2003-05

Final Report

Characteristics of Erosion Control Measures and Their Impact on Erosion

Minnesota Department of Transportation

Research

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
MN/RC – 2003-05		

4. Title and Subtitle	5. Report Date
CHARACTERISTICS OF EROSION CONTROL MEASURES AND THEIR IMPACT ON EROSION	June 2002
	6.
7. Author(s)	8. Performing Organization Report No.
Udai Singh, Anita Thompson, Bruce Wilson, Hung Nguyen and Brad Hansen	
9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
Department of Biosystems and Agricultural Engineering University of Minnesota 1390 Eckles Avenue St. Paul, MN 55108	11. Contract (C) or Grant (G) No. (c) 74708 (wo) 139
12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
Minnesota Department of Transportation Office of Research Services 395 John Ireland Boulevard Mail Stop 330 St. Paul, Minnesota 55155	Final Report 2002
	14. Sponsoring Agency Code

15. Supplementary Notes

Contact the Minnesota Department of Transportation for a copy of the appendices for this report.

16. Abstract (Limit: 200 words)

This report presents the results of a field study on the performance of erosion control products under artificial rainfall conditions, bed shear partitioning using a hydraulic flume, and regression analysis of previously published data. Ninety-six runs of different plot lengths, erosion control treatments, vegetative cover, and initial moisture contents were gathered and analyzed. Above-ground biomass varied substantially within the growing season, runoff was most strongly influences by initial moisture content, and sediment load was substantially reduced using erosion control products and mulches. In the hydraulic flume experiments, the percentage of the total shear acting on soil particles was less than 13.2% for all tests. Failure to obtain a large data base of product characteristics greatly limited the use of regression analysis to explain the performance of erosion control blankets.

17. Document Analysis/Descriptors		18.Availability Statement
Erosion Control Products Vegetation Establishment	Soil Erosion Slope Hydrology	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	72	

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Final Report

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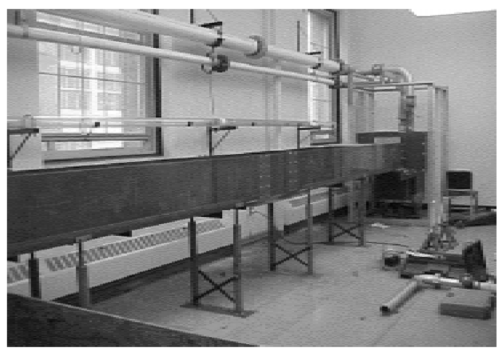

June, 2002

Published by
Minnesota Department of Transportation
Office of Research Services
Mail Stop 330
395 John Ireland Boulevard
St. Paul, Minnesota 55155-1899

Acknowledgements

This project was conducted with funding provided by the Center for Transportation Studies (CTS) with financial resources and technical support of the Minnesota Department of Transportation (Mn/DOT.) The CTS supports the research mission of the University of Minnesota with a broad program covering many topics related to transportation. The program includes both fundamental and applied research, with the goal of expanding the existing body of transportation knowledge. In addition to providing financial support, Mn/DOT assisted in locating and preparing the research site, which was essential for the successful completion of the project. This project was also conducted with funding provided by the Minnesota Agricultural Experiment Station, Regional Projects S-273 and S-1004.

The authors appreciate the support of the Office of Environmental Services of the Minnesota Department of Transportation for this research and are indebted to Mr. Leo Holm and Mr. Dwayne Stenlund for their valuable assistance and support. The support of a companion project funded by the Minnesota Local Road Research Board (LRRB) contributed to the success of the project. The authors appreciate the efforts of Mr. Dick Larson, technical liaison of the LRRB project.

The authors would also like to acknowledge several people whose work was instrumental to the completion of this study.

- Leo Holm and Dwayne Stenlund of Mn/DOT for their assistance in identifying the research site and in plot preparation.
- Dan Larsen, Brock and White Company, John Merthan, American Excelsior Company, and Jackson Landscape Company for their donations of erosion control products and their installation.
- Dan Larsen, Brock and White, and Barb Loida and Dan Warzala, Mn/DOT, for their assistance on the Technical Advisory Panel.
- Brian Hetchler, Kris Oveson, Todd Hustrulid and Princesa Van Buren, University of Minnesota, for their aid in constructing instrumentation systems and in collecting experimental data.
- Barb Oliver, University of Minnesota, for the editing of the manuscript.

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Executive Summary

Erosion control blankets are widely used for reducing erosion from construction sites. Their performance has largely been evaluated experimentally. Studies in Minnesota have been further limited to relatively short slope lengths. The goals of this project were to gather and analyze erosion and runoff data for erosion control blankets for longer slopes under Minnesota conditions and to develop a better understanding of the interactions of blankets and basic soil detachment principles. The project had three main components: (1) collection and analysis of field data on relatively long slopes, (2) collection and analysis of flume data to partition bed shear among soil and blanket components, and (3) regression analysis of previously published data to examine relationships between erosion and measurable blanket characteristics.

Twelve plots with slope lengths of 30.5-m and twelve plots with slope lengths of 18.3 m were installed to study erosion from a highway embankment. Four erosion control treatments with three replicates were studied for each set of plot lengths. The treatments for the 30.5-m plots were straw blanket, wood blanket, spray emulsion product, and straw mulch. The treatments for the 18.3-m plots were straw blanket, spray-emulsion product, straw mulch, and no erosion control measures (bare soil). Data were collected for two different stages of vegetative growth (spring and fall) and for two different initial moisture contents (dry and wet). A low-impact sprinkler system was designed and used to apply water to the plots. Runoff and sediment data were collected for ninety-six different runs. Above-ground biomass was also measured.

Above-ground biomass data were measured for each plot twice during the growing seasons: once in the spring and once in the fall after the completion of the wet runs. The spray-emulsion plots had the smallest amount of biomass in the spring. No other trends in biomass data were apparent. Different rainfall depths among plots made direct analyses of runoff depths and sediment loads more difficult. To account for differences in rainfall depths, the curve number was used as an index of runoff characteristics. The curve number appeared to be most strongly influenced by the initial moisture content of the plots. Curve numbers for the fall dry-runs were typically smaller than those observed for the spring dry-runs. Vegetative cover and initial moisture contents were different between these two sets of runs. The curve numbers for the wet

runs in spring and fall were roughly equivalent. With the possible exception of smaller runoff depth from the spray-emulsion plots during the spring runs, no trends in runoff depths with treatment was apparent. Sediment load was substantially smaller for the fall runs than the spring runs, likely the result of greater vegetative cover. Relative sediment loads for the bare treatment were roughly eight times larger than those observed for the other treatments. This trend was observed for both wet and dry conditions and for spring and fall seasons. There were no other apparent trends for the spring runs. For the fall runs, the blankets and spray-emulsion relative sediment load was consistently smaller than that observed for the straw mulch plot.

Particle detachment by surface runoff is fundamentally dependent on the shear forces acting on them (particle shear). The effect of erosion control blankets on reducing particle shear was explored in this study using a laboratory flume and hot-film anemometry techniques. Experiments were conducted to measure the impact of blanket type on the percentage of the total shear acting on the bed. Another set of experiments investigated particle shear as a function of blanket height above the flume floor. These experiments showed a slight increase in particle shear as the distance from the bottom of the blanket to the flume floor increased. Experiments were also conducted to study the effect of fastener spacing on particle shear. The data suggests that stapling density plays an important role in reducing the shear stress responsible for particle detachment. The percentage of total shear acting on the bed was less than 13.2% in all experiments, indicating the importance of shear partitioning in the design of erosion control systems.

The project also attempted to develop predictive relationships of blanket performance using a regression analysis. Sediment load and vegetative density data from TxDOT test facility were compiled and blanket characteristics were requested from manufacturers. The number of blanket characteristics obtained was too limited to evaluate the usefulness of possible regression equations.

Chapter 1
Introduction

Background Information

Erosion control blankets are widely used to reduce erosion from construction sites. These blankets protect the soil from raindrop impact. They can also reduce the bed shear acting on soil particles by shifting a portion of the total shear to the blankets and their fastening stakes. Erosion control blankets are typically installed to provide short-term protection; vegetation growth is used for long-term protection. Consequently, the impact of blankets on the establishment of vegetation is also factor to consider in developing erosion control plans.

Research on soil erosion for construction sites is less extensive than that conducted for agricultural lands. An early study by Barnett, Diseker, and Richardson (1967) examined the impact of mulching methods on highway right-of-ways. Storms of known characteristics were generated using a rainulator. Meyer, Johnson, and Foster. (1972) also investigated the effectiveness of stone and wood chip mulches for controlling erosion from construction sites using a rainulator. Kill and Foote (1971) evaluated the difference in erosion control with long- and short-fiber mulches. Rickson (1990) used an experimental runoff apparatus to examine the impact of different geotextiles and and erosion control blankets. The effectiveness of many erosion control products has been evaluated by Texas Department of Transportation (TxDOT) (Northcutt and McFalls, 1999). This is a relatively large data base where erosion control products were evaluated for soil erosion from clay and sandy soils for 2:1 and 3:1 sideslopes. Experimental results are typically incorporated into the empirical Universal Soil Loss Equation by using an erosion control practice (Israelson, Clyde, Fletcher, Isrealson, Haws, Packer, and Farmer, 1980; Haan, Barfield, and Hayes, 1994).

Benik, Wilson, Biesboer, Hansen, Stenlund. and Headrick. (1998) and Benik, Wilson, Biesboer, and Hansen (2000) evaluated the effectiveness of different erosion control products using natural rainfall events at a highway construction site for conditions in Minnesota. Benik, Wilson, Biesboer, Hansen, and Stenlund (1999) and Benik et al. (2000) also evaluated the effectiveness of erosion control products at the same research site using a rainulator. The runoff hydrograph and sediment loss data sets were collected for plot lengths of 9.75 m with soils composed mostly of clay- and silt-sized particles. Data from these studies were gathered for a relatively short plot length. The importance of rill erosion generally increases with plot length. Blankets that are effective in reducing raindrop impact may become ineffective when used for longer plots of rill-dominated erosion. Since long slope lengths are frequently encountered at construction sites, additional research under Minnesota conditions is needed using plot lengths that are greater than 15 m.

The effectiveness of erosion control blankets is currently evaluated by empirical investigation. Although this approach is extremely useful, each new product requires expensive and tedious experiments under field conditions. Long-term progress in selecting erosion control measures is more likely to be successful by obtaining a greater understanding of the interactions of the control measures with the detachment and transport of sediment. The effectiveness of blankets and turf mats can then be evaluated using simulation tools instead of field experiments. This approach is widely used to assess erosion for different agricultural practices. Similar techniques are needed for construction and roadside sites.

Objectives of the Study

The overall goal of the project is to extend the experimental data base for erosion control blankets and to develop a better understanding of the interactions of blankets and fundamental erosion principles. The specific research objectives are to:

(1) Determine the impact of erosion control blankets on runoff, erosion, and vegetative growth for sandy soils and for relatively long slopes,
(2) Study the role of erosion control blankets on the portion of the total bed shear acting on soil particles, and
(3) Link the blanket and turf characteristics to observed vegetative growth and to soil erosion.

Experimental data for Objective 1 were obtained from a highway construction site located in

Coon Rapids, Minnesota. Details of the experimental design and the results are given in Chapter 2. Unique instrumentation systems were designed and used in an indoor flume to complete Objective 2. The results of this part of the study are given in Chapter 3. The third objective was pursued by using a regression analysis of experimental data gathered by TxDOT and blanket characteristics provided by the manufacturers. The regression analysis is presented in Chapter 4. An overall summary and conclusions from the project are given in Chapter 5.

Chapter 2

Field Experiments Using Different Erosion Control Methods

Introduction

Erosion control blankets reduce interrill or sheet erosion by protecting the soil from raindrop impact. They also reduce rill erosion by protecting the soil from bed shear generated by surface runoff. Detachment by raindrop impact is relatively independent of slope length; whereas detachment by bed shear is strongly dependent on slope length. Most of the previous work with erosion control blankets in Minnesota has been done using plots of relatively short lengths. Blankets that are effective in reducing raindrop impact may become ineffective for longer, rill-erosion-dominated plots. Since these slope lengths are frequently encountered at construction sites, additional research is needed for longer plot lengths.

The objective of this study was to evaluate the impact of different erosion control blankets on runoff and erosion for longer plots at a highway construction site. The original plan was to gather erosion data for natural-rainfall and for rainulator-generated events. Although most of natural-rainfall instrumentation systems were constructed, frequent rains in the spring of 2000 prevented a timely installation. Since natural rainfall events were of marginal usefulness in the Benik et al. (2000) project and because of the likelihood of relatively few events, the collection of runoff and erosion data was limited to rainulator events. This chapter first provides a description of the research site and experimental procedures. Observed runoff, erosion, and biomass results are then described and discussed.

Experimental Procedures

Site Description

The research site was located on the northeast-facing slope of the Highway 10 overpass at University Avenue in Coon Rapids, Minnesota, which is a northern suburb of Minneapolis, Minnesota. The locations of Coon Rapids and the research site are shown in Figure 2.1. Twenty-four plots were used, consisting of four erosion-control treatments with three replicates (A, B and C) for plot lengths of 30.5 m (100 ft) and 18.3 m (60 ft). The general layout of the treatments, superimposed on 0.6 m (2 ft) contour lines, is shown in Figure 2.2. The site has a side slope of roughly 4:1. Erosion control treatments were applied to all plots on June 8 and 9, 2000.

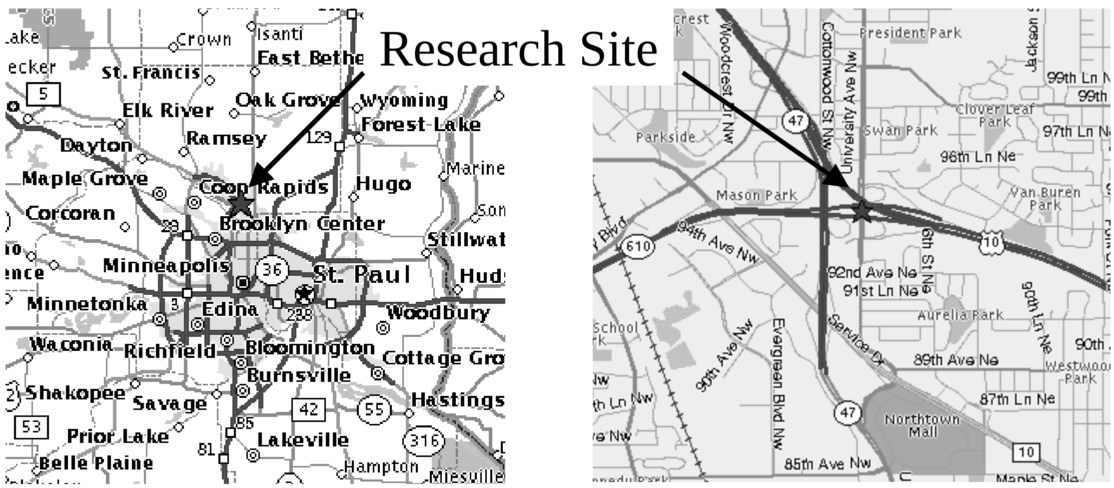

Figure 2.1. Location of Research Site in Coon Rapids, Minnesota.

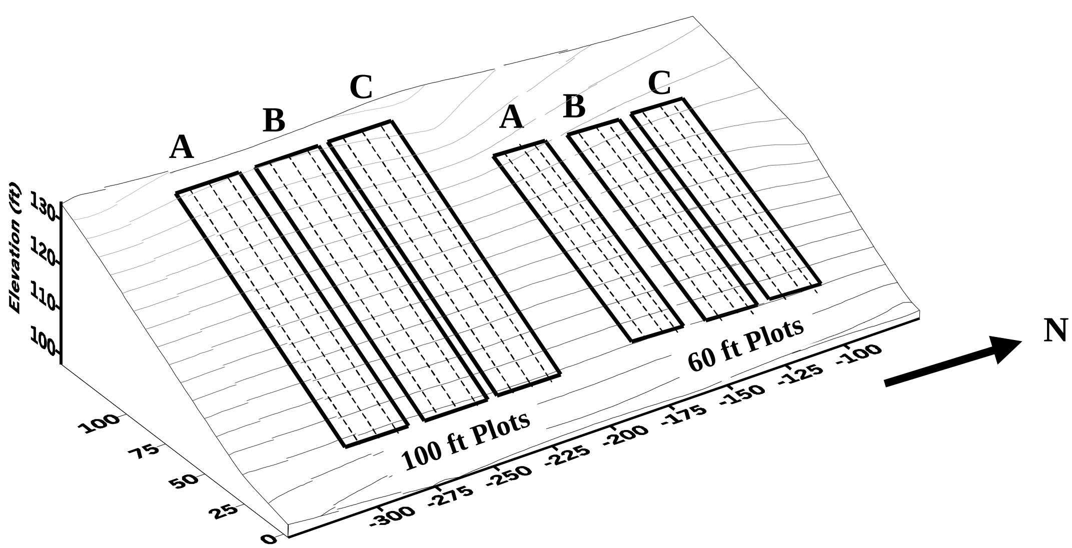

Figure 2.2. Layout of Erosion Plots at the Research Site.

The size distribution of the primary particles for the soil at the site is shown in Figure 2.3. This soil has a high percentage of sand. The organic matter is 3% and the soil has a pH of 7.4. Soil testing resulted in the following concentrations of plant nutrients: 1.8 parts per million (ppm) of nitrate-nitrogen, 21 ppm of phosphorus (Bray 1), 43 ppm of potassium, 12 ppm of sulfur-sulfate, 1.7 ppm of zinc, greater than 100 ppm of iron, 6.7 ppm of manganese, 0.6 ppm of copper, 0.2 ppm of boron, 1316 ppm of calcium, and 132 ppm of magnesium.

