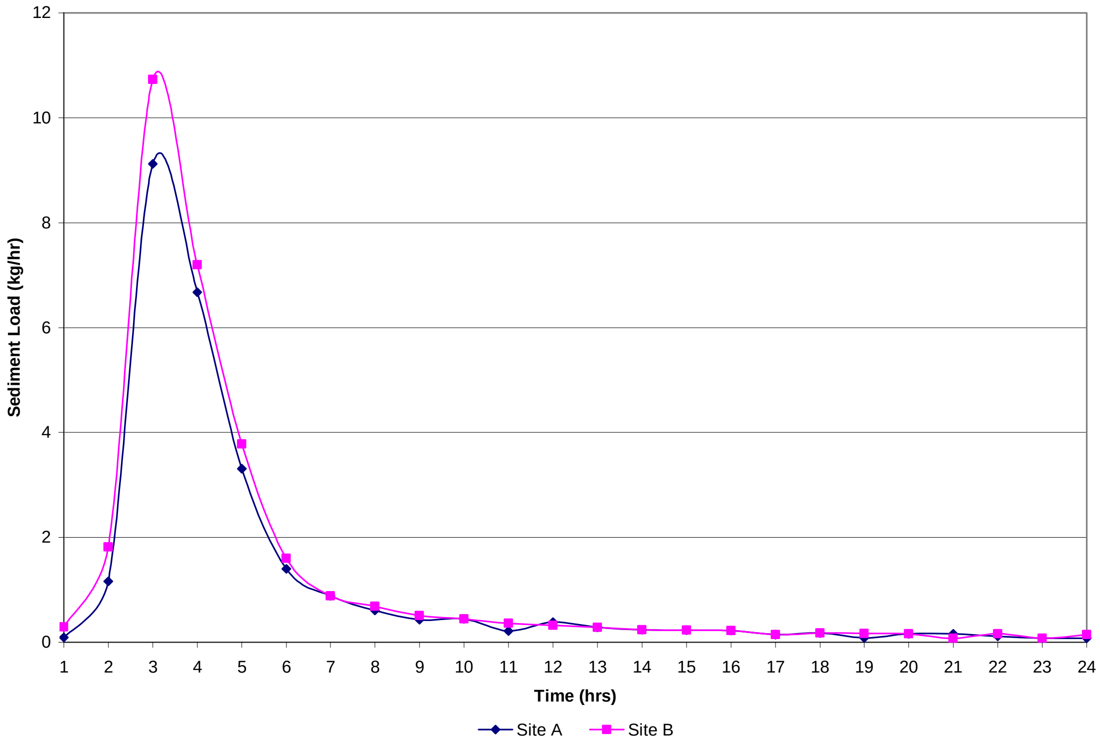


Figure 4.8 – Sediment Load for March 6, 2004 Storm Event

The maximum TSS level measured for this storm event was 170 mg/l and 200 mg/l for the upstream sampler and the downstream sampler, respectively. Conducting the similar computation as before, the sediment load introduced at the crossing for this storm event was 4.01 kg. Table 4.2 summarizes the storm events collected during the maintenance period.

Table 4.2 – Sediment Load summary for storm event on March 6, 2004 and trail maintenance period

Location	**Storm Event**	
	6-Mar-04 Storm (kg)	**Maintenance Period 4 - storm events (kg)**
Site A	26.72	30.19
Site B	30.73	34.87
Sediment Introduced	***4.01***	***4.68***
% of Total	**13.05**	**13.42**

The storm event of March 6 recorded both the largest cumulative rainfall and largest sediment introduction of any storm during the maintenance period. The March 6 storm event was rather small, but yet a relatively large sediment load was introduced into the stream at the crossing. The reason for this could have been because during maintenance, significant disturbance is caused to the trail surface. Maintenance is conducted using a Caterpillar D3C dozer and, while the trail condition is improved, the surface disturbance allows for increased soil detachment resulting in higher sediment losses. Since the March 6 storm event was the first to occur after maintenance commenced, recorded sediment loads were highest because of the very recent disturbance. Once the loose, disturbed surface soil is eroded, more energy is required to move the remaining soil, so the next few storms during the maintenance period do not have the same impact as the March 6th storm had.

Trail Open Period

The trail opening day was April 1, 2004. The trail open period data collection took place from opening day through July 2004. During this period, traffic was allowed on the trails at all times and under any condition. Instrumentation was installed for data collection designed to determine traffic volumes. Eight storm events were recorded for the period while the trail was open and the cumulative rainfall for these events ranged from 0.97 cm to 3.61 cm. Figure 4.9 though 4.12 were recorded from a storm event that took place on April 30, 2004. As before, these figures represent cumulative rainfall, stream flowrate, TSS, and sediment loading. The cumulative rainfall for the April 30, 2004 storm event was 2.24 cm with a peak intensity of 2.64 cm/hr. Other storm events recorded during this period can be found in Appendix C.

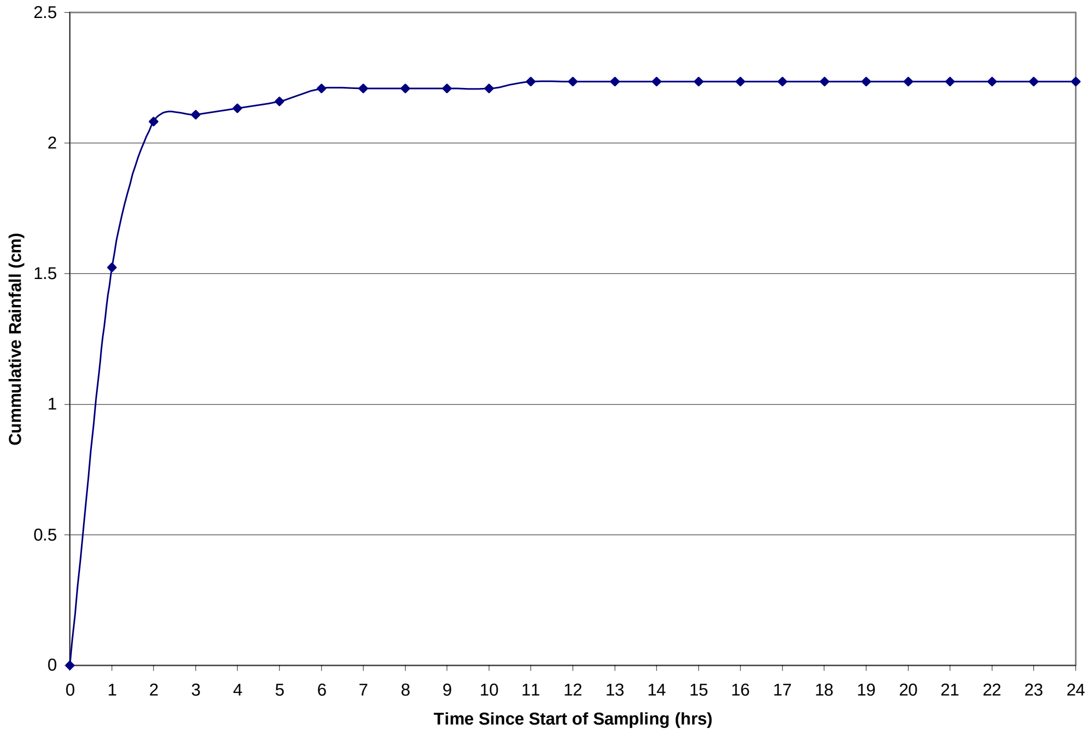


Figure 4.9 – Cumulative Rainfall for April 30, 2004 Storm Event

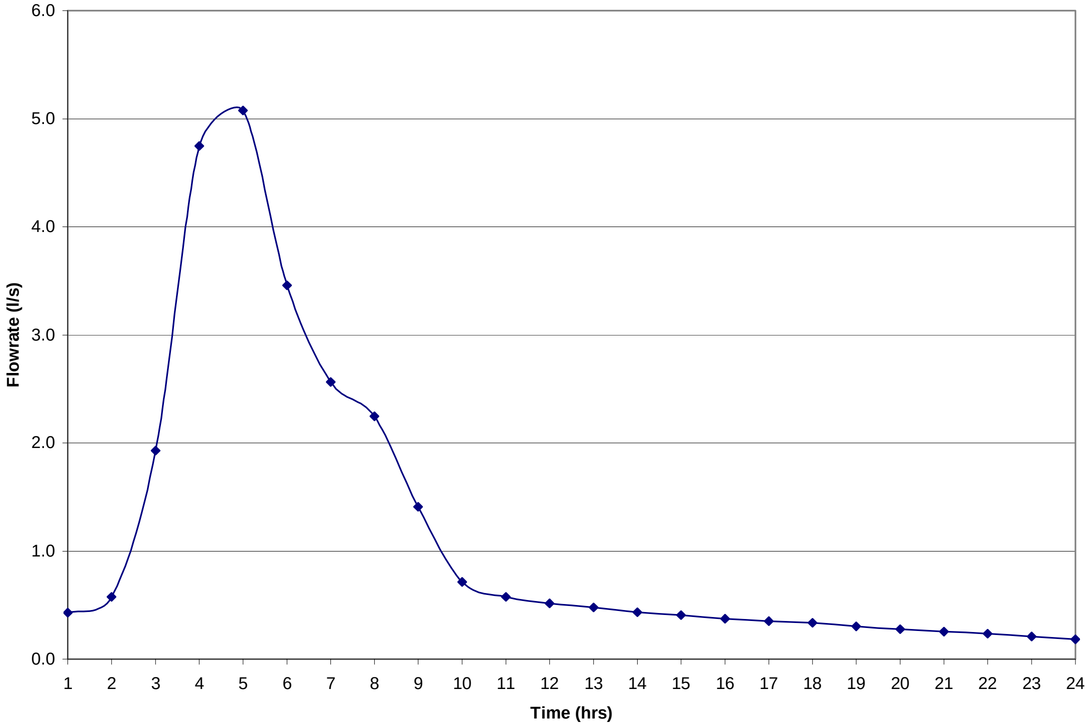


Figure 4.10 – Hydrograph for April 30, 2004 Storm Event

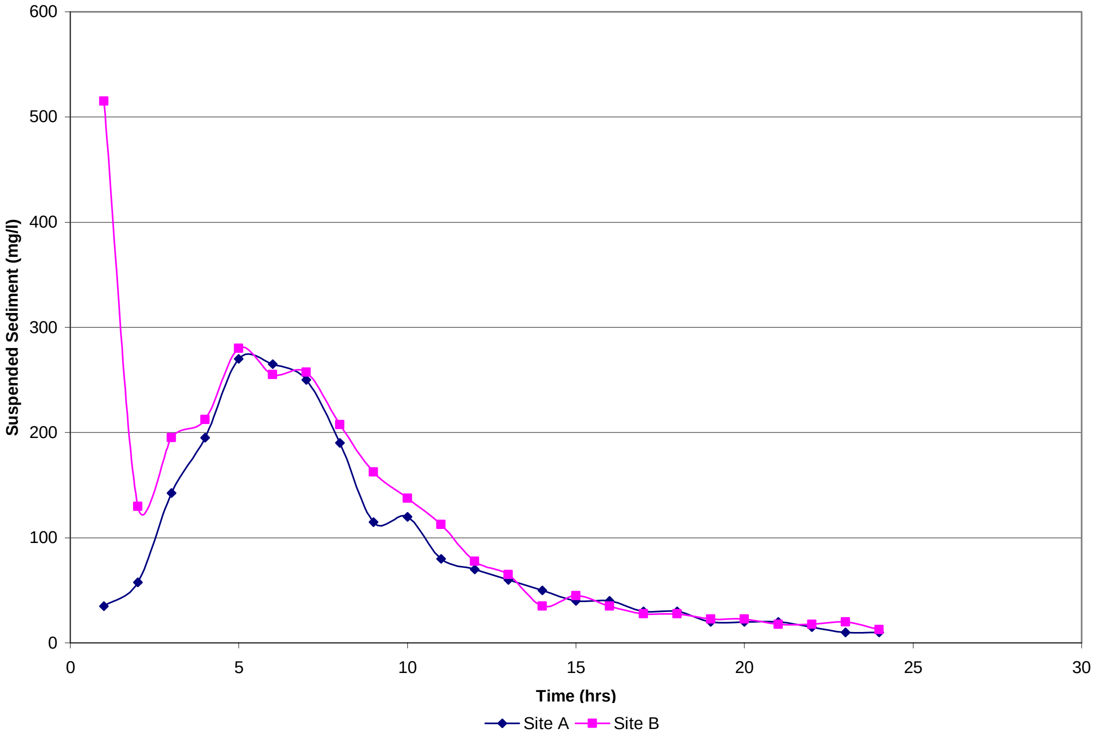


Figure 4.11 – TSS for April 30, 2004 Storm Event

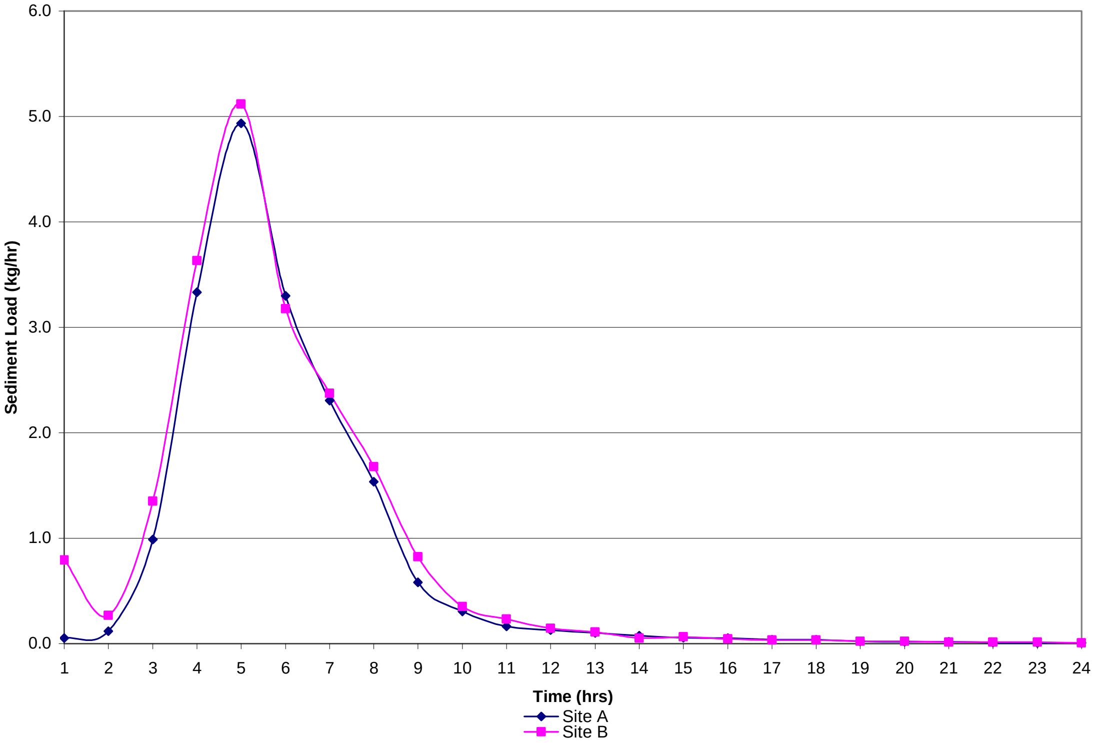


Figure 4.12 – Sediment Load for April 30, 2004 Storm Event

The maximum TSS level for the upstream and downstream sampler recorded for this storm event was 270 mg/l and 280 mg/l, respectively. The sediment load introduced at the bridge crossing during this storm event was 2.2 kg. Figure 4.11 has a peak during the first hour of data collection that may have been caused by leaf and sediment accumulation around the hose intake at the time the first sample was collected. Table 4.3 summarizes the sediment load from this storm event and the sum of sediment loads from all storm events that occurred while the trail was open. The sediment load recorded for the April 30, 2004 storm event was the highest recorded while the trail was open. However, on May 16, 2004 a storm event occurred with a cumulative rainfall and peak intensity of 3.61 cm and 5.99 cm/hr, respectively, both values were larger than that of the April 30, 2004 storm event. Plots for this storm event are displayed in Appendix C.9 through C.12. The hypothesized reason for this storm event having a lower sediment yield is that during the first two weeks of May not a single rain event was recorded. This would cause the soils to be drier so the water storage would be lowered, resulting in a higher infiltration volume before runoff would commence. On April 27th and 28th, two rain events occurred, causing water storage to be almost at peak, so runoff would occur more readily during the recorded April 30 storm event.

Table 4.3 – Sediment load summary for April 30, 2004 storm event and the trail open period

Location	**Storm Event**	
	30-Apr-04 Ex. Storm (kg)	**Open Period 8 - storm events (kg)**
Site A	18.21	53.47
Site B	20.40	60.35
Sediment Introduced	***2.19***	***6.88***
% of Total	**10.74**	**11.40**

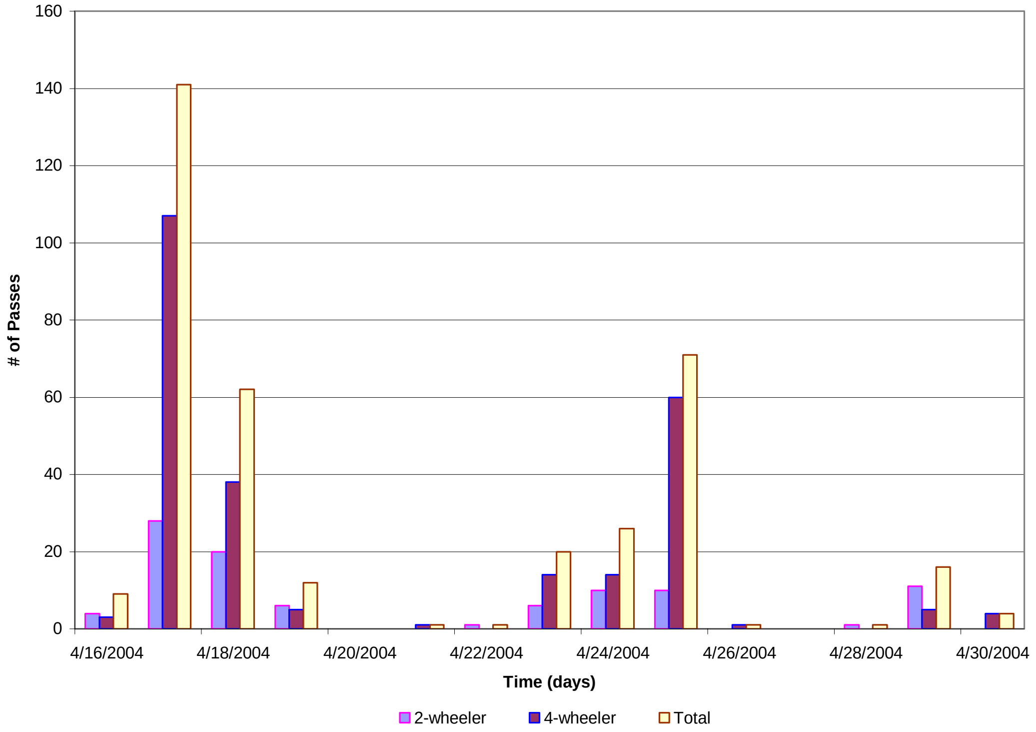


Figure 4.13 – Traffic Volumes for April 2004

The traffic volumes measured on the trail systems were very high and is demonstrated in Figure 4.13 by showing traffic levels during the month of April. Traffic volumes were separated into 2-wheel and 4-wheel vehicles. The weekends of April 17, 2004 and April 25, 2004 reported traffic totals of 141 and 71 passes, respectively. Table 4.4 shows the traffic totals and averages for the data collection period. The data in Table 4.4 shows that in 87 days of traffic volume quantification, a total of 2200 passes were counted resulting in an average of 25.3 passes per day. These traffic totals and averages were much higher than expected. However, the 4-wheeler average exceeding that of the 2-wheelers was expected. The reported total of 2200 does not represent separate riders; rather it is 2200 passes in front of the traffic monitoring station. It should be noted that

Table 4.4 – Daily traffic totals and averages for trail open period

Total Days	**Traffic Totals**			**Total**
	2-wheeler	*4-wheeler*	*Other*	
87	506	1586	108	2200
Average	***5.8***	***18.2***	***1.2***	***25.3***

traffic volumes were not collected for the entire period that the trails were open due to equipment malfunction. Equipment downtime ranged from 5 days to 2 weeks per month. Also, the category of 'Other' includes vehicles other than 2-wheelers and 4-wheelers or vehicles that could not be distinguished due to equipment malfunction.

Overall Sediment Loading

Further analysis between storm events was conducted to determine correlation between cumulative rainfall, stream flowrate, TSS, and sediment load. All storm events were separated into three categories based on rainfall return periods. The first category was for storm events with a return interval of one month or less. This was the equivalent of a cumulative rainfall of 1.5 cm or less, and it included seven storms. The second category was storm events with a return interval between one month and one year. Rainfall for this category was between 1.5 cm and 3.3 cm. It included seven storms as well. The last category included storm events with a return interval longer than one year. Within each category, the TSS levels were averaged and the difference taken and the flowrates were averaged as well. The difference in sediment concentration and the flowrates were plotted for each category as Figures 4.14 and 4.15, respectively.

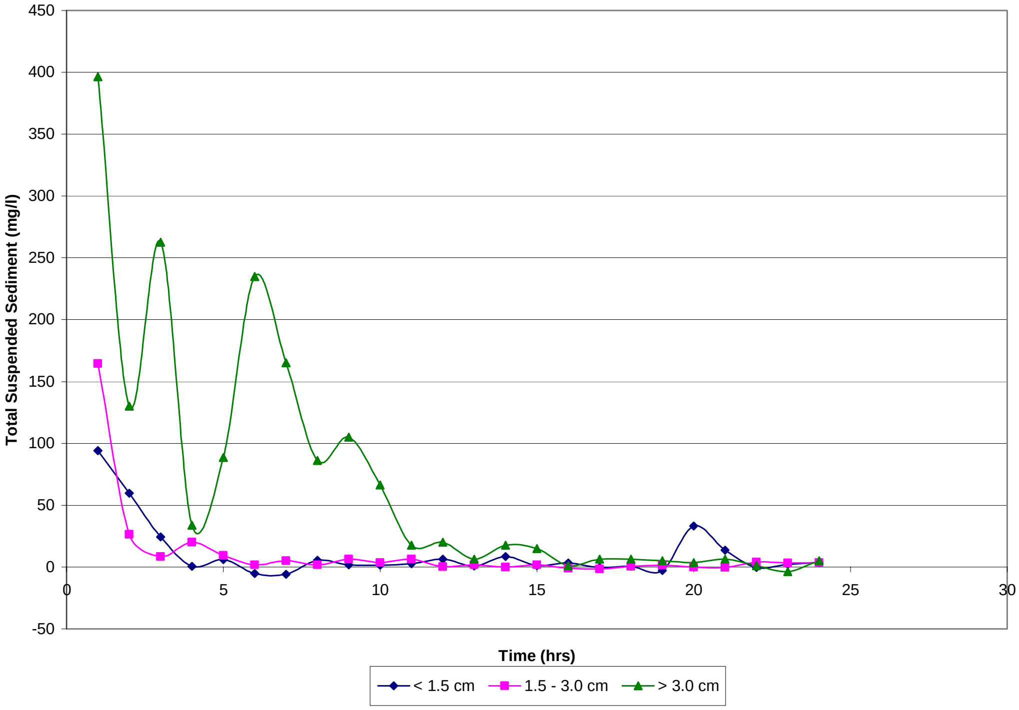


Figure 4.14 – Average Difference in Sediment Concentrations for Categorized Storm Events

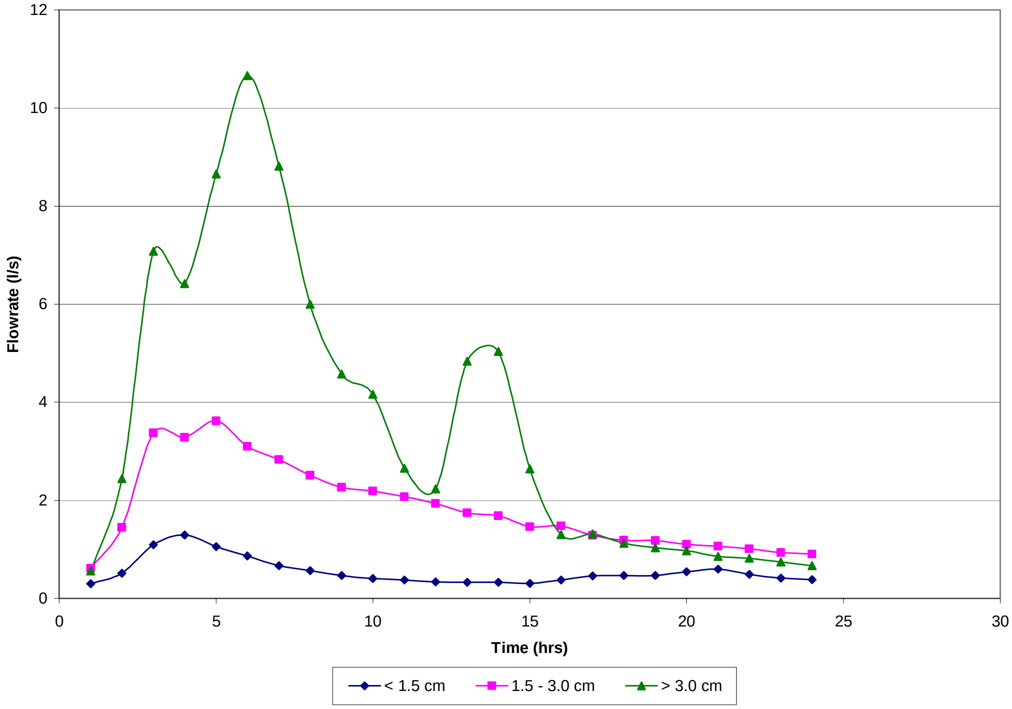


Figure 4.15 – Average Flowrate for Categorized Storm Events

From Figure 4.14, it is noted that the average difference in sediment concentrations has little effect until the cumulative rainfall is in excess of 3.3 cm. Little difference is noticed between the two lower categories in this figure. Figure 4.15, on the other hand, demonstrates that cumulative rainfall significantly affects stream flowrates. A very large difference is noticed when the cumulative rainfall exceeds 3.3 cm. Since variation in TSS levels is minimal, as the cumulative rainfall increases, the flowrates increase, causing the sediment load to increase. Table 4.5 sums the total sediment introduced at the bridge crossing and the cumulative rainfall for each category.
The total sediment for storm events less than 1.5 cm total rainfall is 2.7 kg of sediment which is less than the other categories and as expected. The other two categories followed as expected. The total sediment for storms with greater than 3.3 cm of rainfall were significantly higher. The reason for this is that with increased rainfall, there is a significant increase in flowrate which results in much higher TSS values. Further analysis was conducted and total sediment loads were compared for the three periods, trails closed, trail maintenance, and trails opened. As before, the values are reported in kg of sediment. This comparison is shown in Table 4.6.

Table 4.5 – Sediment Load for Cumulative Rainfall Categories

	Cumulative Rainfall Categories		
	< 1.5 cm	**1.5 - 3.3 cm**	**> 3.3 cm**
Total Sediment Introduced at Crossing (kg)	2.73	7.18	110.99
Total Cumulative Rainfall (cm)	7.14	13.87	3.61

Table 4.6 – Sediment Load for Each Period

Trail Condition	Date	Cumulative Rainfall (cm)	Sediment Load (kg)	Percent of Total (%)
Trail Closed	1/25/2004	2.2	0.13	14
	2/6/2004	4.9	108.98	39
	2/12/2004	2.0	0.14	3
	2/25/2004	1.1	0.11	13
Trail Maintenance	3/6/2004	2.0	4.01	13
	3/16/2004	0.5	0.08	37
	3/20/2004	0.9	0.42	25
	3/29/2004	2.0	0.17	8
Trail Open	4/11/2004	1.3	0.53	31
	4/26/2004	1.8	0.36	43
	4/30/2004	2.2	2.18	11
	5/16/2004	3.6	2.02	22
	6/16/2004	1.3	0.83	3
	6/22/2004	1.0	0.60	70
	7/2/2004	1.6	0.19	10
	12/16/2003	1.0	0.17	28

During this study, storm events that had a cumulative rainfall over 2 cm contributed elevated sediment loads. It was expected that storms occurring during the maintenance period would produce the highest level of erosion due to the increased disturbance that occurred. However, the lowest sediment load was recorded during this period with only 0.08 kg being contributed during a 0.5 cm storm event. The largest contribution of sediment into the stream came during the period when the trails where closed. A 4.9 cm storm event contributed 108.9 kg of sediment at the stream crossing. The main contributing factor for this increased sediment load was the quantity of rainfall.

The relationship between cumulative rainfall and total sediment load was not a linear relationship. Figure 4.16 represents cumulative rainfall vs. sediment load. It can be noted that as the rainfall increases, the sediment load increases as well but at a slower rate until a certain rainfall is reached. This data suggests that ORV trails do not contribute significant sediment loads during small storm events. However, there is a potential for large sediment contributions from storm events with a one year or higher return interval. In Appendix E there is a table with the rainfall and sediment load values.

