To the Graduate Council:

I am submitting herewith a dissertation written by John Raymond Buchanan entitled "The Use of Wood Chips to Control Soil Erosion on Construction Sites." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.

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THE USE OF WOOD CHIPS TO CONTROL SOIL EROSION ON CONSTRUCTION SITES

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee

John Raymond Buchanan
May 2000

DEDICATION

This effort is dedicated to my grandparents

Harold and Shirley Girhard

Robert M. and Sallie West Buchanan

Their lives and mine did not overlap, however their influence on my life is evident.
The Buchanans were farmers and the Girhards were educators.
I became an agricultural Extension engineer.

ACKNOWLEDGMENTS

A student seeking an advanced degree has many requirements imposed upon them Dr James Smoot, serving as my major professor, made sure that I was in compliance with all those requirements. One of those requirements was to conduct an original investigation in such a manner that (hopefully) it will make a contribution to the student's chosen discipline The project that I chose for my investigation was physically demanding and required the services of several talented professionals - this is my opportunity to show my appreciation to those who helped me complete this project.

This project required woodworking, metalworking, plumbing, surveying skills and just plain hard work These requirements were championed by Mr Wesley Wright His willingness to perform these tasks under much less than comfortable conditions and his good-natured companionship are acknowledged and appreciated

This project required the assistance of folks who were willing to do the less glamorous aspects of data collection. Every step that Ms Krista Kelly and Mr. Joe Rainwater took in my behalf was a step that I did not have to take. My feet (and back) appreciate their efforts.

This project required the experience of professionals who represent the various academic disciplines needed to conduct this research. Dr. Paul Denton, Dr. Eric Drumm, and Dr Bruce Tschantz were often consulted for their expertise with soils and hydrology I appreciate their willingness to be involved with this project

An original investigation must begin with an original idea That idea came from Dr Daniel Yoder I appreciate his willingness to share his idea, find the funding to conduct the research and serve as the project leader of this effort

This project required (and received) the cooperation of the Department of Civil and Environmental Engineering, the Department of Agricultural and Biosystems Engineering, the Department of Plant and Soil Science, the Knox County Division of Solid Waste, and Wolf Tree Experts

I think I put together a pretty good team.

ABSTRACT

Wood chips were studied for their efficacy in controlling soil erosion on construction sites that have disturbed soils on steep slopes The purpose of the research was twofold to determine if wood chips could be used to reduce the off-site movement of soil during construction activities, and to find an environmentally sound alternative to the landfill disposal of wood wastes generated in the urban forest The research was conducted using field plots that received natural precipitation and laboratory plots that received simulated rainfall At a local construction site, twelve erodible plots were established on an embankment with a 55 percent slope and an elevation change of nearly 12 m. Each plot had a width of 3 m and a slope length of 10 m A series of flow dividers was installed at the toe of each plot to measure runoff and sediment. The laboratory plots were one meter wide and had a slope length of three meters. A variable slope stand was fabricated to hold the laboratory plots at 40 percent (2 5 1), 50 percent (2 1), and 67 percent (1.5:1) slope steepnesses. The simulated rain events had a constant intensity of 64 mm/h. Four treatments were studied: large wood chips, small wood chips, a mixture of wood chips sizes, and no chips. The wood chips were applied at a rate that provided coverage to 80 percent of the soil surface.

At the construction site, the small wood chip treatment did not produce an erosion rate that was significantly different from the zero-cover plots; the large wood chip and mixture of chip sizes were not significantly different from one another but were significantly different from the zero-cover treatment. Overall, as compared to the zero-cover treatment, the small wood chip treatment reduced erosion by 22 percent, the large wood chips reduced erosion by 78 percent, and the mixture of chips sizes reduced erosion by 86 percent. The results of this project indicate that wood chips should be utilized as a soil cover and need not be discarded as solid waste

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NOMENCLATURE

Throughout this document, the International System of Units (SI) was used as the standard for units of measure. Where appropriate, the equivalent (and traditional) "inch-pound" set of units are included in parentheses English units are the basis of the Revised Universal Soil Loss Equation (RUSLE) and for most of the research literature reviewed for this effort. Most erosion-control practitioners are more familiar with the English-based coefficients that will be used in this document Thus, for the purpose of clarity, the following is a listing of how the units of mass/weight will be used in this document.

ton	English unit of force equal to 2000 pounds
ton/ac.	application rate, English units of force and over an area equivalent to 43,560 square feet.
tonne or metric ton:	metric unit of mass equal to 1000 kilograms.
t/ha	application rate, metric units of mass and over an area equivalent to 1000 square meters

CHAPTER I

INTRODUCTION

Background

Off-site movement of soil disturbed by construction, mining, agriculture, and other land-disturbing activities is known to degrade the value and environmental sustainability of adjacent land and water. On-site, excessive erosion creates gullies, blocks culverts and storm drains, and exposes unproductive subsoil. The site manager then has to incur significant costs in the repair of erosion-induced damage. Soil erosion begins with the detachment of soil particles from the surface by raindrop impact Unless detachment can be prevented or reduced, sediment control methods must be employed to attempt to restrict off-site movement Typical methods include sediment barriers consisting of silt fences or straw bales, and sediment detention basins - all of which are limited in their ability to capture eroded soils and hold them on-site

Generally, on steep slopes it takes very little runoff to transport detached soil particles, thus limiting particle detachment is the crucial component It is well known that the most effective method of preventing detachment is to provide a permeable soil cover to absorb raindrop energy, slow runoff, and increase infiltration (Benkobi et al , 1993; Jennings and Jarrett, 1985, Sarles and Emanuel, 1977, Stocking, 1994) These protective mechanisms can be provided by spreading processed organic material over the disturbed soil Certainly this is not an original notion, but there is an absence of the quantitative information needed to design erosion control systems using organic cover on steep slopes

On another front, local governments are faced with an ever-increasing burden of solid waste disposal. A significant portion of municipal solid waste is composed of leaf litter, tree and shrub trimmings, downed trees, and grass clippings Collectively referred to as yard waste, these organic products are readily biodegradable, relatively clean and free of pathogens, generally collected separately from household solid waste, and can be converted into useful erosion control products instead of occupying valuable landfill space

Justification

Section 303 of the Clean Water Act requires states to list water bodies that cannot support their designated use because of poor water quality (TDEC, 1998). For the majority of water bodies identified in Tennessee as "not supporting," the cause is sediment. New knowledge derived from this research will be used to generate design-oriented and specification-oriented information that can be used by engineers to control the erosion of disturbed soils located on sites with steep slopes. Quantitative information is needed so that engineers can add wood chips to their repertoire of solutions for keeping disturbed soil on-site.

The State of Tennessee Solid Waste Disposal Act of 1991 (TCA 68-211-861) mandated a 25% reduction of refuse disposed of at municipal solid waste facilities and incinerators (on a 1989 weight per capita basis) by the last day of 1995. Most municipal operations no longer collect yard and woody debris in an attempt to be in compliance with the mandate. Since this material has been diverted from the landfills, most of the woody waste generated by utilities, tree trimmers, and site clearing is either being composted, burned, or land-applied on private property.

The overall objective of this project was to determine if yard wastes can be diverted from the solid-waste stream and used for erosion control. Since the composition of "yard waste" is varied and difficult to quantify, it was decided to limit this study to wood chips. Wood chips represent a significant portion of the volume of generated yard waste (Whitter et al., 1995). This research focused on the potential benefit of using wood chips as an erosion control product while also providing an environmentally sound method of allowing this organic waste to function normally within the carbon, nitrogen, and hydrologic cycles. Microbial degradation reduces wood chips to humus, which is a valuable soil amendment that increases the tilth of the soil, provides a habitat for the soil microorganisms, and slows the dehydration of the soil. Each of these factors increases the potential for the germination and long-term survival of new vegetation. As new knowledge is gained about the optimal processing method of yard waste for erosion control, municipalities can make informed decisions about which type of processing methods to prescribe If it is found that processing methods are not a significant factor in the capacity of yard wastes to protect erodible slopes, then this knowledge will save municipalities from over-investing in unnecessary equipment

Information Needs

The primary question that must be answered is whether wood chips can provide erosion protection to disturbed soils on steep slopes, and if so, what are the limitations This concept must be proven before questions about the material costs and how to apply the chips warrant any scientific investigation Once it has been established that wood chips can provide soil protection, then the boundaries of effectiveness need to be explored. Questions need to be answered about the minimum application rate, the maximum application rate (the point of diminishing returns), and the method of processing the wood chips for maximum soil protection

The science of soil erosion by water has made tremendous advances in predicting soil loss through soil erosion modeling Most modeling information was derived from agricultural lands with relatively low slopes One such model is the Revised Universal Soil Loss Equation (RUSLE) and it is commonly used to model erosion at construction sites Questions arise about extrapolating the use of this prediction technology to construction or mining sites that have steep slopes Are correction coefficients needed to better predict the effect of cover on disturbed soil on steep slopes? What is the best method of accounting for factors such as soil compaction, cut or fill slopes, and inverted soils?

Objectives

The following questions need to be addressed in order to pursue the notion of using chipped wood as a soil cover to reduce construction site erosion

1 Can chipped wood provide effective erosion protection for disturbed soils on very steep slopes, and if so, what is the required rate of chip application?

2 Can additional processing of the chipped wood increase the protection afforded to the disturbed soil surface?

3. What b-value is reasonable to select for cover on very steep slopes when using the RUSLE model to estimate soil loss on construction sites?

In order to design a research project that would be repeatable and defendable, the above questions were refined as follows

1 Can wood chips (applied at a rate such to cover 80% of the soil surface) provide significant soil protection (as compared to zero cover) on a 50% (2 1) slope located on a filled-embankment with a slope length of 10 m?

2 Is there any benefit to processing the chips into a specific size before applying the chips to the soil surface?

3 When modeling a steep slope, should the b-value in the surface-cover subfactor be selected based on the soil's tendency to rill, or should an additional correction factor be used to account for the steep slope?

CHAPTER II

REVIEW OF LITERATURE

This review of research literature is composed of citations found by querying the following electronic databases: Agricola (Agricultural On-Line Access of materials acquired by the National Agricultural Library), the Environmental Abstracts, and Compendex (a primary index for engineering literature). The majority of the related literature is from agriculture-based erosion research Keyword phrases, such as "wood chip," "steep slopes," "construction site erosion control," and "soil cover," were used to narrow the citation list

Wood Chips as a Soil Cover

Using wood chips as a soil cover is by no means an original notion Wood chips are often listed as a best management practice for erosion control on sites with shallow slopes (Smoot et al , 1992) Citations on such uses date back to the 1960's. Swanson et al. (1965) evaluated wood chips on 5 to 8% slopes at application rates of 2 to 20 tonnes per hectare (t/ha). They noted that 13 t/ha provided protection equal to 2.24 t/ha of straw Later, Swanson et al (1967) applied 13 metric tons of wood chips and 230 liters of asphalt emulsion per hectare to control erosion on a 33% (3:1) slope. They found that the wood chip/asphalt emulsion provided 1/2 the protection of jute netting, but 10 times more protection than a kraft paper netting Of these reports neither referenced a wood chip moisture content at application, nor did they suggest what percentage of the surface was covered by the chips. In both reports, a rotating-boom rainfall simulator with rainfall intensities of 64 to 127 millimeters per hour was used to supply the erosion energy

In an interim report to the Federal Highway Administration, Swanson (1970) described the application of wood chips on 100% (1.1) cut slopes. Chips were applied to a thickness of 25 to 50 millimeters. It was noted that excellent stands of grass were produced in areas where the chip thickness was only about 25 mm, however, poor stands of grass were produced in areas of thicker wood chip application. It was strongly emphasized that the chips stayed in place during natural rain events This was a feasibility project - the quantitative measures focused on cost rather than actual erosion reduction

<u>Wood Chips and Steep Slopes</u>

Generally speaking, a "steep slope" is defined as an incline too steep to cultivate by modern agricultural equipment Construction and mining operations do not have the same equipment limitations, and therefore create disturbed soils on much steeper slopes. The vast majority of erosion data were collected from agricultural fields with steepnesses of 20% (5H 1V) or less (Israelsen et al , 1980a and Israelsen et al., 1980b).

One of the few articles to actually document the erosion control potential of wood chips on 50 percent (2H.1V) slopes was by Israelsen et al (1980a) Using a rainfall simulator and a tilting soil bed, many combinations of mulches were evaluated for erosion control. Three studies were performed using spruce tree wood chips These tests included loosely spread wood chips applied at a rate of 20 t/ha, the same application of chips plus 1225 L/ha (800 gal/ac) of an unspecified tackifier emulsion, and then an additional 1838 L/ha (400 gal/ac) of tackifier was applied Rainfall intensities used in these studies were extreme At 203 2 mm/hr (8 iph), the first test showed failure after nine minutes. The final study did not show failure until 1 5 hours into a 609 6 mm/hr (24 iph) event. The latter event applied a depth of 914 mm (36 in.) which is approximately 254 mm (10 in) greater than the depth of precipitation generated during the world's greatest rainfall for a 1 5-hour storm (Viessman et al , 1977) In the Knoxville, Tennessee area, a storm of this duration and intensity would have a return period slightly greater than 100 years (Hershfield, 1961). This methodology is not realistic and the results have limited utility

Sarles and Emanuel (1977) applied a hardwood bark mulch to several cut and fill slopes in Southern West Virginia. They studied the re-vegetation effect from different rates of mulch application These researchers recommended that 30 cubic yards of bark mulch per acre be applied on north- and east-facing sites with 50% or less slopes For south- and west-facing sites, for overwinter protection of disturbed sites, and for slopes greater than 50%; they recommended that 50 cubic yards per acre be used Due to moisture content differences between batches of mulch, these researchers found that volume (rather than mass) was a more consistent measure of application

Meyer et al (1972) compared wood chips and gravel mulches for erosion control on construction sites Their plots were on a 20% slope, the erosion energy was provided by a rainfall simulator, and they added water at the top of the slope to simulate longer slope lengths. Application rates of 4.5, 9, 15.7, 27, and 56 t/ha were evaluated While they did not provide a unit weight of the wood chips, they did suggest that the different application rates provided 32, 68, 88, 99, and 100% surface coverage, respectively. The 100% coverage was actually 38 mm deep On 20% slopes, they recommended application rates of 9 to 15 7 t/ha for slope lengths less than 12 m, 27 to 56 t/ha for slope lengths between 12 and 30 m, and 56 t/ha for 30 to 49 m.

Most of the research articles made an application-rate recommendation based on weight of chips applied per unit area None of these articles provided information about the moisture content of the chips There would be a considerable variation in the "percentage of soil-covered" if equal weights of wet-chips versus dry-chips are applied to a unit of area. This creates a problem when trying to reproduce the published results. A potential solution to this issue is to correlate the application rate with the percentage of soil covered Table 1 lists citations from two articles that provided coverage information per application rate.

Meyer and Ports (1976) published a general set of recommendations for the use of various mulches for erosion control on steep slopes (table 2) Wischmeier and Smith (1978) suggested that these recommendations were developed on the basis of field experience and limited research data In other words, the recommendations for the steeper slopes were extrapolated from research conducted on less severe slopes.

Table 1. Surface coverage versus mass-based application of mulches as listed by two authors

Mulch	Application rate t/ha (ton/acre)	Coverage (percent)	Author
Wood chips	4 48 (2)	32	Meyer et al. (1972)
	8 96 (4)	68	
	15.68 (7)	88	
	29.90 (12)	99	
	56 05 (25)	100	
Straw	0.56 (0.25)	34	Meyer et al (1970)
	1 12 (0.50)	49	
	2 24 (1)	71	
	4 48 (2)	92	
	8 96 (4)	nearly 100	

Table 2. Mulch application rates for various slope-steepness and slope-lengths as recommended by Meyer and Ports (1976)

Type of mulch	Mulch rate t/ha (tons per acre)	Land slope (percent)	C-Factor	Slope-length* m (feet)
None	0	all	1.0	–
Straw or hay, tied down by anchoring and tacking equipment†	2.24 (1.0)	1-5	0 20	61 (200)
	2.24 (1.0)	6-10	0.20	30 (100)
	3 36 (1.5)	1-5	0 12	91 (300)
	3.36 (1.5)	6-10	0 12	46 (150)
	4 48 (2 0)	1-5	0 06	122 (400)
	4 48 (2.0)	6-10	0.06	61 (200)
	4 48 (2 0)	11-15	0 07	46 (150)
	4.48 (2 0)	16-20	0 11	30 (100)
	4 48 (2 0)	21-25	0 14	23 (75)
	4 48 (2 0)	26-33	0 17	15 (50)
	4.48 (2.0)	34-50	0.20	11 (35)
Crushed stone, 1/4 to 1-1/2 inch	303 (135)	<16	0.05	61 (200)
	303 (135)	16-20	0.05	46 (150)
	303 (135)	21-33	0.05	30 (100)
	303 (135)	34-50	0.05	23 (75)
	538 (240)	<21	0 02	91 (300)
	538 (240)	21-33	0.02	61 (200)
	538 (240)	34-50	0.02	46 (150)
Wood chips	15.69 (7)	<16	0 08	23 (75)
	15 69 (7)	16-20	0 08	15 (50)
	26.9 (12)	<16	0.05	46 (150)
	26 9 (12)	16-20	0.05	30 (100)
	26.9 (12)	21-33	0 05	23 (75)
	56 1 (25)	<16	0.02	61 (200)
	56.1 (25)	16-20	0 02	46 (150)
	56.1 (25)	21-33	0.02	30 (100)
	56.1 (25)	34-50	0 02	23 (75)

*Maximum slope length for which the specified mulch rate is considered effective When this limit is exceeded, either a higher application rate or mechanical shortening of the effective slope length is required

†When the straw or hay mulch is not anchored to the soil, the C-factor on moderate or steep slopes of soils having K-factor values greater than 0.30 should be taken at double the values given in this table

Supply of Wood Chips

Whitter et al (1995) reported that just more than 13 5E6 m^3 (17.7 million cubic yards) of urban tree residue is generated each year in the continental United States The study classified urban tree residue as chips, logs, mixed wood, tops and brush, leaves, lawn clippings, and stumps Generators of this residue included commercial tree firms, municipal/county park and recreation departments, municipal/county tree care divisions, utility line maintenance companies, nurseries and landscapers; and excavator/land clearance firms. Ninety-five percent of this material either was wood chips or could be processed into wood chips If all of this material could be land-applied to a thickness of 25 mm (one-inch), there would be sufficient mulch to cover more than 52,600 hectares (130,000 acres) of disturbed soil each year

Rigorous Analysis of Mulch Failure

The methods by which mulches provide protection against erosion include absorption of the impact energy from raindrops, reduction of surface crusting (maintains infiltration), absorption of the shear stress created by the sheet flow of water moving across the surface, and the reduction of the velocity of flow which causes deposition to occur on the slope. When the total shear stress is greater than the resistive stresses holding the mulch in place, the mulch will be displaced and its effectiveness is lost. Foster et al. (1982b) suggested that the total shear stress created by flow over a mulch-covered surface is absorbed in two ways - that acting on the mulch and that acting on the soil The presence of mulch on the surface decreases the shear stress imparted to the soil even though the total shear stress and shear stress on the mulch is much greater This increase in total shear stress is greater than the shear stress on the soil with no cover. Assuming that the potential energy is the same, runoff will have less kinetic energy at the bottom of a mulched slope as compared to the same runoff from a smooth-surface slope Thus, more of the potential energy was expended as shear stress on the mulched surface. A successful mulch must be able to resist this increase in shear stress.

During a rain event, the flow of water accumulates as it moves downslope By the continuity equation, as flow increases, so must the velocity and/or depth Graf (1984) explained that flow depth is a component in the determination of shear stress and that velocity is the critical component when considering the water's impact-momentum on the soil particles These concepts suggest that the stress imparted to the mulch increases with the length of the slope. As shown in figure 1, the gravitational component acting on the mulch particle becomes a significant addition to the displacement forces as the slope steepness increases. Designing an erosion control practice using a surface mulch requires an estimate of the critical slope length for overland flow. This critical slope length is the distance downslope where mulch failure occurs.