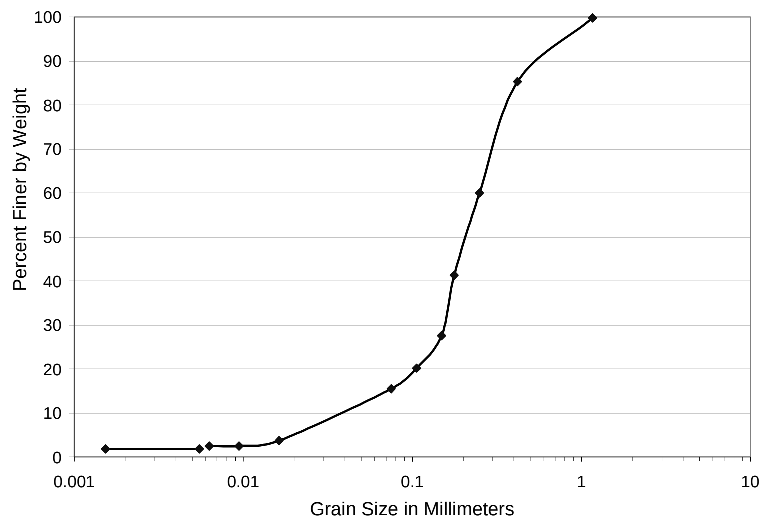

Figure 2.3. Particle Size Distribution of the Soil at Research Site.

Preparation of Erosion Plots

Because the construction of the Highway 10 overpass was completed in 1999, considerable vegetation was growing at the site prior to the start of research plot preparation. To remove this vegetation, the area was first sprayed with a glyphosate herbicide (RoundUp/Ultra^{TM}). The above ground biomass was removed by mowing and bagging the dead vegetation. The site was then disked and hand-raked to remove clods of clay and other surface materials. A photograph of the site after the removal of vegetation is shown in Figure 2.4.

The soil was fertilized prior to the installation of the erosion control treatments. As previously noted, the soil testing indicated that the site was low in nitrogen and moderately low in potassium. A 26-4-4 fertilizer was used and applied at a rate of 17.5 kg-N/ha (15.6 lb_m-N/ac), 2.7 kg-P/ha (2.4 lb_m-P/ac) and 2.7 kg-K/ha (2.4 lb_m-K/ac).

Figure 2.4. Research Site After Removal of Vegetation.

Plots were isolated from each other using plastic edging of 152-mm (6 in) height. Borders were installed parallel to the flow direction. This was accomplished by first placing the bottom edge of the plots along a line of equal elevation determined by a surveyor's level. Prefabricated wooden frames were then used to place the side borders perpendicular to this bottom edge. The installation of edging is shown in Figure 2.5.

After the side borders were installed, a collection system was installed at the bottom of each plot to direct surface runoff to a single outlet pipe. A metal shield was used to prevent rain from entering the collector. Metal diverters were placed along the side borders to direct flow from the edge toward the center of the plots. These diverters were placed at an approximate three-meter (10 ft) spacing.

Seeds for the standard Mn/DOT 15B mixture were broadcasted over the plots at a rate of 33 kg/ha (29 lb_m/ac). This mixture consists of native tall grasses and wildflowers. The grass species and their percentages in the mixture are given in Table 2.1. An equal amount (by weight) of forb species is used in the mixture. The forb species are shown in Table 2.2. The plots were raked after the seeds were broadcasted to ensure good seed-to-soil contact. The last step in plot preparation was the installation and application of the erosion control treatments. As previously discussed, erosion control blankets were installed using recommendations of the manufacturers.

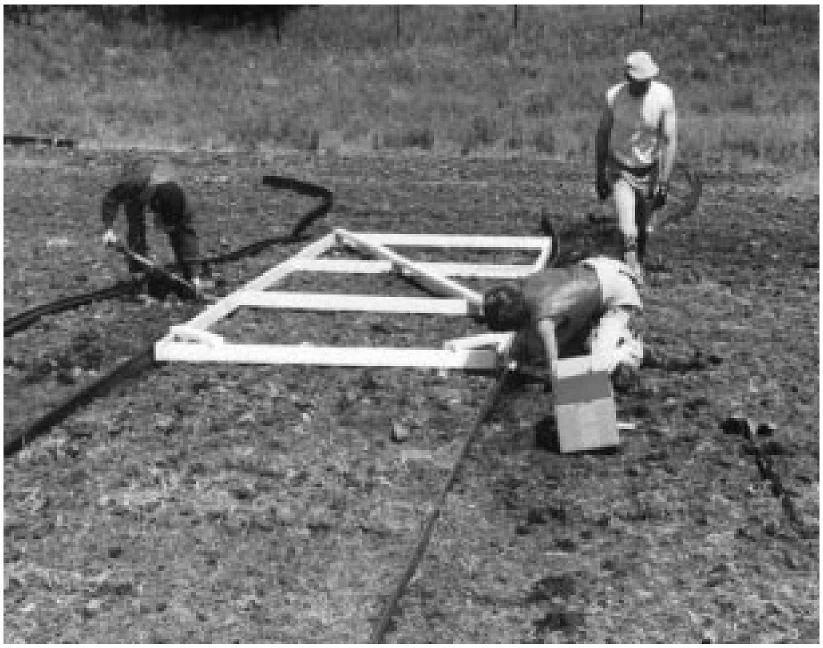

Figure 2.5. Installation of Research Plot Borders.

Table 2.1. Seed Mixture for Mn/DOT 15B.

Common Name	Botanical Name	% of Mix
Bluestem, big	*Andropogon gerardi*	5
Grama, sideoats	*Bouteloua curtipendula*	10
Wild rye, Canadian	*Elymus canadensis*	5
Wheat grass, slender	*Elymus trachycaulus*	5
Rye grass, annual	*Lolium italicum*	10
ReGreen[1]	NA	34
Forbs	See Table 2.2	5
Switch grass	*Panicum virgatum*	2
Bluestem, little	*Schizachyrium scoparium*	12
Indian grass	*Sorghastrum nutans*	12

[1]Sterile wheat/wheatgrass hybrid

Table 2.2 Forbs in Site Seed Mixture.

Common Name	Botanical Name	Common Name	Botanical Name
Milkweed, butterfly	*Asclepias tuberosa*	Blazingstar, tall	*Liatris pycnostachya*
Aster, heath	*Aster ericoides*	Bergamot, wild	*Monarda fistulosa*
Aster, smooth-blue	*Aster laevis*	Penstemon, showy	*Penstemon grandiflorum*
Milkvetch, Canada	*Astragalus Canadensis*	Coneflower, grey-headed	*Ratibida pinnata*
Partridge pea	*Chamaecrista fasiculata*	Black-eyed Susan	*Rudbeckia hirta*
Prairie clover, white	*Dalea candidum*	Goldenrod, stiff	*Solidago rigida*
Prairie clover, purple	*Dalea purpureum*	Spiderwort, Ohio	*Tradescantia ohiensis*
Tick-trefoil, showy	*Desmodium canadense*	Vervain, blue	*Verbena hastata*
Ox-eye, common	*Heliopsis helianthoides*	Vervain, hoary	*Verbena stricta*
Blazingstar, rough	*Liatris aspera*	Alexanders, golden	*Zizia aurea*

Layout of the Research Plots

The layout of the different treatments for the 30.5-m (100 ft) plots is shown in Figure 2.6. The four treatments were (1) straw mulch, (2) straw blanket (North American Green S150), (3) wood fiber blanket (American Excelsior Curlex™ II), and (4) sprayed bonded-fiber emulsion (SoilGuard™). The treatments were randomly assigned to each replicate block. However, to minimize the impact of overspray, the spray-emulsion treatment was limited to the left-most or right-most plots (randomly chosen). The other three treatments were then randomly assigned to the remaining plots. All plots have a width of 2 m (6.6 ft).

The straw mulch was hand applied at a rate of 0.45 kg/m^2 (2 tons/ac). It was anchored by pushing it into the soil with a spade using a 150 to 300-mm (6 to 12 inches) downslope spacing. Figure 2.7 shows a straw mulch plot immediately after placement.

The sprayed-emulsion product was applied to the plot using an application rate of roughly 0.45 kg/m^2 (2 tons/ac). Figure 2.8 shows the application of the sprayed-emulsion product. The straw and wood fiber blankets were stapled according to the manufacturers' recommendations. The wood fiber blanket required a break at a downslope distance of approximately 29 m (95 ft). At the break, the blankets were overlapped and stapled.

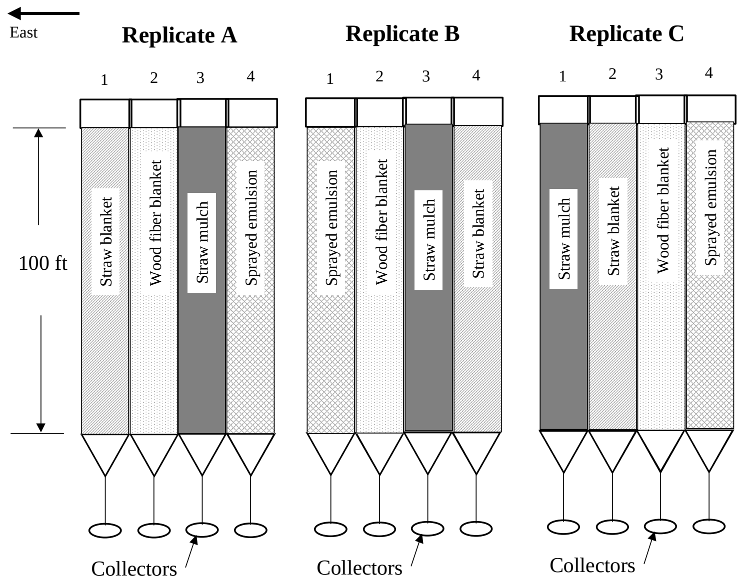

Figure 2.6. Layout of the Research Plots for Plot Lengths of 30.5 m (100 ft).

Figure 2.7. Straw Mulch Plot at Rate of 0.45 kg/m^2 (2 tons/ac).

Figure 2.8. Application of Sprayed Emulsion Product.

Four different erosion control treatments, with three replicates of each, were also installed for the 18.3-m (60 ft) plots. The layout of the different treatments for this plot length is shown in Figure 2.9. The four treatments were (1) straw mulch, (2) bare soil plots, (3) straw blanket (North American Green S150), and (4) sprayed bonded-fiber emulsion (SoilGuard™). The erosion control treatments were assigned and installed using the same procedures as those used for the 30.5-m plots. The width of the bare soil plot was set at 1.2 m because of the potential downslope problems with excessive erosion for this treatment. All other plots have widths of 2 m. The treatments were assigned to each plot using the same pseudo-random process described for the 30.5-m plots.

Rainfall Simulator Design

Erosion studies are often done using rainulators that spray water onto plots at a given intensity. Recent work done in Minnesota suggested that events obtained from a rainulator were more valuable in understanding the effectiveness of erosion control treatments than those obtained from natural rainfall events (Benik et al., 1998; Benik et al., 1999, 2000). The rainulator used in those studies was designed to duplicate the drop size and kinetic energy of relatively large rainfall events. Unfortunately, this rainulator is limited to plot lengths of roughly 9 m (30 ft) and therefore could not be used for this study.

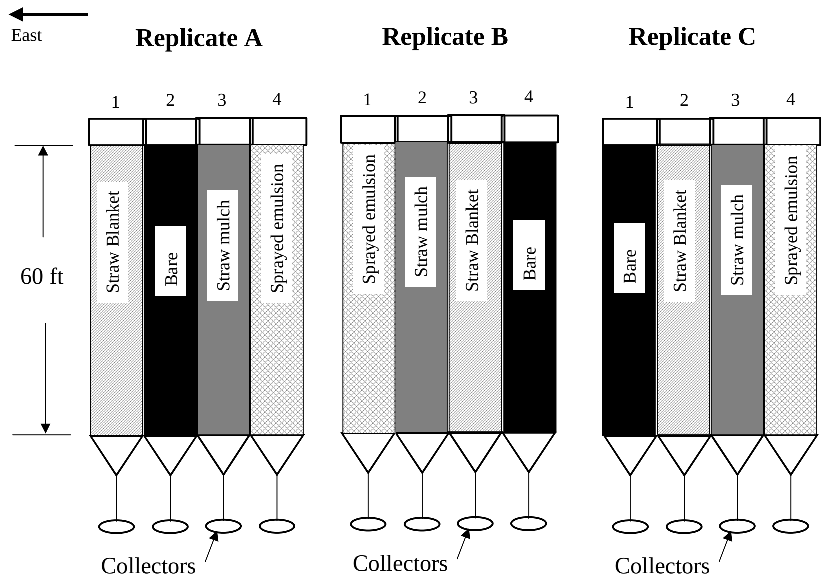

Figure 2.9. Layout of the Research Plots for Plot Lengths of 18.3 m (60 ft).

A sprinkler system was designed to spray water onto the 30.5-m (100 ft) and 18.3-m (60 ft) plots. The sprinkler system is cheaper to build and easier to use than a standard rainulator. The kinetic energy of the droplets is, however, smaller than that of the rainulator, which reduces the erosion caused by raindrop impact. Since similar erosion control products were used in the previous study, the information on the effectiveness of these products in reducing erosion by raindrop impact is available. The focus of this study is on the effectiveness of the erosion control products for longer plots. Longer plots increase the total drainage area and consequently the flow rates and bed shear. Since the impact of different erosion control treatments in reducing erosion caused by bed shear is the primary focus, the low-impact sprinkler system was deemed to be adequate for this study.

A schematic of the sprinkler system used for the 30.5-m (100 ft) plots is shown in Figure 2.10. The top three laterals were removed and the remaining system was used on the 18.3-m (60 ft) plots. The nozzles have a spacing of 3.8 m (12.5 ft). Seven Nelson 7074-15F (full 360 degrees) nozzles were used for interior sprinklers. Sixteen Nelson 7012-15H (half 180 degrees) nozzles were used for the center locations of the outside frame and four Nelson

7071-15Q (quarter 90 degrees) nozzles were used for the corners. The total flow rate from all of the nozzles was roughly 3.8 l/s (60 gpm). A 50.8-mm (2 in) PVC pipe was used to supply water to 31.7-mm (1.25 in) laterals. A NETAFIM low- flow pressure regulator was used to ensure a constant operating pressure of 207 KPa (+30 psi) for the nozzles. Nozzles were supported vertically by 0.3-m (12 in) PVC pipes for runs with little vegetation and by 1.1-m (42 in) PVC pipes with good vegetative growth.

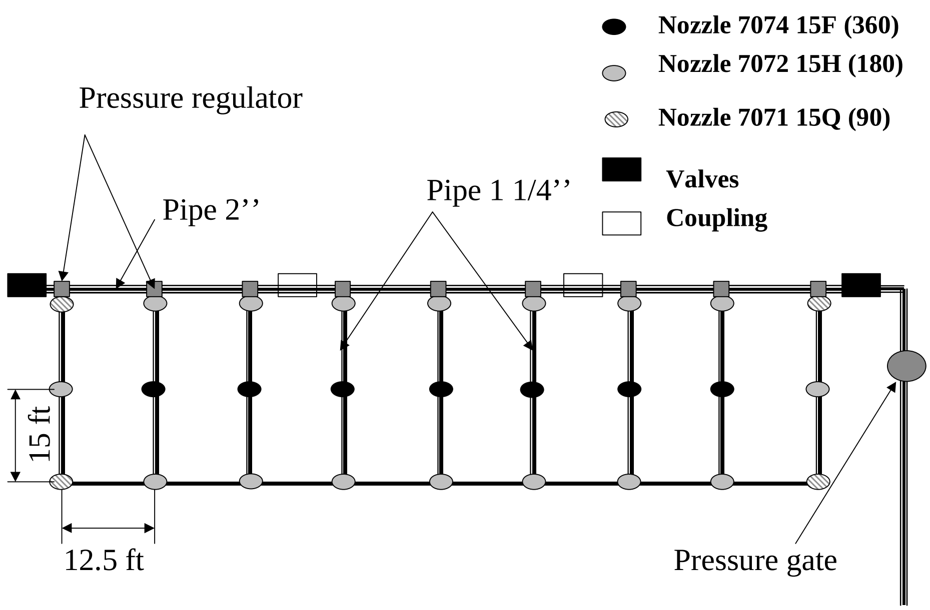

Figure 2.10. Schematic of Sprinkler System.

The water supply for the sprinkler system was obtained from a fire hydrant located near the research site. The hydrant is part of the water supply system for the city of Coon Rapids, Minnesota. A pump was used to ensure adequate pressure for the nozzles.

An important design criterion for the sprinkler systems was spatially uniform rainfall depths over the four plots. The manufacturer indicated that a single nozzle had a uniform pattern. By using this assumption and the area covered by each sprinkler, the difference in the theoretical rainfall depths between the edge and interior plots (due to overlapping patterns) was estimated to be about 5%. Figure 2.11 shows the rainfall pattern for rainulator.