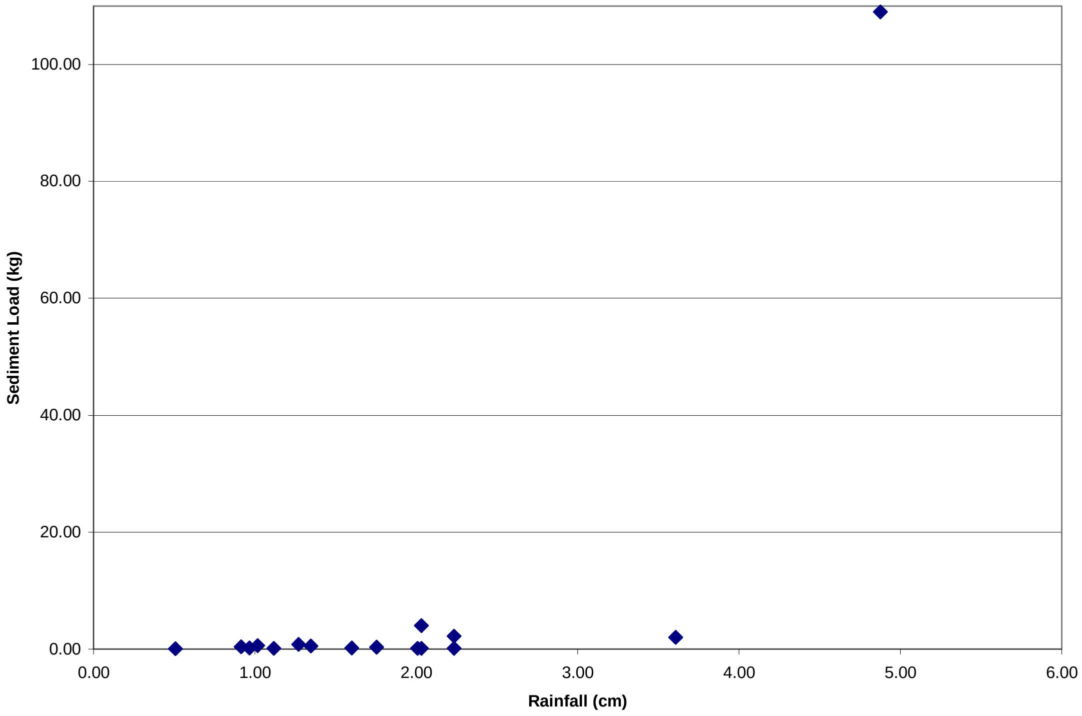


Figure 4.16 – Relationship between Cumulative Rainfall and Sediment Load

Modeling

The web, ArcView, and windows were used to setup the WEPP model for calibration and simulation. The web interface, ROCK:CLIME, was used to create a climate file that was later modified in order to match the climate reported during data collection. The ArcView interface, GeoWEPP, was used to delineate both the watershed of interest and the subcatchments within the watershed. The windows interface of WEPP was used to modify the subcatchments to match the actual trail conditions. With the setup complete, the model was run, calibration conducted, and the various management practices simulated for the determination of BMP's.

Weather Generation

As mentioned before, the weather file to be used with the WEPP model was created using the web interface. The file was then modified to match the storm events that were recorded during data collection. A total of 16 storm events were recorded during the data collection period. During the eight month data collection period, not all storm events were captured. Figure 4.17 shows all the storm events that occurred as well along with the storm events that were monitored. Modifications were made to the values

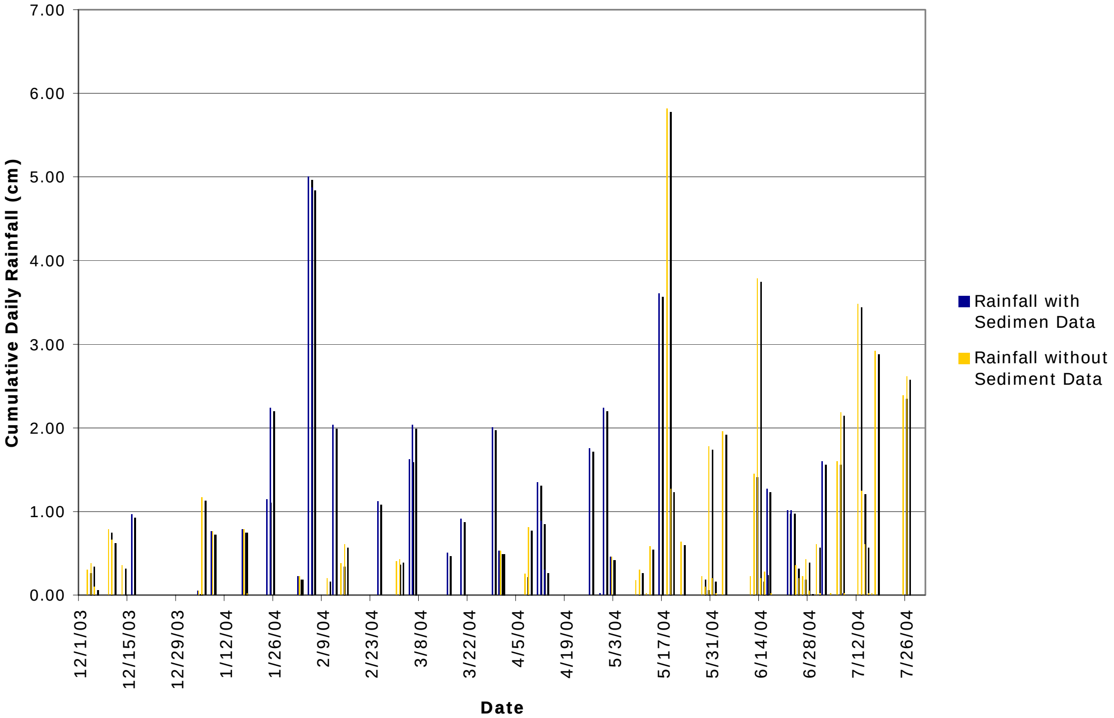


Figure 4.17 – All Storms and Storms with Sediment Data

of precipitation, precipitation duration, time to peak intensity, and peak intensity by verifying values collected by the ISCO 6700 water samplers. Weather information that is used by WEPP, but not modified, were radiation, wind velocity, wind direction, and dew point temperature. Table 4.7 shows the portion of the weather file that was modified to include the storm events that were collected.

Table 4.7 – Portion of modified weather file

Day	Month	Precip (mm)	Duration (h)	Time to Peak (h)	Int. at Peak (mm/h)
25	1	22.35	0.50	0.25	79.25
6	2	48.77	5.50	0.75	38.61
12	2	20.32	4.75	0.25	38.61
25	2	11.76	21.00	0.25	12.20
6	3	20.32	4.75	0.50	22.35
16	3	5.08	0.50	0.25	10.16
20	3	9.14	1.25	0.50	21.34
29	3	20.07	6.25	0.25	10.16
11	4	13.46	2.75	0.25	15.24
26	4	17.53	9.75	0.25	12.19
30	4	22.35	5.50	0.50	29.46
16	5	36.07	3.25	0.50	59.94
16	6	12.70	1.00	0.50	36.58
22	6	10.16	1.75	0.25	15.24
2	7	16.00	1.50	0.50	41.66
16	12	9.65	2.75	0.25	10.16

Parameter Calculation and Model Calibration

Before the model simulations were run, erodibility, shear, and hydraulic conductivity were calculated using the soils data and the equations outlined in the methodology. The soil on the trail surface is classified as a clay loam soil with 27 % sand, 28 % clay, and 44 % silt. Organic matter was 0 and the cation exchange capacity (CEC) was 12. The CEC was taken from NRCS soils data. Soil parameters for the

WEPP model were calculated using these values. These values are shown in Table 4.8. Slope length, buffer length, and slope gradient were also input into the model.

Table 4.8 – Calculated soil parameters

Parameter	Value
Interrill Erodibility (kg*s/m^4)	8.00E+06
Rill Erodibility (s/m)	0.01
Critical Shear (N/m²)	2.91
Effective Hydraulic Conductivity (mm/h)	4.86

Once all the values were inputted into the model, initial attempts to calibrate the model were conducted. It was realized that due to the lack of large storm events in the data set, proper model calibration was very difficult. Calibration of the model was conducted as best possible while understanding the limitations of the data set. After each simulation, the event-by-event summary for each storm was recorded, compared to the measured value, and the Nash-Sutcliffe R^2 calculated to determine model performance. The R^2 calculated from the initial simulation was 0.90. In order to try and increase model performance, a maintenance rotation occurring on March 1st was added as a model parameter. Maintenance consisted of smoothing the trail with a blade that affected 100% of the trail surface and disturbance to a depth of 20 cm. The other value that was adjusted was the effective hydraulic conductivity. The calculated value for effective hydraulic conductivity, as shown in Table 4.8, was 4.86 mm/h. Since the trail surface receives a significant amount of traffic, it was assumed that the hydraulic conductivity would be lower. So, this value was lowered to 2.5 mm/hr. With the maintenance rotation and the lowered effective hydraulic conductivity, the new R^2 value was 0.63. The event-by-event summary was reanalyzed and it was evident that the model was over-predicting the amount of sediment being introduced at the crossing. The same process was repeated using various values for the effective hydraulic conductivity. With the effective hydraulic conductivity set at 3 mm/hr, the resulting R^2 was 0.92. After achieving an R^2 value of 0.92, it was assumed that the model was calibrated as best as could be expected from a limited data set. Figure 4.18 shows the measured values vs. the predicted values for data used to calibrate the model.

From Figure 4.18, it was evident that the model was matching the large storm events accurately, while the smaller storm events were not accurately matched. The large storm event of February 6, 2004 was left out and an attempt was made to recalibrate the model. The same calibration process as before was followed. With the effective hydraulic conductivity lowered to 0.18 mm/hr, an R^2 of 0.20 was calculated. This was the highest R^2 value that could be achieved. Figure 4.19 shows the measured vs. predicted values for the calibration of the smaller storms.

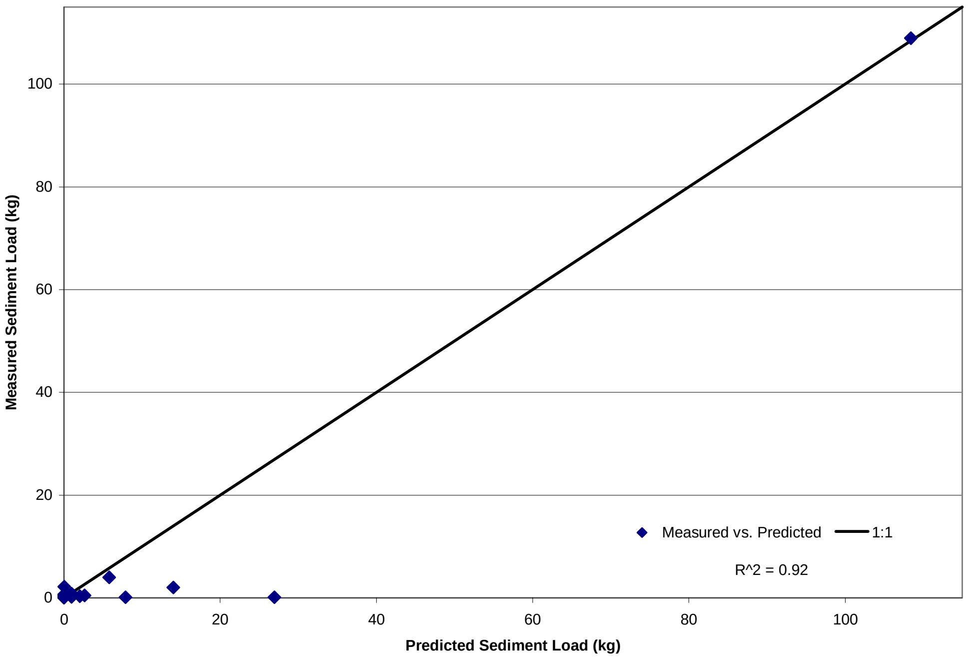


Figure 4.18 – All Measured vs. Predicted Sediment Load Values

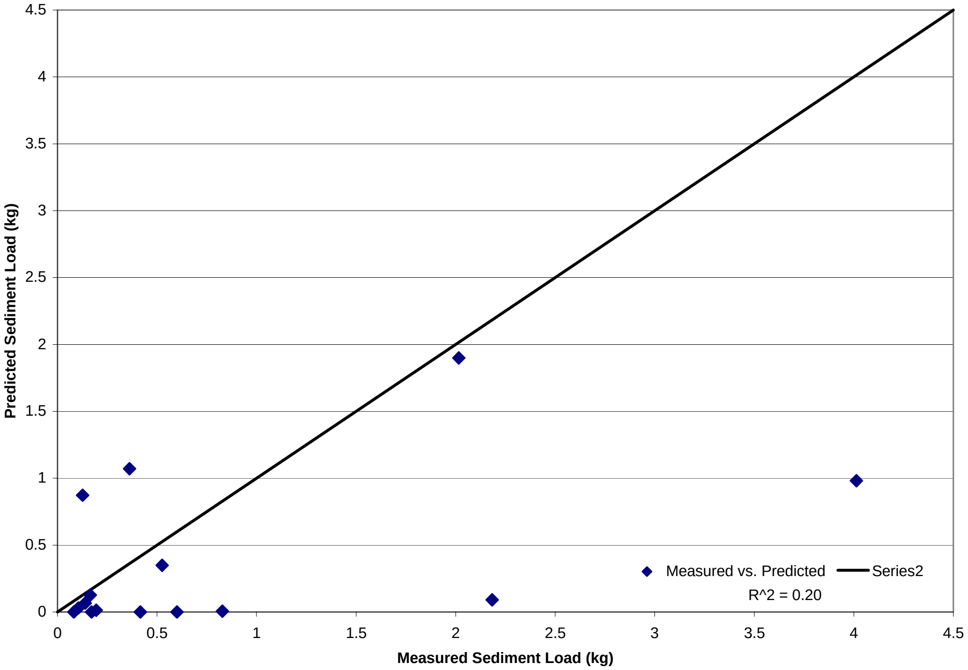


Figure 4.19 –Measured vs. Predicted Sediment Load Values for smaller storm events

The effective hydraulic conductivity was the only valued varied during the calibration. The effective hydraulic conductivity had a very high sensitivity, and varying it by as little as 1 mm/hr caused significant changes in the model output. Typical value ranges for effective hydraulic conductivity along with the other soil parameters are listed in Table 4.9. The soils values calculated and used during these simulations are all within the typical values reported for surrounding soil types.

Table 4.9 – Typical soil parameter ranges

Soil Parameter	Minimum	Maximum
Interrill Erodibility (kg*s/m^4)	1.50E+06	9.80E+06
Rill Erodibility (s/m)	0.0002	0.0227
Critical Shear (N/m^2)	0.2	4.68
Effective Hydraulic Conductivity (mm/hr)	0.1	19.35

From the calibration attempts, it was observed that the WEPP model tended to over-predict average, day-to-day storm events. During both calibration efforts, the two storm events that proved to be most accurately represented were the two that had a cumulative rainfall higher than 3.3 cm. From this, it is concluded that the WEPP model is capable of accurately simulating large storm events, those in excess of 3.3 cm of rainfall, and it tends to over-predict smaller storm events that are witnessed on a daily basis. Due to difficulties encountered while attempting to calibrate the model, it was concluded that proper model calibration would not be possible due to limited number of large storm events in the data set.

Development of Best Management Practices for ORV Trails

To develop best management practices, the non-calibrated model was used. The use on a non-calibrated model was justified by utilizing the soil parameters calculated before. The effective hydraulic conductivity used was 0.18 mm/hr, which is the value recommended by WEPP for low-volume roads. The weather utilized was a CLIGEN generated 30 year climate file. The WEPP model was modified to represent trail conditions under the following management practices: varying distance between water bars, varying gradient, and varying forest buffer lengths. The assumptions that were made during the simulation were regarding water bars. It was assumed that all water bars were designed with turn-outs, all surface flow was diverted off the trail surface, and they were kept in working order. During simulation the output value used to determine the effectiveness of the varying management practices was the average annual sediment yield. The average annual sediment yield is the amount of sediment that is transported through the buffer and deposited into the stream channel. According to Schwabb et. al. (1993), sediment yields from agricultural fields with corn averaged 16 metric tons per hectare over a six year period. From this, the target average annual sediment yield used for these simulation was set to 11 metric tons per hectare (t/ha). If sediment yield for the varying management practices was below this level, they were recommended as a BMP.

Water Bar Spacing and Slope Gradient

Water bars used along with turn-outs allow for water to be diverted from the trail. As the distance between the water bars decreases, the volume of water flowing on the trail decreases, leading to a reduction in erosion. As the slope increases, the velocity of water increases, so the distance between water bars should be decreased (Brinker, 1995). Table 4.10 represents the recommended distance between water bars as the slope increases. The buffer consisted of a 20 year old forest through which the trail crossed a 20 m wide buffer. The recommended water bar distances in Table 4.10 are for sections of trail that are within 20 m of a stream.

Table 4.10 – Recommended water bar spacing with a 20 m forest buffer

Slope Steepness (%)	Distance (m)
4	14
6	11
8	10
10	9
12	8
14	7
18	6
20	6

Brinker (1995) suggested using the following as a rule of thumb to calculate water bar spacing on low-volume roads: (in feet) = (400 / slope %) + 100. All the values in Table 4.10 were less than the values calculated using the equation above. Simulations were conducted using WEPP in order to acquire the values in Table 4.10. The two sections of trail adjacent to the stream were modeled and the predicted sediment load for each were summed and held constant. The upper section of trail, that included the water bars, was simulated for varying gradient and water bar spacing. The predicted values from the upper section were summed with the two lower sections and these values had to be under 11 t/ha. If the values were over 11 t/ha, the slope gradient and water bar spacing was changed and simulations conducted until the values were under the acceptable limit.

Buffer Length

For all the above simulations, the length of the forested buffer was 20 m. If the buffer length is increased, then the values in Table 4.10 are still valid. If the length of the buffer is decreased, then the Table 4.10 is not valid. Alabama Best Management

Practices suggest a minimum buffer length of 10.67 m. Table 4.11 contains the recommended water bar spacing for varying slopes in the case where the manager chooses to use a forest buffer of 10.67 m. The distances for these water bars are for sloped trail sections that are within 10 m of the stream.

Table 4.11 – Recommended water bar spacing with a 10.67 m forest

Slope Steepness (%)	**Distance (m)**
4	8
6	7
8	6
10	5
12	5
14	4

The reason for the spacing between water bars decreasing as the buffer length decreases is because with a smaller buffer, there is less area for sediment deposition, so higher amounts of sediment reach the stream channel. Because of the very close water bar spacing that exists when the slope grade increases and buffer length decreases, it is recommended that minimum buffer length and maximum slope gradient of 20 m and 12%, respectively, be used when designing or modifying trails. In effort to minimize impacts on riparian areas and minimize sediment loading, the section of trail that crosses the stream should be perpendicular to the stream with slopes between 0 and 2%.

The effectiveness of a forest buffer is directly related to the width of the buffer itself. Figure 4.20 demonstrates sediment loss and deposition in relation to its location along the hillside. In the figure, the green line signifies erosion when it is below the hillslope profile and deposition when it is above. The location in which deposition commences is at the position where overland flow encounters the buffer. To demonstrate the importance of a forested buffer, a simulation was conducted with a 5 m buffer on a 10% slope with a water bar spacing of 17 m. The average annual sediment yield for this slope was 63.79 t/ha. This same slope with a forested buffer of 20 m produced an average annual sediment yield of 16.78 t/ha. Simulations were also conducted in which the water bar spacing and slope were held constant at 14 m and 10%, respectively, and the buffer width increased while recording the average annual sediment load. Figure 4.21 represents average annual sediment load vs. buffer length. From the figure, it is noted that as the forest buffer width increases, there is exponential decrease in average annual sediment load.

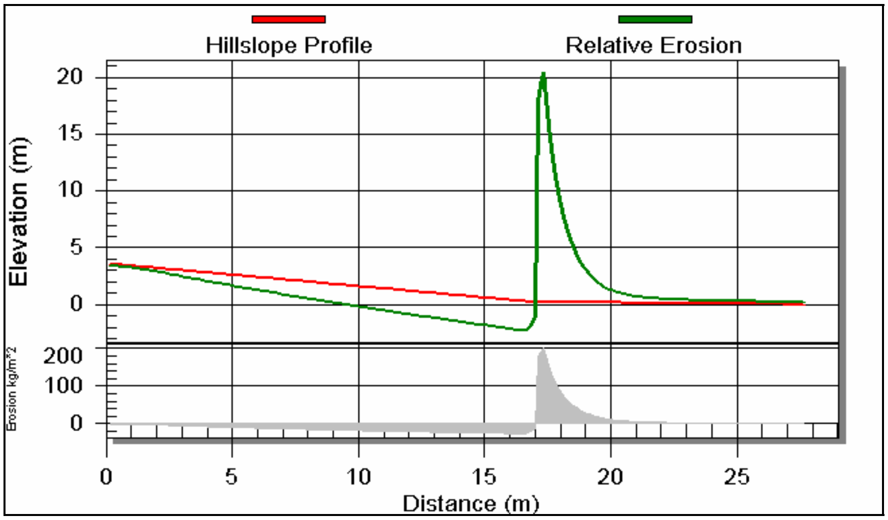


Figure 4.20 – Annual Average Soil Loss and Yield with 10.7 m forest buffer

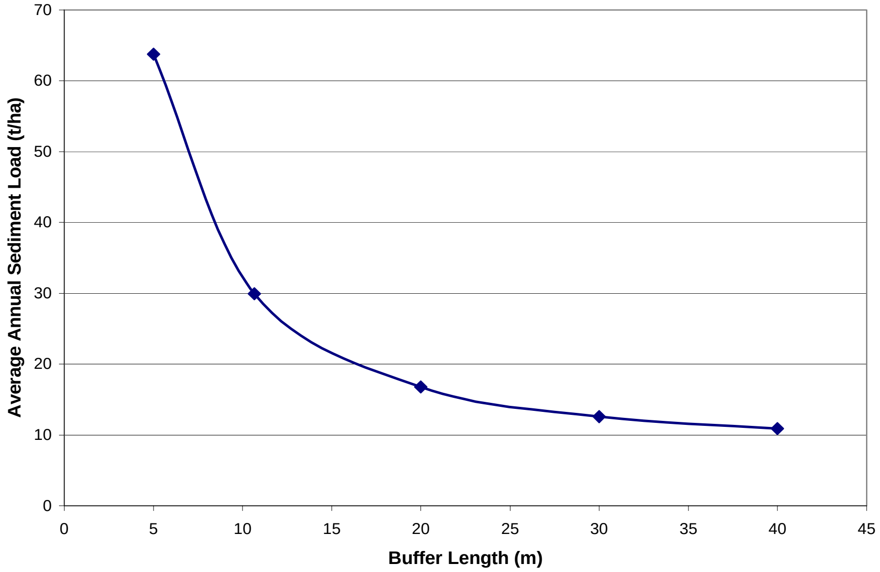


Figure 4.21 – Annual Average Soil Loss vs. Forest Buffer Length

Soil Amendment Assessment

Data collection on trail condition, specifically the formation of ruts, was collected on four plots between October 2004 and January 2005. Two plots were shaped and treated with the soil amendment Envirotac II, and the other two were only shaped and used as controls. Measurements were collected every two weeks and consisted of cross-section profiles taken at three to four locations along the trail sections. The first and last measurements were plotted together on a chart in order to visually represent soil loss or deposition due to the formation of ruts. Through a series of triangle calculations, the differences between the initial and final trail shapes were determined so that net soil losses or depositions could be reported. Net soil losses or depositions are reported as cross-sectional area differences in square centimeters for each profile. In areas where turn-outs were present, profile measurements were extended to determine if deposition was occurring in the turn-out. Figures 4.22 and 4.23 represent cross-section profiles for the upper trail and lower trail sections, respectively, of Control Plot A. Similarly, Figures 4.24 and 4.25 represent upper and lower trail sections for Treatment Plot A. Figures for Control and Treatment Plot B are shown in Appendix E.