From hydraulic theory, the total shear stress of flow, τ (force per unit area) is given by

$$\tau = \gamma \cdot R \cdot s \quad \text{[1]}$$

where γ is the unit weight of the runoff (force per unit volume), R is the hydraulic radius, and s is the dimensionless slope term. Foster et al. (1982b) divided the total shear stress τ into twoparts, τ_s - the portion of the stress acting on the soil, and τ_m - that portion of the stress acting on the

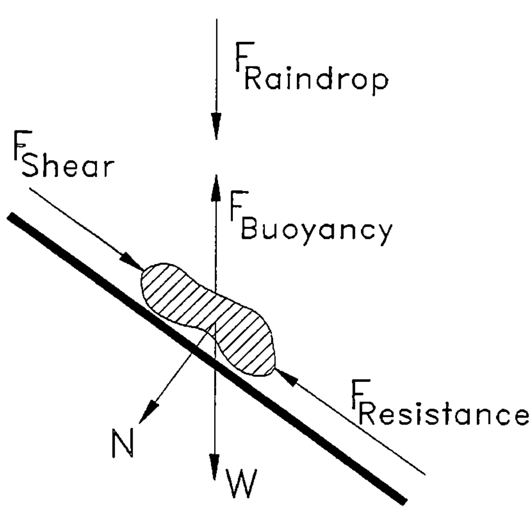


Figure 1 Demonstration of the forces acting upon a mulch particle

mulch Similarly, Manning's equation was used to compute the resistance to flow created by the mulch Manning's equation is

$$V = R^{2/3} \cdot s^{1/2} / n_{to} \qquad [2]$$

where V is the average flow velocity and n_{to} is the total Manning's n for overland flow. Using measured values for velocity, discharge per unit width, and slope, Manning's equation was rearranged to solve for n_{to} Broad sheet flow was assumed, so the hydraulic radius R was assumed to be equal to the depth of flow. The roughness value attributed to the soil (n_{so}) was the n_{to} value calculated from bare plots From this information, Foster et al (1982b) estimated a Manning's n value for the mulch, n_{mo}, by

$$n_{mo} = (n_{to}^{3/2} - n_{so}^{3/2})^{2/3} \qquad [3]$$

Using the Manning's n for the mulch and the measured velocity at mulch failure, the hydraulic radius of the mulch was calculated with Manning's equation. This value was then plugged into equation 1 to solve for the shear stress acting on the mulch τ_m at the time of failure, yielding

$$\tau_m = \gamma \cdot R_{mo} \cdot s \qquad [4]$$

where R_{mo} is the portion of the hydraulic radius due to the mulch

Foster et al. (1982b) proceeded to develop an analysis technique to estimate the critical slope length for wheat straw. The input parameters were application rate of straw, slope, rainfall erosivity, runoff and soil susceptibility to rill erosion Figure 2 is a reproduction of the Foster et al 's (1982b) graphical solution to this relationship It is interesting to note that for the steepest slopes, increases in the application of straw produce very little change in the critical slope length Additionally, as the slope steepness increases, the critical slope length is insensitive to the storm erosivity One potential reason for this insensitivity is the fact that as the slope steepens, for a given rate of precipitation, the depth of flow decreases For example, assume precipitation rate of 64 mm/h on a 50% slope and a slope length of 10 m Using Foster et al 's (1982a) Mannings n-value of 0.1 (for straw mulch at 0 45 kg/m^2), the depth of flow is estimated to be 1.52 mm. This depth is less than the thickness of the mulch particles and therefore limits the effect of buoyancy

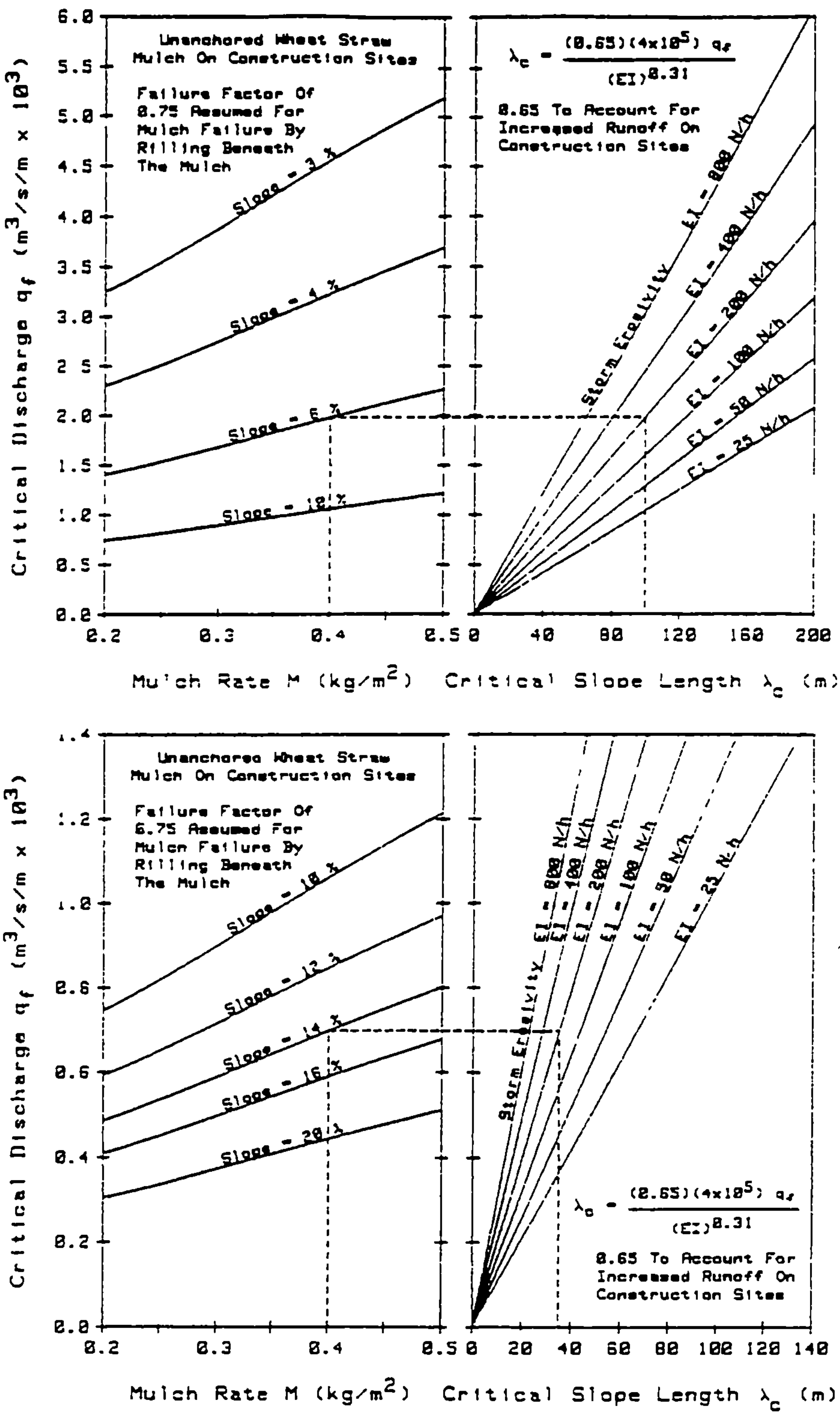


Figure 2. Reproduction of Foster et al.'s (1982b) graphical solution for the determination of critical slope length for wheat straw on slope steepnesses between three and twenty percent (continued next page)

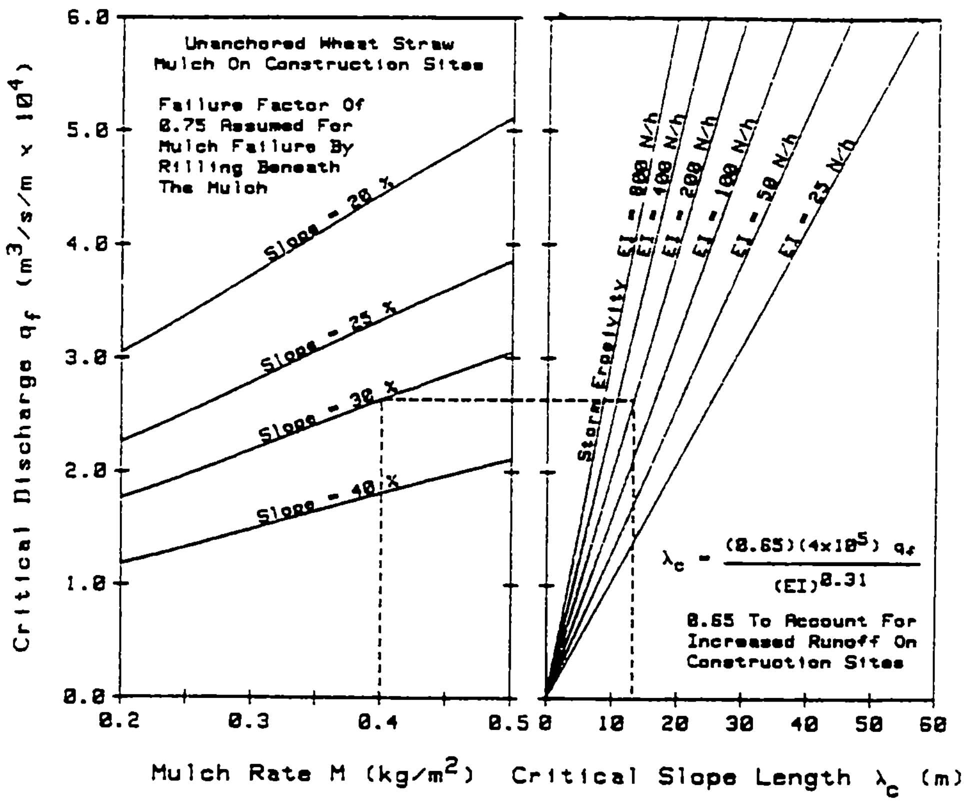


Figure 2 (continued)

Reproduction of Foster et al 's (1982b) graphical solution for the determination of critical slope length for wheat straw on slope steepnesses of 20 to 40 percent.

Processing the Wood Chips

There are several devices that are used to reduce trees into mulch, and each type has a slightly different end product (Anonymous, 1997). In the context of this project, wood chips are the product of either drum-style or disk-style portable chippers. Seemingly, the size of the chip should affect its ability to resist the runoff shear stress. With the exception of Jennings and Jarrett (1985), no other articles were found that quantified any of the physical properties of the wood chip mulch used in their erosion research. Jennings and Jarrett (1985) examined several mulches, including two sizes of pine bark chips. The small bark treatment was composed of chips that had a 3 mm average thickness and 20 mm average diameter. The large chips had a 5 mm average thickness and 60 mm average diameter Three coverage treatments were evaluated - 22.4 Mg/ha of small (85% soil coverage), 22.4 Mg/ha of large (40% soil coverage), and 56.0 Mg/ha of large (98% soil coverage). Because this was an interrill study, the percentage of coverage had a more significant effect than did the size of the mulch particle The 85% coverage of small and the 98% coverage of large were not different from one another, however, they were superior to the large at 40% coverage All mulch treatments reduced interrill erosion compared to fallow soil No statistical evaluations were published in this article. In reference to the rigorous analysis of mulch failure from Foster et al (1982b), the size of the chip would, it appears, change the hydraulic characteristics of the overland flow. It has been observed by Jennings and Jarrett (1985) and by this author that the chip thickness tends to increase with the chip diameter Thus, if large chips were tested against small chips (both at equal surface coverages), the larger chip mulch should create (and bare the brunt of) more shear stress from the overland flow An interesting question is whether the physical properties of the larger chip proportionally offset the increase in shear stress, allowing it to remain in place in the face of higher forces

Referring back to the Jennings and Jarrett (1985) study, it was noted that the 85% and 98% soil coverage did not produce a significant difference in erosion protection Coverage greater than 80 percent may provide diminishing erosion protection as compared to the application expense. Additionally, coverages greater than 80% of the soil may inhibit the germination of permanent vegetation (Smoot, 1997).

Modeling Soil Loss on Construction Sites

The fundamental premise of erosion science is the understanding of the attacking forces that cause soil particle detachment and transport, and of the resisting forces that retard soil erosion (Schwab et al., 1993) Erosion control begins by increasing the resisting forces in order to balance the erosive forces The energy for erosion is supplied by gravity and is delivered in the form of falling raindrops and of flowing water Detachment and transport of soil particles are the two basic processes of soil erosion by water. Soil particle detachment is the disintegration of soil aggregates by the transfer of kinetic energy to the soil surface, either from the impact of rain drops or from the shear-stress imparted to the soil surface by flowing water. Once a particle has been detached, it is susceptible to being transported downslope.

Erosion scientists often refer to the erosion process in terms of interrill erosion and rill erosion Interrill is the erosion that occurs before the formation of rills or in the area between rills The dominant source of soil particles is detachment by raindrop impact These particles can be transported by the percussion of the raindrop splash and by the shallow overland flow. As the flow begins to concentrate into discernible channels, rill erosion begins While interrill erosion takes place across the whole surface, rill erosion is responsible for most of the soil being transported offsite In areas of rill erosion, the dominant source of detachment is the shear-stress of the flowing water in the channel. Once the water becomes concentrated, sufficient turbulent energy can be generated to both detach and transport soil particles downslope Since the rill is the primary source of soil, it grows up-slope in length As the volume of water in the rill increases, momentum of the water begins to erode the sidewalls and widen the channel.

A soil's ability to resist erosion is characterized by its physical and chemical properties Because of the resistive forces, the erosion of soil is not linearly proportional to the input energies Before erosion can begin, a critical energy must be reached to overcome the resistive forces. Texture is a property used to describe the distribution of the sizes of the primary soil particles Generally, the larger the soil particle, the easier it is to detach. Conversely, the smaller the particle, the easier it is to transport. Soil structure is the arrangement of the primary soil particles A well-structured soil has good porosity (increased infiltration and therefore decreased surface runoff), and good aggregate stability (chemical bonds and organic glues).

Soil Erosion Modeling

Scientists in agriculture have achieved success in predicting average annual erosion on cultivated soils Using the Universal Soil Loss Equation (USLE) and now the Revised Universal Soil Loss Equation (RUSLE), different management systems can be evaluated to determine their effect on soil erosion rates (Renard et al , 1997). The fundamental equation that is the basis of the RUSLE model is

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad [5]$$

and the factors represented (as defined by Renard et al., 1997) are·

A The average annual soil loss per unit area, expressed in the units selected for K and for the time period used for R

R rainfall-runoff erosivity factor - the rainfall erosion index plus a factor for any significant runoff from snowmelt.

K Soil erodibility factor - the soil-loss per erosion index unit for a specific soil as measured on a standard plot, which is defined as a 22 1-m (72.6-ft) length of uniform 9% slope in continuous clean-tilled fallow. Physical properties of soil aggregates are important parameters because these properties provide differential resistance to different soil being disintegrated by raindrop impact. Soil texture, structure, organic matter content, and permeability can influence the degree of soil particle detachment that takes place during a given storm energy event

L Slope length factor - the ratio of soil loss from the field slope length to soil loss from a unit-plot length (22.1 m) under identical conditions.

S Slope steepness factor - the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions

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

P Support practice factor - the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to soil loss with straight-row farming, up and down the slope

The RUSLE model has a computational procedure for each of these factors. These procedures are stochastic equations derived from analysis of more than 10,000 plot-years of soil loss data Nearly all the original research for USLE/RUSLE was conducted on relatively flat slopes, and there exist few reliable data for evaluating its accuracy for slopes greater than approximately 20 percent (Israelsen et al , 1980a) It is a common practice nonetheless to apply this technology to construction sites. This extrapolation has not been generally validated, and especially not for sites with steep slopes

Cover Effects

The importance of soil cover as a variable was recognized in the first published attempt to predict soil erosion as described in Meyer and Moldenhauer, 1985 In 1936 Howard L Cook listed the "susceptibility of soil to erosion, the potential erosivity of rainfall and runoff, and the soil protection afforded by plant cover" as the three major factors that must be quantified Mathematically, the RUSLE C-factor is a ratio of the soil loss expected for land under specified conditions to the corresponding soil loss from a similar site that is clean-tilled and in continuous fallow (Wischmeier and Smith, 1965) The original USLE only used the cropping-management factor (C-factor) to account for two soil surface conditions - surface roughness, and plant and/or mulch cover. Values for the C-factor were taken from an extensive data base of lumped parameters and were tabulated in Handbook 537 (Wischmeier and Smith, 1978)

The revision of the USLE promoted the notion that the C-factor can be more accurately determined using site-specific parameters rather than generalized table values The RUSLE incorporates five site-specific subfactors into the determination of what is now referred to as the cover-management factor This factor is calculated by

$$C = PLU \cdot CC \cdot SC \cdot SR \cdot SM \qquad [6]$$

where PLU is the prior-land-use subfactor, CC is the canopy-cover subfactor, SC is the surface-cover subfactor, SR is the surface-roughness subfactor, and SM is the soil-moisture subfactor (Renard et al., 1997). Each of these subfactors have empirically-derived equations containing cropping and land management variables that have been shown to affect soil erosion

The surface cover subfactor (SC) is of particular interest to this project. This factor evolved as a correction to the USLE Laflen et al. (1981) proposed to simplify the USLE system of selecting the C-factor (which was based on tillage system, spring residue weight, and crop residue cover after planting) by using a residue factor. The C-factor would be selected based on a conventional tillage system and for a particular crop stage, and then would be adjusted by a residue factor that contains the predicted or measured percent of residue coverage This adjustment is expressed as

$$C' = C \exp[B(RC-3)] \quad [7]$$

where C' is the adjusted C-factor to be used in the USLE, C is the conventional tillage table value, B is an empirical constant, and RC is the percentage residue cover. The nonlinear form of this equation was shown to be a better overall predictor, and fits well with the intuitive notion that soil loss should asymptotically approach zero as soil cover increases Laflen and Colvin (1981) indicated that erosion prediction technology must take into account the interaction effect of crop residue with soil and/or slope on soil erosion They suggested that this is best accomplished by using a mulch-factor crop-residue relationship of the form

$$\text{mulch factor} = \exp[b \cdot RC] \quad [8]$$

where they suggested the b values might be based on the soil and/or slope.

Dickey et al (1983) conducted research on plots that had been plowed with the slope and plots that had been plowed on contour Using a rotating boom rainfall simulator, they collected soil loss data from both treatments while the plots had various percentages of surface cover By regression, they derived the following equations relating soil loss to percent coverage.

$$\text{Soil loss from slope plowing} = 18\ 92 \cdot \exp[-0\ 032 \cdot RC] \quad [9]$$

$$\text{Soil loss from contour plowing} = 4\ 09 \cdot \exp[-0.024 \cdot RC] \quad [10]$$

It is interesting to note the y-intercepts of equations 9 and 10 At zero cover, the slope-plowing treatment produced 4.6 times more soil loss Dickey et al (1983) noted that in order to reduce erosion by 50%, the slope-plowed treatment would only need 26% surface coverage, while the contoured-plowed would require 33% surface coverage. One could make the supposition that the slope-plowed treatment represented a soil that is susceptible to rill erosion, while the contoured-plowed treatment is less likely to rill. The lesser percentage of coverage required to provide the same reduction in erosion is an indication that cover is more effective in rilling conditions Since the different treatments represent tillage practices, by definition the ratio of the two y-intercepts is equivalent to the P-factor

From this history, the surface cover subfactor equation took the form of equation 11

$$SC = \text{Surface cover subfactor} = \exp[-b\ Sp\ (0.24/Ru)^{0.08}] \quad \ldots \quad [11]$$

In this form, the b-value is the same empirical constant described previously and the Sp term is the percentage of land area covered by surface cover (in percent). Ru is a surface roughness term, which is defined within the surface roughness subfactor This additional term is in recognition of the symbiotic nature of surface roughness and the effectiveness of surface cover Foster et al. (1982a) reported that a rough surface should increase the shear stress of the flow required to move mulch and therefore increase the overall effectiveness of the mulch

The b-value is an indication of the effectiveness of surface cover in reducing soil loss. A higher b-value means a predicted decrease in SC subfactor, a decrease in C-value, and therefore a decrease in predicted erosion. Laflen and Colvin (1981) suggested that additional research is needed to determine exact values of b for major soils and/or slopes They suggested that for soils high in sand on low slopes, values of b might be as large as 0 075, while for soils high in silt on steep slopes, values might be smaller than 0.04 Renard et al (1997) indicated, that the appropriate b-value can be more accurately determined if the dominant form of erosion is known If rill erosion on highly disturbed soils is the primary mechanism of soil loss, then b-values should be about 0 050 If a field is dominated by interrill erosion, the b-value should be about 0.025. Overall, the literature suggests a higher b-value for cover on soils that erode by rill rather than interrill processes

Of interest to Dr. George R Foster, the former Director of the USDA-ARS National Sedimentation Laboratory in Oxford, Mississippi, is the b-value and how well the published values of this parameter hold for predictions on very steep slopes, for different types of cover (outside of crop residues), and for cut slopes versus fill slopes The question becomes: is this b-value slope-dependent? Will the slope factor (S-factor) be adequate for slope adjustment when predicting the effectiveness of mulch to control erosion, or must the b-value also be adjusted?

As discussed by Foster et al. (1982b), as the slope steepness increases, so does the gravitational component on the mulch All other things being equal, it would take less shear stress from the runoff to overcome the forces holding the particle in place Conceptually, this is accounted for in the selection of the critical slope length within the P-factor calculation However, for construction sites, it is a common practice to assume that the P-factor is equal to one Therefore, in order to account for the gravitational component on the mulch, there may be a need to correct the b-value for slope.

Review of Soil Erosion Research Methods

The main objective of this project was to evaluate the utility of using wood chips to control the erosion of disturbed soils on very steep slopes Most of the research literature is derived from experiments performed on shallower slopes, with the results extrapolated out to 50% slopes Many construction sites have cut-slopes or filled-embankments with slope steepnesses that are at or near 50% and therefore, more information is needed regarding the applicability of this extrapolation The research literature provides many examples of how to analyze the effectiveness of a mulch in controlling soil loss However, very few of these citations provide precedence for analyzing the effectiveness of cover on highly disturbed soils located on very steep slopes.

Erodible Plots

The authors of SWCS (1994) report that, for valid results, erodible plots must be formed on or from a representative sample of the landscape, and that knowledge of the erosion process is necessary to insure that the plot can provide samples of this process A research plot must have well-defined boundanes These boundaries must serve as barners to prevent off-site overland flow from entering the plot and direct the runoff from within the plot to a point to where the discharge can be measured and sampled

In order to evaluate wood chip mulch under rilling conditions, Foster (1995) indicated that a minimum slope-length of 10 m was needed to allow the flow to concentrate He also recommended 3 m as the minimum plot width. Generally, plots of this size are located in the field. The Field Manual for Research in Agncultural Hydrology, Handbook 224, (Brakensiek et al., 1979) recommends that for the development of natural-precipitation field plots, researchers should take into account the following the design flow rate from the plot should be equivalent to a maximum five-minute storm with zero abstraction, the design volume of runoff should be equivalent to a 100-year 48-hour storm with zero abstraction, and the design erosion rate should be 112 Mg/ha (50 ton/ac). For the region surrounding Knoxville, Tennessee, a 100-year 48-hour storm would produce approximately 312 42 mm (12.3 in.) of rain, yielding a design runoff volume of 9370 liters (2476 gal) from a 10 m by 3 m plot (Schwab et al ,1993) Likewise, the estimated maximum five-minute intensity is 215 90 mm/h (8.5 iph) which would yield a design flowrate of 1 8 L/s (0.064 cfs) (van der Leeden, 1990).