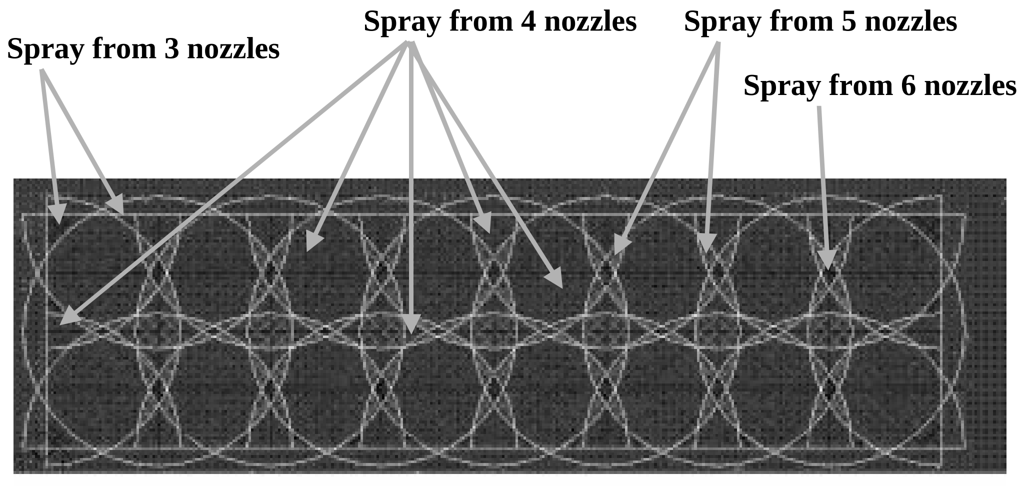

Figure 2.11. Rainfall Pattern for Sprinkler System.

Thirty-five rainfall gages were used to measure the actual rainfall depth for the 30.5-m (100 ft) plots, and twenty-five gages were used for the 18.3-m (60 ft) plots. The location of these gages is shown in Figure 2.12. Gage locations were selected to represent appropriately the rainfall depth for each overlap region.

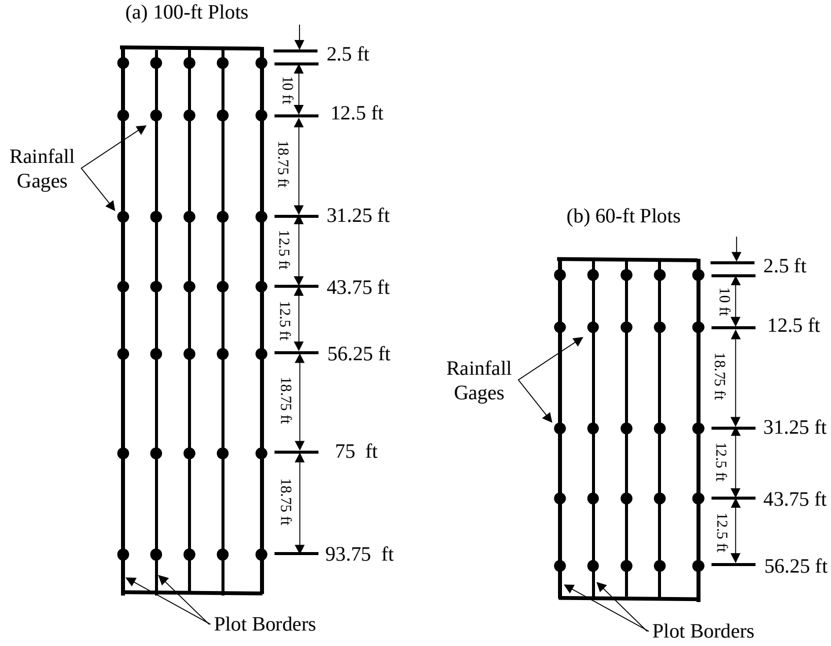

Figure 2.12. Location of Rainfall Gages.

Data Collection

Two sets of experiments were conducted corresponding to different stages of vegetative growth. A “spring” set of data was collected in late June 2000 and early July 2000. This corresponded to little vegetative growth. A second, “fall”, set of data was collected in September 2000, which corresponded to relatively good vegetative cover. Within each seasonal set, data for each plot were collected for “dry” and “wet” soil conditions. The “wet”condition run was collected roughly one day after the dry run for that particular plot.

Runoff from the plots was diverted to a single outlet at the bottom of the plot. The volumetric flow rate was obtained using the time-to-fill-known-volume method. Time to start of runoff was defined as the time corresponding to a cumulated runoff depth of 0.25 mm. Twelve one-liter bottles were used per plot per event for the collection of sediment samples. Samples were gathered more frequently during the initial stages of runoff. Total solid concentrations (TSS) were obtained by carefully filtering the entire sample volume through a 0.5 micron (nominally) filter. High concentrations for a few samples plugged the filter. The concentration for these samples was determined directly by drying the sample at 105 ^{o}C.

The biomass samples for each season were collected by hand-clipping the above-ground vegetation located within a 0.6-m by 0.6 m square. Three samples were taken for each plot. The vegetation was brought back to the laboratory and dried to determine the dry biomass per unit area. The data were collected near the top of the plot for the spring run and collected near the bottom for the fall run. There was no visual trend in vegetal density with hillslope position.

Methods of Data Analysis

General approach

Two general types of analyses are of interest in this study. Absolute (non-relative) values of runoff, sediment yield, and biomass are especially useful in comparing the results to previous studies. Absolute values maintain their units of length and mass per area. Relative runoff, sediment yield, and biomass to a standard treatment are convenient forms for examining the impact of treatments for each replicate. These values are dimensionless. Both types of data are presented in this chapter. Absolute values are presented using tabular data, whereas relative values are presented in graphs.

Observed hydrographs were numerically integrated to determine the runoff volume for each plot. Runoff volume was divided by the surface area of the plot to determine runoff depth. The sedimentgraph for each run was obtained by multiplying the measured flow rate by the observed total solid concentration. Total sediment load was then estimated by numerically integrating the sedimentgraphs. Although varying with each run, the number of flow rate measurements per run was typically fifteen, and the number of concentration samples per run was typically ten. Hydrographs and pollutographs for all of the runs are given in Appendix A. Detailed tabular data for each run are reported in Appendix B.

Out of approximately 900 samples, nine apparent outliers of concentration were removed from analysis of sediment yield (). These outliers correspond to unexpected increase or decrease in concentration. These unexpected values may have been caused by experimental error or by a sudden surge in sediment-laden flow at the time of sampling, perhaps caused by the breaching of small depressions within the plot. For the latter condition, the concentration is not representative of the average value for the numerical time step. Some runs had equipment problems with the sprinkler system. These problems are identified on the graphs in Appendix A.

Relative effectiveness

The relative effectiveness of erosion control treatments is an important component of the study. The widely used and relatively inexpensive straw mulch was chosen as the standard treatment. The relative biomass (B^*_{ij}) is therefore defined as

$$B^*_{ij} = \frac{B_{ij}}{B_{sj}} \tag{2.1}$$

where B_{ij} and B_{sj} are the dry biomasses for the i^{th} treatment and straw mulch treatment, respectively, and for the j^{th} replicate (i.e., A, B, or C in Figures 2.9 and 2.10).

As discussed in greater detail later, drifting of droplets by wind caused noticeable variability in rainfall depth. To account for this variability, runoff and sediment yield data are normalized by the average precipitation depth measured for each plot. Relative runoff depth (D^*_{ij}) is then defined as

$$D^*_{ij} = \frac{D_{ij} / P_{ij}}{D_{sj} / P_{sj}} \tag{2.2}$$

where D_{ij} and P_{ij} are the runoff and precipitation depths for the i^{th} treatment (and for the j^{th} replicate), and D_{sj} and P_{sj} are the runoff and precipitation depths for the straw mulch treatment for the j^{th} replicate. Likewise, the relative sediment load (Y^*_{ij}) is defined as

$$Y^*_{ij} = \frac{Y_{ij} / P_{ij}}{Y_{sj} / P_{sj}} \tag{2.3}$$

where Y_{ij} and Y_{sj} are the sediment loads for the i^{th} treatment and straw mulch treatment, respectively.

General Results

Storm duration, rainfall depth, runoff depth, sediment loss (load) per unit area, curve number (discussed later), initial moisture content (M.C.), and biomass for the dry/wet runs are summarized in Tables 2.3 through 2.6. Analyses of these values are discussed in greater detail in the next sections. As shown in Table 2.3, no sediment data were analyzed for the Replicate B of the spring-dry run on the 30.5-m site. Equipment failure during this run limited the collection of sediment samples. Relatively large sediment loads were observed for the B-1 plot for the 18.3-m site. The treatment for this plot was sprayed emulsion. The load was especially large, compared to other sprayed emulsion plots, for the fall-dry runs (see Table 2.5). The reason for the large value is unknown and may be tied to some unique (and unknown) characteristics of the plot and/or its position on the hillslope. It was decided that the sediment load of B-1 for the fall-dry run was an outlier and therefore was removed from the analysis of sediment yields.

Table 2.3. Summary of Results for the Spring/Dry Runs.

Length	Rep	Treatment	Storm Duration (h)	Rain Depth (mm)	Runoff Depth (mm)	Sed Loss (kg/ha)	Curve Num	Initial M.C. (%)
30.5 m	A	Straw Blanket	2.2	85.6	71.4	437.2	95.0	27.8
		Wood Fiber Blanket	2.2	99.6	55.4	957.6	82.6	29.7
		Straw Mulch	2.2	102.1	68.6	835.2	87.5	25.7
		Sprayed Emulsion	2.2	92.5	36.1	340.9	75.3	22.3
	B	Sprayed Emulsion	1.1	40.4	8.9	N.A.	80.5	27.2
		Wood Fiber Blanket	1.1	50.5	15.2	N.A.	81.0	22.7
		Straw Mulch	1.1	51.6	20.3	N.A.	84.6	24.2
		Straw Blanket	1.1	43.7	26.2	N.A.	92.6	28.3
	C	Straw Mulch	1.5	27.7	11.9	117.5	91.9	30.7
		Straw Blanket	1.5	44.5	26.9	763.5	92.6	28.7
		Wood Fiber Blanket	1.5	66.0	56.6	853.2	96.7	31.9
		Sprayed Emulsion	1.5	76.2	47.2	783.0	88.5	33.7
18.3 m	A	Straw Blanket	1.8	87.4	56.6	54.6	88.2	30.1
		Bare Soil	1.8	96.0	72.4	3836.4	91.5	28.7
		Straw Mulch	1.8	93.0	68.1	475.4	90.9	30.1
		Sprayed Emulsion	1.8	81.0	54.1	210.4	89.7	32.8
	B	Sprayed Emulsion	1.8	82.0	76.2	1106.6	98.1	37.1
		Straw Mulch	1.8	98.8	63.5	333.3	86.6	33.2
		Straw Blanket	1.8	93.0	63.2	248.6	88.8	31.4
		Bare Soil	1.8	72.6	64.0	1631.8	97.0	30.7
	C	Bare Soil	1.7	75.4	75.4	2131.8	100.0	33.1
		Straw Blanket	1.7	92.2	72.4	79.2	92.9	32.5
		Straw Mulch	1.7	99.8	77.2	245.9	91.9	35.7
		Sprayed Emulsion	1.7	78.7	45.5	6.6	86.5	43.3

Average rainfaill depths for individual plots (as reported in Tables 2.3 through 2.6) were determined by using the Thiessen polygon method (Haan et al., 1994) for the rainfall gage locations previously shown in Figure 2.12. Plot depths obtained by the Thiessen polygon method were compared to the depths of the isohyetal method (Haan et al., 1994). The results were almost identical. All measured rainfall depths in and around the plots are reported in Appendix C.

Table 2.4. Summary of Results for the Spring/Wet Runs.

Length	Rep	Treatment	Storm Duration (h)	Rain Depth (mm)	Runoff Depth (mm)	Sed Loss (kg/ha)	Curve Num	Initial M.C. (%)	Biomass (kg/ha)
30.5 m	A	Straw Blanket	1.6	63.8	51.3	27.7	95.5	28.1	777
		Wood Fiber Blanket	1.6	81.0	49.0	301.8	87.3	30.1	1392
		Straw Mulch	1.6	84.6	64.3	398.0	92.6	28.7	1067
		Sprayed Emulsion	1.6	58.2	44.2	251.2	94.8	29.4	713
	B	Sprayed Emulsion	2.0	20.3	2.3	24.5	84.7	30.5	752
		Wood Fiber Blanket	2.0	46.7	5.1	21.2	70.9	29.4	885
		Straw Mulch	2.0	81.3	74.7	509.0	97.8	31.4	843
		Straw Blanket	2.0	103.4	87.6	256.1	94.5	33.3	558
	C	Straw Mulch	1.4	75.7	73.9	422.5	99.4	34.2	723
		Straw Blanket	1.4	76.7	64.0	230.0	95.5	31.5	711
		Wood Fiber Blanket	1.4	68.6	68.6	650.9	100.0	30.6	688
		Sprayed Emulsion	1.4	40.1	22.4	303.4	92.2	35.8	222
18.3 m	A	Straw Blanket	1.2	34.8	22.4	163.9	94.8	35.5	1009
		Bare Soil	1.2	52.1	47.0	1240.9	98.3	31.9	1106
		Straw Mulch	1.2	58.4	48.0	120.2	96.2	30.0	1347
		Sprayed Emulsion	1.2	61.7	42.2	35.5	92.3	31.3	891
	B	Sprayed Emulsion	1.1	49.0	42.7	57.4	97.9	38.9	577
		Straw Mulch	1.1	60.7	46.2	163.9	94.6	40.8	1065
		Straw Blanket	1.1	62.0	45.7	336.1	93.8	31.8	861
		Bare Soil	1.1	55.6	55.6	1040.9	100.0	38.0	1125
	C	Bare Soil	1.1	50.8	50.8	1036.4	100.0	33.5	420
		Straw Blanket	1.1	61.7	53.3	19.1	97.0	33.7	1035
		Straw Mulch	1.1	65.3	53.8	240.4	95.9	39.0	861
		Sprayed Emulsion	1.1	52.3	26.7	1.4	88.6	31.0	432

The overall average rainfall depth for each run (replicate) and the corresponding relative range are shown in Figure 2.13. The results in Figure 2.13 are given by run sequence, that is, the first value corresponds to the first run at the site and the last value corresponds to the last run. Relative range is defined as the difference between the maximum and minimum rainfall depth (average for a plot) among the four plots divided by the replicate average depth.

The precipitation depth for a typical event was roughly 60 mm. The “wet” runs received less water because they responded more rapidly to rainfall. Equipment failure occurred on a few runs because of a broken pipe, pump breakdown, etc. These problems were generally fixed quickly, and the run was completed as planned.

Table 2.5. Summary of Results for the Fall/Dry Runs.

Length	Rep	Treatment	Storm Duration (h)	Rain Depth (mm)	Runoff Depth (mm)	Sed Loss (kg/ha)	Curve Num.	Initial M.C. (%)
30.5 m	A	Straw Blanket	2.4	114.8	67.8	5.9	82.1	22.4
		Wood Fiber Blanket	2.4	122.2	31.8	10.9	60.9	20.0
		Straw Mulch	2.4	113.3	32.3	6.2	64.5	18.1
		Sprayed Emulsion	2.4	75.4	1.0	0.3	46.6	16.8
	B	Sprayed Emulsion	2.3	95.5	39.4	9.1	76.0	17.5
		Wood Fiber Blanket	2.3	97.3	33.8	3.3	71.8	17.1
		Straw Mulch	2.3	87.6	40.9	6.0	80.1	16.3
		Straw Blanket	2.3	64.0	16.0	1.1	74.3	17.2
	C	Straw Mulch	2.2	84.1	55.9	12.7	89.2	15.4
		Straw Blanket	2.2	101.6	45.0	10.0	76.4	17.0
		Wood Fiber Blanket	2.2	101.1	64.0	2.9	86.0	17.8
		Sprayed Emulsion	2.2	80.3	31.0	2.6	77.6	25.3
18.3 m	A	Straw Blanket	1.5	42.9	1.8	1.0	65.6	20.9
		Bare Soil	1.5	59.4	8.4	2.4	68.3	15.9
		Straw Mulch	1.5	69.1	15.7	7.0	71.3	20.9
		Sprayed Emulsion	1.5	69.9	12.4	1.9	67.8	21.4
	B	Sprayed Emulsion	1.8	63.5	26.2	84.7	82.5	21.0
		Straw Mulch	1.8	83.1	37.1	2.4	80.1	20.2
		Straw Blanket	1.8	95.5	33.3	3.0	72.2	20.4
		Bare Soil	1.8	94.0	57.9	64.6	86.1	18.7
	C	Bare Soil	2.1	46.7	14.0	2.0	82.2	23.9
		Straw Blanket	2.1	73.4	26.7	1.7	77.9	36.9
		Straw Mulch	2.1	98.6	49.0	8.7	79.9	23.1
		Sprayed Emulsion	2.1	105.2	43.7	4.3	74.3	23.3

As shown in Figure 2.13, some of the relative range values were large, indicating substantial differences in total precipitation depth among the plots within a replicate. For example, the relative range for Run 5 was greater than one. For this run, the difference between maximum and minimum rainfall depths among the plots was greater than the overall average. Large variability was mostly caused by droplets drifting with the wind. After the first half-dozen runs, data were usually collected in the early morning or late evening to avoid windy conditions. The relative range is noticeably smaller in Figure 2.13 after Run 5.

Table 2.6. Summary of Results for the Fall/Wet Runs.