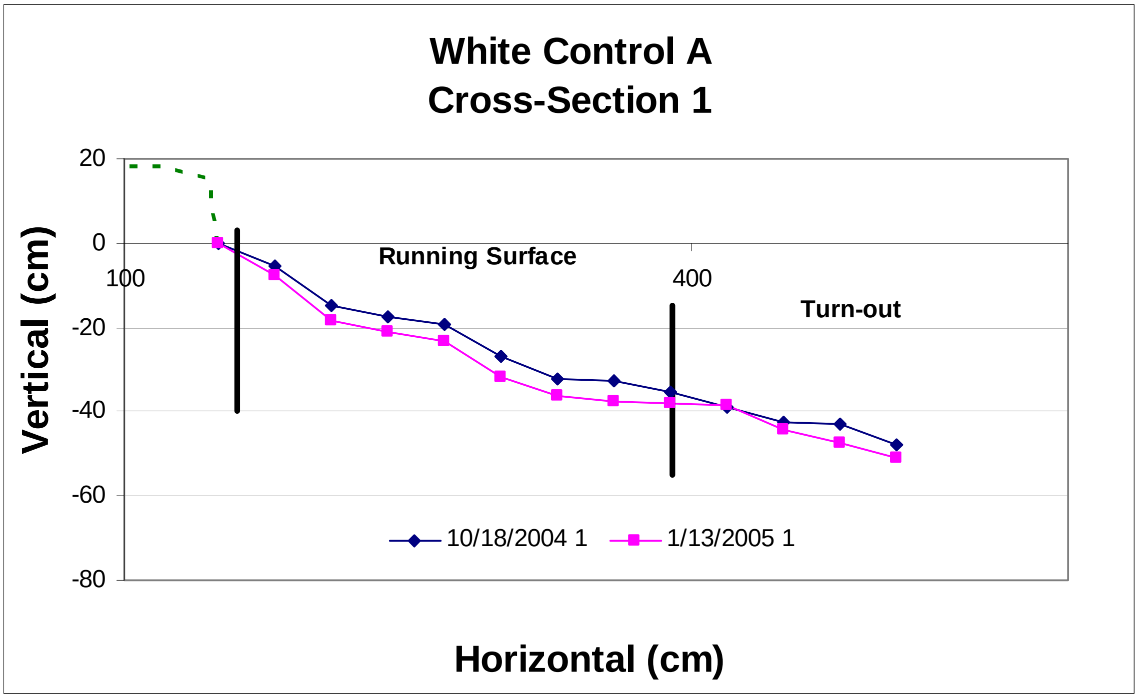


Figure 4.22 – Cross-section Profiles of Upper Section of Control Plot A

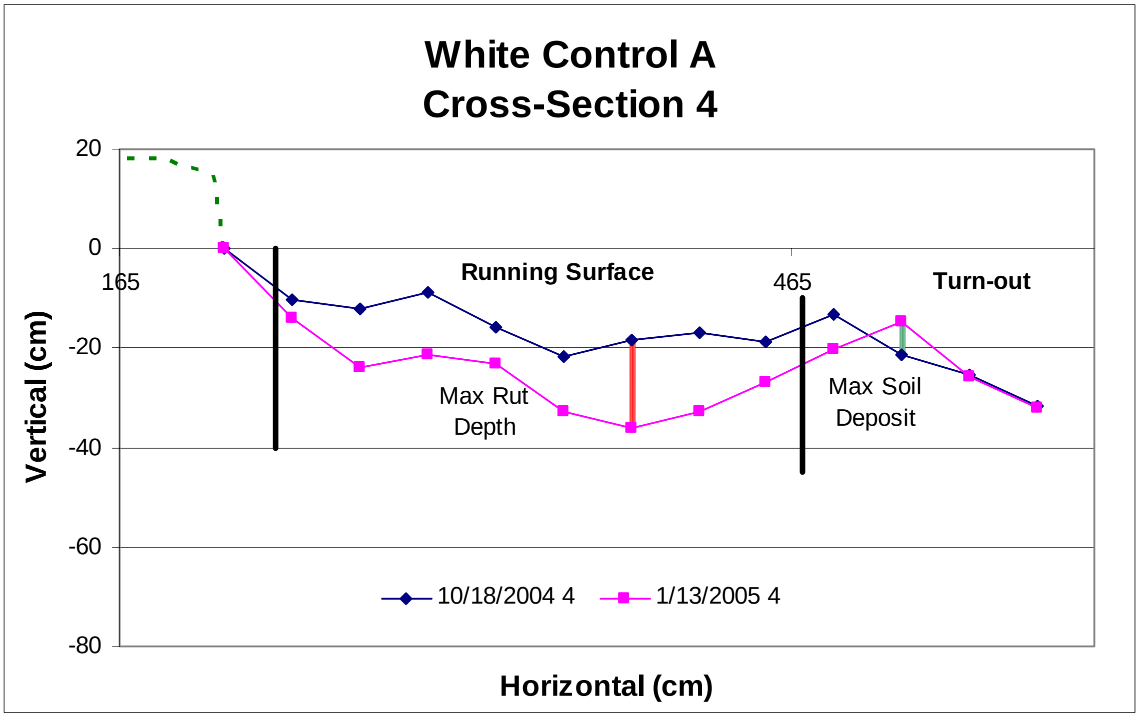


Figure 4.23 – Cross-section Profiles of Lower Section of Control Plot A

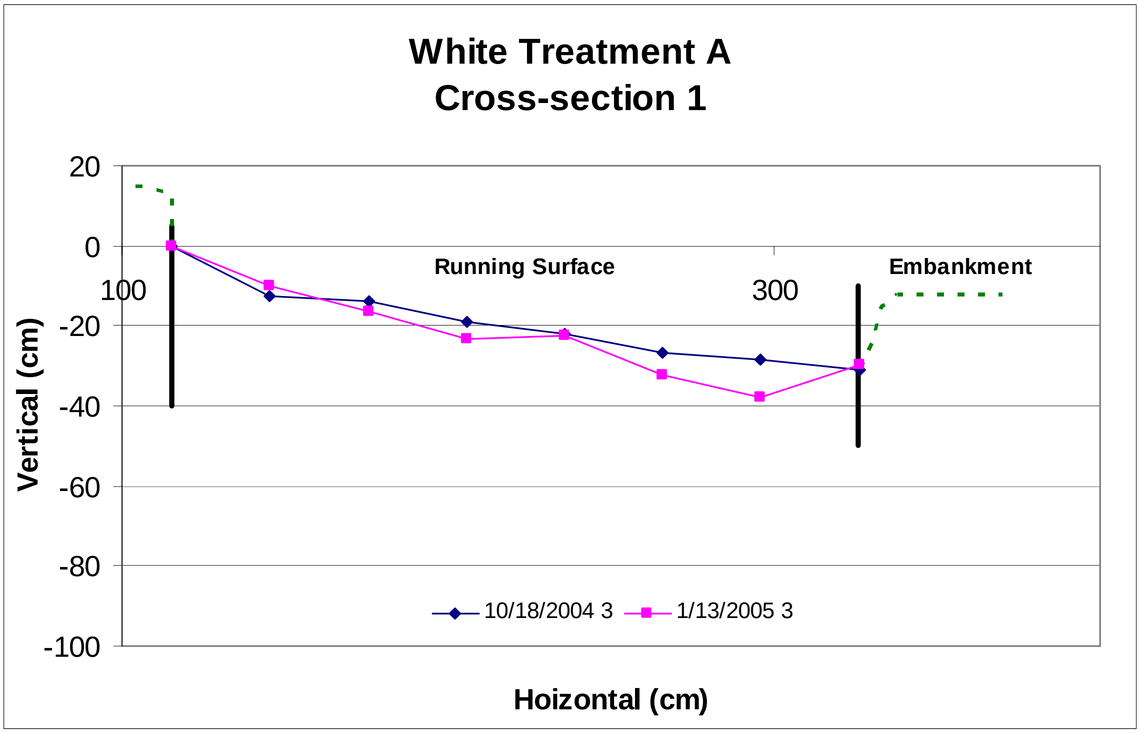


Figure 4.24 – Cross-section Profiles of Upper Section of Treatment Plot A

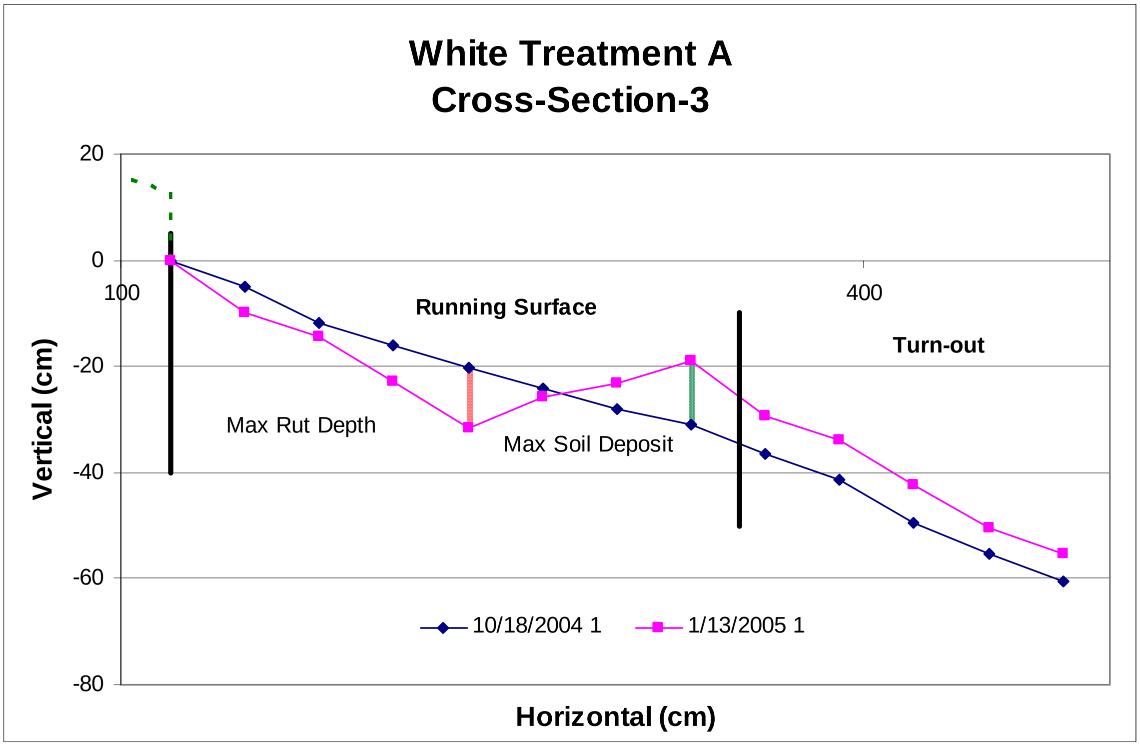


Figure 4.25 – Cross-section Profiles of Lower Section of Treatment Plot A

The formation of ruts on the control plots was very evident. Figures 4.22 and 4.23 represent cross-section profiles along the trail for the control plot. The profile in Figure 4.22 is from the upper section of the slope where the turn-out begins. An evenly distributed soil loss of 588 cm^2 is noted across the entire profile. Figure 4.23 represents the profile for the lower section of the control plot where soil losses are very apparent in the form of ruts. The maximum rut depth measured for this profile was 18 cm resulting in an average soil loss of 49 cm^2. Outside the running surface, in the turn-out, soil deposition occurred resulting in a deposition height of 7 cm. The average soil loss for this entire Control Plot A trail section was calculated to be 84 cm^2.

Rutting on the treated plots was as evident as on the control plots. The profiles for the treated plots are shown in Figures 4.24 and 4.25. Figure 4.24 represents the upper section of the profile before the presence of the turnout. As seen in the control plot, the upper section of the profile had a relatively even soil loss across the profile and was measured to be 42 cm^2. In the lower section of the treated plot, Figure 4.25, the formation of one rut occurred on the running surface and had a measured depth of 11 cm.

Both control plots and treated plots had soil deposition occurring at the lower end of the plots. In the section of the turn-out for the treated plot, a large amount of deposition occurred with a maximum measured height of 12 cm. Due to the large deposition measured in the turn-out, this profile reported an average soil deposition of 27 cm^2 rather than a soil loss, as with the other profiles. This is explained by the understanding of how a turn-out is designed to function. As water travels down the trail it gains energy and detaches sediment from the upper sections and transports it to the lower sections causing deposition as the water loses energy. The turn-out widens the flow path, therefore reducing the speed, which reduces the energy and results in deposition. Table 4.12 summarizes the net and average soil loss or deposition for each cross-section of each plot. Negative values represent soil loss and positive values represent soil deposition in square centimeters.

Table 4.12– Net and average soil loss or deposition for each section.

	Control A	Treatment A	Control B	Treatment B
Net Cross-Section 1	-588	321	-54	-989
Net Cross-Section 2	-514	-221	139	-151
Net Cross-Section 3	-1560	-295	575	-482
Net Cross-Section 4	-1349	n.a.	-415	n.a
Net Soil Loss/Depostion	**-4011**	**-196**	**244**	**-1623**
Avg. Soil Loss/Deposition	**-11**	**-1**	**1**	**-5**

Both treated plots reported a net and average soil loss. On Control Plot A, both the net and average soil losses were much greater for Treatment Plot A. On Control and Treatment Plots B, the opposite occurred. Control Plot B reported a net deposition rather than a soil loss like Treatment Plot B reported. It is difficult to draw conclusions based solely on the numbers reported above because of the variability between plots, so a visual comparison between the treatment and control plots was conducted. The treated plots did not perform as well as expected. The formation of ruts between the control plots and the treated plots was similar. After three months of trafficking, both treated plots and control plots were equally disturbed and in need of maintenance. This may be due to factors regarding application technique, time and season of application, and curing time after application. It appears that further research should be conducted regarding soil amendments for use as a soil stabilizer on ORV trails.

SUMMARY AND CONCLUSIONS

Introduction

The goal of this project was to establish some Best Management Practices for Off-Road Vehicles trails. A stream crossing of the Kentuck ORV trail system located in the Talladega National Forest was monitored for approximately eight months containing three different periods. The three periods were as follows: No Traffic Period, Maintenance Period, and Trafficking Period. Water samples were taken during 16 storm events that occurred throughout the three periods. Along with the water samples, stream flow rate data, rainfall data, and traffic levels were monitored as well. Water samples were analyzed in a laboratory to determine total suspended sediment that was used to calculate sediment loads for individual storm events. Using the sediment load data and rainfall data, an attempt to calibrate the Water Erosion Prediction Project (WEPP) model was conducted. The WEPP model was then used to simulate various management practices in order to develop recommendations for BMP's. During the trafficking period, four sample plots were constructed and Envirotac II, a soil amendment was applied to assess it's effectiveness in reducing the formation of ruts.

Objective 1

During the 16 storm events, a total of 121 kg of sediment was introduced to the stream at the crossing. Storm events with a low cumulative rainfall contribute very little sediment into the stream channel. However, storm events with increased intensity and an elevated cumulative rainfall, can potentially contribute significant sediment loads to the stream channel. Significant sediment loads result from storm events with a one year return interval or longer. The only storm event collected that had a return period higher than one year had a sediment load 109 kg and a cumulative rainfall of 4.9 cm. Since this is the only storm event with a significant sediment load, a long-term study should be conducted to analyze effects of longer return interval storms. Traffic volumes were also monitored in this study and it was determined that an average of 25 riders per day rode the trail system during the trafficking period.

Objective 2

The attempt to calibrate the Hillslope version of the WEPP model proved to be difficult. The rainfall data was used effectively to create a climate file for the data collection period. Along with the rainfall data, soils and slope data were used as input parameters during calibration. During calibration predicted vs. measured values were observed and a Nash-Sutcliffe R^2 calculated to determine performance. Since the data set only contained one large storm event, calibration of the model could not be conducted properly. However, using the limited data, the calibration attempt was continued and an R^2 value of 0.92 was achieved using the Hillslope version of the WEPP model by adjusting the effective hydraulic conductivity. Model performance appeared to be accurate when calibrated to predict larger storm events. The model tended to over-predict smaller storm events, so it was recommended that the model be used only to predict sediment yield resulting from larger storm events.

Objective 3

Using the non-calibrated model, various management practices were simulated in order to recommend BMP's. Simulations on water bar spacing, trail gradient and minimum buffer lengths were conducted using an allowable average annual sediment yield of 11 t/ha. It is recommended that forested buffers always be used with a minimum width of 20 m on each side of the stream. It is also recommended that, when possible, slope gradient be kept below 12 %. On slopes below 12 %, a maximum water bar spacing of 10 m is suggested and on slopes steeper than 12 %, a maximum water bar spacing of 6 m is suggested. These theoretical values are sections of trail near stream channels and for clay loam soils which exist in the Talladega National Forest in Alabama. The values were determined using the Hillslope version of the WEPP model. The Watershed version of the WEPP model was determined to not be suitable for modeling erosion from ORV trails in an effort to develop BMP's. There are two reasons why the Watershed model was considered to be inappropriate. First, when sections of the ORV trail are perpendicular to the stream (i.e. at the crossing) it cannot be accurately accounted for in the model on the watershed scale. Second, the Watershed version does not model sediment transport in perennial streams. Due to these two factors, the best method to model ORV trails for recommending BMP's is to use the Hillslope version of the WEPP model.

Objective 4

The use of the soil amendment Envirotac II was assessed to determine its effectives in reducing the formation of ruts after trafficking had occurred. Maximum rut depths on the control plots A and B were 17.8 cm and 16.2, respectively. The maximum rut depths recorded for the plots A and B, treated with Envirotac II, were 11.43 cm and 17.78 cm, respectively. It is concluded that the plots treated with Envirotac II did not significantly aid in reducing the formation of ruts. Better results may have been achieved if treatments would have been applied during the warmer and drier seasons of the year and overstory vegetation removed to aid in the hardening of the soil surface.

General Conclusion

It is concluded that ORV trails have the potential to produce levels of sediment that may reduce water quality impairing fish habitat and shortening the life of reservoirs. However, through the use of proper BMP's, such as water bar spacing, slope grade, and buffer lengths, theoretical sediment yields can be reduced so as to minimize the degradation of water quality.

Future Research

Future research goals should consist of additional water sampling of stream crossings influenced by ORV trails during periods of traffic, maintenance, and no traffic. Also, by monitoring various types of stream crossings on ORV trails may help to better understand the impact that is being created and may prove to be an important area of research. For comparison purposes, water samples should be collected on a watershed not affected by ORV trails or roads. Further data collection in these areas for multiple years could, in turn, be used to better calibrate the hillslope version of the WEPP model. Research should also be conducted to assess the effectiveness of Envirotac II at reducing rut formation by studying various application techniques. This could be achieved by conducting a study involving the effectiveness of Envirotac II under varying environmental conditions during which temperature, soil, moisture content, lighting, and product concentration are changed. This could lead to a better understanding on product applicability along with product limitations.

BILIOGRAPHY

Baffaut, C., Nearing, M.A., Govers, G. 1998. *Statistical distributions of soil loss from runoff plots and WEPP model simulations.* Soil Science Society of America Journal. 62(3): 756-763.

Blackland Research Center. SWAT Fact Sheet. 2005. http://www.brc.tamus.edu/swat/factsheet.html. Last visited June 7, 2005.

Brinker, R.W. 1995. *Forest roads and construction of associated water diversion devices.* Alabama Cooperative Extension System. ANR-916.

Brooks, E.S. *GPS-assisted road surveys and GIS-based road erosion modeling using the WEPP model.* Presented at the 2003 Pacific Northwest Region meeting sponsored by ASAE. Paper No. PNW-03-109.

Croke, J.C., Hairsine, P.B. *Management of road runoff: a design approach.* Presented at the Soil Erosion Research for the 21st Century, Proc. Int. Symposium. January 2001. ASAE: 701P0007.

Davidson, E., Fox, M. 1974. *Effects of off-road motorcycle activity on Mojave Desert vegetation and soil.* Madrono 22:381-390.

Davis, J.N. 2004. *Assessment of chemical soil amendments for erosion control on off-road vehicle trail.* Auburn, AL. MS thesis, Auburn University

Denver Instruments Balance web page, http://www.denverinstrumentusa.com/media/pdf/literature/apex.pdf. Last visited June 9, 2005.

Eav, L. *Unmanaged recreation.* Key Messages and Talking Points from the Four Threats to Leadership Information Packet, USDA Forest Service, Office of Communication – Washington D.C.

Eckert, Jr., R.E., Wood, M.K., Blackburn, W.H., Peterson, F.F. *Impacts of off-road vehicles on infiltration rates and sediment production of two desert soils.* Journal of Range Management. 32(5), September 394-397.

Egan, A.F. 1999. *Forest roads: where soil and water don't mix.* Journal of Forestry. 97: 8, 18-21.

Elliot, W.J., Foltz, R.B., Luce, C.H. 1999. *Modeling low-volume road erosion.* Transportation Research Record. 1652 V. 2: 244-249.

Elliot, W.J., Foltz, R.B., Robichaud, P.R. 1994. *A tool for estimating disturbed forest site sediment production.* Interior Cedar-Hemlock-White Pine Forests: Ecology and Management. Washington State University Cooperative Extension 233-236.

Elliot, W.J., Hall, D.E., Graves, S.R. 1999. *Predicting sedimentation from forest roads.* Journal of Forestry. August: 23-29.

Elliot, W.J., Luce, C.H., Robichaud, P.R. *Predicting sedimentation from timber harvest areas with the WEPP model.* Presented at the Sixth Federal Interagency Sedimentation Conference, March 10-14, 1996. IX: 46-53.

Envirotac II: soil stabilizer. http://envirotac.us/new/Description.shtml. Last visited April 13, 2004.

Flanagan, D.C., Renschler, C.S., Cochrane, T.A. *Application of the WEPP model with digital geographic information.* Presented at the 4th International Conference on Integrating GIS and Environmental Modeling, September 2-8, 2000. GIS/EM4 No. 149.

Fogg, G.E. 2002. Park Guidelines for OHV's. National Off-Highway Vehicle Conservation Council.

Franson, M.H. 1985. Standard Methods for the Examination of Water and Wastewater. Port City Press, Maryland.

Laflen, J.M., Elliot, W.J., Simanton, J.R., Holzhey, C.S., Kohl, K.D. 1991. *WEPP soil erodibility experiments for rangeland and cropland soils.* Journal of Soil and Water Conservation. January-February: 39-44.

Laflen, J.M., Lane, L.J., Foster, G.R. 1991. *WEPP a new generation of erosion prediction technology.* Journal of Soil and Water Conservation. January-February: 34-38.

Liban, C.B. 1998. *Non-point source pollution*. National Forum. 78:3. 7-9
Lull, H.W. 1959. *Soil Compaction on forest and range lands.* U.S. Department of Agriculture, Forest Service. Misc. Pub. No. 768. Washington D.C. 33 p.

Miller, G.A., Azad, S. 2000. *Influence of soil type on stabilization with cement kiln dust.* Construction and Building Materials. 14. 89-97.

Morfin, S., Elliot, B., Foltz, R., Miller, S. *Predicting effects of climate, soil and topography on road erosion with WEPP.* Presented at the 1996 ASAE Annual International meeting, Paper No. 965016. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659 USA.

NRCS HecRas Training. http://www.ndcsmc.nrcs.usda.gov/Training/BASICHECRAS.html Last visited June 7, 2005.

Patric, J.H. 1978. *Harvesting effects on soil and water in the in eastern hardwood forests.* Southern Journal of Applied Forestry. 2: 3, 66-73.

Porbaha, A., Pradham, T.B.S., Yamane, N. 2000. *Time effect of shear strength and permeability of fly ash.* Journal of Energy Engineering. April:15-31.

Rhee. H., Fridley, J.L., Foltz, R.B. 2004. *Modeling erosion from unpaved forest roads at various levels of geometric detail using the WEPP model.* Transactions of the ASAE. 47(3): 961-968.

Sawyer, T. 2002. *Military construction: High-tech tools and hard, hard work at FOB Rhino*. McGraw-Hill Construction ENR. http://www.enr.construction.com/features/technologyeconst/archives/020225c.asp#. Last visited April 13, 2004.

Schwab, G.O., Fangmeier, D.D., Elliot, W.J., Frevert, R.K. 1993. Soil and Water Conservation Engineering. John Wiley and Sons, Inc. New York.

Soil Ecology and Research Group. 2002. *San Clemente Island ATV trail system-installation of erosion control demonstrations.* http://www.serg.sdsu.edu/SERG/restorationproj/channel_islands/erosion/project%20report.html Last visited June 8, 2005.

Sojka, R.E., Lentz, R.D., Trout, T.J., Ross, C.W., Bjorneberg, D.L., Aase, J.K. 1998. *Polyacrylamide effects on infiltration in irrigated agriculture*. Journal of Soil and Water Conservation. 53:4. 325-333.

Sparrow, S.D., Wooding, F.J., Whiting, E.H. 1978. *Effects of off-road vehicle traffic on soils and vegetation in the Denali Highway region of Alaska.* Journal of Soil and Water Conservation. January-February: 20-27.

Spruill, C.A., Workman, S.R., Taraba, J.L. 2000. *Simulation of daily and monthly stream discharge from small watersheds using the SWAT model.* Transactions of the ASAE. 43(6): 1431-1349.

Strom, J.M., Wilkins, M. 1990. *Environmental assessment for the management of off-road vehicles in the Talladega National Forest.* Shoal Creek and Talladega Ranger Districts. National Forests in Alabama.

Tysdal. L.M., Elliot, W.J., Luce, C.H., Black, T.A. 1999. *Modeling erosion from insloping low-volume roads with WEPP watershed model.* Transportation Research Record. Vol. 2, No. 1652: 250-256.

Washington State Department of Transportation. *Polyacrylamide (PAM) application for soil erosion control*. Environmental Affairs Office. Water Quality Program.
Weaver, T., Dale, D. 1978. *Trampling effects of hikers, motorcycles and horses in meadows and forests.* The Journal of Applied Ecology. 15(2): 451-457.

Wilshire, H.G., Nakata, J.K. 1976. *Off-road vehicle effects on California's Mojave Desert.* California Geol. 29:123-130.

Wu, L. 2001. *Polyacrylamide (PAM) – effective erosion fighter and infiltration enhancer but not a conserver of water*. http://esce.ucr.edu/soilwater/spring_2001.htm. Last visited April 19, 2004