Researchers use small plots to study interrill erosion separately from rill erosion Although small plots are often installed in field settings, the most common use of small plots is in the laboratory under controlled conditions (SWCS, 1994) Frequently referred to as box-plots, the research literature provides many examples of how to conduct soil-loss analysis in the laboratory (Lattanzi et al , 1974, Khan et al., 1988; Jennings and Jarrett, 1985). However, the majority of these citations are directed toward simulating soils under cultivation. No citations were found that described a procedure for the placement of a highly compacted soil in a box plot

A particular advantage of box plots is rapid evaluation. A prescribed series of storm events can be simulated and then the box plot can be quickly repacked and resurfaced. Maintaining a smooth soil surface is an important consideration for evaluating surface cover With a smooth soil surface, the ability of the mulch to adhere to the soil surface will be tested, rather than the soil's ability to hold the mulch due to surface roughness

Rainfall Simulators

The research literature provides many examples of rainfall simulators being used on both field and laboratory plots Typically, a 60-minute rain event is conducted. The following day, two 30-minute events are conducted, with 15 minutes between events This methodology produces conditions which represent precipitation on dry soil, wet soil, and then very wet soil (Meyer et al , 1970, Meyer et al., 1972, Foster et al., 1982a). Simulated rain events should have sufficient duration to allow infiltration to reach a constant rate and thus to allow runoff to become well established Therefore, the dry-soil event has the longest duration. Just as natural rain events occur at different levels of soil moisture content, simulated rain events must occur at different antecedent moisture levels to increase the probability of collecting realistic erosion data

The literature suggests that 64 mm/hr (2.5 iph) is the most commonly-used rainfall intensity. For the area surrounding Knoxville, Tennessee, a 64 mm/h event with a duration of one hour represents a storm with a return period of approximately 23 years Moldenhauer (1965) recommends that 15 cm (6 in) is sufficient soil depth to allow surface saturation without completely saturating the soil profile in a standard 60-minute, 64 mm/h (2 5 iph) simulated rain

Edwards (1997) currently uses the Spraying Systems' Fulljet HH30WSQ nozzles for rainfall simulation These nozzles were similarly used by Shelton et al. (1985) This nozzle was chosen for its ability to produce reasonable drop sizes at the desired intensity of 64 mm/h Laws and Parsons' (1943) work on determining natural-raindrop size distribution is a well-accepted standard Their work suggests that for a rate of 64 mm/h, the expected drop sizes should range from 0 25 mm to 6.25 mm and should have a median drop diameter of 2.7 mm (by volume). Rajbhandari (1983) found that this nozzle (at 21 kPa) produces drops that have diameters between 0.5 and 3.5 mm, with 2.6 mm being the median drop size. Rajbhandari also found that a fall distance of 2.44 m (8 ft) is sufficient for drops to achieve terminal velocity.

Runoff Measurement and Sampling

When conducting soil erosion research, the mass of soil loss from the plot is the primary information that must be collected Soil solids will leave the plot in the form of dissolved solids, suspended solids, and as a bedload (SWCS, 1994) Also, information about the total runoff volume and the peak rate of runoff are often collected to gain understanding about the hydrology of the plot In order to collect information on all these parameters, there must be a considerable investment in equipment and labor. Most researchers will develop priorities within the above parameters and forfeit precise information about the remainder

As suggested by Brakensiek et al. (1979), a considerable storage volume is needed to collect all the runoff from natural rain-event field plots Collecting all the runoff and then removing all the water would be the definitive method of determining volume of runoff and the total mass of eroded soil soils However, even for small plots, this procedure is impractical Various configurations of sub-sampling equipment have been mentioned in the literature. The most common method of collecting information from large volumes of discharge was described by Brakensiek et al. (1979) Water flumes with stage recorders are commonly used to estimate the total volume and the peak discharge rate of the runoff The discharge is then subsampled with the sampling interval proportioned either on a time, volume, or flowrate basis Building a system that can collect information over a wide range of flows (as would be expected in natural rain events) usually compromises measurement sensitivity Most flumes measure flow based on the depth of water as it passes through a critical-flow cross-section (Grant, 1989) Water enters this cross-section in a sub-critical state and allows sediment to be deposited. This deposition can lead to errors in flow measurement, and this deposition sediment may inadvertently get flushed in with the sediment from the next storm A counterbalance float on a pulley is a common method of measuring depth Devices with "moving parts" are a maintenance concern when used in the field

Flow dividers, with no moving parts, have been developed that can accurately estimate the runoff volume. Rich (1997) used a series of flow-dividers to measure the total runoff volume, collect the mass of readily-settleable solids, and estimate the mass of suspended solids Flow division was performed by 24 v-notch weirs The discharge from one weir was passed to a second divider Each divider had a stilling well of approximately 21 L These wells allowed sediment to settle and provided a quiescent approach to the weirs. Using 51 mm, 22 5° v-notch weirs, these dividers had the capacity to measure runoff at a maximum rate of 6.68 L/s (0.236 cfs). The assumption was made that the suspended solid concentration of the water in the stilling wells represented the concentration of suspended solids of the water that passed through the dividers The total mass of suspended solids was estimated by multiplying the concentration of suspended solids in the stilling well by the volume of water that passed through the divider

CHAPTER III

METHODS AND MATERIALS

Overview

An embankment was located in Knox County, Tennessee in the southern drainage of Brown's Mountain This site is the property of the Knox County Division of Solid Waste and was filled to provide a level surface for the construction of a new solid waste convenience center. The embankment was established as a transition from the fill elevation down to the natural grade The embankment was constructed with a consistent 50% (2 1) slope and with an average 12 m (40 ft) elevation change

Twelve plots were established on the embankment (hence known as the field plots) Each plot was three meters wide with a 10 m slope-length (measured horizontally) These plots were used to measure the erodibility of the fill material and to judge the effectiveness of the wood chip mulch under riling conditions. Additionally, a series of laboratory-plots (hence known as the box plots) was constructed with the same fill material as the embankment These plots had a three-meter slope length (at a 50% slope) and were one meter wide The soil at both locations was compacted to within 95% of the maximum dry unit weight at the optimum moisture content as determined by performing standard-effort Proctor compaction tests as specified by TDOT, 1995 The box plots were tested at slope steepness settings of 40%, 50%, and 67%. Simulated rainfall was used for the rapid evaluation of the erosion-control ability of the wood chip mulch Using an intensity of 64 mm/hr, it was hoped that the slope length of the box plots would be long enough to critically analyze the ability of the wood chips to remain on a smooth, hard-packed soil surface

Wood Chip Gradation

Wolf Tree Experts of Knoxville, Tennessee was a cooperator in this project, and they provided access to their equipment for chip sampling. Four sampling events occurred during

June and July of 1998. Chips were removed from the chipper trucks with scoops and plastic barrels Approximately 1 1 m^3 (1 4 yd^3) of chips were extracted and sorted during each sampling event

Determination of Chip-Size Distribution

A sieve-shaker was constructed to provide a nearly-linear screen movement with a frequency of 260 strokes per minute and an amplitude of 48 mm per stroke Screens were mounted on a 61 cm by 61 cm frame that was 9 cm deep Hardware cloth served as the screen material for the 6.4 mm (1/4 in) and the 13 mm (1/2 in) screens The 25 mm (1 in) screen was woven out of 12 gauge electric cable.

Grading was performed in batches and began by transferring approximately 0 08 m^3 (1 ft^3) of chips to the 6.4 mm screen A two-minute sieve time was used to separate sizes. Material that passed through the 6 4 mm screen was primarily saw dust and ground leaves. All the overs were then sieved by the 13 mm screen Chips that passed through this screen were placed in a "6 4 mm to 13 mm" bin The overs from the 13 mm screen were then passed over a 25 mm screen Chips that passed through this screen were placed in a "13 mm to 25 mm" bin while the overs were put in the "25 mm and over" bin. In order to clearly quantify the effect that size might have on the soil protection ability of wood chips, it was decided to use the 6.4 mm to 13 mm chips as the small chips, the 25 mm and over chips as the large chips, and a mixture of chip sizes that simulated the distribution of chips found in trucks as the mixed chips The distribution is noted in table 3 The fines that passed the 6.4 mm screen were not included because it was assumed that this material would rapidly decompose While tree species was not a treatment effect in this study, it was observed that hardwoods and softwoods were well-mixed in the extracted samples. Hardwood leaves and pine needles were separated out during the gradation process

Table 3. Size distribution produced by chipper-style wood grinders*

Size	Description	Volume (m^3)	% of Total Volume	% of Small, Medium, and Large
6 4 mm and under	mostly sawdust and ground leaves	1 46	33	0
6 4 to 13 mm	small chips	0 83	19	28
13 to 25 mm	medium chips	1.52	34	51
25 mm and over	large chips	0 61	14	21

*A total of 4 4 m^3 of chips were collected during four separate sampling events from Wolf Tree Experts in Knoxville, Tennessee

Volume of Chips Required for Soil Coverage

A pseudo-plot was established on an asphalt surface that had the same on-slope measurements as a field plot This plot was used to practice applying the chips to achieve the 80% coverage and to estimate the volume of chips that would be required Table 4 lists the typical volume and mass values determined for the different chip treatments It is difficult to quantify the chip application rate in a strict mass per area basis because of the variation in moisture contents

Table 4. Application rates of wood chips required to achieve 80% coverage

Size of chip	Volume basis	Dry mass basis
Small chips	18 89 m^3/ha (10 yd^3/ac)	3.31 t/ha (1 47 ton/ac)
Mixture of chip sizes	58 57 m^3/ha (31 yd^3/ac)	10.25 t/ha (4 55 ton/ac)
Large chips	94 47 m^3/ha (50 yd^3/ac)	16 54 t/ha (7.40 ton/ac)

Determination of Soil Physical Properties

Soil Classification

The USDA Soil Survey for Knox County, Tennessee identified the soil used to create the embankment as a Tellico Clay Loam. This soil series is part of a unit of soils that are hilly and steep, dark red, clayey and loamy soils from calcareous sandstone. This mapping unit represents over 200,000 acres of the southeastern edge of the Ridge and Valley Region of East Tennessee The Tellico series makes up about 50% of this mapping unit (Spinger and Elder, 1980). Grain size analysis was performed to determine the sand and clay fraction of this soil (ASTM D 422-63, 1998). Using a 75 µm (No. 200 sieve) as the standard, the sand fraction was determined by wet sieving defloculated samples. The hydrometer method was used to determine the clay fraction and 2 µm was used as the standard for clay This procedure determined that the soil was 38.2% sand, 38.3% clay, and 23.5% silt Using the USDA textural triangle, the soil was classified as a clay loam (Hann et al., 1994). Further analysis using the Atterberg limits tests (ASTM D4318-95a) identified this soil as either a CL or ML under the Unified Soil Classification System; and as an A-7-5 under the AASHTO classification (Bardet, 1997) Appendix D contains the results of the analyzes performed to determine the physical properties of the soil

Fill Soil Compaction

A series of standard-effort Proctor compaction tests were conducted on the soil (ASTM D-698, 1998) As shown in figure 3, the maximum dry unit weight and optimum moisture content were determined to be 15.2 kN/m^3 (96.7 pcf) and 24.9, respectively These figures are in agreement with values obtained by the engineering contractor who was in charge of the field plot site's development The fill material on this site was compacted to the optimum density by vibratory sheep-foot rollers.

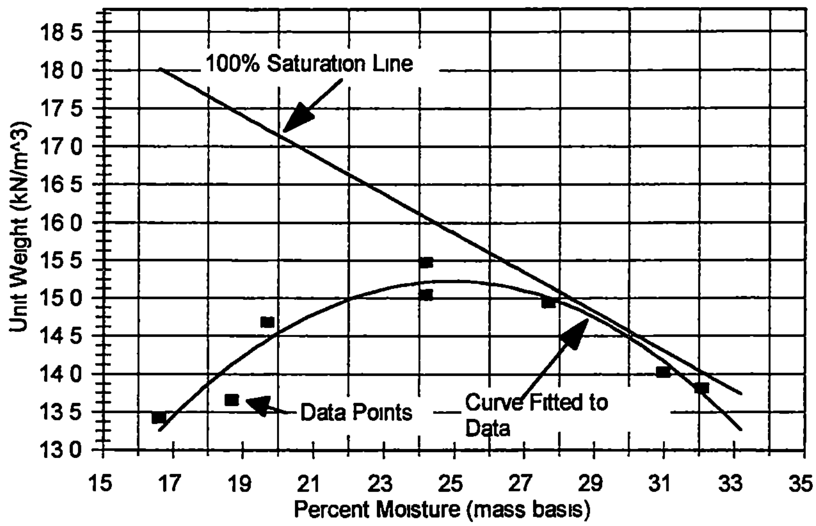


Figure 3 Results of Proctor test on fill soil from site

Soil Erodibility (K) Factor

The erodibility nomograph portion of the RUSLE model was used to estimate a K-factor for the clay loam subsoil Five inputs are needed for this calculation and they are listed in table 5. By USDA standards, very fine sand is the sand fraction between 0.05 and 0.10 mm (Brady,1974) The grain size analysis performed on this soil separated sand and silt at 0 075 mm and therefore did not provide information about the percentage of very fine sand For

Table 5. Values used by the RUSLE for the K-factor calculation

Percent silt plus percent very fine sand	52.2%
Percent clay	38 3%
Percent organic matter	2.7%
Soil structure	medium to coarse granular
Permeability	slow to moderate

Calculated K-factor 0 033 (t ha·h)(ha MJ mm)$^{-1}$ [0.25 (ton acre·hour)(100 ac·foot tonf inch)$^{-1}$]

the purpose of estimating a K-factor, the percentage of very fine sand was assumed to be three-fourths of the total sand percentage. A value of 0 033 (t·ha h)(ha·MJ mm)$^{-1}$ [0.25 (ton·acre hour)(100 ac foot tonf·inch)$^{-1}$] was derived for the K-factor The University of Tennessee, Department of Plant and Soil Science has records that list the K-factor at 0.032 (0.24) and at 0.037 (0.28) For soil loss modeling, the fill material at this site was assigned a K-factor value of 0.037 (metric units)

Development of Field Site

Assignment of Treatments

It was observed that some of the plots were slightly concave and it was decided to statistically block these plots together. A 15-point topographical survey of each plot was performed to evaluate the uniformity of the surface of each plot. A representative profile of each plot was created by averaging the three elevations taken (across the width of the plot) at the 2 73 m, 5 46 m, and 8.19 m slope-lengths. As shown in figure 4, a line was drawn from the top to the bottom of each plot Each plot was examined for its deviation from that line The measurement deviations were squared and summed. Blocks of four plots each were formed by arranging the sum of the squared deviation in decreasing order The blocks were designated as A-more concave, B-less concave, and C-nearly linear. Within each block, the treatments were assigned using a random number table. The experimental configuration was a random complete block design (table 6).

Determination of Topographic (LS) Factors:

Using the surface information gained from the topographic survey, each plot was assigned a LS-factor value. The RUSLE version 1.06 was used to calculate this value. Additional information needed by the RUSLE model included the texture (clay loam) and the land use (disturbed fill, subsoil with no rock cover)

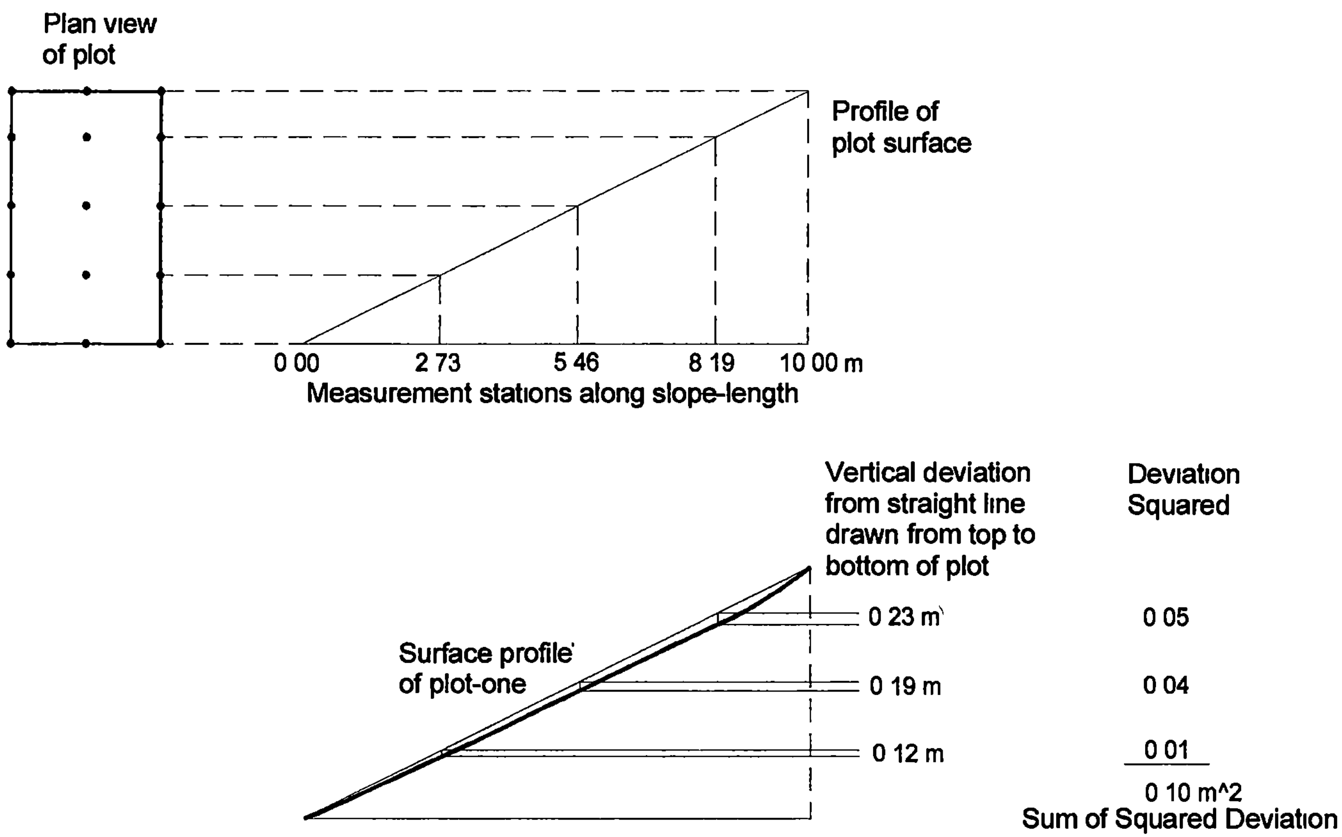


Figure 4 Demonstration of procedure used to determine the concavity of each field plot.

Table 6 Listing of treatment assignment, LS-factor and equivalent slope for each plot

Treatments (chip size)	Sum of Square (m^2)	Plot Assignment	Overall LS-Value	Equivalent Slope
Group A (more concave)				
Large	0 101	1	4 19	52 8%
Mixed	0.090	6	4 23	53.5%
Small	0.075	2	4.07	50 9%
Bare	0.076	5	4.02	50.1%
Group B (less concave)				
Large	0.058	4	4 09	51.1%
Mixed	0.064	3	4 08	51.1%
Small	0.049	9	4.29	54 4%
Bare	0.059	8	4.28	54.3%
Group C (nearly linear)				
Large	0.013	10	4.36	55.5%
Mixed	0.016	11	4 43	56.6%
Small	0.033	12	4 30	54 5%
Bare	0.033	7	4.22	53.2%

Runoff Collection

A border was installed at the top and the sides of each plot by entrenching 15-cm plastic lawn edging The edging was trenched 10 cm into the soil, and was then solidly set by compacting the soil from the outside edge of the plot toward the edging. Any joints in the edging were sealed with cement-grout. The edging at the top of the plot was entrenched in a semi-circle to divert upland surface flow around the plots

The bottom edge of each plot was delineated by slotting in 152 μm thick (6-mil) black plastic sheeting. A triangle was formed by wrapping the sheeting around 51 mm x 102 mm x 2 4 m timbers The collection triangle was at the same slope as the soil surface. A 4-inch diameter PVC pipe transferred the runoff from the triangle to the first flow divider This tube was set on a

2% slope to prevent sediment deposition within the pipe Plate 1 is a view of the field plot runoff collection system.

Runoff and Sediment Measurement

Runoff and sediment were measured with two flow dividers in series. The dividers were mounted on 5-gallon, screw-top buckets manufactured by Consolidated Plastics. For the purpose of clarity, the following nomenclature will be used when describing the flow dividers: runoff from the plot enters divider-1, divider-1 is mounted on bucket-1; divider-2 is mounted on bucket-2; and divider-2 spills into bucket-3 (see figure 5) The first 21-L of runoff filled bucket-1, the remainder of the inflow was divided by twenty-four 51 mm, 22.5° v-notch weirs. The assumption was made that the readily settable solids would be deposited in bucket-1. Flow from one weir was directed to the second divider. Likewise, when 21 L filled bucket-2, the remainder of the input was divided across 24 weirs, with flow from one weir being directed to bucket-3.

There was approximately 2 L of volume between the top of the bucket and the bottom of the weirs To keep from losing this volume of water when the flow divider was removed, a 2 L displacement was placed in the bottom of each bucket-1 and bucket-2. The displacements were removed before the volume of water was measured in each bucket.

The accuracy of the flow division was dependent on the dividers being perfectly level. For each plot, a leveling platform was constructed and trenched into the soil for stability (plate 2) All dividers were placed on a bracket with three leveling screws for precision adjustment. Each time the buckets were serviced, the level was checked with a torpedo-level and the screws were adjusted as necessary The entire flow divider unit was covered with a tarpaulin to prevent precipitation from falling directly into the buckets.

Soil Surface Preparation

The embankment had been stabilized with annual rye and with Verdyol ERO-MAT®, a stitched straw blanket consisting of a double layer of polypropylene netting sandwiching chopped

Plate 1. View of field plot runoff collection system.