Length	Rep	Treatment	Storm Duration (h)	Rain Depth (mm)	Runoff Depth (mm)	Sed Loss (kg/ha)	Curve Num	Initial M.C. (%)	Biomass (kg/ha)
30.5 m	A	Straw Blanket	1.2	54.6	40.6	3.9	94.7	31.8	3251
		Wood Fiber Blanket	1.2	62.0	36.3	7.2	89.3	30.8	3048
		Straw Mulch	1.2	61.7	49.3	53.7	95.5	26.9	2564
		Sprayed Emulsion	1.2	52.8	28.2	10.1	89.2	29.4	3152
	B	Sprayed Emulsion	1.4	63.2	35.8	4.7	88.5	25.7	3260
		Wood Fiber Blanket	1.4	80.0	55.1	6.0	90.5	28.6	3388
		Straw Mulch	1.4	85.6	62.0	11.0	91.2	29.8	2903
		Straw Blanket	1.4	72.1	59.7	3.8	95.5	28.1	2961
	C	Straw Mulch	1.3	34.8	33.8	2.3	99.7	30.1	2439
		Straw Blanket	1.3	57.7	45.7	5.2	95.6	30.0	2528
		Wood Fiber Blanket	1.3	69.6	56.9	1.8	95.5	28.9	2910
		Sprayed Emulsion	1.3	61.7	44.2	5.2	93.3	30.2	2690
18.3 m	A	Straw Blanket	1.3	57.4	37.6	6.0	92.1	30.0	2403
		Bare Soil	1.3	63.0	42.7	15.0	92.1	25.7	2952
		Straw Mulch	1.3	63.2	43.2	13.5	92.2	31.4	2174
		Sprayed Emulsion	1.3	57.7	31.8	4.2	88.9	26.1	1944
	B	Sprayed Emulsion	1.3	65.3	50.5	37.0	94.6	29.1	2150
		Straw Mulch	1.3	69.9	37.8	3.8	86.5	28.8	2603
		Straw Blanket	1.3	67.6	22.4	2.1	77.8	26.9	2765
		Bare Soil	1.3	52.3	36.6	58.9	93.8	26.9	2895
	C	Bare Soil	1.2	62.7	52.3	10.6	96.3	29.1	2049
		Straw Blanket	1.2	63.5	36.8	2.0	89.0	31.0	2531
		Straw Mulch	1.2	64.0	41.4	4.8	91.1	30.5	2205
		Sprayed Emulsion	1.2	49.3	13.5	0.9	80.0	31.3	1529

The runoff depth slightly exceeded the rainfall depth for four runs. These results are caused either by errors in the calculation of rainfall depth for each plot or by errors in measuring the runoff hydrograph. The computation of the curve number requires that the runoff depth be less than or equal to the rainfall depth. Because of the variability of rainfall depths within the replicate, the rainfall depth was increased to equal the observed runoff depth. Once again, these adjustments were small. The original data are reported in the summary tables of Appendix B.

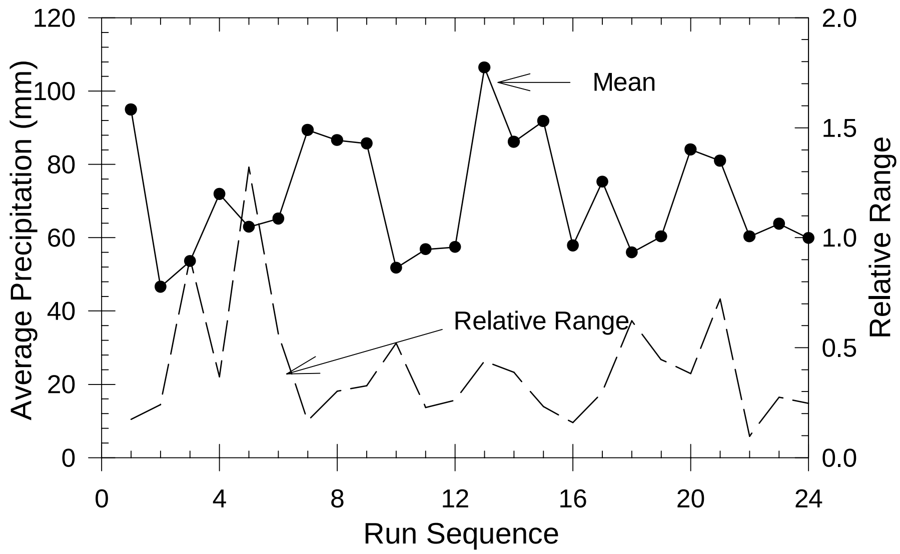

Figure 2.13. Replicate Average and Relative Range of Precipitation Depth for Each Run.

Analysis of Biomass Data

Biomass-per-area data for the 30.5-m and 18.3-m plots are summarized in Tables 2.7 and 2.8. The mean, maximum, and minimum values are reported for each treatment and for spring and fall runs. Biomass samples were collected after the wet runs. For the fall runs, they are a good estimate of the biomass for the dry runs as well. There was rapid plant growth in the spring and therefore the actual biomass during the dry runs was smaller.

There was substantial plant growth between spring and fall runs. Typical values for the spring runs were between 600 kg/ha and 1100 kg/ha; whereas typical values for the fall runs were between 2000 kg/ha and 3000 kg/ha. Measured biomass at the end of the growing season by Benik et al. (2000) were roughly between 1100 kg/ha and 2400 kg/ha for similar erosion control treatments. The biomass data of the two studies are in reasonably close agreement. No obvious differences in biomass between the 30.5-m and 18.3-m plots were apparent.

Table 2.7. Summary of Biomass Data (kg/ha) for the 30.5-m Plots.

	Season	Treatment			
		Straw Blanket	**Woodfiber**	**Straw Mulch**	**Sprayed Emulsion**
Average	Spring	682	988	878	562
	Fall	2913	3115	2635	3034
Maximum	Spring	777	1392	1067	752
	Fall	3251	3388	2903	3260
Minimum	Spring	558	688	723	222
	Fall	2528	2910	2439	2690

Table 2.8. Summary of Biomass Data (kg/ha) for the 18.3-m Plots**.**

	Season	Treatment			
		Blanket	**Bare**	**Straw Mulch**	**Sprayed Emulsion**
Average	Spring	968	884	1091	633
	Fall	2567	2632	2327	1874
Maximum	Spring	1035	1125	1347	891
	Fall	2765	2952	2603	2150
Minimum	Spring	861	420	861	432
	Fall	2403	2049	2174	1529

The relative impact of different plot treatments is assessed using the relative biomass statistic defined by Equation 2.1. Here the biomass per unit area is evaluated relative to that obtained for the straw mulch treatment within the replicate block. Results are summarized in Figure 2.14. The bar height is the average value for all replicates. The solid circles are the maximum and minimum values for each treatment. Results are divided into season and by the length of the plot.

The spray-emulsion plots had the smallest relative biomass in the spring. This is not surprising given the short time from installation to the start of the test runs and the surface condition immediately following its application. There are no strong trends in relative biomass for the fall data. The average value for the spray-emulsion plots exceeded the averages for the straw mulch and straw blanket treatments for the 30.5-m plots. The variability in relative biomass among plots of the same treatment was generally smaller for the fall data set.

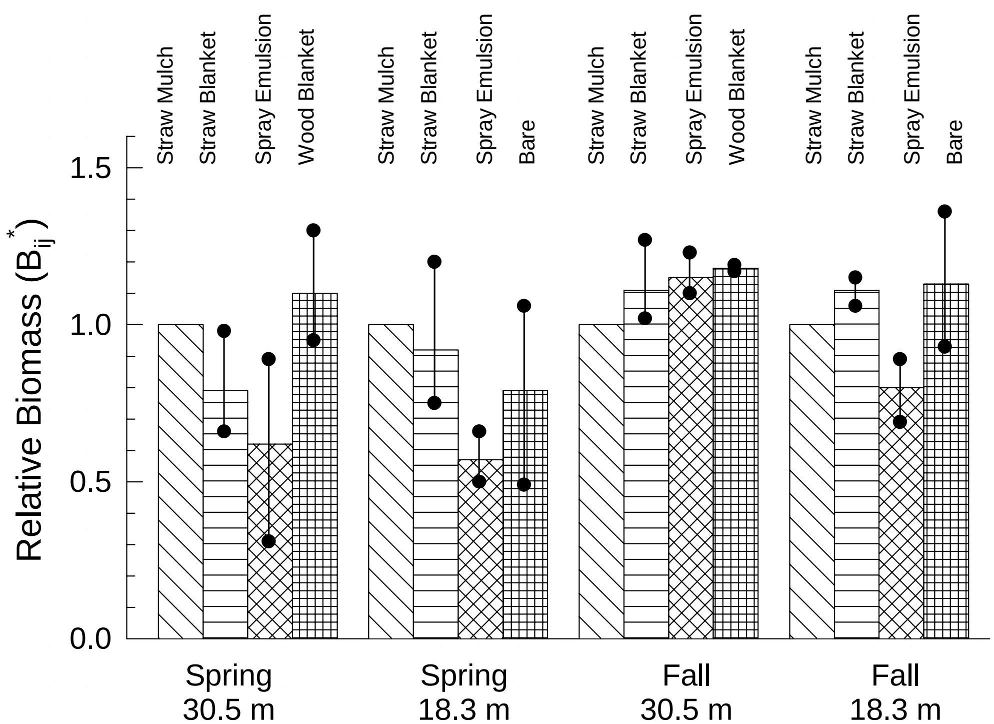

Figure 2.14. Relative Biomass for Different Treatments.
(Bar = Average, Solid Circles = Maximum and Minimum)

Analysis of Runoff Data

Observed runoff hydrographs for the fall dry-run of replicate A of the 30.5-m plots are shown in Figure 2.15. The observed hydrographs for all of the runs are given in Appendix A. For this particular run, the straw blanket responded quickly and resulted in the greatest runoff depth. The spray-emulsion plot absorbed most of the precipitation and had very little runoff depth. The straw mulch and wood fiber blankets had responses that were between these two extremes.

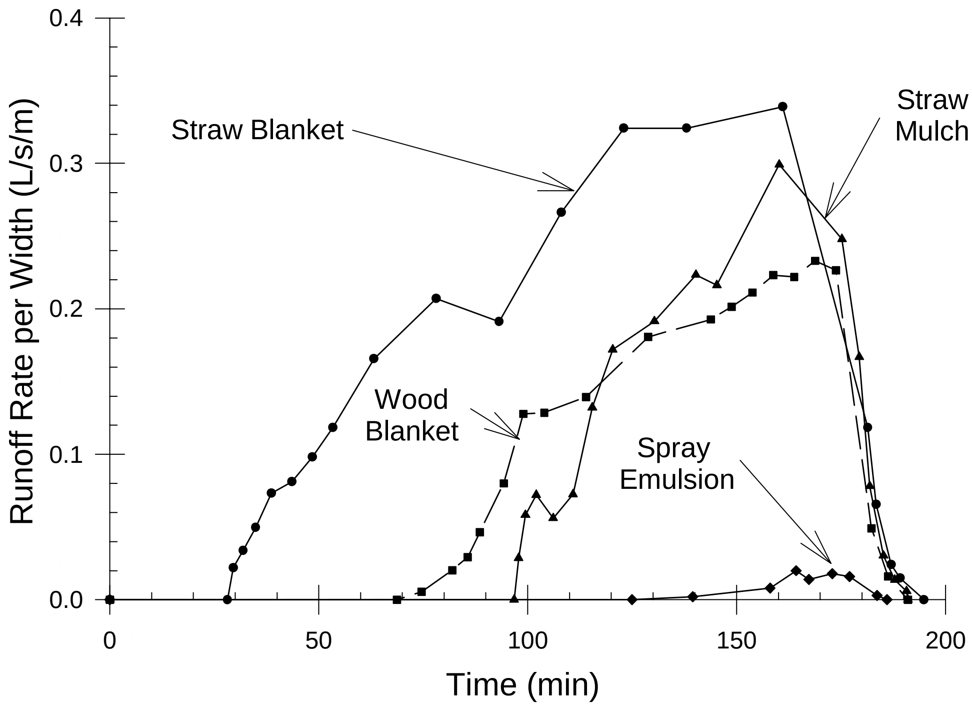

Figure 2.15. Observed Hydrographs of Replicate A for a Fall Dry Run of 30.5-m Plots.

A summary of the runoff depth for each treatment is given in Table 2.9 for the 30.5-m plots and Table 2.10 for the 18.3-m plots. A simple interpretation of these values is not possible because rainfall depths differed among the plots and replicates. No obvious trends with season are apparent. A commonly used index of runoff is the curve number. Curve numbers easily account for differences in rainfall depths among the plots. They are theoretically a function of soil type, land use and initial moisture content. The curve number is defined using units of inches as

$$CN = \frac{1000}{S + 1000} \tag{2.4}$$

where S is an abstraction depth that can be defined from known rainfall and runoff depth from

$$S = 5(P + 2Z - \sqrt{4Z^2 + 5PZ}) \quad (2.5)$$

where P and Z are measured rainfall and runoff depths, respectively, in inches. The curve numbers for each plot have previously been given in Tables 2.3 through 2.6. The results are summarized by treatment for the spring runs in Figures 2.16 and Figure 2.17.

Table 2.9. Summary of Runoff Depth (mm) for the 30.5-m Plots**.**

			Treatment			
	Season	**Type**	**Straw Blanket**	**Woodfiber Blanket**	**Straw Mulch**	**Sprayed Emulsion**
Average	Spring	Dry	41.5	42.4	33.6	30.7
		Wet	67.6	40.9	71.0	22.9
	Fall	Dry	42.9	43.2	43.0	23.8
		Wet	48.7	49.4	48.3	36.1
Maximum	Spring	Dry	71.4	56.6	68.6	47.2
		Wet	87.6	68.6	74.7	44.2
	Fall	Dry	67.8	64.0	55.9	39.4
		Wet	59.7	56.9	62.0	44.2
Minimum	Spring	Dry	26.2	15.2	11.9	8.9
		Wet	51.3	5.1	64.3	2.3
	Fall	Dry	16.0	31.8	32.3	1.0
		Wet	40.6	36.3	33.8	28.2

Table 2.10. Summary of Runoff Depth (mm) for the 18.3-m Plots.

	Season	Type	Treatment			
			Blanket	Bare	Straw Mulch	Sprayed Emulsion
Average	Spring	Dry	64.1	70.6	69.6	58.6
		Wet	40.5	51.1	49.4	37.2
	Fall	Dry	20.6	26.8	34.0	27.4
		Wet	32.3	43.9	40.8	31.9
Maximum	Spring	Dry	72.4	75.4	77.2	76.2
		Wet	53.3	55.6	53.8	42.7
	Fall	Dry	33.3	57.9	49.0	43.7
		Wet	37.6	52.3	43.2	50.5
Minimum	Spring	Dry	56.6	64.0	63.5	45.5
		Wet	22.4	47.0	46.2	26.7
	Fall	Dry	1.8	8.4	15.7	12.4
		Wet	22.4	36.6	37.8	13.5

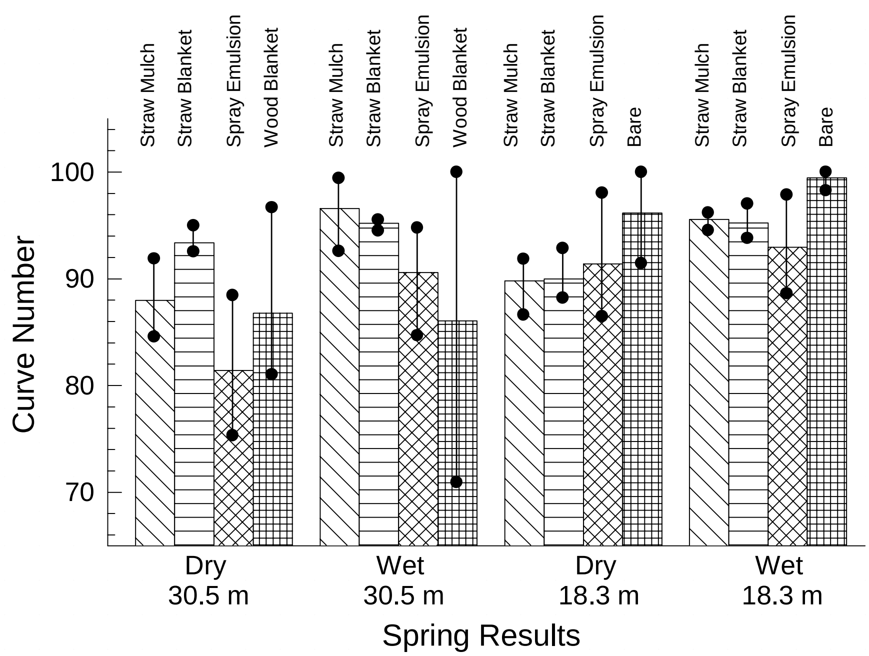

Figure 2.16. Curve Numbers for Different Treatments for Fall Runs.
(Bar = Average, Solid Circles = Maximum and Minimum)

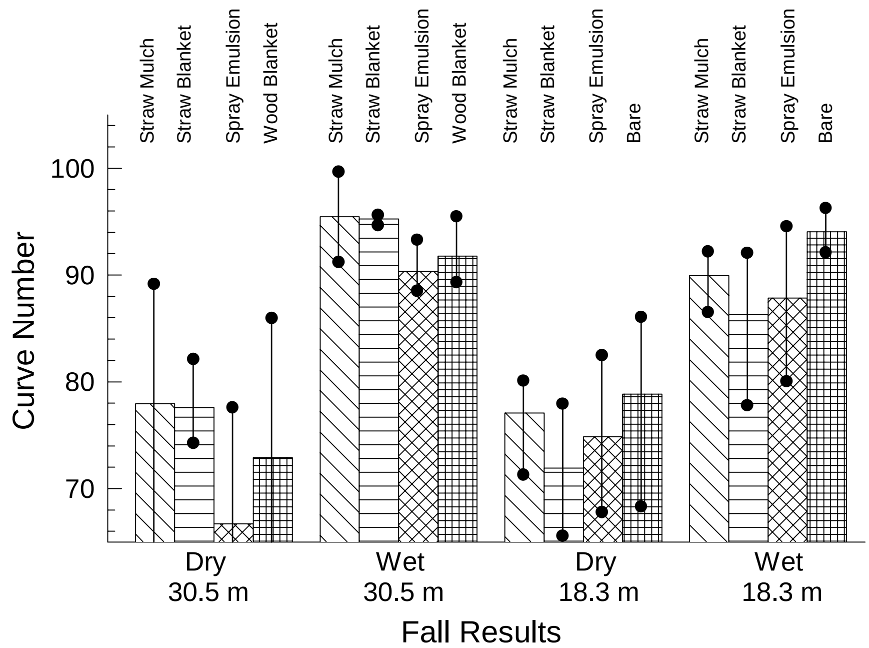

Figure 2.17. Curve Numbers for Different Treatments for Spring Runs.
(Bar = Average, Solid Circles = Maximum and Minimum)

As shown in Figure 2.16, the curve numbers for the spring dry-runs with the 30.5-m plots were predominately between 80 and 95, whereas for the wet runs the curve numbers were predominately between 85 and 100. This increase can be attributed to the wetter soil for the second set of runs. The curve numbers for spring dry-runs with the 18.3-m plots were larger than those obtained for the 30.5-m plots. Natural rainfall events caused the initial moisture content for these plots to be greater. The curve numbers for both dry and wet runs were typically between 90 and 100 for the 18.3-m plots. Another factor that may have influenced the initial moisture content for individual plots was the irregular runoff from Highway 10.