APPENDIX A

TRAIL CLOSED PERIOD

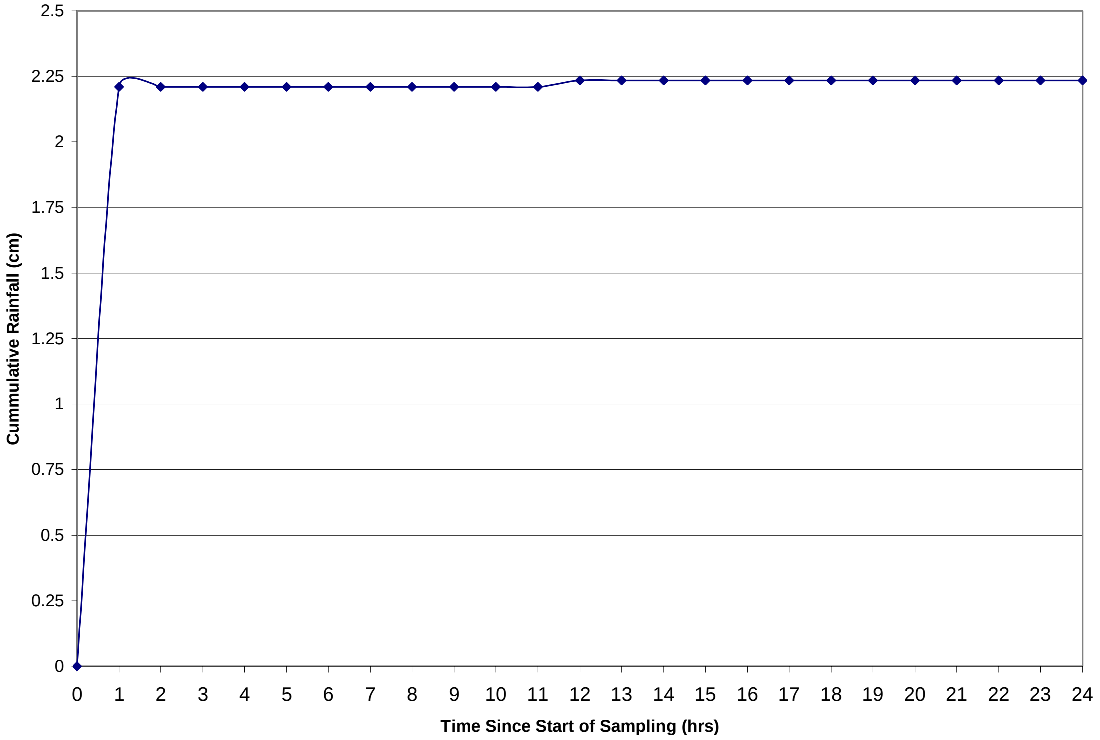


Figure A.1 – Cumulative Rainfall for January 25, 2004 Storm Event

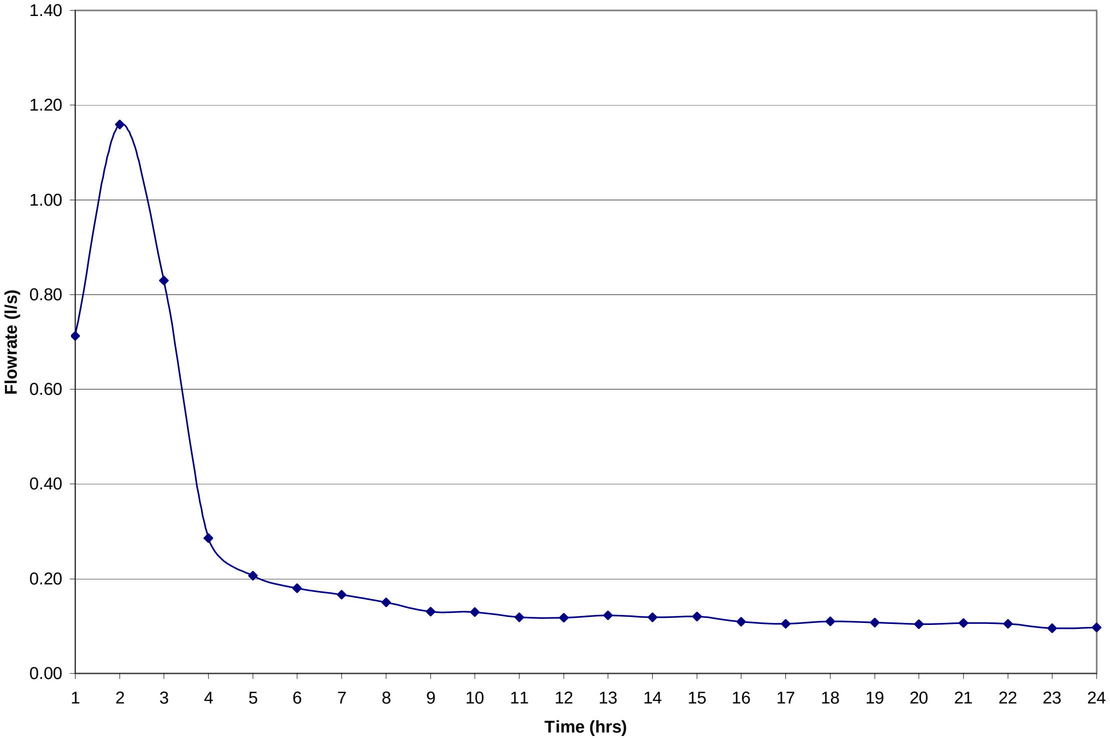


Figure A.2 – Hydrograph for January 25, 2004 Storm Event

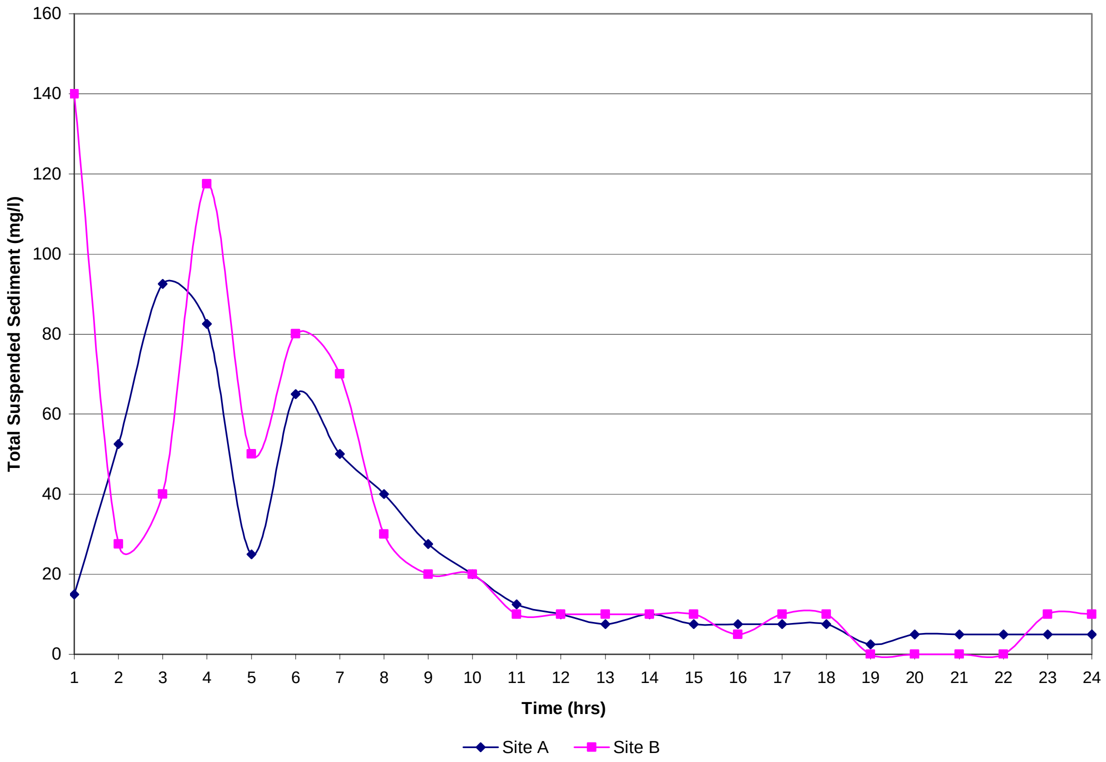


Figure A.3 – TSS for January 25, 2004 Storm Event

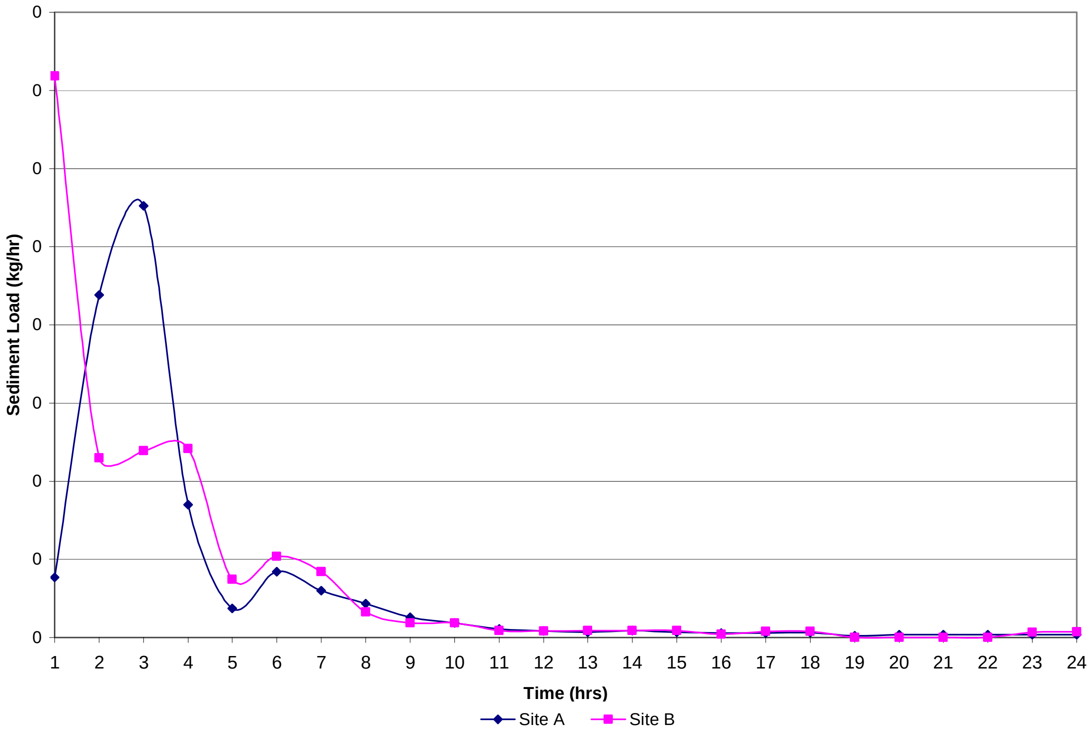


Figure A.4 – Sediment Load for January 25, 2004 Storm Event

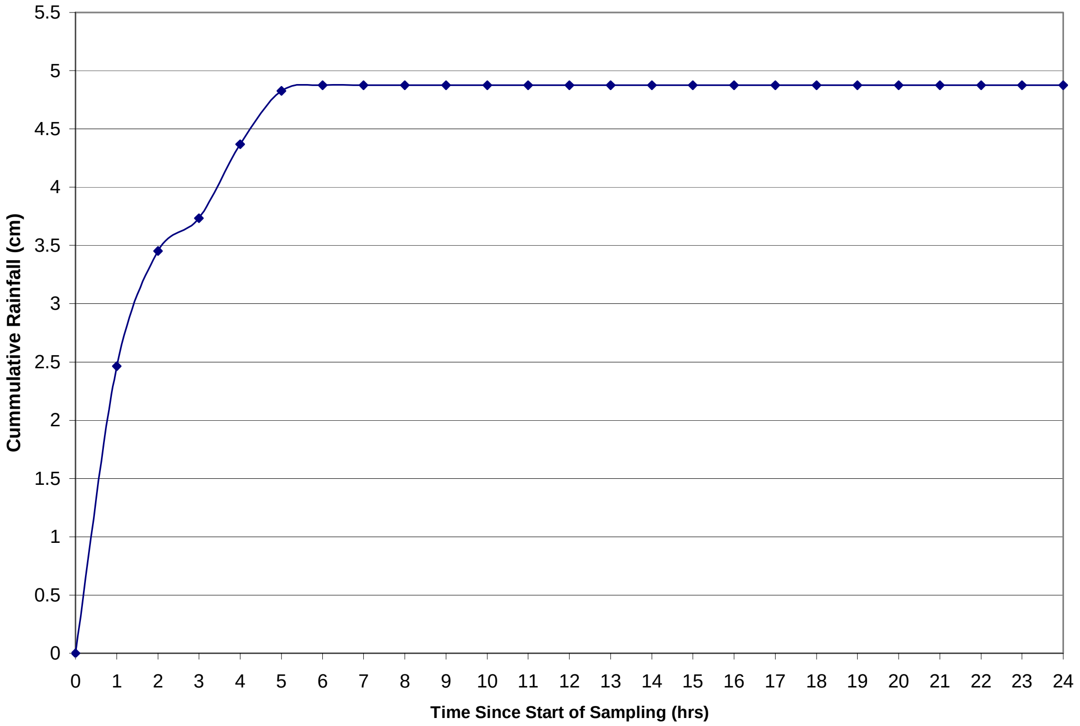


Figure A.5 – Cumulative Rainfall for February 6, 2004 Storm Event

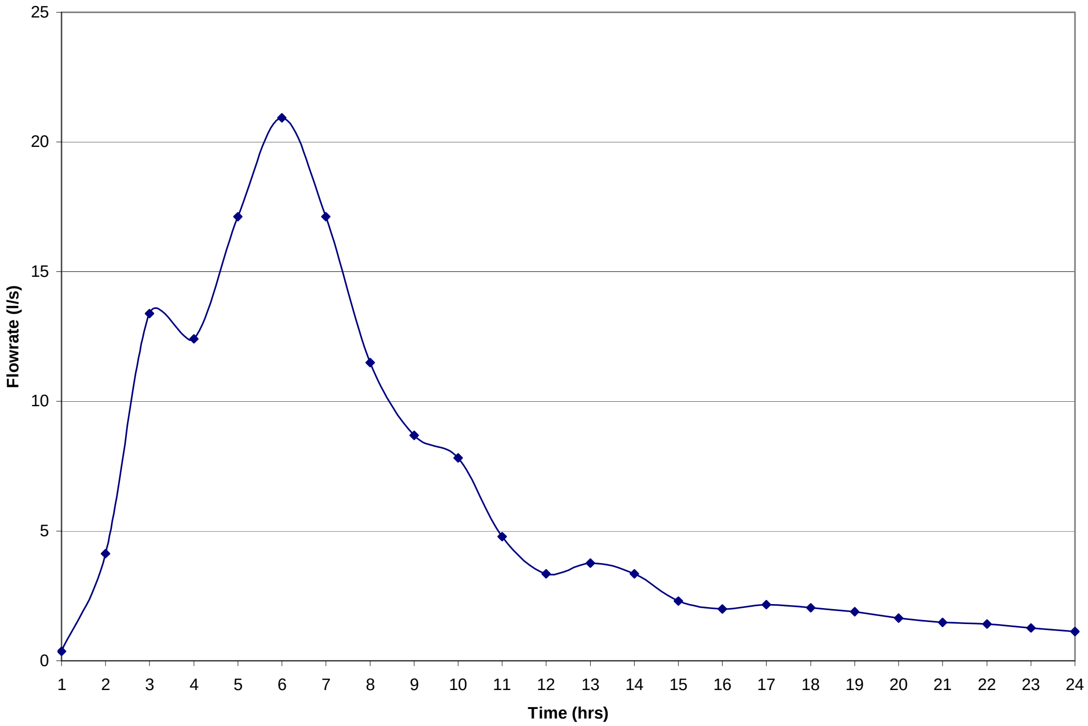


Figure A.6 – Hydrograph for February 6, 2004 Storm Event

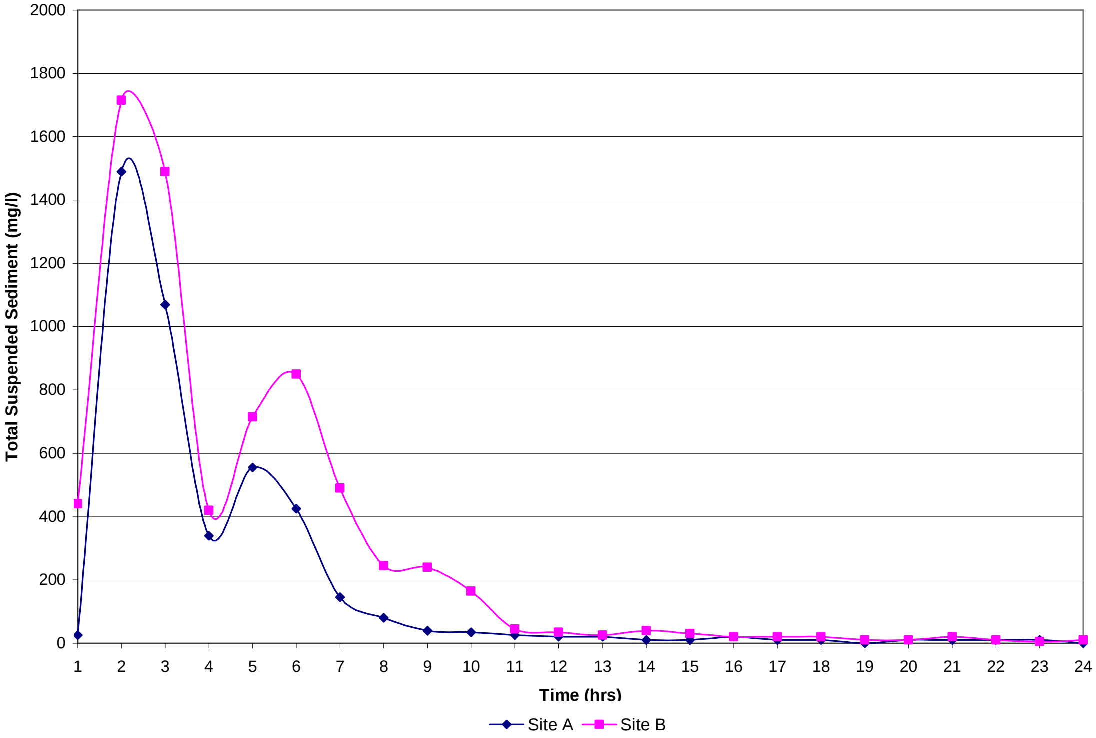


Figure A.7 – TSS for February 6, 2004 Storm Event

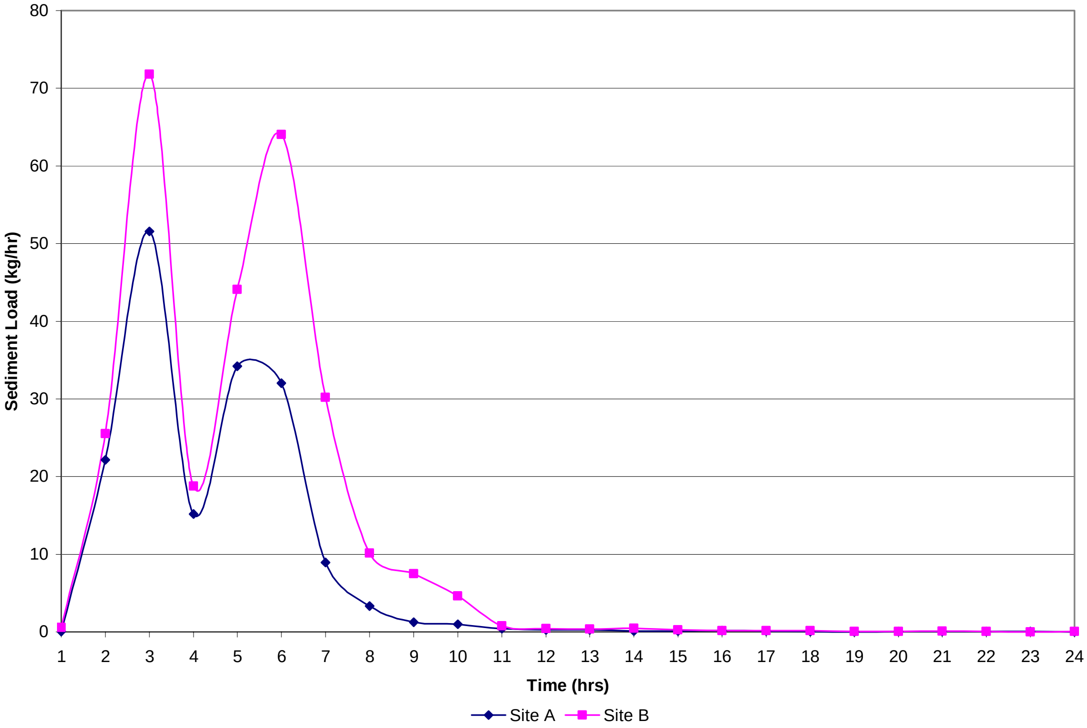


Figure A.8 – Sediment Load for February 6, 2004 Storm Event

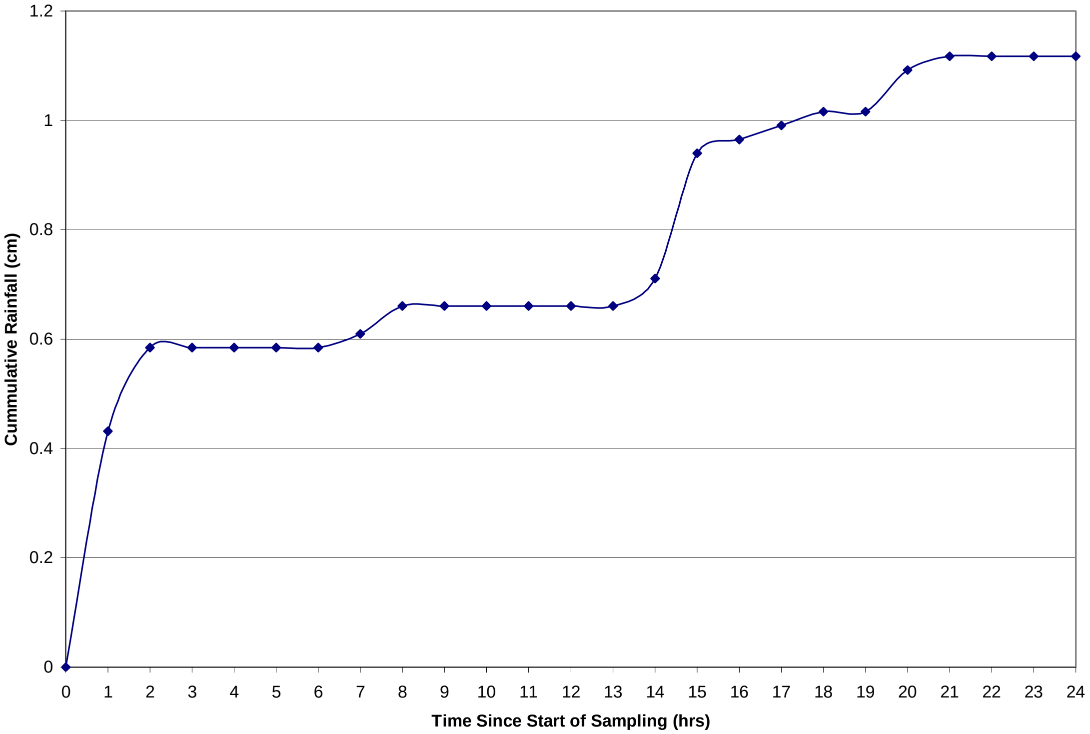


Figure A.9 – Cumulative Rainfall for February 25, 2004 Storm Event

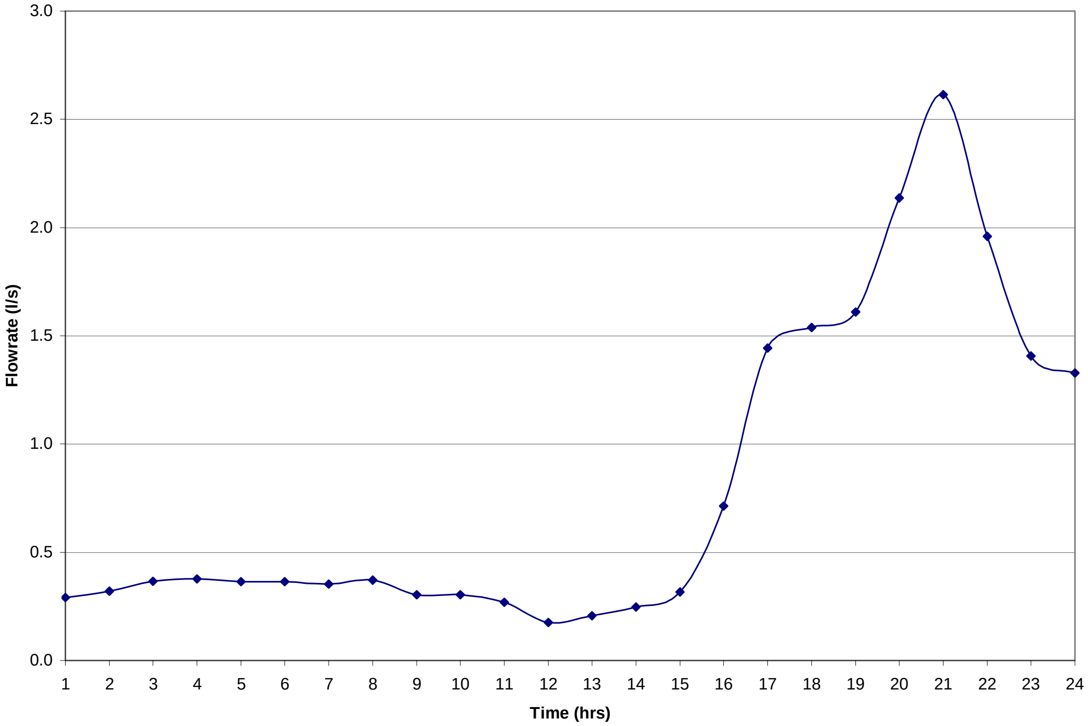


Figure A.10 – Hydrograph for February 25, 2004 Storm Event

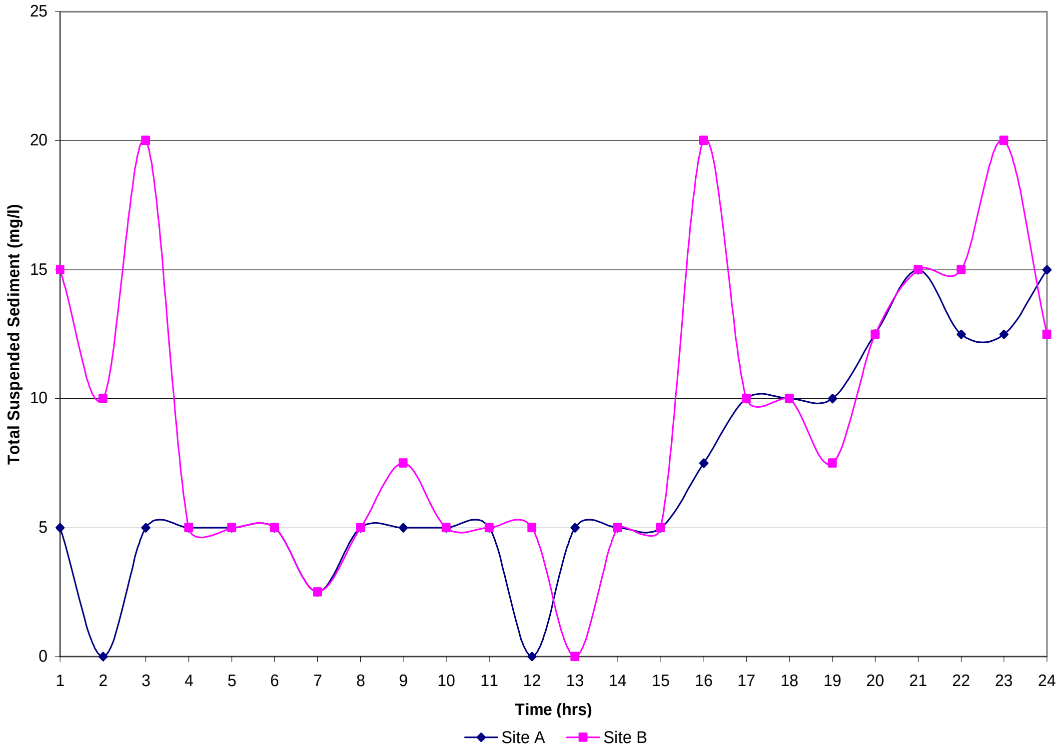


Figure A.11 – TSS for February 25, 2004 Storm Event

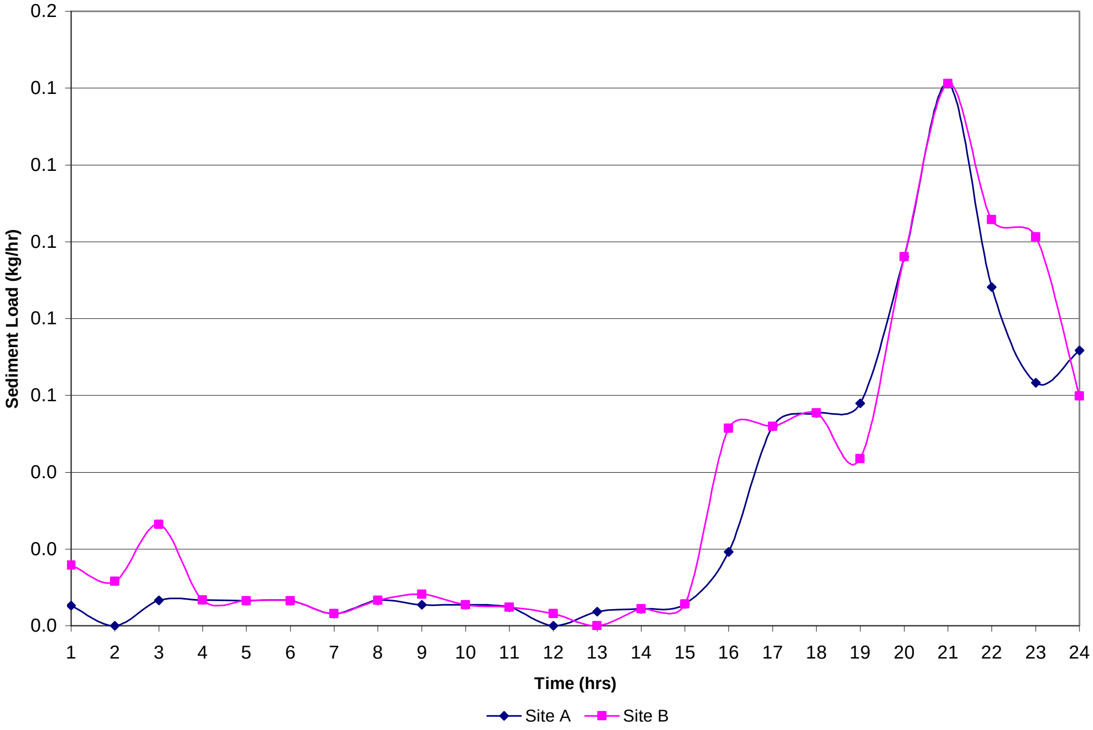


Figure A.12 – Sediment Load for February 25, 2004 Storm Event

APPENDIX B

MAINTENANCE PERIOD

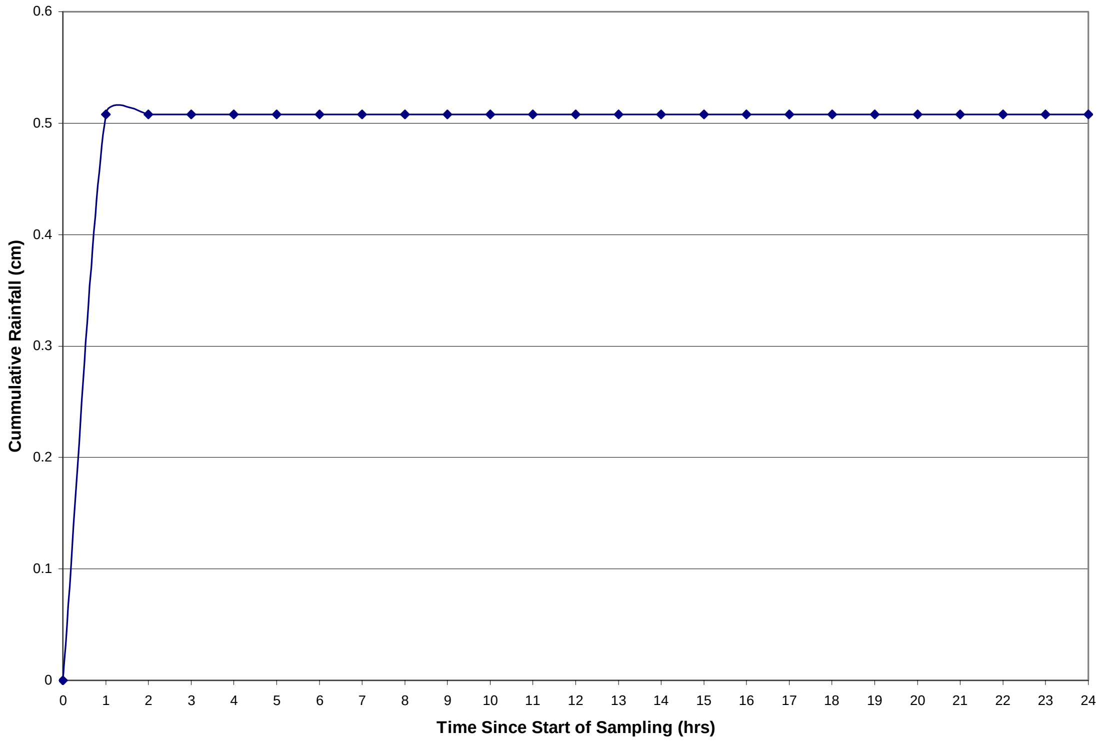


Figure B.1 – Cumulative Rainfall for March 16, 2004 Storm Event

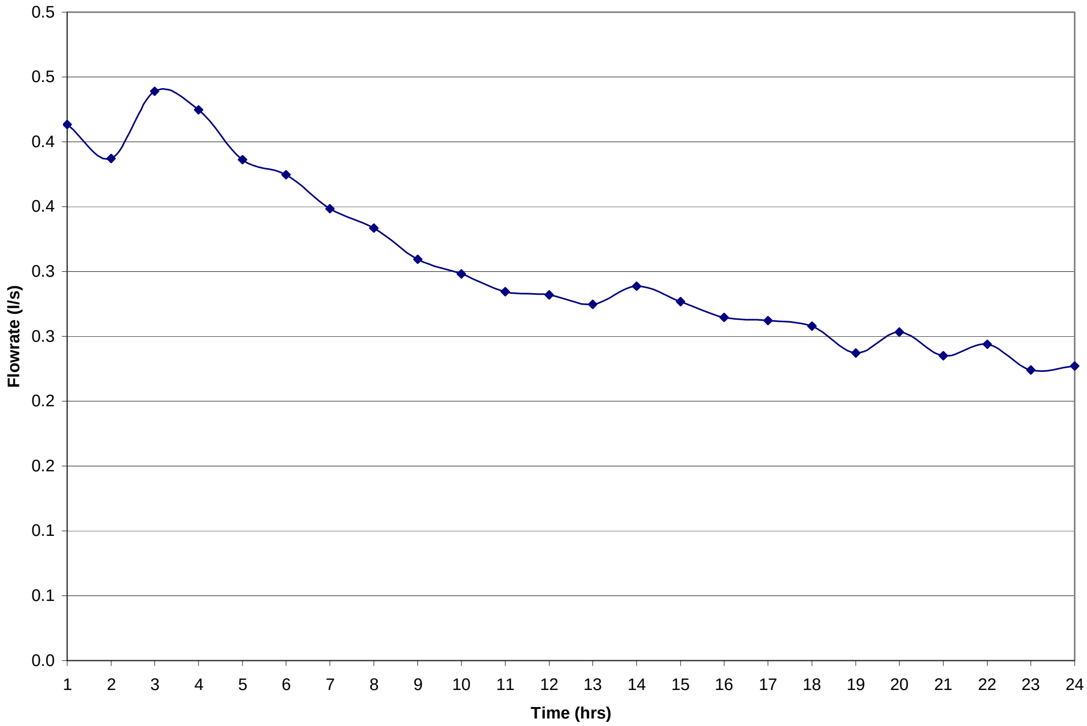


Figure B.2– Hydrograph for March 16, 2004 Storm Event

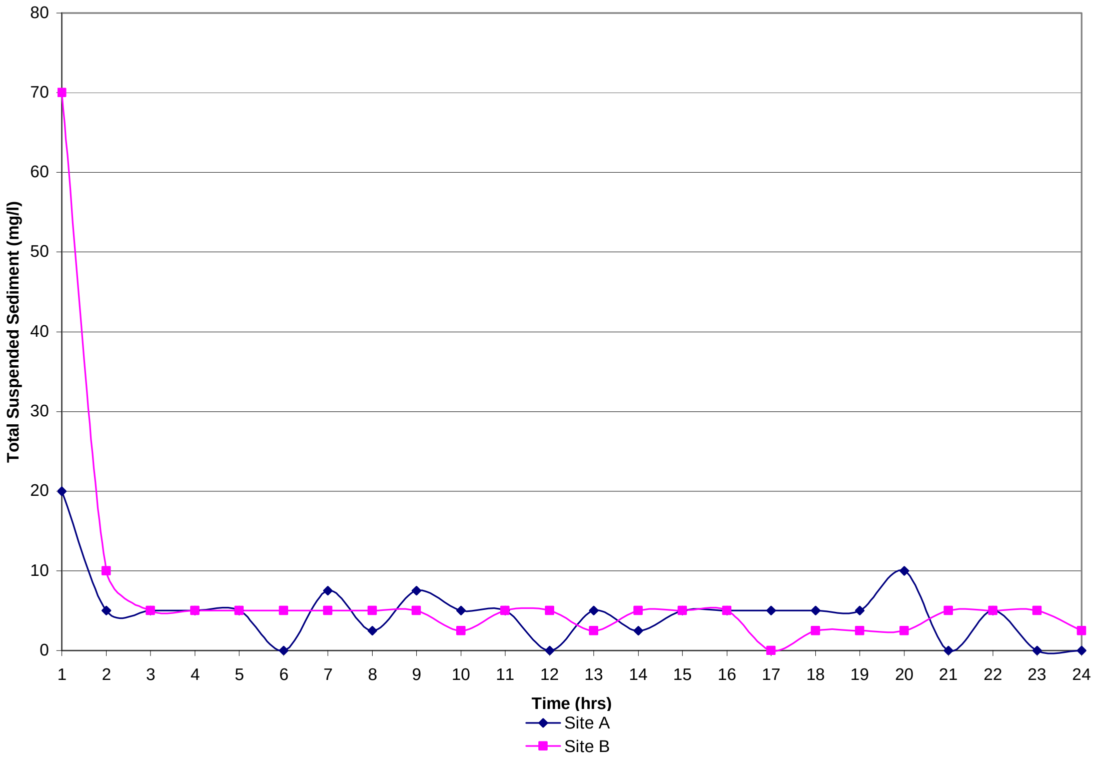


Figure B.3– TSS for March 16, 2004 Storm Event

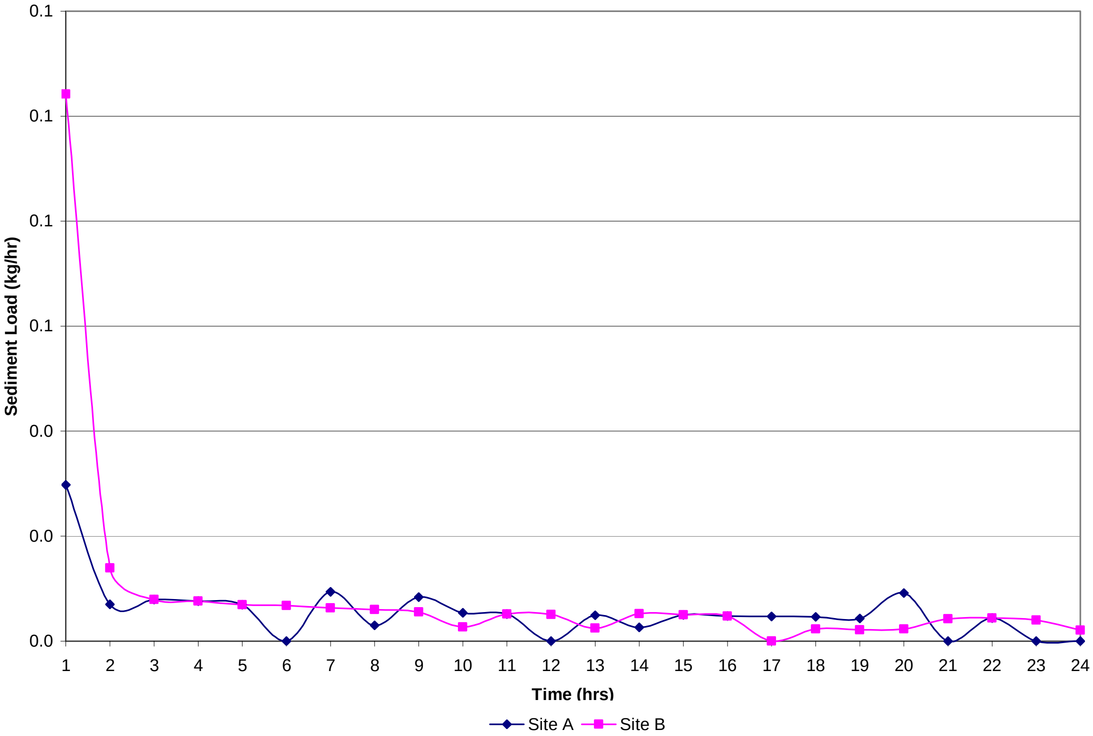


Figure B.4– Sediment Load for March 16, 2004 Storm Event

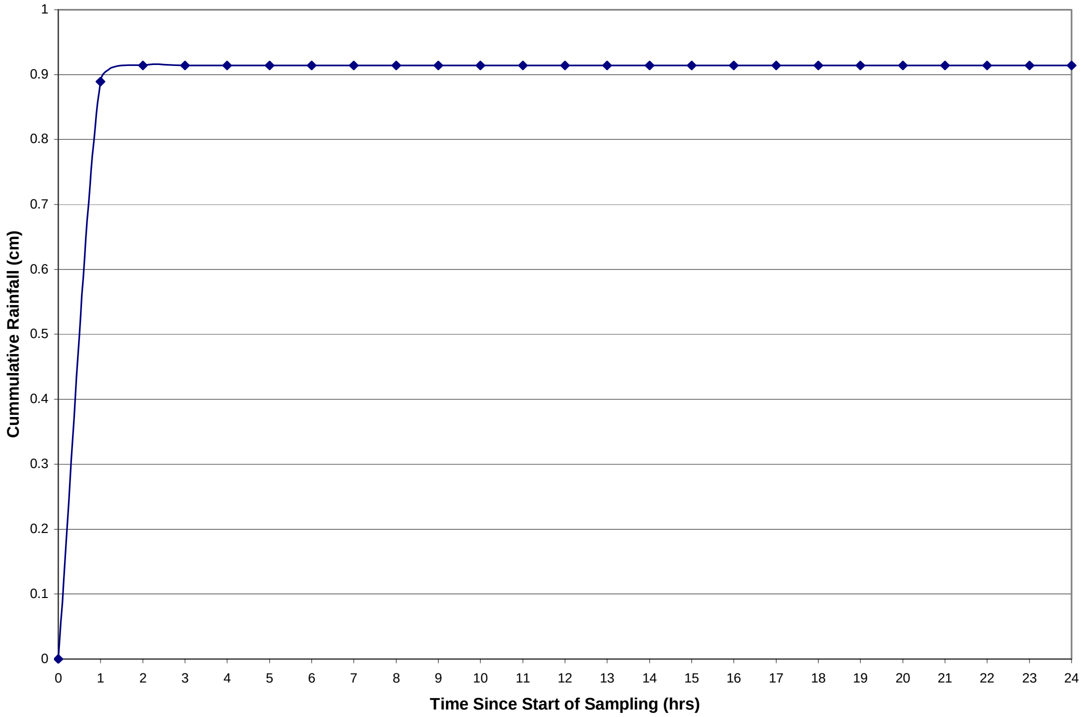