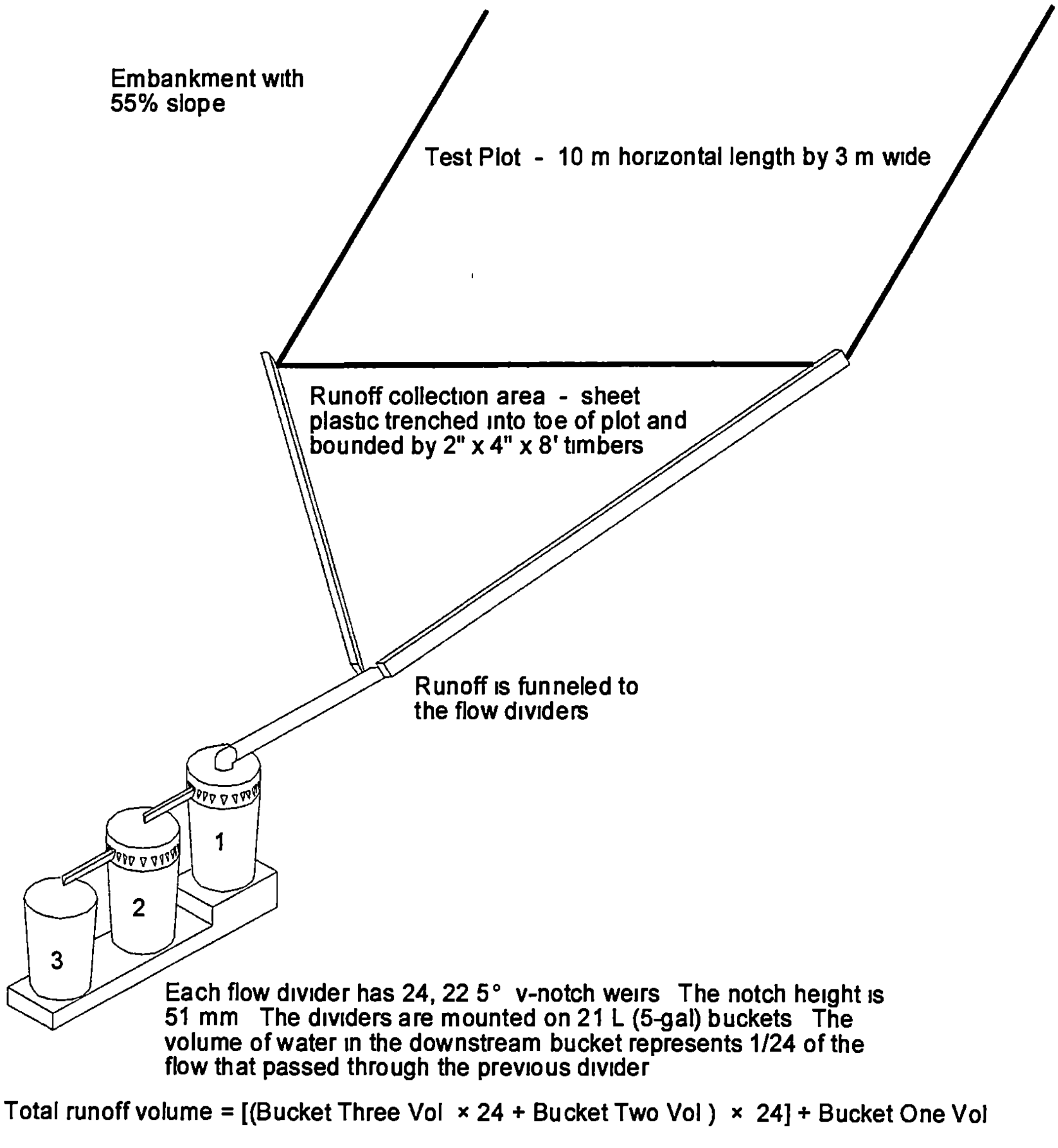


Figure 5 Field plot layout and placement of runoff collection system.

Plate 2. View of flow dividers mounted on leveling platform.

wheat straw Knowing that roots had already been established into the soil, it was decided to kill the rye with Roundup® and to wait for the grass to start to decompose. It was hoped that this method would also break down the roots and lessen their effect on soil stabilization When the grass had been chemically burned for several weeks, a string trimmer was used to mow the thatch down to the level of the netting. All the thatch was removed so that the netting and ground was fully exposed to sunlight for further drying. It was found that if the soil was moist when trying to remove the netting, large soil clods were pulled from the surface. When the soil was dry, the netting cleanly detached from the soil surface. Once the netting was removed, the plots were raked to remove soil loosened during the stripping process. As seen in plate 3, the resulting plots had clean, relatively smooth surfaces Evidence could still be found of the dozer tracks that had been used to shape the surface

Measurement of Rain Depth and Intensity

Near the top of the embankment, a Davis Rain Collector II tipping bucket raingage was installed with an Onset Computer Corporation Hobo Event Logger This tipping bucket has an 203 mm (8 in) opening and each tip is equivalent to 0.25 mm (0.01 in) of rain depth. The datalogger recorded the time of each tip, and therefore allowed for the determination of the various intensities experienced during each of the rain events In case of datalogger failure, a Tenite butyrate manual raingage was similarly mounted. This gage had a 102 mm (4 in) opening and was delineated for 0.25 mm (0.01 in) accuracy

Wood Chip Application

Using the application rate listed in table 4, wood chips were applied until approximately 80% of the soil surface was covered A grid with 100 nodes, set on 10 cm intervals, was employed to determine the percentage of cover The grid was placed on the soil surface over the chips. Each node that had a chip beneath it was counted, and if 80 out of 100 had a wood chip, then the coverage was assumed to be 80 percent The chips were applied by dividing each

Plate 3. View of raking plot surface to remove loose clods and vegetation.

plot into three sections (upper, middle, and lower) and applying the chips until the desired coverage was obtained. In each third of the plot, measurements of coverage were taken. Care was taken to spread the chips uniformly across the length and width of each plot. Plate 4 is a view of plots 2, 3, and 4 which demonstrate the relative sizes of the small, large and mixed treatments, respectively Plate 5 is a view of the site at the completion of the wood chip application.

Development of Box Plots

Box Plot Construction

The box plots were constructed out of pressure treated timbers and plywood Soil depth was set at 15 cm (6 in) measured vertically with the box set on a 50% slope The sides of the boxes were beveled to divert away from the box the water that landed on the edge of the timbers. As shown in figure 6, sheet metal guards were placed along the length of the boxes to catch the across-slope soil splash and divert it to the collection gutter A 25 mm layer of sand was placed across the bottom of the box and a layer of permeable geotextile material separated the soil and the sand.

Fill Soil Placement

In order to minimize edge effects, the boxes were over-packed in length and depth A packing mold was developed that encompassed the box plots. Steel C-channel was placed along the sides to minimize side-wall budging as the soil was being packed Once the boxes were filled and compacted, the excess length was sheared off of the ends of the box The boxes were brought to proper soil-depth by chipping the top layer until the surface was smooth and even with the top of the box walls.

The boxes were filled with the same soil type used for the fill at the field site. Approximately 11 m^3 (14 yd^3) was excavated and delivered to the laboratory The soil was moistened to optimum moisture content and placed in the boxes in approximate 50 mm

Plate 4. View of three coverage treatments - small chips on the left, large chips in the middle, and mixed chips on the right.

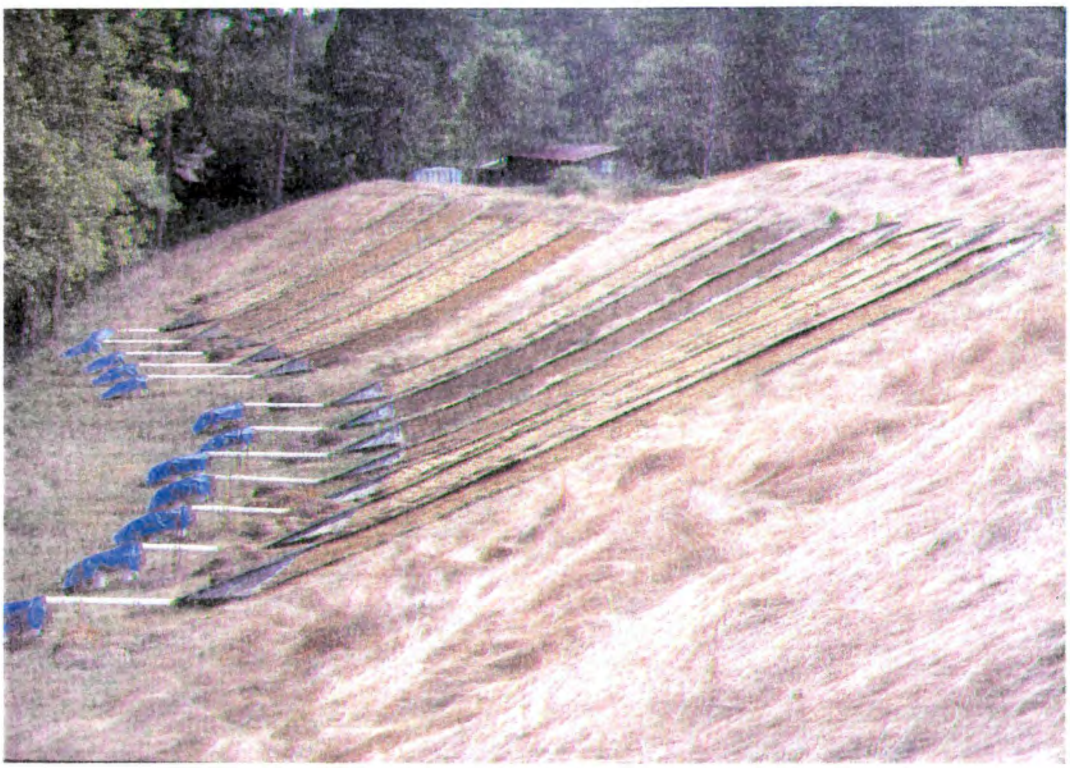


Plate 5. View of field plots after installation was complete.

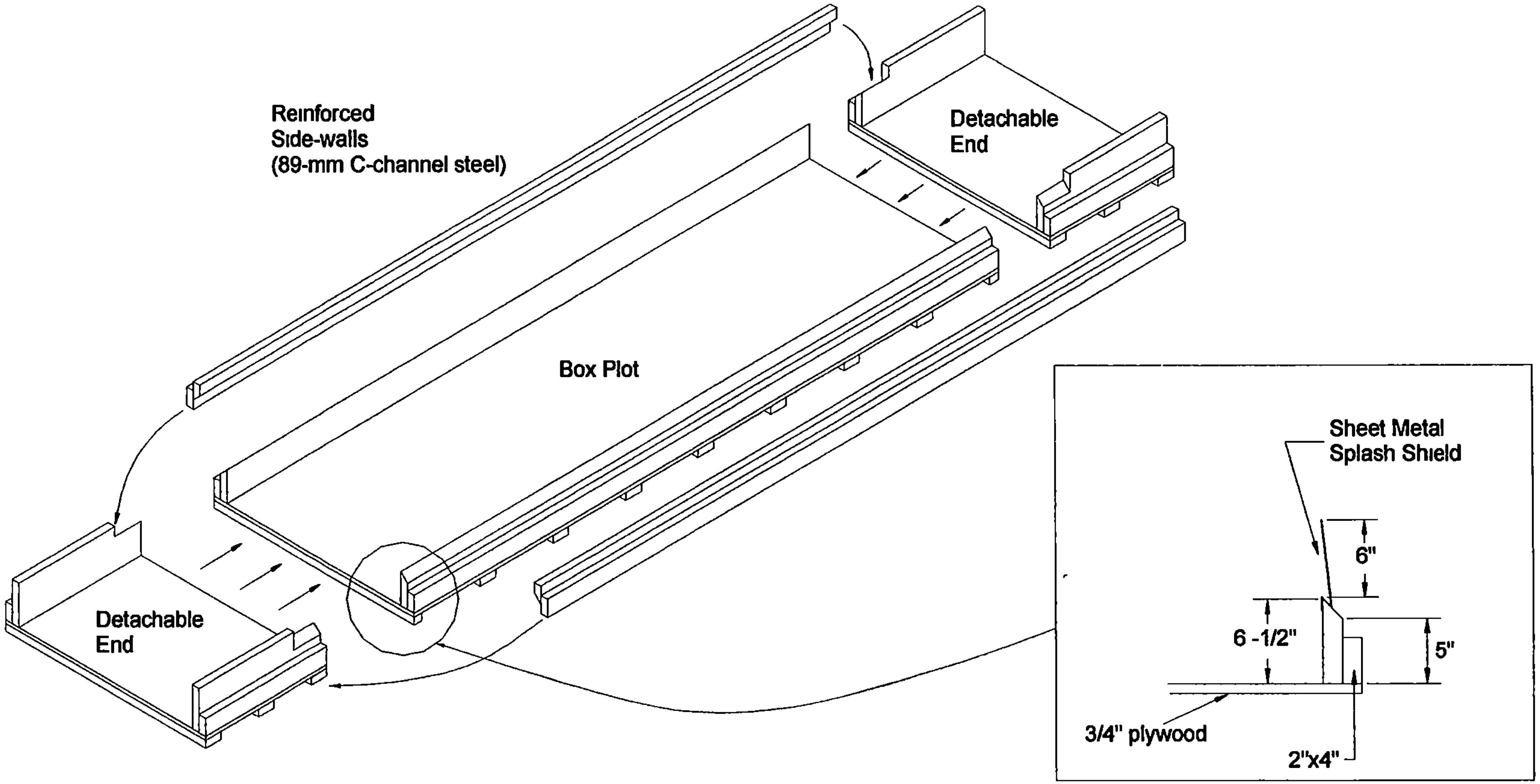


Figure 6. Exploded view of box plot and packing-mold

honzontal lifts A 3.7 kW (5 hp) upnght rammer with a 269 mm by 330 mm shoe was employed to compact the soil The compactor was operated at a constant throttle settıng and was passed over the soil surface at least three tımes per lıft. A Troxler moısture densıty neutron probe was used to determıne the degree of compactıon that had taken place. The compaction process caused plastıc deformation of the soıl and seemingly destroyed the boundary between lifts.

Variable Slope Stand

A stand was constructed to hold two box plots ın posıtıon under the rainfall sımulator Thıs stand was desıgned to be rotated from a flat positıon, for box placement or removal, to the desıred percentage of slope Figure 7 demonstrates the different slope settıngs and how these settıngs affected the honzontal slope length and surface area To prevent the boxes from flexıng when beıng lifted, each box plot was constructed with three steel beams from whıch chains could be attached for transport. As shown ın figure 8, the chains were draped around a steel gantry mounted on a 2724 kg (6000 lb.) capacity fork truck that was used to transport and lıft the boxes onto the stand Once the boxes were placed, the fork truck was moved to the front of the stand and used to lower the assembly into position Fınally, the rainfall sımulator was moved ınto position and connected to the water supply. Plate 6 ıs a view of two box plots positıoned beneath the raınfall simulator.

Determınation of Topographıc (LS) Factors

The RUSLE model was used to determine the LS-factor for each slope settıng. For each slope settıng, the values for the slope and honzontal length were entered into the model These values are shown on figure 7

Raınfall Sımulator

A steel framework was erected to support the four nozzles that provıded the sımulated raıns The framework and nozzle placement was sımılar to Edwards (1997) Four Fulljet 1/2

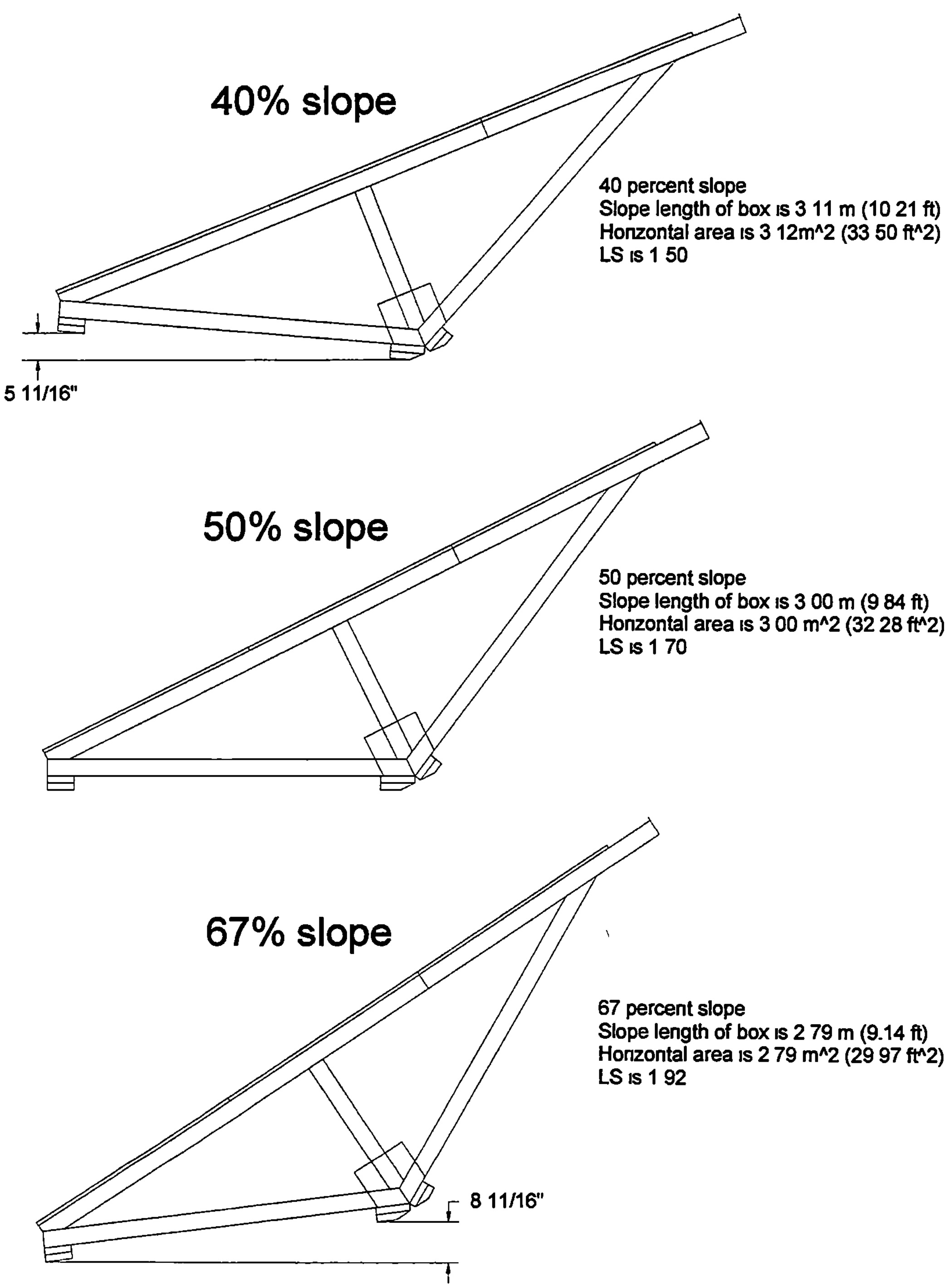


Figure 7. Profile view of each of the three slope settings with a listing of the associated areas and slope-lengths.

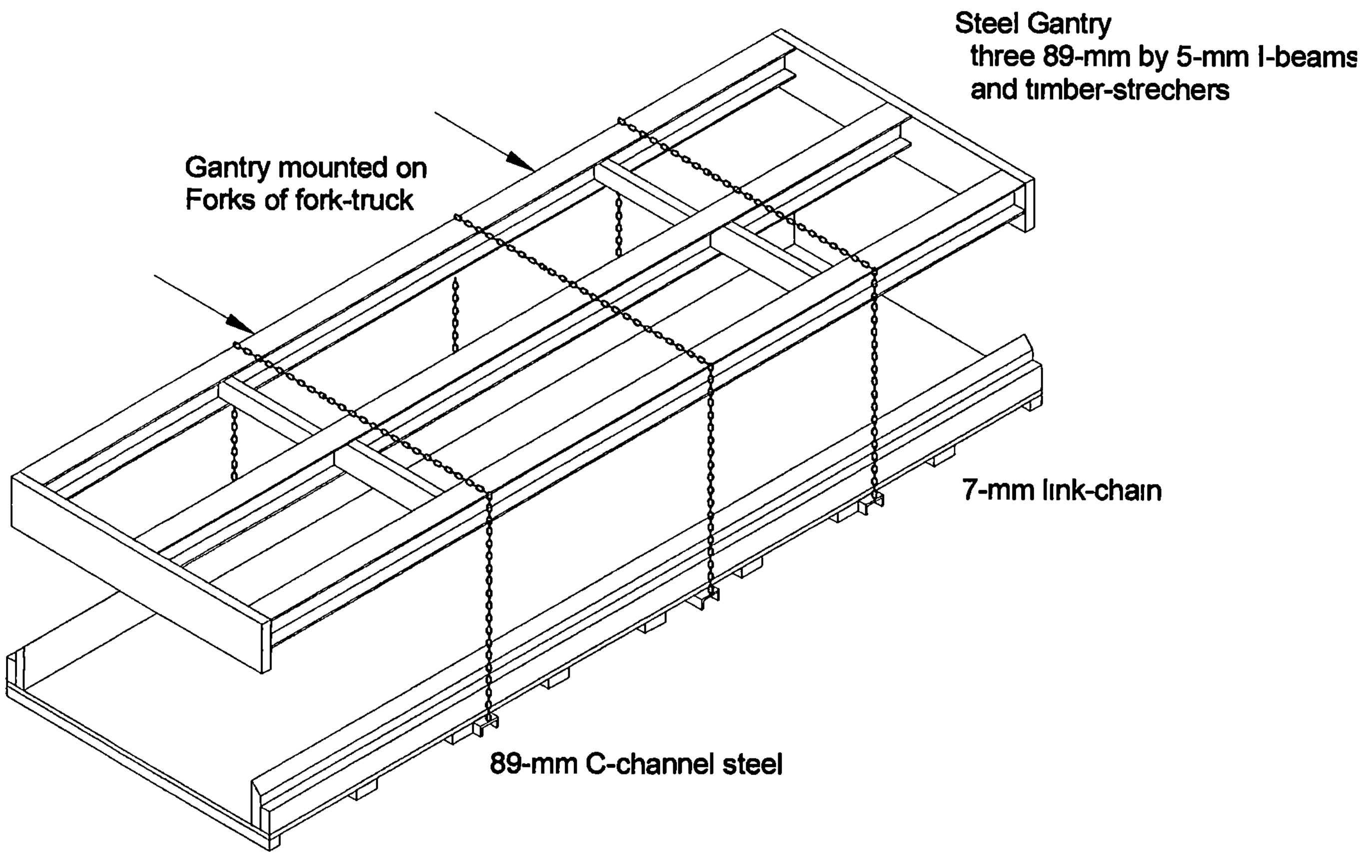


Figure 8 Steel gantry used to maintain a flat surface while lifting the box plot

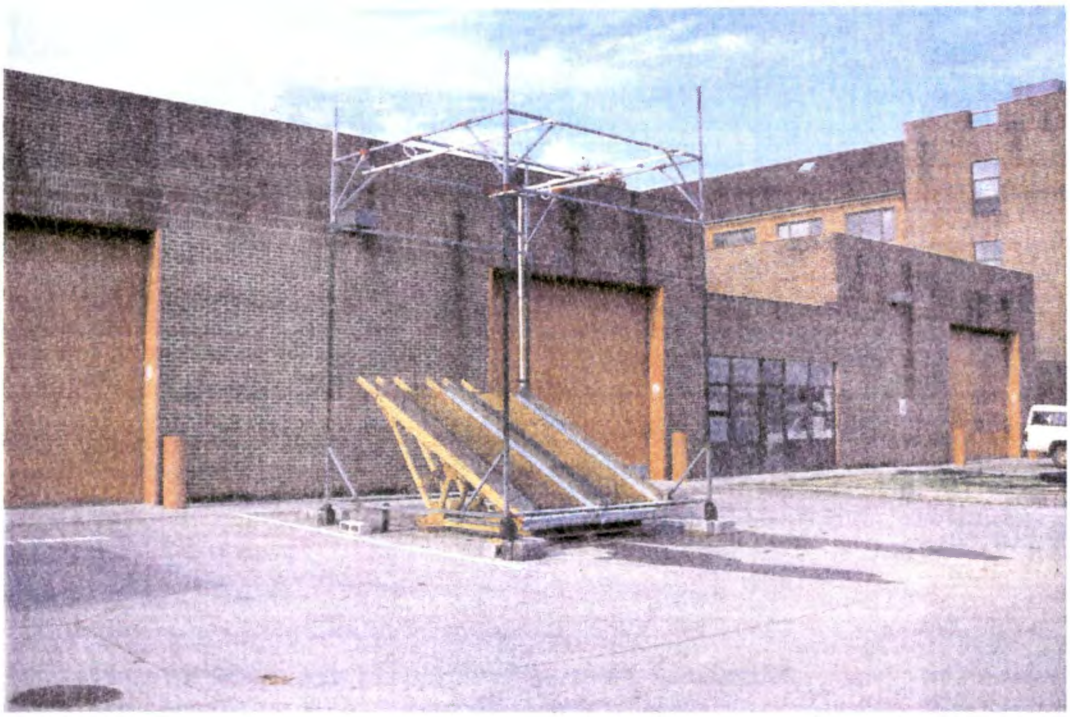


Plate 6. View of box plots, variable-slope stand, and rainfall simulator.