Curve numbers for the vegetative cover of the fall dry-runs were noticeably smaller than those measured for the spring runs. As shown by Figure 2.17, typical values were between 70 and 80. Curve numbers for dry-runs were fairly consistent between the fall replicates for the 30.5-m and 18.5-m plots. In addition to the potential impact of greater vegetative cover, initial moisture contents for the fall dry-runs were lower than those of the spring dry-runs. The impact of initial soil wetness on curve number is apparent by comparing the dry and wet runs for the fall season. Typical curve numbers for the wet runs were between 90 and 100, corresponding to trends observed for wet conditions in the spring. This observation suggests that, for this site, the impact of vegetation on runoff may be relatively minor for wet conditions.

The treatment impacts are evaluated using the relative runoff depth defined by Equation 2.2. The relative depth values are summarized in Figures 2.18 and 2.19 for the spring and fall runs, respectively. Conclusions from these values are complicated by large variabilities within treatments. For example, the runoff depth is generally smaller for the spray-emulsion plots, but there were plots where their runoff depths were actually greater than the straw mulch treatment. Similar to the discussion of curve numbers, relative runoff depths are also influenced by the different initial moisture contents among plots. In addition, the simple adjustment for differences in rainfall depths presumed in Equation 2.3 may be inadequate for the likely nonlinear relationship between rainfall depth and runoff.

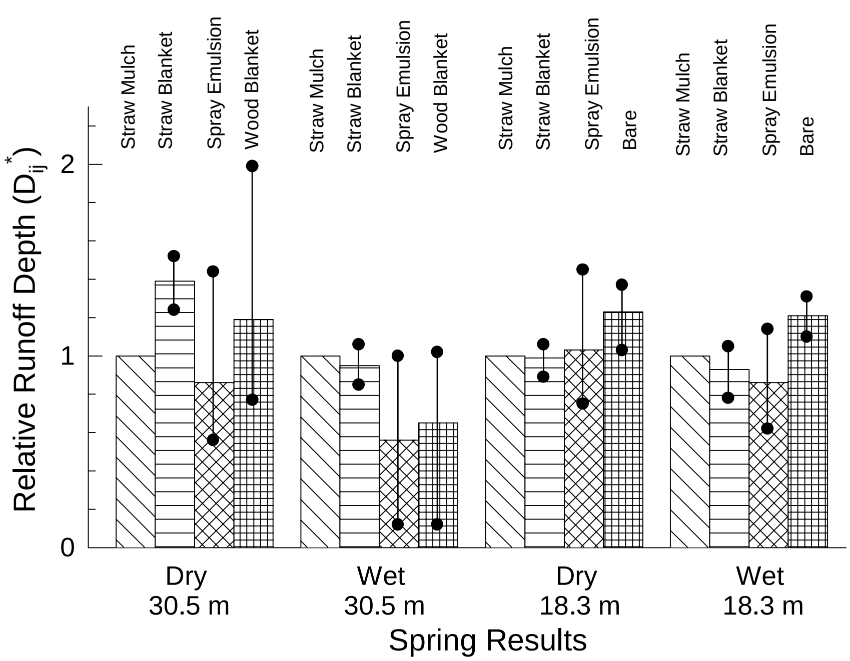

Figure 2.18. Relative Runoff Depths for Different Treatments for Spring Runs.
(Bar = Average, Solid Circles = Maximum and Minimum)

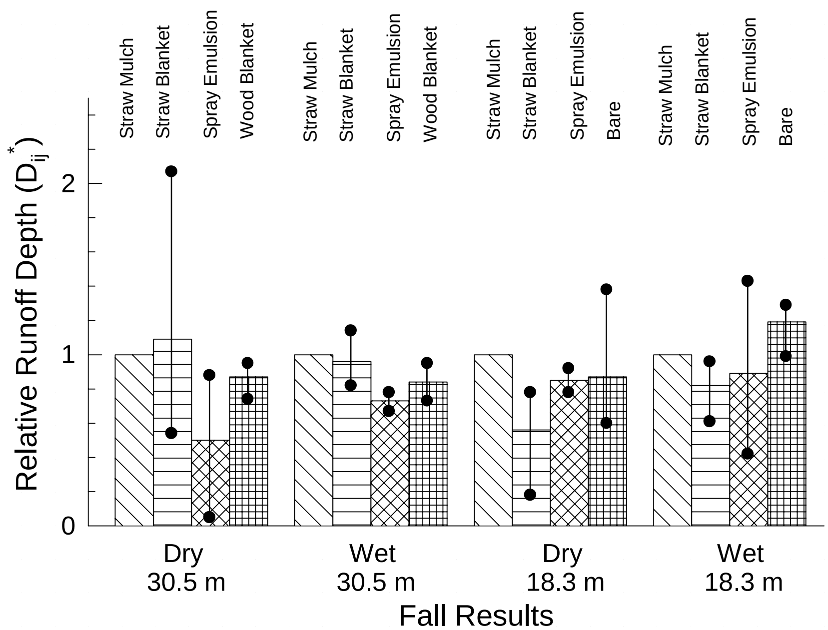

Figure 2.19. Relative Runoff Depths for Different Treatments for Fall Runs.
(Bar = Average, Solid Circles = Maximum and Minimum)

Analysis of Erosion Data

Observed pollutographs for the spring dry-run of replicate C of the 18.3-m plots are shown in Figure 2.20. The observed pollutographs for all of the runs are given in Appendix A. For the particular run shown in Figure 2.20, the largest concentrations were for the bare treatment. These values were roughly ten times greater than those observed for the other treatments. The second largest concentrations were obtained from the straw mulch treatment. The spray-emulsion treatment had the smallest concentrations.

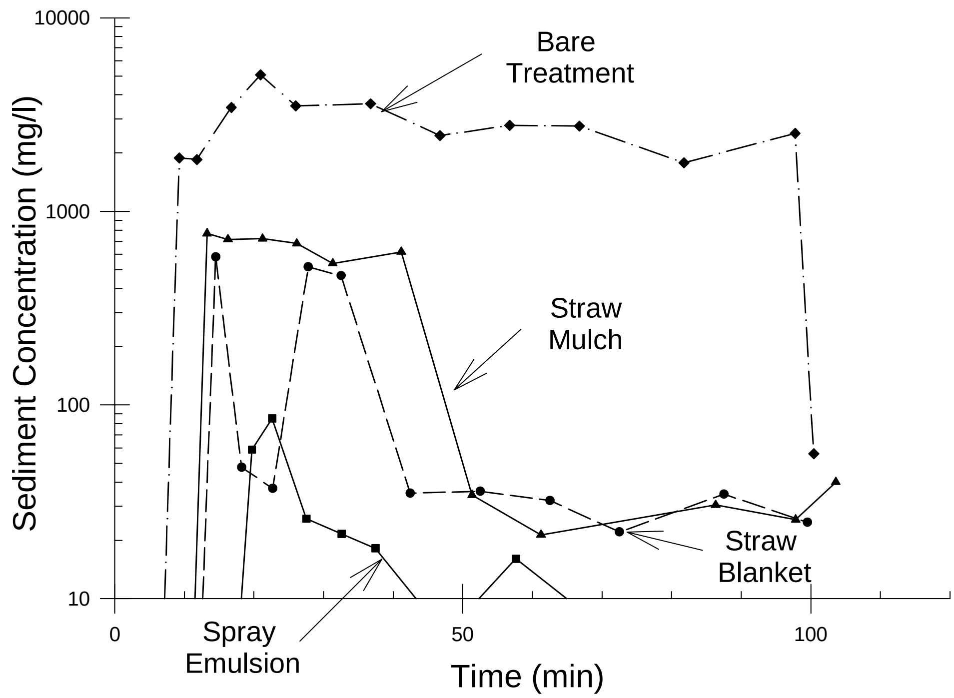

Figure 2.20. Pollutographs for a Spring-Dry Run of a 18.3-m Replicate.

A summary of sediment load by treatment is given in Tables 2.11 and 2.12 for the 30.5-m and 18.3-m plots, respectively. These results need to be considered carefully because of different rainfall depths among plots. Although there was no obvious trend in runoff depth with season, the sediment load is clearly smaller for the fall runs than the spring runs. The average sediment loads for the spring runs were typically greater than 200 kg/ha; whereas the average sediment loads for the fall runs were typically less than 40 kg/ha. The combined effect of vegetation and remaining treatment cover and consolidation of the soil are possible causes for this reduction.

Table 2.11. Summary of Sediment Yield (kg/ha) for the 30.5-m Plots.

	Season	Type	Treatment			
			Straw Blanket	Woodfiber Blanket	Straw Mulch	Sprayed Emulsion
Average	Spring	Dry	400.2	603.6	317.6	374.7
		Wet	171.3	324.6	443.2	193.0
	Fall	Dry	5.7	5.7	8.3	4.0
		Wet	4.3	5.0	22.3	6.7
Maximum	Spring	Dry	763.5	957.6	835.2	783.0
		Wet	256.1	650.9	509.0	303.4
	Fall	Dry	10.0	10.9	12.7	9.1
		Wet	5.2	7.2	53.7	10.1
Minimum	Spring	Dry	437.2	853.2	117.5	340.9
		Wet	27.7	21.2	398.0	24.5
	Fall	Dry	1.1	2.9	6.0	0.3
		Wet	3.8	1.8	2.3	4.7

Table 2.12. Summary of Sediment Yield (kg/ha) for the 18.3-m Plots.

	Season	Type	Treatment			
			Blanket	Bare	Straw Mulch	Sprayed Emulsion
Average	Spring	Dry	127.5	2533.3	351.5	441.2
		Wet	173.0	1106.1	174.9	31.4
	Fall	Dry	1.9	23.0	6.0	30.3
		Wet	3.4	28.2	7.4	14.0
Maximum	Spring	Dry	248.6	3836.4	475.4	1106.6
		Wet	336.1	1240.9	240.4	57.4
	Fall	Dry	3.0	64.6	8.7	84.7
		Wet	6.0	58.9	13.5	37.0
Minimum	Spring	Dry	54.6	1631.8	245.9	6.6
		Wet	19.1	1036.4	120.2	1.4
	Fall	Dry	1.0	2.0	2.4	1.9
		Wet	2.0	10.6	3.8	0.9

In general, the sediment loads are smaller than those reported by Benik et al. (2000). Substantial root mass that likely developed from plant growth in the previous year may have reduced the soil erodibility. The low detachment energy of the small droplets of the sprinkler system may have also contributed to the smaller erosion rates.

The impact of different treatments on sediment load was assessed using the relative sediment load defined by Equation 2.3. The relative yield values are summarized in Figure 2.21 for the spring runs and Figure 2.22 for the fall runs.

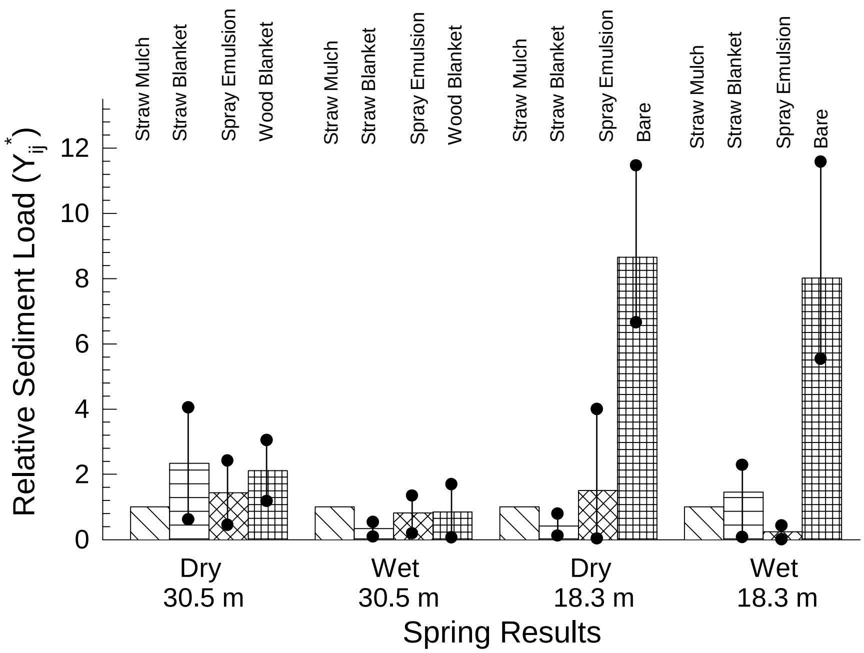

Figure 2.21. Relative Sediment Loads for Different Treatments for Spring Runs.
(Bar = Average, Solid Circles = Maximum and Minimum)

The relative sediment loads for the bare treatment were substantially larger than those observed for the other treatments. This trend was observed for both wet and dry conditions and for spring and fall seasons. The average relative sediment load was roughly eight times greater than that observed for the straw mulch plots. There was no consistent trend for the other treatments for the spring runs: the average relative sediment loads were sometimes less than and sometimes greater than those of the straw mulch plots. For the fall runs, the relative sediment loads for the blankets and spray-emulsion treatments were consistently smaller than those observed for the straw mulch plots.

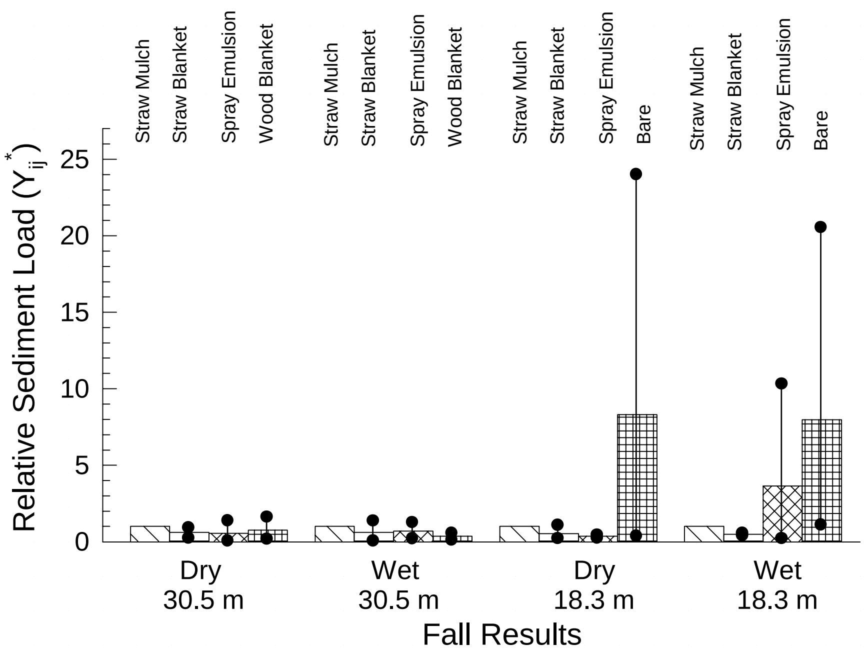

Figure 2.22. Relative Sediment Loads for Different Treatments for Fall Runs.
(Bar = Average, Solid Circles = Maximum and Minimum)

Summary and Conclusions

Previous soil erosion research under Minnesota conditions for construction sites is mostly limited to studies using relatively short plot lengths. Twenty-four, relatively long plots were installed to study erosion from a highway embankment. Four erosion control treatments were studied for two different slope lengths, for two different levels of vegetative cover and for dry and wet soil. A low-impact sprinkler system was used to apply water to the plots. Flow rates and total-suspended-solids concentrations were measured for a total of ninety-six runoff events from the experimental plots. Above-ground biomass was also measured. Absolute (non-relative) values were used to allow easy comparison to other studies. Relative values to the straw mulch treatment were used to examine the impact of the treatment. Because of spatial variability in rainfall intensities, the relative values were also normalized using the plot-rainfall depth.

Biomass data were the most consistent and the easiest to interpret. The spray-emulsion plots had the smallest amounts of biomass in the spring. No other trends with biomass among treatments were apparent. Biomass increased substantially between spring and fall runs. There were no strong trends in biomass among treatment for the fall data. The variability in biomass among plots of the same treatment was generally smaller for the fall data than that observed in the spring data.

Absolute runoff data was difficult to analyze because of different rainfall depths among plots. Because of these different rainfall depths, the curve number was used as an index of the runoff characteristics (non-referenced) for each plot. The curve number appeared to be most strongly influenced by the initial moisture content of the plots. For the relatively wet conditions of the spring dry-runs, the curve numbers were typically between 80 and 95. The curve numbers for the drier fall dry-runs were smaller, typically between 70 and 80. In addition to drier soils, the fall runs also had greater vegetative cover. The curve numbers for the wet runs in both spring and fall were typically between 90 and 100. Relative runoff depths were used to evaluate the impact of treatments on runoff. With the possible exception of smaller runoff depth from the spray-emulsion plots during the spring runs, no trends in runoff depths with treatment was apparent. The simple adjustment for different rainfall depths may be inadequate for the likely nonlinear relationship between rainfall depth and runoff.