Figure B.5– Cumulative Rainfall for March 20, 2004 Storm Event

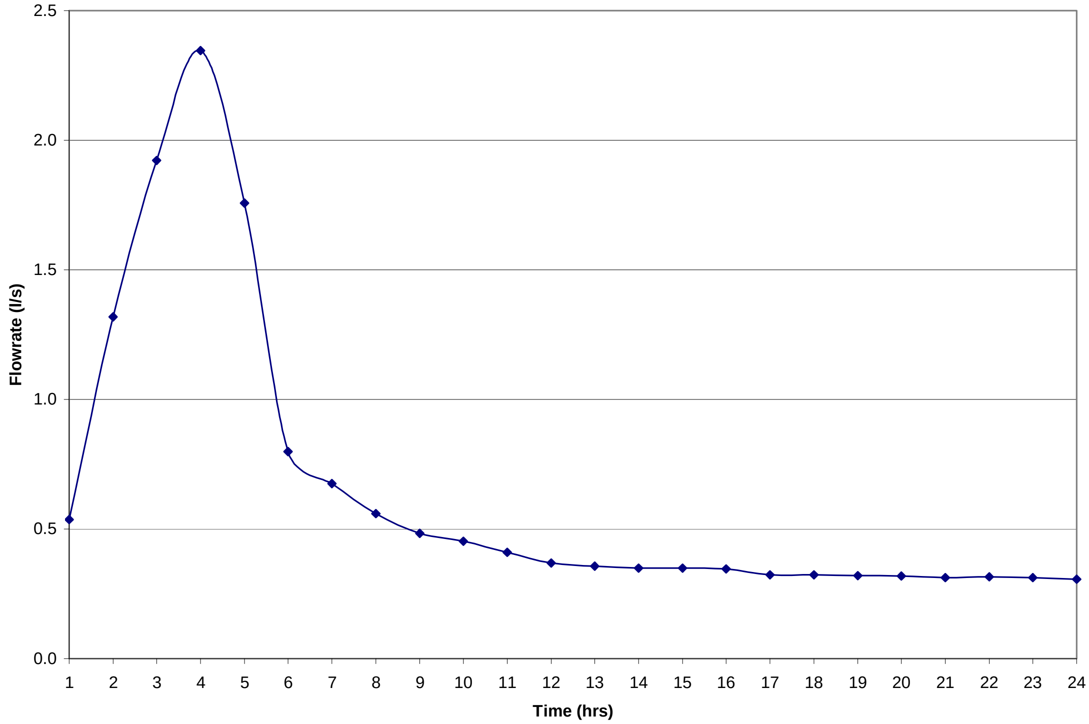


Figure B.6– Hydrograph for March 20, 2004 Storm Event

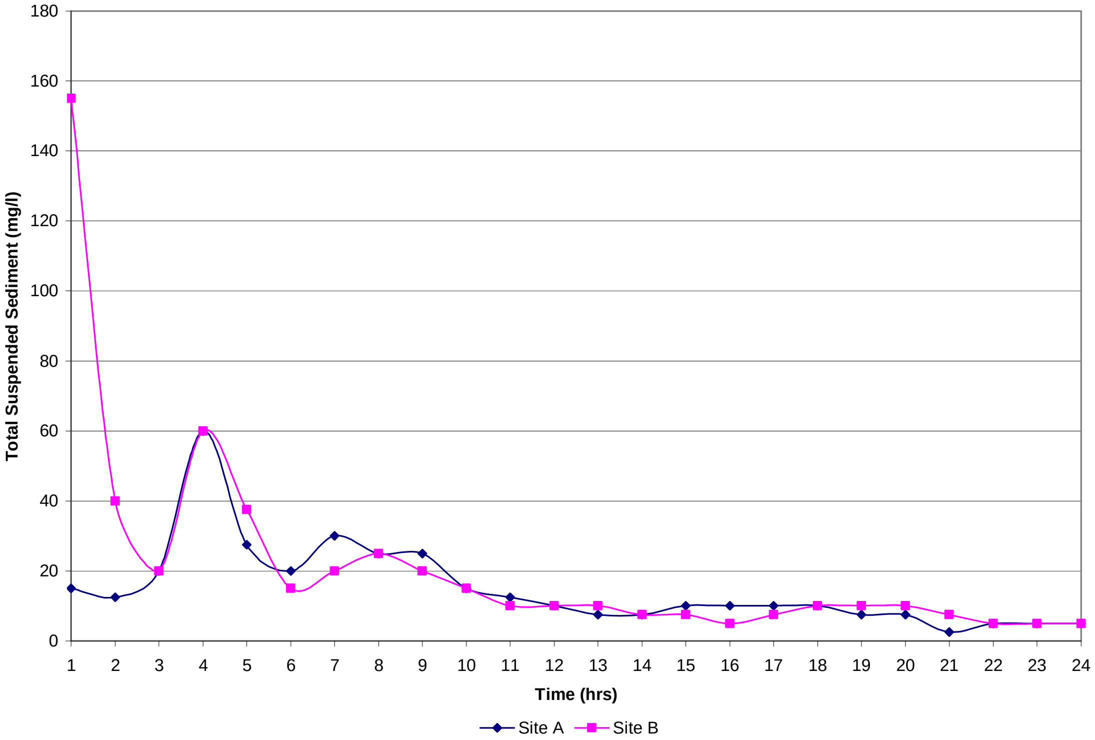


Figure B.7– TSS for March 20, 2004 Storm Event

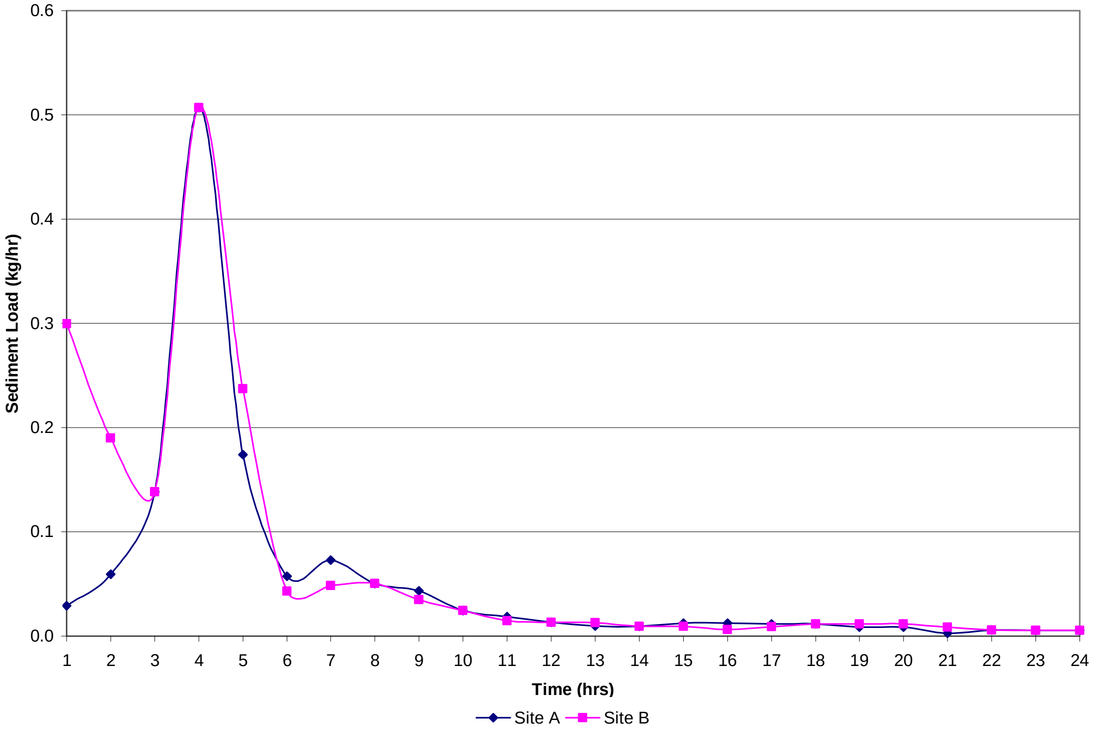


Figure B.8– Sediment Load for March 20, 2004 Storm Event

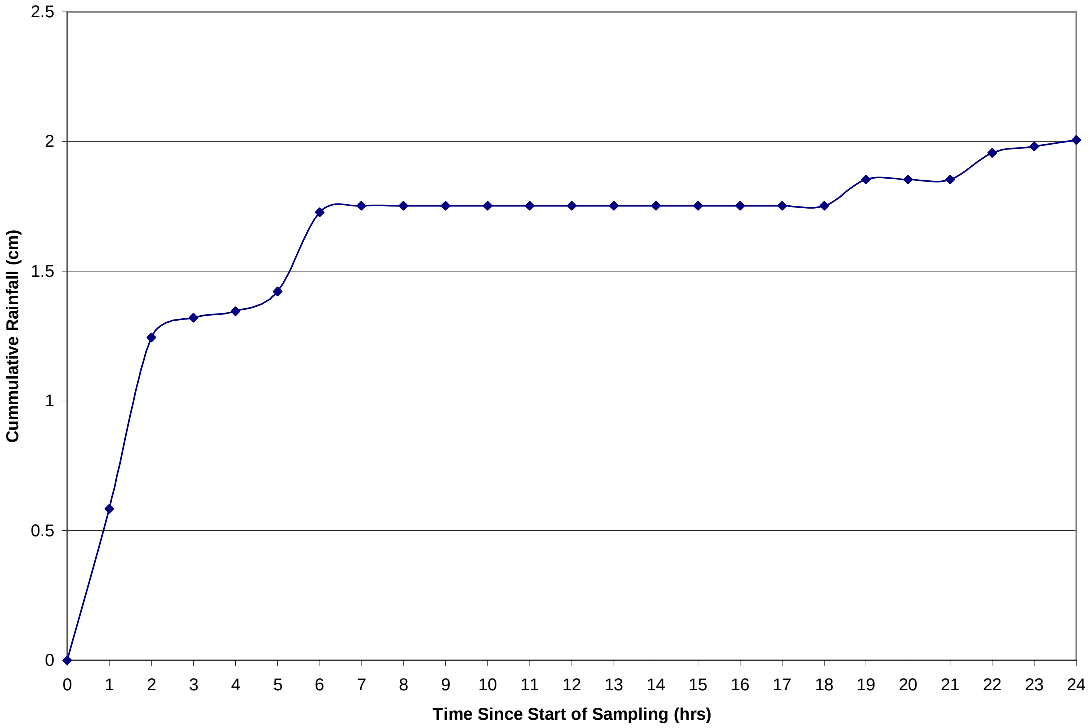


Figure B.9 – Cumulative Rainfall for March 29, 2004 Storm Event

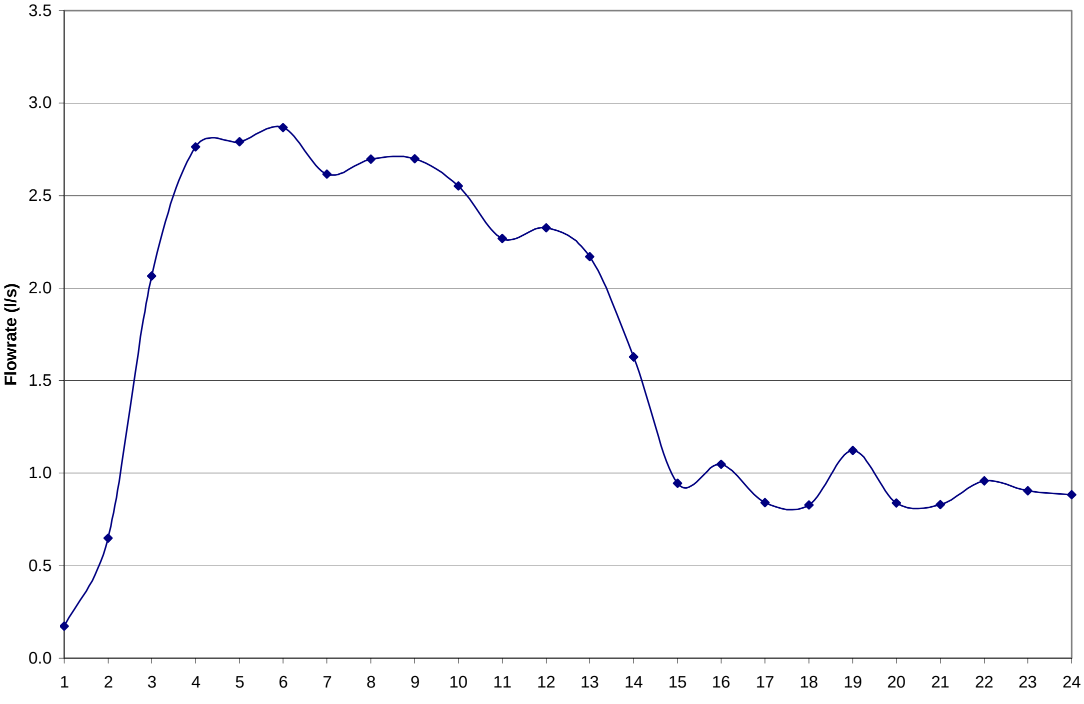


Figure B.10 – Hydrograph for March 29, 2004 Storm Event

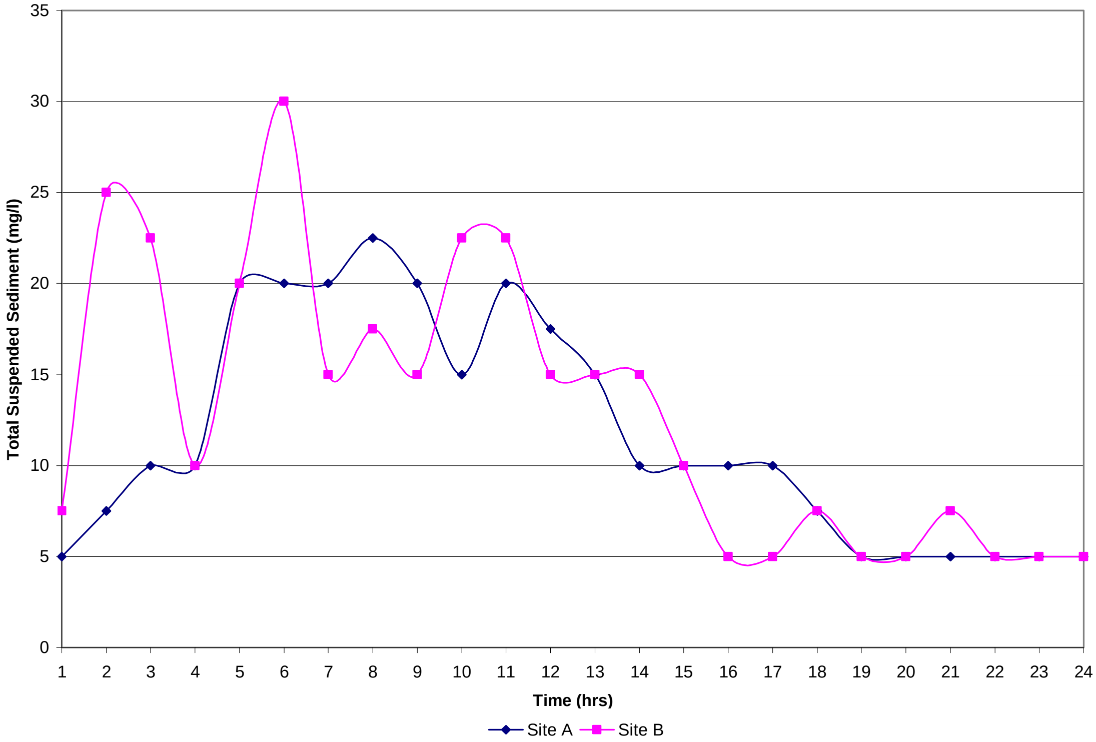


Figure B.11 – TSS for March 29, 2004 Storm Event

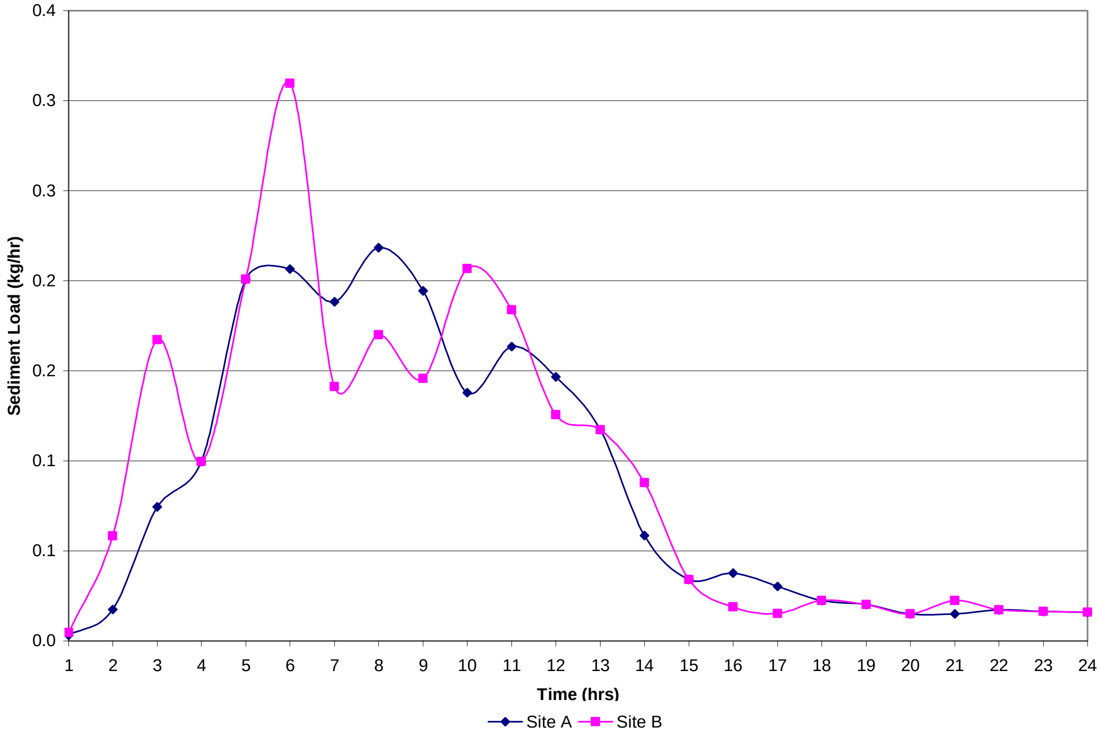


Figure B.12 – Sediment Load for March 29, 2004 Storm Event

APPENDIX C

TRAIL OPEN PERIOD

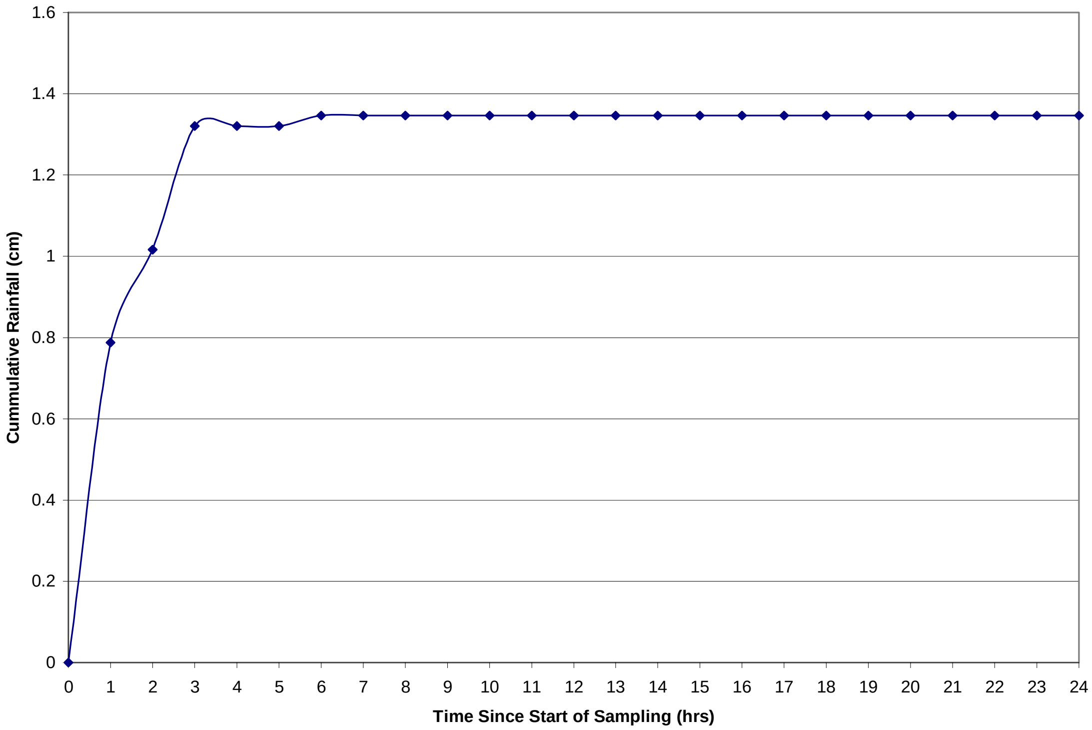


Figure C.1 – Cumulative Rainfall for April 11, 2004 Storm Event

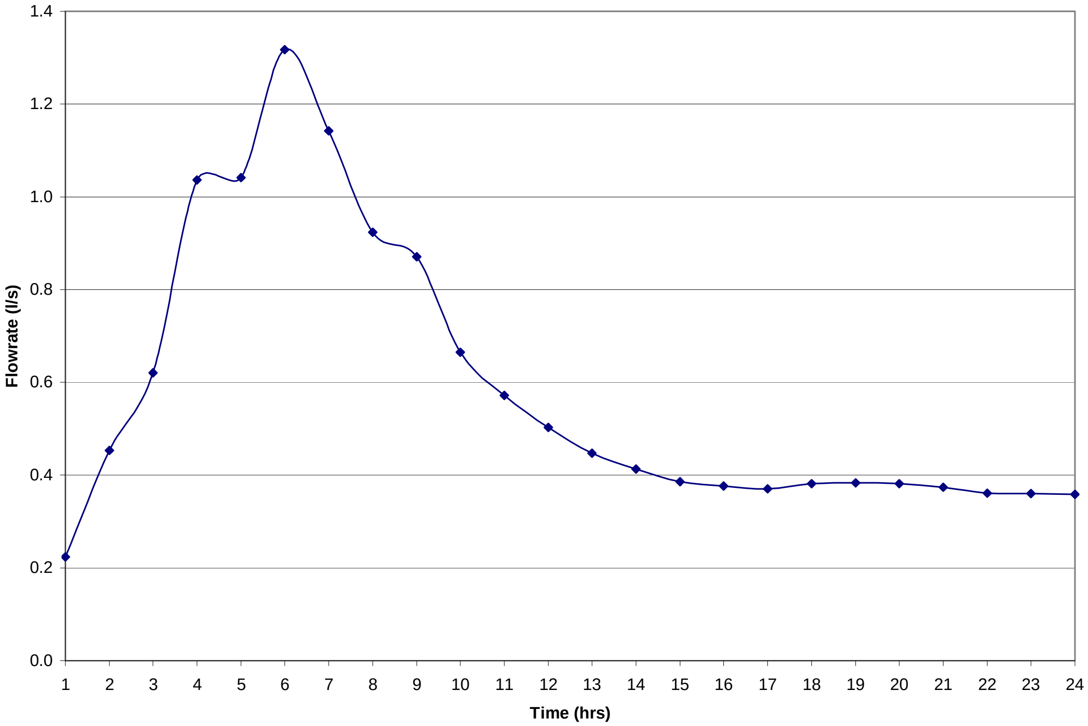


Figure C.2 – Hydrograph for April 11, 2004 Storm Event

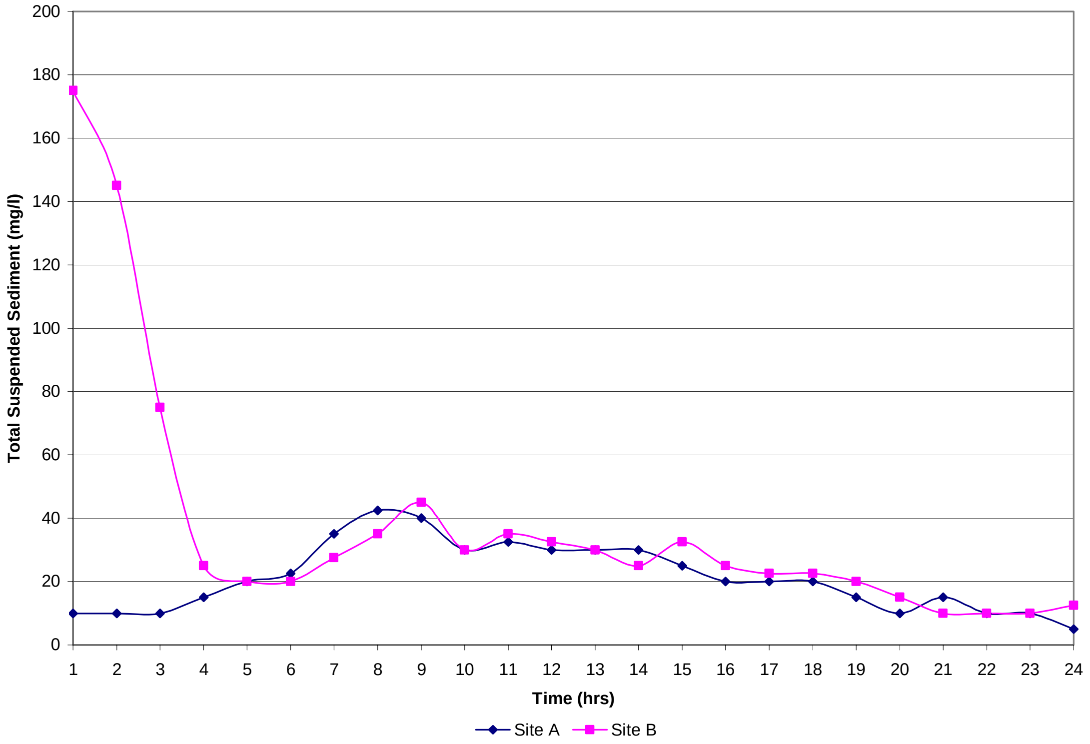


Figure C.3 – TSS for April 11, 2004 Storm Event

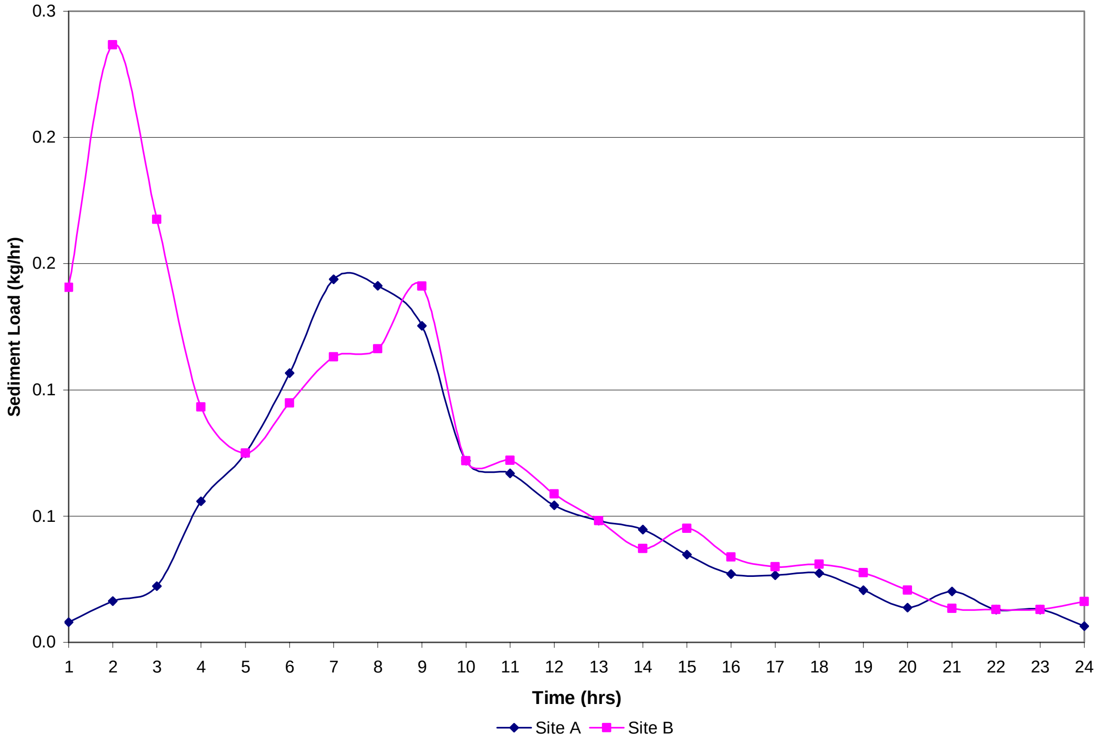


Figure C.4 – Sediment Load for April 11, 2004 Storm Event

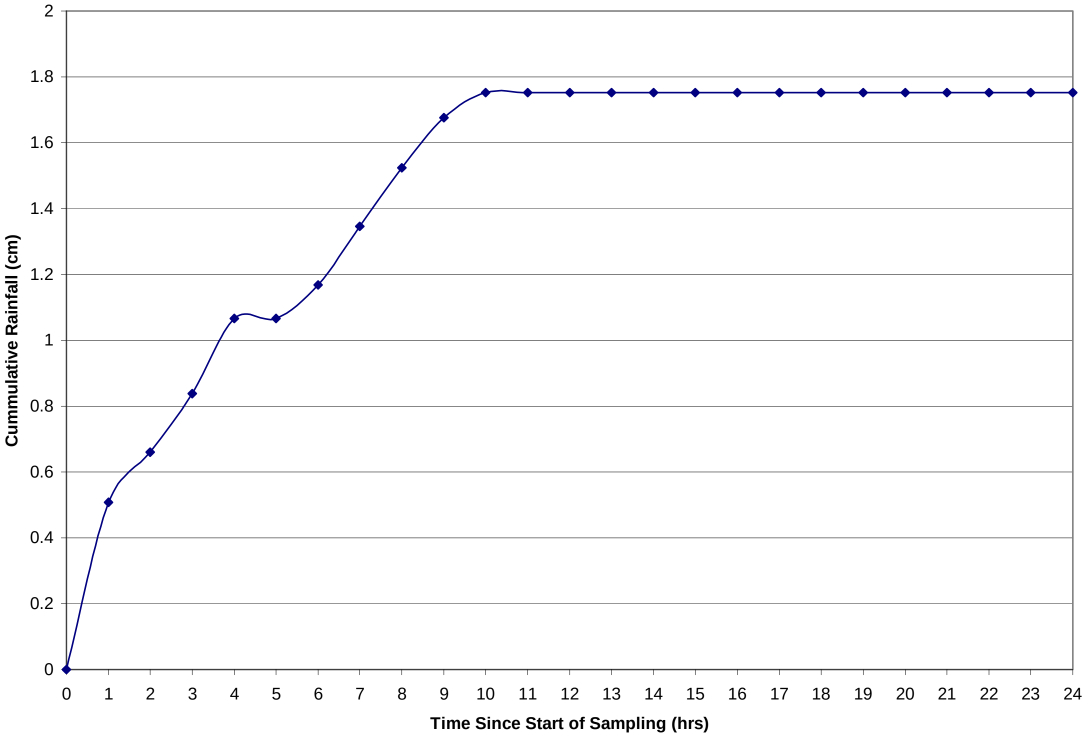


Figure C.5 – Cumulative Rainfall for April 26, 2004 Storm Event

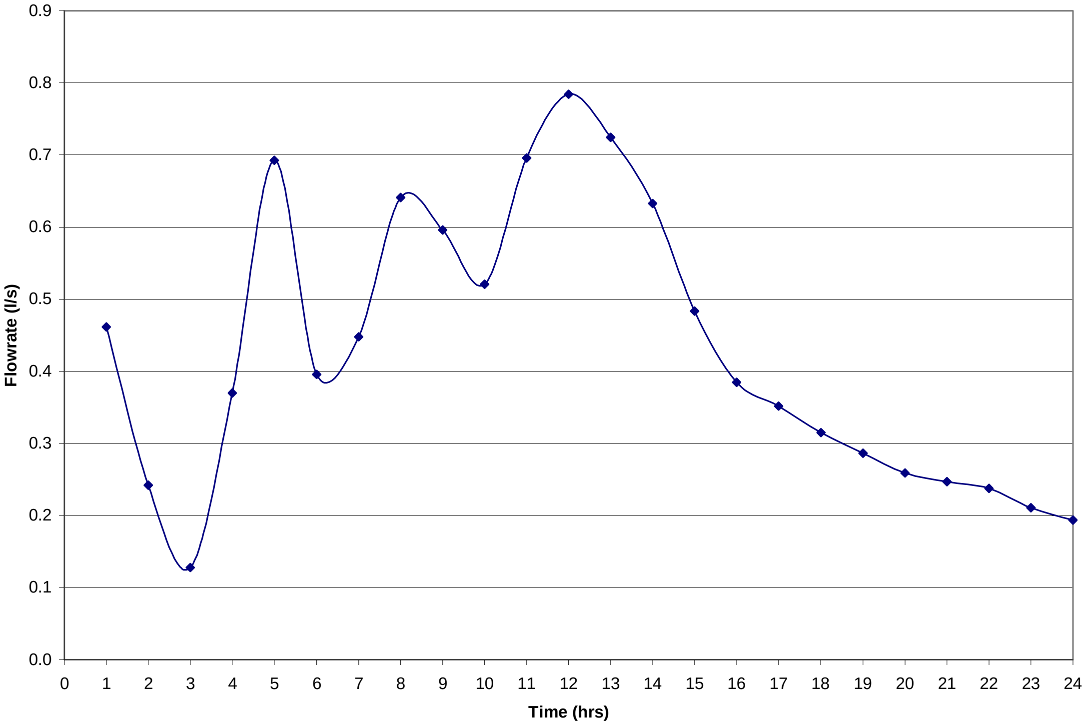


Figure C.6 – Hydrograph for April 26, 2004 Storm Event

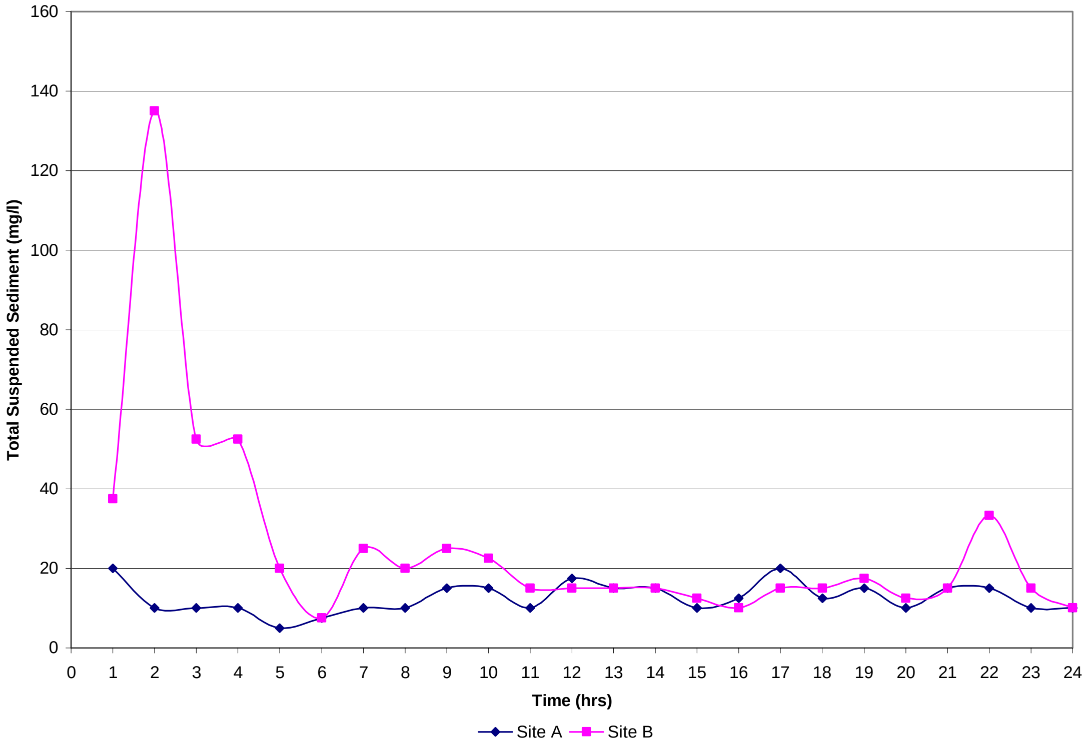


Figure C.7 – TSS for April 26, 2004 Storm Event

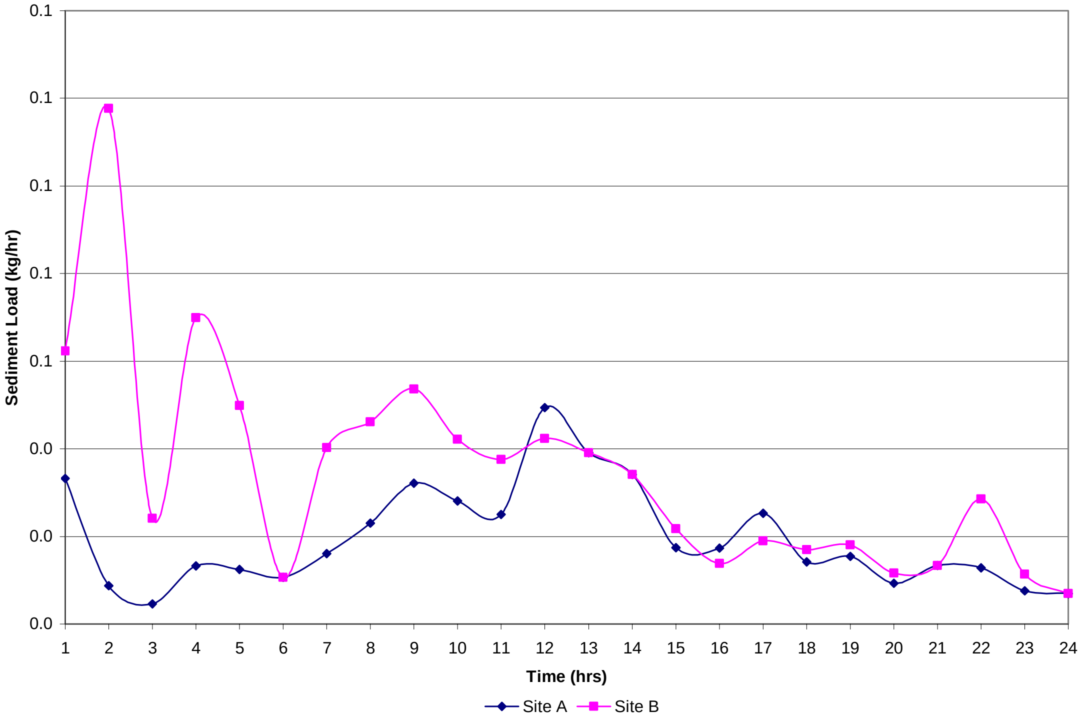


Figure C.8 – Sediment Load for April 26, 2004 Storm Event

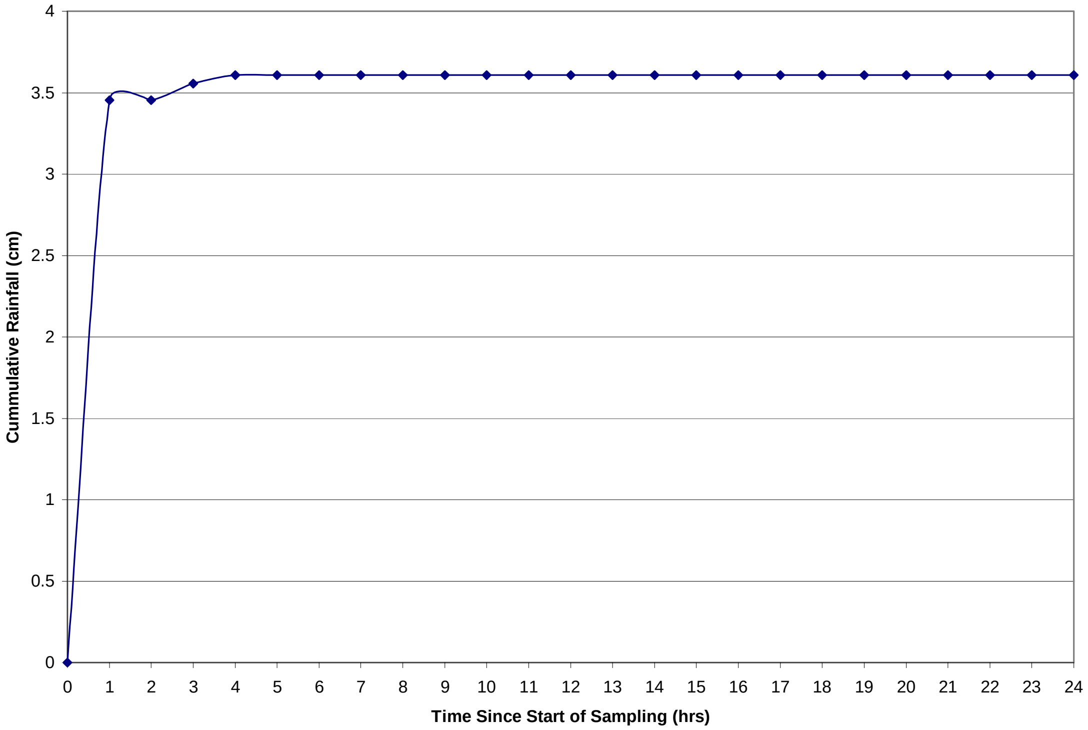


Figure C.9 – Cumulative Rainfall for May 16, 2004 Storm Event

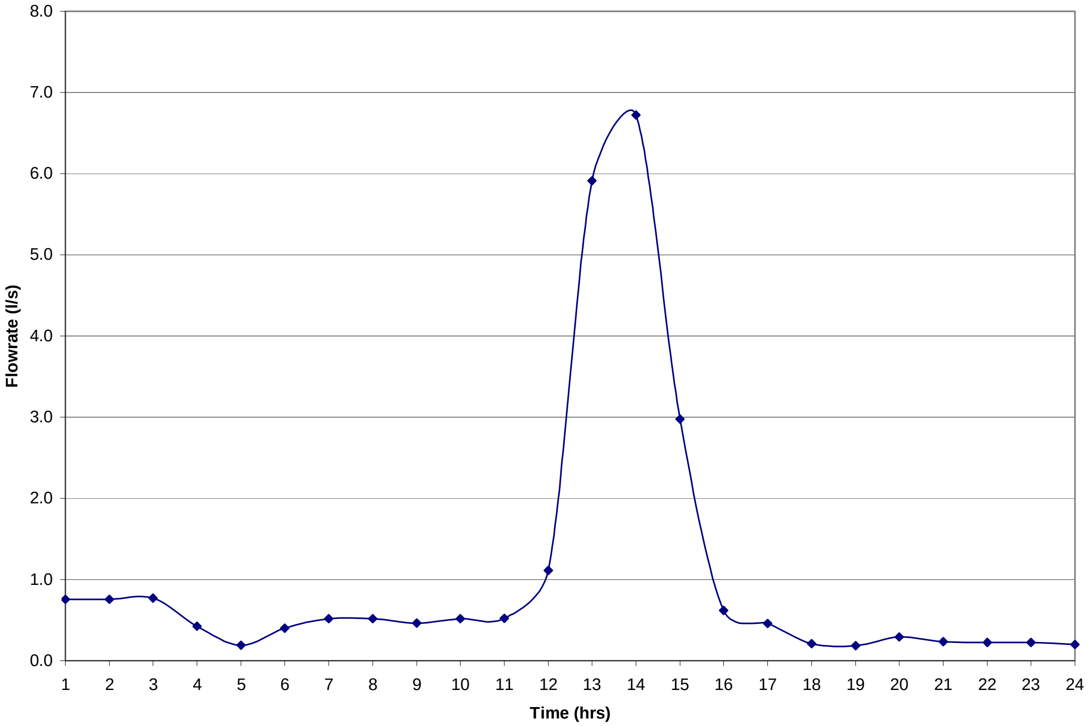


Figure C.10 – Hydrograph for May 16, 2004 Storm Event