HH-30WSQ nozzles, manufactured by Spraying Systems Company, were placed so as to completely overlap the length and width of the box plots The performance of these nozzles is well documented in Rajbhandari (1983). Nozzle pressure was regulated at 34 5 kPa (5 psi) Placement of these nozzles on a 2.44 m (8 ft) on-center spacing produced a nominal intensity of 64 mm/h (2 5 iph). Nozzle height was set at 2 44 m (8 ft) above the highest soil elevation. Shelton et al (1985) determined that 2 44 m was minimum the required fall distance for the drops to achieve near-terminal velocity with minimal horizontal component

Application uniformity was checked by placing a series of cans on an approximate half-meter grid beneath the simulator. The depth of water in each can was measured and the statistics were generated for use in Christianson's uniformity equation (Cuenca, 1989) Uniformity coefficients between 0.85 and 0.90 were measured; a 1.0 would indicate perfect uniformity.

Experimental Configuration

Because of the difficulty of producing identical soil conditions in a series of box plots, it was decided to statistically "block" a set of boxes with a complete set of treatments. After each set of treatments had been tested, the boxes were re-packed. The goal was to keep boxes within a block of tests as identical as possible

Data collection from the simulated rainfall portion of this project took place during the summer of 1999. It was already known at this time that the small-chip treatment had essentially failed in the field study The decision was made to discontinue the small-chip treatment in the box plots and to focus on the large-chip and mixed-chip treatments

The experimental configuration was a Latin-square split-plot design There were six boxes per block, with two treatment replicates (large-chip, mixed-chip, and zero-cover) within each block Treatments were randomly assigned to boxes within blocks and each box within a block received three rain events (dry, wet, and very wet). Two blocks each were completed with the stand set at 40%, 50%, and 67% slopes. Figure 9 is a diagram of experimental configuration

Block A	Bare dry, wet, very wet	Bare dry, wet, very wet	50% Slope
	Mixture dry, wet, very wet	Mixture dry, wet, very wet	
	Large dry, wet, very wet	Large dry, wet, very wet	
Block B	Bare dry, wet, very wet	Bare dry, wet, very wet	
	Mixture dry, wet, very wet	Mixture dry, wet, very wet	
	Large dry, wet, very wet	Large dry, wet, very wet	
Block C	Bare dry, wet, very wet	Bare dry, wet, very wet	40% Slope
	Mixture dry, wet, very wet	Mixture dry, wet, very wet	
	Large dry, wet, very wet	Large dry, wet, very wet	
Block D	Bare dry, wet, very wet	Bare dry, wet, very wet	
	Mixture dry, wet, very wet	Mixture dry, wet, very wet	
	Large dry, wet, very wet	Large dry, wet, very wet	
Block E	Bare dry, wet, very wet	Bare dry, wet, very wet	67% Slope
	Mixture dry, wet, very wet	Mixture dry, wet, very wet	
	Large dry, wet, very wet	Large dry, wet, very wet	
Block F	Bare dry, wet, very wet	Bare dry, wet, very wet	
	Mixture dry, wet, very wet	Mixture dry, wet, very wet	
	Large dry, wet, very wet	Large dry, wet, very wet	

Figure 9 The Latin square split-plot experimental design used for the simulated rain study.

CHAPTER IV

DATA COLLECTION

Field Site

Calculation of Eroded Mass

It was the goal of this project to collect data from every significant storm Renard et al., 1997 defined a significant storm as rain showers greater than 13 mm, unless 6.4 mm fell within 15 minutes. Furthermore, if less than 1.27 mm of precipitation was produced during a six hour period, then the storm should be divided into two events On several occasions, multiple storms were collected as one event due to the inaccessibility of the site during wet conditions The data collection protocol is listed in bullet form

- The tipping-bucket data logger was downloaded and the depth of water in the manual raingage was recorded.
- Working one plot at a time, the identification and location of each flow divider was recorded.
- The flow dividers were separated from their buckets and the volume of water in each buckets was recorded
- The water in buckets 2 and 3 was throughly agitated and a 350 ml grab sample was taken from each to determine its concentration of solids
- The supernatant was siphoned off of bucket-1 to just above the sludge layer. As the supernatant was being extracted, a 350 ml sample was taken for the suspended solids concentration determination. A second measurement of water depth was taken to determine the volume of supernatant removed
- Any sediment deposited in the supply tube and/or the collection triangle was flushed into bucket-1 with clean water. All bucket-1's were sealed for transport back to the laboratory.
- The flow dividers were fitted with clean buckets, repositioned, and leveled using the triangular brackets

In the laboratory, the material in each bucket-1 was dried at 105° C for 72 hours to determine the solids content. Each of the grab samples was throughly shaken and a 50 ml sub-sample was extracted and dried at 105° C to determine the concentration of solids Using the concentration of solids and the volume of water in the bucket from which the sample was extracted, the mass of suspended solids was determined for each bucket For each plot, the total mass of eroded solids was determined

- The mass of solids in bucket-3 was multiplied by 24 to estimate the total solids that passed through divider-2.
- This mass was added to the mass in bucket-2. The sum was multiplied by 24 to estimate the mass of solids that passed through divider-1
- This mass was added to the mass of solids in bucket-1 to estimate the total mass of solids that left the plot

Likewise, the total runoff volume was calculated using the same algorithm

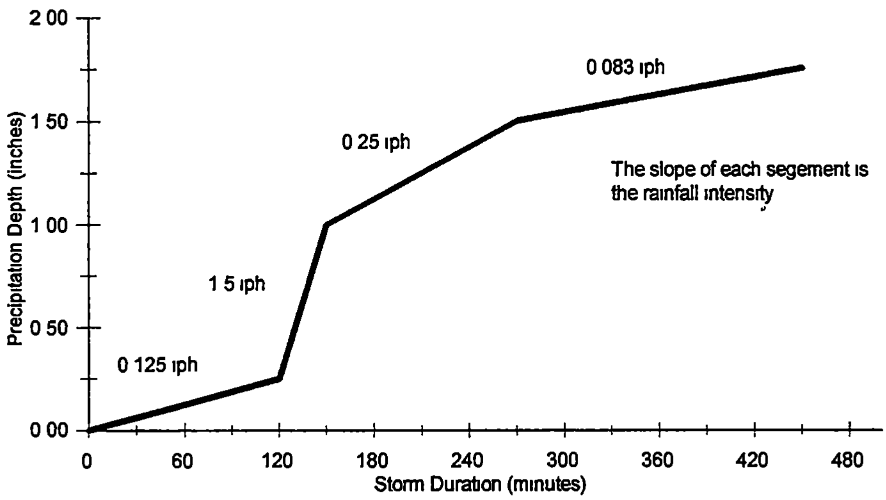
Calculation of Storm EI-30

Using the data from the recording raingage, each storm was divided into periods of relatively constant rainfall intensity For each of these periods, the unit kinetic-energy was determined. The unit-energy was normalized by multiplying it by the depth of rain that occurred during that period. Each of these normalized values were totaled to determine the total energy (E) of the storm. The storm energy was then multiplied by the maximum 30-minute intensity (I_{30}) to yield the storm erosivity (EI_{30}) Figure 10 lists the unit energy equation and demonstrates this calculation procedure

Box Plots

Measurements for Quality Control

Before the "dry" rain of each simulated-rain sequence, the initial moisture content and the bulk density of each box plot was checked with a Troxler moisture-density neutron probe The surface-cover percentage was measured at three locations along the length of the box The volume of runoff was monitored as an indicator of application uniformity. It was assumed that volume lost to infiltration would be minor compared to the volume applied.



$$\text{unit energy} = 1099\left[1 - 0.72\ \exp\left(-1.27\ \ i\right)\right]$$

where *i* is the intensity (inches per hour) for each storm period of relatively constant intensity

Calculation of storm EI_{30}

Intensity (inch per hour)	Unit energy ($ft \cdot tonf \cdot acre^{-1} \cdot in^{-1}$)	Depth (inch)	Total energy ($ft \cdot tonf \cdot acre^{-1}$)
0 125	424	0.25	106 00
1 50	981	0.75	735 75
0.25	523	0.50	261 50
0 083	387	0 25	967 50
			E = 1200 00

Max. 30-min intensity = I_{30} = 1 50 iph

$EI_{30} = 18\ (10^{-2} \cdot ft \cdot tonf \cdot in \cdot acre^{-1} \cdot h^{-1})$

$EI_{30} = 306.36\ (MJ \cdot mm \cdot ha^{-1} \cdot h^{-1})$

Figure 10. Demonstration of the calculation of the storm erosivity from the recording raingage data

Simulated Storm Energy

The one-hour events produced an erosivity of 1133 $MJ \cdot mm \cdot ha^{-1} \cdot h$ (67 $10^{-2} \cdot ft \cdot tonf \cdot in \cdot ac^{-1} \cdot h^{-1}$) and applied 64 mm of water The 30-minute events produced an erosivity of 567 $MJ \cdot mm \cdot ha^{-1} \cdot h$ (33 $10^{-2} \cdot ft \cdot tonf \cdot in \cdot ac^{-1} \cdot h^{-1}$) and applied 32 mm of water.

Calculation of Eroded Mass

Runoff from each simulated event (dry, wet, and very wet) was collected in separate containers. The collection system was composed of a sheet metal apron at the end of the plot, a gutter along the apron, three cascades of sediment traps, and two 130-L drums A sump pump was used to transfer the water from the last sediment trap to the 130-L drums The sediment collected in each of the traps was dried at 105° C The gutter and sediment traps were exposed to the rain, and therefore, the runoff volume was corrected based on the nominal depth of precipitation and on the surface area of those devices The water in the 130-L drums was measured for volume and two grab samples were taken from each Each pair of grab samples was averaged and used to calculate the total mass of suspended solids This mass was added to the mass of settled solids held in the traps to determine the total sediment removed from each box plot Plate 7 is a view of the runoff collection apparatus.

Plate 7. View of the runoff collection system developed for the box plots under simulated rainfall.

CHAPTER V

RESULTS AND DISCUSSION

Field Plot Erosion Data

Four days after completion, the field plots were subjected to the first rain event. During the next 130 days, erosion data were collected for eight storm events (figure 10) The total rainfall-runoff erosivity was 1,338.9 MJ·mm(ha·h)$^{-1}$ [78.67 ft·tonf·in(100·ac·hr)$^{-1}$] for this period This represents approximately 45 percent of the average annual erosivity for the Knoxville, Tennessee area. Figures A-1 through A-8 in Appendix A show the cumulative depth of each storm event with time

Comparison of Cover Treatments

Analysis of variance (ANOVA) was performed by using the general linear model procedure (Proc GLM) from SAS (1997). The ANOVA f-test provided information as to whether the treatment means were significantly different from each other, but did not suggest which means were different Fisher's least significant difference (LSD) was employed to separate significantly different means (SAS, 1997). When ANOVA determined that there was a significant difference, LSD was used to identify how the means were separated This procedure is not valid in reverse Even if the difference among means is larger than the computed LSD, if the probability of making a Type-I error was not equal to or less than 10%, then there was no significant difference assigned to the treatment during a particular storm event

As mentioned previously, the experimental configuration was a random complete block design, with a complete set of treatments per block, and the plots were blocked on slope concavity. Table 7 lists the effectiveness of each treatment on a per-storm basis Storm events four, five, and eight provided very little erosion energy and therefore no significant differences were found between treatments Only in event three could the effect of the small chips be

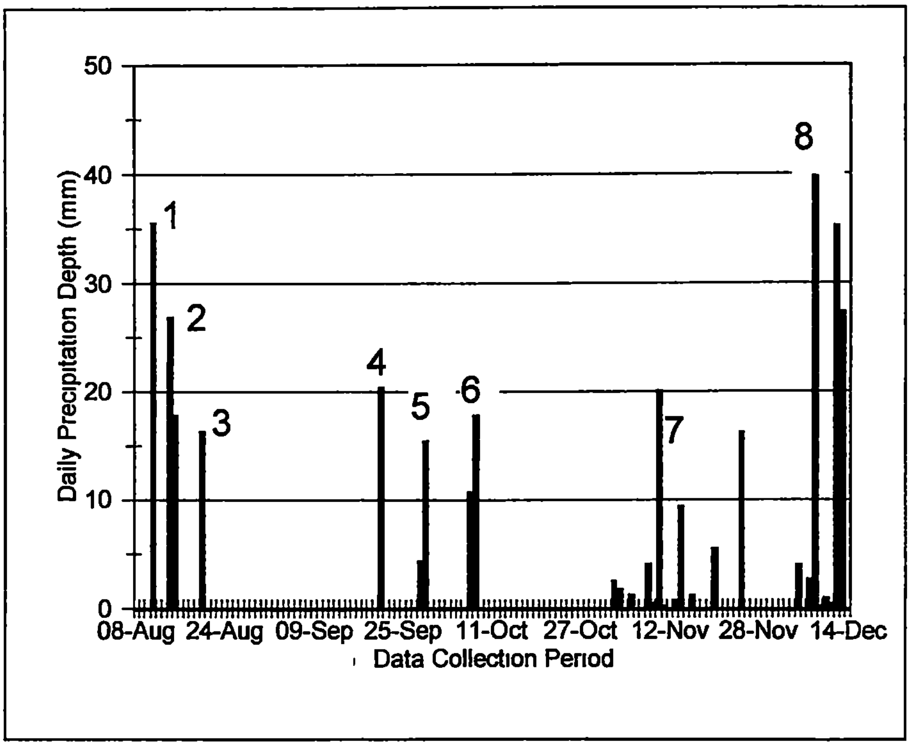


Figure 11 Precipitation data recorded during the field study.

Table 7 Summary of means of total solids eroded from field plots during eight storm events

Event	Storm* Erosivity	Treatment Means (kg)†				F-test‡	LSD§	Storm Date
		Bare	Small	Mixed	Large			
1	612.4	8 40 a	8 27 a	1 00 b	3.05 ab	p=0 10	7.20	08/11/98
2	308 4	10.38 a	7.82 a	2.00 b	1.99 b	p=0.01	4.80	08/16/98
3	135 5	9 90 a	5 39 b	0 89 c	0 90 c	p<0 01	2.27	08/18/98
4	31 8	0.03 a	0.01 a	0.01 a	0 01 a	p=0.58	0.04	09/21/98
5	80 3	0 20 a	0.19 a	0.03 a	0.07 a	p=0.25	0.22	09/29/98
6	38 5	0.59 a	0.70 a	0 06 b	0 23 b	p=0.01	0.40	10/07/98
7	27 2	0 40 a	0.32 a	0 02 b	0 07 ab	p=0 09	0.35	11/11/98
8	104.8	1.19 a	1.53 a	0.21 b	0.55 ab	p=0.14	1.26	12/12/98

*Storm Erosivity MJ·mm(ha h)$^{-1}$ [100 MJ mm(ha h)$^{-1}$ is equal to 588 ft·tonf·in(ac hr)$^{-1}$]
†Means with the same letter in the same storm event are not different
‡F-test from ANOVA, probability that treatment means are not different
§Fisher's least significant difference

distinguished from the effect of having no cover. During storm events one and seven, the effect of the large chips was not significantly different than the small-chip and zero-cover plots However, the results from these two storms indicate that the large chips afforded a degree of protection to the soil. The mixed-chip treatment was the statistically superior treatment in all events that produced erosion During events for which the large-chip and mixed-chip treatments were not significantly different from one another, the results indicate that the mixed-chip treatment provided improved soil protection over the large-chips

Table 8 summarizes the total-erosion data collected during the eight events. Although the effect of the small chips is not significantly different from zero cover, the results do suggest a 22% reduction in erosion Overall, the large-chip and mixed-chip treatments are significantly different from the small-chip treatment, but they are not significantly different from one another. The data suggests that the mixed-chip treatment is superior. Using the results from the zero-cover plots as a baseline, the large-chip treatment reduced erosion by 78%, while the mixed-chip treatment reduced erosion by 86%

Effect of Blocking with Concavity

Although there were measurable differences in the physical topography of the plots, ANOVA did not find any significant differences in the data that could be attributed to these effects Therefore, the calculated differences in the LS-factors for each of the plots are probably

Table 8. Total Solids (kg) Eroded During Field Study (Sum of EI_{30} = 1,338.9)*

Treatment	Block A	Block B	Block C	Mean†		Std Dev
Bare	25 536	40.101	27.598	31.078	a	7.882
Small	29 939	20 609	22.097	24.215	a	5 013
Mixed	2 868	6.525	3.219	4.203	b	2.019
Large	4 151	3.153	13 303	6.869	b	5 594

*Storm Erosivity (MJ mm/ha·h) [100 MJ mm(ha h)$^{-1}$ is equal to 588 ft tonf in(ac·hr)$^{-1}$]
†Means with the same letter are not significantly different, p=0.005, LSD = 12.568

not significantly different While they may not be significantly different, the individual LS factors were still used for modeling the erosion from each plot

<u>Coverage Reduction with Time</u>

The principle concern of using wood chips to control soil erosion was whether they would stay in place during a storm event Chips were initially applied to a nominal coverage of 80 percent The actual initial coverage of each plot was measured and documented. Originally it was planned to document the changes in coverage on a per storm-event basis. However, the steepness of the slope and the cohesive nature of the wet clay loam soil made it impossible to enter the plots and take measurements. A set of coverage measurements was taken during an extended dry period between events three and four. Table 9 contrasts the initial coverage with the coverage measured after three storm events. It should also be noted that these three events were the three highest-energy storm events recorded during the study period. Unfortunately, the slope remained wet for several months after the study was concluded and thus an end-of-study coverage measurement could not be taken

It is interesting to note that the reduction of small-chip coverage seems to correspond to its effectiveness in reducing erosion While small chips could be found floating in the flow dividers, this quantity of chips did not account for the reduction measured on the plot Visual observation of the small-chip plots suggest that a large portion of the coverage reduction is due to the clustering of chips, which left large areas of soil unprotected.

The movement of the smaller chips is thought to be the reason that the mixed-chip treatment showed a greater reduction in coverage than did the large-chip treatment Within the mixture of chip sizes, the smaller chips were observed to cluster against the larger chips It is thought that a "cementing effect" occurred as sediment flowed into the spaces between the large and small particles. As sediment deposited among the wood particles, the chips were held in place by the adhesive and cohesive nature of the water-soil-wood surfaces These phenomena

Table 9 Overall change in coverage after three storm events at the field site.

Time	Average percent coverage by treatment					
	Small-Chip		Mixed-Chip		Large-Chip	
	Mean (%)	Std Dev	Mean (%)	Std. Dev	Mean (%)	Std Dev
Initial Coverage	81.85	1.29	82 55	0.64	74 8	1 19
After Three Storm Events	51 7	1.70	74.1	4 45	71.3	3 43
Coverage Reduction	37% Reduction		10% Reduction		5% Reduction	

increased the runoff flow resistance and allowed even more sediment to deposit around a cluster of chips, thus reducing the mass of sediment that left the plot

Larger chips demonstrated the greatest resistance to transportation As was mentioned previously, as the diameter of the chip increases, there is a trend for the thickness of the chip to increase. This increase in mass affords the larger particle a larger measure of inertia. The large chips are less likely to be moved by raindrop impact As sediment flows around the edges of the larger chips and bonds them to the soil surface, the inertia and the bonding effects make the larger chips the more stable size on the steeper slopes

In general, the movement of chips does appear to be related to the slope length. As shown in table 10, the relative change in coverage of the large-chip and mixed-chip treatments were uniform along the slope length However, the small-chip treatment showed the greatest failure as the runoff energy increased down the slope

Settled-Solids versus Suspended Solids by Treatment

While collecting the erosion data after each storm, it was observed that there seemed to be a relationship between the turbidity of the water in the flow dividers and the treatment from which the divider captured water. It seemed that the water from the zero-cover plots had a higher degree of clarity than did the plots with wood chips The expenmental configuration was not purposely designed to collect information about the eroded particle size However, because

Table 10 Change in coverage by treatment along length of slope after three storm events at the field site

Position	Average coverage by treatment					
	Small-Chips		Mixed-Chips		Large-Chips	
	Mean (%)	Std. Dev.	Mean (%)	Std. Dev.	Mean (%)	Std. Dev
Top 1/3 of slope	60 5	2.9	78 5	3 4	71 5	7 4
Middle 1/3 of slope	46.2	4.2	73 3	4 1	71.7	3.9
Bottom 1/3 of slope	47 7	4.6	70.3	7.8	71 4	1.0

the sediment that settled as a sludge was measured separately from sediment that was suspended in the divider's supernatant, data were collected that suggest that the eroded sediment from the covered plots is less aggregated and does not settle as rapidly (table 11) Likewise, these data also suggest that the cover allows more sediment deposition to take place on the slope rather than further down gradient.