Sediment load data were also influenced by the variability of rainfall depths among plots. There was, however, an obvious decrease in sediment load between spring and fall runs. This is likely the result of greater vegetative cover. The impact of different treatments on sediment load was assessed using a relative sediment load statistic. The relative sediment loads for the bare treatment were roughly eight times larger than those observed for the other treatments. This trend was observed for both wet and dry conditions and for spring and fall seasons. There was no consistent trend for the other treatments for the spring runs. For the fall runs, the blankets and spray-emulsion relative sediment load was consistently smaller than that observed for the straw mulch plot. In general, the sediment yields are smaller than those reported by Benik et al. (2000). Established root mass that reduced soil erodibilities and lower detachment energies of the droplets are likely the causes for the smaller erosion values.

Chapter Three
Shear Stress Partitioning of Erosion Control Blankets

Introduction

The performance of erosion control products is largely evaluated by empirical investigations. Although this approach is extremely useful, each new product requires expensive and tedious experiments under field conditions. Long-term progress in selecting erosion control measures can best be made by obtaining a better understanding of the interactions of the control measure and fundamental erosion principles.

A dominant factor for soil detachment by surface runoff is bed shear. Erosion control blankets partition the total shear stress such that a portion acts on the blanket (form shear) and the remainder on the soil particles (particle shear). The fraction acting on particles is directly involved in subsequent particle detachment. The division of total shear force into the form and particle components is generally referred to as shear stress partitioning.

The concept of shear stress partitioning has been investigated for alluvial streams. Engelund, (1966) divided the hydraulic radius into particle and roughness components, while Alam,. and Kennedy (1969) and Griffiths (1989) used a division of the energy slope to determine the particle shear. Prosser, Dietrich, and Stevenson (1995) indicates that on a densely grassed surface, over 90% of flow resistance is exerted on plant stems. A theoretical approach to shear stress partitioning for wind erosion was proposed by Raupach (1992) and investigated in the field by Wyatt and Nickling (1997). The goal of this study was to evaluate shear stress partitioning for erosion control blankets.

Experimental Equipment

Hot-Film Anemometry

A constant temperature anemometer (TSI, Inc. Model 1750) and flush-mounted hot-film sensor (TSI, Inc. Model 1237W) with immersible probe support (TSI, Inc. Model 1159) were used to measure the boundary (particle) shear stress. Feedback circuitry maintains the sensor at a constant temperature. Since a higher flow velocity, and corresponding larger bed shear, cools the sensor more rapidly, a larger voltage is required to maintain the sensor at a constant temperature (Bruun, H. H., 1995). The change in voltage can then be related to bed shear by a calibration equation.

Voltage from the anemometer was recorded via a Data Translation DT9804 data acquisition board, SCOPE Version 2.0 Software (Data Translation, 2000) and PC. Voltage was recorded at each measurement location at 200 Hz for 60 seconds.

Hot-Film Calibration

A 6.1 m horizontal transparent 7.62 cm PVC pipe was used to calibrate the sensor. Five pressure taps were spaced 1.16 m along the length of the horizontal pipe. Each pressure tap was connected to a glass tube manometer. The five manometers were pressurized with air to reduce the height of the water columns. The manometers enabled measurement of the piezometric gradient in the calibration pipe. For fully developed turbulent pipe flow, the average boundary shear stress is

$$\tau = \rho g R S \qquad (3.1)$$

where τ (Pa) is the average boundary shear stress, ρ ($kg\cdot m^{-3}$) is the density of the fluid, g ($m\cdot s^{-2}$) is acceleration due to gravity, R (m) is the hydraulic radius, and S ($m\cdot m^{-1}$) is the piezometric gradient. The clear pipe allowed for visual confirmation that the pipe was flowing full during the calibrations. The sensor was mounted flush with the inside surface of the calibration pipe, 0.81 m downstream of the fourth pressure tap. Figure 3.1 shows a schematic of the calibration pipe.

Water was supplied to the calibration pipe by a pump connected in series to a 2.84 m^3 reservoir. The rate of discharge was manually controlled by a valve at the outlet of the pipe. Water was continually recirculated through the system. Over time, the pump adds heat to the system, causing the water temperature to increase. Constant water temperature is not maintained in this system and must be accounted for in the calibration. The measurement resolution of the instrumentation system was evaluated by Thompson (2001). The system accuracy was determined to be within 6%.

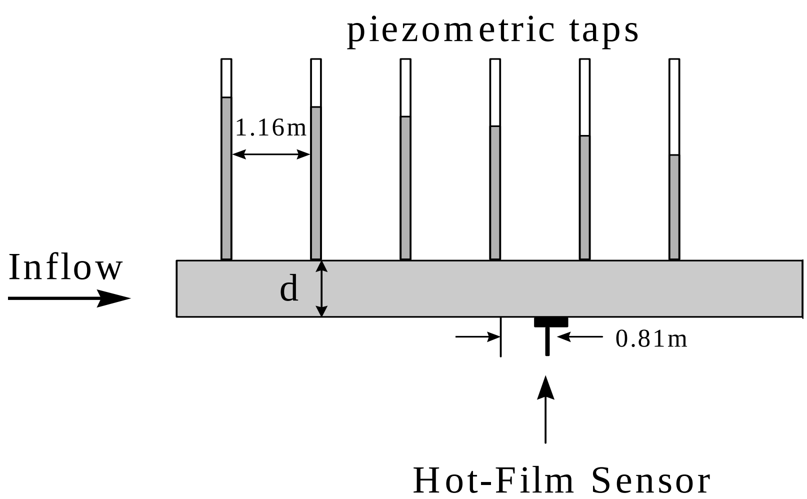

Figure 3.1. Hot-Film Sensor Calibration Pipe.

Laboratory Flume

A unique laboratory flume was designed and constructed to collect detailed spatial shear stress measurements. This system allowed shear measurements to be made using a single sensor, easily moved to any location. Alternative designs were considered, including multiple sensors and manually moving a single sensor to fixed locations within the test array. The significant cost (~$1000 per sensor) of the hot-film sensors and probe support (~$600), economically prevented the use of multiple sensors. In addition to the high cost, considerable time and effort is necessary to calibrate multiple sensors. Manually moving a single sensor to a set of fixed positions was eliminated because of the sensitivity and fragile nature of the sensor.

The designed flume used in this experiment includes a single sensor mounted in a movable section of flume floor over the test section. The inner PVC channel is 7.32 m long and 0.38 m wide, with 0.38 m sidewalls. A 0.91 m length of the original channel floor was removed starting 3.7 m from the channel inlet. Slits between the flume floor and the sidewalls exist both upstream and downstream of the test section. A 3.2 mm thick movable aluminum sheet covered with uniform sand (1 mm diameter) glued to its surface provide a floor for the opening. When centered, the movable floor extends 0.17 m upstream and downstream of the opening and 0.25 m to either side of the sidewalls. This distance varies with movement of the floor. The floor slides over the bottoms of the upstream and downstream sections to place the sensor in the specified location. Support columns connect the movable floor to linear motion guide rails above the flume (Braas Company; Eden Prairie, Minnesota). Precise motion of the guide rails in the X and Y direction is through a separate motor drive and gearbox for each axis (Braas Company; Eden Prairie, Minnesota). The motors are driven by MD-2 Dual Stepper Motor Controls (Arrick Robotics; Hurst, Texas) and MD2 software (Arrick Robotics; Hurst, Texas). A schematic of the inner channel, movable floor, and support columns is shown in Figure 3.2. To contain leakage from the slits, a sealed box was constructed around and below the movable floor. The sensor is mounted in a single location in the center of the movable test section floor. By moving the floor, multiple spatial shear measurements are attainable. The total measurement area is 0.078 m^2 (0.28 m by 0.28 m). Access to the sensor mount was obtained via a hole in the bottom of the outside box, sealed with a removable drain plug. A picture of the system is shown in Figure 3.3.

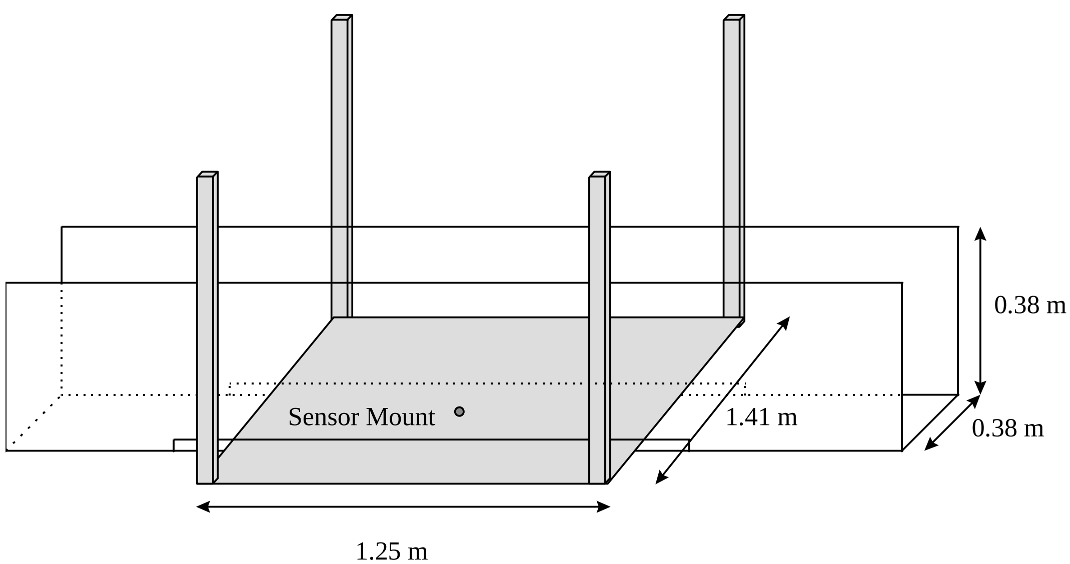

Figure 3.2. Schematic of Flume: Inner Channel, Movable Floor, and Support Columns (Not to Scale).

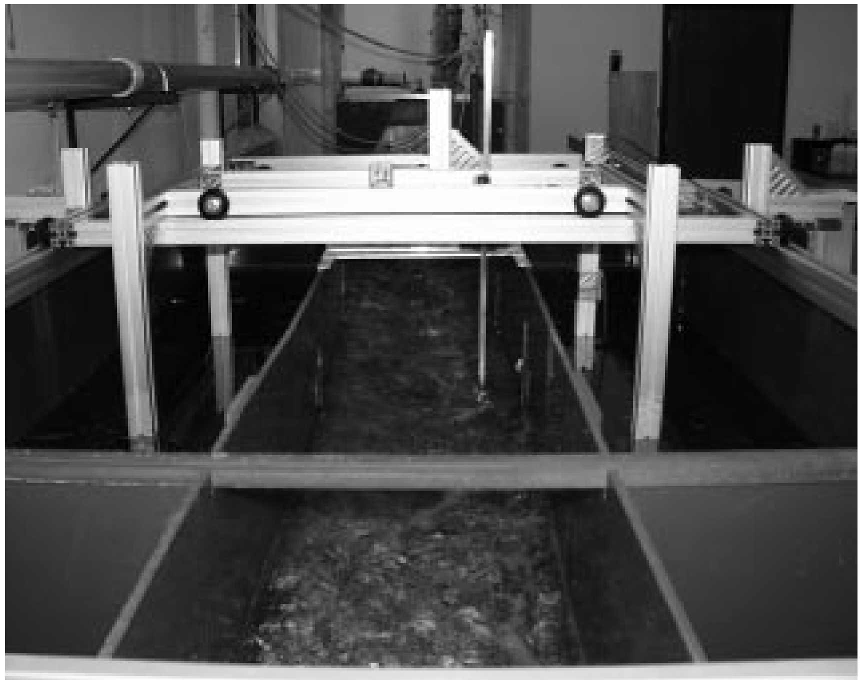

Figure 3.3. Flume: Inner Channel, Movable Floor, Support Columns, and Linear Motion Guide Rails.

Water was supplied to the flume inlet tank by two parallel pipes (7.62 cm pipe diameter for low flows and 15.24 cm pipe diameter for high flows) connected in series to a pump and water reservoir (2.8 m^3) located at the flume outlet. The rate of discharge was controlled manually by valves and measured by calibrated orifice plates connected to differential manometers. The slope of the flume was adjusted via screw jacks positioned lengthwise along the flume.

Due to small deflections in the movable floor, and the small step (3.2 mm) upstream and downstream of the test section, there are slight variations in flow depth within the test section. The depth varies approximately 0.5 cm from the upstream edge of the measurement area to the downstream edge. Uniform flow conditions were reasonable assumptions when the blankets were installed in the flume.

Experimental Procedure

Sensor Calibration

The sensor was calibrated before and after the daily runs due to errors that can result from sensor contamination and changes in water temperature (Bruun, 1995). If the calibrations did not provide similar results, the data was not used. The sensor was calibrated by varying the flow rate through the calibration pipe. Ten flow rates were used for the calibrations. For each flow rate, the piezometric gradient was measured and the voltage from the anemometer and water temperature were recorded. The average boundary shear stress was calculated using equation 3.1. A nonlinear regression of the form

$$\frac{V^2}{\Delta T} = A\tau^B + C \tag{3.2}$$

was fit to the data for each calibration. In equation 3.2, V is the time-averaged voltage, τ (Pa) is the average boundary shear stress, ΔT (°C) is the operating temperature of the sensor minus the water temperature, and A, B, and C are calibrated parameters. Similar calibration procedures were used by Robinson (1989) and Garcia *et al*. (1998).

Blanket Installation

Information on the blankets is given in Table 3.1. The flume was set at 1%. In order to minimize disturbances related to small displacements of the probe from the surface of the flume, the floor of the flume was covered with uniform sand (1 mm diameter) glued to sheet metal. The sensor was moved from the calibration pipe to the flume and positioned in the movable flume floor. Each blanket was cut to match the width and length of the flume, and placed along the bottom of the flume. The blankets were secured at distances described in Table 3.1. Each blanket was secured equal distance upstream and downstream of the measurement area. All blankets were secured by placing square, U-shaped, brass rods (2 mm in diameter) across the width of the blanket and secured with tape to the sides of the flume. Figure 3.4 shows the secured WFIII blanket.

Table 3.1. Blanket Descriptions and Fastening Spacing.

Manufacturer	Product Code	Material	MNDoT Category	Longitudinal Fastening Spacing	Paper Reference
North American Green	S150	Straw	III	0.61 m	SIII
North American Green	SC150	Straw	IV	0.61 m	SIV
North American Green	C125	Coconut	V	0.61 m	CV
American Excelsior Co.	Curlex II	Wood Fiber	III	0.61 m	WFIII
American Excelsior Co.	Curlex III	Wood Fiber	IV	0.61 m	WFIV

Figure 3.4. WFIII Blanket Secured in the Flume Prior to Experiment.

Shear Stress Measurements

The flume floor and sensor were moved to the desired measurement location. Prior to data collection, water was continually recirculated through the system until a desired flow rate came to equilibrium (depth of flow did not change in the test section). Once equilibrium was reached, the flow rate, anemometer voltage and water temperature were recorded. Three separate experiments were conducted and are described below.

The first experiment was used to examine spatial variability in shear. Shear stress, water depth, and the distance from the top of the blanket to the flume floor was measured at nine locations for each of the 5 blankets at 2 flow rates. The flow rates were 0.01 $m^3 \cdot s^{-1}$ and 0.023 $m^3 \cdot s^{-1}$. The nine measurement locations are shown in Figure 3.5.

The second experiment investigated the effect of variations in the height of the blanket above the flume floor. Measurements for this set of runs were only taken at a single location corresponding to position 5 in Figure 3.5. The SIII and WFIV blankets were used. For a constant flow rate, the shear was measured at location 5 (Figure 3.5) as the blanket was incrementally raised above the floor of the flume. The blanket was again secured equal distance upstream and downstream of the sensor. Shear stress, water depth, and the distance from the top and bottom of the blanket to the flume floor were measured.

The third experiment investigated the effect of fastener spacing on shear. Once again, data were only collected at the position 5 location for this experiment. Only the SIII blanket was used for this experiment. First, the blanket was secured every 0.61 m along the length of the flume (Scenario I). This spacing was in accordance with the manufacturer's recommended installation guidelines for low to moderate flow in a channel or shoreline. The blanket was secured equal distance upstream and downstream of the sensor. Scenario I allowed the blanket to float between fastening locations. Although this flotation was reduced slightly at deeper flow depths, a gap ranging from 3.8 cm at low flows to 2.5 cm at high flows still existed between the bottom of the blanket and the floor of the flume. In order to reduce the magnitude of flotation, the blanket was secured 0.13 m upstream and downstream of the sensor as well as 0.61 m upstream of the sensor. This allowed for more even coverage across the test area (Scenario II). Scenarios I and II represent two extreme conditions that were only investigated for the SIII blanket. The flow depth was measured at 3 locations across the flume width (7.6 cm, 19.1 cm, and 30.5 cm), both 0.42 m upstream and 0.52 m downstream of the sensor. The flow rate was increased and the procedure repeated. Nine flow rates ranging from 0.0015 $m^3 \cdot s^{-1}$ to 0.0234 $m^3 \cdot s^{-1}$ were used. The procedure was repeated for Scenario II using 8 flow rates ranging from 0.0013 $m^3 \cdot s^{-1}$ to 0.0224 $m^3 \cdot s^{-1}$.