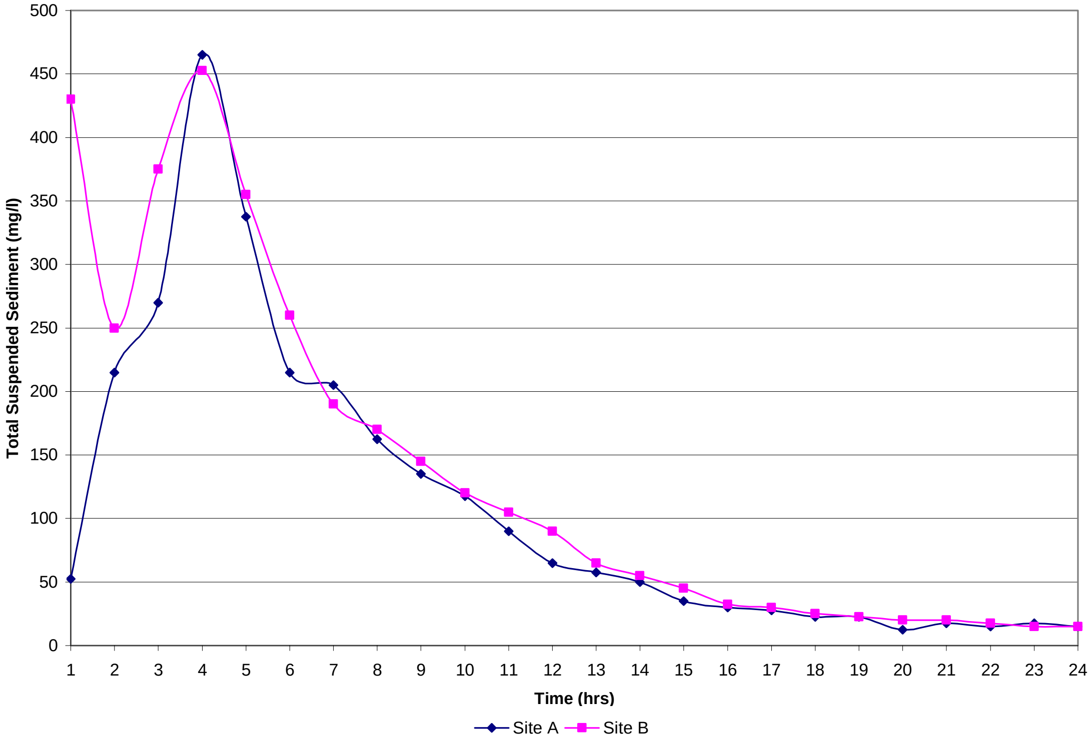


Figure C.11 – TSS for May 16, 2004 Storm Event

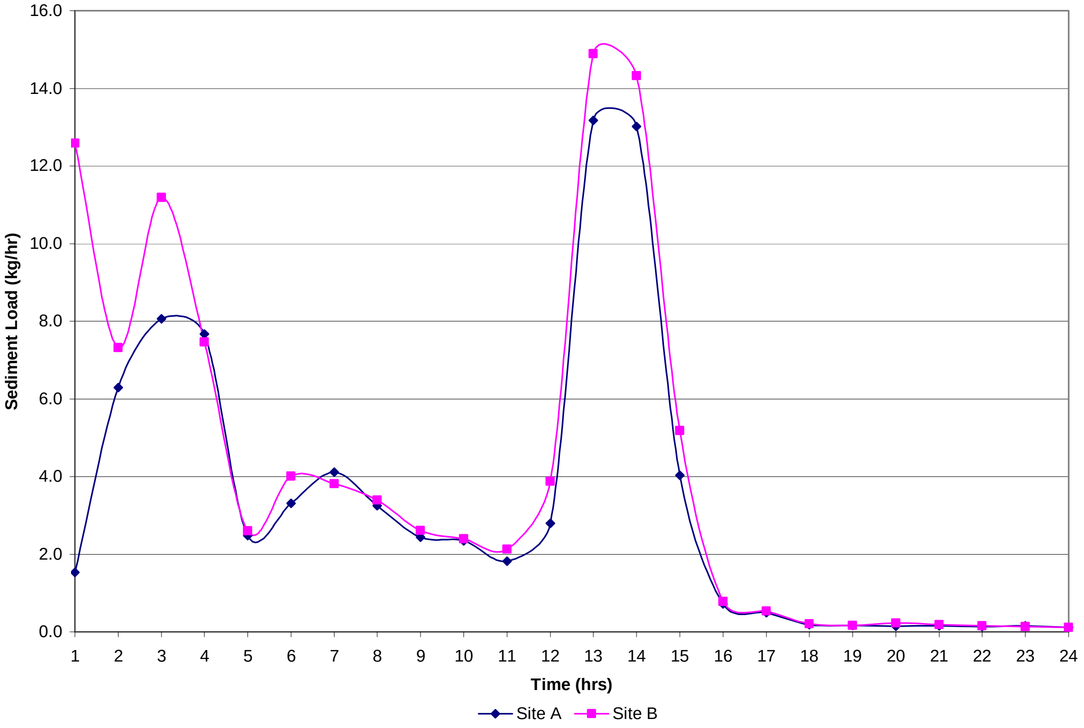


Figure C.12 – Sediment Load for May 16, 2004 Storm Event

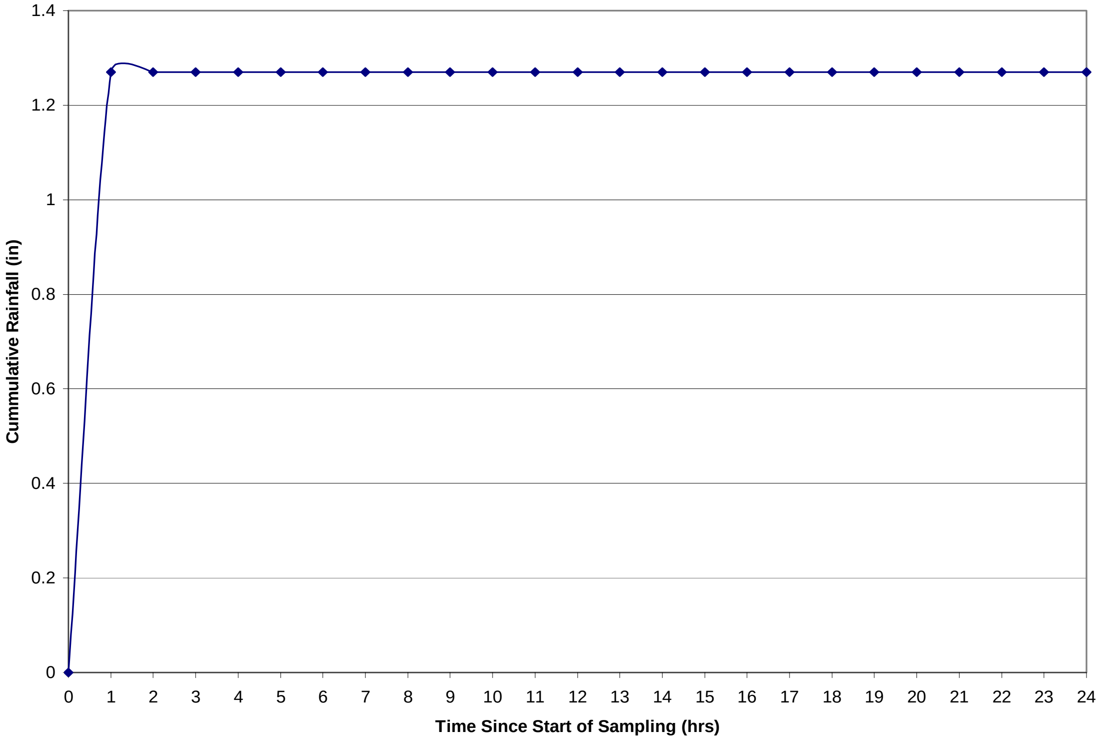


Figure C.13 – Cumulative Rainfall for June 16, 2004 Storm Event

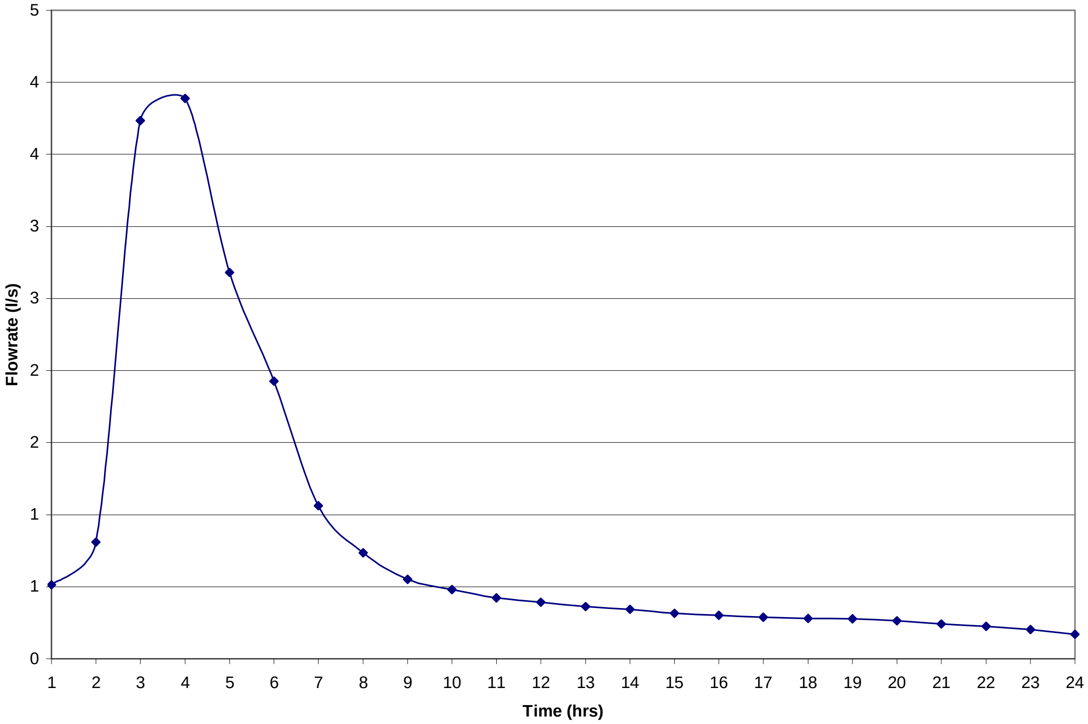


Figure C.14 – Hydrograph for June 16, 2004 Storm Event

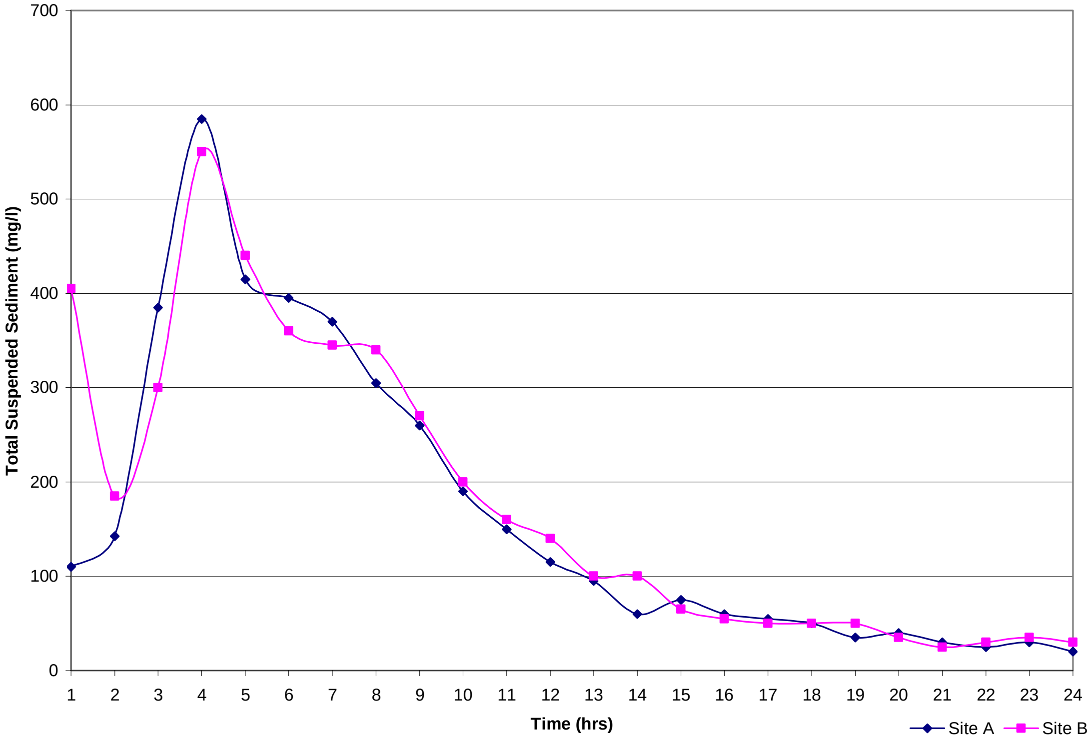


Figure C.15 – TSS for June 16, 2004 Storm Event

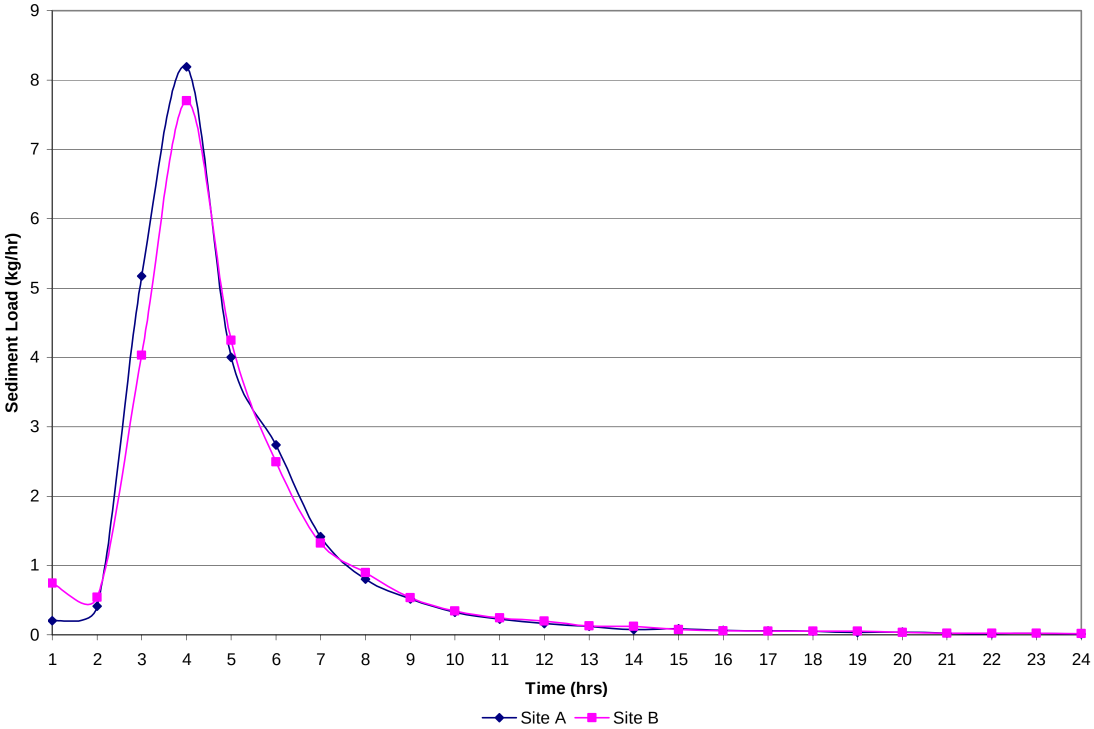


Figure C.16 – Sediment Load for June 16, 2004 Storm Event

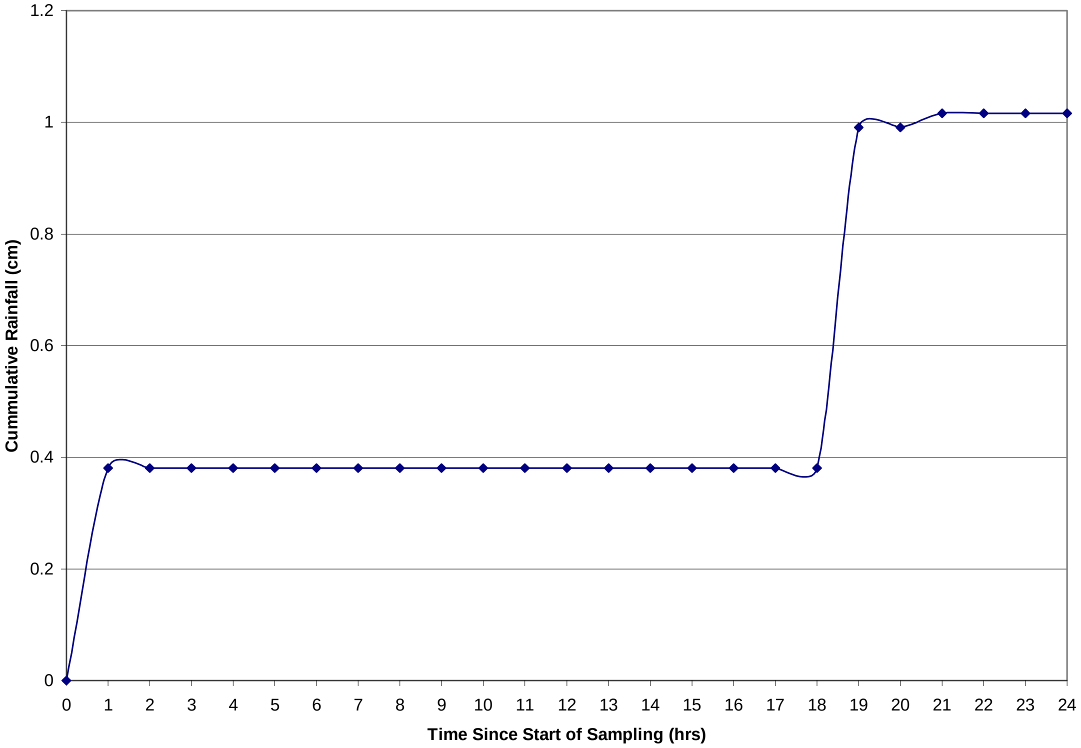


Figure C.17 – Cumulative Rainfall for June 22, 2004 Storm Event

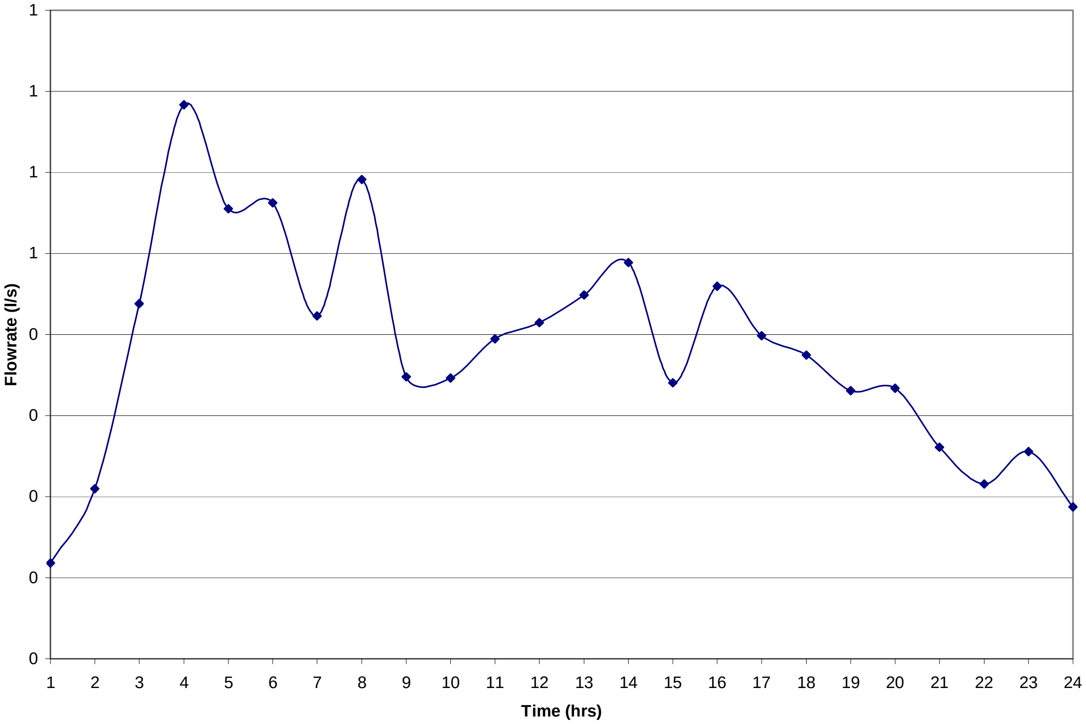


Figure C.18 – Hydrograph for June 22, 2004 Storm Event

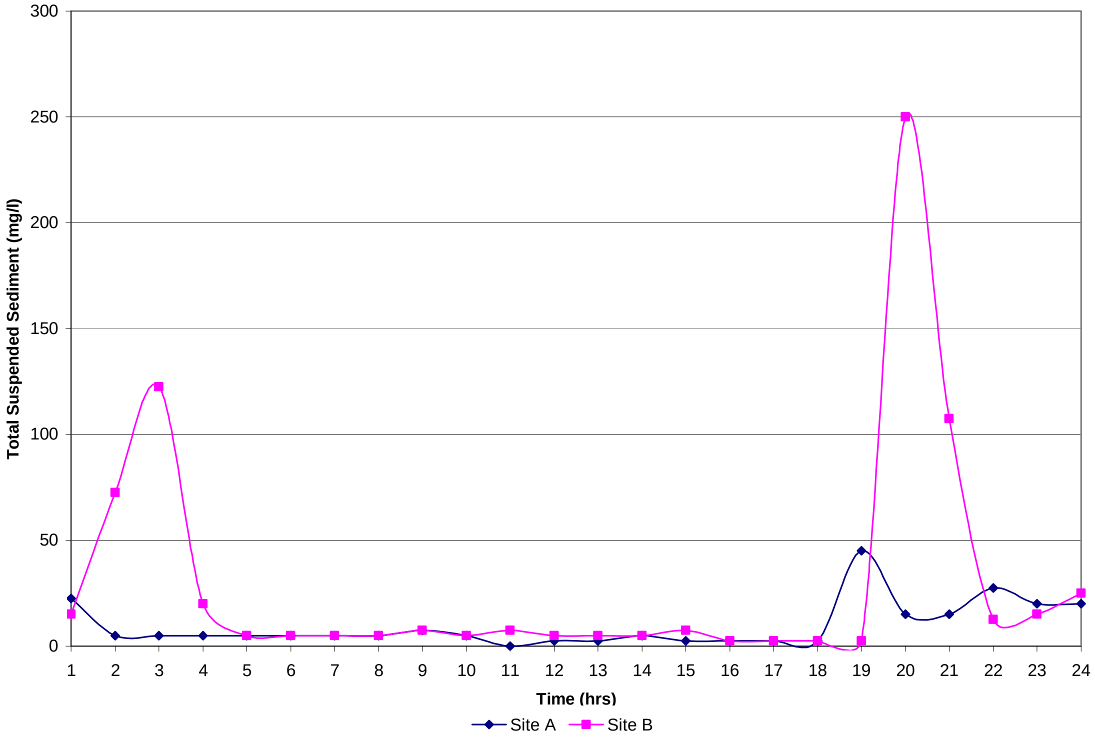


Figure C.19 – TSS for June 22, 2004 Storm Event

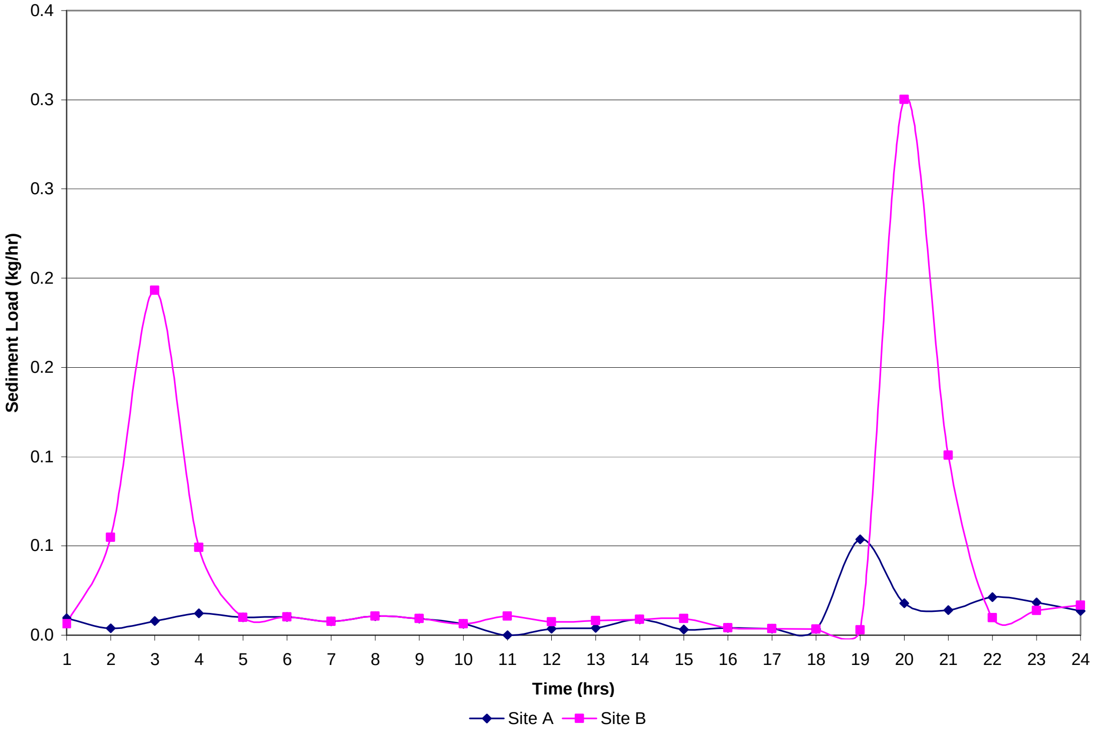


Figure C.20 – Sediment Load for June 22, 2004 Storm Event

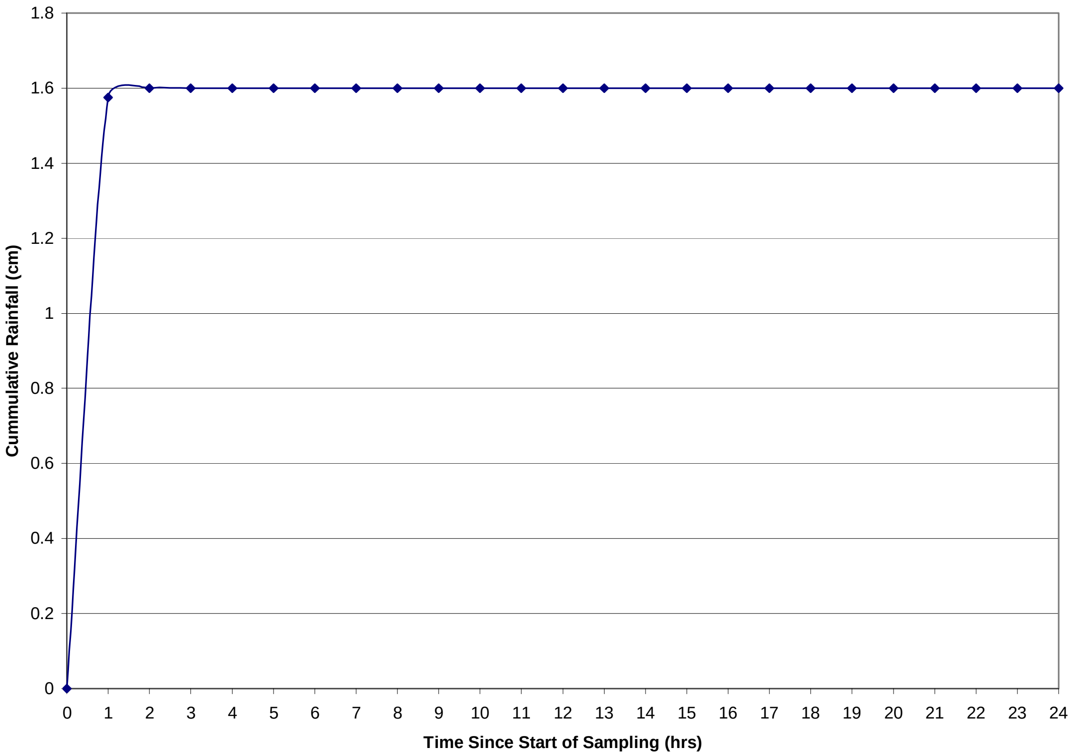


Figure C.21 – Cumulative Rainfall for July 2, 2004 Storm Event

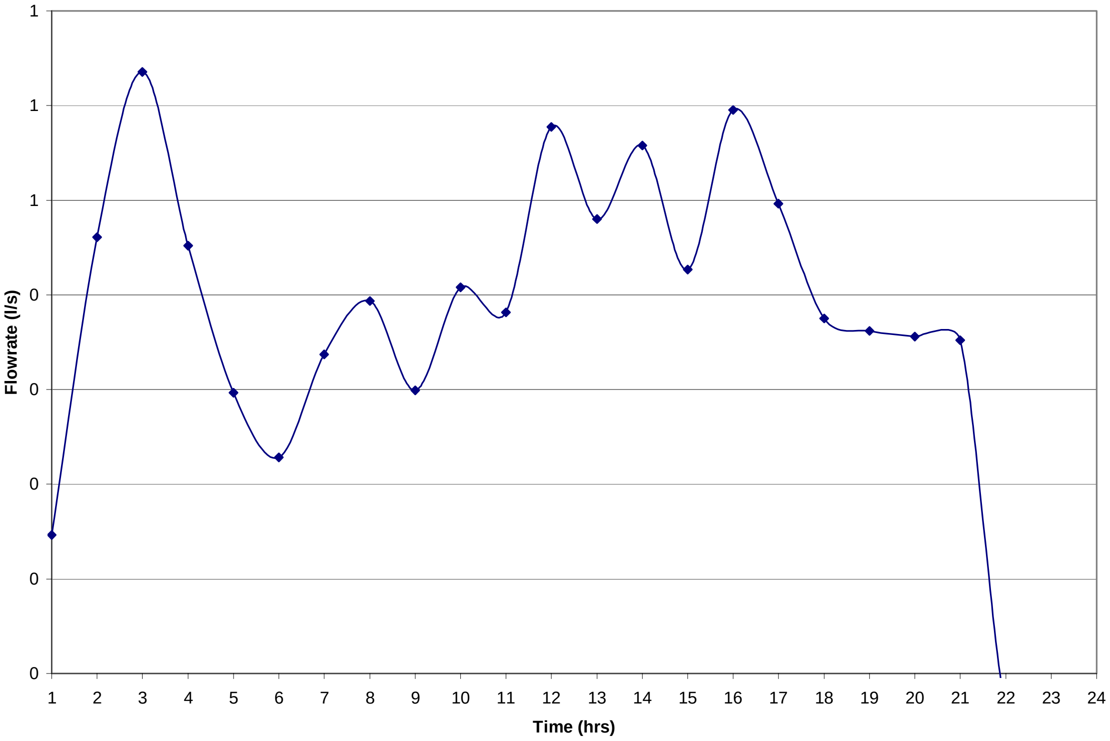


Figure C.22 – Hydrograph for July 2, 2004 Storm Event

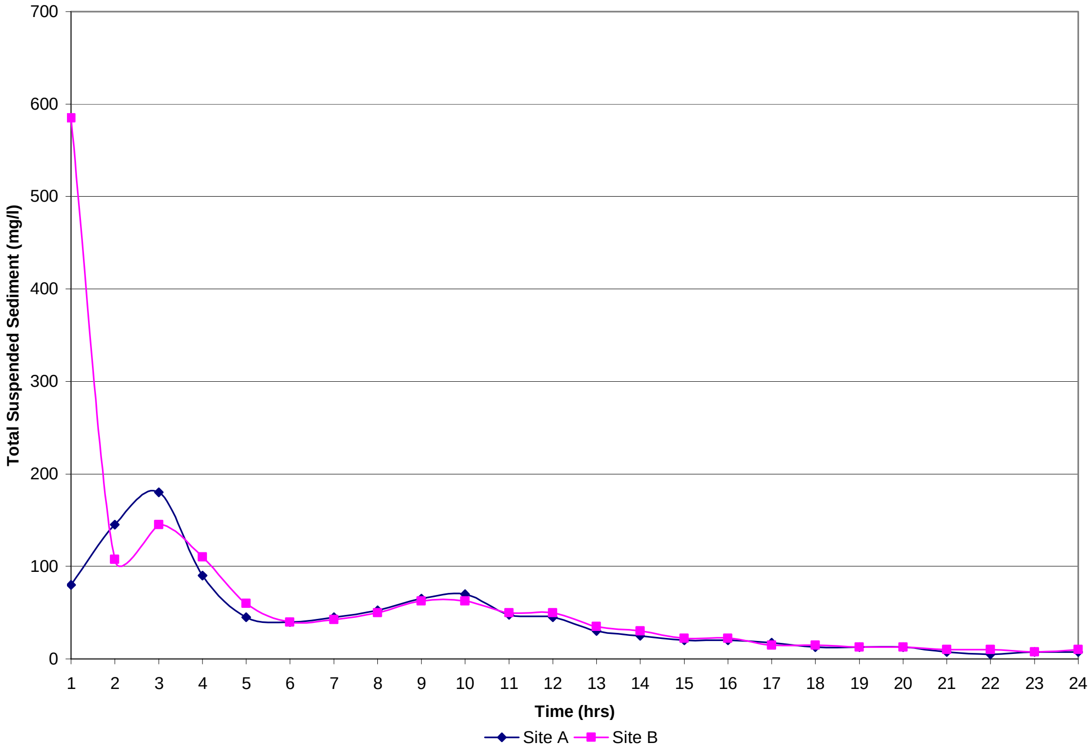


Figure C.23 – TSS for July 2, 2004 Storm Event

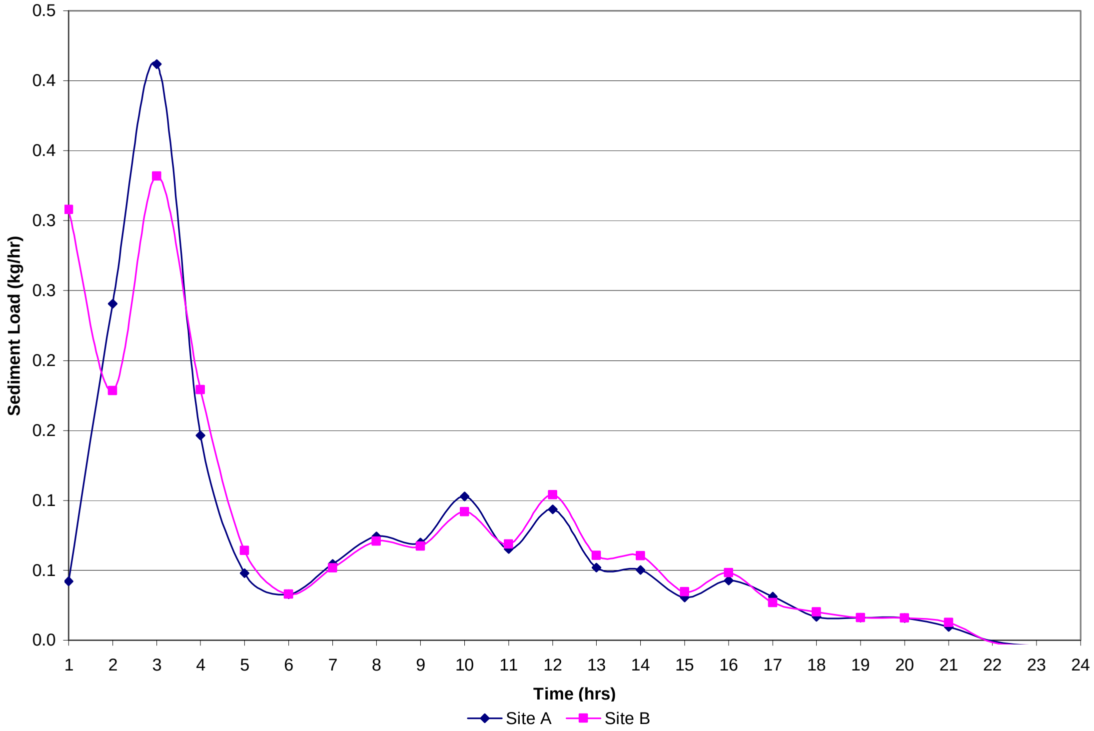


Figure C.24 – Sediment Load for July 2, 2004 Storm Event

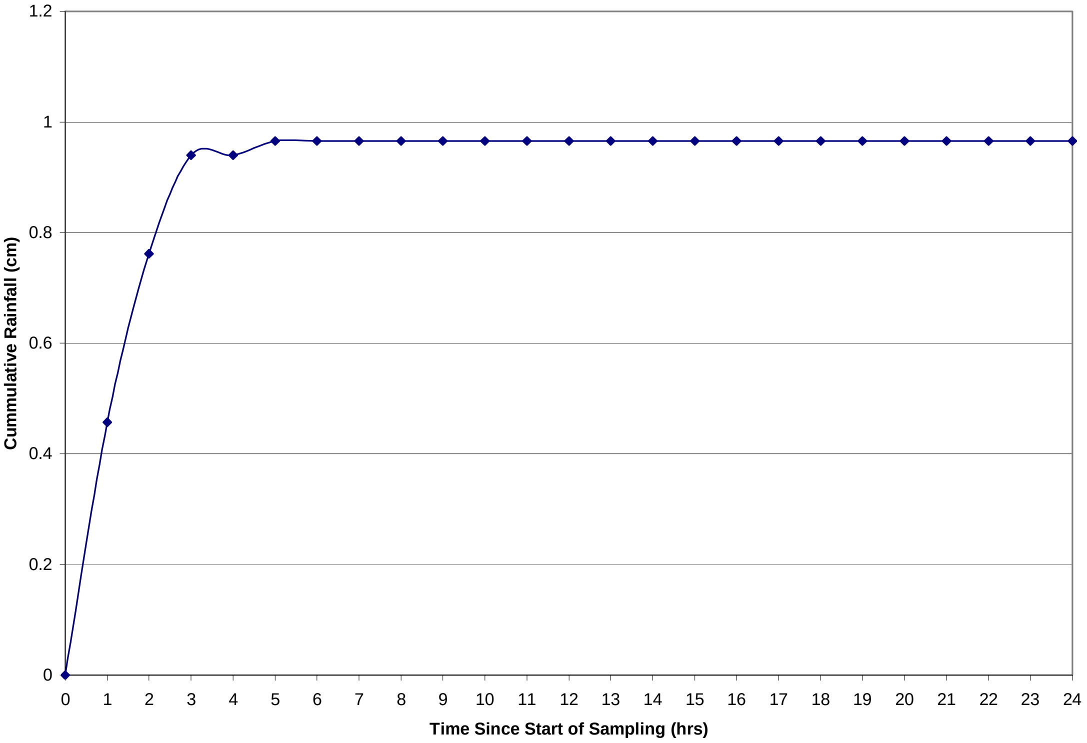


Figure C.25 – Cumulative Rainfall for December 16, 2003 Storm Event

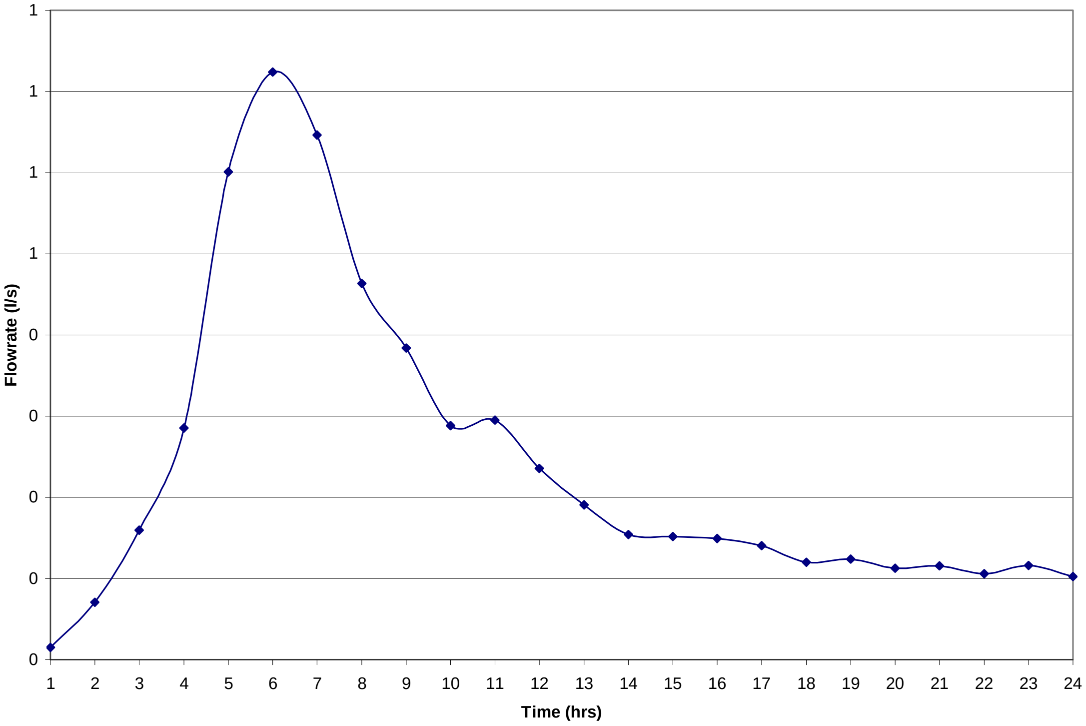


Figure C.26 – Hydrograph for December 16, 2003 Storm Event

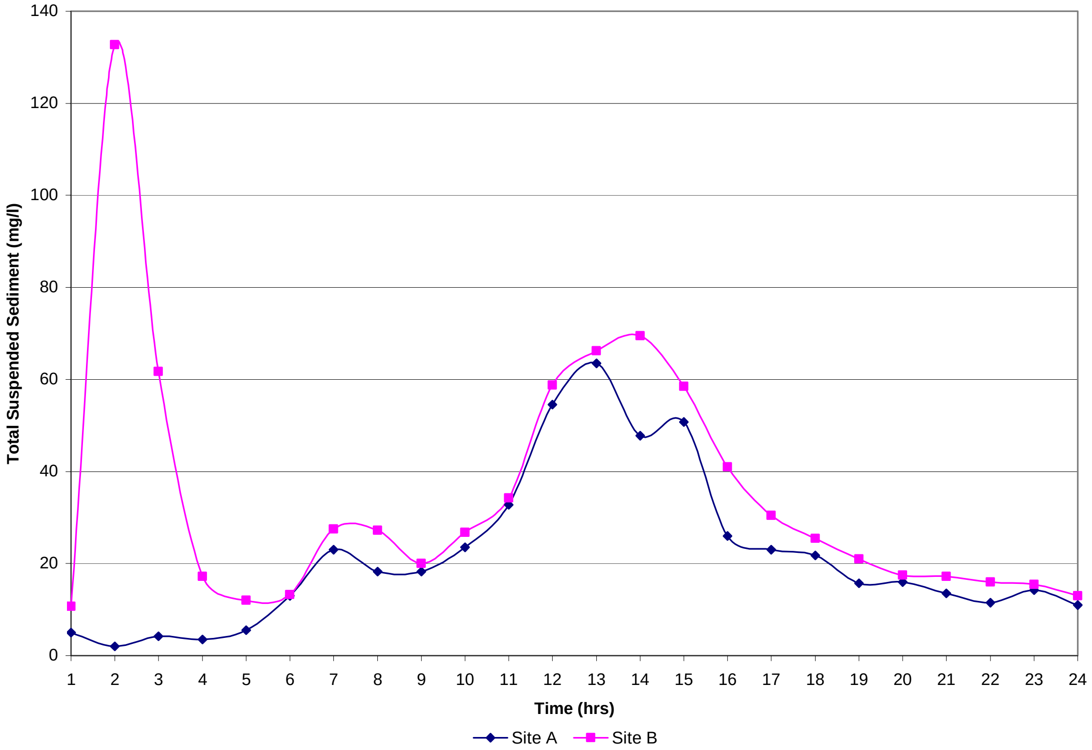


Figure C.27 – TSS for December 16, 2003 Storm Event

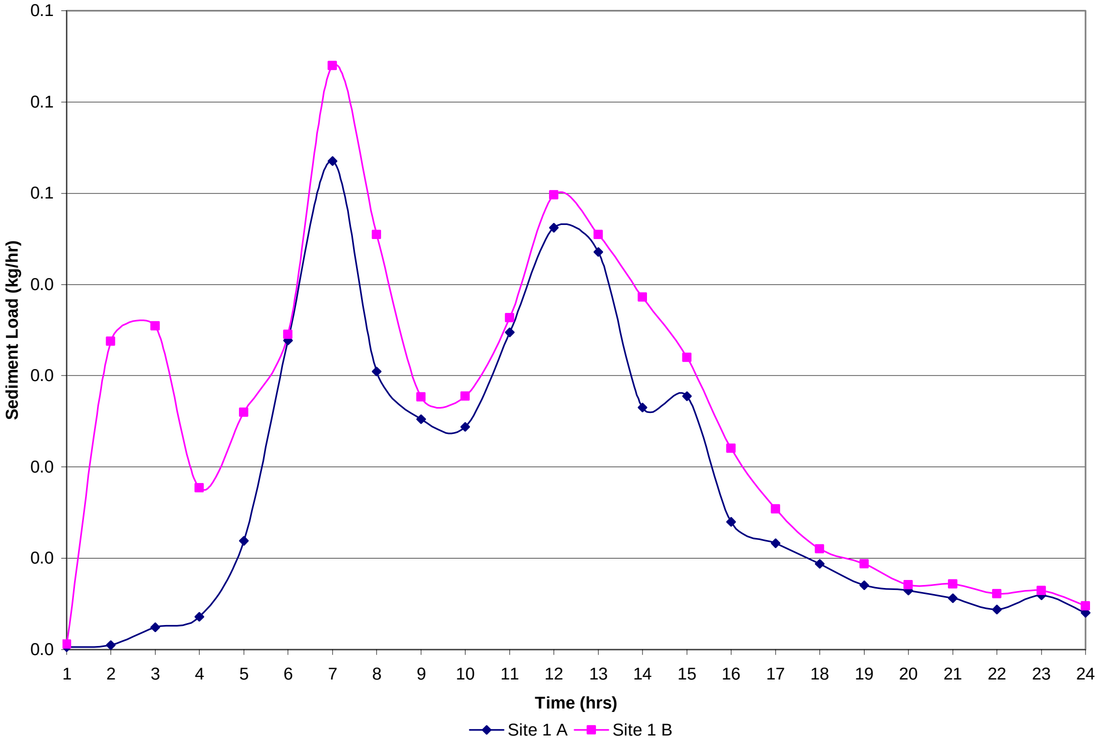