Table 11. Listing of the fraction of sediment collected as settled solids from the field plots

Treatment	Total solids collected (kg)*	Sum of settled soils collected (kg)†	Percent of sediment collected as settled solids
Zero-cover	93.235	90.296	96 8
Small-chips	72.645	70.722	97 4
Mixed-chips	12.609	5.671	45 0
Large-chips	20 607	18.021	87.4

*Within each treatment, the given value represents the sum of the total solids collected from like plots

†Within each treatment, the given value represents the sum of the settled collected from like plots

Box Plot Erosion Data

Companson of Cover Treatments

A latin square configuration allows two different treatments to be performed on the same experimental unit In this case the two treatments were the vanous soil covers and the vanous slopes Information about the surface-coverage effect is summed across slope treatments While this procedure inherently adds noise to the coverage-effect data, the distnbution caused by each coverage-type will be distinguishable from the background noise if the effect is statistically significant. Independent of slope steepness, all the soil loss data were used to create a linear model of the results from each rain event (dry, wet, and very wet). This model was computed using Proc Mixed from SAS (SAS Institute, 1997) Analysis of vanance showed that there were significant variances due to blocking and to treatment effects The ANOVA f-test showed that there was significant difference between the covered treatments and the no-cover treatment. However, there was no difference between the large-chip and mixed-chip treatments. This analysis is summanzed in table 12

The r-squared value produced by Proc Mixed is used to indicate the fraction of vanability that is accounted for in the statistical model. As noted in the bottom of table 12, 93% of the data vanability is accounted for by using blocking, slope, and treatments as the components of the model

As previously descnbed, rain-1 was an one-hour event, rain-2 was a 30-minute event (24 hours after rain-1), and rain-3 was also a 30-minute event (30 minutes after rain-2) The soil loss figures in table 12 represent the soil loss dunng those time periods. It is interesting to note how the rate (mass of soil loss per unit time) decreases through the storm progression. The larger rate of soil loss dunng the first rain may perhaps be due to the process of forming the box plots Just after packing and surfacing, the surface layer of the box plots became very bnttle as the soil dehydrated Although loose soil was swept off the plot, this top layer may have been more

Table 12. Means of soil loss by treatments using box plots (kg)

Treatment	Rain 1 (dry)		Rain 2 (wet)		Rain 3 (very wet)	
	Mean (kg)*	Std. Dev	Mean (kg)	Std Dev.	Mean (kg)	Std Dev
Zero-cover	8 22 a	4 40	2 99 a	1 58	2.31 a	1.03
Large-chips	2 17 b	1 67	0.71 b	0 35	0 44 b	0.27
Mixed-chips	1 43 b	1 21	0.55 b	0 42	0 41 b	0.30
Probability †	$p << 0\ 01$ $R^2 = 0.93$		$p<<0.01$ $R^2 = 0.93$		$p<<0.01$ $R^2 = 0.94$	

*Means with the same letter in the same column are not different
†Probability that treatment means are not different

susceptible to being detached and transported during rain-1. Thus, as the simulation progressed through rain-2 and rain-3, the rate of soil loss declines due to surface layer having a more "typical" resistance to being detached and transported It should be fully expected that there would be "loosened" soil on the surface at construction sites Therefore, it should be expected that there would be an accelerated rate of soil loss measured dunng the first rain event after soil placement and compaction.

This phenomenon is different from how agricultural soils erode Just after tillage, agncultural soils tend to be loose and granular. Dunng the first rain event, this soil provides for very rapid infiltration and thus very little runoff is available for erosion. As time progresses, a thin surface layer is compacted by the raindrop impact (surface crusting) and the infiltration rate is greatly reduced This creates more runoff and therefore, increases the erosion rate

<u>Slope Steepness Effects</u>

Information about the slope steepness effect was derived across cover treatments and, therefore, for each slope the erosion data are summed from each coverage treatment performed at a particular slope The ANOVA did not detect any significant differences in the data due to changing the slope steepness As shown in table 13, the standard deviations are larger than the

Table 13 Means of soil loss by slope from box plots (kg)

Slope	Rain 1 (dry)		Rain 2 (wet)		Rain 3 (very wet)	
	Mean (kg)	Std Dev	Mean (kg)	Std Dev.	Mean (kg)	Std Dev
40% (2.5 1)	4 18	4 07	1 81	1 83	1.17	1 19
50% (2.1)	5 02	5 29	1 45	1 52	1.20	1.21
67% (1 5:1)	2.67	2 50	0.98	0 90	0 76	0.89

difference between means and, therefore, varying the slope steepness within the given range did not significantly affect the soil loss from the box plots

While the results were not statistically different, the means show a decrease in soil loss as the slope steepens This is an indication that interrill was the dominant erosion process. There was less horizontal area as the boxes were tilted, and thus there was less area on which raindrop detachment could occur

Settled-Solids versus Suspended Solids by Treatment

Just as in the field plots, it was observed that the suspended solids from the zero-cover treatments would settle more readily than those from the covered treatments As shown in table 14, for each rain event, the zero-cover treatment had a higher percentage of the total solids deposited in the sediment traps This is an indication of the ability of the cover to reduce the velocity of the runoff and allow the larger particles to settle-out on the plot This reduction in velocity also means a greater depth of flow, which helps to dampen the impact of raindrops against the soil surface.

It is interesting to note that, across treatments, the percentage of settled solids is reduced with progressive rain events. Analogous to the results from table 12, this decrease in the mass of settled solids may be due to the soil loosened during the construction process These pre-loosened soil particles moved off the plot as relatively large aggregates and thus readily settled in the sediment traps As the progression of rain events occurred, more of the

Table 14. Listing of fraction of sediment collected as settled solids (kg) from the box plots

Treatment	Rain 1 (dry)		Rain 2 (wet)		Rain 3 (very wet)	
	Total solids collected (kg)	Percent collected as settled solids	Total solids collected (kg)	Percent collected as settled solids	Total solids collected (kg)	Percent collected as settled solids
Zero-cover	98 598	92.3	35 921	89.5	27.743	87 4
Mixed-chips	17.144	87.1	6 619	80 3	4.924	72 7
Large-chips	26.037	87 7	8.485	80 4	5 321	78.7

finer clay particles became detached and were able to stay in suspension through the sediment traps

Calculation of Cover Management Subfactors from Field and Laboratory Plots

In order to determine a surface cover subfactor for wood chips, the RUSLE equation (equation 5) was rearranged to solve for the cover-management factor (C-factor). For the zero-cover plots, it was assumed that the surface-cover, canopy-cover, surface-roughness, and soil-moisture subfactors (from equation 6) were all equal to one Thus, by solving for the C-factor, a prior-land-use (PLU) value was assigned to field site and to the laboratory plots

Determination of PLU and SC Subfactors from Field Plots

As shown in table 15, the average PLU was determined by averaging the result of dividing the total soil loss from each zero-cover plot by the product of that plot's R·K·LS·P The LS- and K-factors were previously determined (table 6); the R-factor was calculated by summing the EI_{30} for each storm event, and the P-factor was assumed to be one

Table 15 Calculation of PLU-subfactor for compacted clay loam soil at field site

Zero-cover plot I.D.	Total soil loss (t/ha)	(R·K·LS)	PLU-subfactor
5	8 52	197.55	0 0431
8	13 37	210.19	0.0636
7	9.20	207.07	0.0444
			0.0503 mean PLU

Using this average PLU-subfactor, the surface-cover subfactor was similarly calculated for the each of the wood chip treatments These calculations are shown in table 16 It is encouraging to note that the range of values calculated for the surface-cover subfactor of the small-chip treatment is close to the value of one. This treatment provided little soil protection and the RUSLE model assumes a value of one for no surface cover effect

Determination of PLU and SC Subfactors from Laboratory Plots

Data from the zero-cover simulated rainfall plots were used to determine the pnor land use subfactor value of the compacted soil in the box plots Using a procedure modified from Wischmeier et al (1971), the results of the simulated rain events (dry, wet, and very wet) were weighted to approximate the average annual conditions The weighting factors are based on the probability of occurrence of a rain event on dry, field capacity and wet soil-moisture conditions. For the humid Midwest, Wischmeier et al. (1971) computed average annual soil losses per EI unit by summing 13 2.5-inch rains on moderately dry soil, four 1 25 rains on wet soil, and three 2.5-inch rains on wet soils. This procedure was originally used by Wischmeier et al. (1971) to convert data collected from standard unit-plot conditions with simulated rainfall into an average annual K-factor for the soil. They combined the data from the wet and very wet rains to get 2.5

Table 16. Calculation of surface-cover subfactor for each wood chip treatment from the field plots

Plots by Treatment	Total soil loss (t/ha)	(R·K·LS·PLU)	Surface-cover subfactor
Small			
2	9 98	10.065	0 992
9	6 870	10 609	0.648
12	7.366	10.634	0.693
			0.778 mean
Mixed			
3	2 175	10 090	0.216
6	0.955	10.461	0 091
11	1 073	10.955	0.098
			0.135 mean
Large			
1	1.384	10.362	0 134
4	1 051	10.115	0 103
10	4 434	10.780	0 411
			0.216 mean

inches of rain on wet soil Barfield et al (1988) provided the mathematical interpretation of this procedure given in equation 12

$$K = \frac{A}{R} = \frac{13(A_d) + 4(A_w) + 3(A_w + A_{vw})}{13(R_d) + 4(R_w) + 3(R_w + R_{vw})} \quad \ldots\ldots\ldots\ldots [12]$$

The subscripts d, w, and vw represent dry, wet and very wet respectively It is a reasonable extrapolation to use the above procedure to approximate the value of the average annual effects that each of the different cover treatments are likely to produce. For the zero-cover plots, it was assumed that the surface-cover, canopy-cover, surface-roughness, soil-moisture subfactors were equal to one and, thus, the prior land use subfactor would equal the C-factor. Equation 12 was modified to include the assigned K-factor value for the soil and then arranged to solve for the C-factor, thus assigning a prior-land-use subfactor value to the soil compacted in the box plots

$$C = PLU\ SC = \frac{13(A_d) + 4(A_w) + 3(A_w + A_{vw})}{13(R_d\ LS_d \cdot K) + 4(R_w\ LS_w \cdot K) + 3(R_w\ LS_w\ K + R_{vw}\ LS_{vw}\ K)} \quad \ldots [13]$$

Because zero-cover data were used from different slopes, the LS-value from each slope was used to normalize the soil loss data. Subsequently, all the data were weighted for each moisture condition Table 17 is a lists how the data were processed The weighted values were plugged into equation 13 which resulted in a PLU subfactor value of 0.35 for the box plots (equation 14).

$$\frac{13(313\ 80) + 4(113\ 56) + 3(113.56 + 88\ 02)}{13(817.17) + 4(472\ 07) + 3(472\ 07 + 485.28)} = 0.35 \quad \ldots\ldots [14]$$

Table 17 Calculation of PLU-subfactor from zero-cover box plots

Slope	RUSLE Factors	Dry run	Wet run	Very wet run
50%	$\sum$ t/ha	126.72	38 23	30.94
	$\sum EI_{30}$	4,131 10	2,318.10	2,163.10
	LS·K	0 063	0 063	0 063
40%	$\sum$ t/ha	113.65	48 74	33 00
	$\sum EI_{30}$	3,939 51	3,187 71	3,093.84
	LS·K	0 056	0.056	0 056
67%	$\sum$ t/ha	73 43	26 59	24.08
	$\sum EI_{30}$	4,736.66	2,077 74	2,475 31
	LS·K	0.071	0 071	0 071
$\sum$ (t/ha) from each slope		313.80	113.56	88.02
$\sum$ (R·LS·K) from each slope		817.17	472 07	485.28

The data from the large-chip and mixed-chip treatments were then processed in a similar fashion, except that the PLU-subfactor was incorporated into equation 13 as a known value as demonstrated by equation 15.

$$SC = \frac{13(A_d) + 4(A_w) + 3\left(A_w + A_{vw}\right)}{PLU[13(R_d\ LS_d\ K) + 4(R_w\ LS_w\ K) + 3(R_w\ LS_w\ K + R_{vw}\ LS_{vw}\ K)]} \qquad [15]$$

The results of this procedure are listed in table 18 for the large-chip treatment and table 19 for the mixed-chip treatment.

Calculation of the b-Value for All Field and Laboratory Plots

The b-value within the surface cover subfactor equation is an indication of the effectiveness of the surface cover in reducing soil erosion. Values for the SC subfactor have been estimated from the data collected at both the field plots and the simulated rainfall plots. By rearranging the SC subfactor equation, b-values were generated for each coverage treatment at each site

$$\frac{\ln(SC)}{S_P\left(\frac{0.24}{R_u}\right)^{0.08}} = -b \qquad [16]$$

The S_p term is the percentage of land area covered by the surface cover From Table 9, an average of the two measured-coverage values was used for S_p for each of the chip treatments at the field site. A nominal value of 80 percent was used for the S_P term for all the box plot treatments The RUSLE model uses a value of 0.24 for R_u (surface roughness) for smooth, hard surfaces Table 20 provides a listing of the b-value calculations for each of the treatments

Summary of Results for Cover-Management Modeling

These b-values compare very well with values given in the research literature As previously mentioned, if the dominant erosion process is known, a higher b-value should be used

Table 18 Calculation of sc-subfactor from large-chip treatment from the box plots

Slope	RUSLE Factors	Dry run	Wet run	Very wet run
50%	∑ t/ha	48 76	12.06	9.42
	∑ EI_{30}	4,409 24	2,281.74	2,323 42
	LS·K·PLU	0.021	0 021	0 021
40%	∑ t/ha	15.74	7 44	3.97
	∑ EI_{30}	3,714 00	2,035 10	2,483 70
	LS·K·PLU	0 019	0 019	0.019
67%	∑ t/ha	19.57	7 69	3.74
	∑ EI_{30}	4,252.16	2,093.46	2,061.31
	LS·K·PLU	0 024	0 024	0 024
∑ (t/ha) from each slope		84.07	27.19	17 13
∑ (R·LS·K·PLU) from each slope		265.21	136.83	145 45

The large-chip surface cover subfactor is 0.27

Table 19 Calculation of sc-subfactor from mixed-chip treatment from the box plots

Slope	RUSLE Factors	Dry run	Wet run	Very wet run
50%	∑ t/ha	23 83	7 13	7 11
	∑ EI_{30}	3323 15	1738 17	2396.63
	LS·K·PLU	0 021	0.021	0 021
40%	∑ t/ha	20 16	9.89	6 82
	∑ EI_{30}	3408.86	2902 2	2810 73
	LS·K·PLU	0 019	0 019	0.019
67%	∑ t/ha	10.2	3 68	1 55
	∑ EI_{30}	3941 08	1938.39	1949.74
	LS·K·PLU	0 024	0 024	0.024
∑ (t/ha) from each slope		54 19	20 70	15 48
∑ (R·LS·K·PLU) from each slope		229 14	138 16	150 53

The mixed-chip surface cover subfactor is 0.20

Table 20 Comparison of field and laboratory surface cover subfactor values and cover-management factor values

Treatment	SC subfactor	S_p value	Calculated b-value*	Calculated C-factor†
Field Site (PLU=0.05)				
Large-chip	0.216	73	0 021	0 011
Mixed-chip	0.135	78	0.026	0 007
Small-chips	0.778	67	0.004	0.039
Box plots (PLU=0.35)				
Large-chip	0 27	80	0.016	0 095
Mixed-chip	0.20	80	0.020	0 070

*Assuming a R_u value of 0.24 for smooth surface
†Assuming SM = SR = CC = 1

for rill erosion and a lower b-value should be used for interrill erosion The results listed in table 20 reflect this trend. For similar coverage treatments, the field values are higher. The field plots had sufficient slope length for rill erosion to occur; the box plots should have been dominated by interrill erosion

The calculated b-values are well within the range of values given by Renard et al., (1997). Toy and Foster (1998) recommended a b-value of 0 025 for mulch on steep construction sites with highly cohesive soils While the experimental b-values are generally lower than the published values, they are probably not different enough to suggest that the b-value should be slope-dependent. When modeling a construction site, the b-value must be selected with care The b-value is part of an exponential term. Slight changes in the b-value produce order of magnitude changes in the surface cover subfactor value Generally, highly disturbed soils on steep slopes will tend to be dominated by rill erosion, and therefore a mulch surface cover is considered very effective. The literature suggests that the appropriate b-value should be 0 05. For this project, even though some rilling occurred, interrill erosion was probably the dominant source of eroded soil In this case, the literature suggests a b-value of 0.025 The mixed-chip treatment produced a measured b-value of 0 025 Toy and Foster (1998) dιd not ιndιcate any limιtatιons on how steep the slope could be before the b-value was ιnvalιd

Table 20 also lιsts the C-factor values calculated usιng the derived surface cover and pnor land use subfactors Before the revisιon of the Universal Soιl Loss Equatιon, the C-factor for construction sιtes was selected from a table (similar to table 2 in thιs document) from Agncultural Handbook Number 537 (Wιscheιer and Smith, 1978). For a 50% slope and 10 m slope length, table 2 suggest that a wood chιp applιcatιon rate of 56 t/ha wιll yιeld a C-factor value of 0.02 for slope lengths up to 23 m. From Meyer at al (1972), thιs applιcation rate is a 38 mm thιck layer of chιps across the surface. Data from thιs proȷect suggests that only an 80% coverage ιs needed and that the C-factor value ιs 0.007 As a companson, table 2 suggests that if 4 5 t/ha (dry weight) of anchored wheat straw were used on this slope, the C-factor value would be 0.20 The data suggest that, ιf a 80% coverage of wood chips (and a C-factor value of 0 007) were used, the soil loss would be reduced by over twenty-fold The C-factor denved from the data demonstrates that prevιous C-factor values were conservatιve extrapolatιons made from data taken from expenments usιng lesser slopes

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Wood Chips as a Soil Cover

The data provide conclusive results regarding the effectiveness of using wood chips to control the erosion of highly disturbed soils on 50% (2:1) slopes and slope-lengths of 10 m The large-chip treatment reduced erosion by more than 70% in both field and laboratory plots. The mixed-chip treatment reduced erosion by over 80% in both field and laboratory plots. As shown in figure 12, the large-chip and the mixed-chip treatments demonstrate the ability to protect the soil over a wide range of storm erosivities

When a wooded site is cleared, the wood that is not marketable as pulp or timber should be chipped and spread over disturbed soils This process will save on hauling and landfilling costs, reduce the cost of purchasing other soil-cover materials, and allow sediment-control devises located on the site boundaries to work more effectively By processing and stockpiling wood chips on-site, an effective cover can be rapidly applied to disturbed soils when there is going to be a period of soil-work inactivity

By controlling erosion (rather than sediment), on-site erosion damage will be minimized. The repair of erosion damage is not productive work and is a waste of labor and equipment costs. Wood chips as a soil cover will not relax the need for good on-site storm water control Upland water will still need to be diverted, channels will still need to be created to move concentrated flows of water downslope, and permanent cover will still need to be established

Processing the Wood Chips

There is no benefit to separating the chips by size. Overall, the mixed-chip treatment proved superior in providing soil protection When generating wood chips, it will be important to monitor the chipper to insure that the final product is “not all small chips” or “not all large chips.”

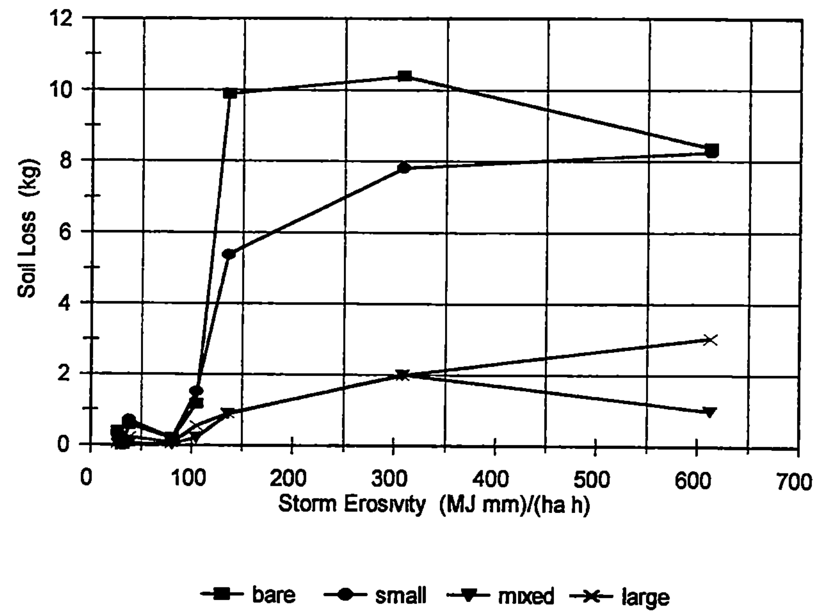


Figure 12 Effect of chip treatments on erosion as a function of storm erosivity

Not requiring size segregation simplifies the use of wood chips as a soil cover, and new technologies are more likely to be adopted if the process is simple. This is an important implication for the adaption of using wood chips as an erosion control best management practice (BMP) As this practice is adopted, an entrepreneur will develop an efficient method for applying the wood chips to the soil surface. Although the "dust fraction" of the particle size distribution was not specifically analyzed by this project, on the short-term, it is likely to enhance the erosion resistance that wood chip mulch can provide to disturbed soils.

Modeling Soil Loss on Construction Sites

The b-value derived from the experimental data compares very well with published values for effective cover on slopes with cohesive soils This project was not able to test a range of slope steepnesses under rilling conditions, and therefore, no conclusive answer can be issued as to the slope steepness dependency of the b-value However, for the purpose of modeling the effectiveness of surface cover, it seems reasonable to follow the RUSLE recommendation of using the erosion process as the basis for selecting the b-value

Recommendations

It is recommended that wood chips be considered for use as an erosion control material rather than disposing of them as a waste. It has been found that an 80% coverage of wood chips can reduce erosion by 80% on slopes as steep as 50% (2:1) and with horizontal lengths up to 10 m as compared to unprotected slopes After trees have been taken down to clear a site for new construction, these trees could be chipped on-site and the chips stockpiled for application over disturbed soil when there is a period of inactivity in soil-moving operations If trees are not harvested, then chips could be obtained from arboriculturists and other generators of wood chips Care will have to be taken to make certain that the wood chips remain free of trash and other debris that could lead to the classification of the chips as a solid waste.