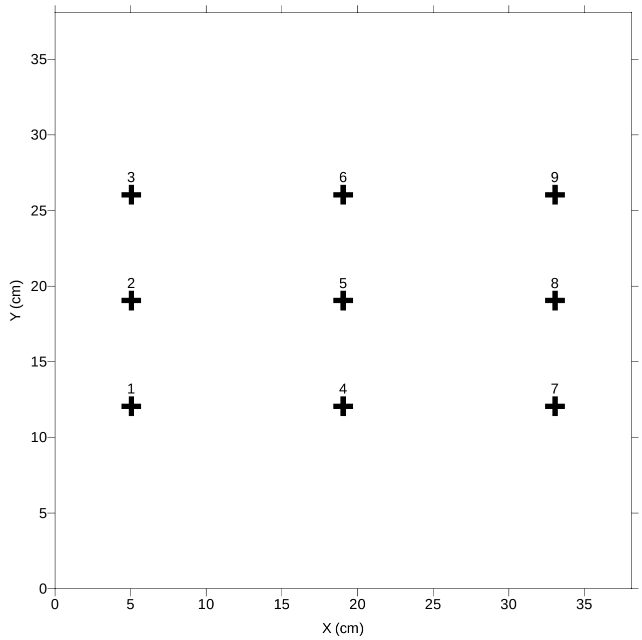

Figure 3.5. Measurement Locations.

Results

Spatial Variability

Figures 3.6 and 3.7 show measured particle shear as a function of measurement location (1-9; Figure 3.5) for the low and high flow rates, respectively. There is not a clear trend in shear with measurement location nor significant variability in shear among locations with the exception of the CV blanket. Therefore, a spatial average was determined for each blanket and flow condition. Higher shear values for the CV blanket are accounted for in the spatial average. As previously discussed, the fraction of the total shear that acts on the particles is of interest in predicting soil erosion. The spatial averages are used to evaluate the shear acting on particles for each of the five blankets.

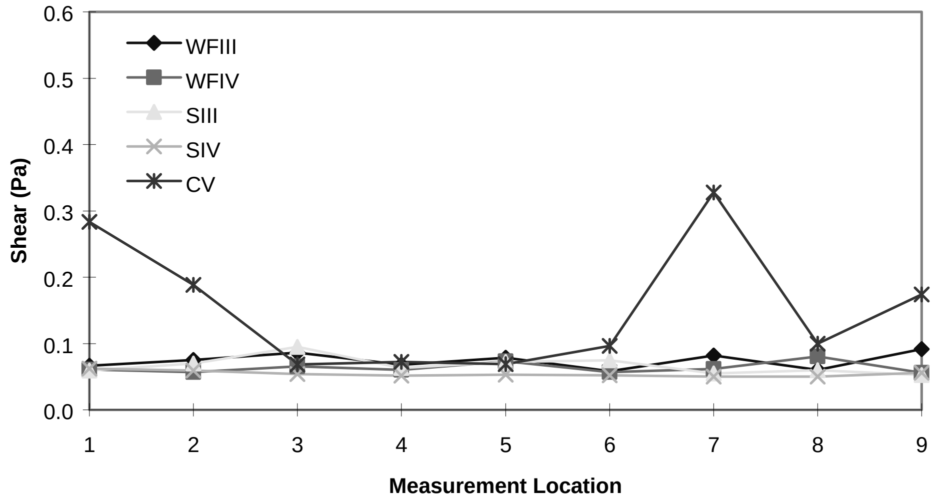

Figure 3.6. Shear as a Function of Measurement Location; Flow 0.01 $m^3 \cdot s^{-1}$.

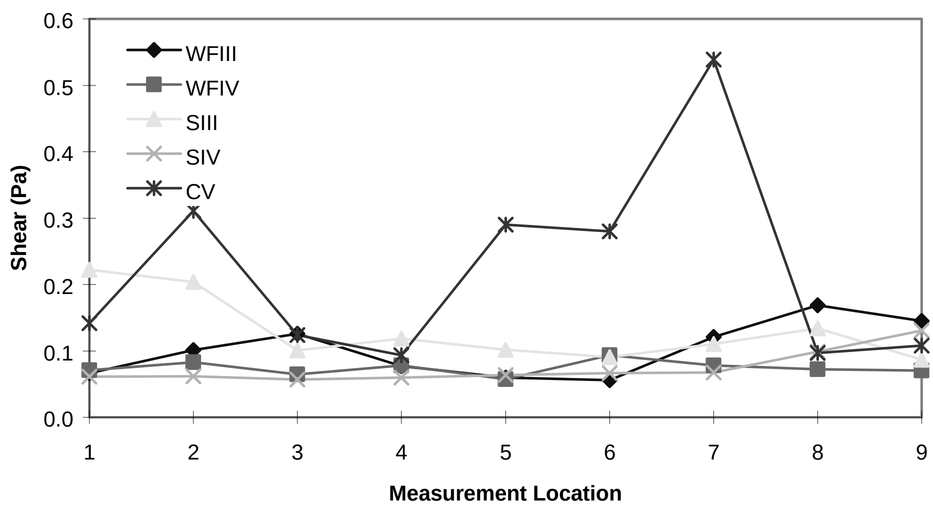

Figure 3.7. Shear as a Function of Measurement Location; Flow 0.023 $m^3 \cdot s^{-1}$.

The total shear stress is also needed for shear stress partitioning. The total shear stress in the flume was computed using Equation 3.1, where, R is the hydraulic radius of the channel flow and, for uniform flow, S is the slope of the channel bed. The total shear obtained from Equation 3.1 represents the total boundary shear (boundary average) for the blanket and the particles. By using this result with the measured spatially averaged shear from the anemometer system, the fraction of the total shear acting on the particles is easily obtained as

$$\tau_* = \frac{\tau_P}{\tau_T} \tag{3.3}$$

where τ_p is the spatially averaged particle shear (using Equation 3.2) and τ_T is the total shear from Equation 3.1.

Figure 3.8 shows the spatial average of particle shear, total shear, and shear partition for all blankets as a function of Reynolds number, or

$$\mathrm{Re} = \frac{Ud}{\nu} \tag{3.4}$$

where U is the average flow velocity ($m \cdot s^{-1}$), d is the flow depth (m), and ν is the kinematic viscosity of water ($m^2 \cdot s^{-1}$). In general, there is a slight increase in particle shear, total shear, and the shear partition with increasing Reynolds number. The dimensionless Froude number was also considered in representing the observed trends. The most interesting trends were found with Reynolds number.

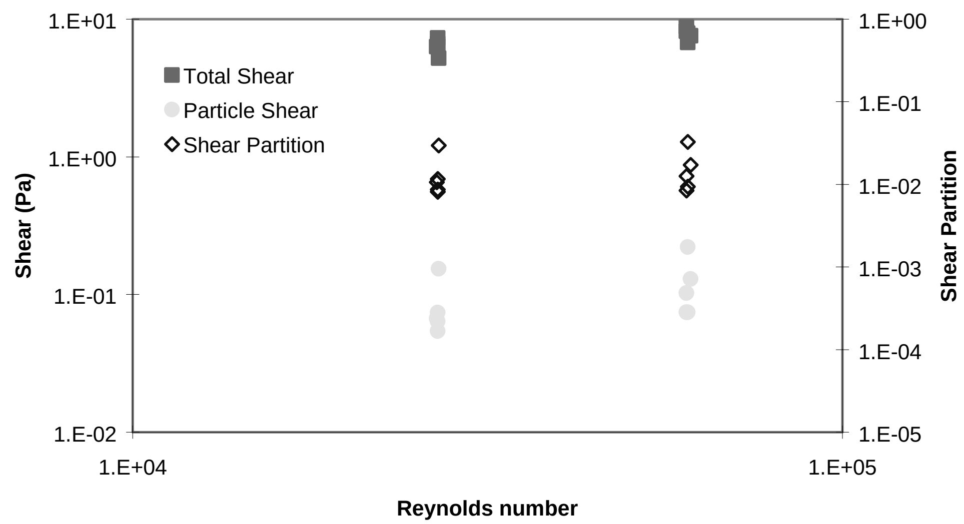

Figure 3.8. Spatial Average of Total Shear, Particle Shear, and Shear Partition (All Blankets).

Height of Blanket

The second set of experiments was used to examine the impact of the height of the blanket above the flume floor on bed shear. Since there was little variation in shear with location, this analysis was only done for a sensor located at position 5 shown in Figure 3.5. Figure 3.9 shows the measured particle shear for constant flow rate as the distance from the bottom of the blanket to the flume floor increases. As expected, there is a slight increase in shear as the blanket gets further from the flume floor. This distance allows more flow under the blanket and, consequently, higher shear. For the SIII blanket, there is an initial decrease in shear as the blanket changes from resting on the flume floor to a distance of approximately 0.05 m above the flume floor. This trend is unexpected and is difficult to explain. It might be related to the straw lying directly on the sensor and thereby influencing the heat transfer between the sensor and moving fluid. Similar trends are shown in Figure 3.10 for the shear partition.

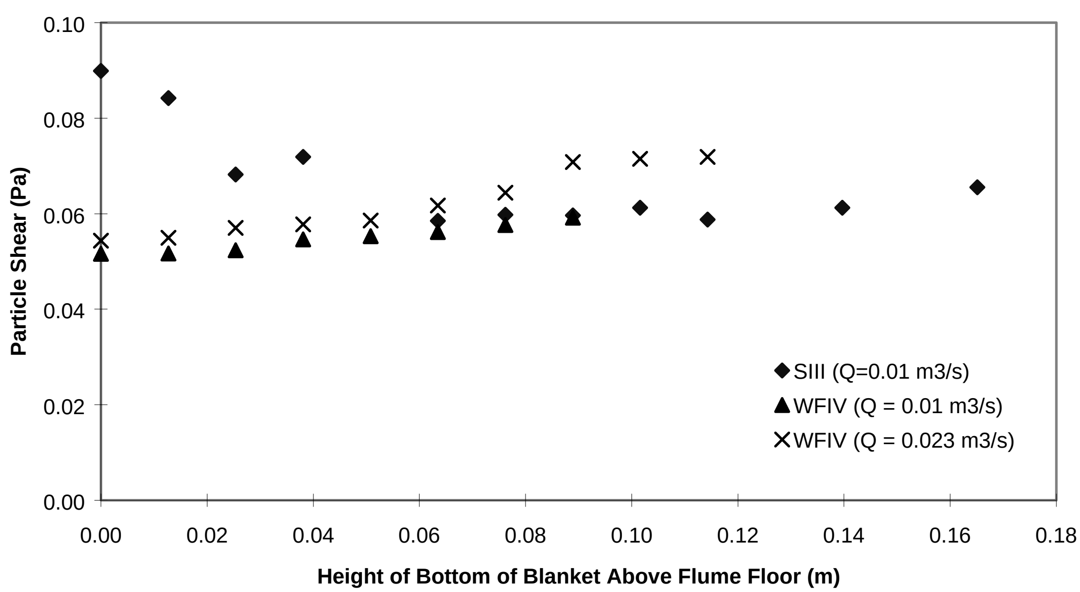

Figure 3.9. Particle Shear as a Function of Height of Mat Above Flume Floor.

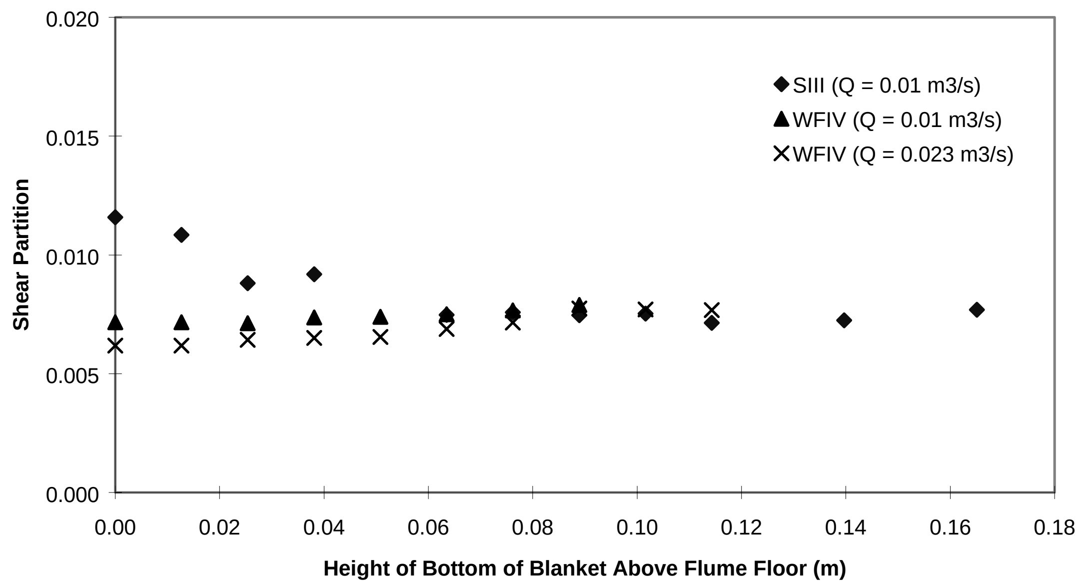

Figure 3.10. Shear Partition as a Function of Height of Mat Above Flume Floor.

Fastener Location

Figure 3.11 shows the results of the shear for the two fastening scenarios described in the previous section. The total shear for both scenarios increases with increasing Reynolds number. However, it is slightly higher for Scenario I than Scenario II due to greater flow resistance from the floating blanket, which corresponds to a greater hydraulic radius and total shear. The particle shear in Scenario I increases slightly with Reynolds number and appears to reach a constant value of approximately 0.8 Pa. Scenario II does not allow significant flow along the bed of the flume and the particle shear remains relatively constant at approximately 0.22 Pa.

Figure 3.11 also shows the shear partition for both scenarios. The two scenarios exhibit opposite trends. For Scenario I, the fraction increases with increasing Reynolds number and reaches a maximum at a Reynolds number of approximately $2.6x10^4$. This is likely because blanket flotation plays less of a role for these Reynolds numbers. The fraction of particle shear to total shear in Scenario II decreases with increasing Reynolds number. This is a result of the continual increase in total shear with increasing Reynolds number, while the particle shear remains relatively constant. For all of the runs, the shear acting on the particles was always less than 14% of the total shear. Differences in shear stress between the two scenarios indicate the importance of stapling density in reducing particle shear stress.

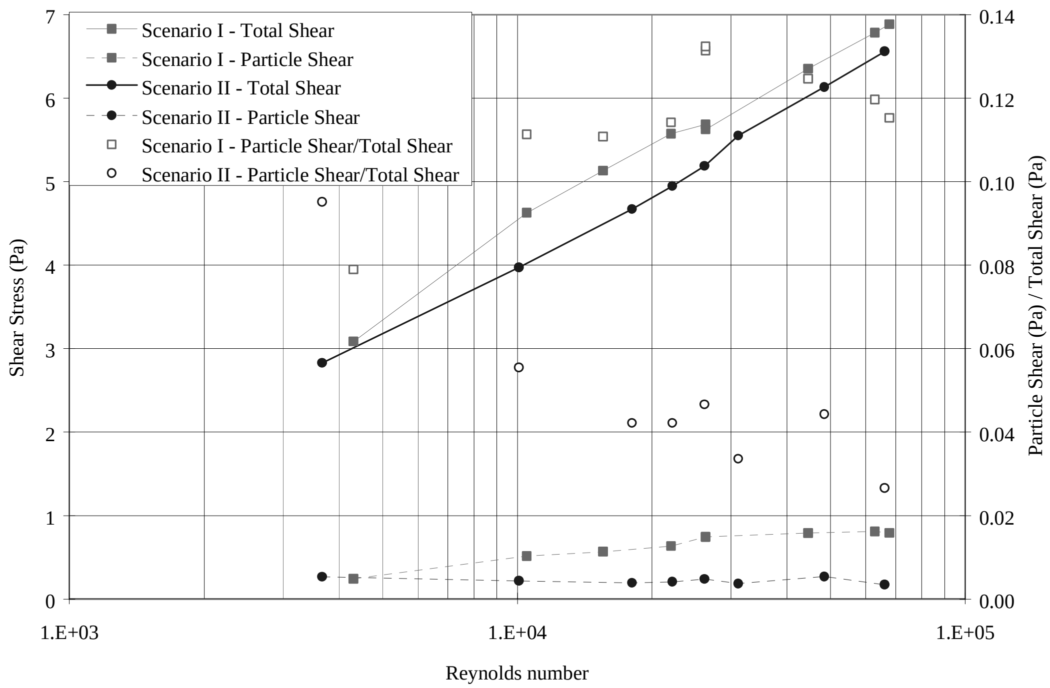

Figure 3.11. Total Average Shear τ_T, Particle Shear τ_P, and Fraction of Total Shear Acting on Particles τ_* for SIII Blanket.

Summary

Understanding the interactions between erosion control blankets, overland flow, and fundamental erosion processes is important in understanding erosion. A fundamental component influencing particle detachment is particle shear. The effect of erosion control blankets on reducing particle shear was explored using a laboratory flume and hot-film anemometry techniques.

Three experiments were conducted. The first experiment investigated spatial variability in shear for 5 blankets and 2 flow conditions. Little spatial variability was found between blankets and measurement locations. A spatial average was used to evaluate the shear partition. The second experiment investigated shear as a function of blanket height. For a constant flow rate, there was a slight increase in particle shear as the distance from the bottom of the blanket to the flume floor increased. The third experiment investigated the effect of fastener spacing on shear. Two installation scenarios were considered. Both scenarios show a significant reduction in particle shear stress. It appears, based on the trends observed for the two installation scenarios, that stapling density plays an important role in reducing the shear stress responsible for particle detachment. The percentage of the total shear acting on the particles ranged from 2.7% to 13.2%. This reduction indicates that shear partitioning is an important process that needs to be considered in erosion modeling.