Figure C.28 – Sediment Load for December 16, 2003 Storm Event

APPENDIX D

TRAFFICKING DATA

Date	**Traffic**			
	2-wheeler	*4-wheeler*	*Other*	**Total**
7-Aug	4	12	2	18
8-Aug	11	10	3	24
9-Aug	52	111	5	168
10-Aug	34	44	1	79
11-Aug	11	32	2	45
12-Aug	2	11	0	13
13-Aug	3	16	0	19
14-Aug	1	0	0	1
15-Aug	2	33	0	35
16-Aug	13	90	4	107
17-Aug	1	41	0	42
13-Oct	4	8	0	12
14-Oct	1	5	0	6
15-Oct	21	59	1	81
16-Oct	11	33	11	55
17-Oct	10	8	0	18
18-Oct	0	2	0	2
19-Oct	2	5	0	7
20-Oct	5	0	0	5
21-Oct	5	0	0	5
22-Oct	4	34	4	42
23-Oct	0	21	2	23
11-Nov	2	7	20	29
12-Nov	0	0	0	0
13-Nov	1	31	1	33
14-Nov	13	81	3	97
15-Nov	1	45	1	47
23-Nov	9	21	2	32
24-Nov	0	0	0	0
25-Nov	1	5	1	7
26-Nov	1	25	1	27
27-Nov	0	0	0	0
28-Nov	18	26	2	46
29-Nov	59	95	3	157
30-Nov	18	29	2	49
4-Dec	0	2	0	2
6-Dec	0	9	0	9
7-Dec	6	29	1	36
8-Dec	0	3	1	4
9-Dec	2	3	0	5
12-Dec	0	1	0	1
13-Dec	0	7	0	7
14-Dec	3	11	0	14
15-Dec	0	4	0	4
16-Dec	0	1	0	1
17-Dec	0	3	0	3
19-Dec	0	4	3	7
20-Dec	5	29	4	38
21-Dec	13	29	0	42
22-Dec	7	8	0	15
23-Dec	2	1	0	3
24-Dec	0	8	2	10
25-Dec	2	2	0	4
26-Dec	7	18	0	25
16-Apr	4	3	2	9
17-Apr	28	107	6	141
18-Apr	20	38	4	62
19-Apr	6	5	1	12
21-Apr	0	1	0	1
22-Apr	1	0	0	1
23-Apr	6	14	0	20
24-Apr	10	14	2	26
25-Apr	10	60	1	71
26-Apr	0	1	0	1
28-Apr	1	0	0	1
29-Apr	11	5	0	16
30-Apr	0	4	0	4
1-May	7	31	0	38
2-May	4	7	0	11
3-May	2	0	0	2
4-May	2	3	0	5
5-May	2	0	0	2
20-May	0	1	0	1
21-May	1	17	0	18
22-May	3	15	0	18
23-May	3	10	0	13
18-Jun	0	12	0	12
19-Jun	2	16	2	20
20-Jun	4	13	4	21
21-Jun	0	2	0	2
22-Jun	1	2	0	3
23-Jun	0	9	0	9
25-Jun	0	13	1	14
26-Jun	10	51	2	63
27-Jun	0	8	0	8
28-Jun	0	3	0	3
29-Jun	1	9	1	11

Total Days	**Traffic Totals**			**Total**
	2-wheeler	*4-wheeler*	*Other*	
87	506	1586	108	2200
Average	**5.82**	**18.23**	**1.24**	**25.29**

APPENDIX E

CUMULATIVE RAINFALL AND SEDIMENT LOADING