Future Research Needs

The soil used for this project was very cohesive and is representative of the types of soil that are commonly found in East Tennessee This soil does not have the tendency to rill on short slope lengths, so more research is needed to examine the use of wood chips as a cover on soils that have a higher tendency to rill

A common question throughout this project is how the chips would be applied to a steep slope. This project was limited to proving the concept that wood chips could serve as an erosion control BMP on steep slopes. Now that this concept is proven, efficient and effective methods of applying the chips to steep slopes need to be developed and tested

The RUSLE model computes the cover-management factor from five subfactors The prior land use subfactor was used by this project to account for the condition of the soil in relation to how placement and compaction may have affected its erodibility. It was suggested by Harin et al (1994) that additional subfactors need to be incorporated into the cover-management factor calculation that specifically addresses the soil conditioning unique to construction activities. As it is becoming more common to use the RUSLE to model non-agricultural soil disturbances, more research needs to be focused on mathematically correlating the erosion processes that occur with highly disturbed soils located on very steep slopes.

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APPENDICES

APPENDIX A

Data From Field Plots

Erosion Data from Field Plots for Each Event

Table A-1 Total Solids (kg) Eroded During Event One (EI_{30}=612 4)

Treatment	Block A	Block B	Block C	Mean		Std. Dev
Bare	3.690	13 518	7 993	8.400	a	4.927
Small	11 328	7.372	6.102	8.267	a	2 726
Mixed	0 604	1 374	1 007	0 995	b	0.385
Large	2 376	0.541	6 236	3 051	ab	2 907

Means with the same letter are not significantly different
ANOVA p=0 10, least significant difference = 7.189
Maximum Intensities: I_{30} = 63 mm/hr, I_{15} = 120 mm/hr, I_{10} = 162 mm/hr, I_5 = 168 mm/hr

Table A-2 Total Solids (kg) Eroded During Event Two (EI_{30}=308 4)

Treatment	Block A	Block B	Block C	Mean		Std. Dev
Bare	11.761	10 845	8 527	10 378	a	1.667
Small	10 598	6.577	6.285	7.820	a	2.410
Mixed	0.701	4 417	0 841	1 996	b	2.098
Large	0.847	0.545	4 572	1.988	b	2.243

Means with the same letter are not significantly different
ANOVA p=0 01, least significant difference = 4.800
Maximum Intensities: I_{30} = 38 mm/hr, I_{15} = 63 mm/hr, I_{10} = 75 mm/hr, I_5 = 91 mm/hr

Table A-3 Total Solids (kg) Eroded During Event Three (EI_{30}=135.5)

Treatment	Block A	Block B	Block C	Mean		Std. Dev
Bare	8.088	11.934	9 672	9 898	a	1.933
Small	5.009	4 632	6.525	5 389	b	1.002
Mixed	1 056	0.646	0 955	0 886	c	0 214
Large	0 626	0 388	1.672	0.895	c	0.683

Means with the same letter are not significantly different
ANOVA p<<0.05, least significant difference = 2.266
Maximum Intensities I_{30} = 32 mm/hr, I_{15} = 52 mm/hr, I_{10} = 61 mm/hr, I_5 = 82 mm/hr

Table A-4 Total Solids (kg) Eroded During Event Four (EI_{30}=31 8)

Treatment	Block A	Block B	Block C	Mean		Std. Dev
Bare	0.066	0.004	0.007	0 026	a	0.035
Small	0.025	0.002	0.000	0 009	a	0.014
Mixed	0.013	0 008	0 000	0.007	a	0.007
Large	0.000	0.009	0 016	0.008	a	0.008

Means with the same letter are not significantly different
ANOVA p=0 58, least significant difference = 0.036
Maximum Intensities: I_{30} = 12 mm/hr, I_{15} = 16 mm/hr, I_{10} = 17 mm/hr, I_5 = 18 mm/hr

Table A-5 Total Solids (kg) Eroded During Event Five (EI_{30}=80 3)

Treatment	Block A	Block B	Block C	Mean		Std. Dev
Bare	0.460	0.027	0.098	0.195	a	0 232
Small	0.363	0.192	0.001	0 185	a	0.181
Mixed	0.083	0.004	0 000	0.029	a	0 047
Large	0 083	0.050	0.071	0 068	a	0 017

Means with the same letter are not significantly different
ANOVA p=0.25, least significant difference = 0.217
Maximum Intensities: I_{30} = 23 mm/hr, I_{15} = 31 mm/hr, I_{10} = 37 mm/hr, I_5 = 43 mm/hr

Table A-6 Total Solids (kg) Eroded During Event Six (EI_{30}=38 5)

Treatment	Block A	Block B	Block C	Mean		Std. Dev
Bare	0 627	0.705	0.443	0.591	a	0.135
Small	0.728	0.965	0.400	0 698	a	0.284
Mixed	0 107	0.007	0 063	0.059	b	0 050
Large	0.148	0 174	0.374	0.232	b	0.124

Means with the same letter are not significantly different
ANOVA p=0 01, least significant difference = 0.359
Maximum Intensities: I_{30} = 10 mm/hr, datalogger failure - used airport hourly rain data

Table A-7 Total Solids (kg) Eroded During Event Seven (EI_{30}=27.2)

Treatment	Block A	Block B	Block C	Mean		Std Dev
Bare	0.200	0.815	0.199	0.404	a	0.355
Small	0.207	0.551	0.193	0 317	a	0.203
Mixed	0 012	0 007	0.039	0.019	b	0.017
Large	0.034	0.078	0 105	0.072	ab	0 036

Means with the same letter are not significantly different
ANOVA p=0.09, least significant difference = 0.350
Maximum Intensities: I_{30} = 11 mm/hr, I_{15} = 17 mm/hr, I_{10} = 21 mm/hr, I_5 = 24 mm/hr

Table A-8 Total Solids (kg) Eroded During Event Eight (EI_{30}=104.8)

Treatment	Block A	Block B	Block C	Mean		Std. Dev
Bare	0 644	2.253	0 659	1.185	a	0.925
Small	1.681	1.103	1 806	1.530	a	0.375
Mixed	0 289	0.062	0.284	0.212	b	0.130
Large	0.037	1.368	0 257	0 554	ab	0.713

Means with the same letter are not significantly different
ANOVA p=0.14, least significant difference = 1 261
Two rain events - one data collection
Rain event one I_{30} = 13 mm/hr
Rain event two I_{30} = 10 mm/hr

Frontal event that drizzled rain for nearly 30 days Two significant rain events were recorded, however, runoff was only collected once Too wet to gain access to the site

Table A-9 Total Solids (kg) Eroded During Field Study (EI_{30}=1338.9)

Treatment	Block A	Block B	Block C	Mean		Std. Dev.
Bare	25 536	40.101	27 598	31 078	a	7 882
Small	29.939	20.609	22 097	24.215	a	5.013
Mixed	2 868	6 525	3 219	4 203	b	2.019
Large	4.151	3.153	13.303	6.869	b	5.594

Means with the same letter are not significantly different
ANOVA p=0 005, least significant difference = 12.568

Table A-10 Raw data from the field site on a per storm basis

Plot	Runoff Volume (L)	Total Solids (kg)	Fraction of Settled Solids	Type of Cover	Event ID	Block	EI30 english units	Days from Start	Overall L S	Equivalent Slope	Tons per acre
Storm One											
1	259 6	2 376	0 97	Large	1	A	35 98	1	4 19	52 8	0 354
2	228.4	11.328	0.99	Small	1	A	35 98	1	4 07	50 9	1 686
3	992.32	1 374	0.85	Mixed	1	B	35 98	1	4 08	51 1	0 204
4	435 04	0.541	0	Large	1	B	35 98	1	4 09	51 1	0 081
5	750 4	3.69	0 97	Bare	1	A	35 98	1	4.02	50 1	0 549
6	305.68	0.604	0	Mixed	1	A	35.98	1	4 23	53 5	0 090
7	78 4	7 993	0.99	Bare	1	C	35 98	1	4 22	53 2	1 190
8	149 68	13 518	0 99	Bare	1	B	35 98	1	4.28	54.3	2.012
9	1516 48	6 102	0 97	Small	1	B	35 98	1	4 29	54.4	0.908
10	377.2	6.236	0 98	Large	1	C	35 98	1	4 36	55 5	0 928
11	520	1.007	0 94	Mixed	1	C	35 98	1	4 43	56.6	0 150
12	211.6	7.372	0 99	Small	1	C	35.98	1	4 3	54 5	1 097
Storm Two											
1	147 04	0 847	0 92	Large	2	A	18.12	6	4 19	52 8	0 126
2	1268 8	10 598	0.98	Small	2	A	18.12	6	4 07	50 9	1 577
3	5231.68	4.417	0	Mixed	2	B	18 12	6	4.08	51.1	0.657
4	808	0 5446	0	Large	2	B	18 12	6	4.09	51 1	0.081
5	2708 8	11.761	0 95	Bare	2	A	18 12	6	4.02	50 1	1.750
6	460	0.701	0.79	Mixed	2	A	18 12	6	4 23	53 5	0 104
7	472 48	8 527	0.97	Bare	2	C	18 12	6	4.22	53 2	1 269
8	744.64	10 845	0.97	Bare	2	B	18 12	6	4 28	54 3	1.614
9	520	6 2854	0 98	Small	2	B	18 12	6	4 29	54 4	0.935
10	6625 6	4 572	0.95	Large	2	C	18 12	6	4.36	55 5	0 680
11	928 96	0 8706	0 91	Mixed	2	C	18 12	6	4 43	56.6	0 130
12	1792.96	6.577	0.98	Small	2	C	18 12	6	4.3	54 5	0.979

Table A-10 Cont Raw data from the field site on a per storm basis

Plot	Runoff Volume (L)	Total Solids (kg)	Fraction of Settled Solids	Type of Cover	Event ID	Block	EI30 english units	Days from Start	Overall L S	Equivalent Slope	Tons per acre
Storm Three											
1	177.04	0.626	0.94	Large	3	A	7.96	8	4 19	52.8	0 093
2	465 04	5.009	0.97	Small	3	A	7 96	8	4.07	50 9	0.745
3	472 48	0 646	0 31	Mixed	3	B	7.96	8	4.08	51 1	0.096
4	515 2	0 388	0 47	Large	3	B	7 96	8	4.09	51 1	0 058
5	520	8 088	0 96	Bare	3	A	7 96	8	4 02	50.1	1 204
6	635 2	1 056	0 38	Mixed	3	A	7 96	8	4.23	53 5	0 157
7	1051 648	9.672	0 96	Bare	3	C	7.96	8	4.22	53 2	1.439
8	1051.648	11 934	0 96	Bare	3	B	7 96	8	4 28	54 3	1.776
9	1516.48	6 525	0 94	Small	3	B	7 96	8	4 29	54.4	0 971
10	249 76	1.672	0 96	Large	3	C	7 96	8	4.36	55 5	0 249
11	457 6	0.955	0.76	Mixed	3	C	7 96	8	4.43	56 6	0.142
12	520	4.632	0.96	Small	3	C	7 96	8	4 3	54 5	0 689
Storm Four											
1	42 952	0	0	Large	4	A	1 87	41	4 19	52 8	0 000
2	40 384	0 025	1	Small	4	A	1.87	41	4.07	50 9	0 004
3	23 8	0 008	0 88	Mixed	4	B	1 87	41	4.08	51 1	0 001
4	101.44	0.009	1	Large	4	B	1 87	41	4.09	51 1	0 001
5	160	0 066	0 98	Bare	4	A	1 87	41	4 02	50.1	0 010
6	20.8	0 013	0 92	Mixed	4	A	1 87	41	4.23	53.5	0 002
7	87.04	0.007	1	Bare	4	C	1.87	41	4.22	53 2	0 001
8	20 8	0 004	1	Bare	4	B	1 87	41	4 28	54.3	0.001
9	57.04	0	0	Small	4	B	1 87	41	4 29	54.4	0.000
10	44 224	0.016	1	Large	4	C	1 87	41	4 36	55.5	0 002
11	20 8	0	0	Mixed	4	C	1 87	41	4 43	56.6	0 000
12	76.48	0 002	0 5	Small	4	C	1.87	41	4 3	54.5	0.000

Table A-10 Cont Raw data from the field site on a per storm basis

Plot	Runoff Volume (L)	Total Solids (kg)	Fraction of Settled Solids	Type of Cover	Event ID	Block	EI30 english units	Days from Start	Overall L.S	Equivalent Slope	Tons per acre
Storm Five											
1	151 12	0 083	0.95	Large	5	A	4.72	49	4.19	52.8	0 012
2	144 16	0 363	0.95	Small	5	A	4.72	49	4.07	50 9	0.054
3	30 4	0 004	0	Mixed	5	B	4 72	49	4 08	51 1	0 001
4	141 52	0 05	0 96	Large	5	B	4 72	49	4.09	51.1	0.007
5	464.8	0.46	0 96	Bare	5	A	4 72	49	4 02	50.1	0.068
6	36 544	0 083	1	Mixed	5	A	4 72	49	4.23	53 5	0 012
7	56 8	0.098	0 96	Bare	5	C	4 72	49	4.22	53 2	0.015
8	20 8	0 027	0 85	Bare	5	B	4 72	49	4.28	54 3	0.004
9	97 6	0.001	0	Small	5	B	4 72	49	4.29	54 4	0.000
10	137 44	0 071	0.92	Large	5	C	4.72	49	4.36	55 5	0 011
11	30 4	0	0	Mixed	5	C	4.72	49	4.43	56.6	0 000
12	157 84	0.192	0 98	Small	5	C	4 72	49	4 3	54.5	0.029
Storm Six											
1	328	0.148	0.76	Large	6	A	2 26	57	4 19	52 8	0 022
2	237.04	0 728	0 97	Small	6	A	2 26	57	4.07	50 9	0.108
3	40 48	0 007	0 43	Mixed	6	B	2 26	57	4 08	51.1	0.001
4	520	0.174	0 81	Large	6	B	2 26	57	4 09	51.1	0 026
5	490 24	0.627	0 94	Bare	6	A	2 26	57	4 02	50 1	0.093
6	118 72	0.107	0 9	Mixed	6	A	2.26	57	4.23	53 5	0.016
7	224 32	0 443	0.93	Bare	6	C	2.26	57	4.22	53 2	0 066
8	20 8	0 705	1	Bare	6	B	2 26	57	4 28	54 3	0 105
9	465.04	0.4	0.91	Small	6	B	2 26	57	4 29	54 4	0.060
10	405.52	0 374	0 91	Large	6	C	2.26	57	4.36	55 5	0 056
11	252.4	0 063	0 59	Mixed	6	C	2 26	57	4 43	56 6	0 009
12	381.76	0.965	0 99	Small	6	C	2.26	57	4.3	54 5	0 144

Table A-10 Cont Raw data from the field site on a per storm basis

Plot	Runoff Volume (L)	Total Solids (kg)	Fraction of Settled Solids	Type of Cover	Event ID	Block	EI30 english units	Days from Start	Overall L S	Equivalent Slope	Tons per acre
Storm Seven											
1	82.96	0 034	0.97	Large	7	A	1.60	91	4 19	52 8	0 005
2	208 72	0 207	0 91	Small	7	A	1 60	91	4 07	50 9	0.031
3	28.96	0 007	0 71	Mixed	7	B	1.60	91	4.08	51 1	0 001
4	396 64	0 078	0 33	Large	7	B	1 60	91	4.09	51 1	0 012
5	439.6	0 2	0 96	Bare	7	A	1 60	91	4.02	50 1	0 030
6	109.36	0 012	1	Mixed	7	A	1 60	91	4 23	53 5	0 002
7	215 92	0.199	0.92	Bare	7	C	1.60	91	4 22	53.2	0.030
8	347 92	0.815	0 95	Bare	7	B	1.60	91	4.28	54.3	0 121
9	137 44	0 193	0.95	Small	7	B	1.60	91	4 29	54 4	0 029
10	141 52	0.105	0 95	Large	7	C	1.60	91	4 36	55.5	0 016
11	20.8	0.039	1	Mixed	7	C	1.60	91	4 43	56.6	0 006
12	427.6	0 551	0 97	Small	7	C	1 60	91	4 3	54 5	0 082
Storm Eight											
1	520	0 037	0.97	Large	8	A	6.16	133	4 19	52 8	0 006
2	1205.44	1.681	0.93	Small	8	A	6 16	133	4.07	50.9	0 250
3	189 28	0 062	0 75	Mixed	8	B	6 16	133	4.08	51 1	0.009
4	12500 8	1 368	0 62	Large	8	B	6.16	133	4 09	51 1	0 204
5	3613.12	0.644	0.86	Bare	8	A	6 16	133	4.02	50 1	0 096
6	430 72	0.289	0.95	Mixed	8	A	6 16	133	4.23	53 5	0 043
7	1919 68	0.659	0.89	Bare	8	C	6 16	133	4 22	53 2	0 098
8	520	2 253	0 99	Bare	8	B	6 16	133	4.28	54 3	0 335
9	6251 2	1 103	0.94	Small	8	B	6 16	133	4 29	54.4	0 164
10	6631.36	0 257	0.98	Large	8	C	6.16	133	4.36	55 5	0 038
11	8722 24	0 284	0.94	Mixed	8	C	6.16	133	4.43	56 6	0 042
12	520	1.806	0.98	Small	8	C	6.16	133	4 3	54 5	0.269

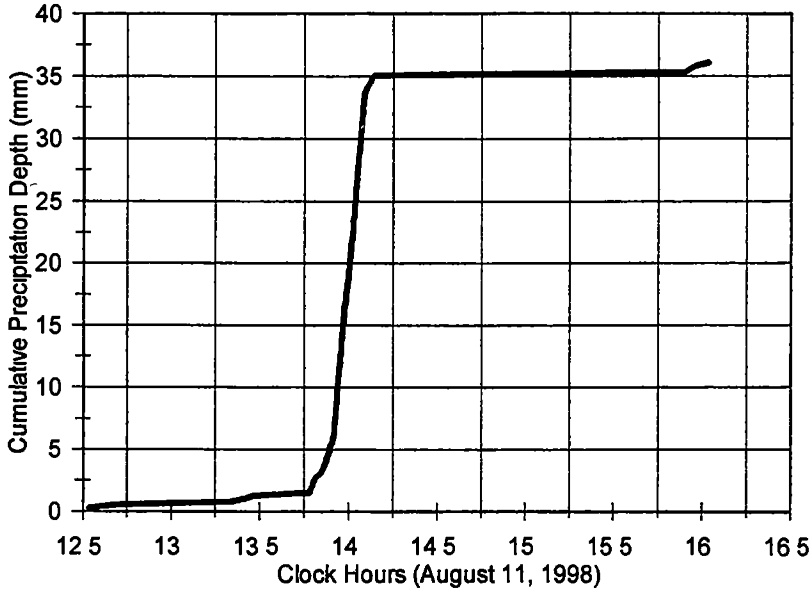

Figure A-1. Rainfall depth and intensity data from storm one.

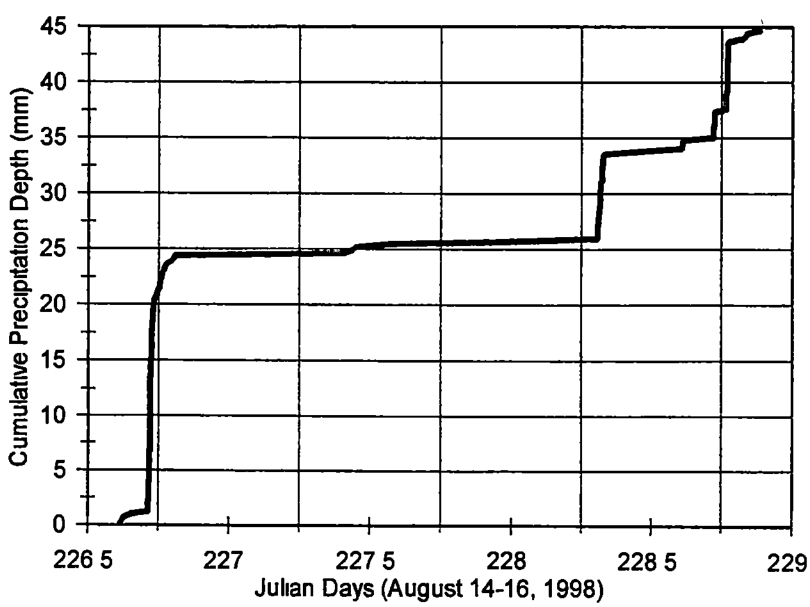

Figure A-2 Rainfall depth and intensity data from storm two.