Chapter Four
Statistical Analysis of Erosion Control Blanket Characteristics

Introduction

Erosion control blankets are typically selected by using an empirical data base obtained using the general approach that was used in Chapter 2. Each erosion control blanket is installed at a site or research test facility. Rainfall is applied to the plot and the observed sediment loss is then measured. Although this approach is very useful, it is inherently time consuming and expensive to experimentally evaluate each new erosion control product. An alternative approach is to predict their performance by using measurable characteristics of the blanket itself. Regression analysis is one possible tool for developing this type of predictive relationship.

The overall goal of this component of the project was to explore the use of regression analysis to develop predictive relationships for blanket performance (dependent variable) based on measurable blanket characteristics (independent variables). Regression analysis requires a good (and preferable large) data set of matching dependent and independent variables. The relatively large soil erosion data gathered at the Texas Department of Transportation (TxDOT) Test Facility were used as the dependent variables of blanket performance (Northcutt and McFalls, 1999). Individual manufacturers were contacted to obtain information on the characteristics of blankets corresponding to the TXDOT data set. The data sets are first discussed in the next section. A regression analysis of these data sets is then presented and discussed.

Data Sets

Erosion and Biomass Data

Texas Department of Transportation and the Texas Transportation Institute have designed and built a hydraulic and erosion control laboratory to test different erosion control products. This facility is located on the Texas A&M University's Riverside Campus near Bryan, Texas. Sideslope ratios of 3:1 and 2:1 are available at the site. Tests are conducted using sand and clay soils. Vegetation density, defined as percentage of final cover, is also measured for the different erosion control products.

The erosion and vegetation densities were obtained from TxDOT and entered into a spreadsheet. Data from approximately 145 different erosion control blankets were entered. A list of the products is given in Appendix E. While the data were being entered, the manufacturers of the blankets were contacted to obtain the characteristics of their products. This step is discussed in the next subsection.

Blanket Characteristics

A letter was sent to thirty-nine manufacturers requesting specifications and technical information associated with their products. Table 4.1 shows the address list of these manufacturers. Phone calls were also made to follow up the letter request for their information. Unfortunately, the response was disappointingly small. Only ten manufacturers responded to our request. The type of information provided for each product varied with the manufacture. Examples of information include weight per unit area, dry tensile strength (machine and cross directions), wet tensile strength (machine and cross directions), percentage of open area, thickness, water absorption percentage, and netting size.

The relatively low response rates by the manufacturers limit the usefulness of a regression analysis to identify significant variables. In addition, blanket characteristics that were available for products were frequently not tested by TxDOT. This further reduced the number of products that could be evaluated by a regression analysis. A summary of blanket characteristics that also had sediment load and vegetative density for the TxDOT test facility is shown in Table 4.2.

Table 4.1 List of Manufacturers Contacted by Request Letter

	Manufacturer or Distributor
1	Greenstone Industries, 3264 Villa Lane, Napa, CA 94558
2	U.S. Gypsum Co., 700 North Highway 45, Libertyville, IL 60048-1296
3	American Fiber Manufacturing Inc., 1701 Bench Mark Drive, Austin, TX 78728
4	Belton Industries, Inc., 8613 Roswell Road, Atlanta, GA, 30350
5	RoLanka International, Inc., 6476 Mill Court, Morrow, GA 30260
6	Conwed Fibers, 1002 Buck's Industrial Dr., Statesville, NC 28677
7	American Excelsior Company, 900 Avenue H East, PO Box 5624, Arlington, TX 76011
8	Earth Chem, Inc., PO Box 272627, Fort Collins, CO 80527
9	Erosion Control Systems, Inc., 1800 McFarland Blvd., Suite 180, Tuscaloosa, AL 35406
10	Canadian Forest Products, Panel and Fibre Division, 430 Canfor Avenue, New Westminister, B.C., Canada V3L 5G2
11	Colbond Geosynthetics, PO Box 1057, Enka, NC 28728
12	AKZO/NOBEL, PO Box 7249, Asheville, NC 28802
13	Southwest Environmental Services, Inc., PO Box 134, Tyler, TX 75710
14	Tascon, Inc., PO Box 41846, Houston, TX 77241
15	Evergreen Global Resources, Inc., P.O. Box 130189, Tyler, TX 75713;
16	American Excelsior Company, 900 Avenue H East, PO Box 5624, Arlington, TX 76011
17	Enviro Group, Inc., 290 Noble Street, Suite A, Greenwood, IN 46142
18	Conwed Fibers, 1002 Bucks Industrial Park, Statesville, NC 28677
19	US Gypsum Corporation, 700 North Highway 45, Libertyville, IL 60048
20	Kenaf Marketing, Inc., 11690 Indian Hill Rd., Amarillo, TX 79124-2374
21	Greenfix America, 604 East Mead Rd., Brawley, CA 92227
22	Greenstreak, Inc., 3400 Tree Court Ind. Blvd., St. Louis,MO 63122
23	Oklahoma Wood Fibers, Inc., P.O. Box 761, Idabel, OK 74745
24	Nedia Enterprises, 89-66 217th St., Jamaica, NY 11427
25	Synthetic Industries / BonTerra, 4019 Industry Drive, Chattanooga, TN 37416
26	Nicolon Mirafi Group, 3500 parkway Ln., Suite 500, Norcross, GA 30092
27	Tenax Corporation, 4800 East Monument St., Baltimore, MD 21205
28	North American Green, Inc., 14649 Highway 41 North, Evansville, IN 47711
29	International Cellulose Corporation, 12315 Robin Road, Houston, TX 77045
30	Pennzoil Products Company, PO Box 2967, Houston, TX 77252-2967
31	Western Excelsior, PO Box 659, Mancos, CO 81328
32	Chemical Lime Company, PO Box 121874, Fort Worth, TX 76107
33	Tascon, Inc. 7607 Fairview, Houston, TX 77041
34	Central Fiber Corporation, 4815 Fiber Lane, Wellsville, KS 66092
35	Mat, Inc. 12402 Highway 2, Floodwood, MN 55736
36	AMOCO Fabrics and Fibers, 260 The Bluffs, Austell, GA 30001
37	The Tensar Corporation, 1210 Citizens Pkwy, Morrow, GA 30260
38	Acumen International, PO Box 41303, Houston, TX 77241
39	Verdyol Alabama, Inc., PO Box 605, Pell City, AL 35125

Table 4.2 Summary of Blanket Information Provided by the Manufacturers.

Product Name	Weight (g/sq.m)	Dry Tensile Strength (kN/m)	Wet Tensile Strength (kN/m)	Open Area (%)	Thickness (mm)	Water Absorp (%)	Number Data Values
BioBioD-Mesh 60	600	6.6	6.8	50	8.8	NA	2
Curlex I	400	NA	NA	NA	NA	NA	4
Curlex II	400	NA	NA	NA	NA	NA	4
KoriMat400	399	7.4	5.26	65	NA	163	2
GeoCoir 700	700	19.6	9.3	50	NA	NA	2
NAG S75BN	387	3.9	NA	NA	NA	NA	2

Data Analysis

As shown in Table 4.2, the largest number of observations is available for the independent variable of weight per unit area. There was a total of sixteen observed sediment loads and vegetative densities for five different weights. These observed values include the results for 2:1 sideslope ratios and for both clay and sand soils. Sediment load and vegetative trends with weight are shown in Figures 4.1 and 4.2, respectively. As shown by these figures, large differences in sediment load and vegetative density are possible for the same weight of the product because of the importance of sideslope ratio and soil type. Because of these trends, further regression analysis was not performed. A larger data base is needed before a more rigorous statistical analysis is warranted.

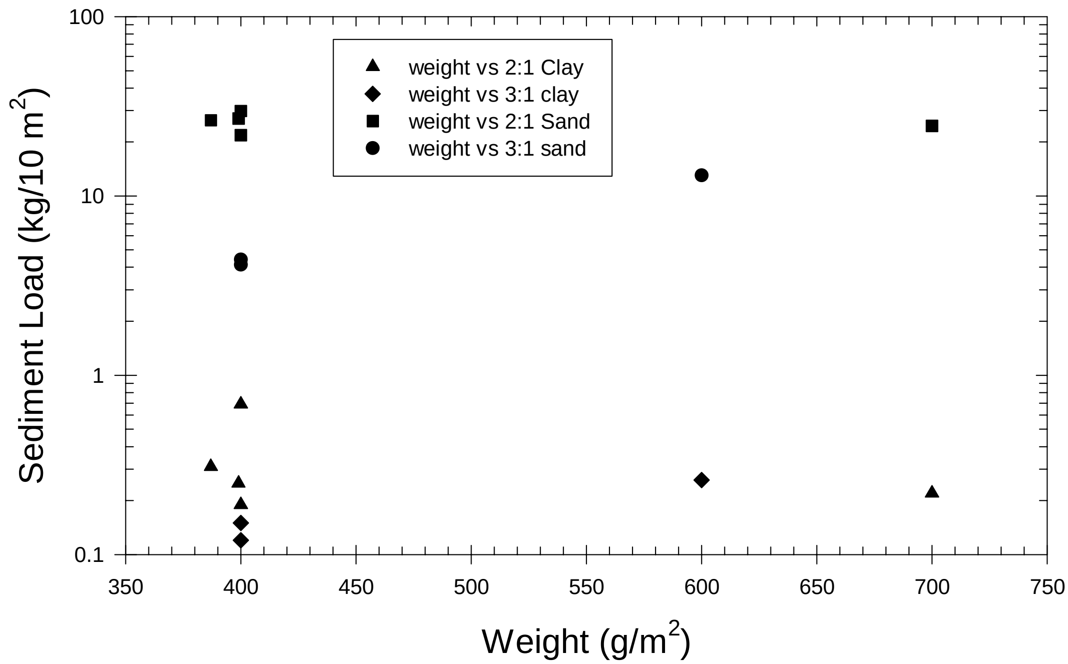

Figure 4.1. Impact of Weight of Erosion Control Products on Sediment Load.

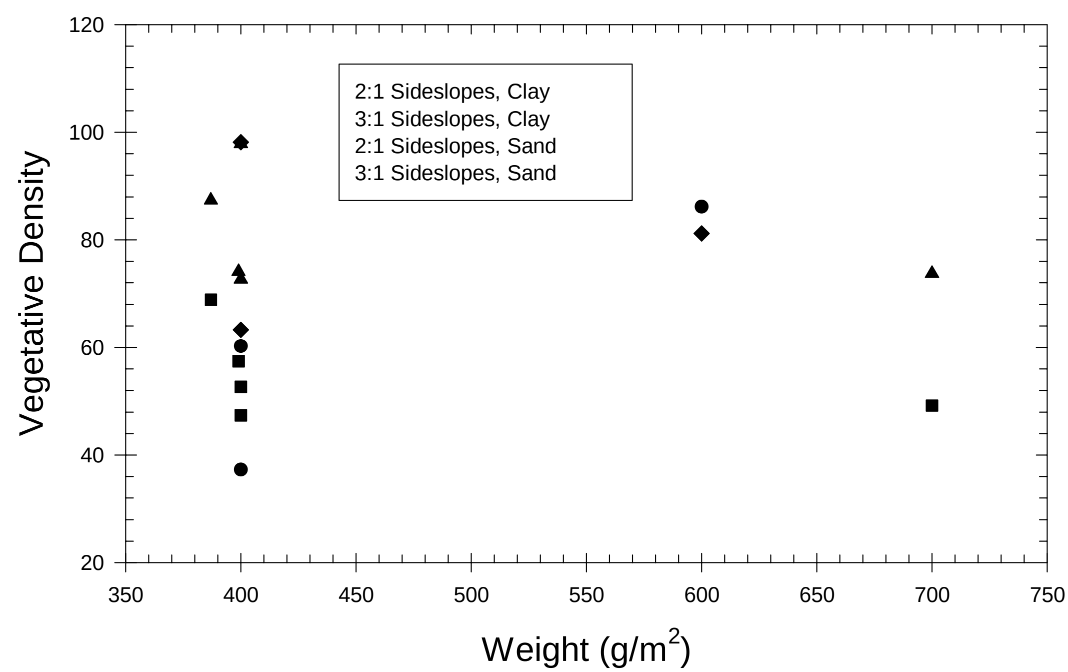

Figure 4.2. Impact of Weight of Erosion Control Products on Vegetative Density.

Summary

The goal of this component of the project was to developed predictive relationships of blanket performance using a regression analysis. Sediment load and vegetative density data from approximately 145 different erosion control products gathered by the TxDOT test facility were obtained and entered into a spreadsheet for possible analyses. This data base included results from sideslope ratios of 2:1 and 3:1 as well as values from clay and sand soil types. Thirty-nine different manufacturers were contacted by letter requesting information on measurable characteristics of their erosion control products. Only ten manufacturers responded with data to use in the regression analysis. Possible trends of sediment load and vegetative density with the weight of the product were examined. A larger data base was needed to separate the impact of the product weight from sideslope and soil factors. The number of products with both performance data and measurable characteristics was too small to warrant a more rigorous statistical analysis.

Chapter Five
Summary and Conclusions

Erosion control blankets are an important method for reducing erosion from construction sites. These blankets protect the soil from raindrop impact and from detachment forces of surface runoff. Research is limited on their effectiveness to reduce erosion for long slopes and on their integration into fundamentally based erosion mechanics. The goals of this project were to extend the experimental data base for erosion control blankets for longer slopes and to develop a better understanding of the interactions of blankets and basic soil detachment principles. The project had three main components: (1) collection and analysis of field data on relatively long slopes, (2) collection and analysis of flume data to partition bed shear among soil and blanket components, and (3) regression analysis of previously published data to examine relationships between erosion and measurable blanket characteristics.

Twelve plots with slope lengths of 30.5-m and twelve plots with slope lengths of 18.3 m were installed to study erosion from a highway embankment located in Coon Rapids, Minnesota. Four erosion control treatments with three replicates were studied for each set of plot lengths. The treatments for the 30.5-m plots were straw blanket, wood blanket, spray emulsion product, and straw mulch. The treatments for the 18.3-m plots were straw blanket, spray-emulsion product, straw mulch, and no (bare) erosion control measures. Data were collected for two different stages of vegetative growth (spring and fall) and for two different initial moisture contents (dry and wet). A low-impact sprinkler system was designed and used to apply water to the plots. Runoff and sediment data were collected for ninety-six different runs. Above-ground biomass was also measured.

Above-ground biomass data were measured at three locations within each plot after the completion of the spring and fall wet-runs. The average of these three values was analyzed for trends with time and among treatments. The spray-emulsion plots had the smallest amount of biomass in the spring. No other trends in the spring data were apparent. Biomass increased substantially between spring and fall runs. There were no strong trends in biomass among treatments for the fall data. The variability in biomass among plots for the same treatment generally decreased between the collection of spring and fall data.

Different rainfall depths among plots made a direct analysis of runoff depths more difficult. To account for differences in rainfall depths, the curve number was used as an index of runoff characteristics. The curve number appeared to be most strongly influenced by the initial moisture content of the plots. Typical curve numbers for the spring dry-runs were between 80 and 95 and for the fall dry-runs between 70 and 80. Vegetative cover and initial moisture contents were different between these two sets of runs. The curve numbers for the wet runs in both spring and fall were typically between 90 and 100. With the possible exception of smaller runoff depth from the spray-emulsion plots during the spring runs, no trends in runoff depths with treatment was apparent.

Although also influenced by the variability of rainfall depths among plots, sediment load was substantially smaller for the fall runs than the spring runs. This reduction is likely the result of larger vegetative cover. The impact of different treatments on sediment load was assessed using the ratio of sediment load per area per rainfall depth to that of the straw mulch plots. Relative sediment loads for the bare treatment were roughly eight times larger than those observed for the other treatments. This trend was observed for both wet and dry conditions and for spring and fall seasons. There were no other apparent trends for the spring runs. For the fall runs, the blankets and spray-emulsion relative sediment load was consistently smaller than that observed for the straw mulch plot. In general, the sediment yields of this study are smaller than those reported by Benik et al. (2000). Established root mass that reduced soil erodibilities and lower detachment energies of the droplets likely contributed to the smaller erosion rates.

Particle detachment by surface runoff is fundamentally dependent on the shear forces acting on them. With blankets, the shear generated by surface runoff is partitioned between components acting on soil particles and components acting on the blanket itself or its fasteners. The effect of erosion control blankets on reducing particle shear was explored in this study using a laboratory flume and hot-film anemometry techniques. Blanket type, flow conditions and fastener impacts were all considered in the experimental design.

Three types of experiments were conducted. The first type of experiment investigated spatial variability in shear for five different blankets under two different flow conditions. With the exception of the coconut fiber blanket, no trends in shear measurement with location could be identified. The second set of experiments investigated shear as a function of blanket height. For a constant flow rate, there was a slight increase in particle shear as the distance from the bottom of the blanket to the flume floor increased. The third type of experiment investigated the effect of fastener spacing on shear. Two installation scenarios were considered. Both scenarios show a significant reduction in particle shear stress. It appears that stapling density plays an important role in reducing the shear stress responsible for particle detachment. The percentage of the total shear acting on the particles ranged from 2.7% to 13.2%. This reduction indicates that shear partitioning is an important process that needs to be considered in design and erosion modeling.

The final component was to developed predictive relationships of blanket performance using a regression analysis. Sediment load and vegetative density data were obtained from previously published studies of the TxDOT test facility. Manufacturers were contacted by letter requesting information on measurable characteristics of their erosion control products. Only ten manufacturers responded with data to use in the regression analysis. A larger data base is need from the manufacturers to explore possible trends in blanket performance from measurable blanket characteristics.

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