Storm Date	Rainfall (cm)	Sediment Load (kg)
12/16/2003	0.97	0.17
1/25/2004	2.24	0.13
2/6/2004	4.88	108.98
2/12/2004	2.03	0.14
2/25/2024	1.12	0.11
3/6/2004	2.03	4.01
3/16/2004	0.51	0.08
3/20/2004	0.91	0.42
3/29/2004	2.01	0.17
4/11/2004	1.35	0.53
4/26/2004	1.75	0.36
4/30/2004	2.24	2.18
5/16/2004	3.61	2.02
6/16/2004	1.27	0.83
6/22/2004	1.02	0.60
7/2/2004	1.60	0.19

APPENDIX F

SOIL AMENDMENT ASSESSMENT

Figure E.1 – Cross-section of upper slope of Treatment A

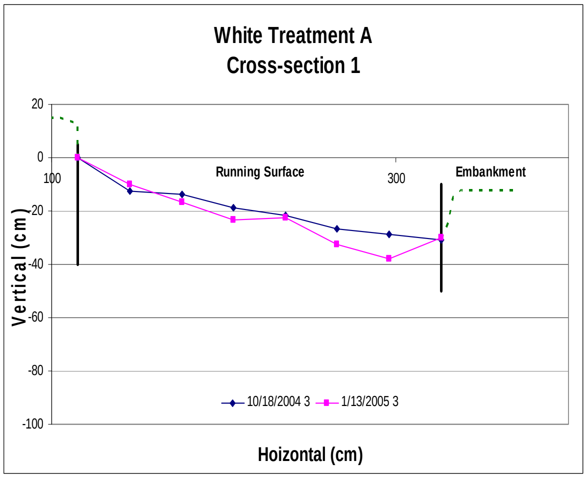


Figure E.2 – Cross-section of mid-slope of Treatment A

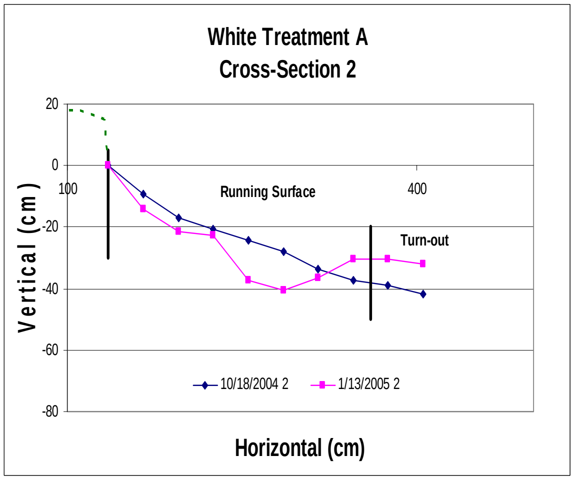


Figure E.3 – Cross-section of lower-slope of Treatment A

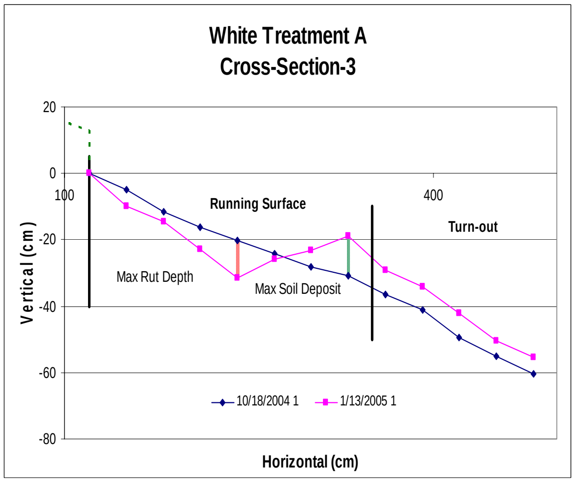


Figure E.4 – Cross-section of upper-slope of Treatment A

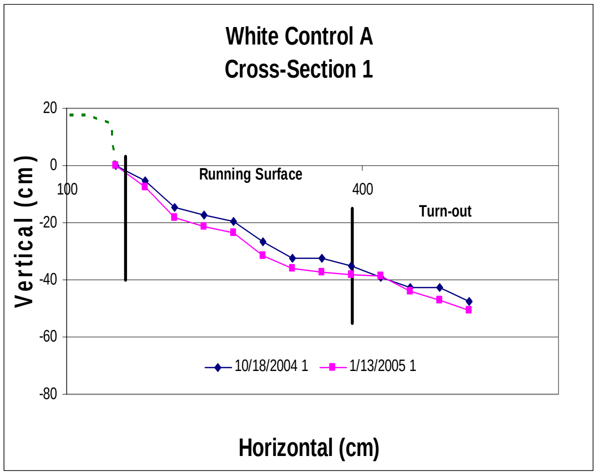


Figure E.5 – Cross-section of mid-slope of Treatment A

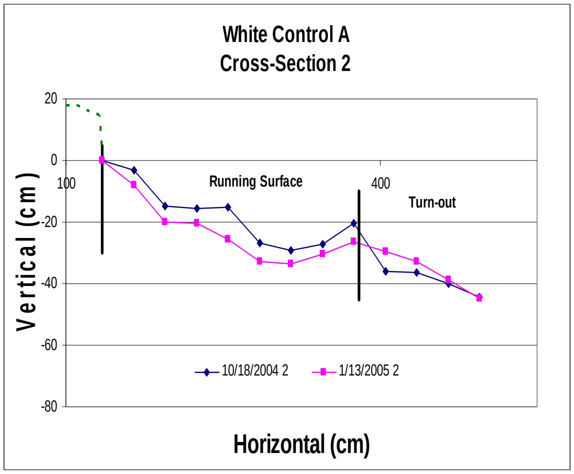


Figure E.6 – Cross-section of mid-slope of Treatment A

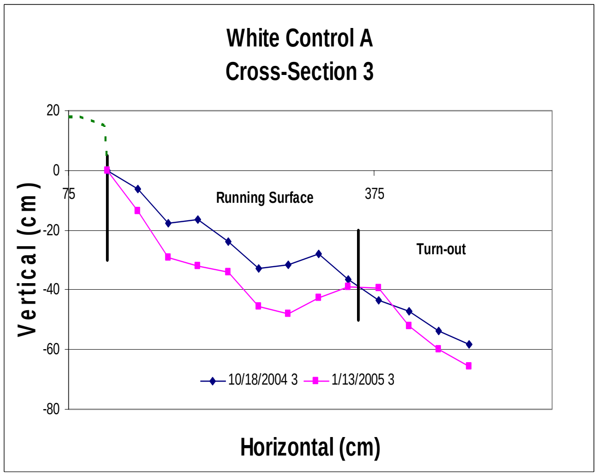


Figure E.7 – Cross-section of lower-slope of Treatment A

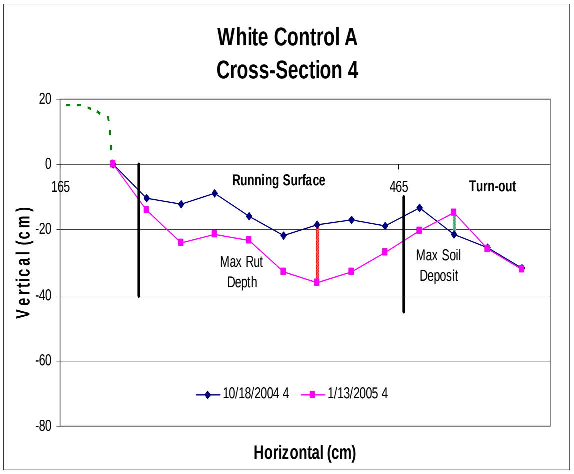


Figure E.8 – Cross-section of upper-slope of Treatment A

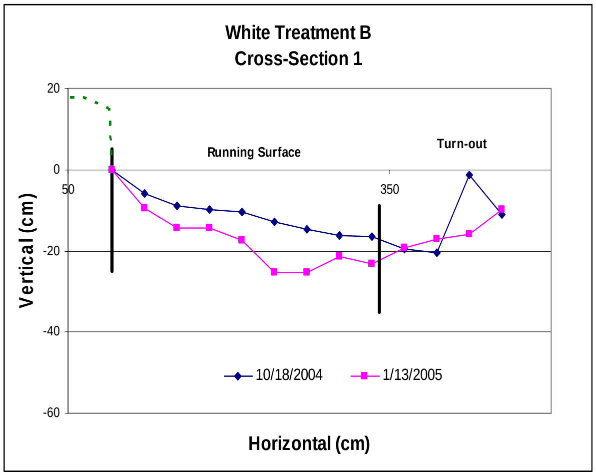


Figure E.9 – Cross-section of mid-slope of Treatment A

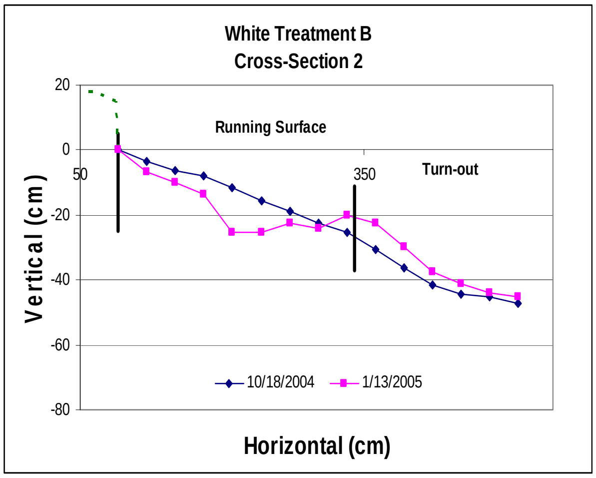


Figure E.10 – Cross-section of lower-slope of Treatment A

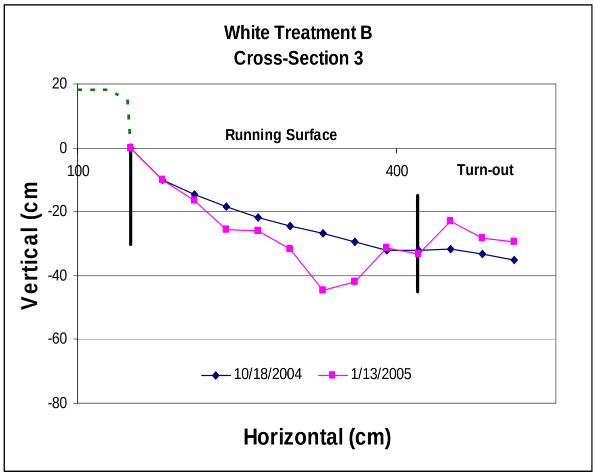


Figure E.11 – Cross-section of upper-slope of Treatment A

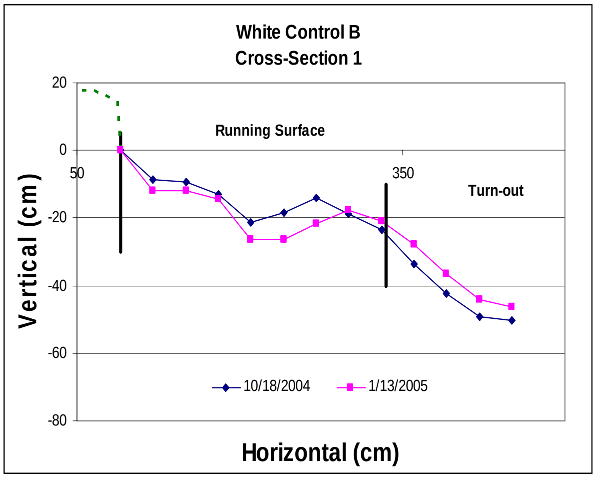


Figure E.11 – Cross-section of mid-slope of Treatment A

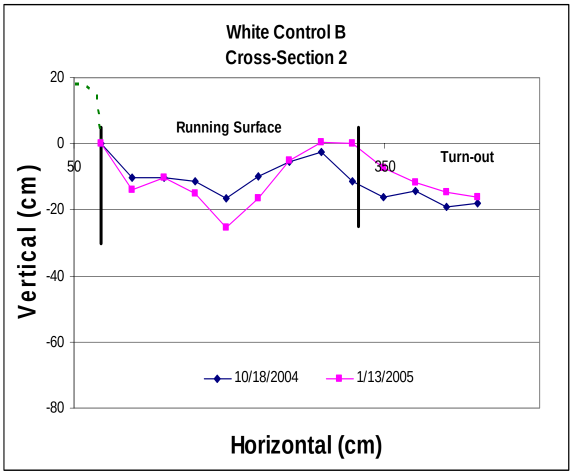


Figure E.13 – Cross-section of mid-slope of Treatment A

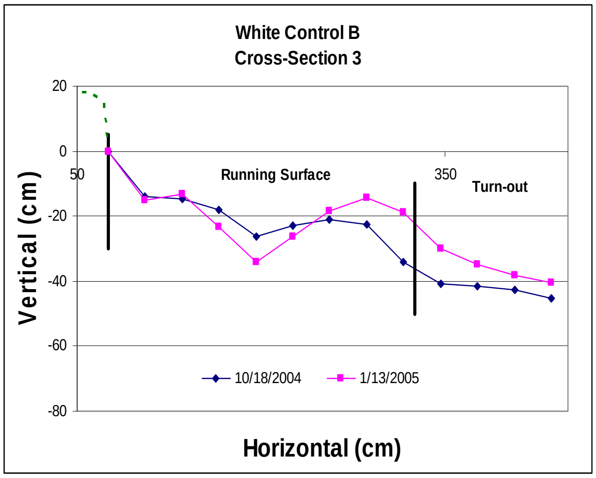


Figure E.14 – Cross-section of lower- slope of Treatment A