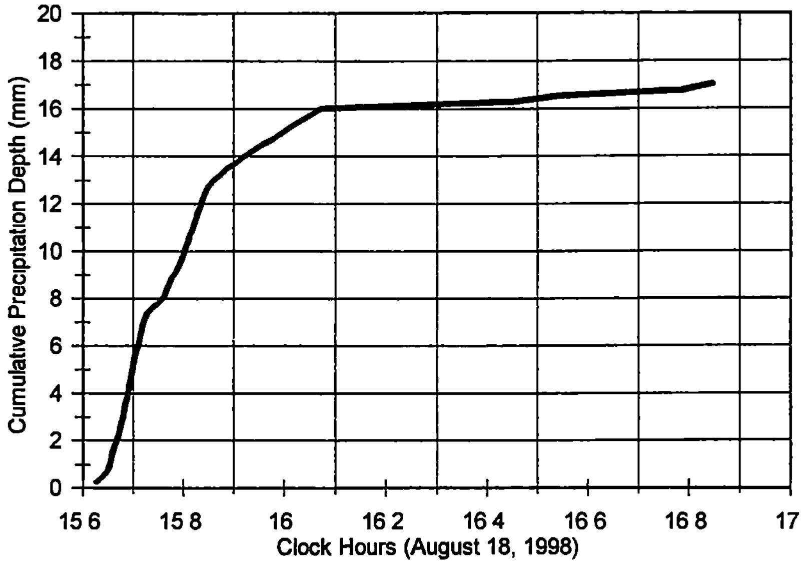

Figure A-3. Rainfall depth and intensity data from storm three

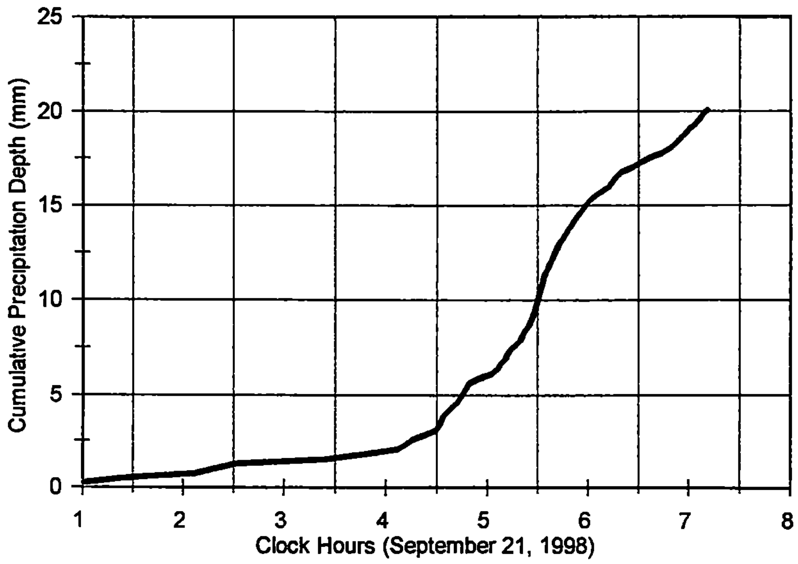

Figure A-4 Rainfall depth and intensity data from storm four

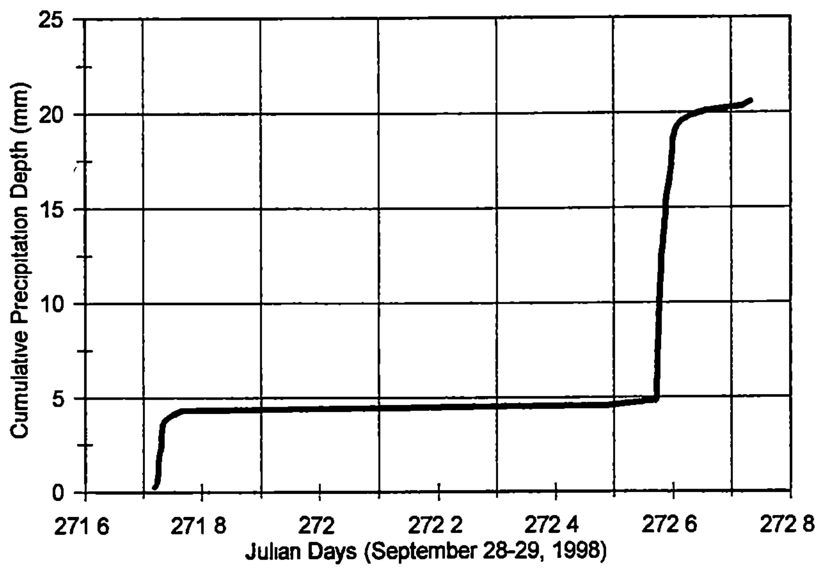

Figure A-5 Rainfall depth and intensity data from storm five

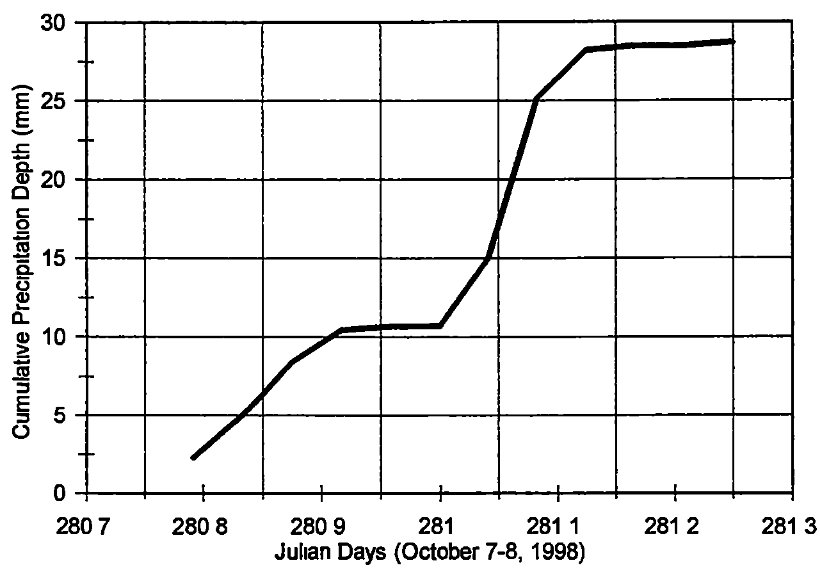

Figure A-6. Rainfall depth and intensity data from storm six.

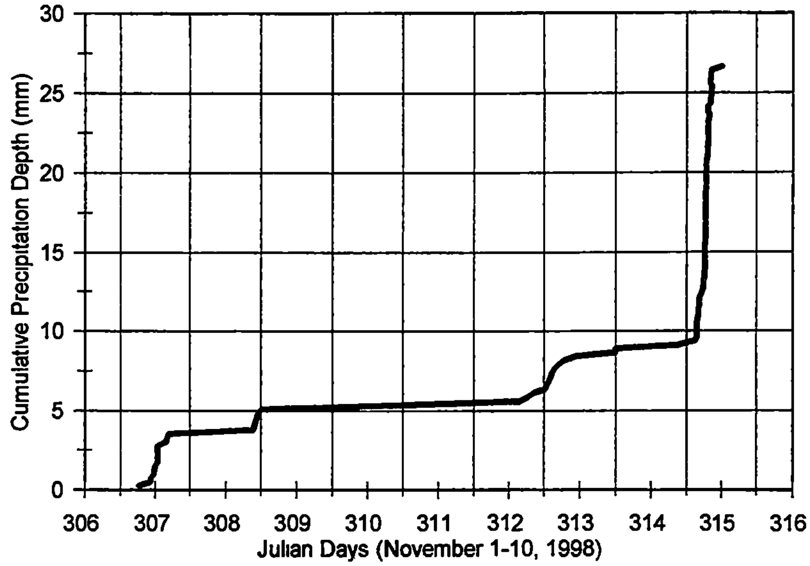

Figure A-7 Rainfall depth and intensity data from storm seven

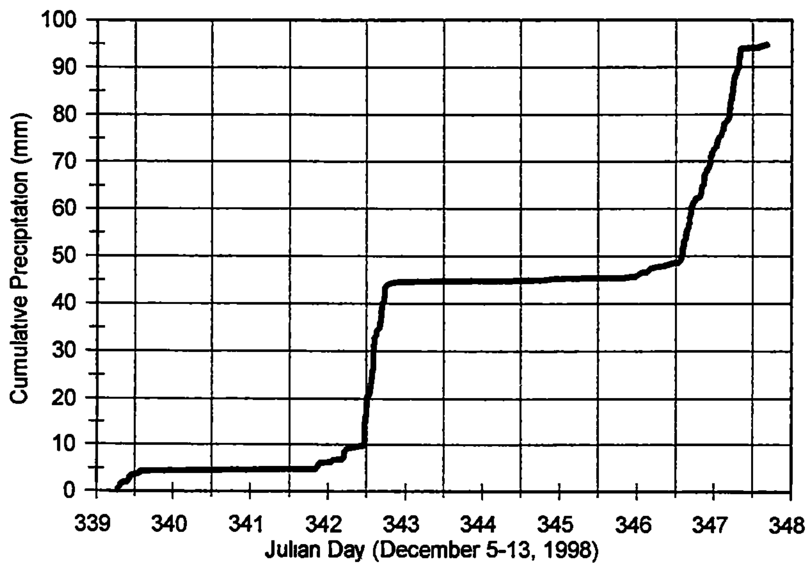

Figure A-8 Rainfall depth and intensity data from storm eight

APPENDIX B

Data From Box Plots

Table B-1 Quality control data from the construction of the box plots

Block	Slope	Box	Treatment	Date Packed	Date of First Run	Density at First Run (pcf)	Moisture at First Run (%)	Percent Cover (%)
A	50%	1	Large	16-Jun-99	12-Jul-99			80.0%
A	50%	2	Bare	16-Jun-99	28-Jun-99			0 0%
A	50%	3	Large	16-Jun-99	06-Jul-99			80.0%
A	50%	6	Mixed	16-Jun-99	12-Jul-99			80.0%
A	50%	7	Bare	16-Jun-99	06-Jul-99			0 0%
A	50%	8	Mixed	16-Jun-99	28-Jun-99			80.0%
B	50%	2	Bare	15-Jul-99	21-Jul-99	99 3	22.5%	0.0%
B	50%	8	Large	15-Jul-99	23-Jul-99	94.0	26.6%	80.0%
B	50%	4	Mixed	15-Jul-99	26-Jul-99	89.5	28 3%	82.0%
B	50%	5	Bare	15-Jul-99	21-Jul-99	94.4	25.3%	0 0%
B	50%	7	Mixed	15-Jul-99	23-Jul-99	92.9	25.3%	80.0%
B	50%	3	Large	15-Jul-99	26-Jul-99	95 9	24.8%	80.3%
C	40%	1	Large	29-Jul-99	30-Jul-99	96.7	22.0%	82.0%
C	40%	2	Mixed	29-Jul-99	04-Aug-99	101.0	17.5%	80.0%
C	40%	5	Bare	29-Jul-99	30-Jul-99	96.7	21.0%	0 0%
C	40%	6	Bare	29-Jul-99	02-Aug-99	99.1	20.8%	0.0%
C	40%	7	Large	29-Jul-99	02-Aug-99	93 5	22.4%	80.3%
C	40%	8	Mixed	29-Jul-99	04-Aug-99	91.9	20.6%	81 0%
D	40%	1	Mixed	06-Aug-99	13-Aug-99	90.4	30.3%	80.0%
D	40%	3	Mixed	06-Aug-99	09-Aug-99	91.9	29.1%	80.0%
D	40%	4	Bare	06-Aug-99	13-Aug-99	92.8	29.9%	0.0%
D	40%	5	Large	06-Aug-99	11-Aug-99	97.2	27.0%	79 7%
D	40%	6	Large	06-Aug-99	11-Aug-99	93.3	27 7%	79 3%
D	40%	7	Bare	06-Aug-99	09-Aug-99	93.2	26.4%	0 0%
E	67%	2	Large	17-Aug-99	18-Aug-99	96.2	25.3%	79.3%
E	67%	3	Bare	17-Aug-99	22-Aug-99	97 9	25 5%	0.0%
E	67%	5	Mixed	17-Aug-99	22-Aug-99	97 4	23.7%	83.0%
E	67%	6	Mixed	17-Aug-99	20-Aug-99	96.9	28 3%	79.0%
E	67%	7	Large	17-Aug-99	20-Aug-99	91.9	26 4%	78 0%
E	67%	8	Bare	17-Aug-99	18-Aug-99	96.4	27.9%	0.0%
F	67%	1	Bare	24-Aug-99	27-Aug-99	99.5	20.8%	0 0%
F	67%	2	Mixed	24-Aug-99	25-Aug-99	94.0	26.8%	84.0%
F	67%	4	Mixed	24-Aug-99	25-Aug-99	98 0	27 0%	80.3%
F	67%	6	Large	24-Aug-99	27-Aug-99	95.0	26.3%	82 3%
F	67%	7	Bare	24-Aug-99	26-Aug-99	90 1	30 1%	0.0%
F	67%	8	Large	24-Aug-99	26-Aug-99	96 3	28.3%	83 0%

Table B-2 Raw data from box plots

Block	Slope	Box	Treatment	Settled Solids Run 1 (kg)	Settled Solids Run 2 (kg)	Settled Solids Run 3 (kg)	Suspend Solids Run 1 (kg)	Suspend Solids Run 2 (kg)	Suspend Solids Run 3 (kg)	Collected Water Run 1 (L)	Collected Water Run 2 (L)	Collected Water Run 3 (L)
A	50%	1	Large	5.824	1 083	0 921	0 676	0 203	0 183	245 453	127 793	115 945
A	50%	2	Bare	11.585	3 989	3 671	0 772	0.411	0 262	195.565	116 656	104 949
A	50%	3	Large	3 664	1 074	0 672	0 447	0 156	0.142	230 912	122.193	127.793
A	50%	6	Mixed	3 855	0.73	0 659	0 396	0 201	0 258	207 259	115.388	123 479
A	50%	7	Bare	17.704	4.61	3 123	0.748	0 198	0.342	225 77	124 769	112.093
A	50%	8	Mixed	1 332	0.532	0 53	0 2	0 125	0 144	190 876	91.932	116 656
B	50%	2	Bare	3 293	1.087	0 803	0 433	0 218	0.203	246 751	118 959	127 793
B	50%	8	Large	2 012	0.409	0 347	0.272	0.119	0.135	239 885	127 793	127 793
B	50%	4	Mixed	0 419	0 19	0 21	0.157	0 085	0.111	215 508	100.839	127 793
B	50%	5	Bare	3 305	0 855	0 755	0.422	0 179	0 187	255 585	127.793	127 793
B	50%	7	Mixed	0 703	0 228	0 172	0 129	0.063	0 067	219 725	115 388	127.793
B	50%	3	Large	1.67	0.507	0 376	0 218	0.109	0.081	240.654	106 189	118.959
C	40%	1	Large	0.738	0 403	0 168	0.242	0 13	0 085	255.585	114.123	158 742
C	40%	2	Mixed	1.273	0.724	0 428	0 153	0 137	0 131	230.561	173.303	167.501
C	40%	5	Bare	7 014	1 954	1.519	0 702	0 332	0.42	239 885	111 603	138 164
C	40%	6	Bare	7 651	3.499	2 4	0.983	0 438	0.365	240 654	146 042	143.162
C	40%	7	Large	1 755	0 607	0 34	0 279	0 266	0 1	234 347	137 824	143 744
C	40%	8	Mixed	0 672	0 228	0.148	0 129	0 125	0 139	212 392	159 06	158 647

Table B-2 Cont Raw data from box plots

Block	Slope	Box	Treatment	Settled Solids Run 1 (kg)	Settled Solids Run 2 (kg)	Settled Solids Run 3 (kg)	Suspend Solids Run 1 (kg)	Suspend Solids Run 2 (kg)	Suspend Solids Run 3 (kg)	Collected Water Run 1 (L)	Collected Water Run 2 (L)	Collected Water Run 3 (L)
D	40%	1	Mixed	2 671	1 241	0 671	0 382	0 273	0 204	255 585	150 926	142.958
D	40%	3	Mixed	1 265	0 491	0 444	0 223	0 1	0.125	246 751	118 959	124 769
D	40%	4	Bare	8 43	5 372	3 208	0 482	0 583	0 429	217 327	150 982	155 897
D	40%	5	Large	0.825	0 387	0 221	0 171	0 119	0.065	217 905	127 793	127 793
D	40%	6	Large	0 995	0 365	0 258	0 185	0 182	0 074	255 585	124 769	119 63
D	40%	7	Bare	11.418	3 576	2.225	0 872	0 364	0 343	293 114	205 935	179 648
E	67%	2	Large	0 815	0 264	0 188	0 17	0 087	0.056	243 738	108 68	114 123
E	67%	3	Bare	5 867	2.118	2 23	0.712	0.136	0.24	290 537	119 63	127 793
E	67%	5	Mixed	1.841	0.62	0 118	0.204	0.083	0 067	228 481	119 63	116.656
E	67%	6	Mixed	0.719	0.272	0.155	0.139	0.049	0.05	229.589	124.769	124 769
E	67%	7	Large	1.432	1 028	0.305	0 194	0 138	0.077	218.169	124 769	124 769
E	67%	8	Bare	5 534	1 701	1 442	0.473	0.181	0.181	252.562	108.68	124.769
F	67%	1	Bare	6 283	2 355	1 977	0 581	0 348	0.339	219 631	132 328	136 358
F	67%	2	Mixed	0.108	0.024	0 016	0 054	0 041	0 031	271 013	123 479	124 769
F	67%	4	Mixed	0 067	0.034	0 03	0 053	0 023	0 016	246 985	116 656	119 63
F	67%	6	Large	2 518	0 54	0 278	0.269	0 113	0 097	272.984	141 097	124 963
F	67%	7	Bare	2.958	1 044	0 904	0 376	0 373	0 175	285 466	134 179	148 529
F	67%	8	Large	0.586	0.153	0 111	0.08	0 043	0 041	262 094	119.63	127.372

APPENDIX C

Listing of SAS Programs Used to Analyze Erosion Data

SAS Program Used to Analyze Treatments Effects in Field Plots

```
title "Event ?",
options ls = 75  ps = 55;
data one,
input plot volume solids concen treat $ event block $;
cards;

(data inserted here)

,
proc glm;
class block treat;
model solids=block treat;
means treat/lsd,
means treat,
run;
```

SAS Program Used to Determine Coverage Effects in Box Plots

```
title "  ";
options ls=77 ps=50,
data one,
     input block $ slope $ box cover $ solids,
cards,

(data inserted here)

;
proc sort; by block cover,
proc means no pnnt;  by block cover,
     var solids,
     output out=mmm mean=msolids,
run,

proc plot,  plot msolids*cover=block,
run,
proc glm data=one,
     class block cover,
     model solids = block cover block*cover,
     test h=cover e=block*cover,
lsmeans cover /s p e=block*cover,
means cover,
output out=rr r=rcover,
run,

proc univariate plot normal;
     var rcover,
run,
```

<u>SAS Program Used to Determine Slope Effects in Box Plots</u>

```
title "Box Plot Data - Dry Run Using kg per EI-30 -  Proc Mixed";
options ls=77 ps=50,
data one,
     input block $ slope $ box cover $ usol1 usol2 usol3;
cards,

(data inserted here)

,
proc sort, by block cover,
proc means noprint;  by block cover;
     var usol1;
     output out=mmm mean=musol1;
run,

proc plot;  plot musol1*cover=block,
run;
proc mixed data=one,
     class slope block cover,
     model usol1 = slope|cover/predicted,
     random block(slope) cover*block(slope),
lsmeans cover|slope / pdiff;
 make 'diffs' out=ppp noprint;
 make 'lsmeans' out=mmm noprint;
 make 'predicted' out=rrr noprint,
run,
%include 'a:pdmix612.sas';
```

[See Dr. Arnold Saxton, Institute for Agriculture, Department of Statistical and Computing Service for a copy of this copyrighted subroutine]

```
%pdmix612(ppp,mmm),
run,

proc univariate plot normal data=rrr,
     var _resid_;
run;
```

APPENDIX D

Results of Analyzes of Soil Physical Properties

Grain Size Analysis

Table D-1 Determination of sand fraction (percent passing)

	Sample 1	Sample 2	Sample 3
#8 sieve	100%	100%	100%
#16 sieve	100%	100%	100%
#40 sieve	99 9%	99 5%	99 4%
#200 sieve	63 7%	63 9%	57 6%
% sand	36 6%	36 1%	42 4%

Table D-2 Results of hydrometer analysis

Sample	Time (min)	hydrometer reading (g/L)	Temp (C)	Corrected distance (cm)	grain size (mm)	% finer by weight
one	1	32 0	26 0	10 11	0 0406	59 5
	2	30 5	26 0	10 35	0 0290	56 5
	3	30 0	26 0	10 43	0 0238	55 5
	4	29 5	25 0	10 51	0 0209	54 0
	8	29 0	25 0	10 59	0 0149	53 0
	15	28 0	25 0	10 75	0 0109	51 0
	30	25 8	24 0	11 10	0 0079	46 2
	60	24 5	25 0	11 31	0 0056	44 0
	240	22 0	25 0	11 71	0 0029	39 0
	900	21 0	24 0	11 87	0 0015	36 6
two	1	32 0	26 0	10 11	0 0406	59 5
	2	31 0	26 0	10 27	0 0289	27 5
	3	30 5	26 0	10 35	0 0237	56 5
	4	30 0	25 0	10 43	0 0208	55 0
	8	39 5	25 0	10 51	0 0148	54 0
	15	28 5	25 0	10 67	0 0109	52 0
	30	27 0	24 0	10 91	0 0079	48 6
	60	26 0	25 0	11 07	0 0055	47 0
	240	24 0	25 0	11 39	0 0028	43 0
	900	21 2	24 0	11 83	0 0015	37 0

Results: 38.3% clay, 23.5% silt, and 38.2% sand

Atterberg Lımits and Standard Effort Procter Results

Table D-3 Results of the Atterberg lımıts test

sample no.	pan + wet soıl (gr)	pan + dry soıl (gr)	water lost (gr)	dry soıl (gr)	tare (gr)	moisture content	blows
1	9.55	7 18	2 37	5 36	1.82	0.44	55
2	14 15	10.24	3 91	8 42	1.82	0 46	26
3	13.70	9 77	3 93	7 95	1.82	0 49	15
4	13 56	10 16	3 40	8.33	1 83	0.41	60
5	15.37	11 24	4 13	9 42	1 82	0 44	49
6	13 98	10 19	3.79	8.37	1 82	0.45	36
7	11.03	8 00	3.03	6 18	1.83	0 49	16

Liquid limit = 46.78 moisture content

Plastic limit = 34.83 moisture content

Plastic Index = 46.78 - 34.83 = 11.95

Table D-4 Results from Procter tests on fill soıl

test one	dry weıght (kN/m^3)	moısture content	100% saturatıon
	13 66	18 7	17.35
	15.04	24.2	15.82
	14.94	27 7	14.97
	14.02	31 0	14.25
test two	13.42	16.6	18 02
	14.68	19 7	17.05
	15 47	24.2	15.82
	13 81	32 1	14.03

polynomıal fit to data unıt weıght = -15 3 + 9.01(%moısture) - 0 18(%moısture)^2

optimum moisture = 24.8 and maximum unit weight = 15.2 kN/m^3

VITA

John Raymond Buchanan was born May 19, 1962 in Davidson County, Tennessee Soon thereafter, the family moved to Cheatham County, Tennessee where John attended public school at East Cheatham Elementary and graduated from Cheatham County Central High School in June 1980. The following September he entered The University of Tennessee, Knoxville and in June 1985 received the degree of Bachelor of Science in Agricultural Engineering. Following graduation, John accepted the position of Production Manager Trainee with Purina Mills Inc., in Nashville, Tennessee He was subsequently promoted to Shift Supervisor and then to Production Supervisor at Purina Mills Inc.'s Sioux City, Iowa plant

In September of 1989, John accepted the position of Research Associate at the University of Tennessee, Agricultural Experiment Station in the Department of Agricultural Engineering. At the same time, he reentered The University of Tennessee, Knoxville to pursue graduate work in engineering. In May of 1993, John received a Master of Science degree in Agricultural Engineering with a minor in Environmental Engineering John anticipates receiving the degree of Doctor of Philosophy, with a major in Civil Engineering in May of 2000 and will continue to serve in the faculty position he accepted in September of 1998 with the Tennessee Agricultural Extension Service as a Soil and Water Conservation Extension Engineer.

John is married to the former Miss L Darlene Taylor who is a tenured teacher at Central Elementary School in Morgan County, Tennessee. They reside in Roane County, Tennessee